HD Radio™ FM Transmission System Specifications

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TRADEMARKS

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1 Scope

1.1 System Overview

The iBiquity Digital Corporation HD Radio™ system is designed to permit a smooth evolution from current analog amplitude modulation (AM) and frequency modulation (FM) radio to a fully digital in-band on-channel (IBOC) system. This system delivers digital audio and data services to mobile, portable, and fixed receivers from terrestrial transmitters in the existing medium frequency (MF) and very high frequency (VHF) radio bands. Broadcasters may continue to transmit analog AM and FM simultaneously with the new, higher-quality and more robust digital signals, allowing themselves and their listeners to convert from analog to digital radio while maintaining their current frequency allocations.

1.2 Document Overview

This document details specifications of the iBiquity Digital Corporation HD Radio FM IBOC system. Included in this document are specifications that ensure reliable reception of the digital audio and data, provide precise digital-analog synchronization, define subcarrier power levels, and minimize harmful spectral emissions.

2 Referenced Documents

[1] Federal Communications Commission, Code of Federal Regulations, Title 47, Part 73.

[2] iBiquity Digital Corporation, "HD Radio™ Air Interface Design Description – Layer 1 FM," Doc. No. SY_IDD_1011s, Revision E.

3 Abbreviations and Conventions

3.1 Abbreviations and Acronyms

AM	Amplitude Modulation
BPSK	Binary Phase Shift Keying
FCC	Federal Communications Commission
FM	Frequency Modulation
GPS	Global Positioning System
IBOC	In-Band On-Channel
kbit/s	kilobits per second (thousand bits per second)
L1	Layer 1
L2	Layer 2
MF	Medium Frequency
MP1–MP6	Primary Service Modes 1 through 6
MS1–MS4	Secondary Service Modes 1 through 4
N/A	Not Applicable
OBE	Out of Band Emissions
OFDM	Orthogonal Frequency Division Multiplexing
P1–P3	Primary Logical Channels 1 through 3
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
S1–S5	Secondary Logical Channels 1 through 5
SSB	Single Side Band
VHF	Very High Frequency

3.2 Presentation Conventions

Unless otherwise noted, the following conventions apply to this document:

- All vectors are indexed starting with 0.
- The element of a vector with the lowest index is considered to be first.
- In drawings and tables, the leftmost bit is considered to occur first.
- Bit 0 of a byte or word is considered the least significant bit.
- In representations of binary numbers, the least significant bit is on the right.
- When presenting the dimensions of a matrix, the number of rows is given first (e.g., an n x m matrix has n rows and m columns).
- In timing diagrams, earliest time is on the left.

4 FM Transmission Specifications

4.1 Introduction

This document presents the key transmission specifications for the FM HD Radio system.

4.2 Carrier Frequency and Channel Spacing

The HD Radio system operates in-band and on-channel, within the existing allocations and channel spacing as authorized by the FCC in accordance with [1]. The Hybrid and All Digital HD Radio waveforms are centered on the assigned FM band channel frequency.

4.3 Synchronization Tolerances

The system supports two levels of synchronization for broadcasters:

Level I: Network synchronized (Assumed using Global Positioning System (GPS) locked transmission facilities)

Level II: Non networked synchronized (Non-GPS-locked transmission facilities)

It is recommended that transmission facilities operate as Level I facilities in order to support numerous advanced system features.

4.3.1 Analog Diversity Delay

The absolute accuracy of the analog diversity delay as defined in [2] in the transmission signal shall be within ±68 microseconds (μs) for both synchronization Level I and Level II transmission facilities.

4.3.2 Time and Frequency Accuracy and Stability

The total modulation symbol-clock frequency absolute error of an HD radio broadcast system shall meet the following requirements:

±0.01 ppm maximum for Synchronization Level I facilities

±1.0 ppm maximum for Synchronization Level II facilities

The total digital carrier frequency absolute error shall meet the following requirements:

The total digital carrier frequency absolute error of a Synchronization Level I broadcast system as observed at the RF output shall be ±1.3 Hz maximum.

