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ENGINEERING EXTRA

DESIGNER INTERVIEW

Clarence M. Beverage

The Engineering Of Radio Signals

Clarence Beverage Talks About Designing Radio Stations to Put the Signal Where You Want It

By Michael LeClair

Engineering consultants are a bedrock of our radio broadcasting system. In order to create a reliable and consistent broadcast service, rules and laws have been fashioned, creating standards for the way we use the basic physics of radio communications. Over the many years since radio began, these rules have sometimes been changed to reflect new

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Improved Spectral Compliance for FM HD Radio Using Digital Adaptive Pre-Correction

Feedback Technique Ensures Minimal Interference Under Varying Load Conditions

By Tim Hardy

The author is head of development for Nautel Ltd. in Bangor, Maine.

HD Radio implementation has introduced a great deal of discussion about spectral re-growth problems when digital carriers intermodulate with the primary FM carrier, causing spurious emissions on adjacent channels. Pre-correction systems may be implemented to mitigate the effects of transmitter system non-linearity giving rise to the out-of-band emissions.

However, conventional fixed pre-correction techniques have not provided a sufficient solution to ensure spectral integrity in a changing environment. Changes in VSWR, an adjustment in the output power of the transmitter, a change in amplifier temperature, or aging and failures of RF amplifiers can result in serious transgressions of the HD Radio mask and interference with other stations.

This paper presents theory and measured performance of digital adaptive pre-correction under unstable environmental conditions. Comparison is made between fixed pre-correction curves and adaptive pre-correction under typical conditions at broadcast sites.

BACKGROUND

The trend in the broadcast industry is now toward digital communications standards. The Ibiquity FM HD Radio system employs a digital modulation technology known as Orthogonal Frequency Division Multiplexing, or OFDM. This modern communications technique provides both excellent bandwidth efficiency and high tolerance to the multipath fading environment common in urban settings.

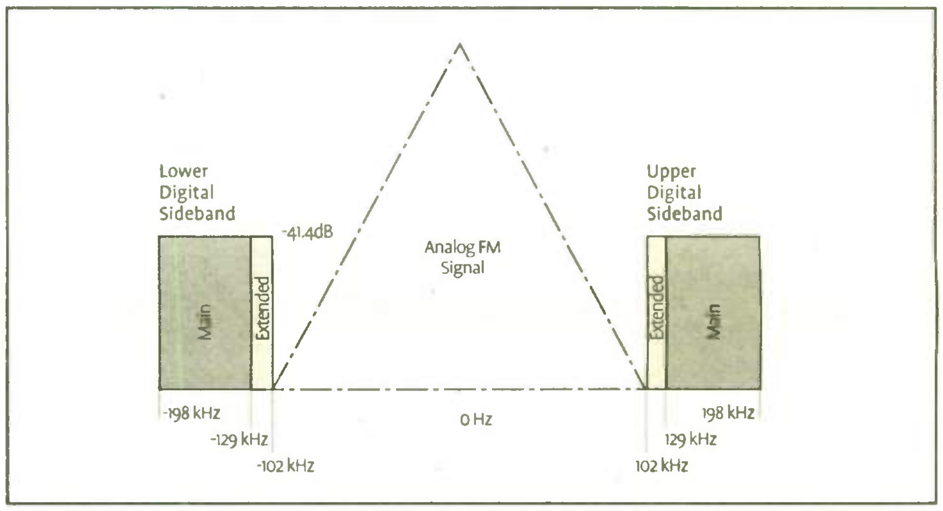

Fig. 1: Hybrid FM HD Radio Spectrum

All HD Radio systems going on the air today are "hybrid" systems, which means the transmitted signal consists of both an analog FM modulated portion and digitally modulated OFDM carriers. The digitally modulated portion consists of many Quadrature Phase Shift Key modulated OFDM carriers spaced 363 Hz apart. The carrier spacing and carrier symbol rate are such that they are orthogonal; they do not interfere with each other. In the basic hybrid mode the "main" OFDM spectrum contains 382 carriers from approximately 130 kHz to 200 kHz, both above and below the channel center frequency.

In the extended hybrid modes the spectrum contains up to 534 carriers from approximately 100 kHz to 200 kHz, both above and below the channel center frequency (see Fig. 1).

With the introduction of OFDM, transmitter designs have had to evolve due to a new requirement: linearity. Traditional FM transmitters operated highly nonlinear class C amplifiers. This was acceptable due to the constant envelope nature of the FM signal. The OFDM envelope

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- Telephone: (703) 998-7600
- Business Fax: (703) 998-2966
- Editorial Fax: (703) 820-3245
- E-mail: radioworld@imaspub.com
- Online: www.rwonline.com

The staff may be contacted at the phone extensions listed, or via e-mail to radioworld@imaspub.com.

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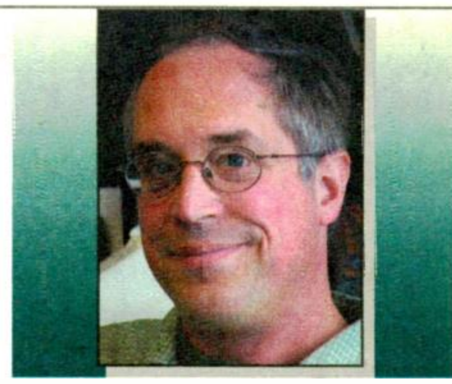
Full Steam Ahead For HD Radio

By Michael LeClair



Michael LeClair

The NAB Broadcast Engineering Conference in April was its usual hotbed of new ideas and equipment introductions. But more than anything, the central theme for radio broadcasters at NAB2005 continues to be the developments in digital radio.

As if this was not enough, the new information capabilities of HD Radio were highlighted as the first implementations of Program Associated Data are now being shown. Multiple channels of PAD can be generated to match multiple program streams. With a comparatively generous data rate, considered next to the current RBDS system, creative possibilities are just beginning to be explored.

Imagine the power of being able to create a completely new radio program stream in the top 10 radio markets of the country with the addition of a modest quantity of new equipment.

Everywhere vendors showcased products that were aimed at digital radio. Several manufacturers launched new transmitters that are IBOC-compatible, both on the AM and the FM side. Even over at Continental Electronics, they had a tube transmitter on display that could successfully pass IBOC, although the majority of new transmitter products were solid-state. Also on exhibit were new audio processors specifically aimed at digital radio, now incorporating the audio-delay circuitry to eliminate the risky strategy of using a computer as a critical component of the analog program chain.

But it was the unfolding of new possibilities for digital radio that was the real eye-opener at the show.

THE NEXT GENERATION

While hundreds of stations were busily deploying digital radio in its first-generation form, it turns out that manufacturers were just as busy developing the second-generation architecture, which can do even more than the original. In one important change, new designs now allow the audio processor to return to the studio from the transmitter, and save costs on the STL at the same time by reducing the amount of data needed for the digital signal.

This is particularly important in light of the demonstration of multicasting, or the transmission of multiple audio program streams over the digital portion of the FM signal. A local Las Vegas radio station was broadcasting no fewer than three discrete audio streams and offering listening tests on the floor in a car with a prototype receiver. Prototype portable receivers were also shown on the floor.

Imagine the power of being able to create a completely new radio program stream in the top 10 radio markets of the country with the addition of a modest quantity of new equipment, compared to the cost of purchasing or attempting to license a new station. Multicasting is real, and it is coming to HD Radio now. This capability will have a transforming effect on our industry.

To coincide with this display of new equipment, the National Radio Systems Committee formally voted to implement the technical standard for IBOC based on Ibiquity Corp.'s HD Radio system. This seemingly small step is actually quite crucial as it moves the regulatory process to the final stage of setting rules for digital radio so that radio stations, receiver manufacturers and broadcast equipment companies can move forward in the knowledge they will be working toward a common goal.

MORE CAPABILITIES

I have to admit my own surprise at the sheer speed at which HD Radio is taking off in just the three or four years since people first began to regularly operate those early experimental digital radio signals, often put together with prototype equipment and with no receivers available to even monitor their own broadcasts.

With the weight of literally thousands of group-owned radio stations formally committed to digital conversion, many of which made announcements at the Consumer Electronics Show in January, HD Radio is going full steam ahead. In my own market, digital conversions are happening so quickly that in some cases they are getting stacked up due to a lack of local engineering staff to handle the equipment installation.

This deployment speed is being matched by the design of second-generation hardware with expanded capabilities. During the many years the HD Radio system was under development, we have heard hints and ideas of what could become possible with a digital system. At a remarkable rate, new hardware is being released that expands the capabilities of HD Radio to meet the growing demand for this new system. As the advantages of digital radio become more widely understood, what once seemed a far-off goal, the complete conversion to digital broadcasting, may be nearer than we think.

Taking a step back, it is hard not to have a sense of wonder at being a part of the creation of an entirely new radio broadcast system that will likely be at the heart of mass communications for decades. To put it another way, this is a good time to be a radio engineer. The creative process of building new systems is what attracted most of us to radio engineering in the first place. We have a great opportunity to bring this new system to life and take pride in the work we do as engineers.

In this issue, we have a fine technical paper from Tim Hardy, head of development at Nautel, explaining adaptive correction and its use in linear amplifiers for IBOC. For AM engineers, sharpen your pencils and follow along with Cris Alexander as he explains the basics of broadbanding AM radio stations.

We also have Ben Dawson on diplexing AM stations on a common antenna and some of the pitfalls to avoid.

In the continuation of our Designer Interview series, Clarence Beverage talks about the role of the engineering consultant in building new radio stations. Finally, in this issue for the first time we will begin printing some of the letters that we are getting from readers.

Want to join in the conversation? E-mail your comments, suggestions and ideas to me at *mlrwee@verizon.net*. ■

In This Issue

Beverage

CONTINUED FROM PAGE 1

ways of using the electromagnetic spectrum. It is the engineering consultant who takes these basic principals and applies them to the design of new radio facilities.

In this issue's interview we speak with Clarence Beverage, president of Communications Technologies Inc., a broadcast engineering consulting firm in Marlton, N.J., in the suburbs of Philadelphia.

Please explain the role of an engineering consultant in a typical broadcast project.

That is a very interesting question since there are so many different ways that a project can go or that a client might ask for assistance. Let's take one example and work that through as a starting point.

An AM station has lost, or is going to lose, its site. Let's assume the station is a regional facility operating with nondirectional day and directional night antenna systems. The owner knows that they need a new site at a minimum. An astute owner is aware of options such as diplexing, city of license coverage requirements, FCC grandfathered overlap regulations and the requirement to reduce night power in directions where you are in another station's 50 percent RSS night limit.

Our first task is to do day and night allocation studies to ascertain the radiation limits in all directions. With that information, along with population density data for the market, we can begin to describe an area to locate the new site. That area is examined by using aerial photos, terrain maps and other resources to further refine the study area. Part of the study process involves the identification and elimination of areas that are unusable due to proximity to high-tension power lines, aeronautical paths that restrict tower height, natural obstructions and land use restrictions.

At this stage, we have a good idea of how many towers are required and property dimensions. Work with local station people, real estate experts, a planner, a civil engineer and a local land-use attorney begins as specific parcels are considered. Once the property is pinned down, the final antenna system design can be perfected and an FCC application for construction permit prepared. In some cases, a test transmitter facility may be erected to obtain local soil conductivity data allowing for facility maximization. (See Fig. 1.)

From that description it appears that a consultant should be involved at the very beginning of a project?

That is true and it saves the station a lot of wasted time and effort if they seek expert input before they make decisions that cannot be altered. On more than one occasion we have seen an AM station owner agree to the sale of a site, due to the land value, only to find out after the fact that there are no suitable alternative sites that can be afforded.

What types of services do you provide as part of a project? Do you assist in purchasing of equipment also, such as towers, transmission line, transmitters, etc?

Our first function is to specify the best possible transmission facility design in the FCC application for construction permit. One has to look carefully at the available land dimensions, signal restrictions and tower height limits to design an antenna system that will be stable, absent deep nulls in the pattern where possible, and have good pattern and impedance bandwidth for both analog and HD transmission.

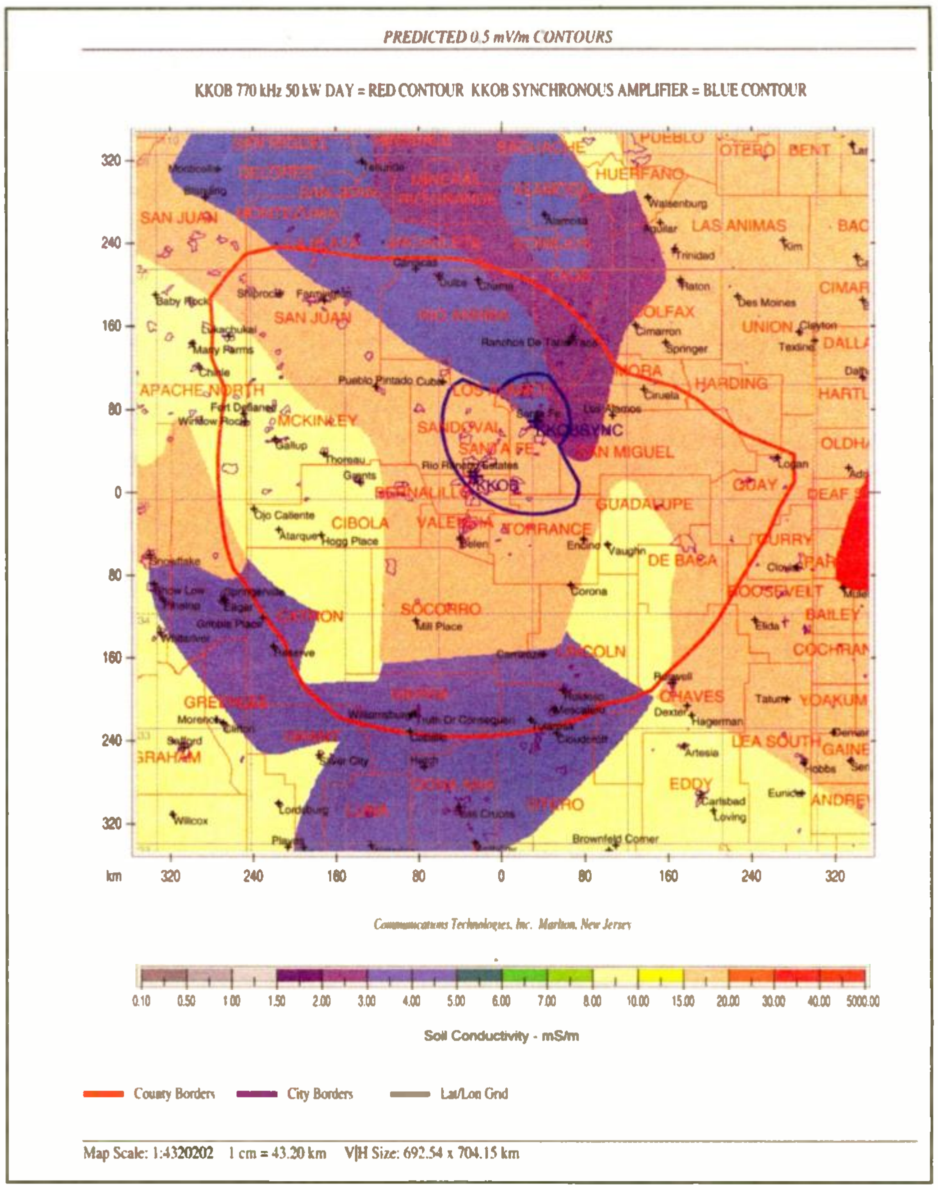


Fig. 1: Map of predicted coverage and terrain conductivity

Once the design is complete we like to work with the client to develop a set of bid specifications to send out to equipment vendors and installers. The specifications can be as simple as a set of uniform standards so that the bids are truly "apples to apples." In other cases, we specify the phasing equipment at the component level, and provide detailed site plans and surveyor oversight in terms of locating the towers on the property.

We like to have bidders come to the job site so that they are familiar with local conditions. Frankly, none of us are perfect. Bidders often will see something, based on their experience and expertise, which is the best way to do a particular job. We encourage that type of response and often find that the station can save significant costs when an open-minded approach is taken to the bid review process.

Conversely, some companies often bid unnecessarily high thinking that their reputation means that they deserve the job despite the cost. A good bid specification allows the station to clearly understand what is being bid and what the true costs are.

What can a consultant do before a station is built or modified to analyze and improve potential coverage?

This is a nice opportunity to segue us to the FM and TV area. I know that the focus of this newspaper is radio, but I would like to touch on TV as well since the physics of wave propagation is equally applicable to FM and VHF TV.

We started using the Longley-Rice method for predicting real-world signal levels almost 30 years ago when our only source for the technology was the NTIA (National Telecommunications and Information Administration) Telecommunications Analysis Services Time Share facility in Boulder. The FCC method of computing distance to contours only looks at terrain elevations out to a distance of 10 miles from the transmitter site, and no more. The Longley-Rice method looks at terrain from the transmitter to the receiver allowing a much more precise computation of signal level at the receiver. (See Fig. 2 on page 6.)

In the early '90s, innovative engineers/programmers such as Dr. Harry Anderson at EDX Engineering in Eugene, Ore., brought Longley-Rice propagation study capability to the personal computer. In the intervening years, accuracy has been increased through the use of better terrain databases and the ability to integrate land-use data into the calculations. Today we are seeing even greater accuracy as satellite procured terrain data is being error-corrected and brought online.

Is there a field component to your work or does it mostly involve computer modeling these days?

