HD Radio™ AM 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 AM 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 AM," Doc. No. SY_IDD_1012s, 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
MA1	Primary AM Hybrid Service Mode
MA3	Primary AM All Digital Service Mode
N/A	Not Applicable
OFDM	Orthogonal Frequency Division Multiplexing
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
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 AM Transmission Specifications

4.1 Introduction

This document presents the key transmission specifications for the AM 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 for in accordance with [1]. The Hybrid and All Digital HD Radio waveforms are centered on the assigned AM band channel frequency.

4.3 Synchronization Tolerances

The system shall support 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 shall 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 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 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 carrier frequency absolute error shall meet the following requirements:
The total (analog and digital) carrier frequency absolute error of a Synchronization Level I broadcast system as observed at the RF output shall be ±0.02 Hz maximum.
The total (analog and digital) carrier frequency absolute error of a Synchronization Level II broadcast system as observed at the RF output shall be ±2.0 Hz maximum.

4.3.3 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 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 AM Analog Host Performance (Hybrid Transmissions)

The introduction of digital subcarriers shall not compromise the performance of the host analog AM signal as follows: The analog signal shall meet the FCC emissions mask specifications contained in 47 CFR §73.44.
For Hybrid transmissions that limit the analog audio bandwidth to 5 kHz, the power spectral density of the modulated AM carrier measured with the HD Radio digital component disabled, at frequencies removed from the carrier frequency by more than 5 kHz and up to 20 kHz shall not exceed -65 dBc/300 Hz.

For Hybrid transmissions that limit the analog audio bandwidth to 8 kHz, the power spectral density of the modulated AM carrier measured with the HD Radio digital component disabled, at frequencies removed from the carrier frequency by more than 8 kHz and up to 20 kHz shall not exceed -65 dBc/300 Hz.

0 dBc is defined as the total power of the unmodulated AM carrier.

4.5 AM Spectral Emissions Limits

The requirements for the spectral emissions limits for the Hybrid transmissions and the All Digital transmissions are given in Subsections 4.5.1, 4.5.2 and 0.

4.5.1 Spectral Emissions Limits for Hybrid Transmissions 5 kHz Analog Bandwidth

For Hybrid transmissions, measurements of the analog and digital signals shall be made by averaging the power spectral density of the signal in a 300 Hz bandwidth over a 30 second segment of time. 0 dBc is defined as the total power of the unmodulated analog AM 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 4-1and Table 4-1.*

The measured power spectral density at frequencies greater than 5 kHz, up to and including 10 kHz, from the carrier frequency shall not exceed -36.5 dBc/300 Hz.

The measured power spectral density at frequencies greater than 10 kHz, up to and including 15 kHz, from the carrier frequency shall not exceed -26.8 dBc/300 Hz.

The measured power spectral density at frequencies greater than 15 kHz, up to and including 15.2 kHz, from the carrier frequency shall not exceed -28 dBc/300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 15.2 kHz, up to and including 15.8 kHz shall not exceed -39 - (| offset frequency in kHz | - 15.2) · 43.3 dBc/ 300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 15.8 kHz, up to and including 25 kHz shall not exceed -65 dBc/ 300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 25 kHz, up to and including 30.5 kHz shall not exceed -65 - (| offset frequency in kHz | - 25) · 1.273 dBc/ 300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 30.5 kHz, up to and including 75 kHz shall not exceed -72 - (| offset frequency in kHz | - 30.5) · 0.292 dBc/ 300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 75 kHz, shall not exceed -85 dBc/300 Hz.

If discrete components exceed the limits established in Table 4-1 and in Figure 4-1, the following conditions shall be met when averaging the power spectral density of the signal in each 300 Hz bandwidth over a 30 second segment of time:

1. No more than two discrete components within 75 kHz of the carrier frequency shall exceed the spectral emission limits by more than 10 dB.
2. No more than four discrete components removed from the carrier frequency by more than 75 kHz shall exceed the spectral emission limits by more than 5 dB.

