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Short Course on Isolators and FM Antennas

By Bob Surette

The author is manager of RF engineering for Shively Labs.

Isolators have been around for more than 50 years, and during that time have been used in applications across a wide electromagnetic spectrum. Until recently, however, they have not been widely used in the FM band, and the uses that did exist did not require the development of units that could handle more than a few hundred watts.

Now, as stations begin to go on the air with digital radio in ever-increasing numbers, FM isolators are receiving a great deal of attention as a key component in a number of IBOC installations. Early deployment has been limited by the low power ratings of the available units, but power capacity is rising quickly as manufacturers devote time and resources to developing isolators specifically to address the needs of the new FM market. On the other side of the fence, RF engineers rapidly are familiarizing themselves with the principles of isolators and their advantages and limitations.

As with any emerging technology, integrating various components of the

ISOLATORS, PAGE 4

Evaluating Emissions of Your New IBOC Transmitter

Measuring Digital Signals Requires New Methods

By David Maxson

The author is managing partner of Broadcast Signal Lab.

So you are putting in your IBOC transmitter and want to be sure you've got your numbers right. How does a broadcast engineer do a "proof of performance" on a new IBOC transmitter? Let's walk through some of the measurement techniques for "proofing" a hybrid IBOC station.

As we all know, the FCC has some basic requirements for making sure a new analog transmitter is not a source of interference (Part 73.1590, Equipment performance measurements).

Analog FM rules require a simple RF bandwidth occupancy test against the RF mask, with little guidance on how to measure. Analog AM rules also have an RF mask test, with specified spectrum analyzer settings. The key measurement criteria for AM measurements are a 300 Hz resolution bandwidth (RBW), no video filtering and 10 minutes of collecting peak hold samples. On the FM side, it is customary to employ a 1 kHz resolution bandwidth. Peak hold is a convenient way to capture intermittent spurs that might exceed the mask.

Now IBOC comes along, and everything you know about analog spectrum occupancy measurements won't be enough. Digital waveforms have peculiar characteristics. Fundamentally, they are engineered to be as noise-like as possible. That is, the distribution of energy in the bandwidth over time is made as uniform as possible. Digital signals are more spectrally efficient the more (pseudo) randomly they behave. They tend to have flat tops and steep sides on a spectral display. This contrasts with the "triangular" spectral occupancy of AM and FM signals where there is more energy closer to the carrier frequency than at the band edge.

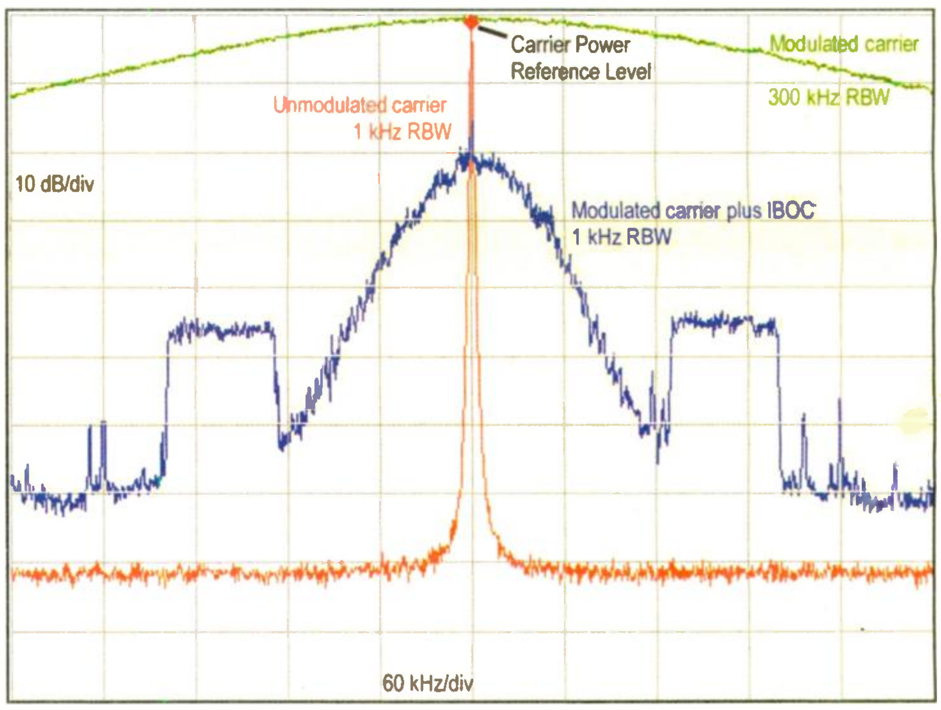

Fig. 1: FM hybrid IBOC signal, 1 kHz resolution bandwidth, sample detector averaged over 40 sweeps, taken 15 miles from transmitter (elevated noise floor).

SETTING THE REFERENCE LEVEL

How does this affect our measurement on a spectrum analyzer?

With an analog signal, it is pretty easy to obtain a power measurement. With a digital signal, the spectral characteristics are less

EMISSIONS, PAGE 8

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The Engineering Dialog

By Michael LeClair

Michael LeClair

It's nearly time for the engineer's annual migration to Las Vegas for the annual convention of the National Association of Broadcasters, a show known affectionately to most of us as just "NAB."

My calendar is always marked for this mid-April event as it represents the largest engineering conference and equipment show in the United States. If you are planning to purchase a lot of new equipment for a new studio or transmission system, it often makes sense to wait until after April to write the final order so that you can take a close look and compare before you buy. Even if you aren't in the market for a major purchase, just strolling around the equipment floor can keep you up to date on the latest designs and technologies.

FACE TIME

But this only scratches the surface of the NAB show, which is actually a conglomeration of many broadcast-related conferences, all sponsored by or coordinated with the association.

Want to find out what initiatives members of the Federal Communications Commission are planning to roll out this year? You can hear them speak and even ask them questions at the FCC breakfast meeting.

Is Congress planning to make changes in telecommunications policy and law that might affect your operations? Members of both the House and Senate Telecommunications Committees also host an early morning meeting during which they comment on important issues related to broadcasting, such as new fines for indecency.

Then there are the awards ceremonies. Many categories of achievement by radio stations are recognized by NAB and other organizations, including best local news coverage and best public service to a community. One of my personal favorites is the Technology Luncheon, at which NAB's Engineering Achievement Award is given to deserving people from the radio and television fields. Over the years the list of the winners reads like a "Who's Who" of engineering pioneers. Given that engineers often tend to work in the background, this ceremony gives us engineers a rare chance to recognize the technical innovation and creativity that is the underpinning of the broadcast business.

I tend to get a little bit crazy when I'm in Las Vegas. Well, not in the way that you might think; I don't think I have spent any serious time in a casino in about 10 years. And once you've explored the various sites on the Strip a few times there isn't really a need to see them again.

No, I mean I tend to fill my schedule with an almost unreasonable number of events, starting around 7 a.m. and continuing until midnight most nights. I can catch up on my sleep later; there is so much to pack into just a few short days.

The Radio/Audio Hall equipment exhibits easily can consume more than an entire day if I want to talk to just a small fraction of the manufacturers that are present with their new products. Not to mention the week it would take to see even half of the exhibits in the TV/Video/Film Halls. As if that isn't enough to see, how many times have I told myself to set aside at least a half day to peruse the Multimedia exhibit halls (the Wild, Wild West of the NAB) only to find there are not enough hours in the day to do more than just quickly skim through?

NIGHT OWL

After the exhibit halls close down, I am meeting with various friends in the industry and talking about what is happening in their world. This might involve anything from finding out about a public radio group building a new station, meeting a manufacturer with new products to introduce on the floor or touching base with one of our consultants. These meetings continue well into the night, over dinner and in the hallways outside evening sessions as the opportunities arise.

But I also must not forget about the incredible wealth of technical papers and presentations that are at the heart of the Broadcast Engineering Conference. These technical sessions represent the latest thinking and practice on the engineering arts. Some sessions describe a technological breakthrough or innovation that will lead to a more efficient or improved way to accomplish what we do. Other sessions combine many presentations to create an open engineering dialog as the industry ponders a significant technical challenge, such as the development of the IBOC standard for digital broadcasting. It is this sharing of ideas and research that allows broadcast engineering to continually evolve as the demands of the radio market change around us.

I will be watching the engineering technical sessions closely, both to keep my own knowledge current and also to look for interesting topics we can bring to you as part of Radio World Engineering Extra. This way, you too can keep up with the dialog as it unfolds.

PROOF IT

I am particularly excited about the issue that you have in your hands right now as we have such a wealth of great papers and columns for you. Are you adding digital HD Radio to your facility? Then the paper from David Maxson on proof-of-performance measurements is a must read. This is information that is simply not to be found anywhere else.

We have a fine technical primer on the basics of digital communications from Tim Dittmer of Harris Corp. This paper can help you understand the principals that are at the core of how digital transmission systems operate.

Bob Surette of Shively Labs has contributed a paper exploring the use of isolators in FM transmission, a hot topic for combined antenna systems adding IBOC operation.

We have new technology from Dielectric, and columns from Barry Blesser, Cris Alexander and masked engineer Guy Wire.

Hope to see you in Las Vegas! ■

Paul McLane Named Editor in Chief, Radio World/U.S.

Paul McLane has been promoted to Editor in Chief of Radio World's U.S. publications by IMAS Publishing (USA) Inc. The announcement was made by Publisher Carmel King.

"This reflects growth at IMAS that has occurred over several years, the most recent of which is the addition of our Radio World Engineering Extra," King said.

The Radio World/U.S. family serves engineers, owners and managers of U.S. broadcast radio stations.

"Paul now is responsible not just for the editorial content of 26 issues of Radio World, a position he continues to hold," King said, "but also six annual issues of the new Engineering Extra, overseeing and working with new Technical Editor Michael LeClair; plus the content of RW Online; our weekly RW Newsbytes e-mail newsletter; and the annual RW Sourcebook & Directory.

"Paul also contributes substantially to several special supplements and other IMAS projects including The NAB Daily News, and has hosted in our series of online Webinars."

McLane joined IMAS in 1996 as managing editor of Radio World and was promoted to editor in 1998. He oversees several editors and a large pool of free-lance columnists and writers producing more than 1,000 articles and news items a year.

"I hear from readers all the time that there has never been a more exciting technical time to be in radio, thanks to digital, multi-channel and the onset of new media," McLane said. "It's gratifying to see these trends played out in the pages of Radio World and our related offerings."

McLane's background is unique in the radio broadcast trade industry; he has experience both as a trained, award-winning journalist, and as a sales and marketing executive for radio broadcast equipment suppliers. He also has edited three books and is active as an actor in Washington's professional theater community.

ISOLATORS

CONTINUED FROM PAGE 1

FM IBOC transmission chain has had both successes and setbacks. Isolators have been involved in both. As with all test sites, some of the early deployments were more educational than successful, but as often as not these setbacks were not so much the fault of the isolators themselves, as much as the inexperience of the engineers deploying them and their imperfect understanding of the environment in which the isolators were to operate.

Had the early units been more robust, some of these problems might not have been so apparent. However, the relatively low power rating of the early units meant that in many cases they were being used at or near capacity, so that even small miscalculations in the isolation and return losses of a system were critical. The two immediate results were that designing higher-power isolators became a priority, and that antenna engineers took a long, hard look at the design of their radiators and the techniques they used for achieving isolation.

As this paper is being written, isolators are available that can handle combined forward and reflected power of 2 kW or more. This limit is expected to continue to increase. Contrast this to the 500 W that was considered the practical limit for stable operation only a few years ago. "Practical" has been an important consideration along the way, as advances in power rating sometimes came with conditions that limited the usefulness of the units. Size, weight and cooling requirements that might be suitable at some sites made the units impractical at others. For example, in at least one application, an isolator capable of handling the return power of the station was only efficient enough to do so when it was warmed up. While this might be fine for some systems, this would probably not be the best equipment to employ at a cold-start auxiliary site.

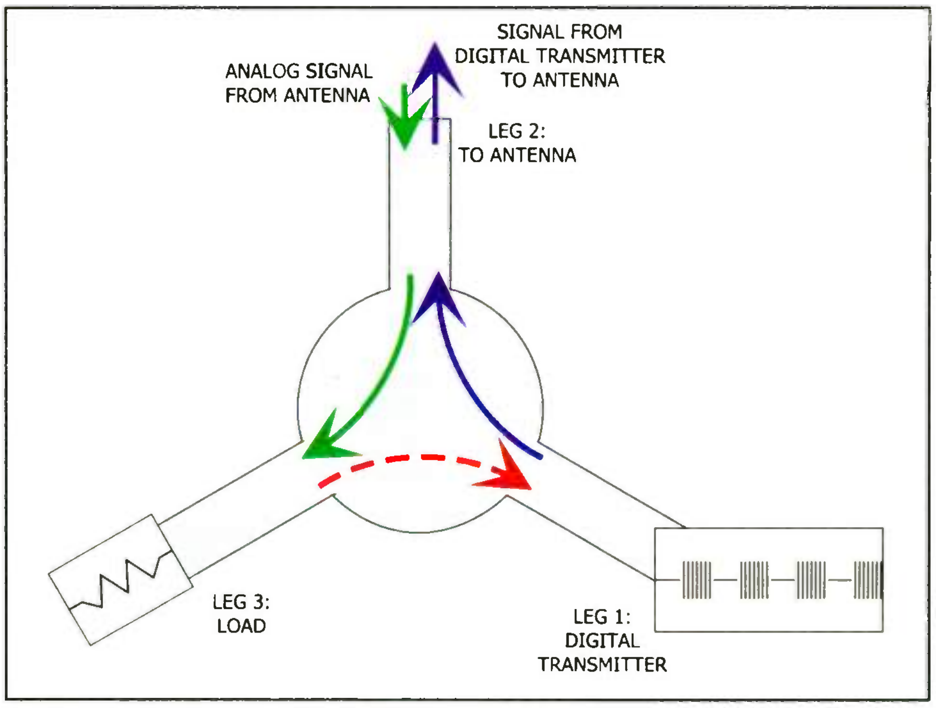


Fig. 1: Basic Isolator Configuration

As the technology evolves, isolator problems are becoming less frequent, but they have left many with the impression that isolators should be avoided if at all possible. Some equipment manufacturers have even gone so far as to promote their equipment as superior because it doesn't require the use of an isolator. In other cases, manufacturers have been slow to admit that problems were the result of the poor electrical performance of their radiators and the inability of the isolators then available to compensate adequately. While no one would argue in favor of retaining unnecessary components, it would be unfortunate for viable implementation strategies not to be considered simply because of an imperfect understanding of how the equipment is designed to perform.

Isolators are an important component in IBOC implementation. Engineers weighing implementation strategies need to understand the capabilities and limitations of current designs, and have a realistic understanding of the needs of their systems.

This paper should give the reader a basic knowledge of how and why isolators are used in IBOC implementation and a general understanding of how they relate to other components of the broadcast chain, particularly the antenna. Hopefully the reader will come away with enough understanding of how these systems work to be able to understand why isolators are suitable and successful in some installations, while not in other, similar, systems.

BASICS OF ISOLATORS

An isolator comprises a circulator and a load. The load is a simple dummy load identical to those found in many applications in broadcasting. As part of an isolator, its design criteria are the same as for any load. It must comfortably handle the maximum power it is expected to see without overheating.

The circulator is the heart of the isolator and the component that limits its performance. It is the circulator that is the focus of research and design to enhance the capabilities of isolators. Circulators come in many varieties and configurations. The isolators being supplied for most IBOC installations use distributed-constant style circulators with three legs.

In a circulator, the signal moves between legs in only one circular direction, giving the device its name. While it is theoretically possible for the signal originating at any given leg to reach any other leg, complete circulation is interrupted by the existence of one high-impedance leg, which traps energy trying to move across it and shunts it off to a dummy load. Thus, it is possible to configure the circulator to allow the signal from the transmitter to flow freely out the adjacent antenna leg, but energy returning through the antenna leg is interrupted before it can reach the transmitter leg.

This is shown in Fig. 1. The signal from the digital transmitter is fed into the isolator at Leg 1. It flows out Leg 2 on the transmission line toward the antenna, its further progress being thwarted by the high impedance of Leg 3. At the same time, any signal from the antenna enters the circulator at Leg 2 and is directed to the dummy load at Leg 3. This ability of isolators to trap on-frequency signals headed in the wrong direction and shunt them harmlessly off to a dummy load is key to a number of IBOC analog-digital combining strategies that employ separate digital and analog transmission paths, and where the combining method does not afford at least 35 dB of isolation between the digital and analog transmitters.

Strategies that combine analog and digital signals in antenna radiators, or use separate analog and digital radiators in close proximity, do not have enough isolation between the analog and digital components, and require isolators. These are among the most popular IBOC implementation strategies because they minimize the size and cost of the digital transmitter and reduce the energy wasted. Isolators are not used where the analog and digital signals are already combined in the transmitter (low level), combined through a hybrid providing at least 35 dB of isolation (mid-level), or combined using a coupler/injector providing at least 35 dB of isolation (high level).

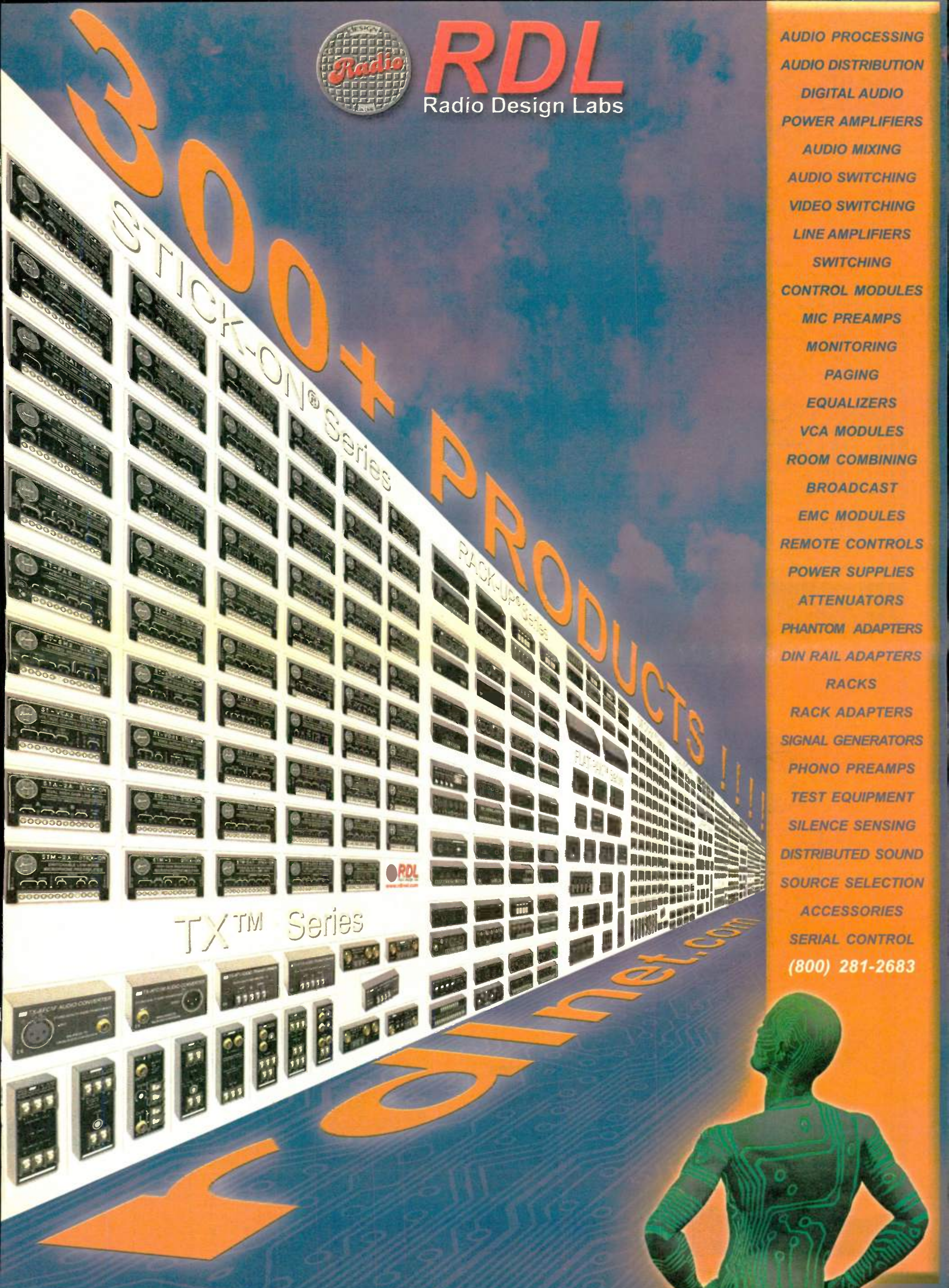
The basic isolator configuration is shown in Fig. 1.

