CONVERSION REQUIREMENTS FOR AM & FM IBOC TRANSMISSION

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IBOC provides a unique opportunity for broadcasters and consumers to transition from analog to digital broadcasting without service interruption while maintaining the current dial positions of existing radio stations. Consumers who purchase digital radios will receive their favorite AM and FM stations *with superior digital quality, free from the static, hiss, pops and fades associated with today's analog radio reception. In addition to offering digital audio quality and crystal clear reception, IBOC offers the broadcaster the lowest entry cost into the wireless data industry.*

Through careful attention to the equipment decisions made today, broadcasters may significantly reduce the cost of conversion. This paper defines the requirements and guidelines for cost effective equipment selection for IBOC conversion.

INTRODUCTION

IBOC establishes a new level of radio station audio and RF performance and in doing so commands greater attention to hardware selection and implementation.

Equipment decisions made today will affect conversion costs for IBOC tomorrow. When upgrades and replacement take into consideration the specific needs of IBOC, a large percentage of the costs of conversion can be absorbed into the normal equipment replacement cycle.

To gain an understanding of the requirements for IBOC station conversion we should begin by first looking at the make-up of the hybrid and all-digital waveforms.

IBOC WAVEFORMS

In-band on-channel (IBOC) as the name implies, allows a digital signal to be added to the existing analog service within the stations FCC channel assignment. This simultaneous transmission of digital and analog information is known as the IBOC "hybrid mode" and applies to both the AM and FM implementations.

The IBOC FM hybrid mode places low-level digital carriers in the upper and lower sidebands of the analog spectrum as shown in Figure 1. These carriers are modulated with redundant information to convey the digital audio and data.

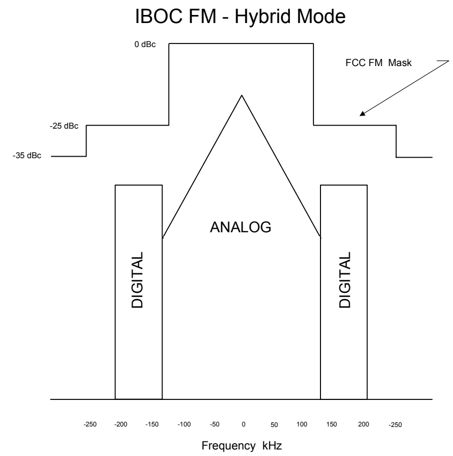

Figure 1 FM IBOC Hybrid waveform

The implementation on AM is similar in that the upper and lower sidebands contain low level digital signals. Since, the analog AM signal is amplitude modulated (as opposed to frequency modulation), the AM IBOC hybrid signal can carry digital information in a quadrature phase component. Thus some of the digital information can be placed directly beneath, or in quadrature to the analog modulation as shown in Figure 2.

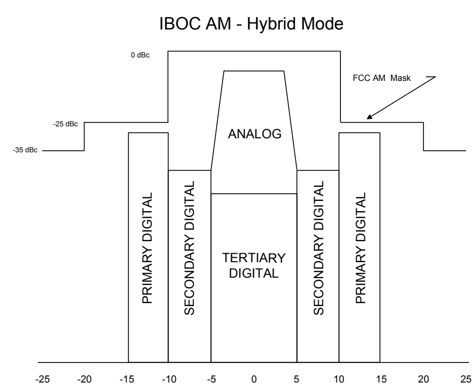

Figure 2 AM IBOC Hybrid waveform

This design allows for a future transition to all digital broadcast where additional data capacity is added into the spectrum formerly occupied by the analog signal. Changes to the all-digital FM IBOC waveforms can be seen in Figure 3.

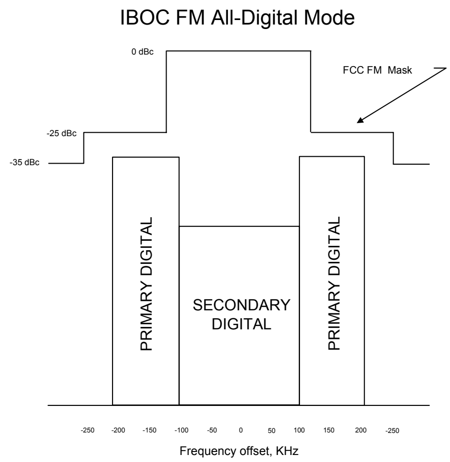

Figure 3 FM IBOC all-digital waveform

Likewise all-digital AM IBOC places digital information in the spectrum formerly occupied by the analog signal as shown in Figure 4.

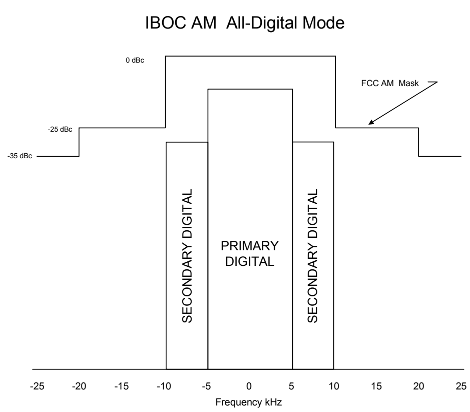

Figure 4 AM IBOC all-digital waveform

The IBOC digital carriers possess the ability to transmit digital audio quality directly to the radio listener. However, high-quality source material is required to maximize audio quality.