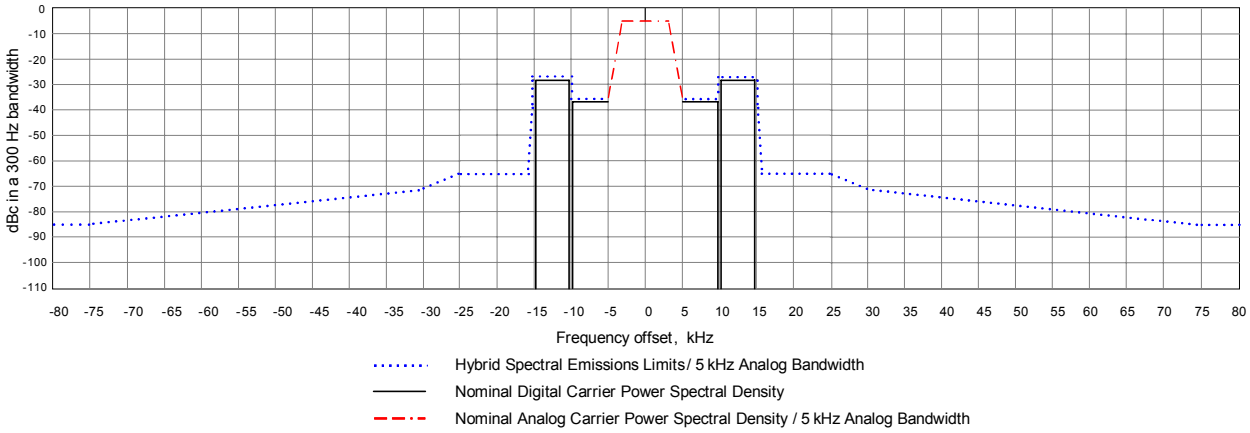

Figure 4-1 HD Radio AM Hybrid Waveform Spectral Emissions Limits for 5 kHz Analog Bandwidth

Table 4-1 HD Radio AM Hybrid Waveform Spectral Emissions Limits for 5 kHz Analog Bandwidth

Frequency Offset Relative to Carrier	Level Relative to Unmodulated Carrier (dBc per 300 Hz)
5 to 10 kHz offset	-34.3
10 to 15 kHz offset	-26.8
15 to 15.2 kHz offset	-28
15.2 to 15.8 kHz offset	-39 – (|frequency offset in kHz| - 15.2) · 43.3
15.8 to 25 kHz offset	-65
25 kHz to 30.5 kHz offset	-65 – (|frequency offset in kHz| - 25) · 1.273
30.5 kHz to 75 kHz offset	-72 – (|frequency offset in kHz| - 30.5) · 0.292
> 75 kHz offset	-85

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

4.5.2 Spectral Emissions Limits for Hybrid Transmissions 8 kHz Analog Bandwidth

For hybrid transmissions, measurements of the analog and digital signals shall be made by averaging the power spectral density of the signal in a 300 Hz bandwidth over a 30 second segment of time. 0 dBc is defined as the total power of the unmodulated analog AM 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 4-2 and Table 4-2.†

The measured power spectral density at frequencies greater than 8 kHz, up to and including 10 kHz, from the carrier frequency shall not exceed -36.5 dBc/300 Hz.

The measured power spectral density at frequencies greater than 10 kHz, up to and including 15 kHz, from the carrier frequency shall not exceed -26.8 dBc/300 Hz.

The measured power spectral density at frequencies greater than 15 kHz, up to and including 15.2 kHz, from the carrier frequency shall not exceed -28 dBc/300 Hz.

The measured power spectral density of the hybrid signal at frequencies removed from the carrier frequency by more than 15.2 kHz, up to and including 15.8 kHz shall not exceed -39 - (| offset frequency in kHz | - 15.2) · 43.3 dBc/ 300 Hz.

The measured power spectral density of the hybrid signal at frequencies removed from the carrier frequency by more than 15.8 kHz, up to and including 25 kHz shall not exceed -65 dBc/ 300 Hz.

The measured power spectral density of the hybrid signal at frequencies removed from the carrier frequency by more than 25 kHz, up to and including 30.5 kHz shall not exceed -65 - (| offset frequency in kHz | - 25) · 1.273 dBc/ 300 Hz.