The total digital carrier frequency absolute error of a Synchronization Level II broadcast system as observed at the RF output shall be ±130 Hz maximum.

4.3.3 Frequency Translators

Frequency translators may be classified as either synchronization level I or II regardless of the classification of the primary station. All of the requirements of subsection 4.3.2 shall apply. In addition, if the translator transmission equipment is operating as synchronization Level I, and therefore is indicating such condition over the air as part of the SIS data stream, it is strongly recommended that the translator broadcast its own GPS coordinates independently from that of the primary station. This will enhance receiver position-determination capabilities.

4.3.4 On-Channel Boosters

The following requirement shall apply to the use of on-channel boosters:

An on-channel booster shall maintain the same synchronization level as the primary station. All of the requirements of subsection 4.3.2 shall apply.

In addition, on-channel boosters shall synchronize the content and OFDM symbol timing of their transmissions within ±75 μs relative to the primary station timing at all times, as observed within the coverage area of the booster station. Appropriate delays may be necessary in the studio feed and/or RF transmission path to meet this requirement.

For the purposes of this specification, OFDM symbol timing of 75 μs shall be maintained in the area of mutual interference where booster to main protection ratio is greater than -20 dB. For FM Hybrid transmissions, the booster may be applied to just the digital portion of the Hybrid signal. In this case, the booster antenna to primary antenna field strength ratio shall be computed based on only the digital portion of the signal.

4.3.5 L1 Frame Timing Phase

For Level I transmission facilities, all transmissions shall phase lock their L1 frame timing (and the timing of all OFDM symbols) to absolute GPS time within ±1 μs.

If the above specification in a Synchronization Level I transmission facility is violated, due to a GPS outage or other occurrence, it shall be classified as a Synchronization Level II transmission facility until the above specification is again met.

4.4 FM Spectral Emissions Limits

The requirements for the spectral emissions limits for the Hybrid transmissions and the All Digital transmissions are given in Subsections 4.4.1and 4.4.2.

4.4.1 Spectral Emissions Limits for Hybrid Transmissions

For Hybrid transmissions, measurements of the combined analog and digital signals shall be made by averaging the power spectral density of the signal in a 1 kHz bandwidth over a 30-second segment of time. Compliance will be determined by measuring the composite power spectral density of the analog and digital waveforms. 0 dBc is defined as the total power of the unmodulated analog FM carrier.

Noise and spuriously generated signals from all sources, including phase noise and intermodulation products, shall conform to the limits as described in the following paragraph and shown in Figure 4-1 and Table 4-1.

The measured power spectral density of the Hybrid analog and digital signals at frequencies removed from the center of the channel between 100 kHz and 200 kHz shall not exceed -40 dBc/kHz.

The measured power spectral density of the Hybrid analog and digital signals at frequencies removed from the center of the channel by 200 – 215 kHz shall not exceed [-61.4 - (|frequency in kHz| – 200 kHz) · 0.867] dBc/kHz.

The measured power spectral density of the Hybrid analog and digital signals at frequencies removed from the center of the channel between 215 kHz and 540 kHz shall not exceed −74.4 dBc/kHz .

The measured power spectral density at frequencies removed from the center of the channel by more than 540 – 600 kHz shall not exceed [-74.4 – (|frequency in kHz| – 540 kHz) · 0.093] dBc/ kHz.

The measured power spectral density at frequencies greater than 600 kHz from the center of the channel shall not exceed -80 dBc/kHz.