STUDIO CONSIDERATIONS

Advancements in digital studio equipment have greatly improved the quality of audio that radio stations are able to reproduce. AM and FM IBOC digital radio offers broadcasters the opportunity to capitalize fully on these improvements by transmitting digital information directly to a listener's receiver. However, IBOC broadcasts are only as good as the audio that is fed into the system. IBOC cannot overcome any noise or audio impairment introduced *before* transmission. Studios wired without attention to good engineering practice are likely to have noise and crosstalk issues that may impact IBOC audio quality.

Digital program source material that is bit reduced (digitally compressed) may degrade across multiple compression platforms. If high levels of bit reduction are employed, the likelihood of system degradation will increase. Some hard-disk music storage and retrieval systems employ some form of low-loss digital compression. If incompatible digital audio storage components are integrated with elements of the air chain, quality issues may arise. With digital storage costs rapidly decreasing, revisiting the methods of audio storage employed at the studio is advisable. In general, bit reduction should be avoided unless required by cost or technical limitations. If bit reduction is employed, it is suggested that one stays within a family of coding products to reduce the severity and frequency of trans-coding effects caused by multi-layer coding. Program content also influences the degree to which compression impacts audio quality. Some formats will be more forgiving with higher levels of bit reduction than will others. In short, digital compression should be used cautiously.

Another issue that relates to the studio is real-time, off-air monitoring of program content. IBOC DAB employs several methods of error correction that introduce delays between the analog and digital signal. This time diversity allows backup audio channels to be substituted (blending) gracefully if any information is lost in the digital component of the IBOC signal. Because this delay makes it impossible to monitor directly off the air, a pre-delay (live studio) feed to the talent's studio monitor and headsets is suggested. It is also advisable to install an automated alarm, which monitors signal or program loss.

STUDIO-TO-TRANSMITTER LINK

If audio processing will be performed at the transmitter site, a common studio-to-transmitter link (STL) system may be employed. With this option, one signal may be fed to the two independent audio processing chains—one for the IBOC digital component of the signal and one for the analog component. If audio processing will be performed at the studio, it may be desirable to add to the STL capacity. In this case, two discrete audio paths—one for the IBOC digital component of the signal and one for analog component—could be transported to the transmitter site.

A fundamental consideration in the broadcast facility is whether the STL will be a linear or compressed system. While the goal is to be as linear as possible, this is often impractical due to technical or budgetary constraints.

As discussed in the section on studio equipment, the usage of bit reduction must be carefully monitored. Recent trends in STL development have centered on reducing the bandwidth requirements of both RF and Telco based digital STL systems. In the case of RF based systems, this was to facilitate a digital stereo program feed within the limited spectrum of the FCC licensed auxiliary service channel. Bandwidth optimization has also been employed on Telco based systems to allow usage of lower cost, lower capacity data service lines. Stations that employ compressed STL channels are at greater risk for artifacts caused by compression.

If the STL employs compression, then the facility manager must also be concerned with the placement of audio processing. Compression techniques rely upon dynamic models as they relate to audio metrics. Undesirable anomalies may occur in the decoded audio if critical harmonic relationships are disturbed in the source audio fed to the coder.

AM IBOC digital radio, like its FM counterpart, is a stereo system. To benefit fully from AM IBOC, monaural AM facilities will have to upgrade to a stereo program path. To accomplish this, a facility can consider migrating existing equipment from a sister FM facility to the new IBOC AM. This can most readily be accomplished if a discrete channel analog or digital STL path is utilized on the existing FM. However, it is possible to retrofit composite STL systems with digital encoding and decoding equipment to provide either AES/EBU or discrete audio channels.

AUDIO PROCESSING

The US AM channels are presently allocated with a 10 kHz spacing and 20 kHz bandwidths. This results in overlapping bandwidths between first adjacent channels. Over the years many of the manufacturers of AM automotive receivers have reduced receiver bandwidths to minimize the effects of first adjacent channel interference. Optimal AM performance would be best achieved if AM channels did not overlap. As a first step in minimizing this overlap the National Radio Systems Committee (NRSC) petitioned the FCC to reduce the AM bandwidth from 30 kHz to the present 20 kHz standard. The NRSC standard achieved its goal of reducing second adjacent channel interference, however, it did not decrease first adjacent channel interference. Tests conducted in 2001 show that most automotive receivers in the marketplace have reduced the bandwidths since the adoption of the NRSC standard to approximately 3.5 kHz (Figure 5).

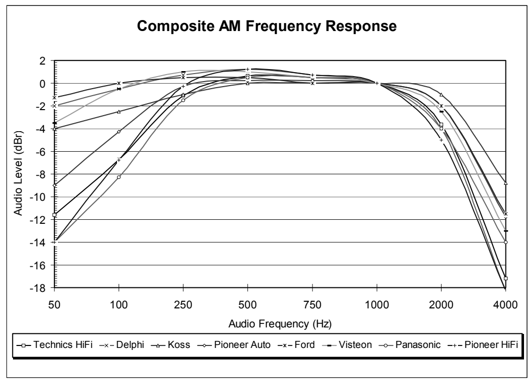

Figure 5 AM analog receiver audio response

AM IBOC will limit the analog transmission bandwidth to 5 kHz, which allows receiver manufacturers to increase the receivers analog bandwidth to 5 kHz and eliminate the first adjacent channel overlap. This will improve the fidelity of the analog portion of IBOC transmission and maximize the available spectrum for IBOC. However, this newly defined bandwidth is best implemented with audio processing that has been optimized for a 5 kHz audio passband.