The measured power spectral density of the hybrid signal at frequencies removed from the carrier frequency by more than 30.5 kHz, up to and including 75 kHz shall not exceed -72 - (| offset frequency in kHz | - 30.5) · 0.292 dBc/ 300 Hz.

The measured power spectral density of the hybrid signal at frequencies removed from the carrier frequency by more than 75 kHz, shall not exceed -85 dBc/300 Hz.

If discrete components exceed the limits established in Table 4-2 and in Figure 4-2, the following conditions shall be met when averaging the power spectral density of the signal in each 300 Hz bandwidth over a 30 second segment of time:

1. No more than two discrete components within 75 kHz of the carrier frequency shall exceed the spectral emission limits by more than 10 dB.
2. No more than four discrete components removed from the carrier frequency by more than 75 kHz shall exceed the spectral emission limits by more than 5 dB.

When a station operates in the Hybrid 8 kHz mode; an HD Radio™ receiver will treat the enhanced carriers as complimentary. Complimentary carriers require that both the upper and lower sidebands be recovered for demodulation. Therefore, in the 8 kHz mode, digital coverage of a Hybrid station may be adversely impacted by adjacent transmission. The severity of the impact will be dependent upon whether the interference is from a first or second adjacent and if it is an Analog, Hybrid or All-Digital transmission.

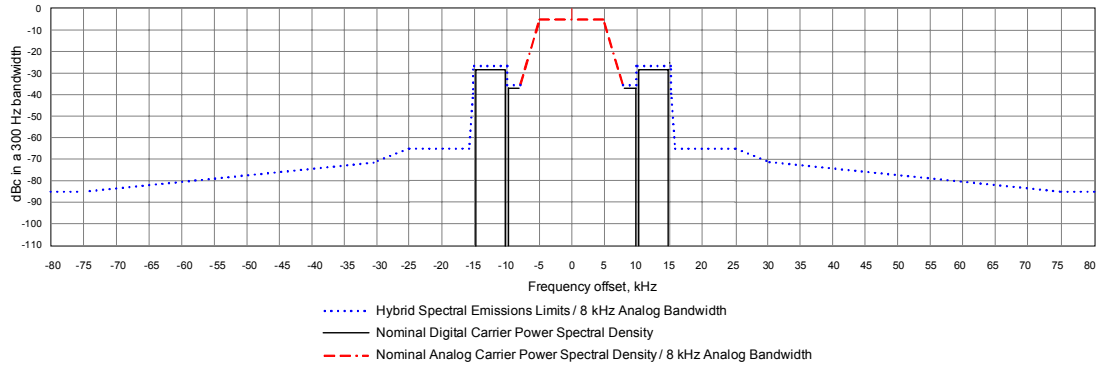

Figure 4-2 HD Radio AM Hybrid Waveform Spectral Emissions Limits for 8 kHz Analog Bandwidth

Table 4-2 HD Radio AM Hybrid Waveform Spectral Emissions Limits for 8 kHz Analog Bandwidth

Frequency Offset Relative to Carrier	Level Relative to Unmodulated Carrier (dBc per 300 Hz)
8 to 10 kHz offset	-34.3
10 to 15 kHz offset	-26.8
15 to 15.2 kHz offset	-28
15.2 to 15.8 kHz offset	-39 – (|frequency offset in kHz| - 15.2) · 43.3
15.8 to 25 kHz offset	-65
25 kHz to 30.5 kHz offset	-65 – (|frequency offset in kHz| - 25) · 1.273
30.5 kHz to 75 kHz offset	-72 – (|frequency offset in kHz| - 30.5) · 0.292
> 75 kHz offset	-85

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

4.5.3 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 in a 300 Hz bandwidth over a 30-second segment of time. 0 dBc is defined as the allocated power of the unmodulated AM carrier and is equal to the reference level used in Subsection 4.5.1.

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 4-3and Table 4-3.‡

The measured power spectral density of the All Digital signal at frequencies removed from the carrier frequency by more than 9.8 kHz, up to and including 10.5 kHz shall not exceed -28 - (| offset frequency in kHz | - 9.8) · 42.86 dBc/ 300 Hz.