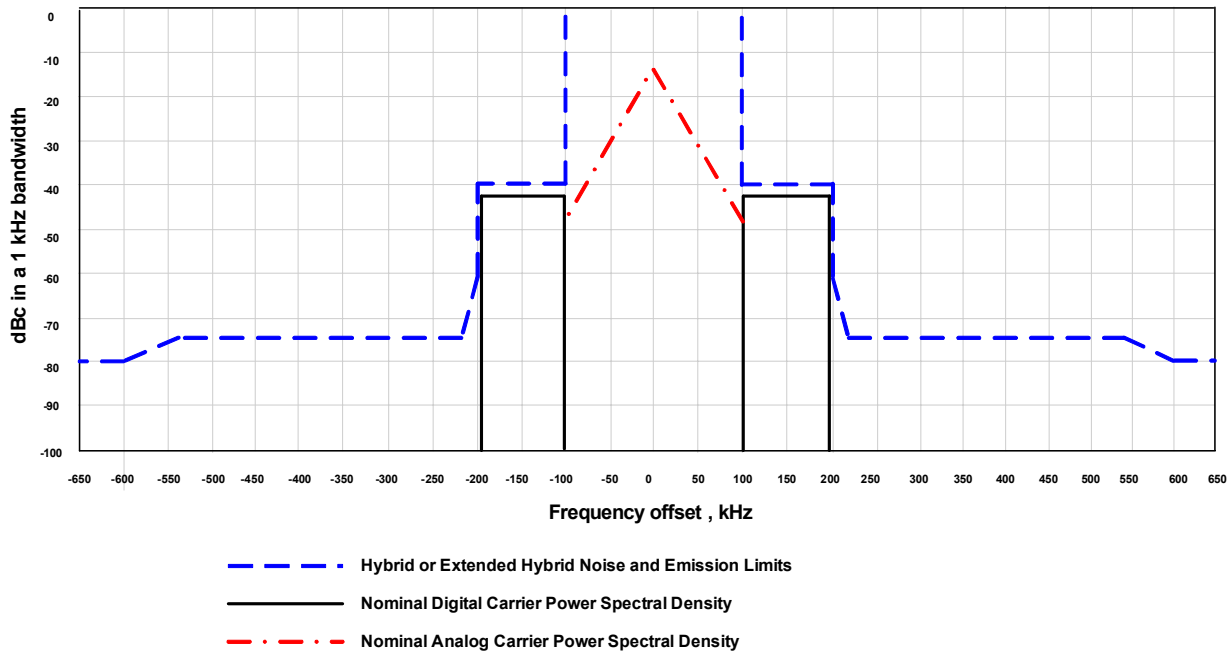

Figure 4-1 HD Radio FM Hybrid Waveform Noise and Emissions Limits

*Table 4-1 HD Radio FM Hybrid Waveform Noise and Emissions Limits**

Frequency Offset Relative to Carrier	Level, dBc/kHz
100-200 kHz offset	-40
200-215 kHz offset	[-61.4 - (|frequency in kHz|-200 kHz) · 0.867]
215-540 kHz offset	-74.4
540-600 kHz offset	[-74.4 - (|frequency in kHz|-540 kHz) · 0.093]
>600 kHz offset	-80

* The requirements for noise and spurious emission limits defined in this subsection reflect acceptable performance criteria. In certain circumstances, additional measures (filtering, active emissions suppression, etc.) may be needed to reduce the spectral emissions below the limits given in this subsection in order to reduce mutual interference between broadcast stations.

4.4.2 Spectral Emissions Limits for All Digital Transmissions

For All Digital transmissions, measurements of the All Digital signal shall be made by averaging the power spectral density of the signal in a 1 kHz bandwidth over a 30-second segment of time. Compliance shall be determined by measuring the digital waveform at the input of the broadcast antenna. 0 dBc is defined as the nominal power spectral density in a 1 kHz bandwidth of the digital Primary Main sidebands.

Noise and spuriously generated signals from all sources including phase noise and intermodulation products, shall conform to the limits as described in the following paragraph and as shown in Figure 4-2 and Table 4-2.‡

The measured power spectral density of the All Digital signal at frequencies removed from the center of the channel by 200 – 207.5 kHz shall not exceed [-20 – (|frequency in kHz – 200 kHz|) ·1.733] dBc/kHz.