The purpose of audio processing for AM and FM is two-fold: to control levels within a predetermined range to maximize transmission compatibility and secondly, to introduce a “signature” sound quality.

Dynamic range, as used in this discussion, may best be described as the ratio of the largest signal to the smallest signal in volts peak to peak, measured at a given single frequency. To optimize the transmitted signal for IBOC, it is neither necessary nor desirable to implement the same amount of dynamic range limitation as in an analog broadcast.

In an analog-to-digital conversion, there are "hard" dynamic limits that relate to the limitations of a digital processor. When these limits are exceeded, unpredictable and, possibly, undesirable effects are produced. It is therefore advisable to employ some form of audio processing whenever an analog-to-digital transfer will take place. This should entail both *limiting* to prevent exceeding the dynamic range capability of the processor and *level control* to maximize the signal to noise ratio. In the digital-to-analog conversion process, the dynamic range of the system is set by the resolution (number of bits) of the digital-to-analog (D/A) converter. In this transfer mode, the dynamic range of the digital system will not exceed that of the analog system as long as the absolute peak levels are set equally.

In a digital-to-digital exchange, such as when an AES/EBU interface is used, it is impossible to exceed the upper dynamic range limit of the device (i.e. clipping). The absolute dynamic range is limited by the respective resolutions of the source and object of the transfer. While it is impossible to overdrive the upper limit of the dynamic range, it is possible to under-drive and therefore not fully utilize the dynamic range of the system.

Because the digital domain has absolute limits and the analog domain has variable limits, the audio transfer function is critical. Extreme care should be taken to employ limiting and level control when feeding audio from an analog source to a digital system. If the dynamic range of the digital processor is exceeded, the audio will become extremely distorted as it exceeds these limits and produces "digital clipping". As the signal is clipped, it will produce unwanted products within the desired audio band-pass. This is true of all digital processors when the entire dynamic range of the device has been exceeded.

Digital (Digital Signal Processor based) Audio Processors offer the broadcaster a vehicle to deliver repeatable audio performance with increased separation, audio definition and long-term stability. However, strict guidelines on interface of dissimilar systems must be adopted to take advantage of this performance.

Having said all this, the goal of audio processing for IBOC is to introduce only as much dynamic range limitation as will be required to maintain audibility in an automotive environment. While the IBOC system is capable of reproducing nearly the complete dynamic range of the source material, it is not suggested, since a great deal of program content will be lost in the ambient noise level inside a car. Processing will always be a subjective issue and it is well outside the scope of this document to explain the ramifications of audio processing on time spent listening. Simply stated, it is desirable to offer the listener an improvement in fidelity in the transition to digital.

It is important to note that changing the amount of audio processing for the digital signal will not affect total modulation level or coverage. In general: it is best to use large signal levels without clipping to optimize signal-to-noise. In addition to input and output gain of the audio processor, possible adjustments include: level into the exciter, level out of the exciter, DC carrier level in the transmitter (if used), and audio gain in the transmitter.

AM TRANSMITTERS

AM broadcast transmitters must provide ample bandwidth and minimal phase distortion to pass the IBOC waveform. Group delay is critical since the center carrier serves as a phase reference signal. An audio proof of the AM transmitter will provide a reasonable indication of its bandwidth. The transmitter will likely have problems passing the digital IBOC signal if the measured frequency response falls off at higher modulation levels and higher frequencies.

To date, existing tube AM transmitter designs have not shown sufficient linearity to pass the IBOC waveform. Multiphase Pulse Duration Modulation (PDM) and digitally modulated solid-state AM transmitters are as a rule compatible with only minor modification to the input. Figure 6 depicts AM IBOC implementation.

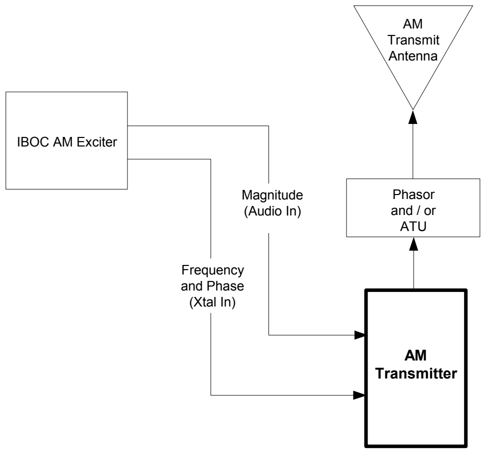

Figure 6 AM IBOC transmitter implementation

FM TRANSMITTERS

Three methods exist for producing the IBOC hybrid FM signal. Initial station conversions will likely utilize what is known as "high-level combining" or "separate amplification" shown in Figure 7. With this method, the existing station transmitter will have its output combined with the output of a separate digital transmitter compatible with IBOC technology. The resulting hybrid signal will then be fed to the existing station antenna.