20 dB DIFFERENTIAL BETWEEN ANALOG AND DIGITAL SIGNALS

Under the current IBOC standard, a station's digital signal is launched 20 dB below the analog signal. However, this does not mean that there is a 20 dB differential between the analog and digital signals in an IBOC transmission system.

An exact 20 dB differential will only occur if both signals are feeding antennas or portions of the same antenna that have the same gain. In practice, this usually occurs only when they are feeding the exact same radiators. If the signals do not see the same antenna gain, then the output of one transmitter (usually the digital) will need to be increased to compensate.

ISOLATORS, PAGE 6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ISOLATORS

CONTINUED FROM PAGE 4

However, for simplicity, we will assume a 20 dB differential between the signals and that the signals feed common radiators. There is validity in using this assumption, as in some respects this represents the worst case. Where the signals are most apt to have different gains (interleaved analog-digital antennas and spatially separated antennas), isolation is likely to be greatest. Differences in elevation patterns, physical distance between the radiators and alternation of the polarization of the radiators all enhance isolation. In practical terms for the isolator, this means that although an increase in digital transmitter power to compensate for lower gain may require a larger circulator, this increase will be mitigated by a reduction in analog power flowing back toward the transmitter, in turn reducing the size of the load required.

As we work through this discussion of system isolation requirements, keep in mind that the transmitters (most likely the digital) might require a few extra dB of isolation to compensate for differences in gain.

ISOLATION AND TRANSMITTERS

How much isolation is sufficient is a matter of some debate, but for reasons explained below it is generally considered to be in the range of 30 dB of isolation of the analog transmitter from the digital signal, and 35 dB for the digital transmitter from the analog signal. Isolation is achieved by a combination of factors, including differences in transmitter power, transmission line losses, isolation between radiators or inherent to the design of a radiator, isolation inherent in combining components such as hybrids or couplers, or the addition of an isolator.

Combining an analog signal and a digital signal in an IBOC installation differs from combining two analog-only signals in a classic multi-station installation in two important respects. First, the digital and analog signals are adjacent, with the digital signals located right at both edges of the analog channel, compared with an 800 kHz separation in the closest analog-to-analog schemes. Second, in analog-to-analog combining schemes, both transmitters react similarly to signals from the other transmitter, so that unwanted signals must be suppressed to the same degree. In analog-to-digital combining, the transmitters react differently to each other's signal, so each side of the transmission path is best considered separately.

ISOLATING THE DIGITAL TRANSMITTER FROM THE ANALOG SIGNAL

Digital transmitters typically "fold back" when confronted with interfering signals approximately 15 dB below carrier. This is equivalent to a 1.5:1 VSWR. Because the analog power is initially about 20 dB higher than the digital, in order for the digital transmitter to operate correctly the analog signal needs to be suppressed by a total of 15 + 20 = 35 dB. An isolator can accomplish 26 dB of this suppression, requiring the remaining 9 dB be achieved in the antenna and transmission line. While digital-only transmission lines need not be large to handle the power of a digital transmitter, they are usually oversized to minimize losses and in turn the size and cost of the digital transmitter. Therefore, the line doesn't usually contribute more than a dB or two to the total isolation. This leaves 7 – 8 dB of analog energy to be accommodated by the isolation of the antenna. This level of isolation is realistic, given that separately-fed radiators regularly see values of 20 dB or more, and even the worst performing commonly-fed radiators can be expected to achieve a minimum of 9 dB.

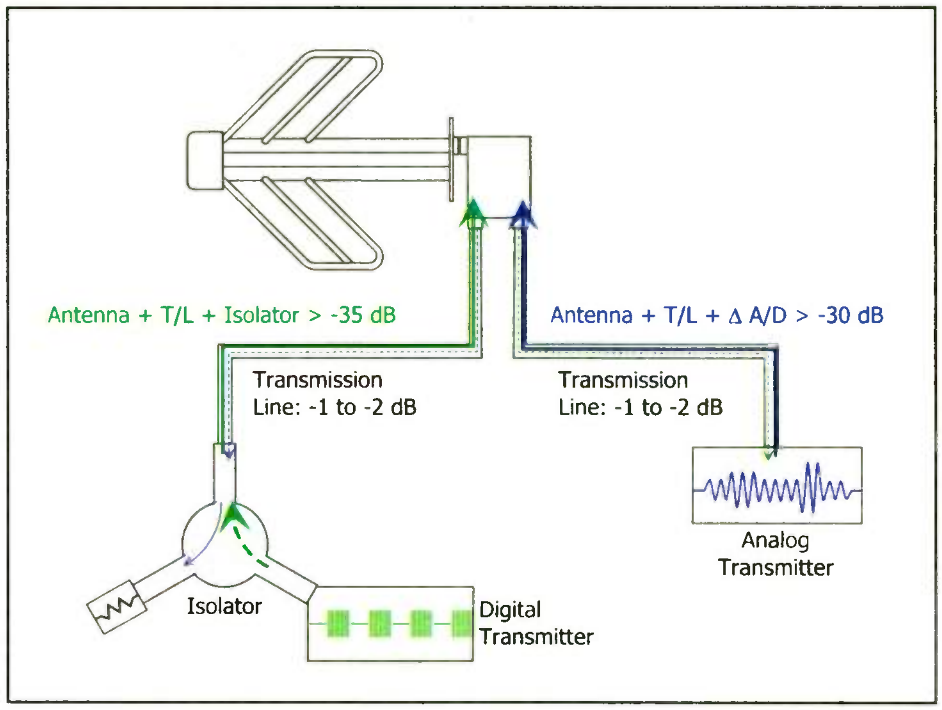


Fig. 2: Single Antenna Fed by Analog and Digital with Isolator

Without an isolator, the antenna would need to achieve 33 dB or more of isolation in order to prevent the digital transmitter from folding back. With the isolator in place, this value drops into ranges regularly achieved by today's antennas. Antenna manufacturers are working hard to improve the isolation characteristics of their antennas, and are promoting each advancement. This has left some with the impression that isolators are an unproven, unstable component and are to be avoided. However, the use of isolators remains a powerful and cost-effective means of achieving sufficient isolation.

As we will see below, the issue is the maximum power-handling capacity of current isolator designs and the ease with which a poorly designed antenna can overwhelm that capacity. Many of the early problems in deploying systems with isolators arose not from problems with the isolators themselves, but rather from poor understanding of the characteristics of the radiators. With a properly designed radiator, isolators are a cost-effective, reliable way to increase the total isolation of a system.

ISOLATING THE ANALOG TRANSMITTER FROM THE DIGITAL SIGNAL

The system design goal for isolating the analog transmitter from the digital signal is about 30 dB below the analog carrier. Since the digital power is 20 dB below the analog to begin with, this leaves only the remaining 30 - 20 = 10 dB to be achieved by the transmission system. As with the digital side of the equation, the analog transmission line can probably be counted on for a dB or two, and the antenna for at least 9 dB.

Therefore, it is usually taken for granted that if the antenna meets the isolation requirements of the digital transmitter, the analog transmitter will be also be satisfied. The 5 dB advantage in the isolation required is the reason why isolators are not needed between the analog transmitter and the antenna. This is fortunate, as almost all analog transmitters would overpower today's circulators.

It should be mentioned that the 30 dB of total isolation is considered a very safe value and no one knows for sure what is actually required. To date, no one we spoke with could cite installation problems with the digital affecting the analog, so no one knows for sure at what point problems would actually occur.

SIZING AN ISOLATOR

General

Sizing an isolator correctly is a two-step operation: the sizing of the circulator, and the sizing of the load. The circulator must be sized to handle the sum of the digital transmitter power passing through the circulator to the antenna, and the unattenuated analog power reaching the circulator from the antenna. The unattenuated analog power level alone determines the size of the load.

Example 1

Let's take the example of a single station with an ERP of 6 kW, using a four-bay, full-wave-spaced panel antenna with a power gain of 2.12. In addition, let's assume that the analog and digital signals are broadcast over the same radiators of the panel and that these radiators receive the signals over separate transmission lines having insertion losses of 1 dB. Let's also assume in this example that the isolation between the analog and digital portions of the radiators is 20 dB.

The antenna in this example (Fig. 2, showing a single antenna fed by analog and digital with isolator) would require 2,830 W of analog power at its input to achieve the required ERP. Since the analog and digital portions of the antenna would have the same gain and the digital signal is launched 20 dB below the analog, the antenna would require 28 W at the digital input. With 1 dB of attenuation in the transmission line, 35 W of digital power would need to pass through the circulator on its way from the digital transmitter to the antenna. The antenna isolation of 20 dB means that 28 W of analog power will travel down the digital transmission line, where it will be attenuated by 1 dB and arrive as 23 W at the isolator. This means that the circulator must be sized to handle 35 + 23 = 58 W, while the load must comfortably handle 23 W.

This is a classic isolator application, and the circulator in this example will be running well within the capacity of even the oldest technology. This will be the case for the vast majority of Class A stations and many Class B stations that use medium- or high-gain antennas. Problems begin to arise with higher-power stations running medium- to high-power transmitters, and with installations where the antenna isolation is poor.

Example 2

Take the example above with the same assumptions, except with the analog ERP increased to 60 kW. The circulator now must be sized to handle approximately 580 W and the load 230 W. These power levels are well within the range of common loads, but until recently, this was pushing the limit of circulators. The same size isolator components would also be required if the isolation of the antenna in the first example were only 10 dB instead of 20.

Multiple Stations

Let's assume that the same panel antenna is being used for three different stations, fed through a three-station balanced combiner. Fig. 3 shows a three-station digital-analog system.

Example 3

For the sake of comparison, let's assume that each station has the same ERP of 60 kW and the same gain of 2.12. In this example, as in the previous one, the isolator located at the digital input port of each balanced combiner module will see approximately 580 W through the circulator and 230 W to the load, assuming that the isolation of the antenna at each frequency is 20 dB. This is true, even though there is approximately three times as much combined analog + digital power returning down the digital transmission line, because the analog power, not on frequency, will be attenuated by at least 50 dB by the combiner module itself.

It should be noted that each circulator in this installation will also receive a small amount of analog power arriving at the circulator directly from the analog input of the hybrid, but this will be very small, typically much less than 30 dB down from the analog transmitter power.

Multiple Stations in the Real World: Different Isolations

In the real world, the isolation of any three stations (unless they are very close in frequency) will differ, because it is not possible to build a radiator that achieves a completely flat isolation value at a reasonable power level across the entire 88-108 MHz FM band. Isolation can be optimized for any frequency or for a small, closely spaced group of frequencies; this is often done for broadband radiators that will only be used for one or two stations. However, when a radiator is being used for the entire band, the center frequency will typically have the best isolation values, and isolation will decrease significantly at each end of the band. How significantly it will decrease depends on how optimized the isolation is at center frequency. As the isolation value at the center of the band is increased, the isolation at the ends of the band will decrease. Similarly, optimizing the isolation at any given frequency will have a tendency to decrease isolation at other parts of the band disproportionately.

Experience has shown that a well-matched radiator, where the individual radiating elements also track each other closely electrically, can achieve an isolation differential between the center and the ends of the band as low as 6 dB. Poorly matched or poorly tracking radiators will have a much higher differential.

Example 4

Revisit the example of the three-station antenna above, but use 20 dB of isolation for Station A, 17 dB for Station B and 14 dB for Station C. We find that the isolator for Station A will see 580 W through the circulator and 230 W into the load. Station B will now see 798 W through its circulator and 448 W into its load, and Station C will see 1,245 W through its circulator and 895 W into its load. Fig. 3 shows varying load sizes to emphasize this.

This shows that even with medium-power stations operating on a high-quality broadband panel antenna, we can expect some stations to approach the operating limits of conventional isolator technology, even as the other stations on the system are well within comfortable ranges. This is also an example of why antenna manufacturers are so concerned with antenna isolation.

As a side note, at Shively Labs we often are approached by engineers concerned that the reject loads on their combiners are hotter than on the other stations in the system. This example demonstrates why this is a normal operating state.

POORLY MATCHED RADIATORS

Let's see what happens when we put a poorly matched radiator into the equation.

In a panel radiator, isolation corresponds directly to how well each dipole element of the radiator is matched across the entire FM band. The second component with which radiator designers concern themselves is how well the performance of each individual radiating

ISOLATORS, PAGE 8

EMISSIONS

CONTINUED FROM PAGE 1

user-friendly. The simplest way to measure an analog station's power on a spectrum analyzer is to remove all modulation from the carrier (AM or FM) and look at the carrier frequency on the center of the display.

FM signals have (nominally) constant power, when considering the entire bandwidth of the signal. If it is inconvenient to interrupt modulation on the FM station, the modulated signal can be measured with the spectrum analyzer resolution bandwidth set to look at the total power of the FM sidebands.

I have had good results setting the RBW to a common value available on spectrum analyzers, 300 kHz. This works because the FM carrier is modulated +/- 75 kHz and the vast majority of the station's power is contained in the 200 kHz channel. In contrast, a 100 kHz RBW would miss some energy, while a wider RBW of 1 MHz might take in undesired energy.

To set the carrier level as a reference, it is just a matter of centering the display at carrier frequency, choosing the RBW for a modulated or unmodulated signal, and using the instrument's reference level setting to adjust the center point of the trace to the top of the analyzer display.

Fig. 1 shows three traces. One is the modulated hybrid FM IBOC signal at 1 kHz RBW, from which no reference level can be set. The other two traces, the unmodulated carrier at 1 kHz RBW and the modulated carrier at 300 kHz RBW, produce identical reference levels. The top of the display becomes the analog FM signal power reference level for analog mask and IBOC measurements.

With AM signals, the carrier is at licensed power when there is no modulation. Of course, with modulation the power varies, and it may vary asymmetrically (positive vs. negative peaks) so time-averaging the power within the entire modulated bandwidth will not produce a reliable reference power level. Peak hold overstates the level. Time-averaging a narrow RBW (300 Hz or less) at center frequency is most representative of the reference power level. With care, this can produce a reasonable power reference level on your analyzer without interrupting modulation. Adjust the analyzer reference level to put this value at the top of the display.

From Offset	To Offset	Measured power spectral density shall not exceed
kHz	kHz	(dBc in 1 kHz Resolution Bandwidth)
100	200	Target -41.4; Suggested mask -40 dBc
200	215	[-61.4 - (|offset frequency in kHz| - 200) x 0.867] dBc
215	540	–74.4 dBc
540	600	[-74.4 - (|offset frequency in kHz| - 540) x 0.93] dBc
600	And up	–80 dBc
Source: iBiquity Digital Corporation		

Table 1: FM Hybrid IBOC Spectral Density Mask

PROCEED WITH CAUTION

Before we get into sampling IBOC energy, let's pause for an important industrial hygiene message: Your spectrum analyzer needs the electrical equivalent of safety glasses. Whenever sampling RF signals in a new environment, it is crucial that the analyzer not be fed more power than it can handle. Understand the nature of the energy on your point of sampling, whether it is a line tap or an antenna. The whole RF spectrum arrives at your analyzer's front end, unless you prefilter it. Con-

EMISSIONS, PAGE 10

ISOLATORS

CONTINUED FROM PAGE 7

element tracks the others electrically; that is, how symmetrical the electrical response is between dipoles. Tracking can change with very subtle differences in the geometry of each element and its relationship to other components of the radiator and back plane.

Until recently, antenna designers have been primarily concerned with a single analog input for each radiator. Designers gained valuable bandwidth either by altering the internal feeds of the radiators, or by adding reflectors and rings external to the radiators. These reflectors and rings make it very difficult to produce a radiator where the radiating elements track well and are matched well across the band.

Until the introduction of analog-digital combining techniques that used the isolation port of the hybrid to accommodate the second feed, designers were not as concerned with the match as with the tracking. Adequate tracking enabled the excessive reflected power produced in poorly matched radiators to simply be shunted to the isolation port of the radiator hybrid, where it was either absorbed in a dummy load or reflected back into the radiator by a tuned short. Now that the load or short has been removed to accommodate the digital feed, this excessive reflected power passes through the hybrid port to the isolator where it could quickly overwhelm the capacity of the circulator.

