HD Radio™ FM Transmission System Specifications

Rev. F

August 24, 2011

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 Reference Documents

STATEMENT
Each referenced document that is mentioned in this document shall be listed in the following iBiquity document:

- Reference Documents for the NRSC In-Band/On-Channel Digital Radio Broadcasting Standard Document Number: SY_REF_2690s

3 Abbreviations, Acronyms, 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
L1	Layer 1
L2	Layer 2
MER	Modulation Error Ratio
MF	Medium Frequency
MP1 – MP3, MP11, MP5, MP6	Primary Service Modes 1 through 3, 11, 5, and 6
MS1 – MS4	Secondary Service Modes 1 through 4
N/A	Not Applicable
NRSC	National Radio Systems Committee
OBE	Out of Band Emissions
OFDM	Orthogonal Frequency Division Multiplexing
P1 – P4	Primary Logical Channels 1 through 4
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.

3.3 Arithmetic Operators

The arithmetic operators used throughout this document are defined below:

Category	Definition	Examples
| x |	Indicates the absolute value of x	| -5 | = 5 | 3 - 4 | = 1

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 [12]. 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 [1] 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 4.4.1 and 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 minimum time span of 30 seconds and a minimum of 100 sweeps. Compliance will be determined by measuring the composite power spectral density of the analog and digital waveforms. The measurement point and the test configuration shall be as described in Subsection 4.2 of Reference [26].

Zero dBc is defined as the total power of the analog FM carrier.

Under normal operation with analog modulation present, the following requirements shall be met at all times:

> 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. These limits are applicable for all permissible power levels of the upper and lower sidebands, as defined in Subsection 4.5.
>
> 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 -30.0 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 to 207.5 kHz shall not exceed [-30.0 - (|frequency in kHz| - 200 kHz) · 4.187] dBc/kHz.
>
> The measured power spectral density of the Hybrid analog and digital signals at frequencies removed from the center of the channel by 207.5 to 250 kHz shall not exceed [-61.4 - (|frequency in kHz| - 207.5 kHz) · 0.306] dBc/kHz.
>
> The measured power spectral density of the Hybrid analog and digital signals at frequencies removed from the center of the channel between 250 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 to 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 -80.0 dBc/kHz.