The measured power spectral density at frequencies removed from the center of the channel by more than 207.5 kHz - 250 kHz shall not exceed [-33 – (|frequency in kHz – 207.5 kHz|) · 0.2118] dBc/kHz.

The measured power spectral density at frequencies removed from the center of the channel by 250 – 300 kHz shall not exceed [-42 – (|frequency in kHz – 250 kHz|) · 0.56] dBc/kHz.

The measured power spectral density at frequencies removed from the center of the channel by more than 300 kHz and up to 600 kHz shall not exceed -70 dBc/kHz.

Any emission appearing on a frequency removed from the center of the channel by more than 600 kHz shall not exceed -80 dBc/kHz.

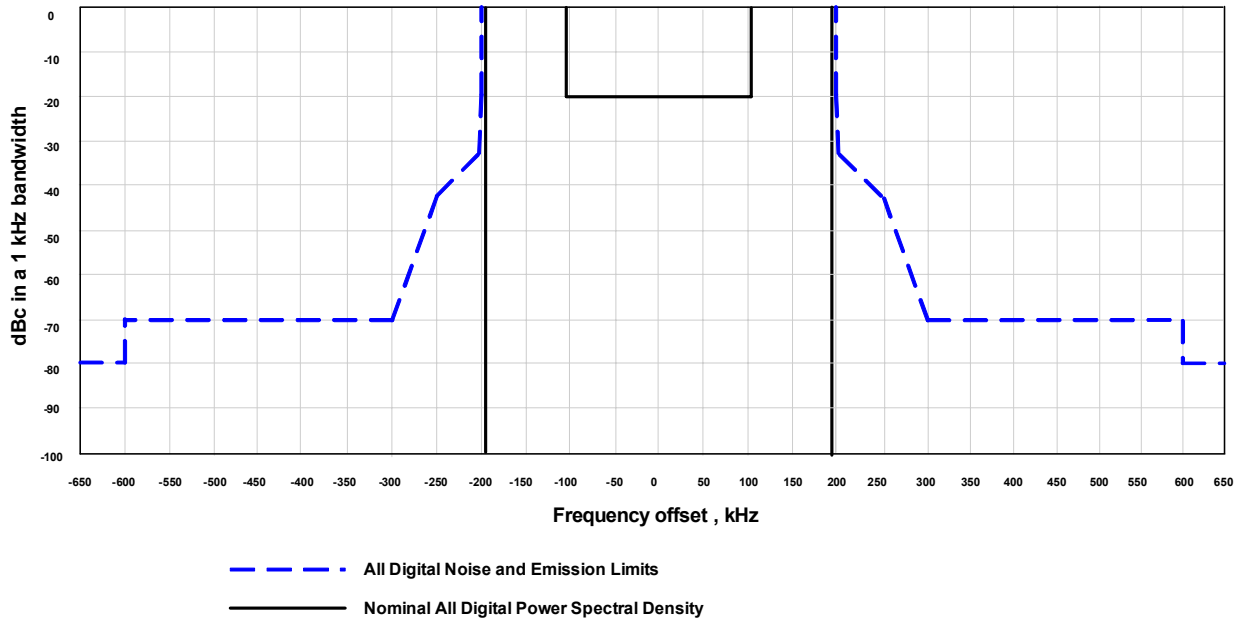

Figure 4-2 HD Radio FM All-Digital Waveforms Noise and Emission Limits

Table 4-2 HD Radio FM All Digital Waveforms Noise and Emission Limits‡

Frequency Offset Relative to Carrier	Level, dBc/kHz
200-207.5 kHz offset	[-20 - (|frequency in kHz|-200 kHz) •1.733]
207.5-250 kHz offset	[-33 - (|frequency in kHz|-207.5 kHz) • 0.2118]
250-300 kHz offset	[-42 - (|frequency in kHz|-250 kHz) • 0.56]
300-600 kHz offset	-70
>600 kHz offset	-80

‡The requirements for noise and spurious emission limits defined in this subsection reflect acceptable performance criteria. In certain circumstances, additional measures (filtering, active emissions suppression, etc.) may be needed to reduce the spectral emissions below the limits given in this subsection in order to reduce mutual interference between broadcast stations.