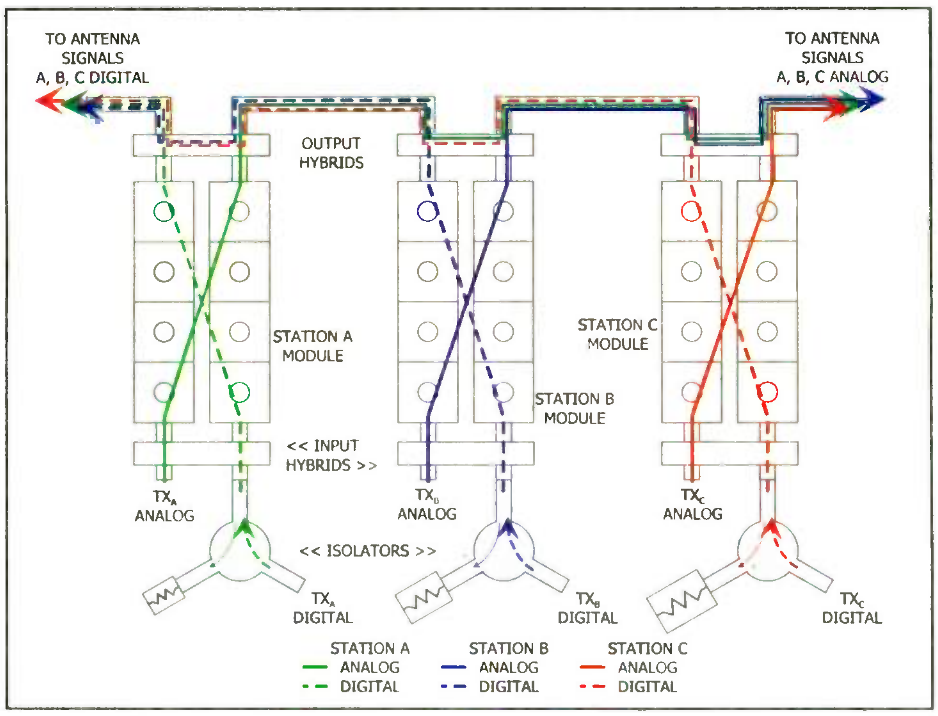


Fig. 3: A Three-Station Digital-Analog System

Example 5

Returning to the example of the three-station balanced system, if the isolation of Station C is decreased only an additional 3 dB (9 dB down from optimum), its circulator will now need to accommodate 2,136 W of energy, and its load will see 1,786 W. This approaches the maximum capacity of circulators on the market today. Should the deviation in the radiator increase to something even greater than 9 dB, the lack of a viable circulator would mean that Station C would need to consider a different method of combining digital and analog signals.

CONCLUSION

Isolators are an important component in IBOC implementation. Engineers weighing the various implementation strategies need not only understand the capabilities and limitations of current isolator designs, but also have a realistic understanding of the needs of their systems. As the power-handling capacity of FM isolators increases, they will become easier to integrate into new and existing systems. Until then, however, careful attention must be paid to the efficiencies of each system, particularly the antennas, to ensure that the isolator isn't overloaded.■

Case Study

Simple EAS Switching

Solution developed for numerous Logitek customers

THE ISSUES:

- Analog EAS system, digital transmission chain—how do you route the audio?
- Analog AUX audio source also needs to be switched
- Switching needs to happen automatically when EAS relay activates

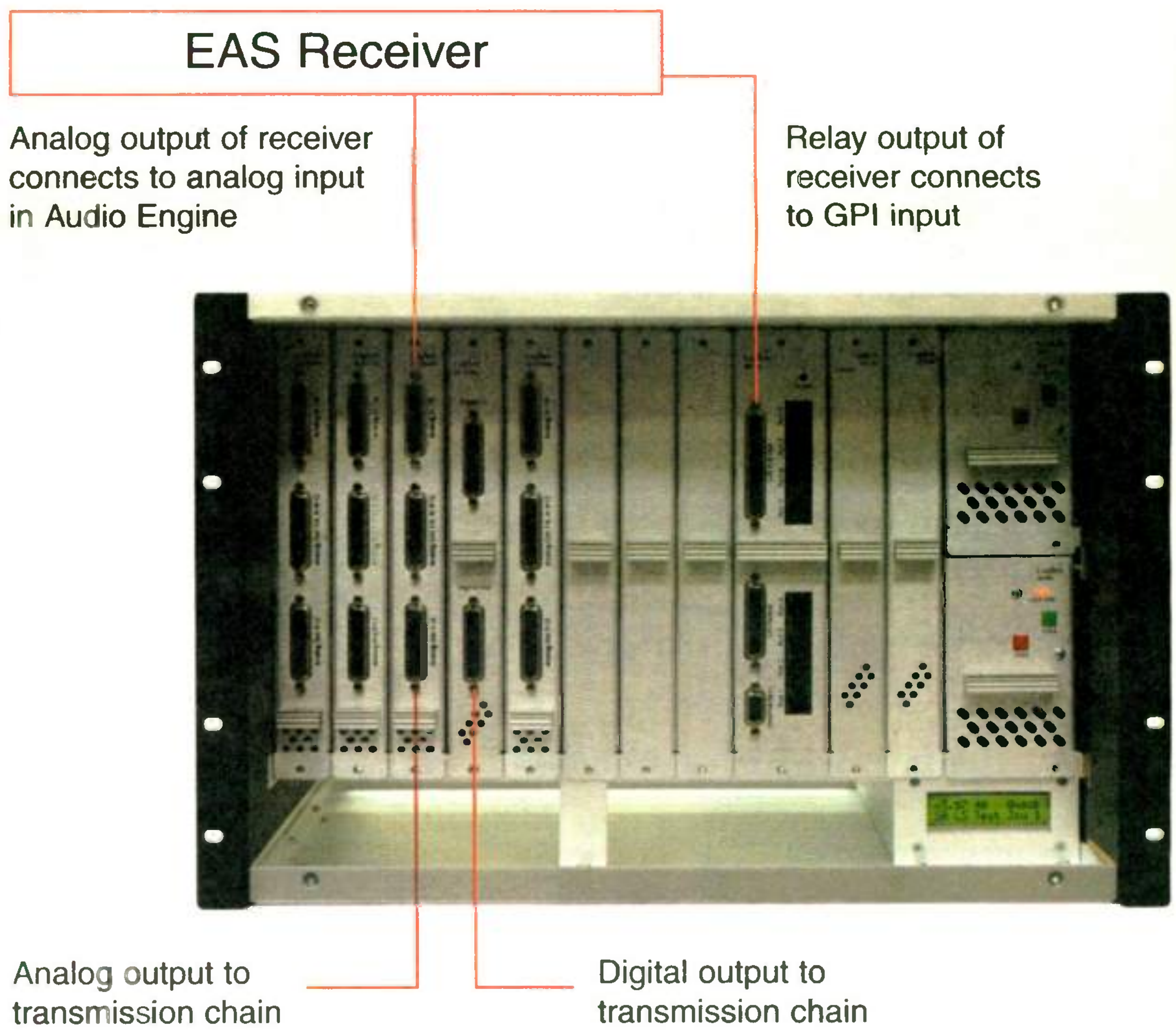
It's a common problem: *You have an analog EAS system located somewhere in your facility, and when it activates, you need to switch all of your program output channels (for all stations under your roof) to the EAS output.*

When you have a digital transmission chain, the problem is compounded: *How do you get that analog input to your digital output without a lot of trouble?*

THE LOGITEK SOLUTION:

Logitek's full featured digital audio router, the Audio Engine, is used along with a trigger set in the Logitek Supervisor software for the Audio Engine. The EAS receiver is connected to the Audio Engine as shown. Analog and digital outputs from the Audio Engine are set up for automatic switching to the EAS signal when the EAS relay activates. With multiple stations, a networked Audio Engine system will accommodate switching for everyone. When the relay releases, another trigger automatically reverts audio to the designated program and auxiliary sources.

With the Audio Engine as your audio routing source, you can provide a clean program feed to yet another auxiliary output so the EAS signal isn't included in program recording.



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CONTINUED FROM PAGE 8

sequently, another station at the same site, or one using the same transmission line, or one being received incidentally via your transmitting antenna, or some RF source you didn't count on, could pollute your measurements or toast your instrument.

Good spectrum analyzer hygiene includes testing your new sampling point, if need be, with a power meter, or by using a good broadband coaxial pad. The pad becomes your instrument's "safety glasses," protecting it from too much power. Even though the instrument has its own internal stepped attenuator, it is wise to put on a sacrificial external pad with an unfamiliar signal source. Your first order of business is to look at the entire spectrum to see if the total incoming RF power is low enough that you can get a good picture of the signal under test.

Spectrum analyzers have a compression figure that indicates how much incoming signal level causes the instrument to compress the incoming signal and give erroneous results. Check your manual. The compression level might be in the vicinity of -5 dBm while the maximum safe input to the instrument might be +20 or +30 dBm. Be sure that the *total* power input to the analyzer's mixer is less than the compression level. It is tempting just to set the desired signal level to the top of the display without regard for the other signals on the input that you can't see on the display. Take care with this step; input compression causes exaggerated intermodulation artifacts, products that might be mistaken for the real thing.

Digital waveforms have peculiar characteristics.

If in doubt about compression, measure a high signal level on the display and then add, say, 10 dB of input attenuation. If the level of the signal on the display changes by less than 10 dB, the input levels are driving compression. When a one-to-one correlation occurs between a change in the input attenuation and in the measured signal level, compression is avoided. If you are operating on a multi-station combiner, this is a particularly important thing to check. Sometimes it is advisable to insert a filter to reduce unwanted energy. Care must be taken to account for the impact of any filtering on the signals under test.

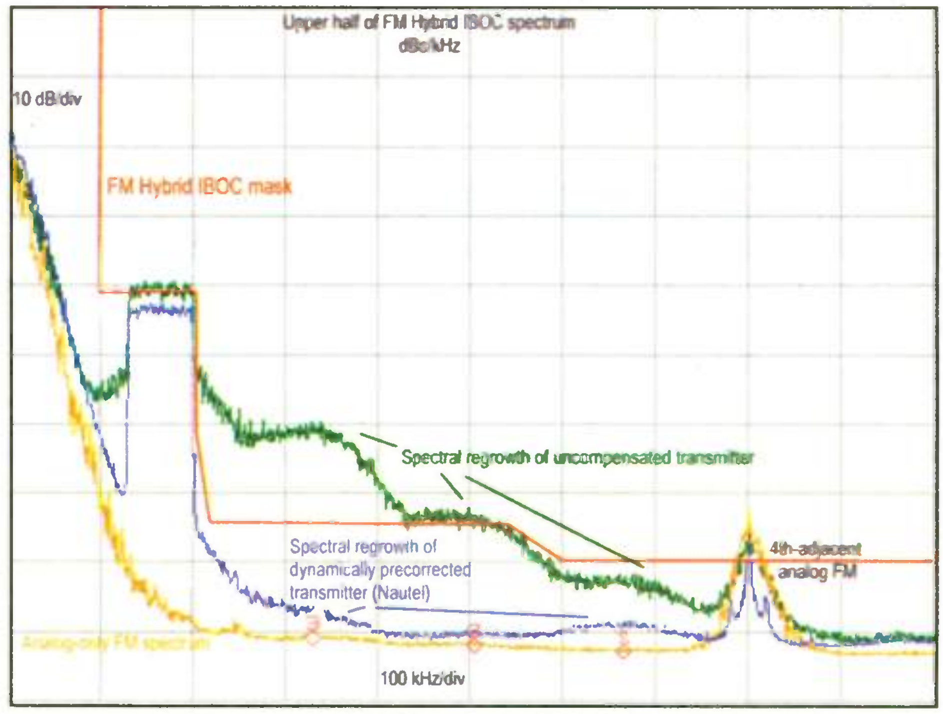


Fig. 2: Current version of the FM hybrid IBOC 1 kHz power spectral density mask (upper half of spectrum) with FM hybrid IBOC spectral regrowth comparisons — analog only, hybrid IBOC through an uncompensated transmitter, and hybrid IBOC through a Nautel dynamically pre-corrected transmitter. Thanks to Mike Pappas at KUVO.

POWER RATIOS

Finally, the analyzer is safely and accurately set up with the carrier power of the station under test set as the reference level. (By the way, because the total digital power on hybrid FM IBOC is only 1 percent of the analog power, it is OK to set the analog FM carrier reference level with or without the IBOC digital signal on.)

Now it is time to take a peek at the power ratios in hybrid IBOC operation. The term "hybrid IBOC" refers to the combined transmission of the analog signal and the digital saddlebags hanging on either side of the analog energy.

The ratio between the analog FM power and the digital sideband power is the first thing to check in your station proof. The FCC has not established any explicit proof requirements yet, but requires stations to adhere to the Ibiquity specifications. (See Table 1)

On an FM station, the digital portion of the hybrid signal consists of hundreds of low-level digital carriers, each transmitting a fairly low rate. In combination, the raw symbol rate of these carriers running in parallel is 344.5 symbols per second times 382 carriers, or 131.6 kilosymbols per second. (One hybrid FM symbol equals two bits of information).

These digital carriers comprise two groups of digital sidebands, called the Primary Main (PM), upper and lower sidebands (USB and LSB). See Figs. 1 and 2. There are also additional optional carriers that can be added, squeezing closer to the station's analog spectrum. These are the extended hybrid carriers, and are ignored for this discussion.

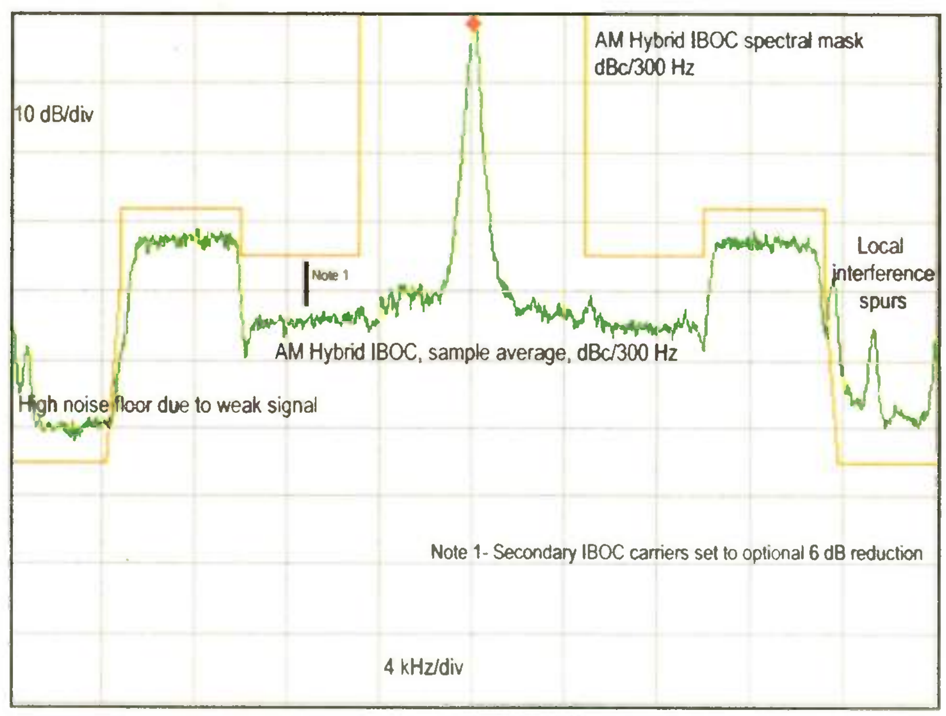


Fig. 3: Current version of the AM hybrid IBOC 300 Hz power spectral density mask close to carrier frequency. AM hybrid IBOC signal recorded 20 miles from transmitter (elevated noise floor and interfering signals)

There are 191 PM carriers in one FM IBOC PM sideband. Each carrier is transmitted at an average power level that is 45.8 dB below the FM analog carrier. However, with a spacing of 363.4 Hz, a single modulated carrier from the PM sideband will not be readily resolved by the spectrum analyzer. Instead, a 1 kHz resolution bandwidth will capture the energy of almost four carriers in one sampling "bin." That amounts to 4.4 dB more power in 1 kHz bandwidth than in the 363.4 Hz bandwidth. A spectrum analyzer set at 1 kHz RBW should show the

EMISSIONS, PAGE 12

EMISSIONS

CONTINUED FROM PAGE 10

FM PM carrier power spectral density at -41.4 dBc/kHz. That is, with the FM analog power reference at the top of the screen, the average level of the PM sidebands in any 1 kHz bin should be about 41.4 dB down.

One entire PM sideband is 69.4 kHz wide. The total power of that sideband is therefore 69.4 times the power within 1 kHz. Converting to decibels,

10 Log (69.4/1) = 18.4 dB

Hence, the total power of one PM sideband is 18.4 dB greater than in 1 kHz of bandwidth. The total power in one PM sideband, then, is

-41.4 dBc/kHz + 18.4 dB =
-23 dBc/69.4 kHz.

If your analog and digital signals reside in the same pipe (low-, intermediate- or high-level combining), take a sample off the combined transmission line. If you have separate or dual-fed antennas, there is no transmission line point to sample. It may be sufficient to measure the power on each transmission line, account for line losses and antenna gain, and arrive at an indirect power measurement of the hybrid IBOC power with respect to analog FM power. Be certain your IBOC power meter is accurate with a digital signal. Alternatively, a carefully placed test antenna can receive a reliable sample of the analog-to-digital ratio. Be sure to be close enough to keep signal levels within the dynamic range of the instrument, keeping the PM sideband energy well above the noise floor of the measurement (better than 10 dB is advisable). Fig. 1 was taken off the air 15 miles from the station, and the noise floor is only -80 dBc/per kHz. This should be enough to resolve the PM sideband performance, but is insufficient to accurately measure intermodulation products that might appear on adjacent channels.

Suggested Setup for Hybrid IBOC Measurements		
	AM	FM
Analog carrier frequency set to center of display (f_0)	Span 40-50 kHz	Span 500-600 kHz
Set trace avg. analog carrier level to top of display (0 dBc)	300 Hz RBW	300 kHz RBW
RBW for digital measurement	300 Hz RBW	1 kHz RBW
Channel Power utility (If available)		
Detector mode, display mode, Video Band Width	Auto, Log, ≥1kHz	
Centers of channel power measurements	f_0 ± 12.5 kHz, Primary f_0 ± 7.5 kHz, 2nd-ary	f_0 ± 164 kHz, Primary
Bandwidth of channel power measurements	5 kHz	70 kHz
Target channel power value of a Primary sideband	-15.6 dBc/5 kHz	-23 dBc/70 kHz
Target channel power value of a 2nd-ary sideband (two optional power levels)	-22.6 (or -28.6) dBc/5 kHz	---
Measuring from trace		
Trace Averaging		
Detector mode, display mode, Video Band Width	Sample, Log, >1kHz	
Number of sweeps averaged	25-100	
Video Filtering		
Detector mode, display mode, VBW	Sample, Log, 10 Hz	
Single sweep	No trace averaging	
Average Detection (If available)		
Detector mode, display mode, VBW	Average *Power* Det., Log, >1kHz	
Single sweep	No trace averaging	
Target Values: 1 kHz/300 Hz RBW Measurements		
Primary IBOC carriers	Target: -27.8 Limit: -25 dBc/300 Hz	Target: -41.4 dBc/kHz Limit: -40 dBc/kHz
Secondary IBOC carriers	Target: -34.8, (or -40.8) Limit: -32 dBc/300 Hz,	

Table 2: Suggested Spectrum Analyzer Settings

CHANNEL POWER MEASUREMENT

Now the instrument is set up, and it is time to measure the PM sidebands. What's the best way to do it?

There are so many options: trace averaging, video bandwidth, peak hold, max/min and more. Each technique has its errors and uncertainties. A good way to measure the full bandwidth of a PM sideband is to use an analyzer that has a *channel power* measurement utility.

I set my analyzer to show about 500-600 kHz of the band centered on the FM frequency (see Table 1). Then I set the channel power utility to measure the ~70 kHz bandwidth of the PM carriers on one of the sidebands (FM frequency +129 kHz to +199 kHz for the upper sideband, and -129 to -199 kHz for the lower sideband). If no such utility is available, trace averaging or video averaging can accomplish the task, with a little more wiggle room in the results.