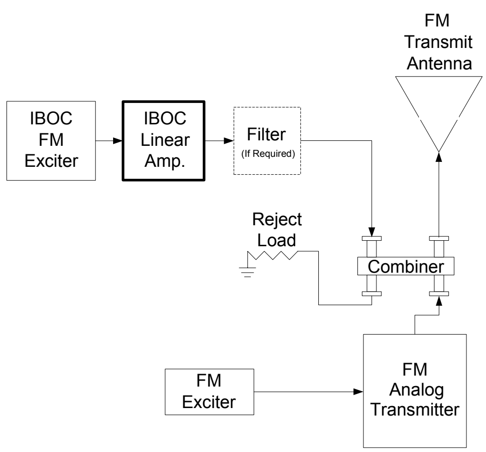

Figure 7 FM IBOC high-level, separate amplification

In the high-level combining method, power loss occurs due to power differences of the combined signal. Combiners used in IBOC testing result in a loss of about 0.5 dB (10%) of analog power and 10 dB (90%) of digital power. However, because the digital power requirements in iBiquity Digital's IBOC technology are low (–20 dB relative to analog power), this loss is tolerable. Since the phase coherence of the OFDM subcarriers varies with time the IBOC signal varies in phase and amplitude with a peak-to-average (PAR) ratio of about 5.5 dB.

For example, in the case of an FM station with an analog transmitter power (TPO) output of 10 kW, the digital carrier power of the IBOC signal would be 100 Watts. Assuming combiner loss as given above, the analog transmitter would need to be increased to 11.1 kW to overcome combiner insertion loss. The digital transmitter will have to output an average power of 1kW to overcome the 10 dB combiner loss. The digital transmitter will also need to be sized to accommodate 5.5 dB of additional overhead for PAR. This sizing for peak will amount to three to four times the average power.

Another method is known as "low-level combining" or "common amplification" is depicted in Figure 8. In this implementation, the output of an analog FM exciter is combined with the output of an IBOC exciter. The combined outputs are then fed into a common broadband linear amplifier to raise the signal to the desired TPO. This method reduces the number of independent elements in the broadcast chain and may reduce floor space requirements and reduce the total consumed power. Manufacturers are evaluating linearized versions of their transmitter design to determine required levels of headroom and linearity. This common amplification method would reduce overall power consumption and minimize impact to transmitter plant equipment layout.

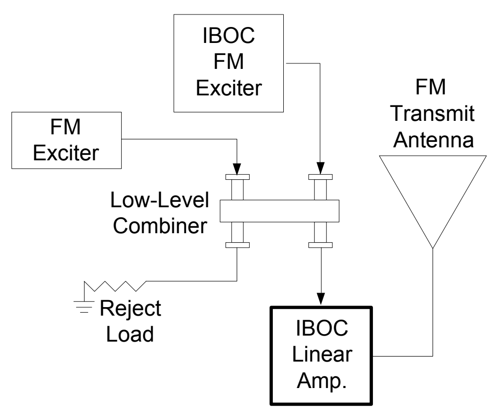

Figure 8 FM IBOC low-level, common amplification

Separate antenna implementation (see Figure 9) is a method presently under investigation. Preliminary tests indicate that an IBOC signal may be transmitted from an independent antenna provided the analog and digital antennas have a minimum of 40 dB of isolation. To achieve this level of isolation requires careful placement and measurement of the antenna elements.

The advantage of this methodology is the elimination of the combiner loss resulting in a significantly smaller IBOC transmitter required to develop the IBOC carrier.

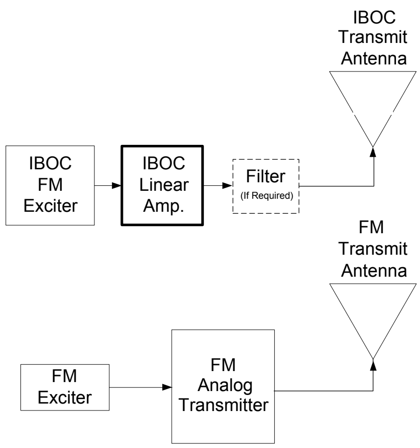

Figure 9 FM IBOC separate antenna implementation

FM ON CHANNEL REPEATERS

The use of orthogonal frequency division multiplexing [OFDM] in the FM IBOC system allows on-channel digital repeaters to fill areas of desired coverage where signal losses due to terrain and/or shadowing are severe. A typical application occurs where mountains or other terrain obstructions within the station service areas limit analog or digital performance.

To avoid significant intersymbol interference the effective coverage in the direction of the primary transmission system should be limited to within 14 miles. Specifically the ratio of the signal from the main transmitter to the booster signal should be at least 10 dB at locations more than 14 miles from the repeater in the direction of the main antenna. Performance and distances between on-channel boosters can be improved through the use of directional antennas to protect the main station. The coverage in the direction pointing away from the primary antenna can be arbitrarily large, but must conform to the FCC coverage allocation for that station.

AM ANTENNA SYSTEM

IBOC transmission requires similar performance from of the antenna as AM stereo. Because a solid-state transmitter will likely be used for transmitting the IBOC signal, most of the antenna system parameters would be required to keep the transmitter operating optimally.

IBOC AM has been tested on several types of antennas including omni-directional, directional and even long-wire antennas. In deep nulls, neither analog nor digital reception is possible. However, the null area on directional antennas is smaller for digital transmission.

For optimal IBOC transmission characteristics, the antenna common-point impedance should be kept as close to 50 Ω as possible. The measured antenna system should display Hermitian symmetry (Conjugate Symmetric: $X(-k) = X(k)$) (see Figure 10) in RF waveform over a +/- 5 kHz region. That is, the side bands should be as symmetrical as is practical. Amplitude symmetry should also be within 0.02 dB. Proper tuning keeps quadrature information in quadrature and minimizes crosstalk between the digital and main channel and vice versa.