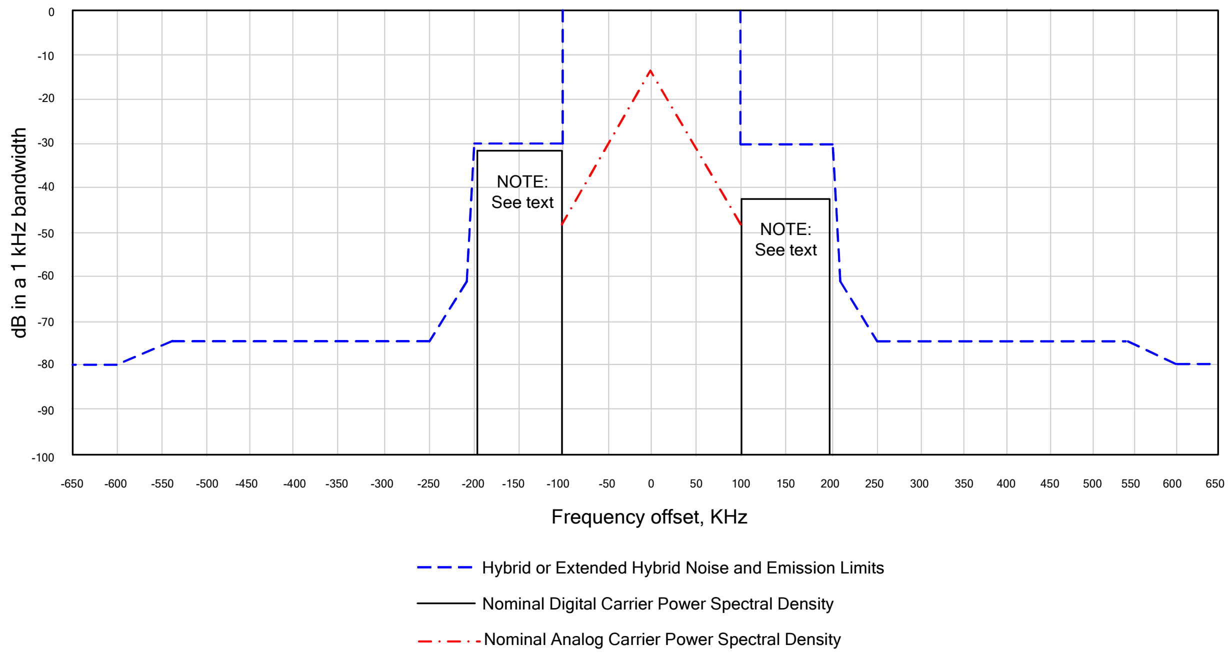

Figure 4-1: HD Radio FM Hybrid Waveform Noise and Emissions Limits

NOTE: The upper and lower sidebands may differ in power level by up to 10 dB (asymmetric sidebands). Normally, the sideband power levels are equal, but under certain scenarios, asymmetric sidebands may be useful for mitigation of adjacent channel interference. Figure 4-1 shows a power-level difference of 10 dB for purposes of illustration. It shall be noted that even though the upper and lower sidebands have different power levels, the upper and lower spectral emissions limits are the same.

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

Frequency Offset Relative to Carrier	Level, dBc/kHz
100 – 200 kHz offset	-30.0
200 – 207.5 kHz offset	[-30.0 - (|frequency in kHz| - 200 kHz) • 4.187]
207.5 – 250 kHz offset	[-61.4 - (|frequency in kHz| - 207.5 kHz) • 0.306]
250 – 540 kHz offset	-74.4
540 – 600 kHz offset	[-74.4 - (|frequency in kHz| - 540 kHz) • 0.093]
>600 kHz offset	-80.0

* 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 minimum time span of 30 seconds and a minimum of 100 sweeps. The measurement point and the test configuration shall be as described in Reference [26].

Zero dBc is defined as the nominal power spectral density in a 1-kHz bandwidth of the digital Primary Main sidebands.

Under normal operation, the following requirements shall be met at all times:

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 to 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 to 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 to 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.

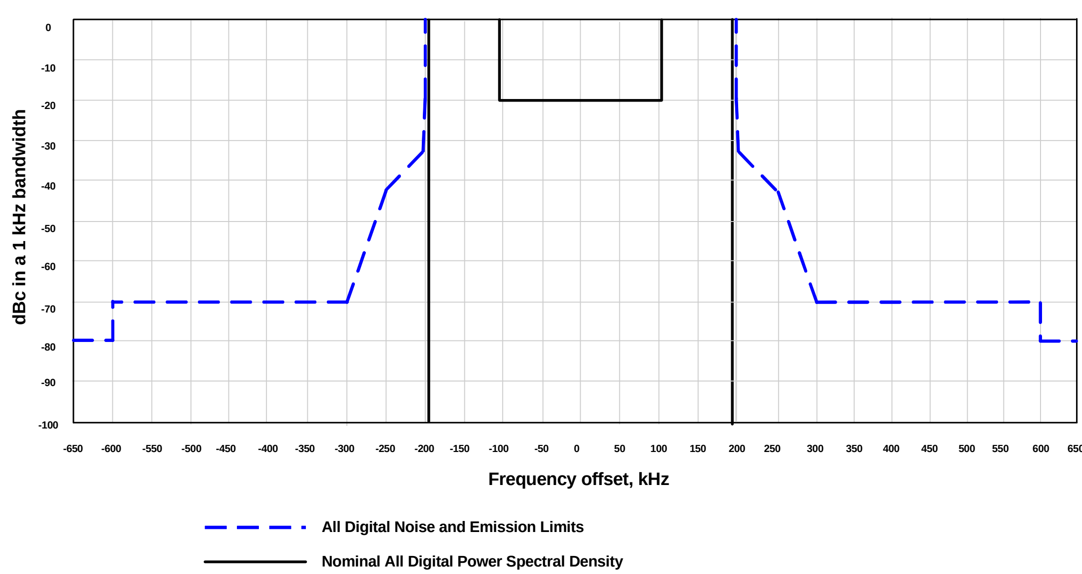

Figure 4-2: HD Radio FM All Digital Waveform Noise and Emissions Limits

Table 4-2: HD Radio FM All Digital Waveform Noise and Emissions 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 minimum values of a_{0U} and a_{0L} were 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. The power of each primary sideband may be individually increased according to the maximum values shown in Table 4-3. Therefore, total average power in each primary main digital sideband (upper or lower) is subject to an upper limit of 13 dB below the total power in the unmodulated analog FM carrier. Normally, the upper and lower sideband power levels are equal, but under certain scenarios, asymmetric sidebands may be useful for mitigation of adjacent channel interference