A word about digital spectrum analyzer detectors is in order. The "bin" referred to above is the data point on the display that represents a certain frequency. As the analyzer sweeps up in frequency, the RBW filter establishes the bandwidth of each bin and the sweep rate determines how long the analyzer lingers in each bin. From a set of data points in the bin the analyzer's detector picks a value to display. *Peak* and *pit* (i.e., *max* and *min*) detectors look for the greatest and least voltage in the bin's data. The *sample detector* just grabs the n^{th} data point in each bin. Newer detectors rely on the availability of cheap processing power, such as the *average detector*, which runs a computation on all the data points in the bin to produce a result for the display.

Measuring a complex waveform challenges the accuracy of a spectrum analyzer. With a more traditional detector,

From Offset	To Offset	Measured power spectral density shall not exceed
kHz	kHz	(dBc in 300 Hz Resolution Bandwidth)
0	5	Tertiary carriers -41.8 to -47.8 dBc, beneath analog bandwidth. Not addressed in detail in this article.
5.0	10.0	Target -34.8 (optionally -40.8); Suggested mask -32 dBc
10.0	15.0	Target -27.8; Suggested mask -25 dBc
15.0	15.2	–28 dBc
15.2	15.8	–39 – (|offset frequency in kHz| -15.2) x 43.3 dBc
15.8	25.0	–65 dBc
25.0	30.5	–65 – (|offset frequency in kHz| -25) x 1.273 dBc
30.5	75.0	–72 – (|offset frequency in kHz| -30.5) x 0.292 dBc
75.0	And up	-85 dBc
Source: iBiquity Digital Corporation		

Table 3: AM Hybrid IBOC Spectral Density Mask

such as the peak, the analyzer assumes it sampled a sinusoidal signal and makes a conversion to RMS, which is the value shown on the display. If you average several sweeps of peak values of a modulated waveform, the average of the peaks could overstate the power in the bin. The sample detector gets around this by behaving as a random sampler of the waveform in each bin. Averaging samples from several sweeps produces a better estimate of average power in the bin. This is most accurate with sinusoidal signals. However, depending on the nature of the digital waveform, there could be as much as a 2.5 dB understatement of level when using these detectors. The more noise-like the sample, the more the average of several sweeps will deviate from the true RMS value.

Averaging multiple sweeps is called *trace averaging*. Trace averaging is not the same as the average detector. While the average detector computes the average power or voltage in each bin, trace averaging takes a series of sweeps, no matter how the bins are detected, and averages them to produce an average of the sweeps. The *video filter* averages in a different way, effectively averaging all the data points in one bin at a time using a low-pass filter.

Table 2 shows some suggested settings for common spectrum analyzers. These methods tend to produce results within a couple of dB of each other. The stations I have measured with these methods so far have been entirely at or below the -41.4 dB/kHz spec.

AM IBOC MEASUREMENTS

Measurements of the primary and secondary sidebands of a hybrid IBOC AM station are similar to those of the FM PM sidebands. The differences are: 1) the analyzer RBW should be 300 Hz; and 2) the digital carrier levels are separated into three groups, each with different level criteria. See Tables 2 and 3, and Fig. 3.

When taking an AM measurement off the air, use the same location at which you make the FCC-mandated occupied bandwidth measurements in FCC Part 73.1590 and 73.44. Be sure there is enough signal-to-noise ratio to resolve the digital signals above the in-band noise and the analyzer noise. A good loop antenna, such as the LP-3 offered by Chris Scott & Associates (www.scott-inc.com), will aid in capturing a clean strong signal.

Hybrid AM signals also have a tertiary component that resides under the occupied bandwidth of the analog signal. To test for occupied bandwidth compliance with the mask, it is not necessary to determine the actual level of these digital carriers; it is only necessary to show that the emissions remain below the mask. This is helpful because analog modulation would have to be interrupted to see the tertiary carriers well.

In both the cases of AM and FM hybrid operation, there is the potential for intermodulation among the digital carriers and with the analog host. These products, sometimes called *spectral re-growth*, appear at regular intervals up and down the band from the station's frequency. On the FM band, these products can appear at 164 kHz intervals. See Fig. 2. On AM, they are most likely to be seen at 12.5 kHz intervals. Once the power level of the analog host and the PM sidebands is established, it is a simple matter to scoot the analyzer over to the location of the spectral re-growth and measure the levels. Just leave the RBW at the 1 kHz or 300 Hz levels already employed on the initial measurements. Leave the reference level alone. Refer to the hybrid IBOC RF masks for the power spectral density limits outside the bandwidth of the hybrid signal. (See Figs. 2 and 3; Tables 2 and 3.) It is helpful to use a spectrum analyzer that has a 100 dB vertical display, to enable a full view from reference level to system noise floor.

Before we get into sampling IBOC energy, let's pause for an important industrial hygiene message: Your spectrum analyzer needs the electrical equivalent of safety glasses.

This article has covered a wide range of measurement topics with just a little bit of depth. Countless manufacturers' application notes and operation manuals were the sources of information on the inner workings of spectrum analyzers. To accurately measure power spectral density of digital signals requires more careful attention to the way spectrum analyzers work. Hybrid IBOC signals marry high-level analog waveforms having triangular power spectral density footprints with low-level digital waveforms having flat-topped power spectral density footprints. Care must be taken to ensure signal levels are set to provide the necessary dynamic range between noise floor and compression. With a good analyzer and proper precautions, the measurements that appear on the analyzer display will provide valuable information about the spectral occupancy of the hybrid IBOC signal.■

Digitally Modulated RF Systems

A Primer on Current Techniques

By T. W. Dittmer

The author is director of television engineering for Harris Corp.'s Broadcast Division

ABSTRACT

The purpose of this paper is to provide a tutorial overview of various digital communication techniques currently applicable to broadcasting, and thereby provide an understanding of the key issues and implementation choices. This is intended to provide a foundation for understanding the merits of the various methods relative to one another and to prior analog methods.

BASIC DIGITAL MODULATION TECHNIQUES

Not that long ago, most forms of electronic communication were analog from input to output. While this tended to minimize system complexity, the result was a communication link with less than optimal noise rejection, spectral efficiency and/or reliability. With the rapid advances being made in integrated circuitry, specifically in the field of high-speed digital signal processing, many communication links are now being designed to utilize digital modulation.

Advantages Outweigh Complexity

Despite the typically higher system complexity, there is good justification for communication link (modem) design utilizing digital modulation. For a given bandwidth and signal/noise ratio, greater information capacity is attainable. This is fundamentally due to the fact that the baseband information may be readily processed to appear more random, allowing better utilization of the RF spectrum. Furthermore, the additional complexity is primarily implemented digitally and often in software, making the system more stable and reliable than simpler analog links.

Fundamental Concepts

Numerous types of digitally modulated systems exist. For simplicity, we'll begin with single-carrier systems, in which all modulation information is encoded in the phase and amplitude of one (RF) carrier.

Quantization

Fundamental to most digital communication is conversion from analog to digital and back, sometimes multiple times. This is certainly true in audio and video broadcasting, where the original program material, the transmission channel and the final output are all analog. So the first stage in the communication link must convert from the analog to the digital domain.

In contrast to analog modulation, the digitally modulated signal exhibits discrete levels or states of amplitude and/or phase, at least at discrete sampling times. Depending on the number of states utilized, varying amounts of information are transmitted.

Rate

Correct representation of a sinusoidal signal with discrete samples requires a finite number of such samples to be taken during each cycle. Nyquist showed this minimum number was 2. Therefore, if we are assured our analog signal is of frequency no greater than F_i, we must sample at a frequency no less than $2F_i$. Frequencies above F_i will be "aliased" in the sampling, appearing as artifacts at $F_a - F_i$, where F_a is the under-sampled frequency. Thus, analog anti-aliasing filters are used to limit signal bandwidth, as is over-sampling (above the minimum Nyquist rate).

Accuracy

Some of the efficiency gain of digital modulation is related to the fundamental loss of information involved in quantization. Whereas the analog signal has infinite precision (in the absence of noise), the digital facsimile has to approximate the instantaneous values to some predetermined level of precision. Precision, of course, is proportional to system complexity, as more digital bits must be used to represent signals with less error. Fortunately, a practical limit generally exists where further accuracy is of insignificant benefit. The expression for quantization noise in dB is:

$$SNR_{rms} = 1.76 + 6.02N_b$$

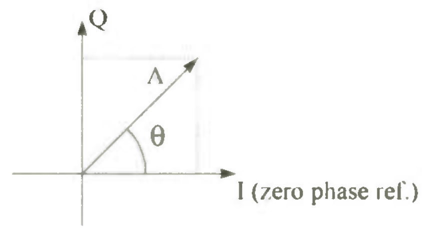
where:

N_b is the number of quantization bits

Phasor Representation

It is helpful to focus on the nature of modulation without the distractions inherent in the time-domain representation of the high-frequency carrier. Thus, we use what is commonly referred to as the phasor (or vector) representation of a signal, as shown in Figure 1.

In this representation, the carrier signal is "frozen" in time, its amplitude and relative phase represented by A and **θ**, respectively. The axis labeled "I" represents the zero-phase or in-phase reference. The "Q" axis is shifted 90 degrees from this reference, thus taking the name of "quadrature." The actual analog signal is s(t), shown mathematically above. Inspection of the exponential notation used will further reveal this phasor concept, as the carrier



$$s(t) = A\cos(\omega t + \theta)$$

$$= \mathrm{Re}\{e^{j(\omega t+\theta)}\} = \mathrm{Re}\{e^{j\omega t}e^{j\theta}\}$$

Fig. 1: Phasor Diagram

portion $e^{j\omega t}$, is removed from the diagram, leaving only the $e^{j\theta}$ phasor portion.

Finally, then, we refine the phasor diagram slightly, as shown in Fig. 2.

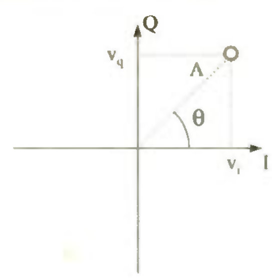


Fig. 2: Complex Modulation

Now the phasor is simply shown as a constellation point. We have added projections to the I and Q axes, representing the voltages obtained when the carrier is quadrature-demodulated, i.e., down-converted using the recovered carrier frequency and its 90 degrees phase-shifted version. This point also represents an information symbol.

Amplitude Modulation/ASK

With this phasor notation we are now equipped to examine a multitude of digital modulation techniques. Let's first apply amplitude modulation using two levels, zero and one. This is shown in Fig. 3 in phasor notation (on left) as well as time-domain carrier state notation (on right).

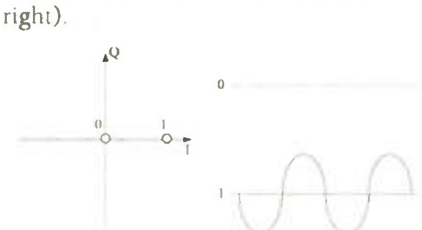


Fig. 3: On-Off Keying (OOK/2-ASK)

The carrier has one of two possible states, labeled "0" and "1," where "0" represents the absence of a carrier and "1" represents maximum carrier amplitude. By switching between these states, a single digital bit may be represented, and information conveyed. This is the simplest form of amplitude shift keying (ASK), and may be viewed as a degenerate form of conventional analog AM.

Phase Modulation/PSK

Just as discrete amplitude levels may be used to carry information, discrete carrier phase "levels" or states may also be used. Application of a discrete phase shift to an unmodulated RF carrier produces the signal shown in Fig. 4.

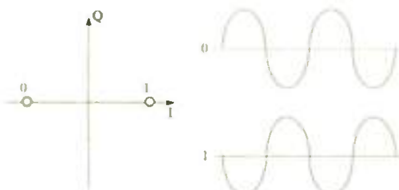


Fig. 4: Binary Phase Shift Keying (BPSK)

In this example, one bit of information is conveyed in the two carrier phase states. This is the simplest form of phase shift keying (PSK), known as Binary Phase Shift Keying.

More constellation points (symbols) may be added, which increases the amount of information that is represented by each. For instance, if we had four discrete phases, there are four unique symbols, so $\log_2(4) = 2$ bits of information may be encoded in each symbol interval. This is quadrature or quaternary phase shift keying, as illustrated in Fig. 5.

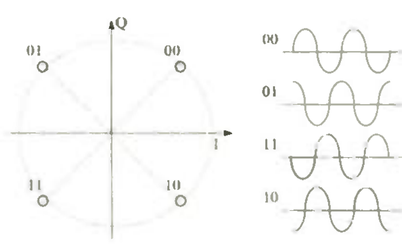


Fig. 5: Quadrature Phase Shift Keying (QPSK/QAM)

This is also referred to as quadrature amplitude modulation, as the amplitude of the two quadrature components (I and Q) is being simultaneously modulated to create the constellation points (carrier phasors) shown.

Complex Modulation/QAM

It is possible to combine discrete phase and amplitude modulation in one modulation format. Shown in Fig. 6 is 16 QAM,

RF SYSTEMS, PAGE 18

broadcast studio system.

lio broadcast studio system. Damned marketers.

Scalable, flexible, reliable... pick any three.
An expensive proprietary router isn't practical for smaller facilities. In fact, it doesn't scale all that well for larger ones. Here's where an expandable network really shines. Connect eight Axia 8x8 Audio Nodes using Cat-6 cable and an Ethernet switch, and you've got a 64x64 routing switcher. And you can easily add more I/O whenever and wherever you need it. Build a 128x128 system... or 1024x1024... use a Gigabit fiber backbone and the sky's the limit.

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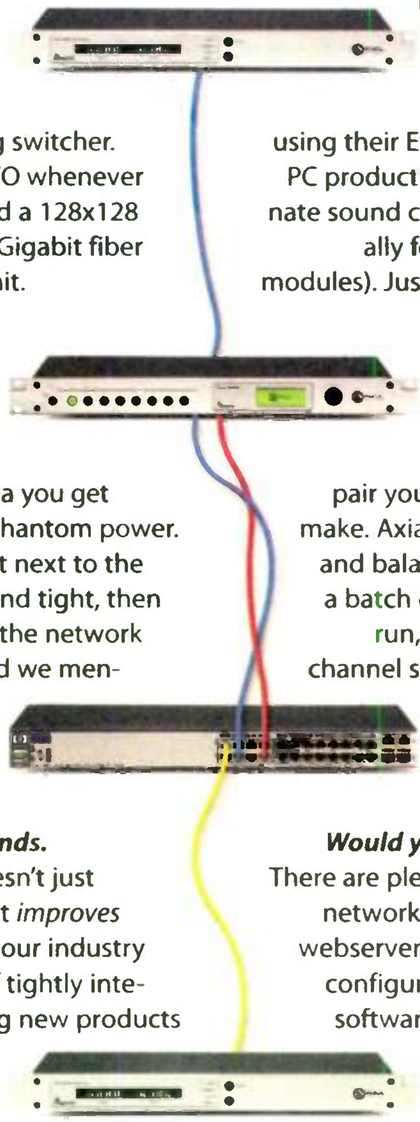

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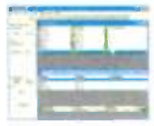

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RF SYSTEMS

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which comprises several different amplitudes and phases.

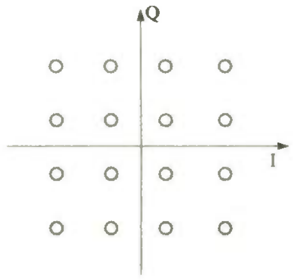

Fig. 6: 16 QAM

This combination is capable of conveying $\log_2(16) = 4$ bits of information per symbol interval.

Channel Capacity

The preceding discussion was that of the choice of constellation design, or symbol *alphabet*. This alphabet is a fundamental determinant of channel capacity, as it determines how many bits of digital information may be encoded on each transmitted symbol. If we chose an alphabet of M constellation points, we can then encode $\log_2(M)$ bits of information on each symbol. Such passband Pulse Amplitude Modulated (PAM) systems are fundamentally limited to 1 symbol/sec/Hz, which makes the overall capacity $\log_2(M)$ bits/sec/Hz (bps/Hz). Adding an excess bandwidth factor α to allow for practical raised-cosine pulse shaping gives the expression for overall channel capacity as:

$$R = \frac{\log_2(M)}{1+\alpha} \text{ bps/Hz}$$

This capacity, however, is not without bound. Greater alphabet size (M) implies smaller spacing between constellation points for a given output power, reducing the tolerance of noise or distortion. This effect is expressed in the well-known Shannon-Hartley Limit shown here:

$$N_b = \log_2(1+\text{SNR})$$

where:
N_b: *Number of bits/symbol*

$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} = 10^{\frac{\text{SNR[db]}}{10}}$$

thus, for large signal-to-noise ratio (SNR):

$$N_b \approx \log_2\left(10^{\frac{\text{SNR[db]}}{10}}\right)$$

$$\approx \frac{\text{SNR[db]}}{10\log_2} \approx \frac{\text{SNR[db]}}{3.01}$$

This relation clearly indicates the heavy price paid for large alphabets in terms of additional transmit power or other SNR improvement; each additional bit requires ~3 dB higher SNR. In actuality, an even higher SNR is required for a low Bit Error Rate (BER); typically an additional 5 to 10 dB is sufficient.

Advanced Concepts

With the fundamental concepts now in place, some of the more advanced ones are appropriate to cover.

Inter-Symbol Interference

Up to this point, we have simplified our discussion of symbol pulses so that one might infer an abrupt change occurs from, for example, a "1" to a "0" in the "I" channel. While this results in a correct transmission, spectral efficiency is low due to the high bandwidth associated with the required rectangular pulse in this channel. Instead, a pulse shape is used that presents the correct analog value only at a discrete sample time. As we are only interested in the value at the appropriate sample time, this sacrifices no information transmission accuracy. Removing the unnecessary restriction of rectangular pulse shape allows the shape to be chosen so that minimum bandwidth is required.