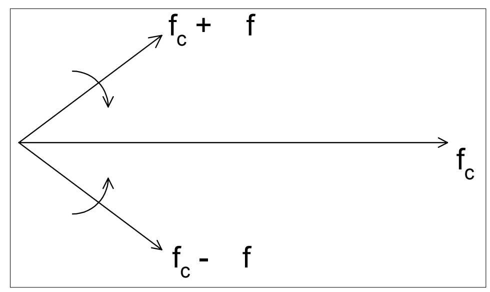

Figure 10 Hermitian symmetry

FM ANTENNA SYSTEM

Field test data indicates that all FM transmission antennas should meet the bandwidth requirements of IBOC.

Group delay requirements and other issues of non-linearity in combined station operation are presently in review. However, results of testing on the master antenna at the Empire State building were favorable.

Manufacturers of combiner and filter assemblies have pioneered much of the development on combiners and filters for high-level implementation of IBOC. More information may be obtained from these manufacturers.

TRANSMITTER CONSIDERATIONS

IBOC FM high-level combining uses two transmitters to produce the transmitted signal. This approach will therefore require the addition of an IBOC digital transmitter, digital exciter, combiner and filter (if necessary). Since both an analog and digital transmitter will be operated at the site, power demands may require the upgrade of electrical service to the facility. Heat load will also increase and may require additional cooling to remain within acceptable limits.

Since the system implementations vary in dimension as well as configuration, the space constraints should be reviewed with equipment manufacturers to determine the appropriate solution.

Low-level combining will use one common transmitter to combine the IBOC digital signal with the host analog signal. This reduces the demand on space requirements and may reduce some of the power demands at the site.

Since AM IBOC uses a common transmitter and has no additional filtering, the site requirements remain virtually unchanged from an analog implementation.

CONCLUSION

Stations that have stayed current with technology will find the transition to digital broadcasting straightforward and affordable. Facilities that have not, should consider a plan of staged hardware upgrades schedule to coincide with IBOC implementation. The key to a successful IBOC station rollout is to start the planning process today.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of Glynn Walden, Rick Martinson, Ashruf El-Dinary, Scott Stull, Brian Kroeger, Harvey Chalmers, Marek Milbar, Roy Stehlik, Russ Mundschenk, Pat Malley, Tom Walker, Harry Revis and all the dedicated members of the iBiquity Digital Corporation IBOC effort.

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2. "Petition for Rulemaking to the United States Federal Communications Commission for In-Band On-Channel Digital Audio Broadcasting," USA Digital Radio Corporation, October 7, 1998
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Chapter

2.5

IBOC FM Digital Radio System

Jerry C. Whitaker, Editor-in-Chief

2.5.1 Introduction[1]

The principal system analysis work on the in-band on-channel (IBOC) digital radio system for FM broadcasting was performed by the DAB Subcommittee of the National Radio Systems Committee. The goals and objectives of the subcommittee were [1]:

- To study IBOC DAB systems and determine if they provide broadcasters and users with: 1) a digital signal with significantly greater quality and durability than available from the analog system that presently exists in the U.S.; 2) a digital service area that is at least equivalent to the host station's analog service area while simultaneously providing suitable protection in co-channel and adjacent channel situations; 3) a smooth transition from analog to digital services.
- To provide broadcasters and receiver manufacturers with the information they need to make an informed decision on the future of digital audio broadcasting in the U.S., and if appropriate to foster its implementation.

To meet its objectives, the subcommittee resolved to work towards achieving the following goals:

- To develop a technical record and, where applicable, draw conclusions that will be useful to the NRSC in the evaluation of IBOC systems.
- Provide a direct comparison between FM IBOC DAB and the existing analog broadcasting system, and between an IBOC signal and its host analog signal, over a wide variation of terrain and under adverse propagation conditions that could be expected to be found throughout the U.S.
- Fully assess the impact of the IBOC DAB signal upon the existing analog broadcast signals with which they must co-exist.

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1. This chapter is based on the following document: NRSC, "DAB Subcommittee Evaluation of the iBiquity Digital Corporation IBOC System, Part 1—FM IBOC," National Radio Systems Committee, Washington, D.C., November 29, 2001.

- Develop a testing process and measurement criteria that would produce conclusive, believable and acceptable results, and be of a streamlined nature so as not to impede rapid development of this technology.
- Work closely with IBOC system proponents in the development of laboratory and field test plans, which would be used to provide the basis for future comparisons.
- Indirectly participate in the test process, by assisting in selection of (one or more) independent testing agencies, or by closely observing proponent-conducted tests to insure that the testing is executed in a thorough, fair, and impartial manner.

2.5.1a Glossary of Terms

The following terms are used to describe the FM IBOC system [1].

ACR-MOS (absolute category rating mean opinion score) A methodology for subjectively testing audio quality where participants are presented with sound samples, one at a time, and are asked to grade them on a 5 point scale. For the NRSC FM IBOC tests, the MOS scale used was 5 = excellent, 4 = good, 3 = fair, 2 = poor, 1 = bad.

after-market A radio designed for purchase and installation some time after purchasing an automobile.

all-digital IBOC The third of three modes in the iBiquity FM IBOC system that increases data capacity by adding additional digital carriers. All-digital FM IBOC uses four frequency partitions and no analog carrier. In this mode, the digital audio data rate can range from 64 kbits/s to 96 kbits/s, and the corresponding ancillary data rate can range from 213 kbits/s for 64 kbits/s audio to 181 kbits/s for 96 kbits/s audio.