For All Digital transmissions, the region within 100 kHz from the center channel shall be reserved for secondary low-level subcarriers.

4.5 Digital Sideband Levels

The amplitude scaling of each OFDM subcarrier within each digital sideband is given in Table 4-3 for the Hybrid, Extended Hybrid, and All Digital waveforms. The values for the Hybrid and Extended Hybrid waveforms are specified relative to the analog FM power. A value of 1 would produce a digital subcarrier power equal to the total power in the unmodulated analog FM carrier. The values for the All Digital waveform are relative to total authorized digital power that is allocated to the broadcast facility.

For the Hybrid and Extended Hybrid waveforms, the value of a_0 was chosen so that the total average power in a primary main digital sideband (upper or lower) is 23 dB below the total power in the unmodulated analog FM carrier.

For the All Digital waveform, the value of a_1 was chosen so that the total average power of all the primary digital subcarriers combined is equal to one. The values for a_2 through a_5 were chosen so that the total average power in the secondary digital subcarriers (upper and lower) lies in the range of 5 to 20 dB below the total power in the All Digital primary digital subcarriers. The selection of one of the values a_2 through a_5 is determined by the amplitude scale factor select (ASF) received from L2.

Table 4-3 OFDM Subcarrier Scaling

Waveform	Service Mode	Sidebands	Amplitude Scale Factor Notation	Power Spectral Density, dBc per Subcarrier	Power Spectral Density in a 1 kHz Bandwidth, dBc
Hybrid	MP1	Primary	a_0	-45.8	-41.4
Extended Hybrid	MP2 – MP6	Primary	a_0	-45.8	-41.4
All Digital	MP5 – MP6	Primary	a_1	-27.3	-22.9
	MS1 - MS4	Secondary	a_2	-32.3	-27.9
		Secondary	a_3	-37.3	-32.9
		Secondary	a_4	-42.3	-37.9
		Secondary	a_5	-47.3	-42.9

4.6 Phase Noise

The phase noise mask for the broadcast system is illustrated in Figure 4-3 and specified in Table 4-4. Phase noise is inclusive of all sources from the exciter input to the antenna output as measured in a 1 Hz bandwidth. 0 dBc is defined as the total power of the carrier being measured.

The total single sideband phase noise of any digital subcarrier at the transmitter RF output as measured in a 1 Hz bandwidth shall be within the mask specified in Table 4-4. This shall be verified by transmitting a single unmodulated digital subcarrier. In addition, for the Hybrid waveform, the analog FM carrier shall be disabled.

Table 4-4. FM Broadcast System Phase Noise Specification

Frequency Offset Relative to Carrier (F)	Level, dBc/Hz
10 Hz–100 Hz	$-2.78\text{x}10^{-1}$ F–39.2
100 Hz–1000 Hz	$-1.11\text{x}10^{-2}$ F–65.9
1 kHz–10 kHz	$-1.11\text{x}10^{-3}$ F–75.9
10 kHz–100 kHz	$-2.22\text{x}10^{-4}$ F–84.8
> 100 kHz	-107.0