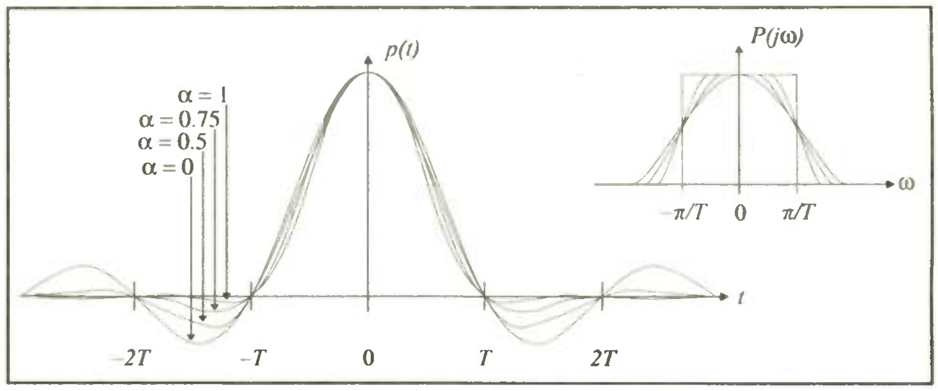

Fig. 7: Symbol Shape and Occupied Bandwidth

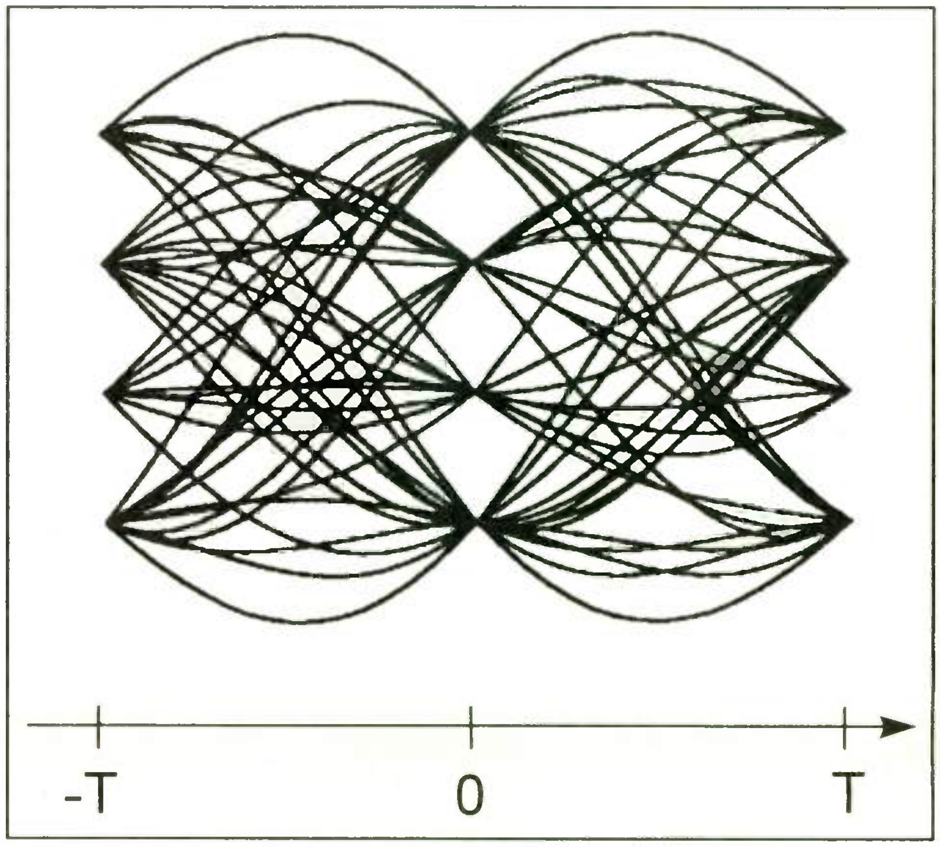

Fig. 8: Eye Diagram — Four Levels

A class of pulses that satisfies these criteria is known as "raised cosine" due to its frequency-domain transfer function. Such a pulse is shown in Fig. 7, for various values of the variable α, which is known as the excess bandwidth factor.

At $\alpha=0$, the occupied bandwidth is rectangular in shape, and the pulse rings forever in the time domain. At $\alpha=1$, twice the minimum bandwidth is used but there is virtually no ringing. For all values of α, the pulse has zero value at all nonzero integer values of T, which is the sample period. Thus, if we can precisely sample at intervals T, synchronized with the signal, we will only measure the amplitude of the desired symbol. This results in all prior and future symbols contributing zero amplitude to the composite signal at the sample time. In Fig. 8 we see such a diagram of this composite signal, drawn for a channel with four levels (e.g., 16 QAM). The "eye diagram" nomenclature results from the shape(s) created by the different symbols at T=0, ideally as "open" as possible.

Practical links are designed with some intermediate value of α, depending on various design compromises. Note, for instance, that $\alpha=0$ would horizontally "close" the eyes shown in Fig. 8 such that no realizable timing recovery circuit could be accurate enough to sample at the correct time.

Unfortunately, most communication links cannot really depend on the complete lack of inter-symbol interference guaranteed by the raised-cosine pulses we have discussed. Specifically, the analog communications channel generally provides some measure of multipath distortion, and analog filters used for selectivity are never ideal. This results in some amplitude or phase response variation vs. frequency, "smearing" the transmitted ISI-free pulses such that there is some interference with nearby symbols. Fortunately, DSP is often able to mitigate this via filters like that shown in Fig. 9. In advanced applications the tap coefficients of the filter may be adjusted in normal operation (but not "real time") to compensate for changing channel characteristics. This is termed "adaptive equalization," and is a very powerful tool enabled by the digital implementation of the communication link. Related adaptive algorithms are even capable of equalizing the various types of non-linear distortion created in power amplifiers.

Noise and Forward Error Correction

Although for simplicity we have previously only discussed a perfectly quantized signal, we must eventually refine this simplification.

Noise is ubiquitous in our analog world, and it becomes superimposed at some level on any signal. In our case, the received analog signal includes noise, its relative level dependent upon signal strength, receiver bandwidth, etc. If we consider only the simplest form of noise, known as white Gaussian noise, we see this interference is random, with the familiar "normal" probability density function (PDF). What this function means is that large amplitude contributions are relatively improbable, while small amplitude ones are more probable.

Superimposing a specific choice of this PDF on our BPSK constellation, for instance, qualitatively reveals some fundamental truths.

As shown in Fig. 10, the quantization ("slicing") level is positioned to best avoid the highly probable midsection of the PDF; in this case the decision boundary is I=0. Nevertheless, there is still some small, but finite, probability that a transmitted "1" is received as a "0" due to an infrequent, large-amplitude noise contribution from the channel. Each such occurrence will result in an error. If, within some interval, we sum these errors and divide by the number of transmitted bits, we arrive at a BER. If these errors are relatively infrequent ($<10^{-3}$), we can correct them through the transmission of redundant data, known as coding or forward error correction. Two BER curves are shown in Fig. 11; the effect of forward error correction is to "square up" the BER vs. SNR curve. This provides virtually error-free operation for normal operation (i.e., right of the crossover point between these curves). The area of degraded BER (left of the crossover point) is usually of little concern, as the BER at these low SNRs is already too high to allow reliable communication.

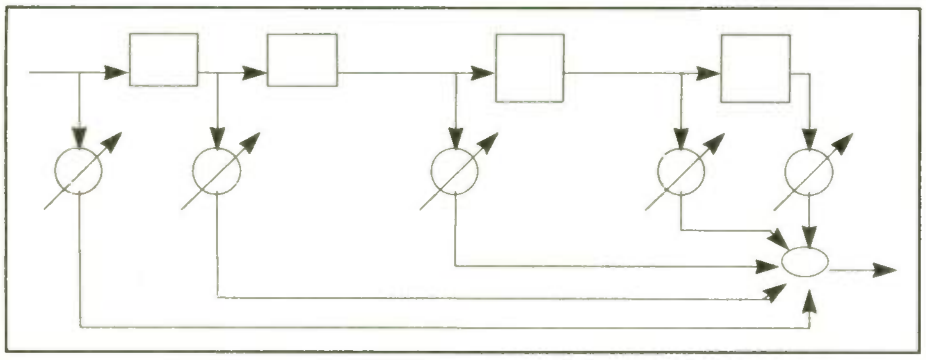
Fig. 9: Digital Equalization

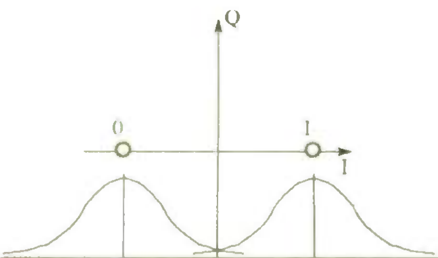

Fig. 10: White Gaussian Noise (BPSK)

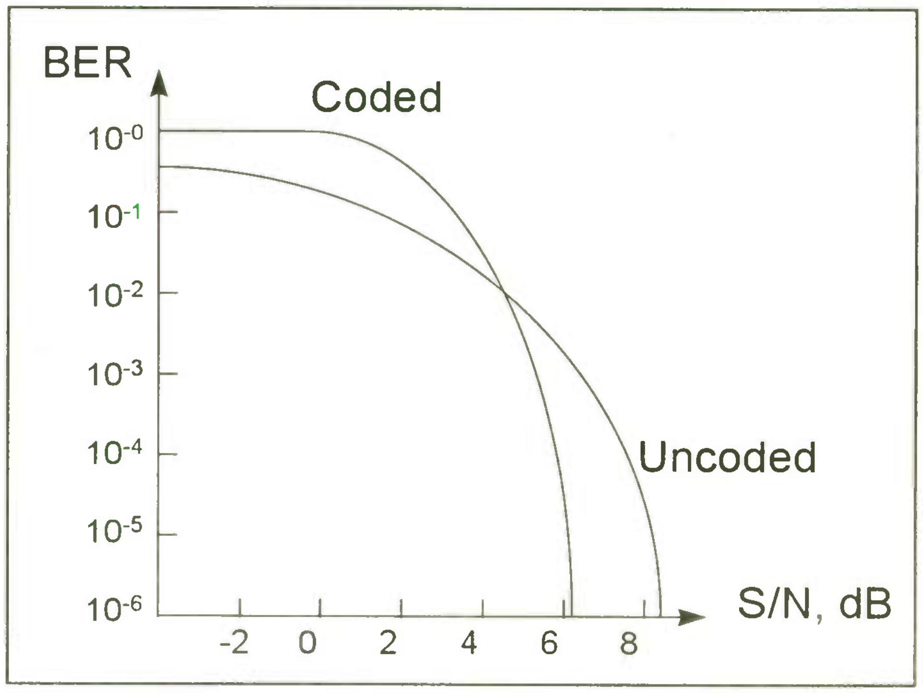

Fig. 11: Bit Error Rates

MULTIPLE-CARRIER SYSTEMS

Multiple-carrier systems incorporate another level of complexity beyond the single-carrier systems described previously, by utilizing several simultaneously modulated pulses, or carriers. One motivation for this additional complexity is the frequency diversity inherent in these multiple carriers. This may be used to overcome channel impairments caused by multipath and other distortions common to RF transmission channels.

Orthogonality

Multiple-carrier modulation is one possible means of transmitting data symbols in parallel, in contrast with the serial method outlined above. This parallel transmission necessitates a method of separating these parallel data streams from one another in the common channel. The property of orthogonality provides that method. Shown mathematically below,

$$\int s_1(t)s_2*(t)dt = 0$$

it simply states that the signals are uncorrelated, which readily allows for separation and individual reception of each, for example in a correlation receiver. One such set of signals is characterized by:

RF SYSTEMS, PAGE 20

CONTINUED FROM PAGE 19

$$s_n = \cos(2\pi f_n t)$$

$$f_n = f_o + \frac{n}{T_s}$$

where:

$$n = \{0,1\ldots N-1\}$$

T_s: Symbol Duration

Over the interval N_s, each s_n has a unique but integer number of cycles. This characteristic results in zero cross-correlation (i.e. orthogonality) that, in turn, allows this signal set to be used as the basis signal set for parallel symbol transmission. Since each s_n is uncorrelated from the others, they may be independently modulated and demodulated, as in the single-carrier case. This particular signal set is the basis for Orthogonal Frequency Division Multiplexing (OFDM).

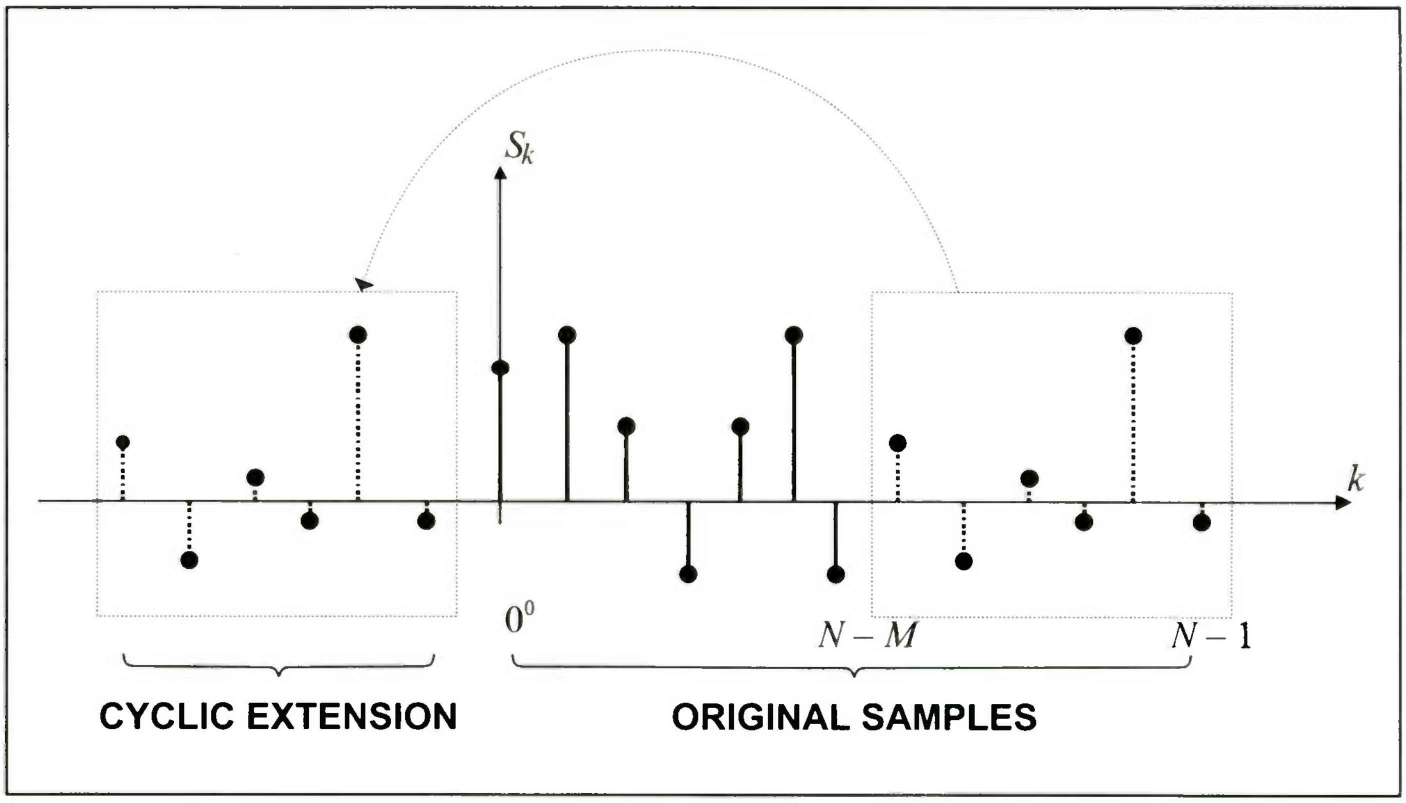

Fig. 12: Guard Interval

Arbitrary Modulation Alphabet

As in the single-carrier case, any choice of symbol alphabet may be made subject to SNR constraints. This choice may also be independently made for each carrier (s_n). This degree of freedom may be utilized to provide, for example, greater robustness for information of greater importance.

Inter-Symbol Interference

For multiple-carrier transmission, inter-symbol interference is normally eliminated via a couple techniques. Minor frequency-response problems, phase offsets, amplitude modulation-to-phase modulation conversion, etc. are often corrected via time-domain equalization as in the single-carrier case, although the implementation is often much simpler. Typically a one-tap filter is all that is needed, due to the narrower percentage bandwidth and lower symbol rate of each carrier.

For multipath-induced ISI, the general technique is to transmit redundant information during an artificially extended symbol interval. This is usually done by cyclic repetition of data symbols as shown in Fig. 12. This extension allows for error-free reception given time-domain echoes separated less than the length of the guard interval.

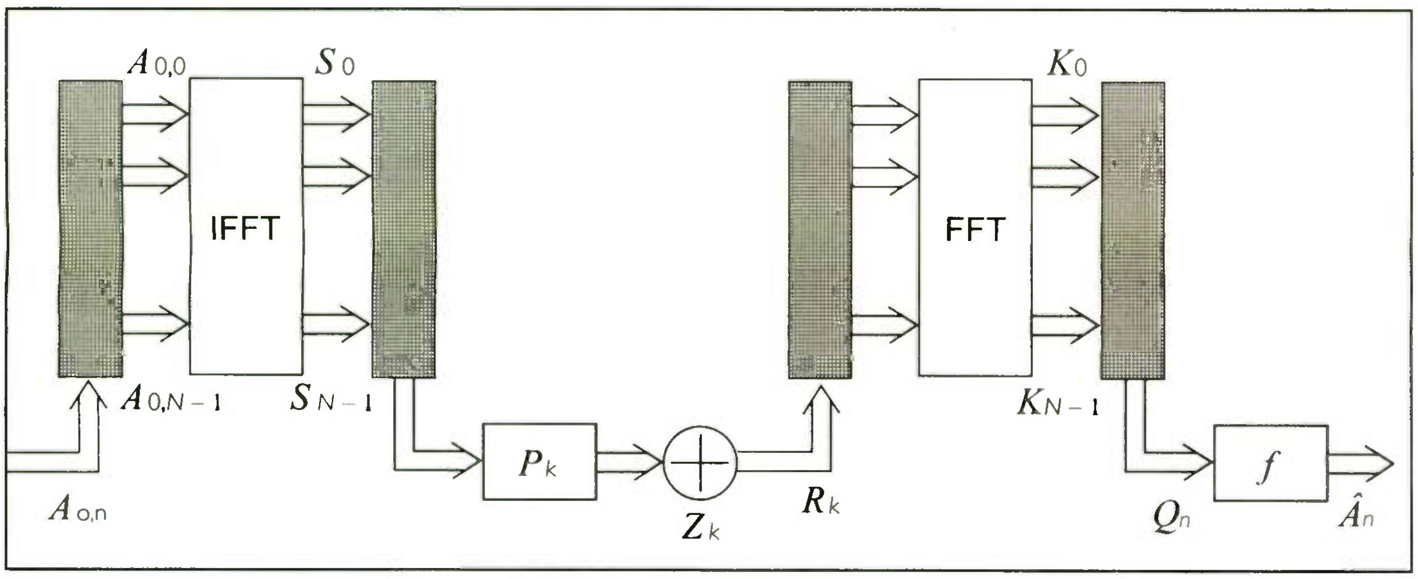

Fig. 13: FFT OFDM System

Channel Capacity

For a channel with additive white Gaussian noise (AWGN) only, the maximum theoretical capacity of OFDM is equivalent to that of a single-carrier system with the same choice of alphabet and same average power. Many implementation choices can affect this equivalence, however, including the error-correction code rates and the guard interval ratio described above.

Despite the typically higher system complexity, there is good justification for communication link design utilizing digital modulation.

Peak Power

In relation to channel capacity, average power may not be the most relevant parameter, as peak power generally governs the required transmitter capacity.

