iBiquity Digital	Test Report

HD Radio™ Asymmetric Sideband Laboratory Test Report

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1. Historical Overview

On January 27, 2010, the FCC Media Bureau adopted an Order establishing new notification and application procedures to permit FM stations to voluntarily increase in-band/on-channel (IBOC) hybrid digital effective radiated power (MM Docket No. 99-325). The order became effective on May 10, 2010. It authorizes a blanket digital power increase of 6 dB (to -14 dBc) over the previously authorized -20 dBc (1 percent of the analog power). Pursuant to this authorization, stations are also able to increase their digital power to a maximum of -10 dBc (10 percent of the analog power), provided that certain 1st adjacent interference criteria are satisfied.

The IBOC hybrid digital signal uses digital subcarriers above and below the analog signal to provide spectral redundancy, grouped into what are called the upper digital sideband (the digital subcarriers higher in frequency than the analog signal) and lower digital sideband (likewise). HD Radio software versions prior to iBiquity Reference System Software (IRSS) 4.4.X only allow *symmetrical* adjustment of digital power, that is, the upper and lower digital sidebands would always be at the same power level. As such, if a station is required to limit digital power on one sideband, both sidebands must stay at that lower level.

Using the interference calculation algorithm in the FCC Order, many stations have no such limitation for both sidebands. Independent adjustment of either sideband's power (called *asymmetric* sidebands) would allow stations to improve coverage by raising the non-limited sideband to its limit, which can be as high as the corresponding single sideband in a -10 dBc (10 percent of analog power) symmetric implementation or -13 dBc.

HD Radio software versions 4.4.x and above allow for independent, asymmetric sideband control by implementing a new peak-to-average power ratio reduction algorithm.

1.1. Peak-to-Average Power Ratio Reduction

Peak-to-average power ratio reduction (PAR) is necessary to effectively transmit an orthogonal frequency division multiplex (OFDM) waveform. If not implemented, transmitter peak power requirements would be significantly higher resulting in the need for larger and more expensive transmitters. Clipping artifacts are a byproduct of PAR algorithms, and will exist somewhere within the transmitted signal spectrum depending upon the algorithm used. Prior to IRSS software version 4.4.X, the PAR algorithm only allowed clipping artifacts within the bandwidth of the digital signal, limiting effectiveness. In addition, the maximum allowable artifact amplitude was set at a constant level for both sidebands.

The IRSS 4.4.X load supports asymmetric sideband adjustment. To accomplish this, the in-sideband artifact limit is scaled per sideband and additional artifacts are allowed to exist out of the digital signal's bandwidth, set to a level determined by the NRSC-5-C RF mask, minus an adjustable "mask offset" margin. This margin is included not only to allow the broadcaster to set artifact limits to accommodate transmitter and other downstream system non-linearities, but also to comply with the NRSC-5-C emission mask. Also included in the IRSS 4.4.X load is the ability to incorporate the analog signal into PAR calculations.

Figure 1-1 characterizes a typical PAR v.1 waveform (v.1 refers to PAR prior to the addition of the asymmetric sideband capability). Clipping artifacts are limited to the bandwidth of the actual digital signals.

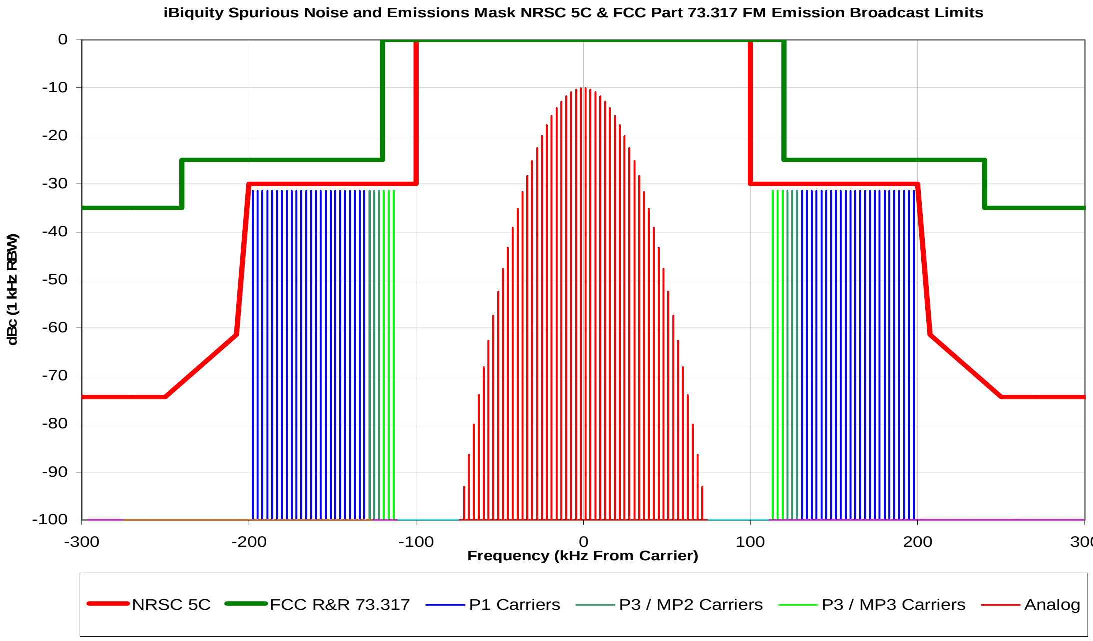

Figure 1-1 Service Mode MP3 / PAR v.1 - Symmetric Transmission @ -10 dBc

Figure 1-2 characterizes a typical PAR v.2 waveform (v.2 refers to PAR with the addition of the asymmetric sideband capability) for a symmetric transmission at -10 dBc digital-to-analog power ratio.
In this example, PAR artifacts are limited to a mask offset of -24 dB.