The measured power spectral density of the All Digital signal at frequencies removed from the carrier frequency by more than 10.5 kHz, up to and including 11.5 kHz shall not exceed -58 - (| offset frequency in kHz | - 10.5) · 7.0 dBc/ 300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 11.5 kHz, up to and including 15 kHz shall not exceed -65 dBc/ 300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 15 kHz, up to and including 20.5 kHz shall not exceed -65 - (| offset frequency in kHz | - 15) · 1.273 dBc/ 300 Hz.

The measured power spectral density of the Hybrid signal at frequencies removed from the carrier frequency by more than 20.5 kHz, up to and including 75 kHz shall not exceed -72 - (| offset frequency in kHz | - 20.5) · 0.239 dBc/300 Hz.

The measured power spectral density of the All Digital signal at frequencies removed from the carrier frequency by more than 75 kHz, shall not exceed -85 dBc/300 Hz.

If discrete components exceed the limits established in Table 4-3 and in Figure 4-3, the following conditions shall be met when averaging the power spectral density of the signal in each 300 Hz bandwidth over a 30 second segment of time:

1. No more than two discrete components within 75 kHz of the carrier frequency shall exceed the spectral emission limits by more than 10 dB.
2. No more than four discrete components removed from the carrier frequency by more than 75 kHz shall exceed the spectral emission limits by more than 5 dB.

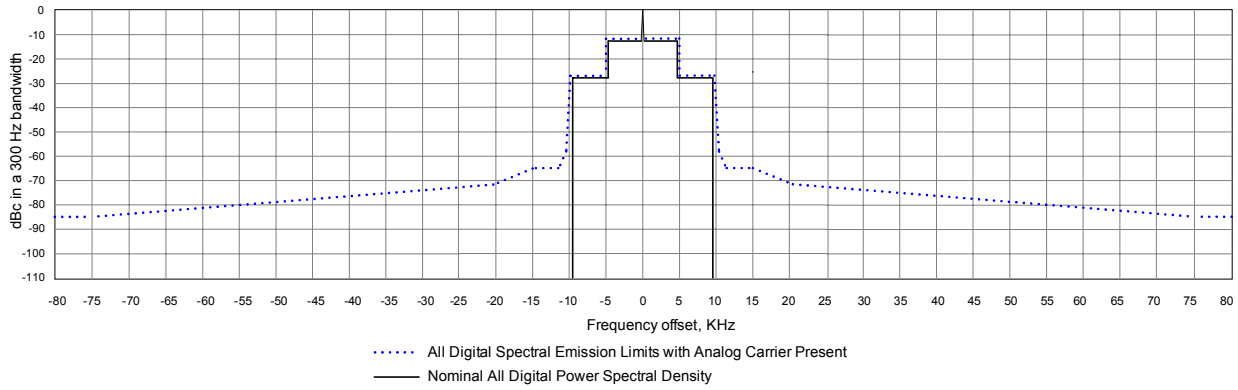

Figure 4-3 HD Radio AM All Digital Waveform Spectral Emissions Limits

Table 4-3 HD Radio AM All Digital Waveform Spectral Emissions Limits

Frequency Offset Relative to Carrier	Level Relative to Unmodulated Carrier (dBc per 300 Hz)
181.7 Hz to 4814.65 Hz offset	-12.3
4814.65 Hz to 9.8 kHz offset	-27.3
9.8 to 10.5 kHz offset	-28 – (|frequency offset in kHz| - 9.8) · 42.86
10.5 to 11.5 kHz offset	-58 – (|frequency offset in kHz| - 10.5) · 7.0
11.5 to 15 kHz offset	-65
15 to 20.5 kHz offset	-65 – (|frequency offset in kHz| - 15) · 1.273
20.5 to 75 kHz offset	-72 – (|frequency offset in kHz| - 20.5) · 0.239
> 75 kHz offset	-85

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

4.6 Digital Sideband Levels

The amplitude scaling of each OFDM subcarrier within each digital sideband is given in Table 4-4 for the Hybrid and All Digital waveforms. The amplitude scale factors are such that the average power in the constellation for that subcarrier meets the average per subcarrier power spectral density shown in dB.