It is very important to be able to validate predicted signal levels with measurement data. We have been involved in a significant amount of TV field strength measurements in the last few years in varied venues. We have looked at TV field strength levels off the Empire State Building and 4 Times Square, both NTSC and DTV, at both VHF and UHF and have done a number of TV signal level studies for head end locations in urban areas

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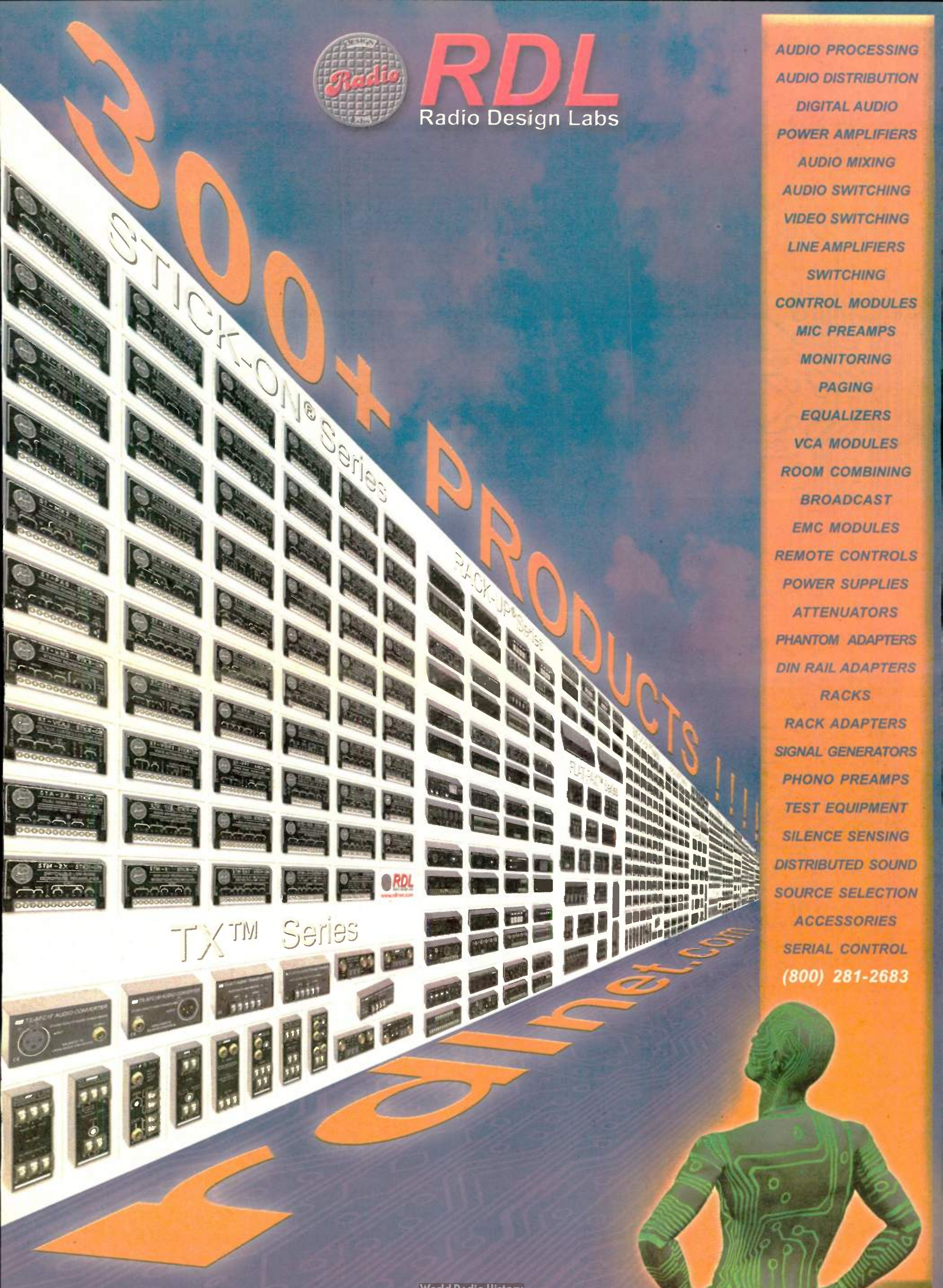
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Beverage

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such as Dallas/Fort Worth and for some small communities in southern California.

Universally, we have found that the Longley-Rice method is a helpful tool to determine estimated signal levels but that the results are only a ball park and rarely correct to within a couple of dB. One of the reasons for this is that the software does not yet have the ability to quantify local building structures and foliage that significantly impact the signal level.

Every firm has their own way of doing things. In our case, we have built a network of excellent, highly experienced and reliable field engineers around the country that we can rely on for fieldwork. This often saves the client transportation time and gives us the benefit of using people in a given geographic area who are aware of local conditions and resources that an outsider may not be aware of.

To answer your question, there is a lot that can be done by the computer but good, accurate field data is still very important as well.

Another example is AM field strength measurements. In some portions of the country we have found that the FCC M3 theoretical soil conductivity map overstates the actual soil conductivity. In that case, taking field strength measurements on existing facilities will demonstrate that their contours are located closer to the site allowing more room for the client station to increase the size of its service area. The FCC requires that the performance of a new AM directional antenna system be verified by field strength measurements and the adjustment and measurements associated with this can be time intensive and expensive. (See Fig. 3.)

What are some of the most difficult projects you may have worked on?

We have been fortunate to work on a number of interesting projects through the years and to work with a number of interesting people in the process.

One of our true long-term projects is the WFUV(FM), Fordham University, FM transmitter site implementation project in New York City that Radio World readers will recall reading about through the years.

Fordham first filed an application for CP to build full Class B NCE FM facilities with the FCC in 1983. A long comparative proceeding, followed by a dispute concerning environmental aesthetics with the New York Botanical Garden, resulted in Fordham halting construction of its 480-foot self-supporting tower at the 260-foot level in 1997.

Fordham and The Botanical Garden, with its own set of experts, worked together to ultimately secure City approval to construct a new tower and antenna system on the roof of a residence complex on the edge of the Montefiore Hospital campus in the Bronx. The final design implemented a 10-bay, polynomial feed antenna designed to carefully control the elevation pattern and provide full protection to sensitive medical electronic equipment in nearby medical buildings.

On April 7, 2005, the FCC issued a construction permit to Fordham and the University anticipates construction to be completed in early 2006, ending an essentially quarter-century-long upgrade project.

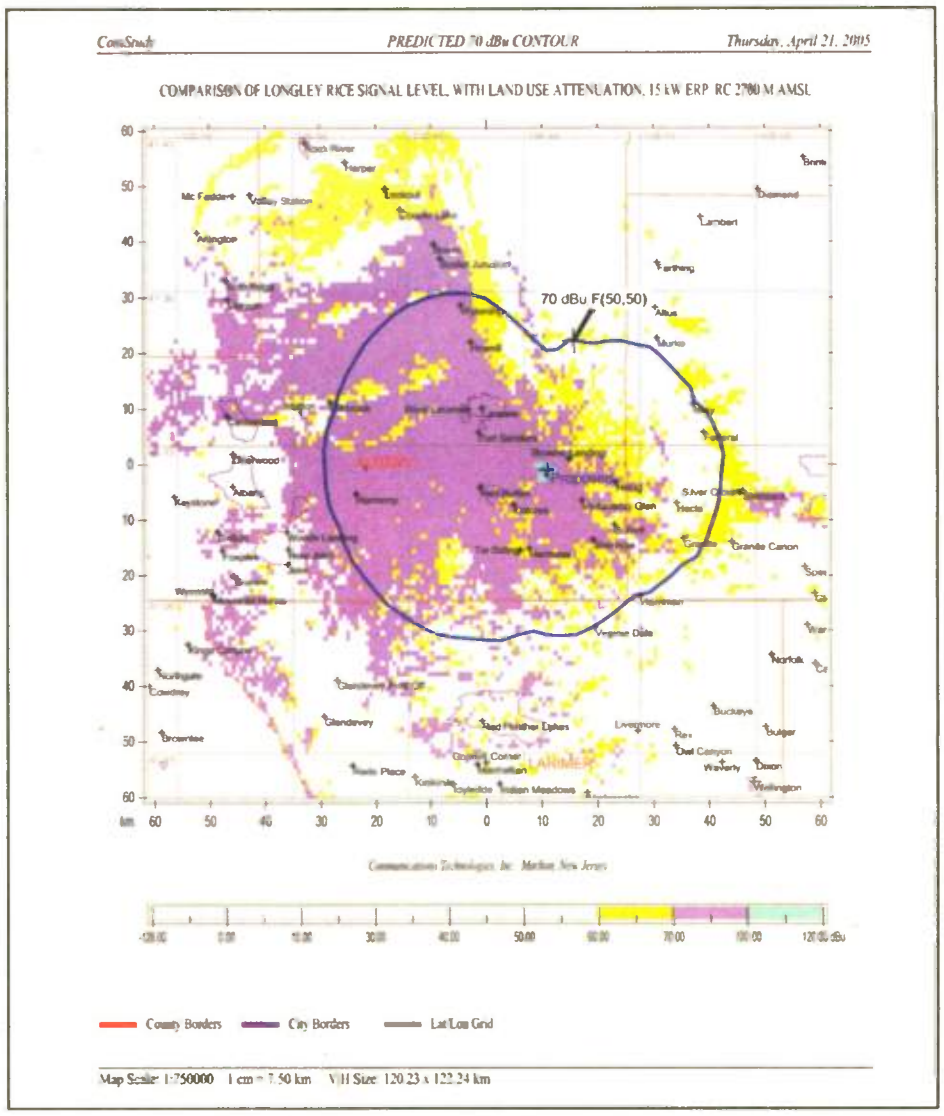


Fig. 2: Comparison of Longley-Rice and FCC Contour

This is a good place to point out the skill sets that a client may need to look for in a broadcast engineering consultant. An FM project like the Fordham project, and many AM site changes, require that the engineer have experience in providing expert testimony before government boards concerning FCC rules and RF safety, an ability to work with and appreciate the limitations placed on a project by environmental specialists, land-use experts, civil engineers, project planners, contractors, adjacent property owners, local legal counsel and FCC legal counsel.

Can you talk a bit about how radio broadcast engineering has changed over the last 20 years?

I think the biggest changes have been associated with the ability to do computations on a PC with accuracy and precision.

In the late '70s, we bought our first multi-user mainframe, manufactured by Alpha Micro Systems. That computer system cost nearly $20,000 and used a 4 MHz CPU. You can imagine how long it took to crank out detailed computations; and everything that was output still had to be hand-plotted on maps.

Needless to say, the prime broadcast software vendors, Radio Soft and V-Soft, have integrated their software in a Windows environment allowing good graphic output and mapping capability with significant accuracy.

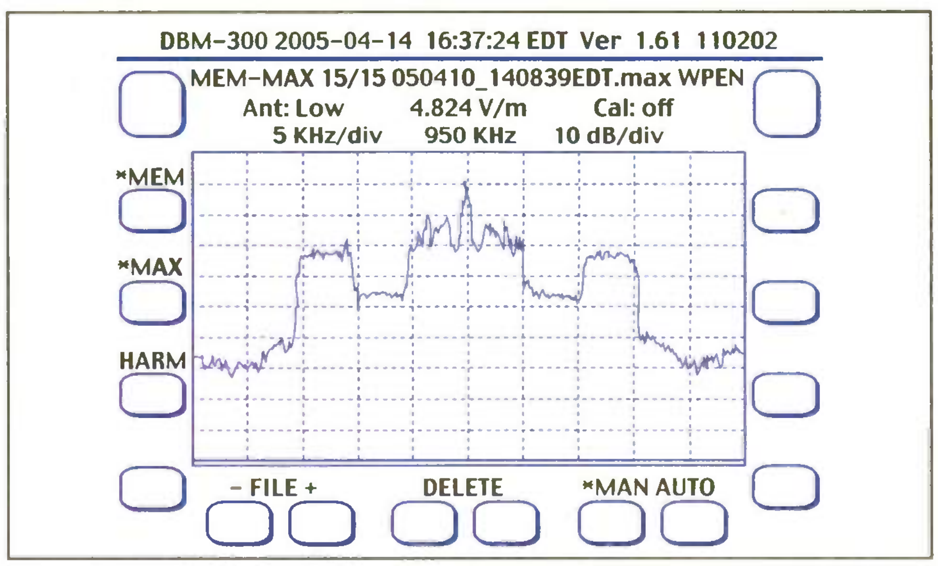


Fig. 3: Digital AM Signal Strength Meter

On the field side, we see modern receivers by companies such as Z-Technology and Audemat, which allow field strength, GPS positioning and mapping data to be integrated together to provide good, comparative signal level data for station use. On the AM side we are at a point where the use of a microprocessor-based product has resulted in the introduction of practical, digital, hand-held, AM field strength meters.

BEVERAGE, PAGE 8

Reader's Forum

Articles Are Keepers

I can't believe how great the "Engineering Extra" that I just read is.

I'm really hoping that the articles by David Maxson and Bob Surette will show up eventually at the Web site with the graphics.

Thanks for the awesome job.

Dave Obergoenner
Director of Engineering
Zimmer Radio Group
Cape Girardeau, Mo.

AM Interference Overstated

I read your Radio World Engineering Extra (Feb. 23) this past weekend and found it to be jam packed, cover to cover with good stuff. Rackley, outstanding, most of LeClair, Schrag, Westberg, Whitlock, Guy Wire, great perspective Blesser ... page after page terrific.

My only issue with the otherwise fine piece by Michael LeClair was that his conclusions concerning AM nighttime IBOC interference are not correct. The truth is, for all but the clear channel AMs, co-channel analog AM stations are and will continue to be the greatest source of interference. Co-channel interference causes tune-out in the vast majority of cases long before IBOC energy has any impact. Most of the letter writers and columnists don't really understand the mechanics of the existing analog interference or that created by IBOC.

Glynn Walden
Marlton, N.J.

Ed. Note: Glynn Walden was instrumental in the development of IBOC; in honoring him with its Radio Engineering Achievement Award, NAB called him "the visionary of the concept, technical design and economics of AM and FM in-band on-channel digital radio broadcasting."

Too Much Math?

Thanks for the RWEE that keeps on coming.

I would say I am more of a TV person now since I've been with TV for the last nine years. Prior to that, I was doing radio engineering for 13 years and just find myself reading every article of RWEE, especially the stuff on directional MW antennas, which I used to work on.

The topics are good except for some that may be using too much math to explain concepts. Not that math is bad, since it does not go beyond high school trigonometry anyway. It is just that for a regular radio technician or engineer, the agenda is, "How can I use this information to do a better job in the station? To come up with better solutions in my facility design or projects?"

Although I am sure that a lot of readers from manufacturing companies are devouring the contents of RWEE, I would presume that the primary target, and correct me if I am wrong, are people manning the stations, those who are in for the daily grind.

Thanks and more power to RWEE.

Rolin Lintag
RF Engineer
Victory Television Network
Little Rock, Ark.

What's your opinion on this topic? Write to mlrwee@verizon.net or radioworld@imaspub.com.

Beverage

CONTINUED FROM PAGE 6

Is HD Radio a good idea for AM or will side effects, such as increased interference in some cases, make the system untenable? Does the prospect of converting the entire band to a digital system have an impact on the design of AM systems today?

I am always concerned when a new technology has a negative impact on existing listeners. There is no doubt that there have been cases of stations reaching a particular market segment with a weak AM signal and having that signal essentially made unusable by the sideband energy of a much stronger second- or third-adjacent-channel signal.

I think there are two answers to your question. One is that transmitter manufacturers, antenna system designers and the firm doing the system adjustment take on the responsibility to reduce spectrum regrowth products to the lowest possible value, not just the Ibiquity minimum allowable value. It may cost a bit more to do that, but I think that is a matter of integrity and responsibility on the broadcaster's part as a good neighbor. The adage "do unto others as you would have them do unto you" is definitely at play here.

Second, there does have to be some give and take in order that the system install base can be developed and a listener base established. The same thing is occurring in TV where there is some allowed interference from DTV during the transition phase to all-digital.

Ultimately, I believe that AM HD will be a benefit to AM; but owners need to begin to ask two key questions. One, how will my existing service area change during the transition; and, two, what will my final HD Radio service area look like?

How about FM IBOC? How is this affecting how stations are being designed?

There are significant changes that we are seeing on the FM side.

When stations purchase a new antenna they are looking to be sure that the antenna is designed to give them sure HD transmission capability even if they are not ready to buy the transmitting equipment at this time. Stations buying new analog transmitters are looking at high-level combining, and, if that will be their choice, being sure that the transmitter has the added headroom for HD combined operation. New products were released for spring NAB 2005. The trend continues toward having the HD equipment at the studio to allow full flexibility for the future including multichannel uses as well as data. This places new burdens on the studio-to-transmitter link for significant Mbps data capacity.

Do you have any comments on the ongoing controversy about LPFM? Is there really no chance for interference as Mitre suggests or should broadcasters remain cautious in this area?

At this point we are really beyond the Mitre report in my opinion. On March 17, 2005, the FCC released a Second Order and Further Notice of Proposed Rulemaking. At the same time, a freeze on the processing of pending FM-translator applications was put into effect. It seems clear that Congress thinks that the third-adjacent-channel restriction should be removed and that the FCC has the comment process underway. In my opinion, broadcasters should consider filing informed Comments and Reply Comments with the commission realizing that it is likely that the restriction will be implemented in new Rules. In that circumstance, my feeling is that comments would want to go toward what is a legitimate interference complaint and how it should be handled.

The items had yet to be published in the Federal Register at press time; comments were to be due 30 days upon publication of the Second Order of Reconsideration and Further Notice of Proposed Rulemaking (MM Docket 99-25). ■

Adaptive

CONTINUED FROM PAGE 1

has large-scale variations due to the changing constructive and destructive interference of the individual RF carriers. This interference is caused by an effectively random phase relationship due to their differing frequencies and modulating data streams.

While the answer to the linearity problem lies in part in the design of the amplifiers themselves, correction techniques are also required in a practical implementation.