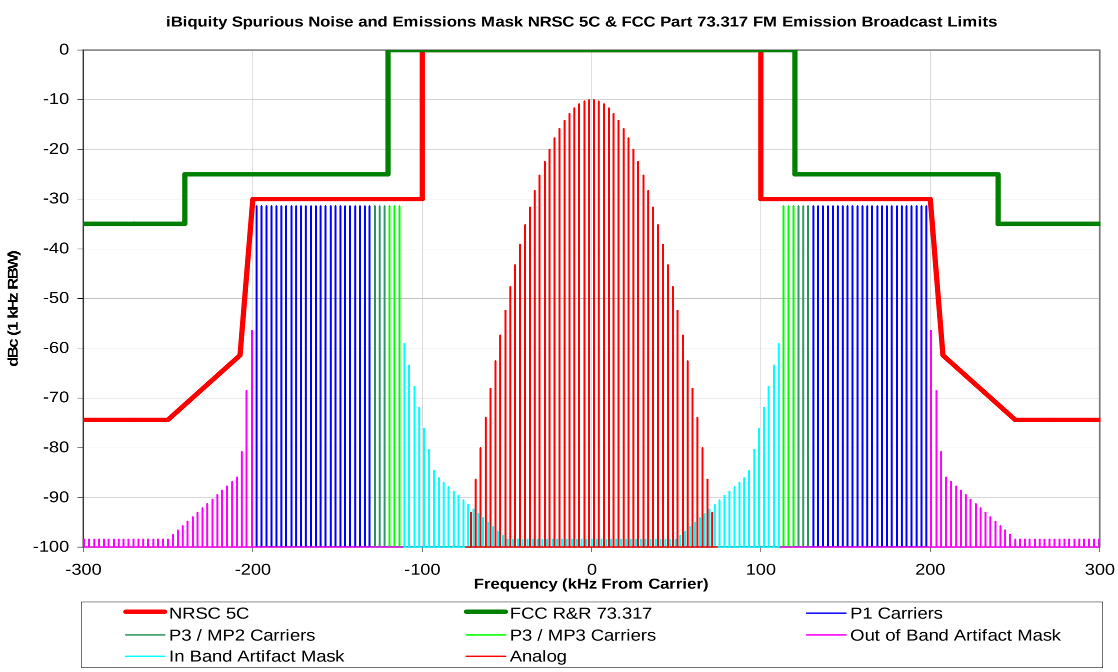

Figure 1-2 Service Mode MP3 / PAR v.2 - Symmetric Transmission @ -10 dBc / Mask Offset @ -24 dB

Figure 1-3 characterizes a PAR v.2 waveform for a symmetric transmission at -10 dBc digital-to-analog power ratio. In this example, PAR artifacts are limited to a mask offset of -3 dB. This configuration results in a very aggressive application of PAR and may be extreme, in that transmission system non-linearities downstream may cause the final transmitted hybrid waveform to exceed the NRSC-5-C mask or cause potential host interference to the analog signal. It is not envisioned that this would be a typical station implementation.

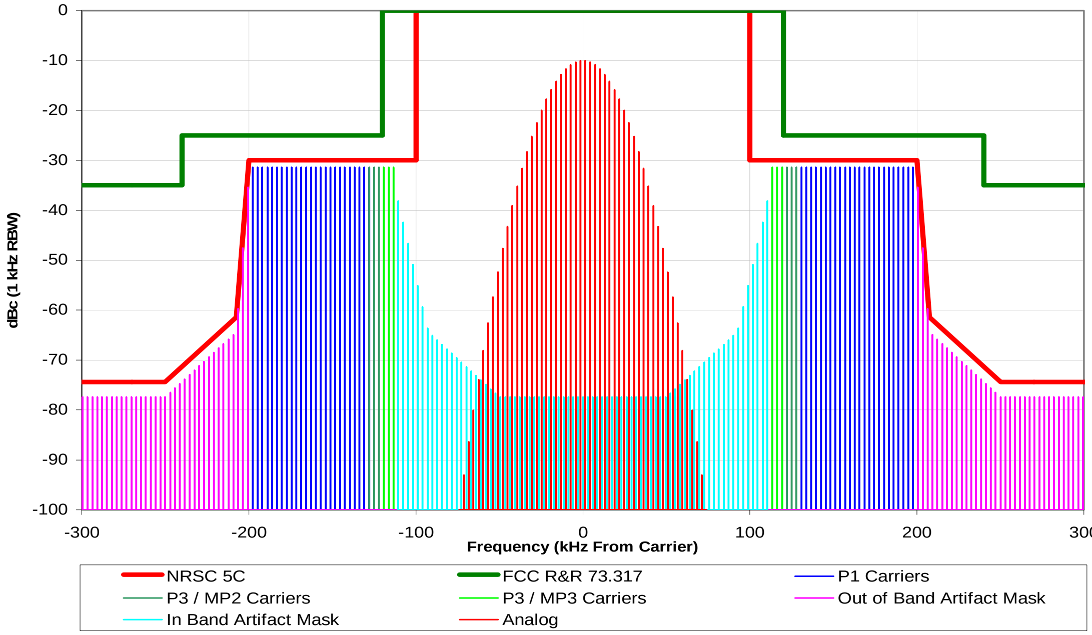

Figure 1-3 Service Mode MP3 / PAR v.2 - Symmetric Transmission @ -10 dBc / Mask Offset @ -3 dB

Figure 1-4 characterizes an asymmetric service mode MP3 waveform operating with a PAR v.2 mask offset of -24 dB. Note that the artifact amplitude near the reduced lower sideband remains at -24 dB.

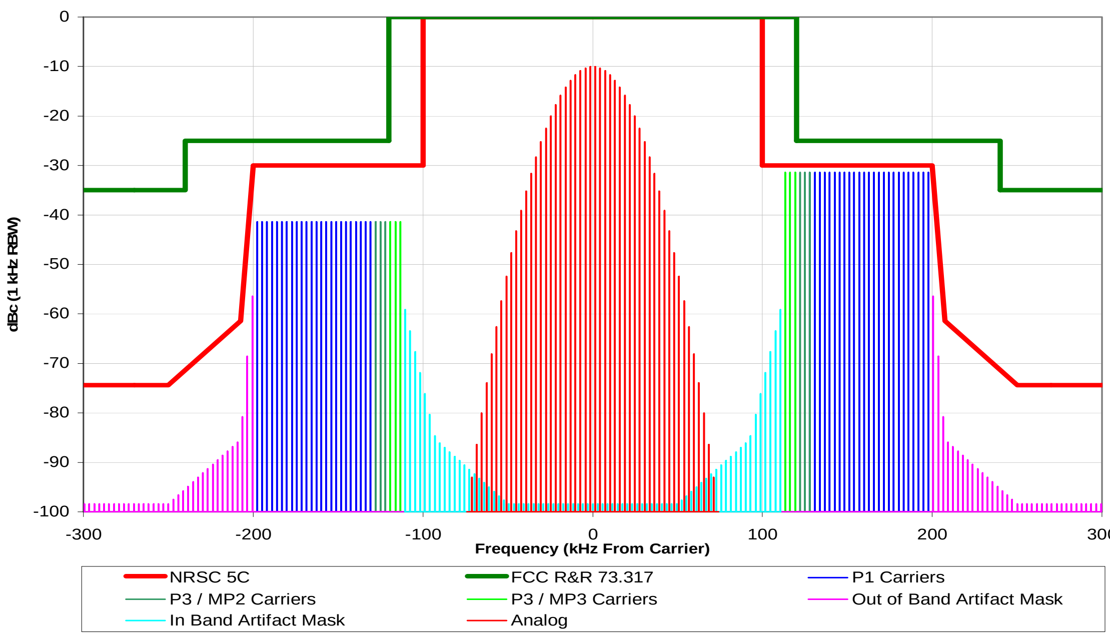

Figure 1-4 Service Mode MP3 / PAR v.2 - Asymmetric Transmission @ -10 dBc / Mask Offset @ -24 dB

Control of PAR parameters and carrier asymmetry is accomplished in the Signal Configuration graphical user interface (GUI) shown in Figure 1-5. iBiquity's software version IRSS 4.4.X and above require the desired digital-to-analog power ratio to be entered for the PAR algorithm to perform correctly.