ATTC The Advance Television Technology Center, the prime lab test contractor for the FM IBOC tests.

AWGN Additive white Gaussian noise, also known as *white noise*, which contains equal energy per frequency across the spectrum of the noise employed. In the context of the FM IBOC system tests, AWGN at radio frequencies was utilized in the laboratory tests to simulate the background noise present in the FM spectrum, which affects the quality of radio reception.

blend to analog The point at which the BLER of an FM IBOC receiver falls below some predefined threshold and the digital audio is faded out while simultaneously the analog audio is faded in. This prevents the received audio from simply muting when the digital signal is lost. The receiver audio will also “blend to digital” upon re-acquisition of the digital signal.

blend to mono The process of progressively attenuating the L–R component of a stereo decoded signal as the received RF signal decreases. The net result is a lowering of audible noise.

BLER (block error rate) A ratio of the number of data blocks received with at least one un-correctable bit to the total number of blocks received.

compatibility When one system has little to no negative impact on another system, it can generally be considered compatible. In the case of FM IBOC tests, compatibility testing was performed to determine the extent to which the addition of an FM IBOC signal would impact analog system performance.

D/U Ratio of desired to undesired signals (usually expressed in dB).

EWG Evaluation Working Group of the NRSC DAB Subcommittee.

extended-hybrid IBOC The second of three modes in the iBiquity FM IBOC system that increases data capacity by adding additional carriers closer to the analog host signal. The extended-hybrid IBOC mode adds two frequency partitions around the analog carrier. In this mode, digital audio data rate can range from 64 kbits/s to 96 kbits/s, and the corresponding ancillary data rate will range from 83 kbits/s for 64 kbits/s audio to 51 kbits/s for 96 kbits/s audio.

hybrid IBOC The first of three modes in the iBiquity FM IBOC system that increases data capacity by adding additional carriers closer to the analog host signal. The hybrid IBOC mode adds one frequency partition around the analog carrier and is characterized by the highest possible digital and analog audio quality with a limited amount of ancillary data available to the broadcaster. Digital audio data rates can range from 64 kbits/s to 96 kbits/s, and the corresponding ancillary data rate can range from 33 kbits/s for 64 kbits/s audio to 1 kbits/s for 96 kbits/s audio.

IBOC In-band/on-channel system of digital radio where the digital signals are placed within the current AM and FM bands and within the FCC-assigned channel of a radio station.

Longley-Rice A model used to predict the long-term median transmission loss over irregular terrain that is applied to predicting signal strength at one or more locations. Longley-Rice computations are employed both by the FCC allocations rules for FM stations to predict signal strength contours and by propagation modeling software to predict signal strengths in a two-dimensional grid on a map. The FCC implementation of Longley-Rice computations employs average terrain computations and an assumed 30-ft receive antenna height.

MPEG-2 AAC Advanced Audio Coder, a high-quality, low bit rate perceptual audio coding system developed jointly by AT&T, Dolby Laboratories, Fraunhofer IIG, and Sony.

multipath An RF reception condition in which a radio signal reaching a receiving antenna arrives by multiple paths due to reflections of the signal off of various surfaces in the environment. By traveling different distances to the receiver, the reflections arrive with different time delays and signal strengths. When multipath conditions are great enough, analog reception of FM radio broadcasts is affected in a variety of ways, including *stop-light fades*, *picket fencing*, and distortion of the received audio.

NRSC National Radio Systems Committee, a technical standards setting body of the radio broadcasting industry, co-sponsored by the Consumer Electronics Association (CEA) and the National Association of Broadcasters (NAB).

objective testing Using test equipment to directly measure the performance of a system under test. For example, the power output of a transmitter can be objectively measured using a wattmeter.

OEM (original equipment manufacturer) Generally describes the “factory” radio installed in a car before purchase.

PAC A flexible high-quality perceptual audio coding system originally developed by Lucent Technologies and later refined by iBiquity. The system can operate over a wide range of bit rates and is capable of supporting multichannel audio.

Perceptual Audio Coding Also known as audio compression or audio bit rate reduction, this is the process of representing an audio signal with fewer bits while still preserving audio quality. The coding schemes are based on the perceptual characteristics of the human ear. Some examples of these coders are PAC, AAC, MPEG-2, and AC-3.

protected contour A representation of the theoretical signal strength of a radio station that appears on a map as a closed polygon surrounding the station's transmitter site. The FCC defines a particular signal strength contour, such as 60 dBuV/m for certain classes of station, as the *protected contour*. In allocating the facilities of other radio stations, the protected contour of an existing station may not be overlapped by certain interfering contours of the other stations. The protected contour coarsely represents the primary coverage area of a station, within which there is little likelihood that the signals of another station will cause interference with its reception.

RDS (Radio Data System) The RDS signal is a low bit rate data stream transmitted on the 57 kHz subcarrier of an FM radio signal. Radio listeners know RDS mostly through its ability to permit RDS radios to display call letters and search for stations based on their programming format. Special traffic announcements can be transmitted to RDS radios, as well as emergency alerts.

SDARS Satellite Digital Audio Radio Service, describes satellite-delivered digital audio systems such as those from XM Radio and Sirius. The digital audio data rate in these systems is specified as being 64 kbits/s.

subjective testing Using human subjects to judge the performance of a system. Subjective testing is especially useful when testing systems that include components such as perceptual audio coders. Traditional audio measurement techniques, such as signal-to-noise and distortion measurements, are often not compatible with way perceptual audio coders work and therefore cannot characterize their performance in a manner that can be compared with other coders, or with traditional analog systems.