LINEARITY AND THE EFFECT ON SPECTRUM

Interference is one of the most significant potential problems when working with the HD Radio FM system. The signal broadcast by any transmitter may be broadly categorized into two classes: intentional and unintentional emissions. Intentional emissions include the FM signal and the OFDM signal.

Unintentional emissions include RF harmonics, spurious emissions and noise. While some interference problems may have been caused by intentional emissions, the focus of this paper is on the mitigation of unintentional emissions due to amplifier nonlinearity. All real amplifiers deviate to some degree from the ideal requirement that the gain is independent of input voltage. Generally, gain is reduced as input levels increase toward amplifier saturation (see Fig. 2). This is referred to as AM-AM distortion.

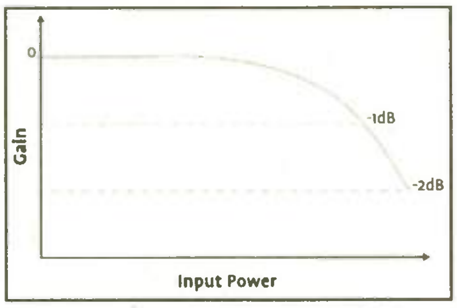


Fig. 2: AM-AM Characteristic

AM-AM distortion may be described by a function that relates the magnitude of the instantaneous gain to the instantaneous input magnitude.

1)
$$\left|\frac{V_o}{V_i}\right| = g_m\left(|V_i|\right)$$

Alternately, the AM-AM characteristic can be modeled by a Taylor series expansion relating the instantaneous input voltage magnitude to the instantaneous output voltage magnitude. Either equation 1 or 2 may accurately represent the AM-AM characteristic of a typical amplifier.

2)
$$|V_o| = a_1|V_i| + a_3|V_i|^3 + a_5|V_i|^5 \ldots a_n|V_i|^n$$

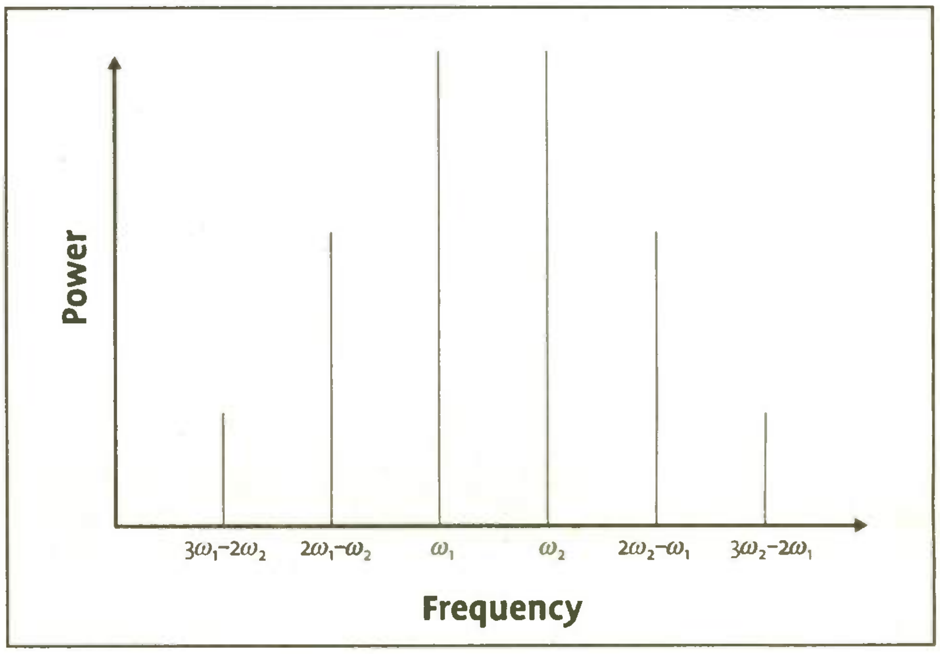


Fig. 3: Output of Fifth-Order Model With Two-Tone Input

The first term of the expansion is the linear term. The coefficient a_1 is the small signal gain of the amplifier. For an ideal amplifier, all higher-order coefficients would be zero. Even-order terms of the Taylor series are often not used as they cannot produce any distortion terms in the band of the fundamental RF term.[1] The effect of this nonlinear model can be illustrated by driving this function with a two-tone input signal.

3)
$$V_i = \cos(\omega_1 t) + \cos(\omega_2 t)$$

The response of the Taylor series model to a two-tone input signal can be determined by expanding and using trigonometric identities. In addition to the fundamental and harmonics of the input tones, distortion products are produced. Third-order intermodulation products, IM3, result from the third-order term of the Taylor series.

IM3 occurs in the spectrum at the following frequencies:

ADAPTIVE, PAGE 10

Case Study

Fixing "Bored Audio" Problems

Solution developed for numerous Logitek customers

THE ISSUES:

- Overnight satellite feed set to the wrong channel
- STL receiver not working correctly
- Other unattended equipment that goes to your air chain not feeding any audio

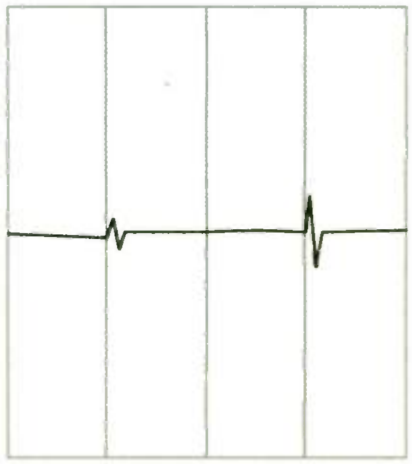
What do you do when you don't have correct program audio going to your transmission chain, but your silence sensor thinks you're OK?

For example, you are supposed to broadcast a satellite program overnight, but somehow the receiver has the wrong channel selected. Instead of an audio feed, you get a steady tone.

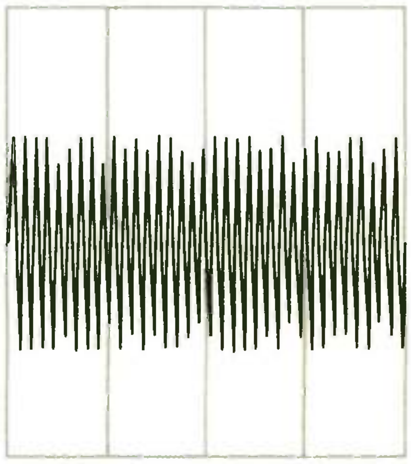
Or, what if your STL receiver is somehow damaged by a storm? It loses the carrier but isn't squelching the audio, which results in static being fed to the rest of the transmission chain.

We call these problems "Bored Audio"...a nice, steady feed of noise or a constant tone.

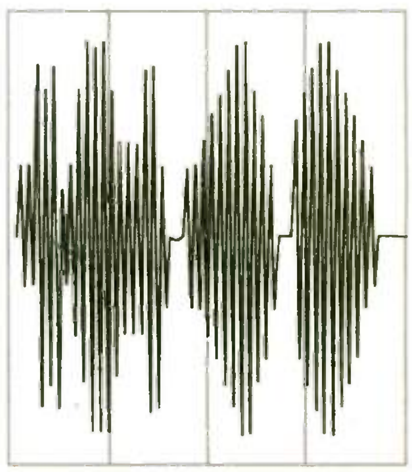
Your silence sensor, which is set for complete drop-outs of audio, doesn't trigger on Bored Audio.



Silence: *No audio. Your silence sensor can detect this.*



Bored Audio: *White noise, or a steady tone. Your silence sensor is happy, but your listeners (and GM) aren't.*



Normal Audio: *What you want on-air...Logitek can help restore it in a hurry.*

THE LOGITEK SOLUTION:

Logitek's SharcAttack DSP card, a useful option for the Audio Engine router, provides both high and low audio alarms. The two can be merged to send out an alert when neither has been activated for a predetermined time period. Since program audio has dynamics which can be easily monitored by the SharcAttack, the Logitek system can tell quickly if you are transmitting Bored Audio and trigger your emergency backup sequence or transmission chain.

With Logitek, you can fix Bored Audio before you lose Bored Listeners (or even better, before the GM calls you in the middle of the night!)

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Logitek

Adaptive

CONTINUED FROM PAGE 8

$\cos(2{*}\omega_1-\omega_2)$ $\cos(2{*}\omega_2-\omega_1)$

The fifth-order term of the Taylor series produces fifth-order intermodulation products, IM5, that occur at these frequencies:

$\cos(3{*}\omega_1-2{*}\omega_2)$ $\cos(3{*}\omega_2-2{*}\omega_1)$

Note that the higher-order terms of the Taylor series also contribute to the lower-order intermodulation products. In this case, the IM3 products also have a contribution from the fifth-order polynomial term expansion. Fig. 3 on page 8 shows the two tones, IM3 and IM5 distortion products.

The nonlinear response of amplifiers may be measured with a network analyzer by doing what is referred to as a power sweep. In this type of measurement, the amplifier is characterized using a single RF input tone of varying voltage. As the voltage is stepped over a wide range, the output of the amplifier is measured. If the

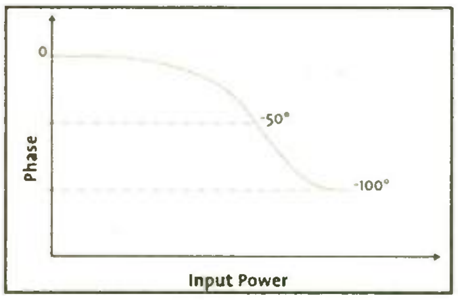


Fig. 4: AM-PM Characteristic

output voltage magnitude is divided by the input voltage magnitude, a gain characteristic describing the amplifier AM-AM distortion is determined.

For example, the fifth-order Taylor series would have the following gain characteristic:

4)

$$Gain(|V_i|) = \frac{|V_o|}{|V_i|} = a_1 + a_3|V_i|^2 + a_5|V_i|^4 = g_m$$

Additionally the network analyzer will tell us that the phase measured between the input and output of the amplifiers was not constant during the power sweep. This phase characteristic is called AM-PM distortion (see Fig. 4).

5)

$$Phase\left(\frac{V_o}{V_i}\right) = g_\Phi(|V_i|)$$

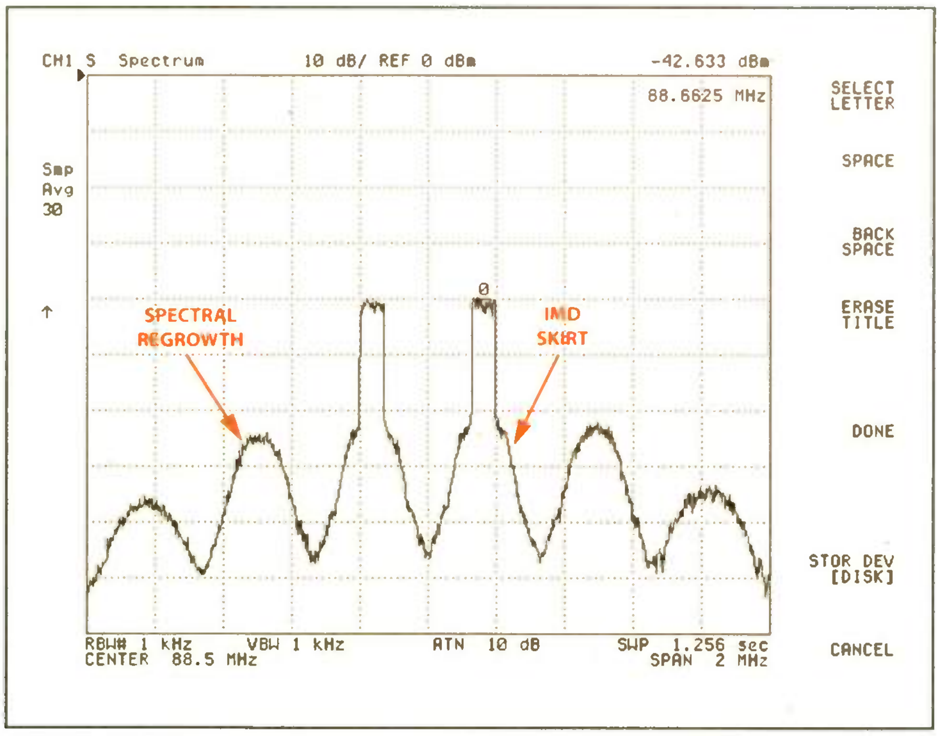


Fig. 5: Uncorrected Amplifier Spectrum

Using the functions g_m and g_Φ representing the AM-AM and AM-PM distortions, the relationship of the input voltage to the output voltage is shown.

6)

$$V_o = V_i g(|V_i|) e^{jg_\Phi(|V_i|)}$$

Equation 6 is useful because it suggests the amplifier characteristic is essentially a complex valued gain defined solely by the input signal magnitude. The amplifier complex gain is also defined by the AM-AM and AM-PM distortions that may be measured and tabulated by a network analyzer.

As was described by the two-tone analysis shown above, if not corrected for, the amplifier nonlinearity will introduce distortion to the signal. Fig. 5 shows the output spectrum for a typical FM amplifier operating with the HD Radio signal.

This signal contains the upper and lower OFDM sidebands that intermodulate in a similar manner as the two-tone test described above. The IM3 and IM5 products can be seen clearly. In addition, the carriers of the individual OFDM sidebands intermodulate causing skirts.

The IM products are unintentional emissions from the transmitter that may cause several undesirable effects if they are not controlled:

✓ Out-of-band interference with adjacent broadcast channels

✓ In-band interference with your HD Radio OFDM signal

✓ In-band interference with your FM signal

Out-of-band interference can happen when the transmitter output contains signals in another broadcast channel. The acceptable out-of-band emissions levels are currently governed by an emissions mask proposed by Ibiquity (see Fig. 6).

In-band interference with the digital signal occurs when the unintentional emissions interfere with the OFDM carriers at the receiver. This is generally less of a concern because the QPSK modulated carriers are very robust and relatively tolerant of noise and interference. It is unlikely that any transmitter linear enough to meet the proposed emissions mask will have a negative effect on the OFDM signal-to-noise ratio at the receiver.

In-band interference with the FM signal may also occur. This may be more significant as the analog signal can be degraded by lower levels of emissions than the digital signal. The problem worsens if the unintentional emissions are close to the center frequency where the FM receiver is most sensitive. Because the FM system is analog, this interference could be perceived as noise or hiss when using analog receivers. Extended hybrid operation may exacerbate this situation as the additional OFDM carriers and their local IM products are closer to the FM carrier.

SOLUTIONS TO THE SPECTRUM PROBLEM

The amplifier linearity may be improved for HD Radio operation by changing the class of operation from class C to A/B or even class A. This generally has the effect of improving the amplifier characteristic at low-power input levels at the expense of efficiency. Highly linear operation may be obtained in this way by increasing the amplifier bias currents and reducing the peak output power. Typically a 3 dB improvement in IM3 products is obtained for a 1 dB reduction in output power. Unfortunately, this cannot be the complete solution due to the increased number of amplifiers required.

Other industries before broadcast radio have been coping with the linearity problem for some time. Many techniques for

ADAPTIVE, PAGE 12

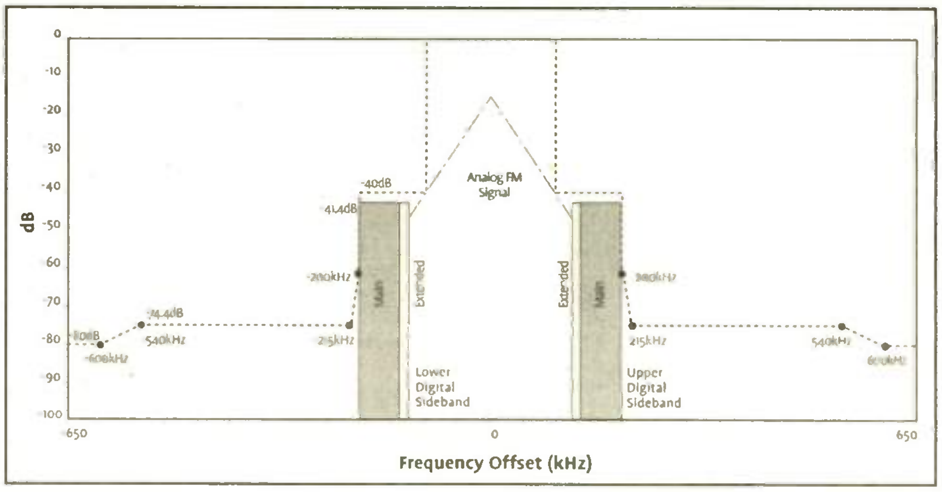


Fig. 6: Proposed HD Radio Emissions Mask

Adaptive

CONTINUED FROM PAGE 10

improving amplifier linearity have been investigated, including feed forward, feedback and Cartesian loop, to name a few.

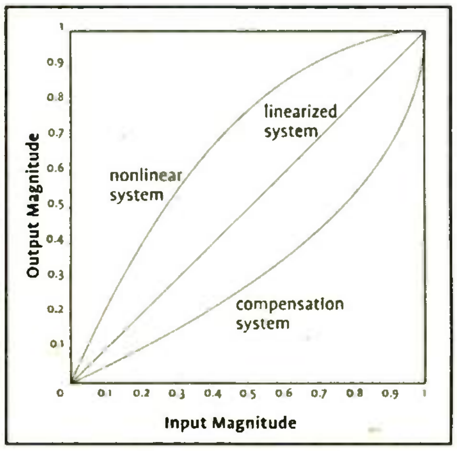


Fig. 7: Complementary Gain Curves Pre-Correction Principle

The technique employed by Nautel and other HD Radio transmitter manufacturers is known as pre-distortion or pre-correction. Pre-correction is the preferred technique for Nautel because of its high performance, stability, low cost and low impact on the transmitter design itself.