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	
				Min	Max	Min	Max
Hybrid	MP1	Primary	a_{0L}	-45.8	-35.8	-41.4	-31.4
			a_{0U}	-45.8	-35.8	-41.4	-31.4
Extended Hybrid	MP2, MP3, MP11, MP5, MP6	Primary	a_{0L}	-45.8	-35.8	-41.4	-31.4
			a_{0U}	-45.8	-35.8	-41.4	-31.4
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	

4.5.1 FM Hybrid and Extended Hybrid Digital Carrier Power

4.5.1.1 Hybrid and Extended Hybrid System Carrier Configuration

Hybrid transmission utilizes two OFDM subcarrier sets (sidebands) located up to 198 kHz above and below the analog carrier center frequency. The basic hybrid (MP1) service mode uses 191 subcarriers per sideband beginning in frequency at approximately ±129 kHz from the center frequency. Extended hybrid service modes MP2, MP3, and MP11 add additional subcarriers closer to the analog carrier, with MP11's subcarriers starting at approximately ±101 kHz.

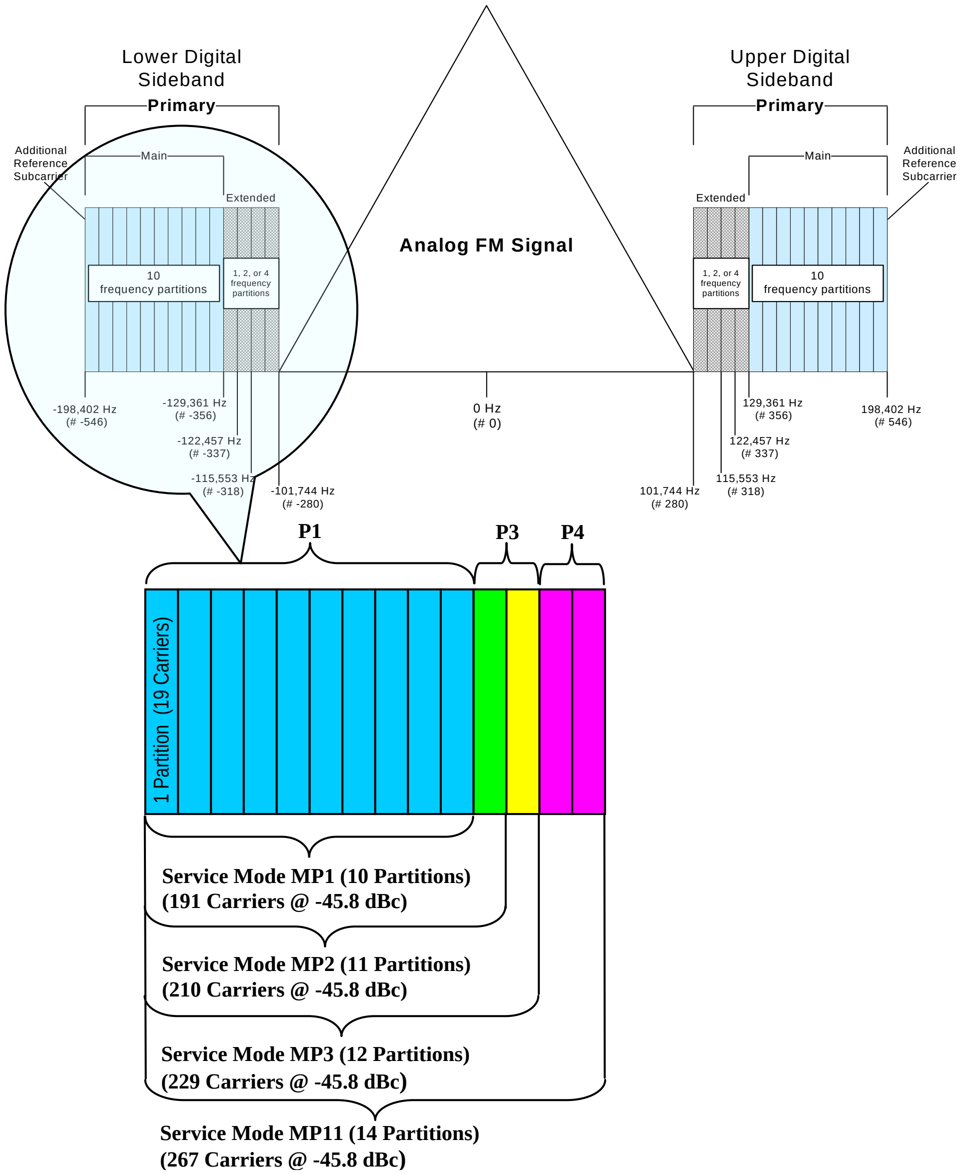

Figure 4-3: Extended Hybrid Waveform – Sideband Detail

As shown in Figure 4-3, each frequency partition consists of 19 subcarriers (except for two extra reference subcarriers at the limits of the primary main partitions). In the Lower Digital Sideband, Figure 4-3 also details each of the sideband groups for each hybrid service mode. The power of each subcarrier is set at -45.8 dBc (dB below the reference analog carrier) for a -20-dBc total integrated digital to analog power ratio in service mode MP1.

Table 4-4 characterizes power at other digital-to-analog power ratios in the four FM hybrid service modes. Since the absolute power of the subcarriers is additive, if 10 subcarrier groups make up the MP1 reference power level, one more group will increase the power by 10% and so on. Note that there is one extra reference subcarrier in each of the primary main sidebands, skewing the power calculation slightly. This amounts to approximately 0.4% of the total power in the MP3 mode or 0.02 dB, which is considered negligible.

4.5.1.2 Digital Power for Hybrid Mode at Various Digital to Analog Power Ratios