WQP (weighted quasi peak) Refers to a fast attack, slow-decay detector circuit that approximately responds to signal peaks, and that has varying attenuation as a function of frequency so as to produce a measurement that approximates the human hearing system.

2.5.2 iBiquity FM IBOC System

The iBiquity FM IBOC system supports transmission of digital audio and auxiliary digital data within an existing FM channel allocation by placing two groups of digitally modulated carrier signals adjacent to an analog FM signal as shown in Figure 2.5.1. These sideband groups are independent in that only one group (either USB or LSB in the figure) is needed for an IBOC receiver to be able to generate digital audio. Orthogonal frequency division multiplexing (OFDM) modulation is utilized. The digital audio modulated onto these OFDM carriers is perceptually coded, allowing for high-quality digital audio using a relatively low bit rate.

The system incorporates a 4-1/2 second delay between the analog and digital (simulcast) audio signals to improve performance in the presence of certain types of interference, which may affect how broadcasters monitor off-air signals.

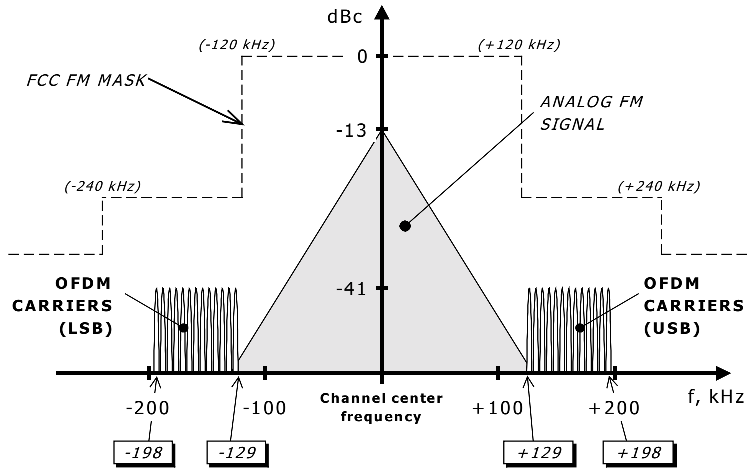

Figure 2.5.1 iBiquity FM IBOC system signal spectral power density. (*From* [1]. *Used with permission.*)

2.5.2a NRSC Test Issues

Some of the specific attributes of the iBiquity FM IBOC system which influenced the design of the NRSC test program include the following [1]:

- Proximity of digital sidebands to first-adjacent channel signals. The digital sidebands of the FM IBOC signal are located such that they could potentially interfere with (and receive interference from) a first-adjacent analog FM signal (Figure 2.5.2). The NRSC test procedures included tests which characterized this behavior, including tests of IBOC performance when there were two first-adjacent channel signals, one on either side of the desired signal (hence both digital sidebands were experiencing interference).
- Proximity of digital sidebands to second-adjacent channel signals. The FM IBOC system design allows for approximately 4 kHz of “guard band” between second-adjacent IBOC digital sidebands (Figure 2.5.3). Because this relatively close proximity could have an impact on performance, the NRSC test procedures included tests for characterizing performance with second-adjacent interference, including dual 2nd-adjacent channel interferers with power levels up to 40 dB greater than the desired signal power (since FCC rules allow a second-adjacent signal to be 40 dB stronger than the desired signal at the desired signal’s protected contour).
- Blend-to-analog. The iBiquity FM IBOC system simulcasts a radio station’s main channel audio signal using the analog FM carrier and IBOC digital sidebands, and under certain circumstances, the IBOC receiver will “blend” back and forth between these two signals. Consequently, depending upon the reception environment, the listener will either hear digital audio (transported over the IBOC digital sidebands) or analog audio (delivered on the FM-modulated analog carrier).

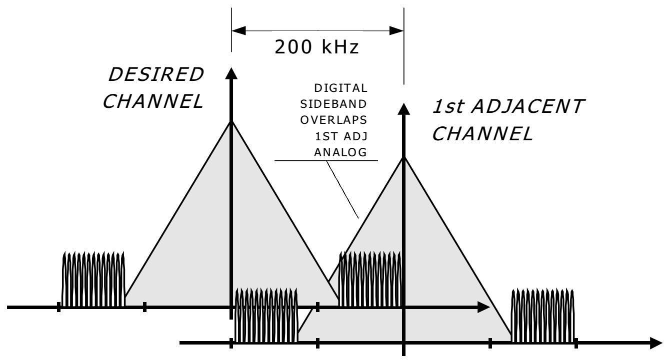

Figure 2.5.2 Illustration of potential interference to/from first-adjacent analog signals by FM IBOC digital sidebands. (*From* [1]. *Used with permission.*)

