Chapter

2.5

IBOC FM Digital Radio System

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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.

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.

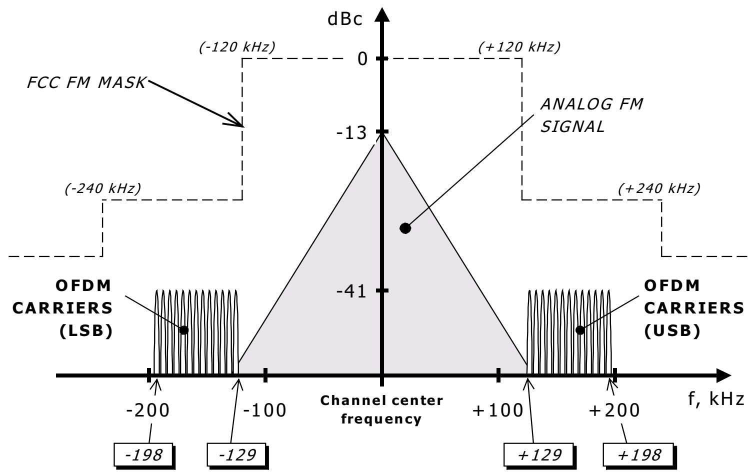

Figure 2.5.1 iBiquity FM IBOC system signal spectral power density. (*From* [1]. *Used with permission.*)

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).

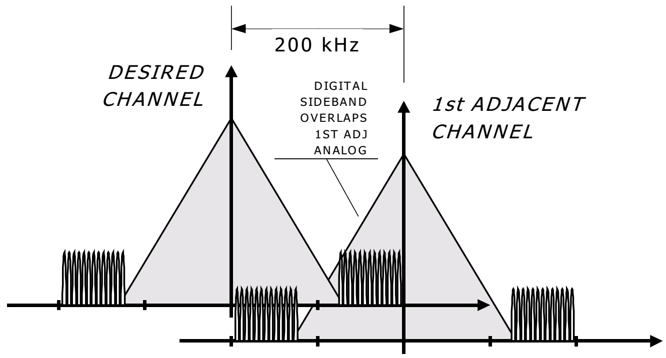

Figure 2.5.2 Illustration of potential interference to/from first-adjacent analog signals by FM IBOC digital sidebands. (*From* [1]. *Used with permission.*)

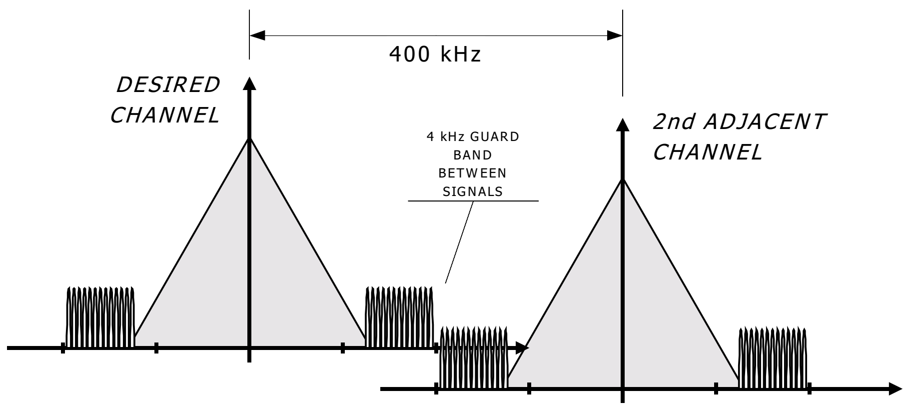

Figure 2.5.3 Illustration of potential interference between second-adjacent FM IBOC signals. (*From* [1]. *Used with permission.*)

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.