Table 4-4 characterizes the total integrated digital power and single sideband power for the four hybrid service modes and various digital to analog power ratios. The nominal digital-to-analog power ratio is derived from Table 4-3 assuming a digital-to-analog power ratio of -20 dBc. Other power ratios are scaled appropriately as referenced in Table 4-4.

Table 4-4: Sideband Power for Various Service Modes and Digital to Analog Power Ratios

Nominal Digital-to-Analog Power Ratio (dBc) Service Mode MP1	Single Subcarrier Power (dBc)	Total Integrated Power of Both Sidebands (dBc)				Total Integrated Power of One Sideband (dBc)			
		MP1 100% of MP1 Power	MP2 110% of MP1 Power	MP3 120% of MP1 Power	MP11 140% of MP1 Power	MP1 100% of MP1 Power	MP2 110% of MP1 Power	MP3 120% of MP1 Power	MP11 140% of MP1 Power
-20.0	-45.8	-20.0	-19.6	-19.2	-18.5	-23.0	-22.6	-22.2	-21.5
-14.0	-39.8	-14.0	-13.6	-13.2	-12.5	-17.0	-16.6	-16.2	-15.5
-13.0	-38.8	-13.0	-12.6	-12.2	-11.5	-16.0	-15.6	-15.2	-14.5
-12.0	-37.8	-12.0	-11.6	-11.2	-10.5	-15.0	-14.6	-14.2	-13.5
-11.0	-36.8	-11.0	-10.6	-10.2	-9.5	-14.0	-13.6	-13.2	-12.5
-10.0	-35.8	-10.0	-9.6	-9.2	-8.5	-13.0	-12.6	-12.2	-11.5

4.5.1.3 Power Limits for Asymmetrical Sideband Operation

If asymmetrical sideband operation is desired, the lower and upper digital sidebands are considered separately and the single sideband power values in Table 4-4 are used. Note that these values are simply three dB less than the corresponding total integrated power for both sidebands. If broadcasting in MP3 mode, for example, setting the lower sideband at -10 dBc and the upper at -14 dBc will result in a total integrated power of:

$$= 10\ \mathrm{Log}_{10}\ (\mathrm{Log}_{10}^{\ -1}\ (\mathrm{Pwr1}\ /10) + \mathrm{Log}_{10}^{\ -1}\ (\mathrm{Pwr2}\ /10))$$

$$= 10\ \mathrm{Log}_{10}\ (\mathrm{Log}_{10}^{\ -1}\ (-12.2\ /10) + \mathrm{Log}_{10}^{\ -1}\ (-16.2\ /10))$$

$$= 10\ \mathrm{Log}_{10}\ (0.060 + 0.024)$$

$$= 10\ \mathrm{Log}_{10}\ (0.084)$$

$$= -10.8\ \mathrm{dBc}$$

Note that the total integrated power is dominated by the highest powered sideband.