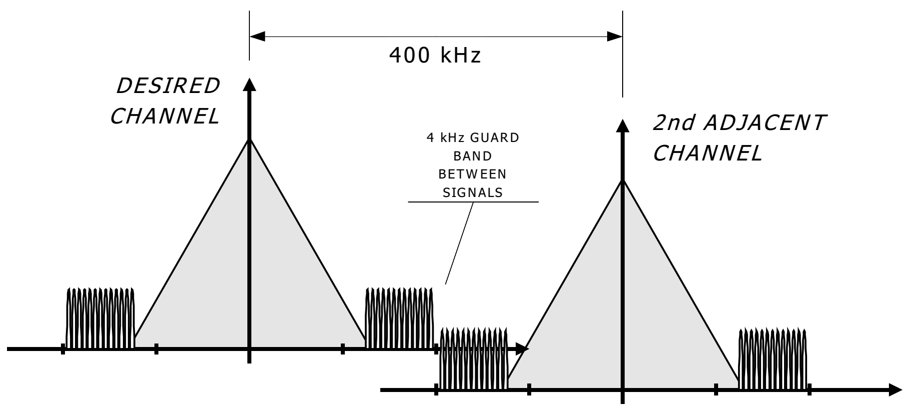

Figure 2.5.3 Illustration of potential interference between second-adjacent FM IBOC signals. (*From* [1]. *Used with permission.*)

The two main circumstances under which an IBOC receiver reverts to analog audio output are during acquisition; i.e. when a radio station is first tuned in (an IBOC receiver acquires the analog signal in milliseconds but takes a few seconds to begin decoding the audio on the digital sidebands) or when reception conditions deteriorate to the point where approximately 10 percent of the data blocks sent in the digital sidebands are corrupted during transmission. Many of the tests in the NRSC procedures were designed to determine the conditions that would cause blend-to-analog to occur.

2.5.2b NRSC Test Program

To evaluate the IBOC FM radio system, two basic types of tests are required [1]:

- **Performance tests.** In the context of the NRSC test procedures, *performance tests* (sometimes called *digital performance tests*) were those used to establish the performance of the IBOC digital radio system itself. Performance test results were obtained using an IBOC receiver or through direct observation of the received signal.
- **Compatibility tests.** In the context of the NRSC IBOC evaluation, *compatibility tests* (sometimes referred to as *analog compatibility tests*) were designed to determine the effect that the IBOC digital radio signal had on existing analog signals (main channel audio and subcarriers). Compatibility testing involved observing performance with IBOC digital sidebands alternately turned on and off; test results were obtained using either analog FM receivers or FM subcarrier receivers (analog or digital) or through direct observation of the received signal.

For each of these, two basic types of measurements were made:

- Objective measurements, where a parameter such as signal power, signal to noise ratio, or error rate was measured, typically by using test equipment designed specifically for that particular measurement.
- Subjective measurements, which involved human interpretation or opinion (not something that can be simply measured with a device). In the NRSC test program, subjective measurements involved determining the quality of audio recordings by having people listen to them and rate them according to a pre-defined quality scale.

Subjective evaluation was especially important when trying to assess the quality of IBOC digital audio because the IBOC radio system relies upon perceptual audio coding for audio transmission. The listening experience of audio which has passed through a perceptually coded system is not accurately characterized by many of the normal objective audio quality measures, such as signal-to-noise, distortion, or bandwidth. The instruments used to make such measurements do not adequately respond to the perceptual aspects of the system.

Lab tests

Laboratory tests are fundamental to any characterization of a new broadcast system such as FM IBOC [1]. The controlled and repeatable environment of a laboratory makes it possible to determine how the system behaves with respect to individual factors such as the presence or absence of RF noise, multipath interference, or co- and adjacent-channel signals. These factors all exist in the real world but because they exist simultaneously and are constantly changing, it is virtually impossible to determine, in the real world, the effect each has on system operation.

Field tests

Field testing of a new broadcast system is necessary to determine performance in the real world where all of the various factors which impact propagation and reception of radio signals exist to varying degrees depending upon time of day, geographic location, and environmental factors [1].

2.5.2c Test Conclusions and Recommendations

The NRSC concluded that the performance of the iBiquity FM IBOC system as tested represented a significant improvement over the existing analog services [1]. The impact of IBOC digital sidebands on the performance of existing main channel audio services was found to be varied. Still, tests showed that listeners should not perceive an impact on the analog host signal, nor on the analog signals on carriers that are either co-channel or second-adjacent channel with respect to an IBOC signal. With respect to carriers that are located first-adjacent to an IBOC signal, listeners within the protected contour should not perceive an impact, but a limited number of listeners may perceive an impact outside of the protected contour under certain conditions.

The NRSC also concluded that the tradeoffs necessary for the adoption of FM IBOC are relatively minor. With respect to the main channel audio signal, evaluation of test data showed that a small decrease in audio signal-to-noise ratio will be evident to some listeners in localized areas where first-adjacent stations, operating with the FM IBOC system, overlap the coverage of a desired station. However, listeners in these particular areas may also be subject to adjacent-channel analog interference which will tend to mask the IBOC-related interference, most appropriately characterized as band-limited white noise, rendering it inaudible under normal listening conditions. Also, the NRSC reported that all present-day mobile receivers include a stereo blend-to-mono function dynamically active under conditions of varying signal strength and adjacent channel interference. This characteristic of mobile receivers will also tend to mask IBOC-related noise. The validity and effectiveness of these masking mechanisms is apparent from the rigorous subjective evaluations performed on the data obtained during NRSC adjacent-channel testing.

Careful evaluation of test data showed that the digital SCA services tested (RDS and DARC) should not be adversely impacted by IBOC. For the case of analog SCA services, some questions remained as to the impact of IBOC on such services

2.5.3 References

1. NRSC: "DAB Subcommittee Evaluation of the iBiquity Digital Corporation IBOC System, Part 1—FM IBOC," National Radio Systems Committee, Washington, D.C., November 29, 2001.