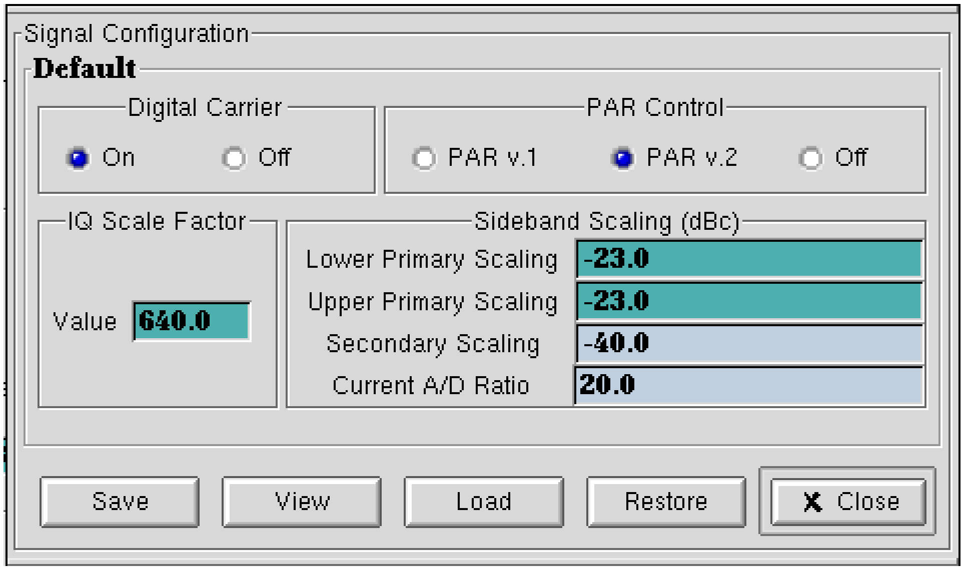

Figure 1-5 Signal Configuration GUI

2. Test Description

This report describes a laboratory evaluation of the expected improvement in digital signal-to-noise ratio (SNR) that may be realized by FM broadcast stations implementing asymmetric sideband HD Radio transmission. Tests were performed using three typical automotive HD Radio receivers, each with a different HD Radio chipset (chipsets represented are ST Micro STA-680, NXP SAF3560, and Texas Instruments Jacinto). The tested receivers are typical of current models, both OEM and aftermarket.

A full description of the test platform and procedures are provided in Sections 4 and 5. A detailed presentation of the results is provided in Section 6.

Briefly, these tests established the bit error rate (BER) performance of the receivers under test as a function of digital SNR for various digital sideband configurations, both symmetric and asymmetric.
Additive white gaussian noise (AWGN) was added to the received HD Radio signal and the noise level was decreased 1 dB at a time until there were either no more bit errors in the receiver or the bit error rate fell below 1 E-9.

Of particular interest was the digital SNR at which the HD Radio receiver BER was reduced to 5 E-5 since this is approximately the point at which the receiver would blend to analog for a main channel audio (MPS) signal or alternatively, where a multicast audio channel (SPS) signal would mute. The “ideal” digital SNR at this operating point, compared to the legacy configuration (equal power sidebands, total digital power of -20 dBc) was established for each configuration tested, and then this was compared to the average of the actual digital SNR measured for these tests.

3. Summary of Test Results

Detailed BER measurement results are presented in Section 6 below. The tables and graphs in this section highlight the digital SNR results for a bit error rate of 5 E-5 (approximate blend-to-analog point for MPS channels and loss of digital audio point for SPS channels). Tests were conducted separately for P1 and P3 partitions.

The results in the tables and graphs that follow are compared to performance of the legacy configuration (equal power sidebands, total digital power of -20 dBc). Note that for the -20 dBc total digital power case (with symmetric sidebands), each sideband is at a power level of -23 dBc. Similarly, for the -14 dBc total digital power case each sideband is at a power level of -17 dBc, and for -10 dBc total digital power, each sideband is at -13 dBc.

Table 1 shows the increase in total digital power for various sideband configurations compared to the legacy configuration of -20 dBc total digital power (with symmetric sidebands). Ideally, the improvement in digital SNR should track this increase in total digital power so that, for example, in the case where the LSB power is set to -23 dBc and the USB power is set to -17 dBc (first case shown in Table 1), and the total increased digital power is 3.96 dB, the expected improvement in digital SNR would also be 3.96 dB.

Table 1. Increase in total digital power for various configurations compared to legacy configuration (-20 dBc, symmetric sidebands)

Description	**LSB Power (dBc)**	**USB Power (dBc)**	**Asymmetry (dB)**	**Increased Total Digital Power Above Legacy (dB)**
LSB equivalent to -20 dBc, USB equivalent to -14 dBc	-23	-17	6	3.96
-14 dBc symmetric sideband case	-17	-17	0	6.00
LSB equivalent to -20 dBc, USB equivalent to -10 dBc	-23	-13	10	7.40
LSB equivalent to -14 dBc, USB equivalent to -10 dBc	-17	-13	4	8.45
-10 dBc symmetric sideband case	-13	-13	0	10.00

3.1. P1 Partition Data

3.1.1. No Interference

For the P1 partition with no interference, an increase in the power of one sideband over a -20 dBc symmetric reference, produces a corresponding improvement in receiver performance as shown in Table 2 and Figure 3-1. As the signal becomes more asymmetric, coding losses produce a slight shortfall over a theoretical symmetric reference.

Table 2. Performance comparison – various configurations to legacy configuration at point of blend - P1 partition data, no interference

Transmit Parameters				Receiver Performance	
LSB Power (dBc)	USB Power (dBc)	Asymmetry (dB)	Ideal Digital SNR Improvement (dB)	Average Digital SNR Improvement (dB)	Difference between Ideal and Average Digital SNR Improvement (dB)
-23	-17	6	3.96	2.98	-0.98
-17	-17	0	6.00	6.12	+0.12
-23	-13	10	7.40	5.73	-1.67
-17	-13	4	8.45	8.39	-0.06
-13	-13	0	10.00	10.06	+0.06