4.5.2 RF Spectral Inversion

The RF spectrum of the digital waveform shall be inverted as compared to its baseband representation. This means that the lower sideband shall occupy the higher frequencies within the RF channel. And the upper sideband shall occupy the lower frequencies within the RF channel. Hence, scale factor a_{0L} shall be used to set the power level of the higher frequency sideband and a_{0U} shall be used to set the power level of the lower frequency sideband.

Refer to Subsection 14.2.2 of [1] for further details.

4.6 Phase Noise

The phase noise mask for the broadcast system is illustrated in Figure 4-4 and specified in Table 4-5. Phase noise is inclusive of all sources from the Exciter input to the antenna output as measured in a 1-Hz bandwidth.

Zero dBc is defined as the total power of the subcarrier being measured. The phase noise mask is applicable for all permissible power levels of the upper and lower sidebands, as defined in Subsection 4.5.

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 4-5. 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 4-5: FM Broadcast System Phase Noise Specification

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

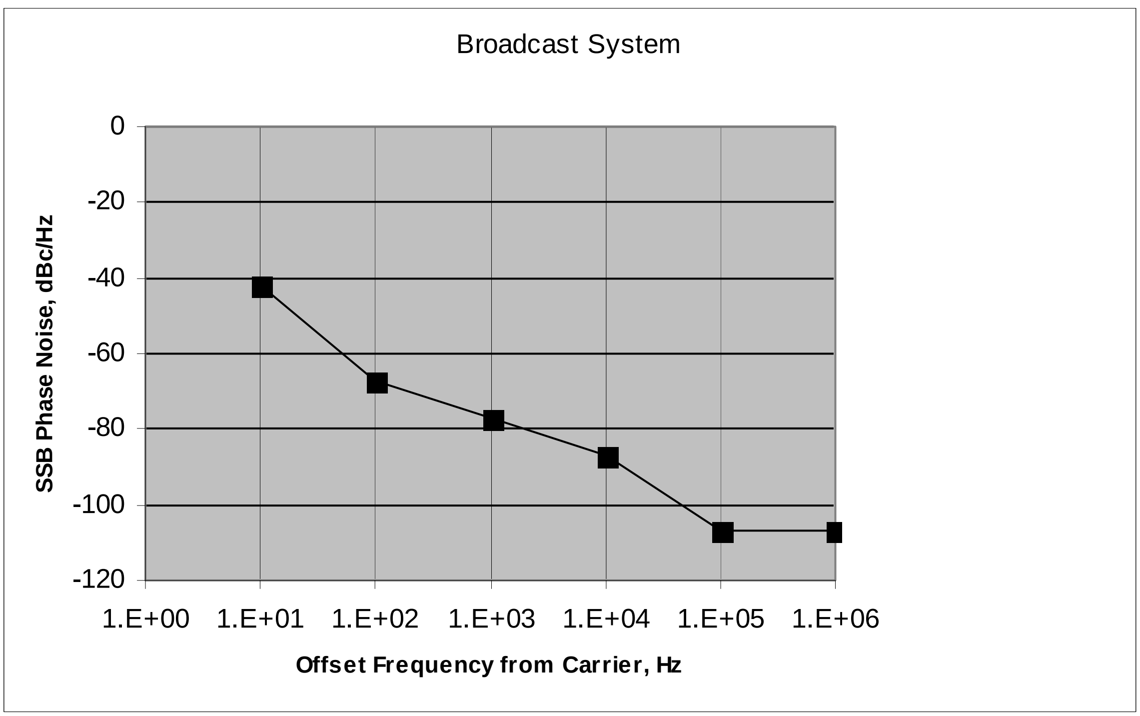

Figure 4-4: FM SSB Phase Noise Mask

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 4-5 provided that for each sub-band, the measured total integrated phase noise does not exceed the total integrated phase noise calculated from Table 4-5.