PRE-CORRECTION

Pre-correction can be defined as placing a complementary nonlinear system at the input of the amplifier stages such that the overall system is linear (see Fig. 7). Because the pre-correction system is at the amplifier input, small signal techniques may be used making this a more practical solution.

Mathematically, a nonlinear amplifier characteristic $g(x)$ may be corrected for with a complementary characteristic $h(x)$ such that $g(h(x)) = Gx$ where G is the constant linear gain resulting from the cascade of the two systems. For this to be true, $G\,h(x) = g^{-1}(x)$. This technique may correct for both AM-AM and AM-PM distortion (see Fig. 8).

Pre-correction systems may be implemented in either the analog or digital domain. Analog pre-correction may be limited in its ability to faithfully produce the required inverse characteristic. The degree of improvement made by pre-correction is determined by how well the two nonlinear characteristics are matched. When properly adjusted, digital pre-correction generally yields excellent results.

However, even if careful manual matching of the pre-correction curve is done, the amplifier characteristic will generally vary over time. The causes of varying amplifier nonlinearity include temperature effects (seasonal or warm-up), load impedance changes due to antenna mismatch or icing and changes in the operating frequency or power level.

ADAPTIVE PRE-CORRECTION

Designing a system that "learns" the nonlinear characteristic will mitigate the sensitivity of fixed pre-correction linearization systems. This is known as adaptive linearization and was first proposed in 1983 by Saleh and Salz.[2]

The Nautel system is implemented completely in the digital domain (see Fig. 9). In the forward path, an ideal digital signal containing the HD Radio carriers and the FM signal (in the case of common amplification) is synthesized. The ideal signal is then pre-corrected using a correction curve stored in a look-up table or LUT, which stores a large number of discrete correction vectors. Each correction vector can correct for the amplifier gain and phase error for a given amplifier input voltage range. As the signal amplitude changes over time, many different correction vectors are used.

Still in the digital domain, the pre-corrected signal is then converted to the correct FM channel frequency and fed to a digital-to-analog converter (DAC). The analog signal is then fed to the transmitter for amplification.

In the reverse path, the transmitter output is sampled using a directional coupler and digitized with an analog-to-

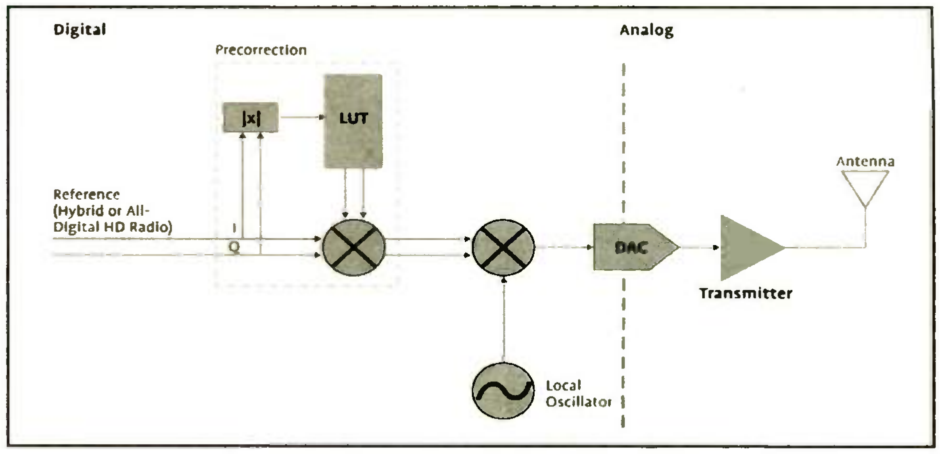


Fig. 8: Fixed Digital Pre-Correction Block Diagram

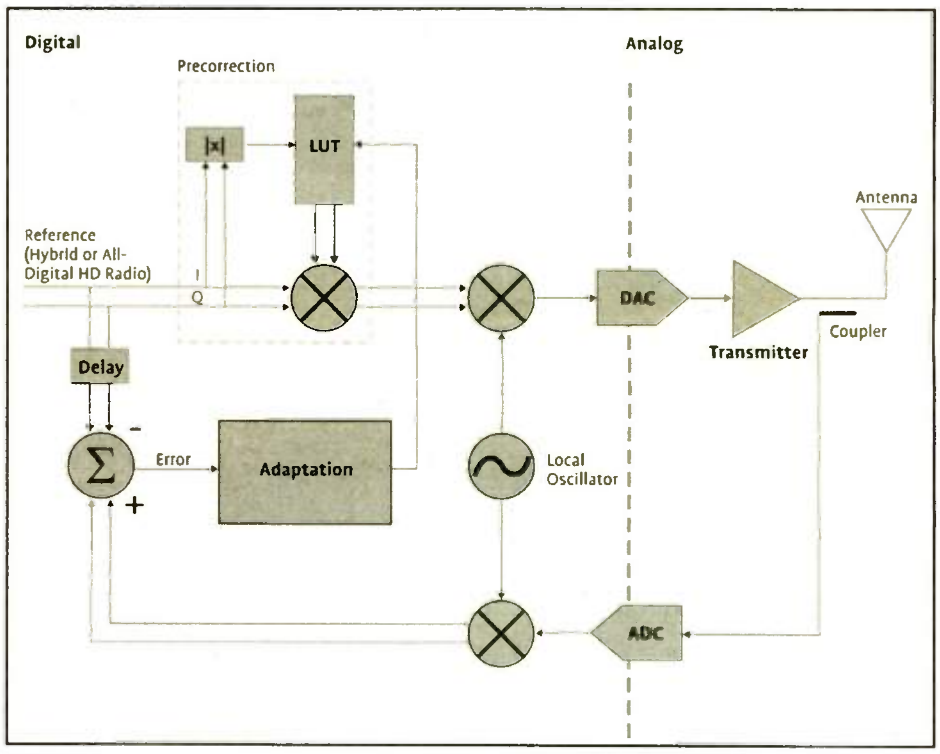


Fig. 9: Adaptive Digital Pre-Correction Block Diagram

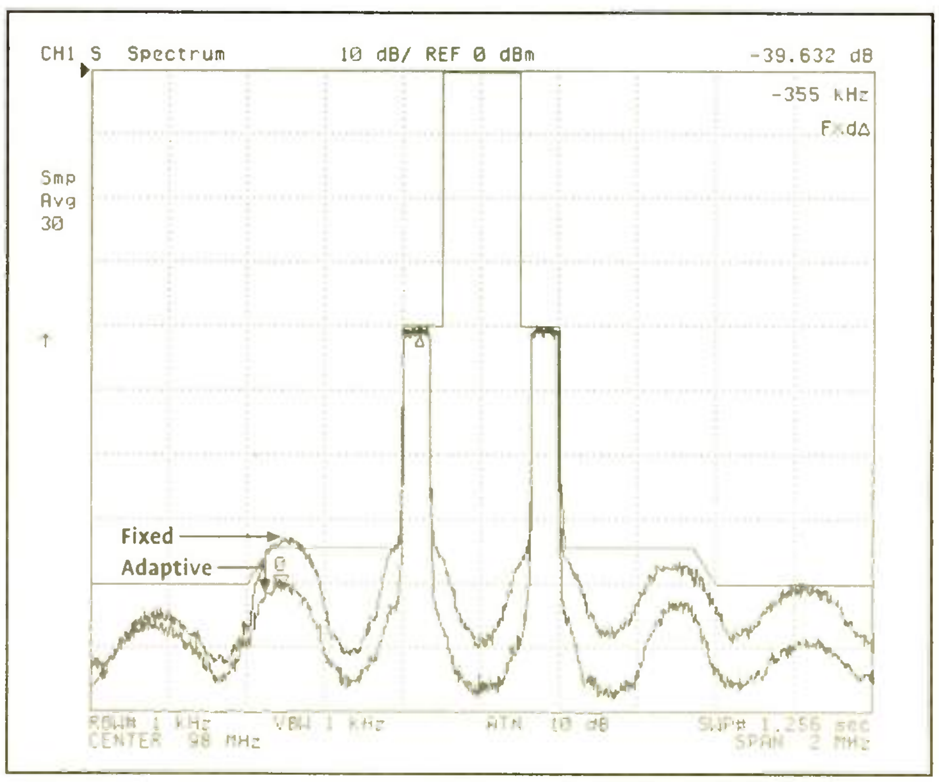


Fig. 10: 1.5:1 VSWR With Fixed and Adaptive Pre-Correction

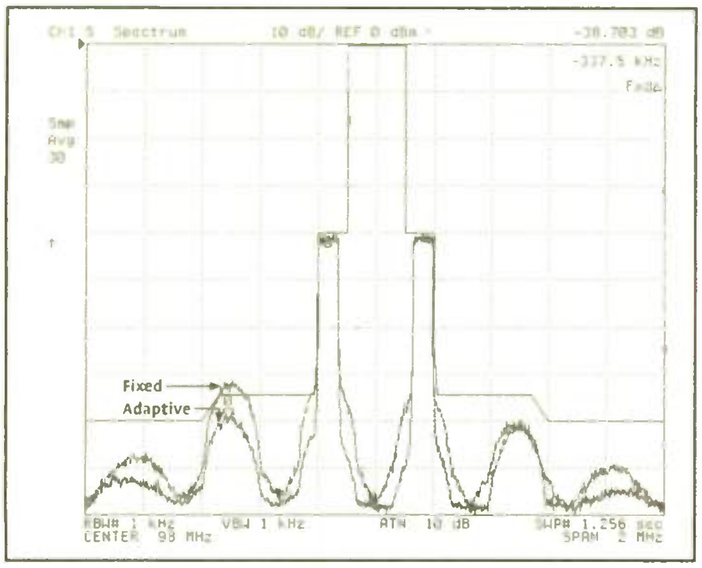


Fig. 11: 29°C Temperature Rise With Fixed and Adaptive Pre-Correction

digital converter (ADC). The output sample is then shifted to the same frequency as the ideal reference signal at the system input. The reference signal is fed through a delay register to time-align it with the sampled transmitter output signal. By subtracting the ideal signal from the actual transmitter output, an error signal is obtained. This error signal describes signal distortion at the transmitter output.

Using a recursive algorithm, the error signal is used to update the pre-correction curve stored in memory. After each iteration of the recursive algorithm, the correction vectors in the LUT converge on the ideal pre-correction solution such that distortion at the transmitter output is minimized.

Utilizing modern digital hardware, the conversion time is on the order of a few seconds, easily fast enough to correct for real-world variations in the amplifier non-linear characteristic.

ADAPTIVE PRE-CORRECTION LIMITATIONS

Saturation: At some point, the amplifier's output power cannot be made to increase when the input power is increased. As a result, the desired output power must be set so that the amplifier saturation point does not significantly distort the signal.

For the HD Radio signal, Ibiquity requires a minimum peak-to-average ratio of 5.5 dB at the transmitter output. For example, a 10 kW transmitter capable of 11,000 W peak power should not be driven beyond 3,100 W average digital power in a separate amplification system. If the digital power is increased significantly beyond this point, amplifier saturation may introduce unacceptable emissions outside the emissions mask.

Amplifier memory: The relatively simple adaptive pre-correction system described assumes that the amplifier is "memoryless." Amplifier memory occurs when the gain at any one instant in time is dependent not only on the current amplifier input, but also on previous amplifier inputs. For signals of relatively low bandwidth, using careful amplifier design techniques, memory effects can be minimized such that the effect is not troublesome.

COMPARISON OF FIXED AND ADAPTIVE PRE-CORRECTION

The following experiments were conducted to determine the improvement obtained by using an adaptive pre-correction system. In each experiment a reasonable deviation of the amplifier's operational environment was made. These changes were intended to represent the real-world conditions that might be found at a typical broadcast site.

These measurements were made on a Nautel V10 operating in all-digital mode as required by the digital transmitter in a separate amplification system. The output power in every case is 3 kW and the operating frequency is 98 MHz. The spectrum analyzer was set to 1 kHz resolution bandwidth and video bandwidth, and sample detection with a 30-sweep average.

Each spectrum plot shows the spectrum resulting from making a change in the operational environment with the adaptation disabled. After the initial measurement is made, the adaptation was enabled and a second measurement was made illustrating the improvement due to the adaptive pre-correction.

VSWR Sensitivity

In this experiment, a 1.5:1 vertical standing wave ratio was introduced by means of a short circuit stub on the transmitter output.

The VSWR test shows that adaptive correction achieved an improvement of 7 dB over fixed correction on the lower or worse IM3 sideband (see Fig. 10). Also note that the fixed pre-correction did not ensure compliance with the emissions mask with a 1.5:1 VSWR.

Temperature Sensitivity

In this test the air intake and exhaust ports were impeded until the exhaust air temperature rose by 50°F. This was intended to simulate a change in the room temperature that might be found with seasonal variations at a site without heating or air-conditioning.

The temperature test shows that adaptive correction achieved an improvement of 8 dB over fixed correction on the lower or worse IM3 sideband (see Fig. 11). Also note that the fixed pre-correction did not ensure compliance with the emissions mask with a 50°F temperature change.

ADAPTIVE, PAGE 24

Isolation Requirements in Diplexed Medium-Frequency Antenna Systems

Antenna Coupling Unit Construction Can Have a Large Impact on Isolation Performance

By Ben Dawson

The author is president/managing partner of Hatfield and Dawson Consulting Engineers, Seattle.

The vast majority of diplexed medium-wave antenna system installations are retrofits, installation of a second frequency on an existing antenna system.

In most cases, if the original antenna feed system was of good quality and has been well maintained, it is retained and the only modification to the geometry of the feed system for the original frequency is the installation of series and possibly shunt filters for isolation.

The advent of modern solid-state transmitters, which have relatively wideband output networks, can make the filtering problem much more intractable than was the case with the high-Q output circuits of tube transmitters. A considerable percentage of existing antenna feed systems use panel and shelf-mounted networks, particularly for ACU installations, which can make filtering difficult because they're not shielded by cabinetry.

New system installations with solid-state transmitters, however, now almost always use cabinet-mounted antenna feed system equipment, even if the cabinets themselves are located in ACU buildings. The tendency of the equipment vendors is to supply equipment in stand-alone boxes. Sometimes these contain both an ACU network and filter, and sometimes, particularly for the filters on the existing frequency, these are in separate boxes. Occasionally, when there is "prematching" common to both feeds, there will be common tower feed from one of the cabinets.

NAGGING IM COMPONENTS

In cases where the frequency spacing is less than about 200 kHz, and separate enclosures are used for the ACUs and filters, we have sometimes encountered substantial difficulty in reducing intermodulation components to -80 dB below carrier as required by the FCC Rules (47 CFR 73.44). In each instance we have investigated, the difficulty was the result of circulating RF current in ground loops created by the cabinetry or panel layout and interconnection practices.

Fig. 1 shows the "retrofit" installa-

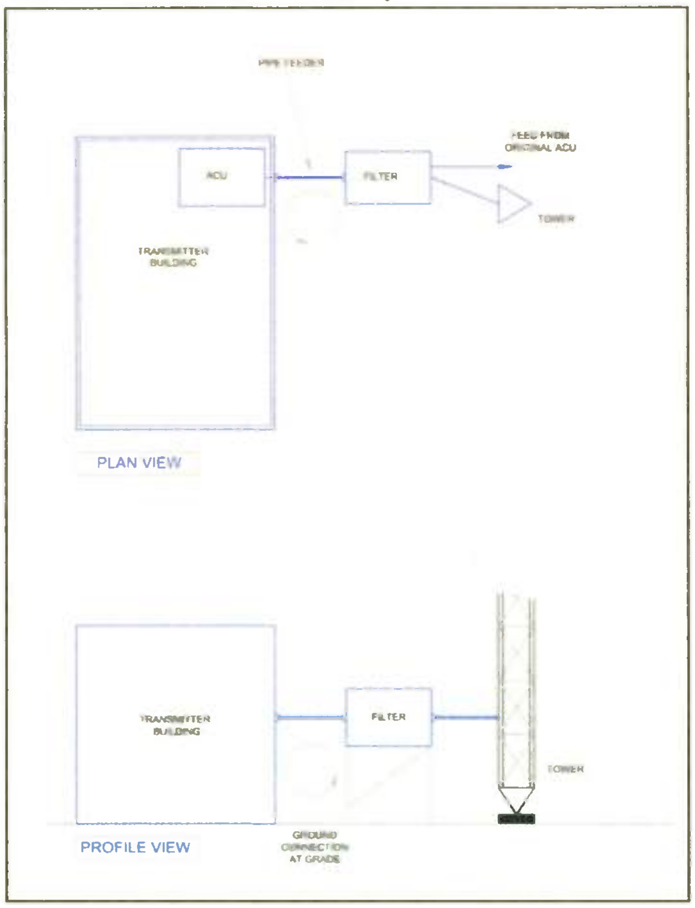


Fig. 1: Retrofit Diplexer Installation

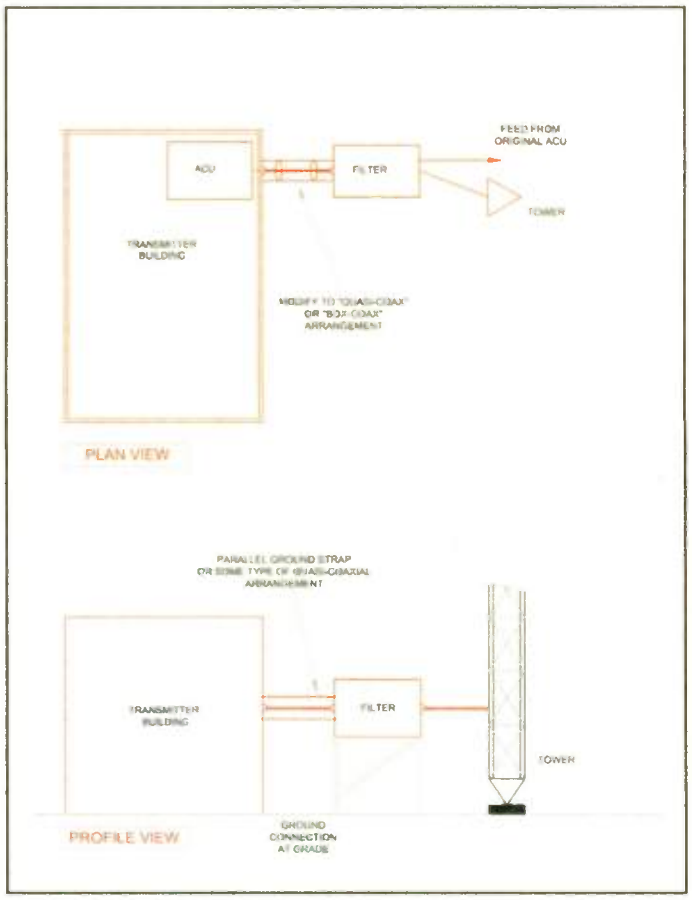


Fig. 2: Retrofit Diplexer Installation Modified to Reduce Induced Current From Tower

tion where the original ACU (not shown) is in a transmitter building to the right, a new ACU is in the new transmitter building on the left, and a cabinet with filters for each frequency and a common pre-match reactance is located between the new building and the tower.