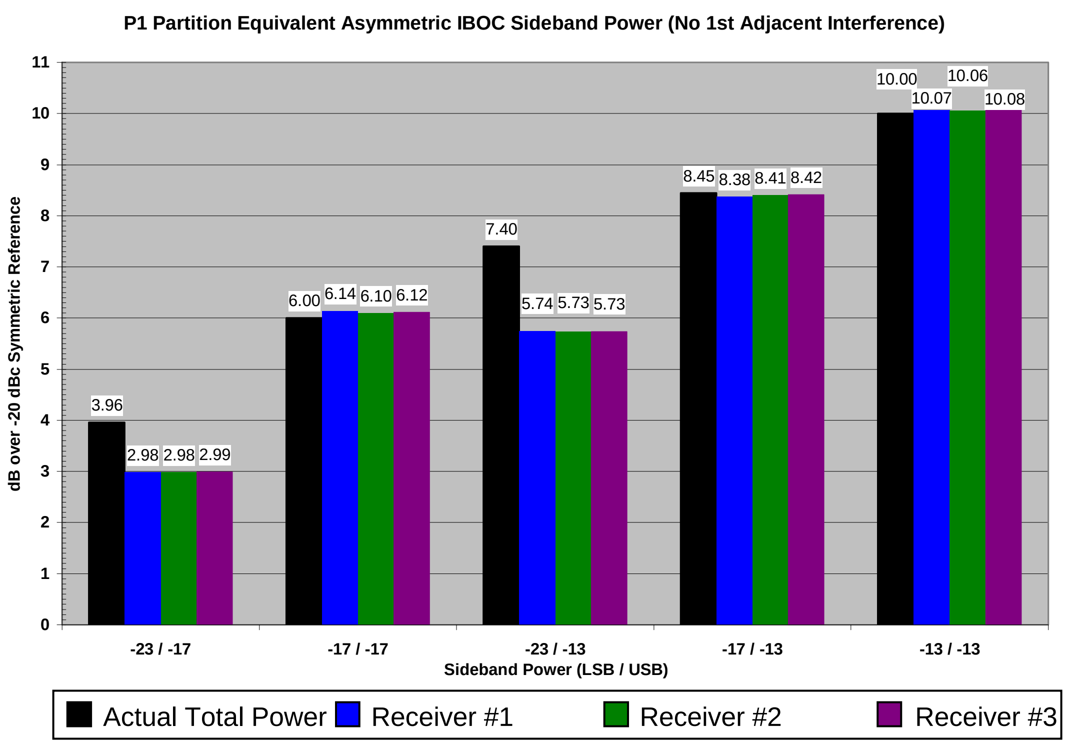

Figure 3-1: P1 Transmit Power vs. S/N Ratio Improvement (No 1st Adjacent Interference)

3.1.2. With 6 dB DU 1st Adjacent Interference

For the P1 partition with a single 6 dB D/U 1st adjacent interferer on the side of the lower power sideband, the test receiver's performance measurements are shown in Table 3 and Figure 3-2. Since only the upper, dominant sideband is being received, the receiver suffers a signal to noise shortfall of about 2 dB at the -20 dBc (-23 dBc/-23 dBc) reference level. As the unimpaired upper sideband's power is increased, it significantly exceeds the noise floor and improves robustness over the -20 dBc reference level. It is noteworthy that in this impaired environment, the measured signal to noise improvement with 10 dB of asymmetry actually exceeds the theoretical improvement at an identical symmetric power level. The redundant coding algorithm used in the P1 partition allows reception even when one of the complementary sidebands is significantly impaired by a first adjacent interferer. It should be noted that the lack of complementary frequency diversity in this case may result in a loss of robustness.

Table 3. Performance comparison – various configurations to legacy configuration at point of blend – P1 partition data, with single 6 dB D/U 1st adjacent channel interferer

Transmit Parameters				Receiver Performance	
LSB Power (dBc)	**USB Power (dBc)**	**Asymmetry (dB)**	**Ideal Digital SNR Improvement (dB)**	**Average Digital SNR Improvement (dB)**	**Difference between Ideal and Average Digital SNR Improvement (dB)**
-23	-17	6	3.96	3.97	+0.01
-17	-17	0	6.00	5.14	-0.86
-23	-13	10	7.40	7.86	+0.46
-17	-13	4	8.45	8.39	-0.06
-13	-13	0	10.00	9.40	-0.60

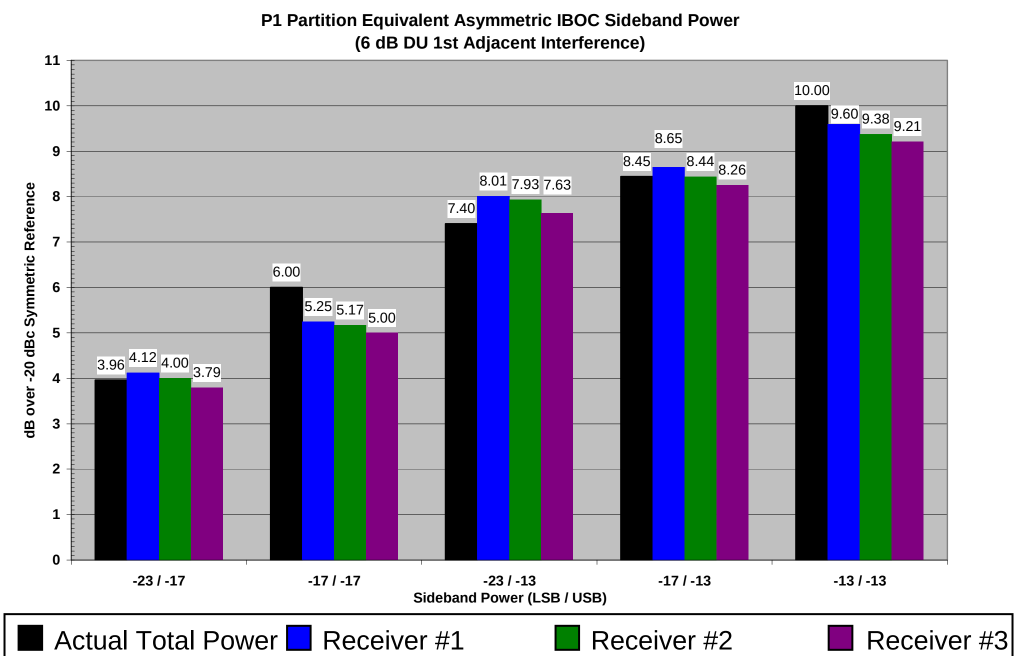

Figure 3-2: P1 Transmit Power vs. S/N Ratio Improvement (6 dB DU 1st Adjacent Interference)

3.2. P3 Partition Data

3.2.1. No Interference

For the P3 partition with no interference, an increase in the power of one sideband produces some improvement in receive performance as shown in Table 4 and Figure 3-3. Large asymmetries produce a large amount of receiver signal to noise shortfall when compared to the actual transmitted power increase, because of the less robust coding method used for the P3 carriers.