For both the Hybrid and All Digital waveforms, the subcarrier levels are specified relative to the total power of the unmodulated analog AM carrier (assumed equal to 1).
Refer to [2] for the selection of CH_{S1}, $\underline{CH}_{T1}[\ ]$, CH_{I1} versus CH_{S2}, $\underline{CH}_{T2}[\ ]$, CH_{I2}.

Table 4-4 OFDM Subcarrier Amplitude Scaling

Waveform	Service Mode	Sidebands	Amplitude Scale Factor Notation	Modulation Type	Maximum Power Spectral Density, dBc/Subcarrier	Maximum Power Spectral Density in a 300 Hz Bandwidth, dBc
Hybrid	MA1	Primary	CH_P	64-QAM	-30	-27.8
		Secondary	CH_{S1}	16-QAM	-43	-40.8
			CH_{S2}	16-QAM	-37	-34.8
		Tertiary	$\underline{CH}_{T1}$ [0]	QPSK	-44	-41.8
			$\underline{CH}_{T1}$ [1]	QPSK	-44.5	-42.8
			$\underline{CH}_{T1}$ [2]	QPSK	-45	-42.8
			$\underline{CH}_{T1}$ [3]	QPSK	-45.5	-43.3
			$\underline{CH}_{T1}$ [4]	QPSK	-46	-43.8
			$\underline{CH}_{T1}$ [5]	QPSK	-46.5	-44.3
			$\underline{CH}_{T1}$ [6]	QPSK	-47	-44.8
			$\underline{CH}_{T1}$ [7]	QPSK	-47.5	-45.3
			$\underline{CH}_{T1}$ [8]	QPSK	-48	-45.8
			$\underline{CH}_{T1}$ [9]	QPSK	-48.5	-46.3
			$\underline{CH}_{T1}$ [10]	QPSK	-49	-46.8
			$\underline{CH}_{T1}$ [11]	QPSK	-49.5	-47.3
			$\underline{CH}_{T1}$ [12:24]	QPSK	-50	-47.8
			$\underline{CH}_{T2}$ [0:24]	QPSK	-44	-41.8
		Reference	CH_B	BPSK	-26	-23.8
		PIDS	CH_{I1}	16-QAM	-43	-40.8
			CH_{I2}	16-QAM	-37	-34.8
All Digital	MA3	Primary	CD_P	64-QAM	-15	-12.8
		Secondary	CD_E	64-QAM	-30	-27.8
		Tertiary	CD_E	64-QAM	-30	-27.8
		Reference	CD_B	BPSK	-15	-12.8
		PIDS	CD_I	16-QAM	-30	-27.8

4.7 Analog Audio Source

The analog signal shall not exceed the modulation levels specified in Title 47 CFR §73.1570.
The HD Radio system is not compatible with existing analog AM stereophonic broadcasts. The input analog signal shall be a monophonic signal.

4.8 Phase Noise

The phase noise mask for the broadcast system is illustrated in Figure 4-4 and specified in Table 4-5; 0 dBc is defined as the total power of the carrier being measured. The total single sideband phase noise at the transmitter RF output as measured in a 1 Hz bandwidth shall be within the mask specified in Table 4-6. This shall be verified by transmitting a single unmodulated digital subcarrier. In addition, for the Hybrid waveform, the unmodulated AM carrier shall be separately verified.

Table 4-5 AM Broadcast System Phase Noise Specification

Frequency, F, Offset Relative to Carrier	Level, dBc/Hz
1 Hz–10 Hz	-1.11F–38.9
10 Hz–100 Hz	$-4.44 \cdot 10^{-1}$F–45.6
100 Hz–1000 Hz	$-5.56 \cdot 10^{-3}$F–89.4
1 kHz–10 kHz	$-1.67 \cdot 10^{-3}$F–93.3
10 kHz–100 kHz	$-1.11 \cdot 10^{-4}$F–108.9
> 100 kHz	-120.0