The $2f_1$-f_2 intermodulation product from the new transmitter was found to be down only about -65 dB, although the similar ($2f_2$-f_1) product from the original transmitter on the site was nearly undetectable — well below -80 dB. The filter, pretuned by the manufacturer, was found to be optimally adjusted when checked. However, a substantial amount of undesired carrier could be observed on the common-point bus of the second, newly installed, feed system equipment.

A visual inspection disclosed that the ground connections between the cabinet and the transmitter building were at grade, although they were made with multiple parallel straps as was recommended. As noted by the "arrow circle" in Fig. 1, however, there was a large loop consisting of the ACU box, the ground strap, the filter box and the feeder.

At the filter end, the feeder-ground connection was essentially zero impedance due to the shunt filter network. At the ACU end, the impedance was modest but not high at the undesired frequency. The orientation of the equipment with respect to the tower and its magnetic ("H") field characteristics near the tower base resulted in substantial current flow at the undesired frequency. This "current loop" is on the input side of the filter, and so current at the undesired frequency appears at the transmitter, resulting in intermodulation.

Photo courtesy Eric Kuhlman, DOE Clear Channel Communications, Oregon

Fig. 3: Use of Strap to Create Quasi-Coaxial Feed

SOLUTIONS

Fig. 2 shows an effective amelioration method.

If the feed itself is paralleled with a ground strap, or better yet, enclosed in a coaxial or "quasi-coaxial" arrangement, the current will flow in the ground or outer conductor of the "quasi-coax" and the induced current into the feed system can be minimized. In low-power installations a short piece of foam Heliax or Foamflex can be used, as long as care is taken not to exceed its voltage breakdown ratings. In high-power installations an "outer conductor" can be fashioned from one-inch or two-inch (2.5 or 5 cm) strap of appropriate thickness.

Of interest is why the ($2f_2$-f_1) product from the original transmitter did not occur at a high level as well. In the geometry of this installation, the feed from the filter to the original ACU is at such an angle to the tower that it is not well coupled to the displacement current-generated H-field, and has approximately equal segments extending each direction from the point closest to the tower, resulting in minimum coupling.

When the pipe feeder was shielded with a new set of coaxial-arranged ground bus straps (see Fig. 3), and the ACU was retuned to compensate for its effects, the ($2f_1$-f_2) product from the second frequency transmitter also fell well below -80 dB from carrier.

It's important to pay attention to the magnetic field coupling among the various portions of this type of interconnected system. In at least one instance a diplexing filter that was on an open panel on the inside of a wood-frame ACU building located about one meter from a tower had enough current from the magnetic field of the tower induced into an inductor to cause a damaging arc, even though the induced energy was picked up from another transmitter site a kilometer or so away.

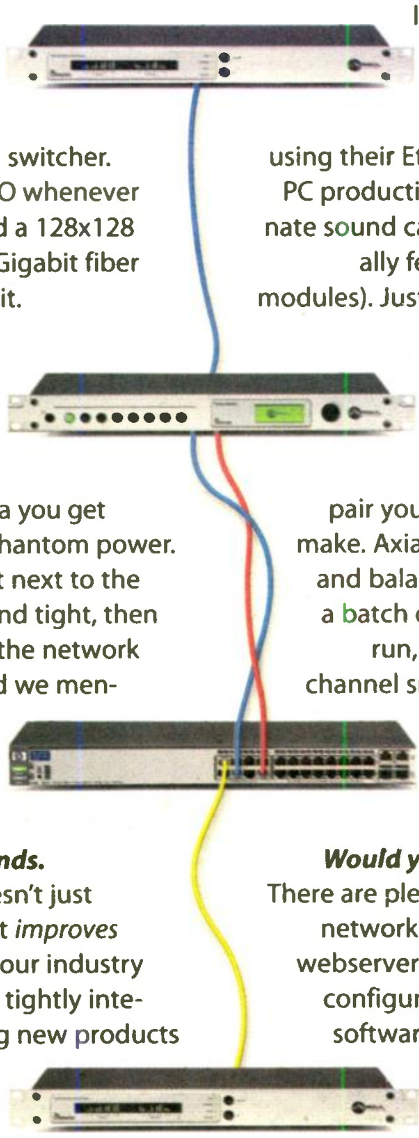
This diplexing equipment had only series filters and very short multiple ground-strap connections between adjacent panels, because the frequency spacing was well over 200 kHz, so the filtering wasn't compromised by the geometry of the equipment.

In general, systems with wide frequency spacing don't usually suffer from unintended coupling since the transmitters themselves offer better discrimination

ISOLATION, PAGE 24

broadcast studio system.

dio broadcast studio system. Damned marketers.



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How to Broadband AM Antenna Systems

Use Calculation and Proper Construction to Optimize Phasor Performance

By W.C. Alexander

The author is director of engineering, Crawford Broadcasting Corp.

Presumably, the FCC eventually will open the door for AM nighttime IBOC. When that happens, a flood of conversions probably will follow. But even now, many stations are making preparations or making the jump to digital.

One thing that engineers are finding, however, is that many of their antenna systems are not quite up to the task.

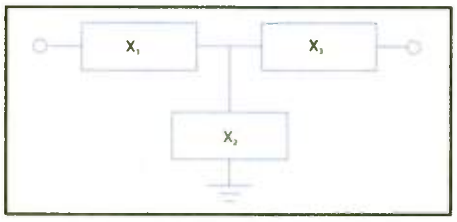

Fig. 1: Tee-Network Block Diagram

AM antenna systems present unique challenges for IBOC transmission. Impedance bandwidth and pattern bandwidth are two measures that have a dramatic effect on a station's performance in the digital mode. Here, we will consider impedance bandwidth, which applies to both directional and nondirectional antennas.

It's fairly easy to match just about any reasonable load to a 50-ohm transmission line. This can be done with an L-network, a tee-network, a pi-network or in some cases, a single series component. As long as we're dealing with an unmodulated carrier, any of these methods will yield acceptable results, presenting a 50-ohm nonreactive load to the transmission line.

The trouble starts when we apply modulation and introduce frequency components that are at other than the center (carrier) frequency. At first glance, one wouldn't think that a 10 kHz difference in frequency would make all that much difference. But at AM frequencies, that can be about 2 percent of the operating frequency. Translated to the FM band, that represents a 2 MHz change, or 4 MHz of overall bandwidth. Thinking in those terms, it becomes clear that we are talking about a significant amount of bandwidth.

For IBOC, tests have shown that to preserve perfect hybrid-mode digital and analog reception, you need variable standing wave ratio (VSWR) values of 1.11:1 or better at ±5 kHz, 1.25:1 or better at ±10 kHz, and 1.40:1 or better at ±15 kHz. The VSWR tolerance can be increased somewhat if a 3 o'clock or 6 o'clock cusp rotation is used. We'll talk more about cusp rotation later.

So our mission becomes one of designing a matching network with load impedance that meets the above specification. This is no small challenge.

Manufacturers of AM tuning and coupling equipment, such as Kintronic Laboratories, have some powerful custom software tools available to them that allow them to tailor a network design to a particular situation. While these tools are nice and a real time saver, the truth is there is no "magic" involved. Every AM engineer has the basic tools necessary to design a broadband matching network. Employing these basic tools to achieve the desired results simply requires tenacity and patience.

To keep things relatively simple, we will limit this discussion to a nondirectional radiator and matching network. The same principles apply to directional systems, as each tower has a matching network. The only caveat with directional systems is that the phase shift of each matching network on the sideband frequencies must be considered.

BEGIN WITH MEASUREMENTS

The starting point for any network design is a set of careful and accurate impedance measurements across the desired network passband. This means that something more than the transmitter and operating impedance bridge (OIB) will be needed.

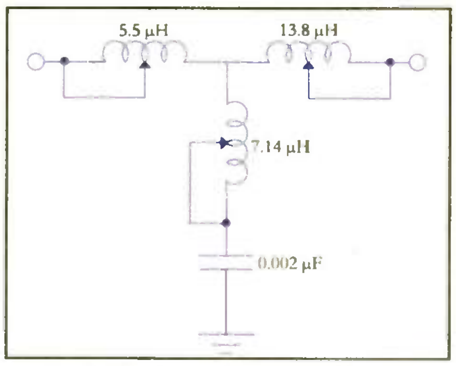

Fig. 2: Simple Tee-Network Schematic

A signal generator, impedance bridge and detector will be needed to measure the impedance at each frequency. I use a Potomac SD-31 combination synthesizer/detector along with a trusty General Radio 1606B impedance bridge. With this hardware, I can very accurately measure a wide range of resistance and reactance while maintaining a degree of immunity from received skywave signals that can confuse the measurements. Other equipment complements can work just as well.

Disconnect the antenna from the existing tuning network, but leave lighting and static drain chokes connected because these are part of the net impedance of the tower. Measure the resistance and reactance in 5 kHz increments. Be sure to correct the measured reactance for frequency in accordance with the instructions supplied with the bridge.

With the impedance sweep in hand, the math begins. Using the standard tee-network formulas, calculate the nominal values for X_1 (input), X_2 (shunt) and X_3 (output) using the measured resistance and reactance values for the carrier frequency. See the block diagram in Fig. 1 for a basic tee-network layout.

Frequency	Resistance	Reactance
985	23.1	-58.0
990	23.4	-j56.0
995	23.8	-j54.0
1000	24.1	-j52.1
1005	24.5	-j50.1
1010	24.9	-j48.1
1015	25.2	-46.1

Table 1: Impedance Sweep of 76-degree Tower

For our hypothetical nondirectional antenna, a -90 degrees network is a good place to start. All three legs in such a network will be of equal absolute value except X_3, which will be adjusted to cancel out the reactance of the load. The tee-network formulas are as follows:

1) $$X_1 = \frac{R_1}{\tan\beta} - X_3$$

$$X_2 = \frac{R_2}{\tan\beta} - X_3$$

$$X_3 = \frac{\sqrt{R_{in}R_{out}}}{\sin\beta}$$

where: β = desired phase shift

Let's run through an example. In this case, the impedance data is from a series-fed 24-inch face tower 76 electrical degrees tall on the 1000 kHz carrier frequency. The measured impedance sweep is shown in Table 1.

Applying the tee-network formulas, a -90 degree network would require the following leg reactances:

X_1 = +j34.7
X_2 = -j34.7
X_3 = +j34.7 + j52.1 = +j86.8

For X_1, 5.5 µH of inductance is required to produce +j34.7 ohms of reactance on 1000 kHz. X_2, the shunt leg, will obviously require a capacitor in series with a coil to achieve the negative reactance for that leg. A 0.002 µF capacitor is chosen in series with 7.14 µH to yield the proper net reactance. For X_3, a 13.8 µH inductor will yield the desired +j86.8 ohms of reactance. Fig. 2 is a schematic of this network.

At carrier frequency, in this case 1000 kHz, the above combination of components will produce 50 j0 ohms at the network input, which is the impedance of the transmission line and thus the desired input impedance of the network. The trouble is that the components used to make up the leg reactances have different reactance values on frequencies other than carrier. For the capacitors, the reactance decreases with increased frequency and vice versa; it is just the opposite with inductors. Thinking this through, it becomes clear that the X_C and X_L go in opposite directions for changing frequency.

Take the shunt leg, for example. Our 7.14 µH inductor has a reactance of +j44.9 ohms on 1000 kHz and our 0.002 µF capacitor has a reactance of -j79.6 ohms. In series, the net reactance is +j44.9 -j79.6 = -j34.7 ohms. Now, let's try this again on 1010 kHz, the +10 kHz sideband frequency. The 7.14 µH presents a reactance of +j45.4 ohms, and 0.002 µF represents -j78.8 ohms. The net is then +j45.4 -j78.8 = -j33.4 ohms, a difference of over an ohm.

If we run the numbers for the shunt and input leg components, we get net reactances of: X_1 = +j34.9, X_2 = -j33.4 and X_3 = +j87.6 at the sideband frequency of 1010 kHz.

With known load impedance and leg values, we can calculate the input impedance of our network using the following formula set. Don't be daunted by the math. The formula set is easily programmed into computer code or a programmable calculator. There are commercial computer programs available to help with the calculations.

The input resistance is calculated by:

2) $$R_{IN} = \frac{B_T}{B_T^2 + Y_T^2}$$

Where:

3) $$B_T = \frac{R_{LOAD}}{R_{LOAD}^2 + X_A^2}$$

$$X_A = X_{LOAD} + X_3$$

$$Y_T = Y_A + Y_B$$

$$Y_A = \frac{X_A}{R_{LOAD}^2 + X_A^2}$$

The input reactance is calculated by:

4) $$X_{IN} = X_1 + X_P$$

Where:

5) $$X_P = \frac{Y_T}{B_T^2 + Y_T^2}$$

BROADBAND, PAGE 20

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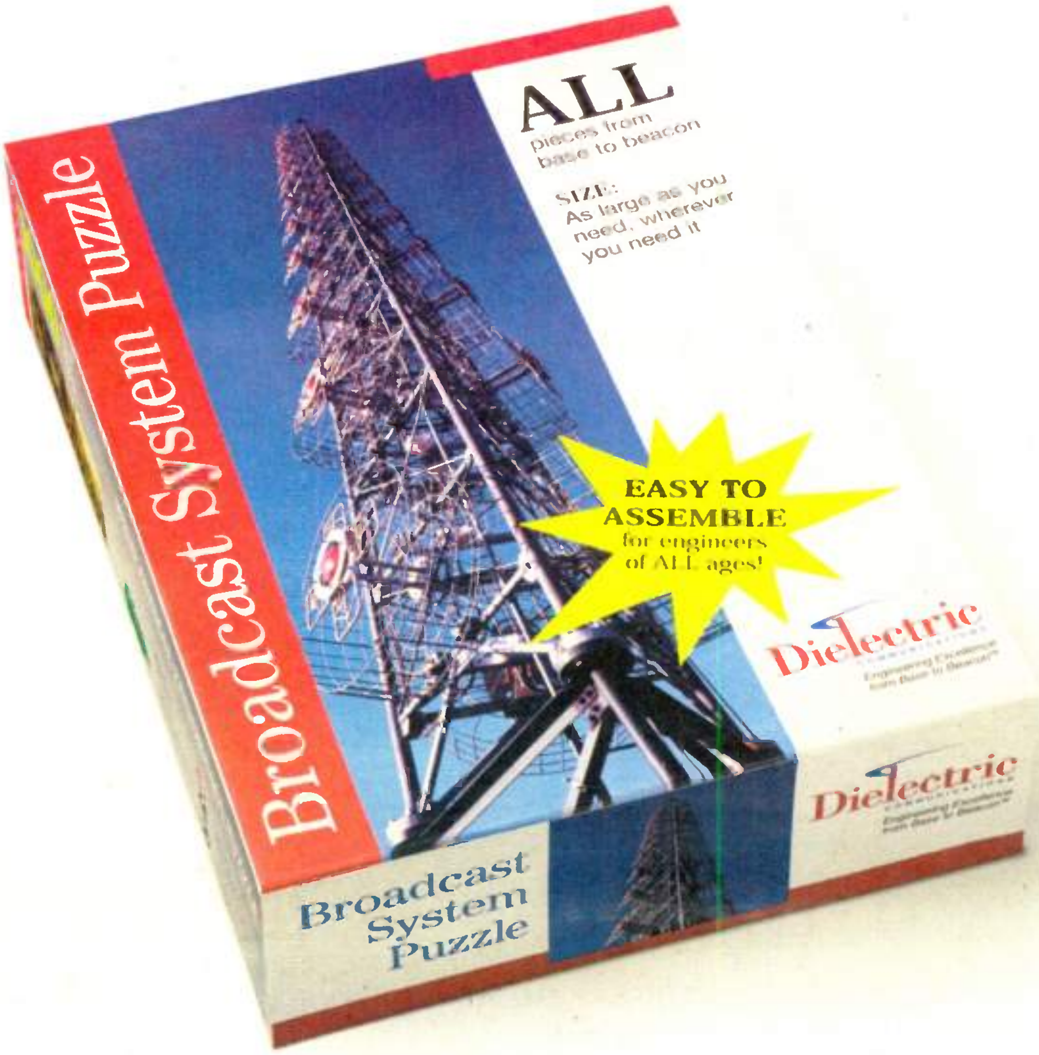

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Broadband

CONTINUED FROM PAGE 18

Now, if we run these 1010 kHz leg reactance values through the above formulas using the 1010 kHz load R and X values, we find that the input impedance of the network will be 42.5 -j8.8 ohms, providing a VSWR of 1.29. VSWR is calculated using the following formula:

6)

$$VSWR = \frac{\sqrt{(z_o+r)^2+x^2}+\sqrt{(r-z_o)^2+x^2}}{\sqrt{(z_o+r)^2+x^2}-\sqrt{(r-z_o)^2+x^2}}$$

Where:

zo = characteristic impedance of the transmission line in ohms

r = input resistance of the network

x = input reactance of the network

That VSWR value of 1.29 does not meet the IBOC specification. Calculating the leg values on 1015 kHz yields a VSWR of 1.46, also outside the IBOC specification. Running the numbers for the whole passband yields the input impedance sweep in Table 2.