For multiple-carriers, the crest factor (peak/avg. power ratio) is:

10 log N
where N = the number of carriers

This becomes very large for typical systems, where N may be greater than 1,000. Fortunately, these occasional peaks due to constructive interference from many carriers are relatively rare and may be clipped subject to sufficient error protection and adjacent channel spurious limits. Even so, these numerous carriers begin to approximate independent random variables with the requisite Gaussian PDF. In practice, a 12 dB crest factor has been shown to characterize the signal 99.99 percent of the time, so clipping to this level would result in BER on the order of 10^{-4}, readily correctable with coding.

FFT Implementation

Due to the large number of carriers involved in modulation, multiple-carrier systems can be prohibitively expensive and complex to implement using conventional hardware-based methods. Fortunately, the Fast Fourier Transform may be used to provide a convenient set of orthogonal basis signals while allowing efficient computation in a DSP. A simplified OFDM system based on this technique is shown in Fig. 13, where transmission of a single pulse is noted.

The incoming data symbols $A_{o,n}$ are first transformed using the Inverse Fast Fourier Transform (IFFT) at baseband. This parallel carrier data is converted to serial (S_k), then analog, and finally up-converted for transmission (discrete-time equivalent channel shown above as p_k, Z_k). Reception is essentially the reverse operation, employing the FFT to separate and demodulate the orthogonal carriers (R_k) into parallel data (K_n). At this point a small time-domain equalizer is often inserted. The demodulated data (Q_n) is quantized, creating the recovered data symbols (A_n).

CONCLUSION

It is hoped this primer helps make the techniques and advantages of digital communication clear. As electromagnetic spectrum becomes increasingly scarce, the efficient spectral utilization offered becomes more and more important, compensating for the additional complexity involved. Alternatively, the increased information capacity can be used to maintain maximum signal quality.■

References for this article include "Digital Communication" by Edward A. Lee and David G. Messerschmitt; and "Introduction to Communication Systems," Ferrel G. Stremler.

The author wishes to thank the Harris Broadcast Engineering staff for their assistance in preparing this manuscript.

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Products & Services SHOWCASE

HDR Dibrid IBOC Combiner

A Way to Optimize Power Loss and Flexibility in HD Radio Installations

By Henry Downs

The author is senior electrical engineer with Dielectric Communications.

The advent of digital radio is no longer fast approaching; it is upon us. This quantum leap, which will allow broadcasters to offer CD-quality digital audio to listeners, also gives them the ability to offer data services that are currently unavailable.

The various coding techniques and implementations have been extensively refined, resulting in the FCC's adoption of Ibiquity Digital Corp.'s HD Radio system as the interim standard. However, the investigation of the methodology to combine the present analog signal to this new dual-sideband digital signal has yet to produce an all-encompassing solution that is universally appealing. The Dielectric HDR Dibrid IBOC Combiner is proposed here as that solution.

THE CHALLENGE

The major hurdle that exists when considering IBOC is how to combine the existing analog signal with the "new" digital signal. Present transmitter development has yet to yield a solution, in a cost-effective manner, which will allow both the analog and digital signals to be combined and produced via one standalone high-power transmitter. In addition, it is believed that most broadcasters would prefer to utilize their present analog transmitters and add the digital systems as a separate entity.

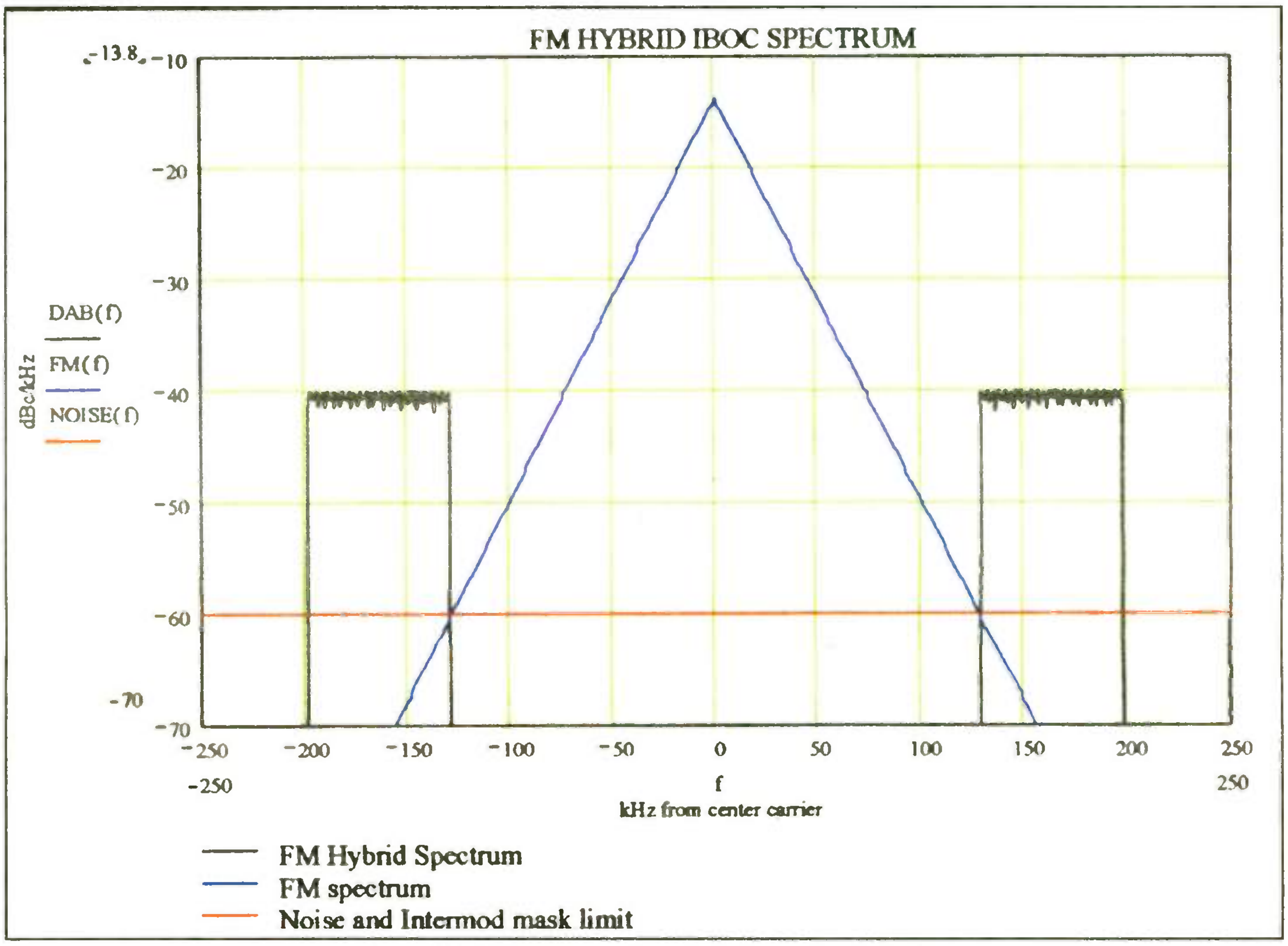
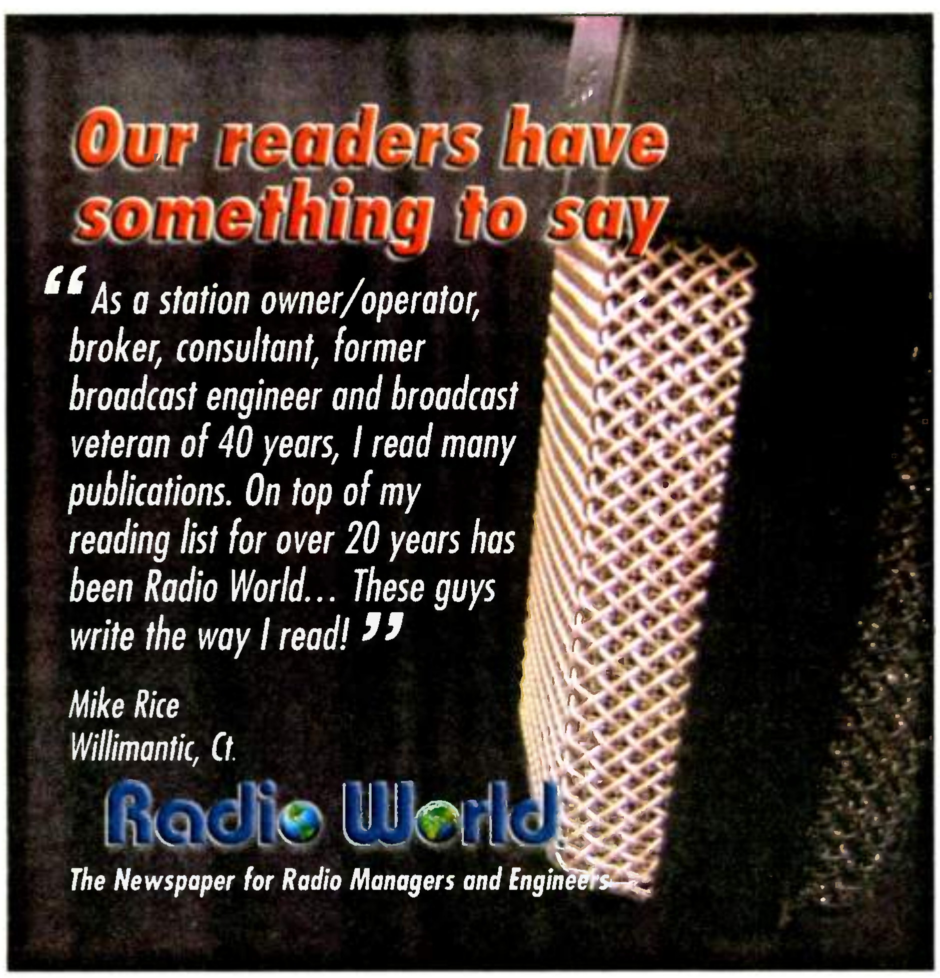


Fig. 1: FM In-Band On-Channel Spectrum As Currently Defined



There are a number of ways to effect this signal combination at high power in the transmitter room, each presenting fairly high loss figures that have been deemed unacceptable by the industry due to cost issues. The difficulty of the combining task at hand may be explained by considering the basic hybrid spectrum for the IBOC FM signal as depicted here (See Fig. 1).

The present analog signal occupies +/- 100 kHz about the carrier and the new digital signal is composed of two sidebands encompassing the regions 101.4 kHz to 198.4 kHz on either side of carrier. The total digital power (sum of both sidebands) is -20dB nominal with respect to the analog carrier. Traditional combining methods for two signals with different frequencies involve the use of frequency selective devices such as filters. However, the extremely close proximity of the sidebands to the analog carrier necessitates, as a minimum, the use of exotic materials for filter implementation. Initial estimates suggest development costs in excess of $500,000 and resulting component costs in excess of $40,000 with no guarantee of success.

PRESENT TECHNOLOGY

Initial testing of the IBOC system was performed through the use of a standard 10 dB coupler. Such devices, which are widely available from many manufacturers, appear to have surfaced as the "best-guess" low-cost solution. A typical device, such as that depicted here, exhibits the following characteristics (See Fig. 2).

The high-power analog signal is fed into port 1. The coupling factor of 10 dB causes 10 percent of this power to be coupled via port 4 and lost into the dummy load. The remaining 90 percent continues via output port 2 towards the antenna.

The digital signal is fed into port 3 and 10 percent is coupled via port 2 towards the antenna, with the remaining 90 percent being dumped via port 4 into the dummy load. Although this combination method allows the IBOC analog/digital spectrum to be realized there are a number of considerations that have to be addressed.

POWER LOSS

Ten percent of the analog transmitter power output and 90 percent of the digital TPO are dissipated via the dummy load. If the analog transmitter has the extra power capability, the TPO can be boosted by approximately 11 percent to allow the station effective radiated power to be maintained. Furthermore, a digital transmitter with a TPO of 10 times the required power is necessary to achieve the correct digital ERP. In addition to the increased cost of analog operation, the heat generated by the analog and digital power being dissipated in the dummy load has to be dealt with, adding a further cost.

ISOLATION

Assuming matched loads at both the dummy load port and the antenna, the analog signal level incident at the digital transmitter would be of the order at -45dBcA. When comparing absolute power levels the relative isolation is somewhat less when compared to the power output level of the digital transmitter.

As an example, consider a case where the existing analog TPO is 35 kW. In order to maintain this 35 kW TPO after the 10 dB coupler, the actual analog TPO has to be raised to 38.9 kW. This yields 3.89 kW to the dummy load and 35 kW to the antenna. Correspondingly, the digital TPO would be 3.5 kW to yield a digital signal of 350 watts, (-20 dB) injected into the antenna output port. The analog signal, which would be incident on digital transmitter output is -45 dB of 38.9 kW = 1.23 watts. With respect to the digital output this is -34.54 dB. If this analog signal level is sufficiently high on the digital transmitter output it could lead to the generation of spurious outputs from the digital transmitter, which would have to be suppressed. In this case a supplemental non-reciprocal isolation device may be employed to increase this isolation to better than 55 dB.

LACK OF VERSATILITY

In most cases in the near future, it will not be necessary to have both the analog and digital signals transmitting 100 percent of the time. Cost containment with respect to power loss is perceived as an important issue. The use of a passive coupling device, such as the 10 dB coupler described above, lacks any versatility, and a transmission system which uses such a device will always require the analog transmitter to be run at an elevated power level. This is true even when the digital signal is not being transmitted unless a switching system is put in place to switch around the coupler. In this case, the transmitters will have to be powered down prior to the switching operation and then brought back up afterwards. The extra costs and analog downtime are, naturally, not well received in the industry.

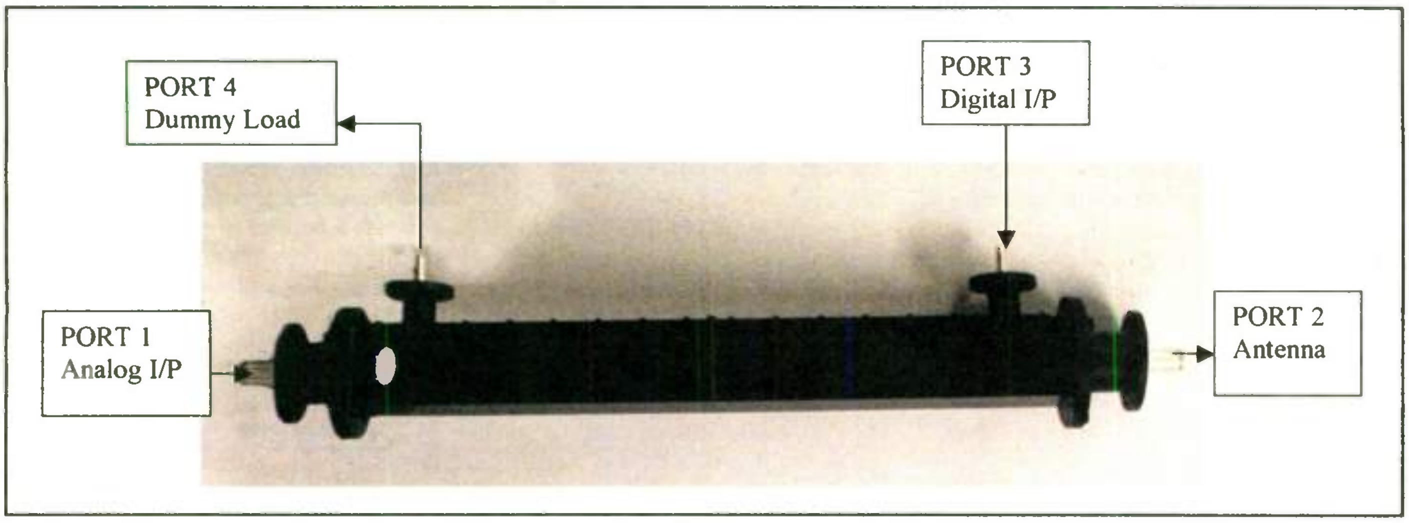


Fig. 2: 10 dB IBOC Injector

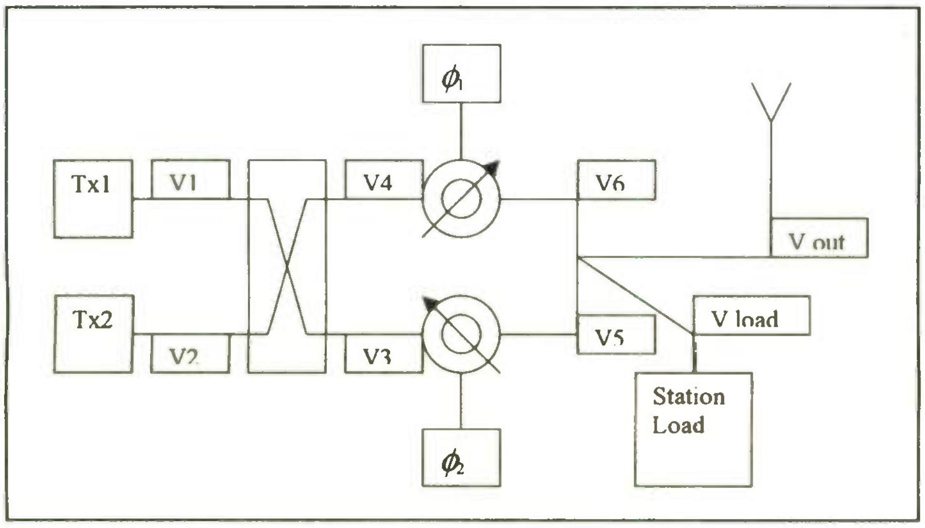


Fig. 3: HDR Dibrid Combiner Circuit Layout

DIELECTRIC'S HDR DIBRID IBOC COMBINER

The use of passive components to combine two signals has been utilized extensively at Dielectric over the past 50 years. Numerous diplexer devices employing a combination of components such as couplers, filters and phase shifters have been investigated and manufactured for numerous markets including broadcast, scientific and defense. The HDR Dibrid IBOC Combiner utilizes a number of standard components to realize a "hot switchable" system, which presents the customer with multiple transmission mode options. The device may be utilized with any envisaged transmitter combination. In each case, the modes may be set up to:

- Select either transmitter to the antenna, with the other directed to the station load; or
- Send a combination of the two transmitters to the antenna with a residual portion of the power directed to the station load;
- Permit versatility with respect to switching between modes, in that the transmitters may remain on throughout the switching process; and
- Permit a transmitter to be switched off and the system reconfigured to give full power to the antenna without turning off the transmitter prior to switching.

Typical Class C analog systems now deployed in the field operate with TPOs of about 35 kW. There is a low-power (up to 10 kW) analog/digital solution available in the form of a single transmitter. In order to achieve the appropriate signal without any changes to the antenna system, anything above this power level requires the use of a high-power combiner. The Dielectric HDR Dibrid IBOC Combiner may operate in either single mode, which utilizes the existing analog transmitter plus a medium-power digital transmitter, or in hybrid mode, which utilizes the existing analog transmitter plus an analog/digital transmitter. Optimum IBOC combination performance may be achieved when using the hybrid mode.