Table 4. Performance comparison – various configurations to legacy configuration at point of blend - P3 partition data, no interference

Transmit Parameters				Receiver Performance	
LSB Power (dBc)	**USB Power (dBc)**	**Asymmetry (dB)**	**Ideal Digital SNR Improvement (dB)**	**Average Digital SNR Improvement (dB)**	**Difference between Ideal and Average Digital SNR Improvement (dB)**
-23	-17	6	3.96	2.54	-1.42
-17	-17	0	6.00	6.04	+0.04
-23	-13	10	7.40	3.90	-3.50
-17	-13	4	8.45	7.91	-0.54
-13	-13	0	10.00	9.91	-0.09

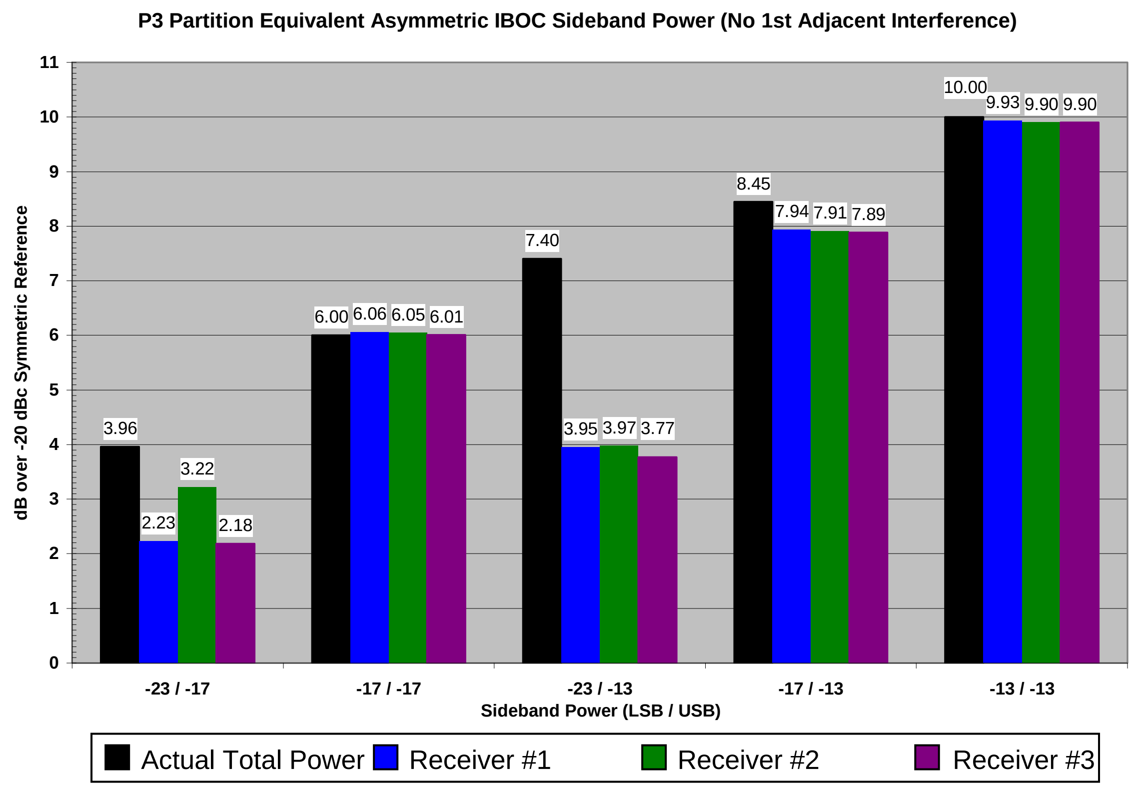

Figure 3-3: P3 Transmit Power vs. S/N Ratio Improvement (No 1st Adjacent Interference)

3.2.2. With 6 dB DU 1st Adjacent Interference

For the P3 partition with a single 6 dB D/U 1st adjacent interferer on the side of the lower power sideband, the performance shown in Table 5 and Figure 3-4 was measured on the test receivers. As with the previous unimpaired example in section 3.2.1, with the coding employed, extreme asymmetry causes performance shortfall over a symmetric reference at the same total power. It should be noted that the lack of complementary frequency diversity in this case may result in a loss of robustness.

Table 5. Performance comparison – various configurations to legacy configuration at point of blend – P3 partition data, with single 6 dB D/U 1st adjacent channel interferer

Transmit Parameters				Receiver Performance	
LSB Power (dBc)	**USB Power (dBc)**	**Asymmetry (dB)**	**Ideal Digital SNR Improvement (dB)**	**Average Digital SNR Improvement (dB)**	**Difference between Ideal and Average Digital SNR Improvement (dB)**
-23	-17	6	3.96	2.16	-1.80
-17	-17	0	6.00	4.60	-1.40
-23	-13	10	7.40	4.43	-2.97
-17	-13	4	8.45	6.99	-1.46
-13	-13	0	10.00	8.94	-1.06

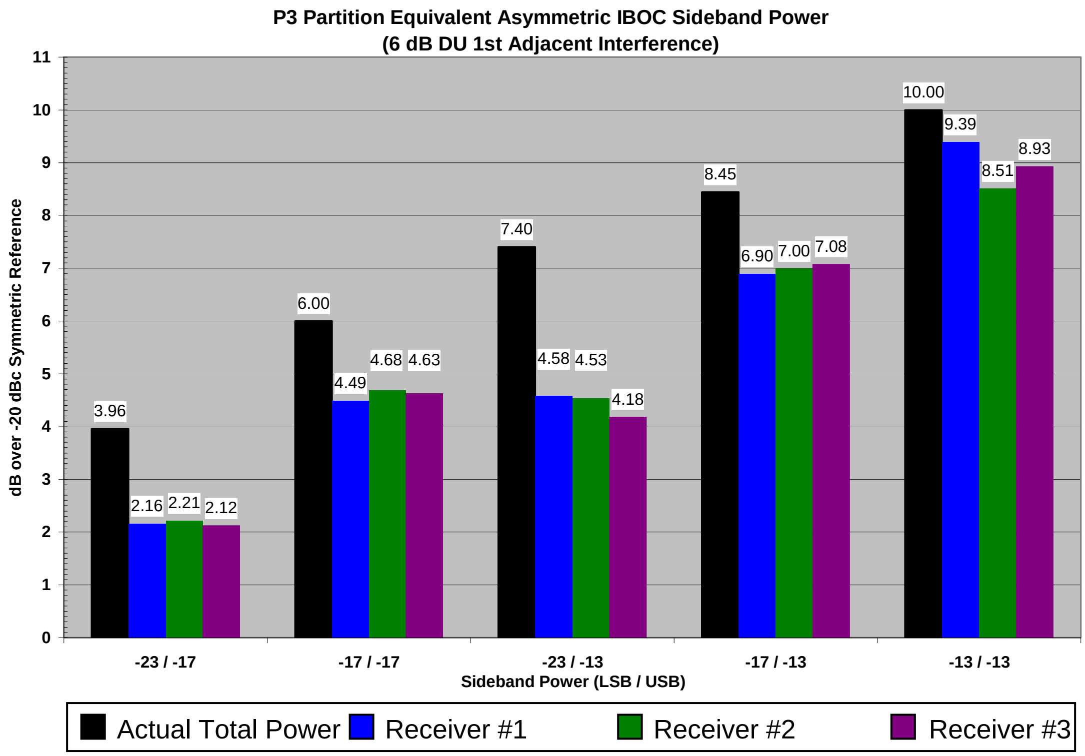

Figure 3-4: P3 Transmit Power vs. S/N Ratio Improvement (6 dB DU 1st Adjacent Interference)

4. Test Platform

The test platform shown in Figure 4-1 was developed to fully characterize the effects of noise and interference on the new asymmetric PAR v.2 waveform transmission.