Freq.	R_{IN}	X_{IN}	VSWR
985	50.2	17.4	1.41:1
990	51.9	+11.7	1.26:1
995	51.7	+5.6	1.12:1
1000	50.0	0.0	1.00:1
1005	46.7	-5.0	1.13:1
1010	42.5	-j8.8	1.29:1
1015	38.22	-11.7	1.46:1

Table 2: Network Input Impedance Sweep, Try 1

A CHANGE OF PHASE

So what can we do to make the network work for us within the IBOC specification?

Quite often, a good place to start is changing the phase shift of the network to obtain a more symmetrical passband. In our example, the lower sideband VSWR is much lower than the upper sideband VSWR. Decreasing the phase shift of the network from -90 degrees to -72 degrees gives better results. Using the tee network formulas, the nominal values for X_1, X_2 and X_3 calculate to be +j20.25, -j36.50 and +j80.77 respectively. The resulting impedance sweep is shown in Table 3.

Note that the reactance decreases with increasing frequency, which is normal. We can counter this slope, however, if we add a high-reactance capacitor to the input leg as illustrated in Fig. 3. The net reactance of the leg on carrier must still be +j20.25 ohms, but the L-C ratio produces a slope that can be beneficial.

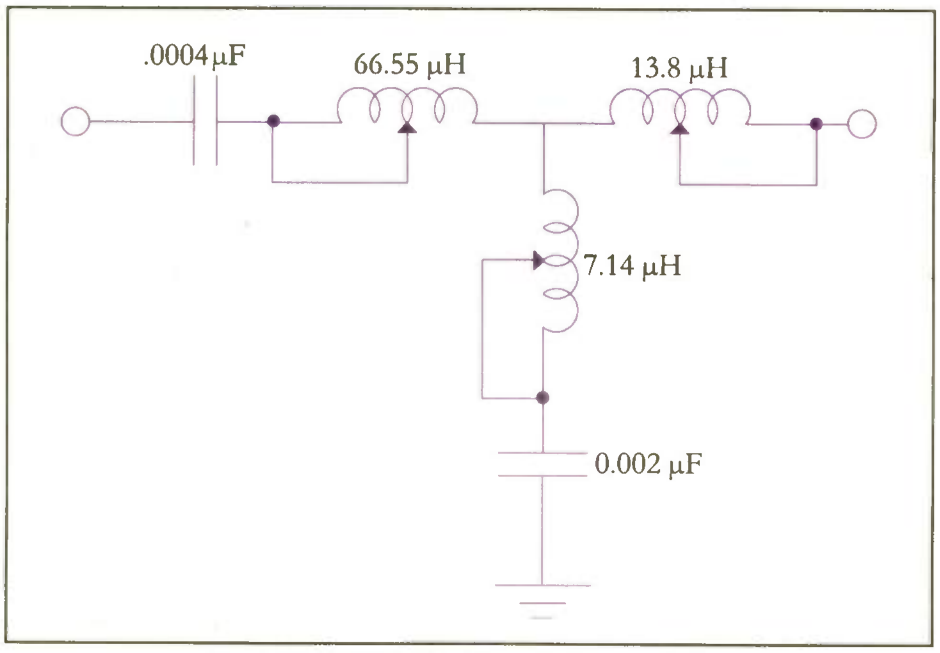

Fig. 3: Tee-Network With Input Leg Slope Correction

In our example, I experimented with different capacitor values and finally settled on 0.0004 µF and 66.55 µH in the input leg. Again, running the input formulas this combination yields the sweep shown in Table 4. Note how this slope counters the slope of the input reactance of the network on the sidebands.

If we check it on the 5 kHz sideband frequencies, we find that we have 1.04:1 on both sides. This presents what appears to be an excellent load for IBOC operation, well within the specification. The caveat here is that IBOC compatibility is more than just impedance bandwidth. Tests have shown that symmetry considerations seem to be more important than the impedance guidelines. For example, a broadband network where the input impedance locus is wrapped around tightly while meeting the stated VSWR limits would likely perform worse for IBOC than a network with a symmetric cusp with the VSWR slightly outside the limits.

Still, slope correcting for bandwidth is a good place to start. From there, you can plot the input impedance sweep on a Smith chart and then experiment with the input leg and the phase rotation, as we have done in Fig. 4, to get the desired symmetry. Our example, by the way, plots on a Smith chart as a more-or-less symmetrical 9 o'clock cusp.

It's true that we arrived at this solution using trial and error. But we did so making educated guesses based on measured data

BROADBAND, PAGE 22

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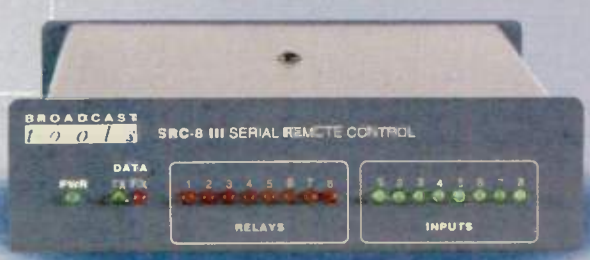
The SRC-32 is a computer interface to the real world. Connection through an RS-232 or RS-422 serial port the SRC-32 can notify your PC software program that any of 32 -optically isolated inputs has been opened or closed and allow your software to control eight SPDT, 1-amp relays and an additional 24 open collector outputs. Communication with the SRC-32 can be accomplished via short burst type ASCII or binary commands from your PC (computer mode). Also, two units can be operated in a standalone mode (master/slave mode) to form a "Relay extension cord," with 32-channels of control in each direction. The unit can communicate using RS422 or RS232, at data rates up to 38400. The SRC-32 may be expanded to 128 inputs x 128 outputs. Optional external Ethernet capabilities may be added with the SP-1. The optional USB-RS-232 adapter may be added for USB operation.

GPI-32

The GPI-32 interfaces 32 optically isolated inputs to a RS-232 or USB port. The GPI-32 is equipped with both dual plug-in Euroblock connectors and two independent DB-37 connectors that may be interfaced directly to the DB-37 connectors located on the StarGuide II/III relay cards. Additional features; dual RS-232 connectors, one for daisy-chaining multiple units on the same legacy serial port and a DB-9 to interface to our USB adapter; LED indicators for power and input activity; twin power connectors allowing up to four units to be driven off of one power transformer. The GPI-32 is powered by a surge protected internal power supply. The optional RM-3 may be added for rack mount applications.

SRC-2/SRC-2x

The tiny TOOLS SRC-2 interfaces two optically isolated inputs and two SPST relays to a RS-232 or USB port, while the SRC-2x does this via a 10/100baseT Ethernet port. Both the SRC-2 and SRC-2x can notify a users PC software program that any of two optically isolated inputs have been opened or closed and allows your software to control two SPST, 1-amp relays. The SRC-2x is also able to send an email when either of the two inputs change state. The user may also add up to 48 ASCII strings per input and 16 user defined string per relay. Communication with the SRC-2(x) is accomplished via short "burst" type ASCII commands from the users PC. Also, two units may be operated in a standalone mode (master/slave mode) to form a "Relay extension cord," with two channels of control in each direction. The SRC-2 communicates using RS-232 at baud rates up to 9600 and the SRC-2x via 10/100baseT Ethernet. The SRC-2(x) is powered by a surge protected internal power supply. Either unit may be rack mounted on the optional RA-1 mounting shelf.



SRC-8 III

The SRC-8 III is a computer interface to the real world. Connection through an RS-232 or RS-422 serial port the SRC-8 III can notify your PC software program that any of 8 opto-isolated inputs have been opened or closed and allows your software to control eight SPDT, 1-amp relays. Communication with the SRC-8 III can be accomplished via short "burst" type ASCII or binary commands from your PC (computer mode). Also, two units can be operated in a standalone mode (master/slave mode) to form a "Relay extension cord," with 8-channels of control in each direction. The unit can communicate using RS-232 or RS-422, at data rates up to 38400. The SRC-8 III may be expanded to 32 inputs x 32 outputs. Optional external Ethernet capabilities may be added with the SP-1. The SRC-8 III may be set on a desktop, mounted on a wall or up to three units mounted on the RA-1, Rack-Able mounting shelf.

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Broadband

CONTINUED FROM PAGE 20

and calculations. And so often, in the world of AM antennas, this is the way things are done.

FUNDAMENTALS OF PHASOR LAYOUT

There are a few other tricks of the broadbanding trade that are worth mentioning. Minimizing stray reactances and coupling through good construction practices and series bandwidth correction circuits are two such tricks.

The key to maintaining good impedance bandwidth in any antenna system is minimizing unwanted reactances. These reactances come in various forms, including lead inductance, distributed capacitance, mutual coupling and the reactance slope of the load. Some of these things we can address during design and construction, but some things we have to live with. Our goal should be to mitigate unwanted reactances as best we can.

Stray reactances from component leads (tubing and strap) are a fact of life. Any given piece of wire, tubing or strap will exhibit both series inductance and shunt capacitance. We know that going in. However, we can often take steps to minimize strays.

The first and most important step in minimizing stray reactances is to keep the plumbing as short as possible. A well-thought-out component layout is crucial to good impedance bandwidth. There are practical — and, often, mechanical — issues to be addressed in the component layout, but where we have a choice, a component layout that keeps the tubing and strap runs to a minimum will result in better impedance bandwidth than other layouts.

If it's possible, for example, to mount a capacitor so that it connects to a series coil with a six-inch piece of tubing without any hard bends and where the groundside flange is bolted directly to the copper ground strap instead of connecting via tubing or strap, the stray reactances will be much lower. We can, of course, tune that leg of the network so that the strays are taken into account on carrier. On the sidebands, however, the strays introduce another set of variables. Getting rid of or minimizing them makes the performance more predictable, improves bandwidth and reduces losses.

Freq.	R_{IN}	X_{IN}	VSWR
985	41.7	+11.9	1.37:1
990	45.2	+8.9	1.24:1
995	48.1	+4.8	1.11:1
1000	50.0	0.0	1.00:1
1005	50.6	-5.6	1.12:1
1010	49.7	-j11.2	1.25:1
1015	47.6	-16.4	1.40:1

Table 3: Network Input Impedance Sweep, Try 2

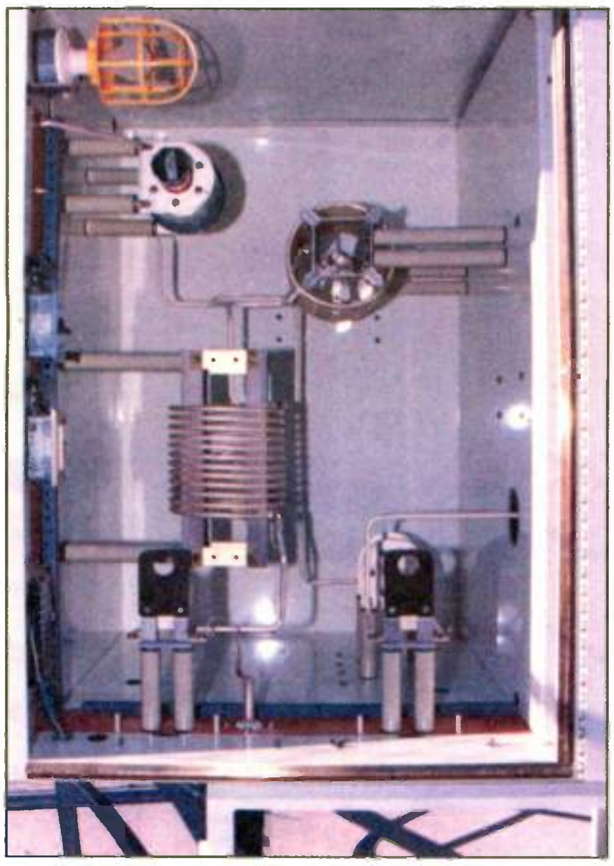

Fig. 5: Use all three axes to minimize coupling.

Mutual coupling and distributed capacitance are bandwidth killers and loss producers. Two coils, for example, that are mounted close to one another and in the same plane do not function only as series inductors. The combination also acts as a transformer with one coil acting as a primary and the other as a secondary. One coil induces a current into the other. The effect that such a configuration will have on bandwidth, phase shift and loss is tough to predict, but it is seldom beneficial.

Space and orientation are the keys to minimizing mutual coupling and distributed capacitance. To have good spacing between individual components and between components and ground, you must have adequate room in the enclosure or chassis. Bigger is better. At the same time, you have no doubt already figured out that increased component spacing runs counter to shorter component leads, and

At first glance, one wouldn't think that a 10 kHz difference in frequency would make all that much difference. But at AM frequencies, that can be about 2 percent of the operating frequency.

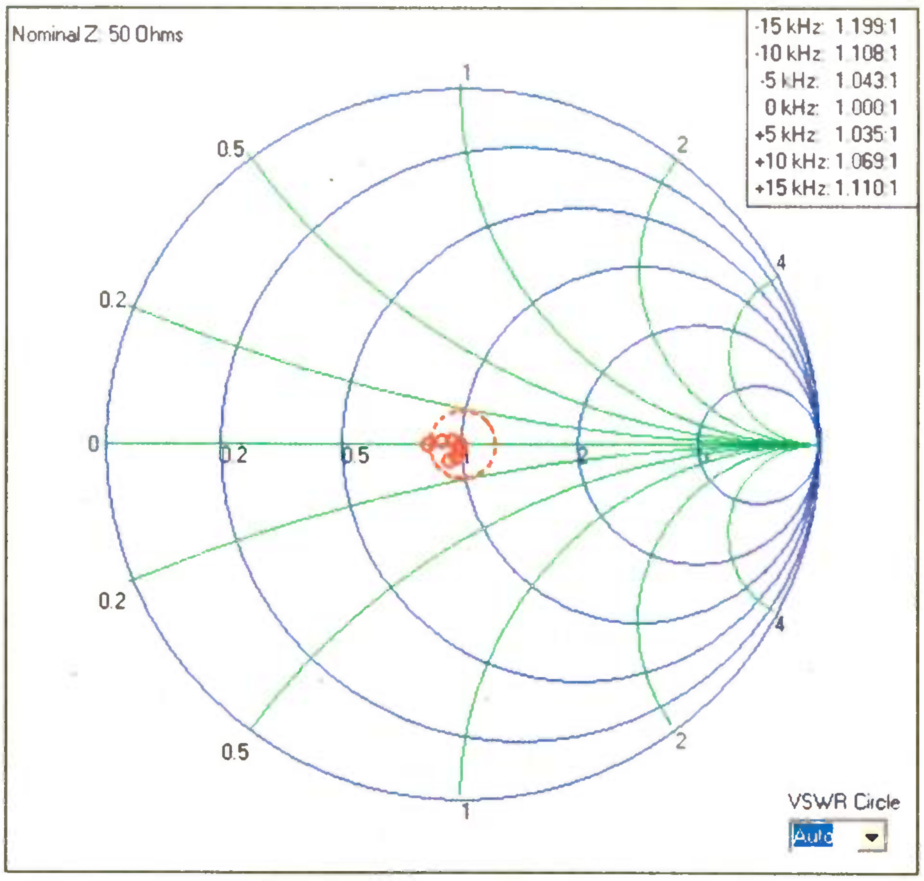

Fig. 4: Smith Chart Plot of Slope-Corrected Network Input

that's very true. It's a trade-off, and the designer has to weigh the pros and cons of each aspect in the layout decision-making process.

In my experience, axis is as important if not more so than spacing. Take the example of two coils in the input and output legs of a network. Mounting those two components close together would be beneficial for minimizing stray reactances, but the two coils will couple like the windings of a transformer, which is not desirable. If we take one of the coils and turn it 90 degrees from the other one (so that the turns of one coil are perpendicular to the turns of the other), we virtually eliminate the coupling. Now we can mount the two coils close enough together to minimize lead inductance.

You might be thinking that this is fine for any two legs of a three-leg tee-network, but what about the third leg? How are we going to mount that component so that it is not in the same axis as either of the other two? The answer is to use all three mounting dimensions.

Within an ATU or phasor cabinet, side walls can be used for component mounting, or partitions can be installed that are perpendicular to the plane of the back wall. Partitions are more useful in many cases than sidewalls because they can be placed in the most advantageous location and they can be used to provide an electromagnetic shield between components.

For example, a coil can be mounted in close proximity to another coil, with their turns parallel and with a grounded partition between them, without much worry about coupling between the two coils. A relatively large-diameter hole must be provided through the partition for the connecting tubing (large diameter to provide adequate spacing), but this has little effect on coupling if the coil is mounted out of the aperture of the hole. Fig. 5 is a photo of a properly constructed network using all three axes.