HDR DIBRID IBOC COMBINER OPERATIONAL CHARACTERISTICS

In order to allow an appreciation of the simplicity and elegance of the HDR Dibrid IBOC Combiner, an analysis of the circuit is presented here (See Fig. 3).

Beginning with the input sources Tx1 and Tx2, where

Tx1 = Analog + Digital Low Power Transmitter, and

Tx2 = Existing Analog High Power Transmitter,

and the respective voltages are

(1)

$$V_{Tx1} = V_A 1 + V_D = V1$$

(2)

$$V_{Tx2} = V_A 2 = V2,$$

where $V_A 1$ is the analog voltage component of V1, emitted by transmitter Tx1, V_D is the digital voltage component of V1, emitted by transmitter Tx1.

Working through the 3 dB quadrature hybrid coupler, the V_3 and V_4 port voltages are

(3)

$$V_3 = -j\frac{V1}{\sqrt{2}} + \frac{V2}{\sqrt{2}},$$

(4)

$$V_4 = \frac{V1}{\sqrt{2}} - j\frac{V2}{\sqrt{2}}.$$

DIBRID, PAGE 24

DIBRID

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Substituting equations (1) and (2) into (3) and (4) yields

(5)

$$V_3 = -j\frac{(V_A1+V_D)}{\sqrt{2}} + \frac{V_A2}{\sqrt{2}},$$

(6)

$$V_4 = \frac{V_A1+V_D}{\sqrt{2}} - j\frac{V_A2}{\sqrt{2}},$$

(7)

$$V_3 = \frac{V_A2 - jV_A1}{\sqrt{2}} - j\frac{V_D}{\sqrt{2}}, \text{ and}$$

(8)

$$V_4 = \frac{V_A1 - jV_A2}{\sqrt{2}} + \frac{V_D}{\sqrt{2}}.$$

Assume that V_A1 and V_A2 are adjusted to be in phase at their respective inputs to the 3 dB hybrid coupler. When the amplitudes of V_A1 and V_A2 differ, the resultant phase of the V_A component in V_3 and V_4 will be different. Let us assume for this example a power ratio of 4:1, equivalent to a voltage ratio of 2:1. Then

(9)

$$V_A1 = 0.5V_A2.$$

Substituting this in equations (7) and (8) above yields

(10)

$$V_3 = \frac{(V_A2 - 0.5jV_A2)}{\sqrt{2}} - j\frac{V_D}{\sqrt{2}}, \text{ and}$$

(11)

$$V_4 = \frac{(0.5V_A2 - jV_A2)}{\sqrt{2}} + \frac{V_D}{\sqrt{2}}.$$

In terms of phase angles, equations (10) and (11) can be expressed as,

(12)

$$V_3 = \frac{1.118V_A}{\sqrt{2}}\angle -26.56° \quad + \quad \frac{V_D}{\sqrt{2}}\angle -90°$$

(13)

$$V_4 = \frac{1.118V_A}{\sqrt{2}}\angle -63.43° \quad + \quad \frac{V_D}{\sqrt{2}}\angle 0°$$

Next, by adjusting phase ϕ_1, of phase shifter 1 and phase ϕ_2 of phase shifter 2 so that

(14)

$$\phi_1 = -36.87°, \text{ and}$$

(15)

$$\phi_2 = 0°$$

the input voltages V_5 and V_6 at the combiner will be

(16)

$$V_5 = \frac{1.118V_A}{\sqrt{2}}\angle -63.43° \quad + \quad \frac{V_D}{\sqrt{2}}\angle -126.87°$$

(17)

$$V_6 = \frac{1.118V_A}{\sqrt{2}}\angle -63.43° \quad + \quad \frac{V_D}{\sqrt{2}}\angle 0°$$

Thus, the analog signal components V_5 and V_6 entering the two legs of the 3 dB Dibrid combiner are in phase and have equal magnitude. Calculating the total analog output $V_{A\,OUT}$ results in,

(18)

$$V_{AOUT} = \frac{1}{\sqrt{2}}V_{5A} + \frac{1}{\sqrt{2}}V_{6A}, \text{ or}$$

(19)

$$= 1.118V_A\angle -63.43°.$$

With a power ratio of 4:1 as originally specified,

(20)

$$P_{AOUT} = 1.25P_{AIN},$$

where $P_{A\,OUT}$ is the total analog power out of the system and $P_{A\,IN}$ is in the analog power furnished from Tx2, the existing high-power analog transmitter.

Thus, with a 3 dB Dibrid combiner fed by two equal-magnitude, in-phase signals, all of the analog power goes to the antenna path.

Consider now the digital signal. The two signals at the inputs to the 3 dB Dibrid combiner are equal in magnitude, but are out of phase by 126.87 degrees. This corresponds to 90 degrees from the input 3 dB quadrature hybrid coupler plus the 36.87 degrees from phase shifter 1 since, as above, the phases ϕ_1 and ϕ_2 of the phase shifters 1 and 2 are set so that

(21)

$$\phi_1 = -36.87°$$

and

(22)

$$\phi_2 = 0°.$$

Accordingly, the input voltages V5 and V6 will be

(23)

$$V_{5D} = \frac{V_D}{\sqrt{2}}\angle -126.87°$$

and

(24)

$$V_{6D} = \frac{V_D}{\sqrt{2}}\angle 0°.$$

The digital component appearing at the sum port of the Dibrid combiner, $V_{D\,OUT}$, is directed to the antenna path, and may be computed as

(25)

$$V_{DOUT} = \frac{1}{\sqrt{2}}V_{5D} + \frac{1}{\sqrt{2}}V_{6D}, \text{ or}$$

(26)

$$= \frac{V_D}{2}\angle -126.87° + \frac{V_D}{2}\angle 0°,$$

which resolves to,

(27)

$$V_{DOUT} = 0.447V_D\angle -63.43°.$$

In terms of power, this translates to the relationship

(28)

$$P_{DOUT} = 0.2P_{DIN},$$

where $P_{D\,OUT}$ is the total digital power output from the system to the antenna, and $P_{D\,IN}$ is the digital power from the Tx1 combined analog/digital transmitter.

The V_{LOAD} signal emitted from the difference port of the 3 dB Dibrid is directed to the station load. This value may be computed as

(29)

$$V_{LOAD} = \frac{1}{\sqrt{2}}V_5 - \frac{1}{\sqrt{2}}V_6, \text{ or}$$

or

(30)

$$= \frac{1}{\sqrt{2}}\left(\frac{V_D}{\sqrt{2}}\angle -126.87° - \frac{V_D}{\sqrt{2}}\angle 0°\right),$$

(31)

$$= \frac{V_D}{2}\angle -126.87° - \frac{V_D}{2}\angle 0°.$$

which resolves to,

(32)

$$V_{LOAD} = 0.894V_D\angle -26.55°.$$

In terms of power,

(33)

$$P_{LOAD} = 0.8\,P_{D\,IN},$$

where P_{LOAD} is the power transmitted to the station load.

The as-broadcast digital power level is required under the IBOC specification to be no greater than –20 dB with respect to the as-broadcast analog power level. In the example given, for the digital power at the output to be –20 dB with respect to $P_{A\,TOTAL}$, where $P_{A\,TOTAL}$ is five times the analog signal level out of Tx1, then

(34)

$$P_{D\,OUT} = 0.05\,P_{A\,Tx1}$$

This is 20 percent of the total digital power output from the analog/digital transmitter Tx1. This means that the digital level of the analog/digital transmitter cannot exceed 0.25 $P_{A\,Tx1}$ to remain within the FCC mandated IBOC mask.

The example shown here was for a 4:1 power ratio between transmitters. However, as is evident, any ratio may be utilized provided the interference between transmitters can be minimized.

HYBRID MODE OPERATION

In hybrid mode, the existing analog transmitter would be used to feed one input and a solid-state analog/digital transmitter would feed the other. This configuration allows the broadcaster the greatest versatility, because there are a number of transmitter output signal combinations that may be utilized.

For the sake of a comparative example, consider the same power requirement of 35 kW for analog ERP as was used in the previous "high-loss" combiner example. In the case of the full-power HD Radio mode, the required signal would consist of 35 kW analog and 350 watts of digital. The analog/digital solid-state transmitter allows this combination to be realized a couple of different ways since it may be used as either a standalone digital or a low-power IBOC transmitter. Optimum performance would be achieved by using the solid-state transmitter as a low-power IBOC transmitter, whose output was a combination of both analog and digital carrier power. As such, the existing analog transmitter may be throttled back and fed into one input of the Dielectric HDR Dibrid Combiner with the other input being fed by the analog/digital low-power IBOC signal from the solid-state transmitter.

For a numerical example, consider the case where the existing analog transmitter could be throttled back to, say, 28 kW, which should enable a much longer life for the tube. In order to achieve the desired HD Radio Signal, the solid-state transmitter would then be set with an analog signal level of 7 kW and a digital signal level of 1.75 kW.

Table 1 depicts the various modes of operation where there is always a signal to the antenna.

SINGLE-MODE OPERATION

In single-mode operation, the existing analog transmitter is utilized to feed one input of the combiner and a medium-power digital-only transmitter is used to feed the other. In order to realize a satisfactory HD Radio signal level it is necessary to boost the output power of the existing analog transmitter to allow for analog losses, which occur only when the combiner is used in single-mode operation. The various combiner modes allow the input signals to be combined to provide the appropriate HD Radio signal and also allow either one of the transmitters to broadcast while the other is powered down or switched into the station Load.

Combiner Mode	Analog TX	Solid-state TX	Antenna	Station Load
1	28 kW	7 kW Analog plus 1.75 kW Digital	Full Power HD Radio 35 kW Analog plus 350 W Digital	1.4 kW Digital
2	35 kW	Full Test Power	Full Power Analog (35 kW)	Solid-State Full Test Power
2	35 kW	0	Full Power Analog (35 kW)	0
3	Analog Full Test Power	Stand Alone HD Radio Signal	Reduced Power HD Radio from Solid-State TX	Analog Full Test Power
3	0	Stand Alone HD Radio Signal	Reduced Power HD Radio from Solid-State TX	0

Table 1: Operating Modes of Dibrid Combiner

Combiner Mode	Analog TX Output	Digital TX Output	Antenna	Station Load
2	35 kW	0	Full Power Analog (35 kW)	0
2	35 kW	Full Power Digital	Full Power Analog (35 kW)	Solid-State Full Test Power
3	35 kW	Full Power Digital	Digital Only	35 kW Analog Power
4	38.9 kW	3.5 kW Digital	Full Power HD Radio (35kW Analog plus 350 W Digital)	3.9 kW Analog plus 3.15 kW Digital

Table 2: Combiner Options in Single-Mode Operation

In effect this single mode is a switchable version of the "high-loss" combiner previously described as the present technology. For the 35 kW example cited above, Table 2 shows the combiner options available.

ENHANCED VERSATILITY USING HYBRID MODE

The selectivity provided by the low-power solid-state IBOC transmitter discussed above is such that, in addition to being able to simply alter the output power level, the analog or digital portion of the signal may be switched on or off at will. This additional level of versatility from this type of transmitter allows more versatility when using the Dielectric HDR Dibrid Combiner. Using the same power levels as the previous examples, Table 3 shows how the combiner modes may be used in conjunction with the various transmitter modes to provide an extremely versatile system. Any combination of the possible transmitter outputs may be utilized.

Combiner Mode	Analog TX	Solid-state TX	Antenna	Station Load
1	28 kW	7 kW Analog plus 1.75 kW Digital	Full Power HD Radio 35 kW Analog plus 350 W Digital	1.4 kW Digital
1	28 kW	7 kW Analog	Full Power Analog (35 kW)	0
2	35 kW	0	Full Power Analog (35 kW)	0
2	35 kW	Full Test Power	Full Power Analog (35 kW)	Solid-State Full Test Power
3	Analog Full Test Power	Stand Alone HD Radio Signal	Reduced Power HD Radio	Analog Full Test Power
3	0	Stand Alone HD Radio Signal	Reduced Power HD Radio	0
3	35 kW	10 kW Analog only	Reduced Power Analog (10 kW)	35 kW Analog Power
3	0	10 kW Analog only	Reduced Power Analog (10 kW)	0
4	38.9 kW	3.5 kW Digital only	Full Power HD Radio 35 kW Analog plus 350 W Digital	3.9 kW Analog plus 3.15 kW Digital

Table 3: Combiner Options in Hybrid-Mode Operation

In Mode 1 the existing transmitter is throttled back to 28 kW and the additional 7 kW required supplied by the new solid-state unit. The digital signal may be on or off.

Mode 2 allows the existing analog transmitter to be run at its existing power level, while having the capability of testing the solid-state transmitter.

Mode 3 allows the full versatility of the solid-state transmitter to be realized. All of the power from the existing analog transmitter is directed to the station load. The output of the solid-state unit, which may be analog only or standalone IBOC, is directed to the antenna.

Mode 4 allows the use of a digital-only input from the solid-state transmitter. In this case the analog power is raised to compensate for losses and the system mimics the current 10 dB coupler method.

The Dielectric HDR Dibrid combiner may be switched between modes while under full RF power and all of the modes described may be achieved remotely if the appropriate interface technology is available. It should be noted here that, although the examples shown throughout utilized a transmitter power ration of 4:1, other ratios are usable also. The limiting factor from a technical standpoint with regard to the hybrid mode operation is how much digital signal power one is prepared to lose to the station load. For the 4:1 (80:20 percent) example, 80 percent of the digital TPO was lost to the load. For a 6:1 ratio, 85.7 percent would be dumped. Practice has shown that the practical limit is of the order of 9:1 where 90 percent of the digital TPO would be lost. This is similar to the digital signal losses using the present "high-loss" 10 dB coupler method but with the major advantage that no analog power is lost.■

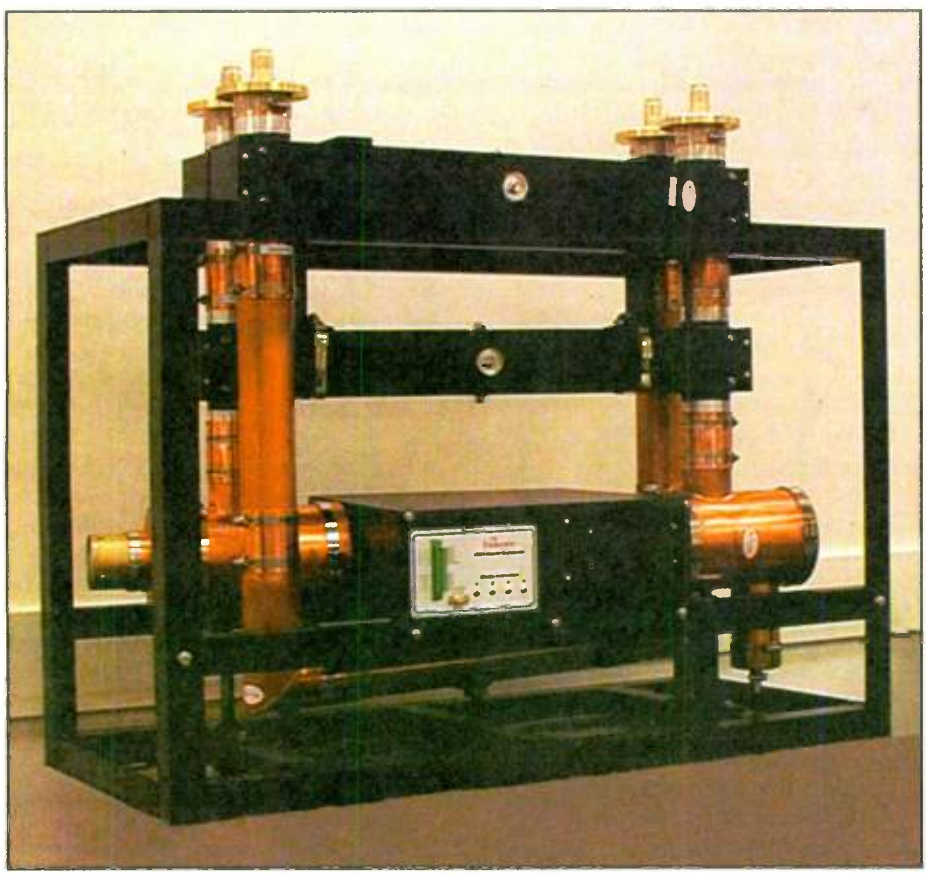


Fig. 4: Dibrid Combiner

An Opportunity to Turn the Bad Into Good

By Cris Alexander

The author is director of engineering for Crawford Broadcasting.

When I was growing up in the 1960s, from time to time I heard a bad word. School was the usual place, and it was seemingly always the same group of boys that used bad language, almost wearing it like some sort of badge. Most of the bad words had four letters, although the verbs could be conjugated many different ways and the nouns could be hyphenated and joined with other words, some innocuous, to form even worse bad words.

As I grew up, many of these words made their way into mainstream culture. Movies became filled with them, as did some music (in those days you had to buy the album to hear the unedited version, however). Before long, except in Christian circles, bad words became acceptable parts of the vernacular.

It has been interesting over the years to see how the English language has changed. Not only has it soaked up a guttural element into the everyday, but the meanings of words have changed, sometimes dramatically. And words that were once far from profane now elicit gasps and murmurs. A few examples (brace yourselves): Tower; Antenna; Transmitter; RF.

Speak those words in certain contexts and you can almost hear the men folk say, "Get a rope."

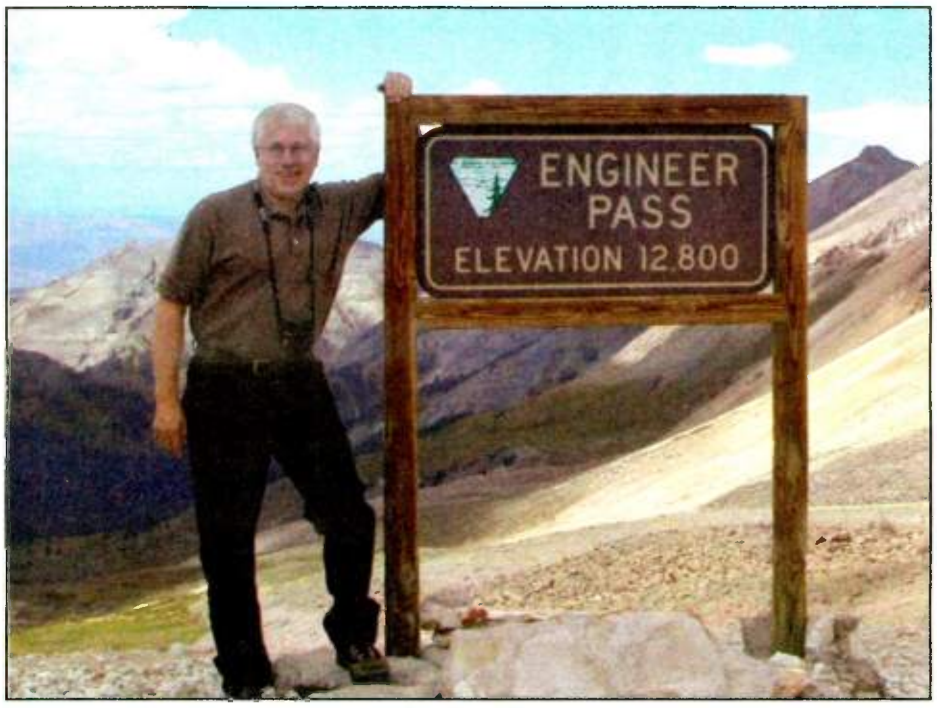
'MOST IRRADIATED'

This seems to be truer in some parts of the country than others. The more densely populated the area is, the more offensive those words are. In Colorado where I make my home, it seems that there is almost always something in the paper or in the news about a fight to keep an antenna or tower from being built, or even to get the ones that have been here for decades removed. There is one community up on Lookout Mountain (where most of the Denver area FM and TV transmitter sites are located) where the resistance is well-organized, well-funded and even passes out T-shirts emblazoned with, "Lookout Mountain: The Most Irradiated Community in America" or some such. It is that group that has (somewhat) successfully prevented over-the-air DTV from coming to the Denver area in a significant way.

