

# 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.

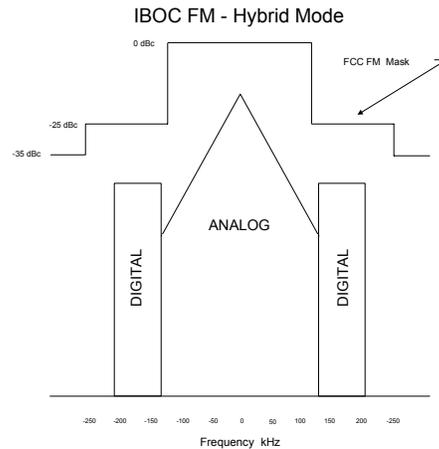


Figure 1 FM IBOC Hybrid waveform

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.

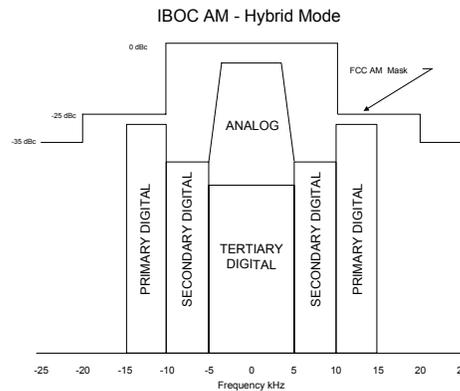
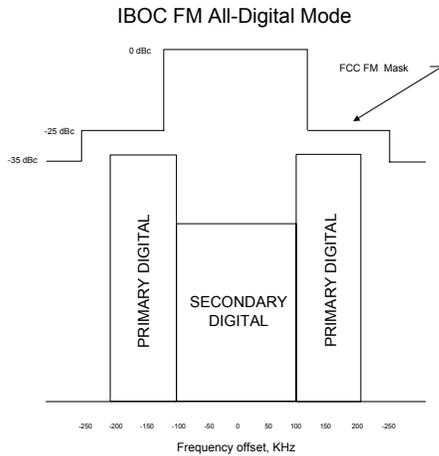


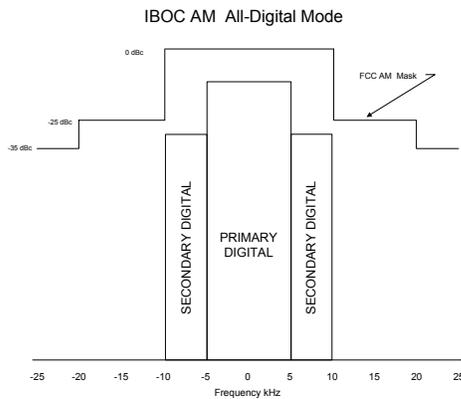
Figure 2 AM IBOC Hybrid waveform

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).

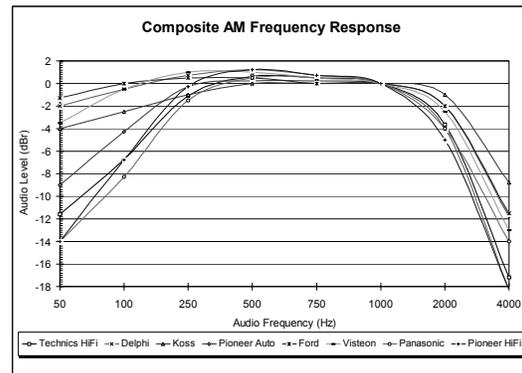


Figure 5 AM analog receiver audio response

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.

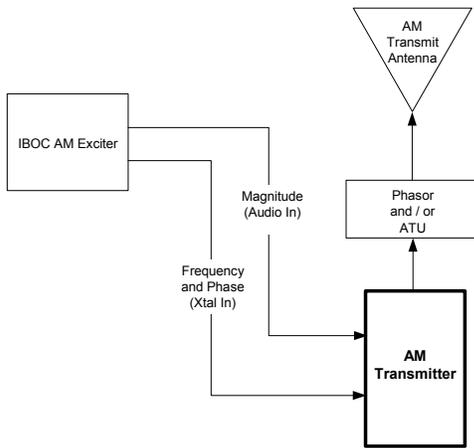


Figure 6 AM IBOC transmitter implementation

### 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.

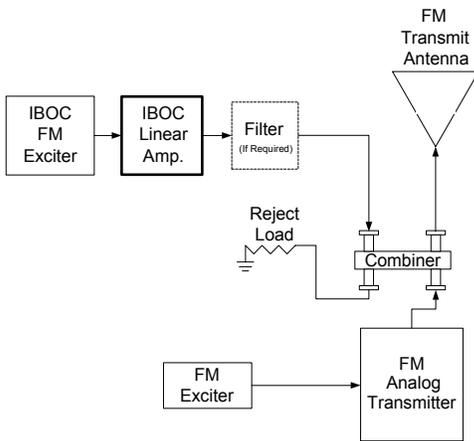


Figure 7 FM IBOC high-level, separate amplification

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.

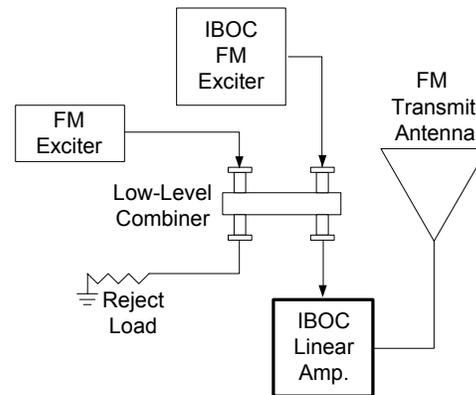


Figure 8 FM IBOC low-level, common amplification

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.

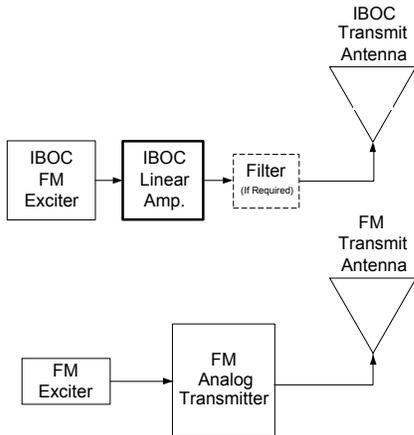


Figure 9 FM IBOC separate antenna implementation

### 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  $\Omega$  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.

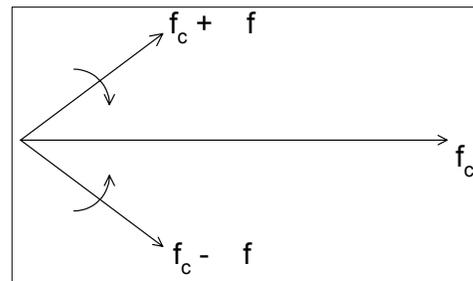


Figure 10 Hermitian symmetry

### 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**

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