Freq.	R_{IN}	X_{IN}	VSWR
985	41.7	-0.1	1.20:1
990	45.2	+0.9	1.11:1
995	48.1	+0.8	1.04:1
1000	50.0	0.0	1.00:1
1005	50.6	-1.6	1.04:1
1010	49.7	-j3.3	1.07:1
1015	47.6	-4.5	1.11:1

Table 4: Network Input Impedance Sweep, Try 3

Frequency	985	1000	1015
Original X	+12	0	-16
Original VSWR	1.37:1	1.00:1	1.40:1
Network X	-6	0	+6
Corrected X	+6	0	-10
Corrected VSWR	1.24:1	1.00:1	1.24:1

Table 5: Effects of Series Correction Network

Another important consideration for minimizing both distributed capacitance and coupling is the routing of interconnecting tubing. Running two pieces of tubing parallel to one another in close proximity for any distance should be avoided. There are almost always situations where such tubing or strap must cross or pass in close proximity, but whenever possible such runs should be laid out so that this takes place with the runs perpendicular to one another.

Long tubing runs parallel to a grounded surface will exhibit significant amounts of distributed capacitance. This can be minimized by increasing the spacing between the tubing and the parallel grounded surface. Use eight-inch standoff insulators, even if four-inch or six-

BROADBAND, PAGE 24

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Broadband

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inch spacing is called for by the voltage. Fig. 6 shows properly oriented and spaced tubing runs within and between networks.

SERIES CORRECTION NETWORKS

With the strays and other undesired reactances minimized to the degree possible by component and tubing layout, what's left is what cannot be changed, the result of the remaining strays, mutual coupling, distributed capacitance and the load impedance. If the slope of this remaining reactance is negative (i.e., decreasing reactance with increasing frequency), a series L-C circuit can sometimes be used to slope-correct this reactance.

Let's take, for example, a network that is otherwise optimized that presents a -15 kHz sideband input impedance of 42 +j12 and a +15 kHz impedance of 47 -j16. Use a series bandwidth correction circuit consisting of a 796 pF capacitor and a 31.8 µH inductor. Look at Table 5 and see what effect such a series network has on the VSWR bandwidth of our otherwise so-so network.

It's clear that we have helped ourselves a great deal by adding this simple network. In this case, it was inserted ahead of the network input, to wash out and make symmetrical the residual reactance there. This plots on a Smith chart as a 9 o'clock cusp, presenting a symmetrical load as shown in Fig. 7.

Sometimes, it may be more advantageous to use such a network as a "prematch" between the network and the load. This is totally dependent on the circumstances; each case must be individually studied and evaluated.

Broadbanding of an antenna system is seldom achieved through a single, simple step. The process has many facets, including careful network design, minimizing stray reactances and coupling through proper component and tubing layout/orientation, and sometimes, additional series correction circuits can help. Each part of the process is important and will have a significant impact on the impedance bandwidth of the antenna. Attention to all the details will pay off with a better sounding, more efficient and IBOC-ready antenna system. ■

Fig. 6: Avoid long parallel tubing runs where possible.

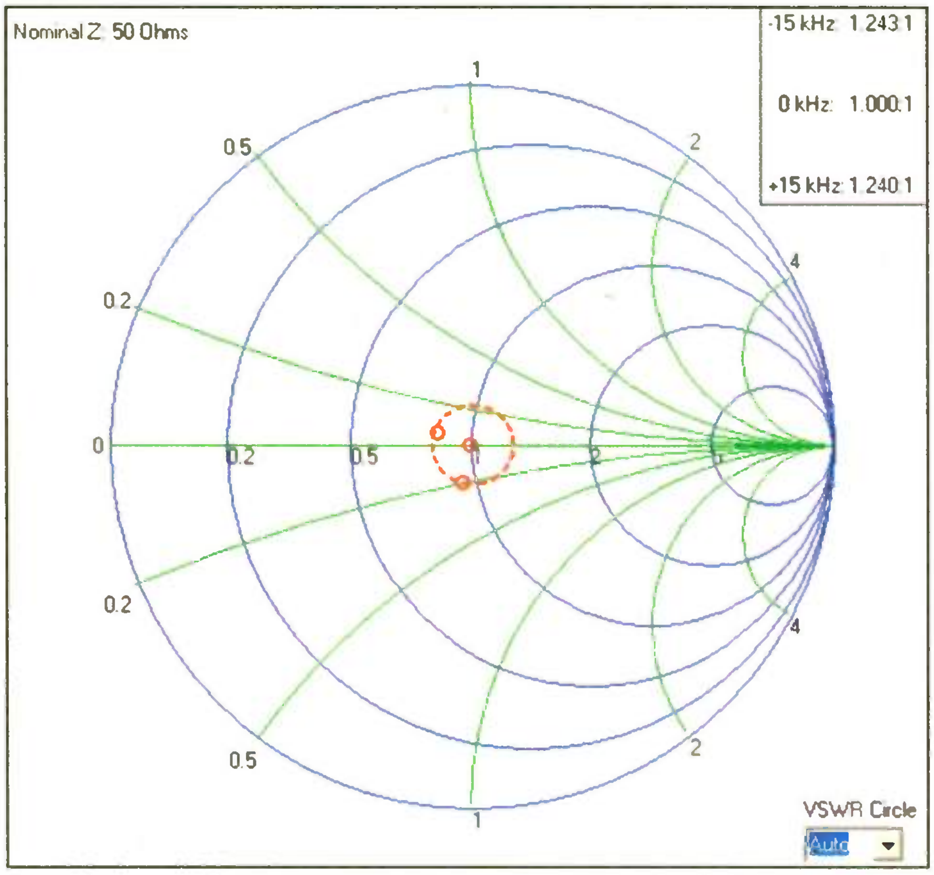

Fig. 7: Smith Chart of Network Input With Series Broadbanding Network

Adaptive

CONTINUED FROM PAGE 13

Frequency Sensitivity (N+1 capability)

In this test the frequency was changed from 88 MHz to 108 MHz with fixed and adaptive pre-correction. While this test is not relevant to most stations because they always operate on a fixed frequency, it is significant in installations where there is a single backup transmitter for multiple stations.

The frequency change test shows that adaptive correction achieved an improvement of 12 dB over fixed correction on the lower or worse IM3 sideband (see Fig. 12). Also note that the fixed pre-correction did not ensure compliance with the emissions mask with frequency change across the band.

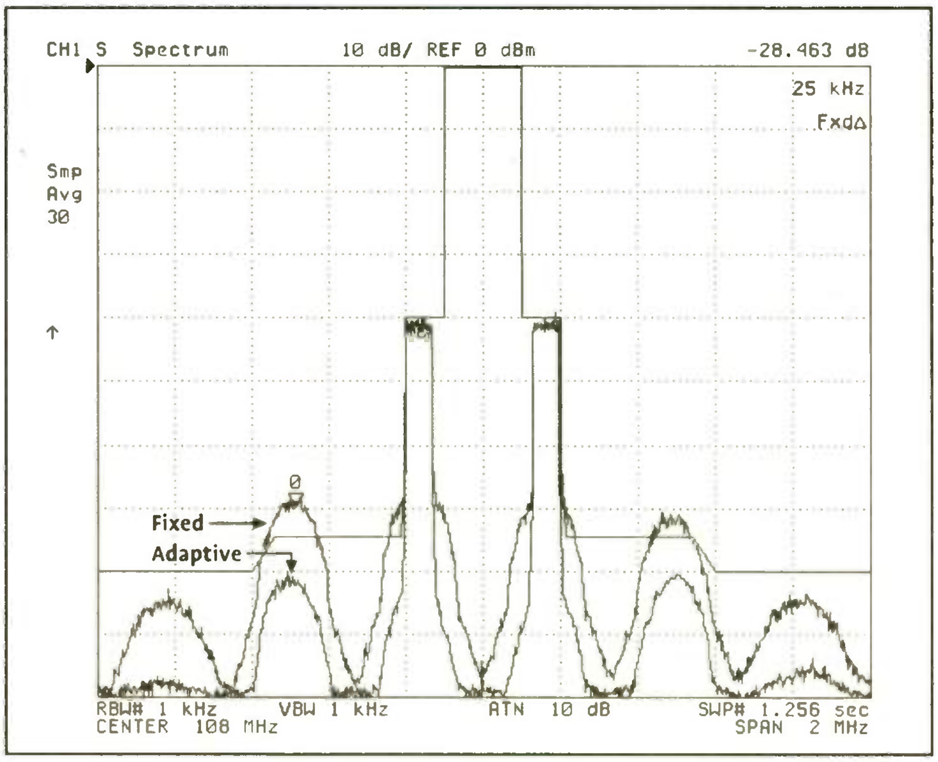

Fig. 12: Frequency Change From 88 to 108 MHz With Fixed and Adaptive Pre-Correction

CONCLUSIONS

Pre-correction is the accepted linearization technique used by FM HD Radio transmitter manufacturers. Pre-correction can correct for AM-AM and AM-PM characteristics that would otherwise result in unacceptable emissions.

Fixed pre-correction systems are unable to correct for the effect of a varying environment on amplifier nonlinear characteristics. Experimental results show that VSWR, temperature and frequency changes typical of many broadcast sites may result in unacceptable emissions as defined by the proposed HD Radio emissions mask. Digital adaptive pre-correction did not suffer a similar degradation. Emissions were maintained within the mask at all times.

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2. Saleh, A.A.M., and Salz, J., "Adaptive Linearization of Power Amplifiers in Digital Radio Systems," The Bell System Technical Journal, Vol. 62, No. 4, April 1983. ■

Isolation

CONTINUED FROM PAGE 15

against the unwanted signal. Systems with wide spacing, and therefore, favorable impedance bandwidth are often constructed with only series filters. The high impedance of series filters, when no shunt filter is present, substantially reduces pickup at the unwanted frequency because the high impedance is a part of the unintended loop.

In another retrofit installation, the equipment manufacturer located the two sets of filters and the newly installed ACU network in a single cabinet with appropriate internal dividers to minimize coupling, but then ran the unshielded combined feed from the output side of the filters back through one of the filter cubicles to an output feed-through to the tower. This system had unacceptable intermodulation when first installed. Because the system power was low, short sections of foam coaxial line were installed to shield the feeders, minimizing the coupling and bringing the intermodulation below the required value.

Similarly, at a site where a new owner replaced the equipment of the original station with new equipment, the interconnection between the newly installed ACUs and the previously installed filter cabinets, which were integral with the ACUs for the second frequency, ran close to the tower base and enough coupling was present to produce unacceptable intermodulation. It was necessary to add cabinet grounding from all corners of all of the equipment cabinets to the tower-base grounding and to add coaxial cable for the interconnections to bring the intermodulation down below the required value.

Completely new installations don't often suffer from these problems, but it's generally because they most often employ a single cabinet for each ACU/filter combination.

Because the whole purpose of a diplexing system is to isolate everything but the radiating antenna towers, make sure the electronic circuitry's purpose isn't compromised by the physical construction or installation geometry of the system. ■


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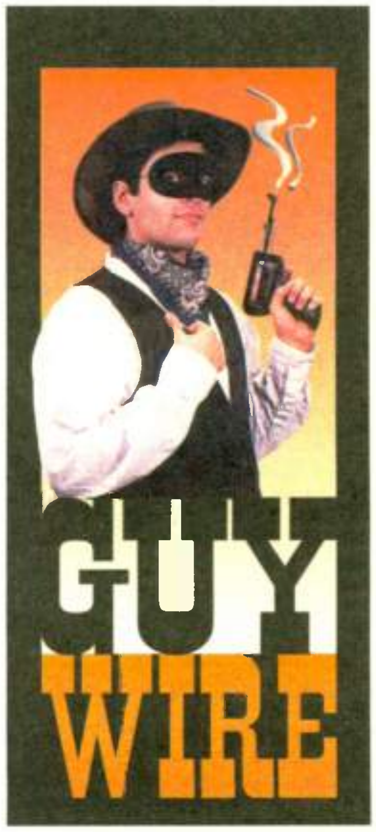
Let's Save the AM Band

It's Time to Reorganize AM's Family Living Arrangements

By Guy Wire

Guy Wire, Radio World's masked engineer, is the pseudonym of a well-known radio veteran. Opinions are his own.



FCC adoption of standards and rules for HD Radio is expected sometime later this year.

NRSC-5 was recently adopted during NAB2005 and is the culmination of many years of work by the NRSC subcommittee on DAB. It no doubt will be substantially adopted by the commission for both FM and AM services, including AM HD nighttime operations.

The industry is for the most part applauding this seemingly long-overdue event, especially for FM. But many are still fearful of serious interference fallout when AM HD is widely deployed full-time.

We've heard that a few subcommittee members were pressed gently after voicing their reservations, to ensure the NRSC-5 standard could pass unanimously. There have been ongoing concerns about reduced coverage, especially at night and during critical hours, caused by adjacent-channel interference from the AM HD side carriers. These land squarely on the first adjacents and have been demonstrated to cause elevated noise interference in second- and even third-adjacent channels, especially on wider bandwidth receivers.

THE INTERFERENCE DILEMMA

Based on results from their own studies, Ibiquity has long maintained that any perceived nighttime HD Radio interference to stations from strong adjacent channels is not going to be a big deal. They say only a few isolated cases will experience significant skywave-to-groundwave interference. Quite a few smaller-market AM owners would disagree.

The more significant problem, which Ibiquity does acknowledge, will be interference to the secondary and skywave coverage areas of clear-channel stations. This will be manifested as holes in areas where previously useful analog reception will be wiped out by groundwave signals of smaller-market stations that light up AM HD operations on nearby channels.

Very little is known about how well HD Radio reception will perform in most interference-limited situations, especially skywave reception for clear-channel stations that reach significant audiences. That little secret worries some NRSC members.

I have long maintained that opening up AM HD Radio for all stations at night will precipitate more problems and formal interference complaints than Ibiquity is suggesting will likely occur. We'll learn over time how well the FCC's proposals for negotiated digital power reductions will work.

Ibiquity and the NAB completely support the notion that deploying AM HD full time will serve the greater good to accelerate AM into a higher-quality digital future despite any potential loss of coverage for many stations.

THE TRUTH

Both parties are more than willing to let the interference chips fall where they may. Unfortunately they continue to ignore the underlying symptoms of a very sick patient and insist on administering a new wonder drug that may induce crippling side effects more than it promotes healing and recovery. At the root of the AM illness are simply too many signals causing too much interference in a channel spacing scheme that allows stations legally to encroach into their neighbor's space. All other broadcast services are allocated with guard-band protection between adjacent channels.

There is a suspicion that some interference is being generated by smaller-market stations that are required by license to drop power radically at night or switch to limited-coverage DA patterns, but that have chosen to 'forget' to switch to night mode.

Many respected engineers have long observed the AM band is already a disaster at night, choked with noise, interference and colliding signal wreckage on most channels. Only a few signals in most markets provide reliable wide-area coverage in most regions of the country.

There is a suspicion, held by quite a few of us, that some of the interference is being generated by smaller-market stations that are required by license to drop power radically at night or switch to limited-coverage directional antenna patterns, but have chosen to "forget" to switch from day to night mode. Many have DA systems that are woefully out of spec due to negligence and lack of maintenance. Too many have been getting away with such blatant illegal operations for very long periods of time, knowing that FCC field offices are under-staffed and under-budgeted to be able to deal with it.

The sad reality about the AM band is that there are only a few stations in most markets that are truly profitable or that can deliver significant listener support. The full-time 50 kW powerhouses will probably always enjoy solid ratings and revenue performance. Almost all rated markets have at least one AM talk or news/talk station that delivers full-time market coverage and can compete near the same level with most FM stations.

After that, sports and maybe a foreign language station or two usually struggle to

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AM Band

CONTINUED FROM PAGE 27

hold their own. At the bottom of the AM food chain are all the rest — mostly automated religious or satellite-fed "repeaters" that make little or no money and get full-time life-support from sister FM stations. Quite a few fail to crack or just barely make reporting minimums to be rated in Arbitron or other surveys.

The band would be better served if most could simply go dark, turn in their licenses and receive some form of meaningful compensation, perhaps from other station owners who would benefit by then being able to expand their own coverage areas.

If it were not for consolidation, many of these stations would have gone dark long ago. Owners keep them alive in hopes HD Radio will increase their value and music formats might again someday be competitive on AM. At a minimum, they are holding out for some religious or ethnic operator to buy them so a profit on their original investment can be made. But values of AM stations that do not enjoy full-time facilities or cover their markets adequately have languished for a long time.

With the explosion of the Internet, satellite radio, portable MP3 players and iPods — and, very soon, cell phones that can stream live content as well as multichannel FM HD Radio — the mass-media playing field has become highly fractionalized.

THINNING THE HERD

The growth and proliferation of infotainment choices is making AM radio's chances for regrowth and long-term success more problematic than ever. It is already causing deterioration of values of marginal AM facilities in many markets. The introduction of multichannel programs on FM HD will undoubtedly accelerate that deterioration.

If there is a viable future for the AM band, it will be dependent on a sweeping initiative to clean it up and thin the herd so that the stronger members can improve and become better prepared for survival. It's the best way AM HD enhancements can be effective for stations that can claim or will be able to secure solid full-time coverage in their markets.

One of the more frequent concerns voiced by smaller AM owners is the cost burden of adding HD Radio and the attendant updating of transmission systems that will be required. Many will simply not be able to afford it. That could be incentive enough for some to sell out and take a loss. But the band would be better served if most could simply go dark, turn in their licenses and receive some form of meaningful compensation, perhaps from other station owners who would benefit by then being able to expand their own coverage areas.

With so many mass media choices out there in markets of all sizes, we have long passed the point of concern that the loss of a local-market AM radio station somehow endangers the citizens of that market from being adequately and properly served with public interest programming. The provision in the rules that a certain minimum number of licensed radio signals must be preserved when facilities are deleted or relocated has become an anachronism in most cases.

AM IMPROVEMENT REINVENTED

For this idea to germinate and grow, the commission needs to freeze all AM facilities' additions or changes and then modify the rules to enable the cleanup. If HD Radio interference mitigation is allowed to be bilaterally negotiated, the opportunity for stations that can reasonably improve their market coverage and service should be allowed to buy out lesser facilities without FCC rules restrictions. But they shouldn't be held up for inflated prices by owners who sense a captive opportunity. Such transactions for this new kind of AM improvement need more help and incentive than just simple buyouts.