NEW TOWERS NEEDED

It was with all that in mind that Crawford Broadcasting Co. put together and filed an application with the Adams County Planning Department for a conditional use permit to build four (gasp!) new towers at the existing KLZ transmitter site just north of Denver. The purpose of these towers is to provide one of our stations with a market nighttime signal on 810 kHz. The station is currently a daytimer on 800 kHz.

Knowing that it sometimes takes six months to get through the local regulatory boards (if they can be successfully navigated at all), rather than waiting on an FCC grant of our modification application, we proceeded with the conditional-use permit application. After months of back-and-forth with the planning commission staff, the hearing at the Planning Commission was set.



Cris Alexander

Wondering what kind of opposition we would face and what kind of reception the commissioners would give us, it was with some trepidation that our local chief engineer, our planner and I entered the commission chambers.

We had a number of things going for us.

One was that the new towers did fit the definition of "collocation," a key factor with a lot of local governing bodies these days. Whenever you can use an established tower, structure or site, you're more likely to find favor with the local jurisdiction.

Another factor was the low visual impact. The site is fairly well screened from view from the residential area across the street by a line of established trees that runs along the right-of-way. The existing two towers are certainly visible because of their height, but the new towers will be short enough that they won't be readily visible. Low visual impact is another key phrase.

Our case was about three-fourths of the way down the docket, behind a couple of simple tract subdivisions, a water pipeline pump station and a planned, new business subdivision. Our position on the docket could have been good or bad — good in that it would give us a chance to observe the commissioners and how they interacted with the other proponents; bad in that we may have to wait a long time and the other cases might tire out or put the commissioners on edge.

As it turned out, it was for the best. By the time our case was called, I had a good feel for the commissioners and their personalities.

Our case was presented in a well-produced PowerPoint slide show by a commission staffer, after which the commissioners turned to me with a number of questions. I was definitely in the hot seat, but it turned into a rare opportunity to explain, in layman's terms, some of the workings of AM transmitter sites, antenna structures and the like.

Here are some of the questions:

"Why does your proposal require four towers when the one we heard last month required only one tower?"

"Why are multiple towers used in AM when in the land mobile industry, many users can share a single tower?"

"If the opportunity presents itself, could another AM station or other user share the proposed towers?"

"Are there buried wires for grounding at the base of each tower?"

One commissioner, the chairman, asked if the improved station would provide nighttime reception at her house.

I was surprised that the questions were so astute. The commissioners — three of them in particular — genuinely wanted to know more about AM antennas and towers, and I was provided with the opportunity to educate them. They listened attentively, asked clarifying questions that indicated they had been listening, and at the end of the back-and-forth, they thanked me for educating them.

The vote? It was unanimously in favor of granting our conditional use permit.

A month later, I had to go before the full County Commission, which is not always a "rubber stamp" of the Planning Commission in such cases. The public again has the opportunity to speak in opposition. In this case, things went very much the same as they had with the Planning Commission. The county commissioners were interested and they did have some concerns. In particular, they asked me about RF radiation and what measures we would take to protect the public.

Again, that invited a mini-lecture on the ANSI/FCC standard, the procedures that we had to go through with the FCC to certify that our proposed facility would protect the public and workers from harmful levels of RF radiation, and the specifics of our installation. As with the Planning Commission, the county commissioners thanked me for educating them. I could tell that they were comfortable with what they had been told. Again, the vote was unanimously in favor of our application; we have our conditional use permit.

EDUCATION HELPS

With the local governing board approvals in hand, I can feel good about the fact that with the current Adams County Planning and County Commissions, the words "tower," "antenna" and "RF" aren't such bad words anymore. Educating those commissioners in large part took care of that. I only wish we could do something to stop the trend throughout our nation.

Those opportunities for me came more or less out of the blue. I certainly didn't expect them. The opportunity for you to educate an individual or group may likewise fall unexpectedly into your lap. Watch for opportunities to dispel the myths, citing verifiable facts in a non-threatening way.

Education is the key to understanding, and being a good neighbor goes a long way, too. Cooperate with neighbors. Help them fix the RFI in their telephones. Take steps that improve the relationship. You'll build goodwill that will pay dividends.

I don't live under the delusion that towers and transmitter sites will someday be welcome neighbors throughout the country. But I do believe that broadcasters can do a lot to dispel the misinformation that is floating around out there about towers, RF and interference. It's up to us to be flexible, provide information and work at being a good neighbor. And by doing those things, perhaps we will be viewed in a better light.■

5.1 Surround Sound Music Needs a Jumpstart

It's Time to Move Toward a Standard for Radio

By Guy Wire

Guy Wire, Radio World's masked engineer, is the pseudonym of a well-known radio veteran who prefers to remain anonymous.

The time for 5.1 surround sound has arrived for radio. At NAB this year you'll hear it touted as a killer app for HD. Consumers have been snatching up 5.1 DVD movies in buckets for their home theatre installations and like what they hear. I've had it in the family room for two years and even my non-technical wife is saying "wow" when I least expect it. Real surround sound is a winner when conveyed with creative and appropriate production techniques.

The satellite services are producing 5.1 surround sound content. XM and Sirius have launched 5.1 offerings on at least one of their channels for testing. While a few new-model cars are being equipped for 5.1, most receivers and car sound systems still need to be updated for satellite subscribers to be able to enjoy the real 5.1 experience. But so far, traditional radio has almost nothing to show in this arena.

TRACING THE ROOTS

Multichannel and surround sound is an old idea that has appeared in various incarnations of recorded audio and video over the past 45 years. My old sparring partner, Skip Pizzi, has traced its evolution in a recent series of RW articles, providing a wealth of historical background and insight into the technology.

Surround sound never was widely embraced as a consumer product until the movie industry settled on the Dolby Digital 5.1 format, now used for most DVDs. The music recording industry can produce 5.1 content for distribution via new audio formats like DVD-A and SACD, but so far they aren't showing much interest in the burgeoning 5.1 market.

The rollout is very slow with limited new titles and almost no existing titles being published. Most record companies seem reluctant to remaster existing recordings to 5.1. In some cases, they are legally restrained from doing so. It's much easier to create 5.1 content from scratch with new releases.

AN OLDIES RENAISSANCE

I think they're missing a golden opportunity here to revitalize their troubled enterprise. Hit songs of the past in all genres and eras are enduring fixtures in our memories. An enhanced entertainment product and experience was created for the consumer when Ted Turner colorized and re-released old black-and-white movie classics. If it's done right, there is no reason that creating new versions of classic hits in 5.1 would not enjoy a sales renaissance for fans everywhere.

The incentive to produce new 5.1 content is also constrained because older surround sound matrix schemes, phase manipulation and other processing techniques allow plain old unencoded stereo to sound "spacious" or "pseudo-surround" in a lot of consumer playback equipment already out there. This confuses the consumer's understanding of what real multichannel surround sound is and can achieve. Too many think they already have it or have heard it on multiple speakers, but sadly, they haven't heard the real thing. The phony surround systems don't work very well and have no doubt poisoned the well for some consumers.

If 5.1 is going to earn its stripes as a bona-fide killer app for HD radio, it deserves the best-performing and easiest-to-implement technology.

While the music industry struggles to release new content in 5.1, the radio industry has its own problems harnessing the opportunity. Not too many radio production folks have any idea how to produce realistic and appropriate surround sound material. There's a lot more to the art form than just playing musical ping-pong from channel to channel with different voices and instruments. A 5.1 learning curve lies ahead for most.

ANOTHER STANDARDS BATTLE BREWING

The larger problem is all about standards. Without a clear industry-wide

GUY WIRE, PAGE 28

Who's on the NRSC?

Stories in Radio World often refer to the National Radio Systems Committee, or NRSC. But what does it do and who is on it?

The NRSC is co-sponsored by the Consumer Electronics Association and the National Association of Broadcasters. Its purpose is "to study and make recommendations for technical standards that relate to radio broadcasting and the reception of radio broadcast signals." Broadcasters and receiver manufacturers can work together on common problems in radio broadcast systems. As such it is an influential organization where notable decisions about the future of the industry are played out.

Anyone with a business interest in technology being investigated by the NRSC can join; members generally are engineers, scientists or technicians. Reporters are not allowed to attend NRSC meetings, which are held as needed and usually scheduled to coincide with NAB and CES conventions.

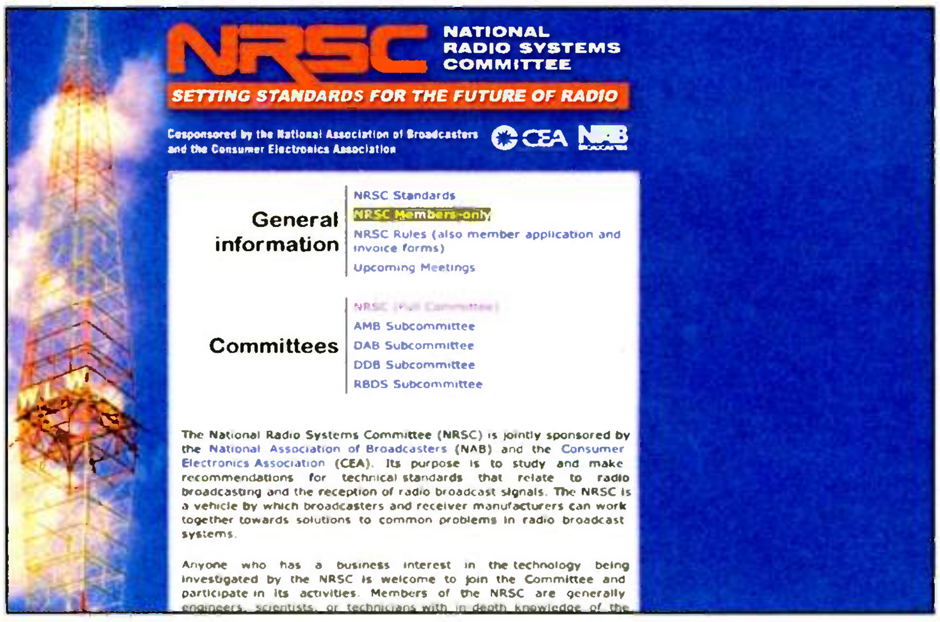
Members participate at their own expense.

NRSC FULL COMMITTEE

The NRSC Full Committee is chaired by Charlie Morgan of Susquehanna Radio and is the umbrella under which other NRSC groups operate. Recommendations to proceed with standards setting may originate within that committee and are assigned to subcommittees for development and adoption.

Subcommitees deal with such topics as AM broadcasting, digital audio broadcasting, digital data broadcasting and the radio broadcast data standard.

These are the current members of the NRSC Full Committee, according to the organization's Web site:



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Readers interested in the NRSC can contact David Layer of NAB at (202) 429-5339 or Dave Wilson of CEA at (703) 907-7421, or visit its Web site at *www.nrscstandards.org*.

GUY WIRE

CONTINUED FROM PAGE 27

technical standard, stations are not compelled to implement the necessary production and transmission infrastructure to deliver HD 5.1. Unless radio stations encode and receivers decode the same 5.1 format, nobody will hear it. There are at least five contending entities in this contest, all with their own techniques and designs.

Dolby Labs and SRS Labs both have established bases of existing surround sound playback systems in the marketplace that decode their modified matrix formats. Fraunhofer/Telos and Coding Technologies/Orban are each proposing new high-performing parametric discrete systems. Neural Audio Labs and Harris appear to have the most easily manipulated and transmitted discrete method using their watermark technique. All produce impressive surround-sound results, but to my ears the discrete systems produce more consistent and faithful spatial accuracy.

The satellite services can pick what they want since they completely control both ends of their proprietary systems to captive subscribers. XM is using Neural while Sirius has chosen SRS Circle Surround. Ibiquity on the other hand is playing the 5.1 application to HD tentatively. So far, they've taken the easy way out and defaulted to a marketplace decision, letting broadcasters choose what transmission method they want since HD will convey any of the methods in its bitstream.

This approach is akin to the FCC's marketplace decision on AM stereo. As a collective industry, have we not learned anything from that painful misadventure? While it might be true that receivers can be built with multiple decoder configurations allowing broadcasters to pick the encoding scheme they like, the AM stereo experience proved unequivocally that this is a messy and woefully inefficient way to deliver new technology in a consumer electronic device.

Broadcasters, receiver manufacturers and the public all want and deserve a single surround sound standard to reduce confusion and allow mass production of compatible, simple-to-use equipment.

If 5.1 is going to earn its stripes as a bona-fide killer app for HD radio, it deserves the best-performing and easiest-to-implement technology. It's time for Ibiquity, the NRSC and CEA to tackle this issue together and develop a fair and equitable method to evaluate and choose the best system. It's out there for the taking, if only nasty politics and lawsuits don't get in the way.

After a single standard is in place, content providers can forge ahead quickly, knowing that producing real 5.1 material for both the consumer and the broadcast markets will likely pay off. You can see the train coming, guys. It's time to get busy and get ready to climb aboard.

RW welcomes other points of view. ■

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The Formal Process of Optimizing Engineering Trade-Offs

By Barry Blesser

We have all experienced negotiation — when we've asked for a salary raise, purchased a new house or created a specification for a broadcast studio. Negotiating is a process for finding a compromise that balances incompatible values, goals, wishes and requirements. Design engineers call it "sorting tradeoffs."

Competing requirements frequently exist between individuals, within a single person or as part of a technical situation. Although we negotiate and sort tradeoffs, few of us have considered that there is a formal technique that makes the process efficient, thereby leading to an optimum solution with a minimum of stress, anxiety and acrimony.

GET TO YES

I did not invent what I am about to describe, but I have used it successfully in a variety of engineering, business and personal situations. For those who want to explore the topic further, I strongly recommend the popular book *Getting to Yes. Negotiating Without Giving In* by Roger Fisher and William Ury. It is available for a few dollars at your local bookstore. It originated from Harvard University's Program on Negotiations; the principles have been applied to international disputes, labor conflicts and home purchases. These techniques are just as useful to engineers functioning in their technical profession.

There are right and wrong ways to negotiate.

The right way begins with goals; the wrong way begins with a proposed solution. Consider a professional example. An engineer who asserts that the radio station needs a new license to broadcast with more power is beginning with a solution. But an engineer who asserts that the station should try to expand its listening audience is beginning with a goal.

The former fixates on a single solution, the latter includes the possibility of installing repeater stations, broadcasting over the Internet or syndicating programs over a national network.

Now consider a personal example. An engineer who desires a shorter workweek is proposing a solution, but an engineer who wants time for a personal activity is articulating a goal. There may be many ways to find extra time that do not involve changing the structure of the workweek. Perhaps there are periodic intervals when the engineer must be present but when there is nothing for him to do. The ideal solution would be for the engineer to use that free time for his personal needs.

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A negotiation process has five recognizable stages, beginning with goals and ending with a solution.

Stage 1

All parties articulate their values and goals while being careful not to include hidden solutions.

For example, a station manager may articulate the following goals: increase profitability for the owner, increase listeners' loyalty, establish a unique sound that is recognized among advertisers and create a pleasant working environment for the staff. At a personal level, an engineer may desire to earn a large income, have an opportunity for professional growth, be within walking distance of his home and become well known in the industry.

Stage 2

Each party sorts goals in order of priority. It is unlikely that a solution exits that will satisfy all goals. Some are obviously more important than others, and the least important ones can be abandoned if the highest priority goals are met. For most people, figuring out what is most important is the hardest stage. Give it the time it deserves.

Stage 3

The parties engage in a dialog to understanding each other's lists of goals. One must not challenge the list; it is a given. Nobody can tell another person what he should want; one must respect everyone's right to have a personal set of goals. Goals are not negotiable.

Stage 4

The parties brainstorm for a comprehensive list of possible solutions but without regard for their quality or utility. With a large enough list, there is the likelihood that some variant of a solution, or some combination of solutions, will match the highest priorities for all parties. Through this process, shared interests emerge.

Stage 5

Only now do the parties explore how to select a solution that matches the highest priorities. Inventing solutions is everyone's job, and that job requires solutions that optimize the collective needs of all parties. By devaluing everyone's low-priority needs in exchange for elevating everyone's high-priority needs, trading takes place. Everyone contributes because everyone's situation is public.

However, goodwill is still required for the process to work. If one party tries to force a solution that matches his goals, while ignoring the goals of the other party, the process becomes a deadlocked stalemate without a solution.

SOLUTIONS VS. EMOTION

Consider an example of how these stages might be applied.

Rather than advocating that a transmitter should be replaced because of its inadequate frequency response, the process begins with the goal: creating a unique sound. The list of values might include the ease of implementation, the cost of the change, the risk that the change would be counterproductive and available skills among the staff. These are sorted.

Proposed solutions might include making the sound hotter and louder, adding reverberation to give it a unique spatial quality, improving the signal strength in fringe areas and so on. Creative people (and most are) can brainstorm for solutions if they are not emotionally committed to their particular proposal.

Finally, everyone works towards the best solution.

Although the approach easily works when everyone understands and believes in the process, negotiations fail, or become problematic, with a rigid personality who only thinks in terms of solutions. Moreover, aggressive personalities may measure their sense of power by their ability to force a solution onto someone else even if it is useless or counterproductive. Egotists can become emotionally hijacked when thwarted.

There are ways of handling such situations, but that topic is for another discussion. Mostly, however, professionals have goodwill as part of their value system, thus making this problem less relevant.

In an earlier article, I advocated the merits of asking the right question when trying to improve quality. Negotiating is just another application of the same idea: Ask the right questions in the correct order. More often than not, that initial question should be, "What problem are you trying to solve?" If someone begins with a solution, help that person translate it into a goal by generalizing the idea.

On a final note, the goal-first approach works when having a dialog with oneself, when writing a specification for a project, when creating a team among diverse individuals and when designing a product. While we all understand the concept of trade-offs, by placing those concepts into the context of negotiating, we are able to use a time-tested set of rules and procedures that is known to work.

Try it. It is fun and harmonious, and it works best when everyone understands the process. If someone is not familiar with the method, get them a copy of "Getting to Yes." For that matter, share it with your friends and family. ■

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