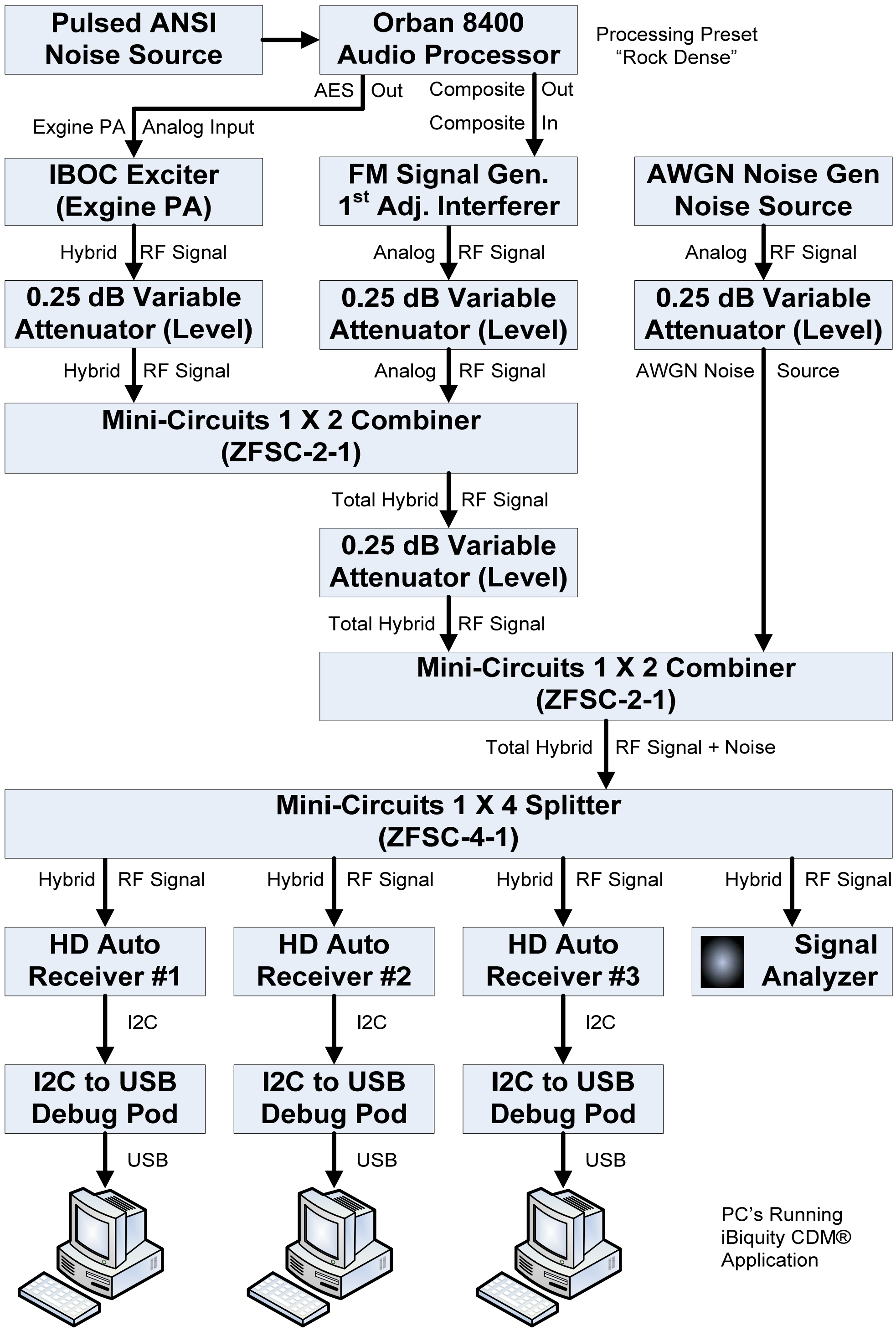

Figure 4-1: PAR V2 Asymmetric Sideband Test Platform (End to end)

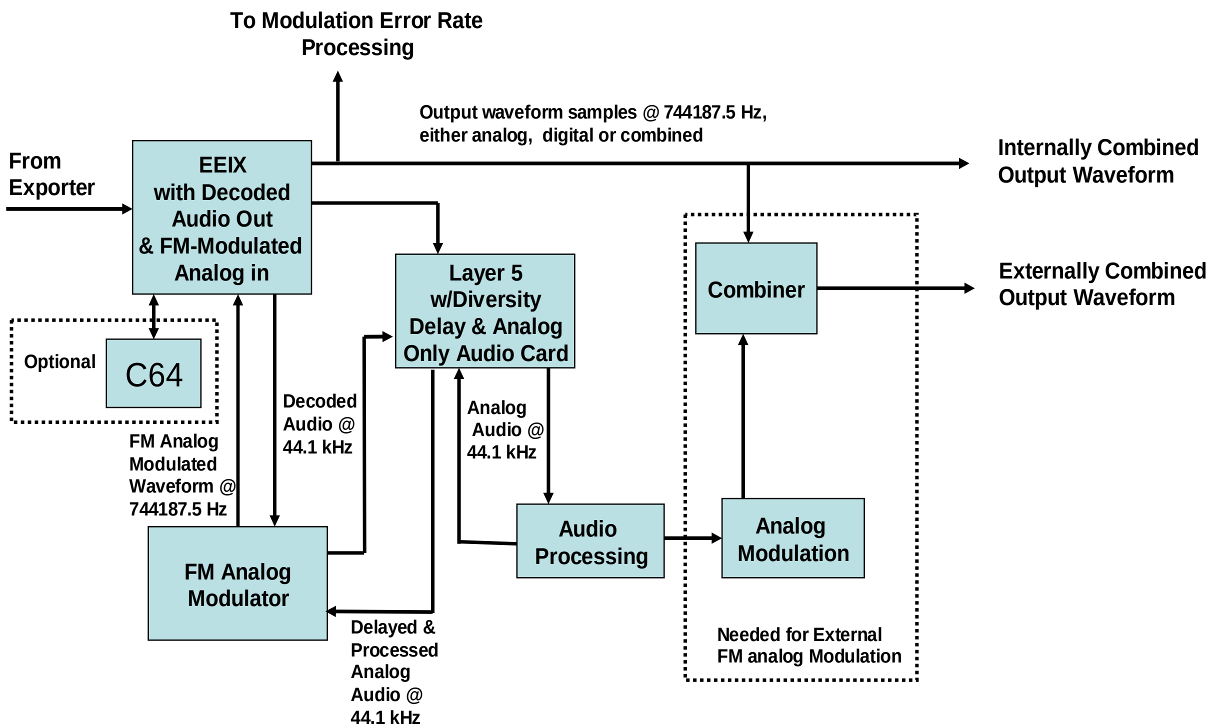

Figure 4-2: Exgine PA Transmission Platform

The test waveform was generated using “Exgine PA,” a feature present in iBiquity’s IRSS 4.4.X releases.