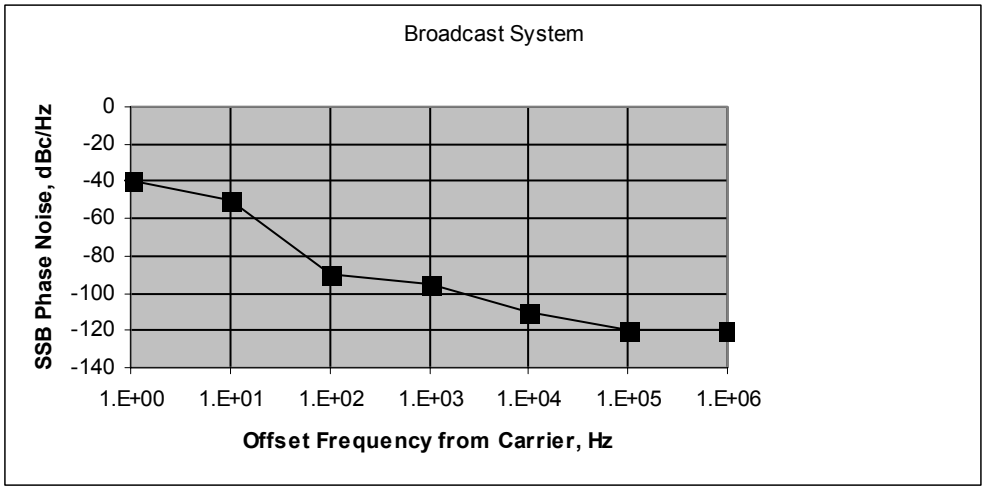

Figure 4-4 AM SSB Phase Noise Mask

4.9 Discrete Phase Noise

For the broadcast system, the spectrum from F_c - 15 kHz to F_c + 15 kHz shall be considered to consist of multiple non-overlapping sub-bands, each with a bandwidth of 100 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 4-5.

4.10 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 QPSK and BPSK transmit subcarriers, measured at transmitter RF output, shall be less than 10% averaged across all subcarriers.

The error vector magnitude of the QPSK and BPSK transmit subcarriers, measured at transmitter RF output, shall be less than 20% for all individual subcarriers.

The error vector magnitude of the 16-QAM (Quadrature Amplitude Modulation) and 64-QAM transmit subcarriers, measured at the transmitter RF output shall be less than 2.5% averaged across all QAM subcarriers.

The error vector magnitude of the 16-QAM (Quadrature Amplitude Modulation) and 64-QAM transmit subcarriers, measured at the transmitter RF output shall be less than 5.0% for all individual QAM subcarriers.

4.11 Gain Flatness

The total gain of the transmission signal path as verified at the transmitter output into a 50 Ohm, non-reactive load, shall be flat to within ±0.5 dB for all frequencies between (F_c-10 kHz) to (F_c + 10 kHz) , where F_c is the RF channel frequency. For frequencies removed from Fc by more than 10 kHz and less than 15 kHz, the gain shall be flat to within ±1.0 dB. 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.

4.12 Amplitude and Phase Symmetry

The amplitude and phase symmetry of the transmission signal path shall be verified at the transmitter output into a 50 Ohm, non-reactive load. For Hybrid transmissions, for any frequency, F, between 0 and 5 kHz, removed from the carrier frequency, Fc, the RF digital transmission must maintain symmetry within the following limits:

i.) The average RF signal power at a frequency (Fc+F) shall be within ±0.25 dB of the RF signal power at the corresponding frequency (Fc-F), where the power is measured in a 300 Hz bandwidth averaged over 30 seconds.

ii.) The phase of the signal at a frequency (Fc+F) shall be equal to the negative of the signal phase at a frequency (Fc-F) within ±2 degrees rms.

For optimal HD Radio digital performance it is recommended that the transmission system, including the antenna, adheres as closely as is practicable to the Amplitude and Phase Symmetry specification. This 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 amplitude and phase symmetry.

4.13 Group Delay Flatness

Group delay of the transmission signal path shall be verified at the transmitter output into a 50 Ohm, non-reactive load. The group delay of the entire transmission signal path (excluding the RF channel) as measured at the RF channel frequency, F_c, shall be flat to within ±3 μs from (F_c -15 kHz) to (F_c + 15 kHz).

For optimal HD Radio digital performance it is recommended that the transmission system, including the antenna, adheres as closely as is practicable to the Group Delay specification. This 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 group delay.