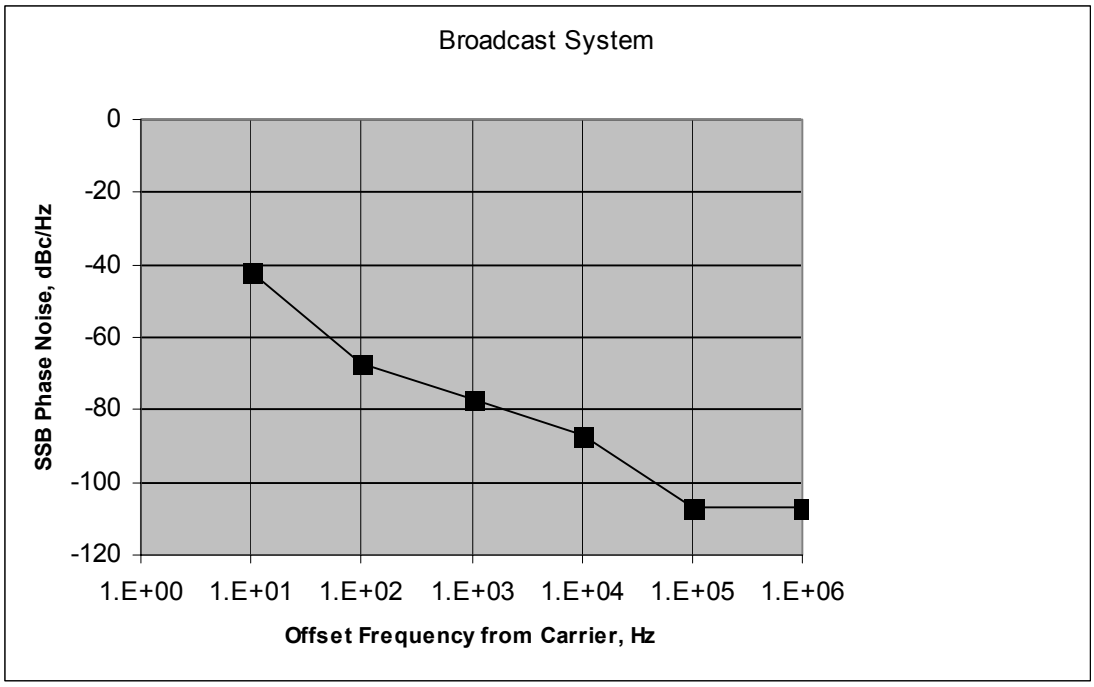

Figure 4-3. FM SSB Phase Noise Masks

4.7 Discrete Phase Noise

For the broadcast system, the spectrum from F_c - 200 kHz to F_c + 200 kHz shall be considered to consist of multiple non-overlapping sub-bands, each with a bandwidth of 300 Hz, where F_c is the carrier frequency. Discrete phase noise components measured at the transmitter RF output shall be permitted to exceed the mask specified in Table 4-4 provided that for each sub-band, the measured total integrated phase noise does not exceed the total integrated phase noise calculated from Table 4-4.

4.8 Error Vector Magnitude

Error vector magnitude is defined as the magnitude of the difference vector between an ideal modulated signal and the signal under test, normalized by the magnitude of a signal point at the corner of the signal constellation.

The error vector magnitude of the Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK) transmit subcarriers, measured at the transmitter RF output shall be less than 10% averaged across all subcarriers.

The error vector magnitude of the Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK) transmit subcarriers, measured at the transmitter RF output shall be less than 20% for all individual subcarriers.

4.9 Gain Flatness

The total gain of the transmission signal path as verified at the antenna output shall be flat to within $\pm$0.5 dB for all frequencies between (F_c–200 kHz) to (F_c + 200 kHz) , where F_c is the RF channel frequency. It is assumed that the source data consists of scrambled binary ones and the power of each subcarrier is an average value.

For optimal HD Radio digital performance it is recommended that the transmission system, including the antenna, adheres as closely as is practicable to the Gain Flatness specification. Performance may be verified using a suitable sample loop on the reference or main tower. In addition to antenna component

selection and adjustment, active pre-compensation of the HD Radio waveform may be employed to improve the effective gain flatness.

4.10 Group Delay Flatness

The differential group delay variation of the entire transmission signal path (excluding the RF channel) as measured at the RF channel frequency (F_c) shall be within 600 ns peak to peak from (F_c–200 kHz) to (F_c + 200 kHz).