This platform (accessible only by password) allows system developers the ability to integrate the modulated analog waveform into the peak-to-average reduction algorithm. This implementation also nulls out any analog host interference to the IBOC carriers with predistortion. The Exgine PA platform inputs preemphasized AES audio and generates a composite stereo analog signal, complete with synchronized 19 kHz pilot and 38 kHz subcarriers. There is no ability as of yet to produce any subcarriers other than the 19 kHz pilot.

5. Test Procedure

An iBiquity Generation 2 Exgine PA running IRSS Version 4.2.2 was used to generate the test signal.

The GUI shown in Figure 5-1 allows for adjustment of asymmetric sideband power parameters, and was used in combination with the test platform attenuators shown in Figure 4-1 to produce the desired signals.

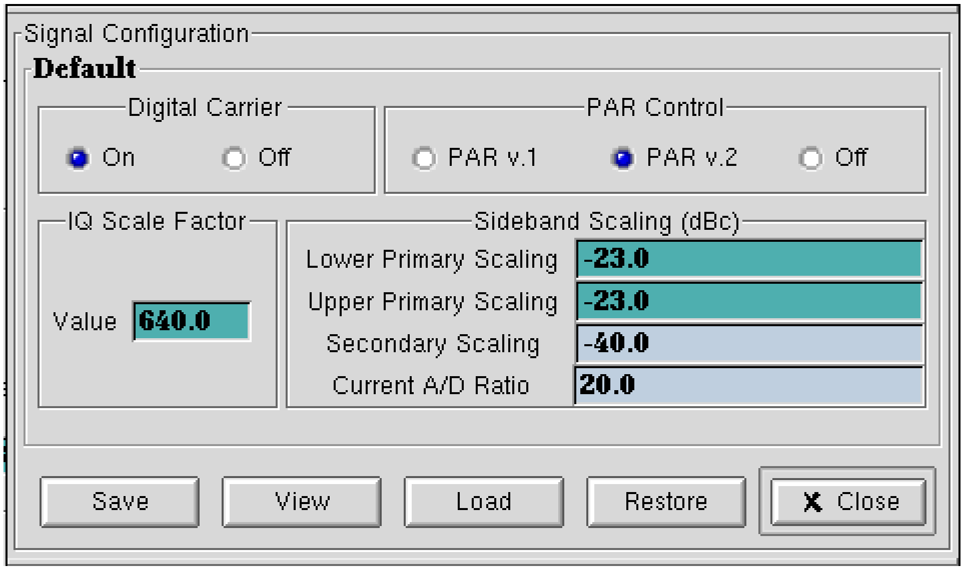

Figure 5-1: Asymmetric Sideband Signal Configuration GUI

The Exgine PA was operated in "BER Mode 3" which transmits a specific bit pattern that is compared to an identical table in the receivers to determine the error rate. The host analog stereo portion of the desired signal was modulated to 100% (total) with processed pulsed ANSI noise.

The Lower Primary Scaling and Upper Primary Scaling Parameters were adjusted to produce the desired digital-to-analog power ratio. Since the analog component is included in the "Exgine PA" platform, the power level of the IBOC carriers themselves is significantly lower than that of "Exgine" and "Exciter." As each new power level was selected, the total hybrid signal level was adjusted to achieve a constant total integrated power of -60 dBm at the receiver RF input.

Additive white Gaussian noise (AWGN) was then added to produce the desired Cd/N0 (digital carrier-to-noise power spectral density ratio) in dB. The Cd/N0 is the total integrated digital power of both sidebands (in dBm) divided by the power spectral density of the noise (in dBm/Hz). A reference Cd/N0 of 53 dB was established as the starting point and the various bit error rate parameters of each receiver were recorded. The noise power was decreased 1 dB at a time until there were either no more bit errors or the bit error rate fell below 1 E-9.

For the measurements with a 1st adjacent interferer, an analog FM signal generator was modulated to 100% (total) with processed pulsed ANSI noise. The appropriate attenuator was adjusted for a desired (hybrid IBOC waveform) to undesired (1st adjacent interferer) total integrated power ratio of 6 dB.

Figure 5-2 shows a typical symmetric IBOC waveform with noise added.

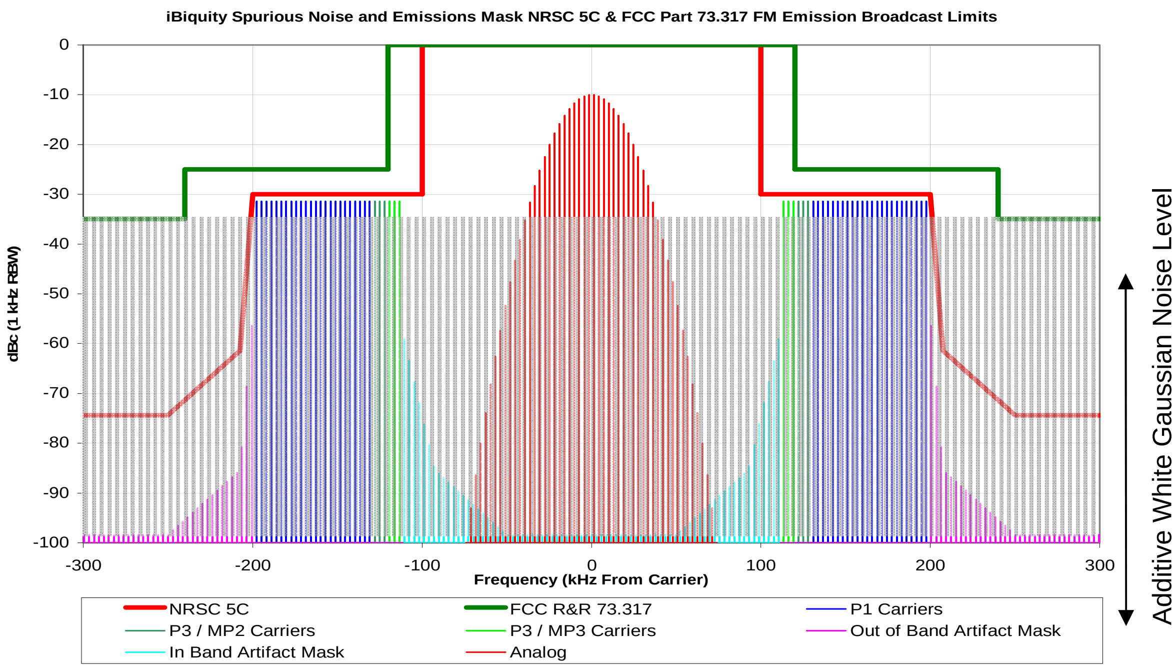

Figure 5-2: IBOC waveform with Additive White Gaussian Noise

6. Test Data

The data in Section 6 compare the performance of the three receivers at various sideband asymmetries, with and without an analog modulated first adjacent interferer whose total integrated power is 6 dB less than that of the desired signal (6 dB D/U).