A marginal AM station with little public service value and a tiny audience is not likely to be missed if it is bought out of existence by other interests who have a better chance of improving service of another station that can reach a larger audience. The commission has long wrestled with the challenge of AM improvement. The rules changes intended to deliver on this goal, like granting local channels 1 kW full time and the nighttime 10 percent "ratchet clause" reduction, have actually been counterproductive in most cases.

INCENTIVES FOR GOING DARK

Various ideas would help entice owners of marginal AM stations to give them up at reduced prices if they could also be rewarded an additional benefit of value. A 100 W or even 1000 W LPFM station, where rules permit, could be awarded to them as partial compensation. Part of the sale proceeds paid by a benefiting AM station owner desiring to improve his station could go back to the government. Such transactions would essentially become a form of spectrum exchange and reallocation.

For group owners and stations in larger-sized markets, the government could award a substantial tax certificate to those willing to surrender licenses of nonproductive AM stations. Tax certificates worked pretty well to help foster increased minority ownership of media outlets. Certainly owners of marginal and under-performing AM stations feel the discrimination of Mother Nature, but also that of more rapidly advancing technological improvements for other media, and the more inflexible and restrictive FCC regulations that govern their service. Almost all AM owners are deserving of some special treatment.

For AM HD Radio to do well both day and night, the band needs to look more like it did around 1950, just before the explosion of new allocations started compromising interference-free listening. AM's golden age ended about then as TV began to flourish, but it continued to enjoy radio dominance for another 30 years until FM flourished.

For the past 25 years, AM has struggled against great obstacles, including vastly higher ambient noise pollution, the loss of AM stereo and the introduction of so many new forms of competing media. Without all-news and talk radio, it could have easily succumbed.

A BETTER BAND

The present inventory of AM stations could probably be cut by almost half and few would notice the loss of real service not available elsewhere. With the aid of the computer models developed for Ibiquity to characterize AM coverage and interference profiles, coupled with Arbitron surveys, a comprehensive study could be commissioned to provide a detailed analysis of which stations would be likely candidates for going dark and which provide the highest levels of interference reduction.

Points could be assigned to such stations according to the level of interference reduction they would generate if they were permanently retired. The higher the point total, the greater the tax certificate amount. The higher the point total, the higher the power of an LPFM facility would be awarded. This would aid such AM station owners in deciding if turning in their license would make economic sense.

As more stations go dark, the ones that remain will benefit as the band becomes less populated. Eventually, many stations would reclaim wider area groundwave and skywave coverage that was previously lost or unattainable and that will certainly deteriorate further if the status quo is maintained. Services now carried by AM stations in the smaller markets that serve small audiences could be replaced by LPFM stations in many areas of the country. In the more densely populated areas, enhanced coverage by the remaining AM stations could take up some of the slack of lost services. Certainly by the time multichannel FM HD Radio penetrates most markets, the fear of any loss of service will be moot. That technology is developing very rapidly and may be implemented sooner than many in this industry expect.

It's time to reorganize the family living arrangements for the senior radio band. Continuing to house and feed the nonproductive welfare recipients is jeopardizing the health and future of the employed breadwinners. The industry cannot do this without the government's help. A good brainstorming session at NAB with industry leaders from all sectors to jump-start the initiative is overdue. Many more enabling ideas are certain to emerge.

This modest proposal should produce winning results for all parties. Some enlightened soul at NAB should take my lead and get it moving. They might eventually become known as the savior of the AM band. If the industry can't find a way to clean up AM now, we might as well go back to my original idea to postpone deploying AM HD Radio until HD receivers become widely used on FM and then convert the entire band to all-digital all at once.

We would only hope it survives that long.

RW welcomes other points of view. E-mail to radioworld@imaspub.com. For Guy Wire commentaries, see www.rwonline.com. ■

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Technology Scarcity and Surplus

A Paradigm Shift Affects the Broadcast Industry

By Barry Blesser

The popular and professional literature is so saturated with discussions about technological changes in broadcasting and communications that the average reader cannot make much sense out of their implications. While futurists, pundits, cynics and opportunists just love the topic, the rest of us treat articles on innovative technology as a diversion, alternately producing excitement and anxiety. Interpreting this massive quantity of data is impossible without carefully framed questions, reflecting how we view our world.

The concept of scarcity and surplus, which is usually applied to commodities and natural resources, is a revealing way to examine the paradigm shifts in the broadcast industry.

I first observed this concept while following the evolution of the computer industry. In its early days, computational power was scarce. Users and designers optimized this scarce resource by restricting applications. Somewhat later, with dramatic advances in processing power, memory became the scarce resource that limited performance. Then, when memory became very inexpensive, communication bandwidth became the bottleneck.

COMPUTER AS COMMODITY

Now, at the beginning of the 21st century, the major attributes of computers are all in surplus, and the heaviest individual users are those who play video games. The computer has become a commodity, not unlike potatoes, coffee and pork bellies. The transformation of computer resources from scarcity to surplus is a paradigm shift. And because of this shift, computers now permeate every aspect of our culture, from toys to management tools, from washing machines to audio editing.

There is also a less obvious manifestation of this same shift. When I began my electrical engineering career in the 1960s, the design of systems for audio and broadcasting was mostly a small-scale craft industry.

For example, over a hundred companies produced high-quality turntables for local audiophile markets, each with a staff of a few hundred. The ratio of large engineering effort to low production volume resulted in high prices — that is, scarcity. In contrast, the core component of the CD player, including the precision cast iron frame, three servos and laser sensors, is manufactured by only a few companies for a worldwide global market. The cost is less than $10.

Similarly, expensive pressing plants for vinyl records have been replaced by millions of computers that can each burn CDs. By increasing the sales volume by many orders of magnitude, globalization made playback technology a surplus commodity.

To be successful with technology surplus, one must embrace its properties rather than dream about the "good, old days" of scarcity.

As an example, consider our newest product at 25-Seven Systems Inc. We buy the motherboards, the operating system, the display, the audio chipsets, the Flash memory and the power supply. Creating this product would only be a packaging exercise except for two scarce components in this soup of commodities: a specialized algorithm for transparent time compression, and a carefully crafted user interface that matches the needs of the broadcast market. A product's value is only determined by those components that are still scarce.

Fifty years ago, designing a product using resistors and transistors was a scarce skill. It is a useless skill because circuit creation is now a narrow specialty rooted in the design of integrated circuits.

In this sense, most products for audio and broadcasting use highly integrated commodity components from companies supporting markets of hundreds of millions, like Microsoft, Intel, Texas Instruments and numerous others. The rest of us ride those elephants, being careful not be trampled by walking in front (being too early), or getting dirty by walking behind (being too late).

The laws of scarcity and surplus also apply to the broadcast industry, which is a subset of the media delivery business. Traditionally, the scarcest commodity for broadcasting was the limited number of licensed frequency channels.

A good metric for measuring the amount of a resource used by an audio delivery system is the geographic area multiplied by occupied bandwidth, which I call the area-bandwidth product. It corresponds to the quantity of listeners at a given audio quality level for a specific number of program choices. Centralized high-power transmitters in a restricted frequency band use a large amount of this scarce resource. With the historic rules for auctioning large quantities of this resource to only a few commercial users, scarcity resulted.

NEW AUDIO TECHNOLOGIES ARE GROWING

Technology has recently created numerous other audio-delivery mechanisms, which dramatically increases the available area-bandwidth product. As an indirect consequence of the dot-com mania during the last decade, the Internet's hard-wired backbone has a surplus of bandwidth; it will take decades before it is fully utilized. Local telephone companies are now installing fiber cable directly to the homes in selected metropolitan areas. Networks using WiFi will shortly spawn WiMax, a wireless wide-band DSL over a 10-mile radius. The proliferation of cell telephone towers produced a multiplicity of radio networks. Satellite broadcasting opens up yet more bandwidth. The amount of surplus bandwidth continues to grow because it is inexpensive and in high demand, just as roads provide transportation for millions of trucks, busses, bicycles, motorcycles, ambulances and automobiles.

When one resource shifts from scarcity to surplus, the scarcity of the next resource in the chain dominates. What is now scarce?

The answer is obvious: mental bandwidth. Each new media delivery system competes with every other delivery system, be it for listening to music, playing with computer games, watching video on television, or conversing with friends. Commoditization of technology allows anyone to distribute music. But with so many thousands of media sources, name recognition is limited by finite headspace, which is ultimately the scarcest resource. As a measure of mental bandwidth, time and attention are a finite resource.

The scarcity of headspace is a widespread phenomenon in a culture that engages in hyper-stimulation for all its citizens, including broadcast engineers. They do not have the time to study the manual of their equipment and they expect the user interface to be intuitively obvious: plug-and-go, preserving mental bandwidth. A good designer will invest in optimizing this scarce resource by focusing on stability and predictability, while ignoring such lofty but irrelevant goals as raising the signal-to-noise ratio from 90 dB to 130 dB.

As a paradox of technical change, progress is actually more circular than linear. We first moved from craft industries with limited niche markets, to a single, homogenized global market where one size fits all. That same surplus technology, however, also allows us to return to niche markets: customizing products for small groups. Using his computer for audio editing and program distribution, any teenager can create specialized entertainment for his personal Internet broadcasting station. Commoditized technology can accommodate small groups with their unique needs, like specialty restaurants that transform food commodities into gourmet dining with signature recipes.

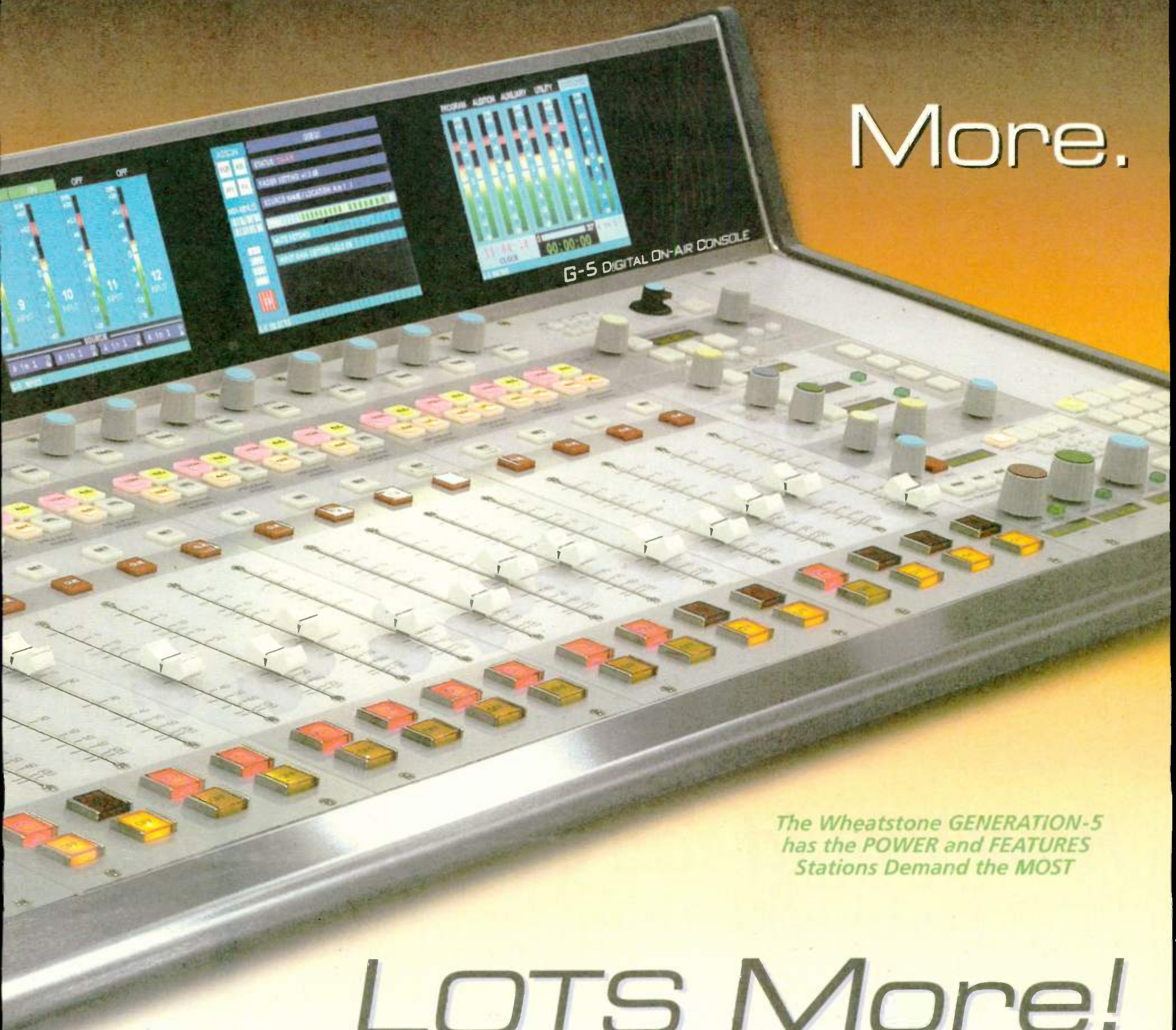
To avoid failure, individuals and companies must remake themselves to match this paradigm shift. Survival depends on wisely using those commodities that are currently in surplus while adding scarce resources that are still valued by the market. A scarce resource can be an algorithm, a design patent, a professional skill, a recognized personality or a unique sound.

The concepts of scarcity and surplus are not new, but only in the last decades have they become applicable to high technology. Engineers now harvest the technical equivalent of the farmer's potatoes and pork bellies.

Please send your comments and suggestions to Barry Blesser at wordfeedback@verizon.net. ■

Barry Blesser

Dr. Barry Blesser, director of engineering for 25-Seven Systems, is a former associate professor at MIT and past president of the AES; he is considered one of the grandfathers of digital audio. His book "Auditory Spatial Awareness of Aural Architecture" will be published by MIT Press in 2005.



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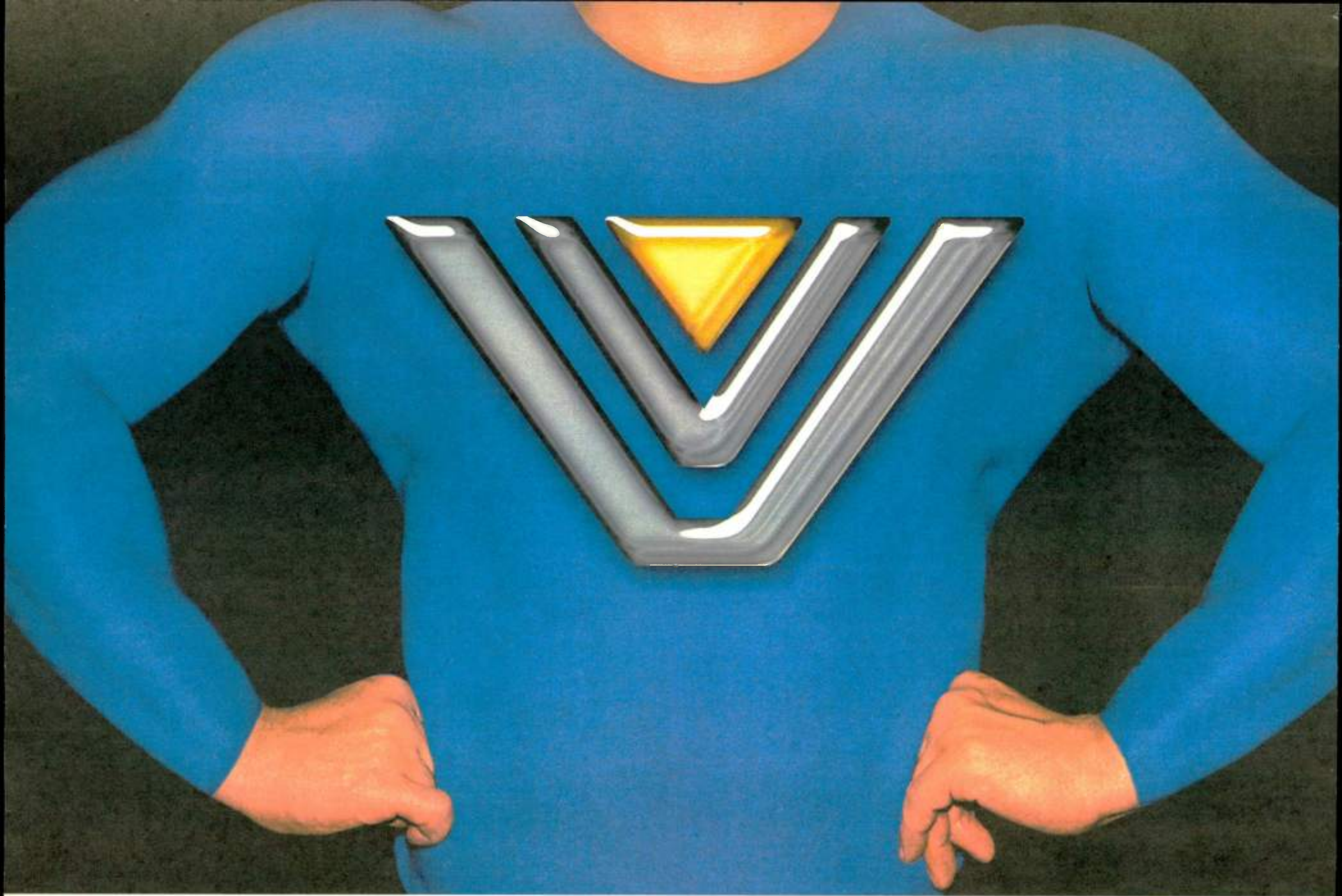

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