If the upper and lower sidebands have different power levels, as permitted in Subsection 4.5, the measurement must account for the fact that the 0-dBc reference level will be different for each sideband.

4.8 Modulation Error Ratio

Modulation Error Ratio (MER) is a useful signal quality metric, quantifying the ratio of the rms noise of one or more subcarriers to the subcarrier nominal magnitude(s). Thus, it is a measure of the signal-to-noise ratio (in units of dB) of the broadcast signal, inclusive of both linear and non-linear distortions within the broadcast system itself. Refer to [27] for details of how MER is measured and computed.

The following specifications shall be met, using the test configuration described in Subsection 4.2 of Reference [26].

4.8.1 Reference Subcarriers

1. The MER for each and every Binary Phase Shift Keying (BPSK) reference subcarrier, measured at the RF output of the transmission system at the connection point to the antenna system (including any RF filters), shall be greater than or equal to {11} dB, as computed by Equation 1. The parameter N in Equation 1, the total number of contiguous symbols used in the average, shall be set to {128}.
2. The average MER of all the Binary Phase Shift Keying (BPSK) reference subcarriers in the upper sideband, measured at the RF output of the transmission system at the connection point to the antenna system (including any RF filters), shall be greater than or equal to {14} dB, averaged across all upper reference subcarriers, as computed by Equation 2a. This computation shall be based on a block of N = {128} contiguous symbols.
3. The average MER of all the Binary Phase Shift Keying (BPSK) reference subcarriers in the lower sideband, measured at the RF output of the transmission system at the connection point to the antenna system (including any RF filters), shall be greater than or equal to {14} dB, averaged across all lower reference subcarriers, as computed by Equation 2b. This computation shall be based on a block of N = {128} contiguous symbols.

4.8.2 Data Subcarriers

1. The MER for each and every Quadrature Phase Shift Keying (QPSK) data subcarrier partition in the lower sideband, measured at the RF output of the transmission system at the connection point to the antenna system (including any RF filters), shall be greater than or equal to {11} dB, as computed by Equation 4a. The parameter N in Equation 4a, the total number of contiguous symbols used in the average, shall be set to {128}.
2. The MER for each and every Quadrature Phase Shift Keying (QPSK) data subcarrier partition in the upper sideband, measured at the RF output of the transmission system at the connection point to the antenna system (including any RF filters), shall be greater than or equal to {11} dB, as computed by Equation 4b. The parameter N in Equation 4b (the total number of contiguous symbols used in the average) shall be set to {128}.
3. The average MER of all the Quadrature Phase Shift Keying (QPSK) data subcarriers in the upper sideband, measured at the RF output of the transmission system at the connection point to the antenna system (including any RF filters), shall be greater than or equal to {14} dB, averaged across all upper data subcarrier partitions, as computed by Equation 5a. This computation shall be based on a block of N = {128} contiguous symbols.
4. The average MER of all the Quadrature Phase Shift Keying (QPSK) data subcarriers in the lower sideband, measured at the RF output of the transmission system at the connection point

to the antenna system (including any RF filters), shall be greater than or equal to {14} dB, averaged across all lower data subcarrier partitions, as computed by Equation 5b. This computation shall be based on a block of N = {128} contiguous symbols.

4.8.3 Data Subcarrier to Reference Subcarrier Power Ratio

In addition to the gain flatness specifications stated in Subsection 4.9, the ratio of the average data subcarrier power to the average reference subcarrier power, as computed by Equations 3a and 3b shall comply with the following limits:

$$-0.5 \le RdB_{upper} \le 1.0 \text{ dB}$$

$$-0.5 \le RdB_{lower} \le 1.0 \text{ dB}$$

4.9 Gain Flatness

The total gain of the transmission signal path as verified at the antenna output shall be flat to within ±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 the case where the upper and lower digital sideband power levels are intended to be different, as defined in Subsection 4.5, the gain flatness specification shall be interpreted as follows:

> Gain flatness is the difference between the measured power spectral density in a 1-kHz bandwidth of each subcarrier frequency, and the power spectral density of the applicable digital Primary Main sideband, normalized to a 1-kHz bandwidth.

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).