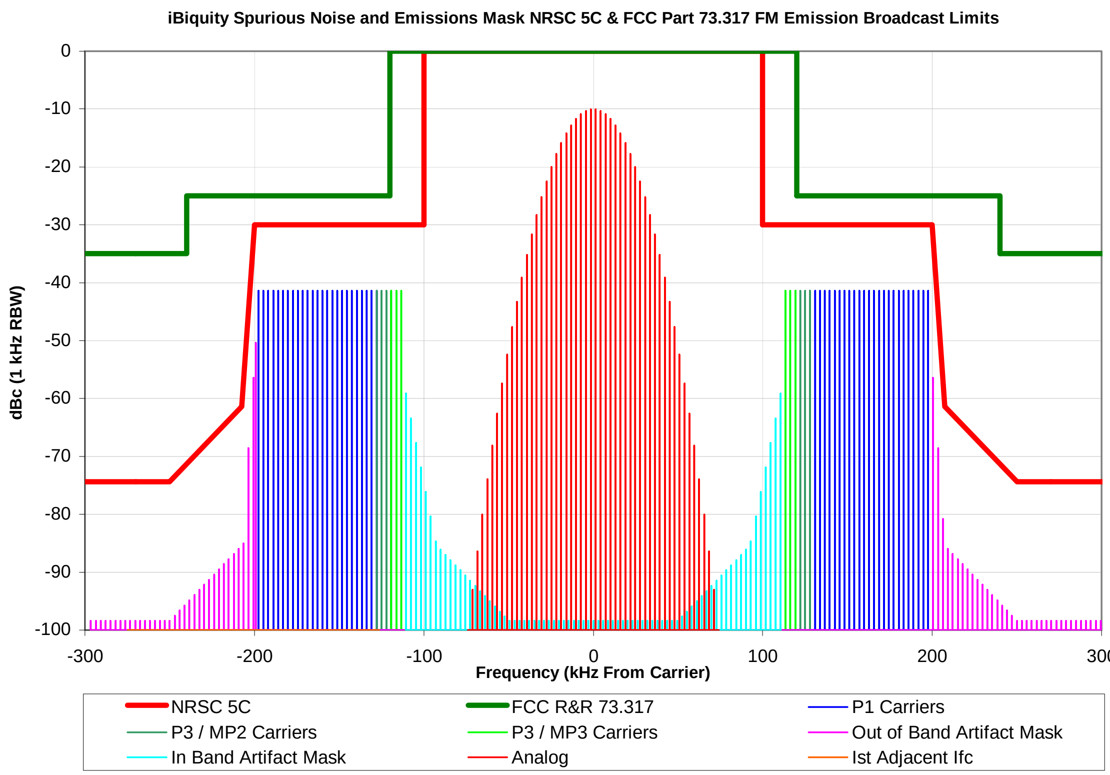

Figure 6-1: LSB @ -23 dBc & USB @ -23 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

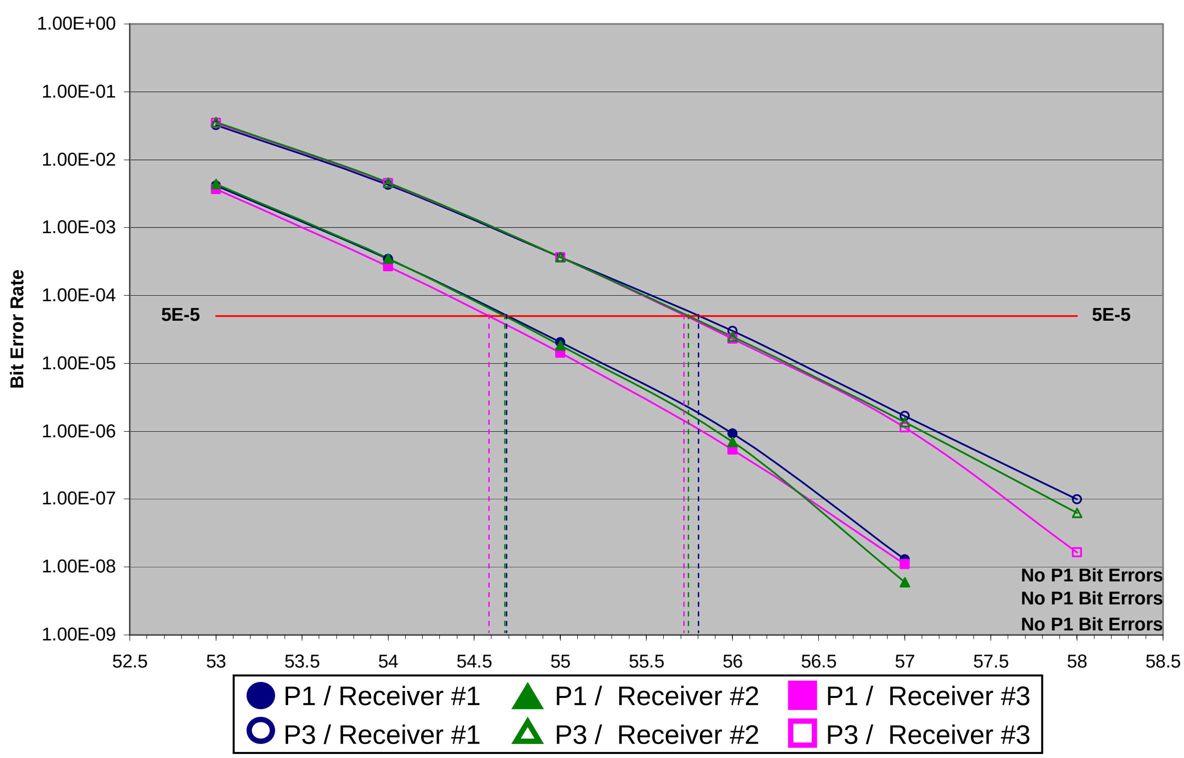

Figure 6-2: LSB @ -23 dBc & USB @ -23 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

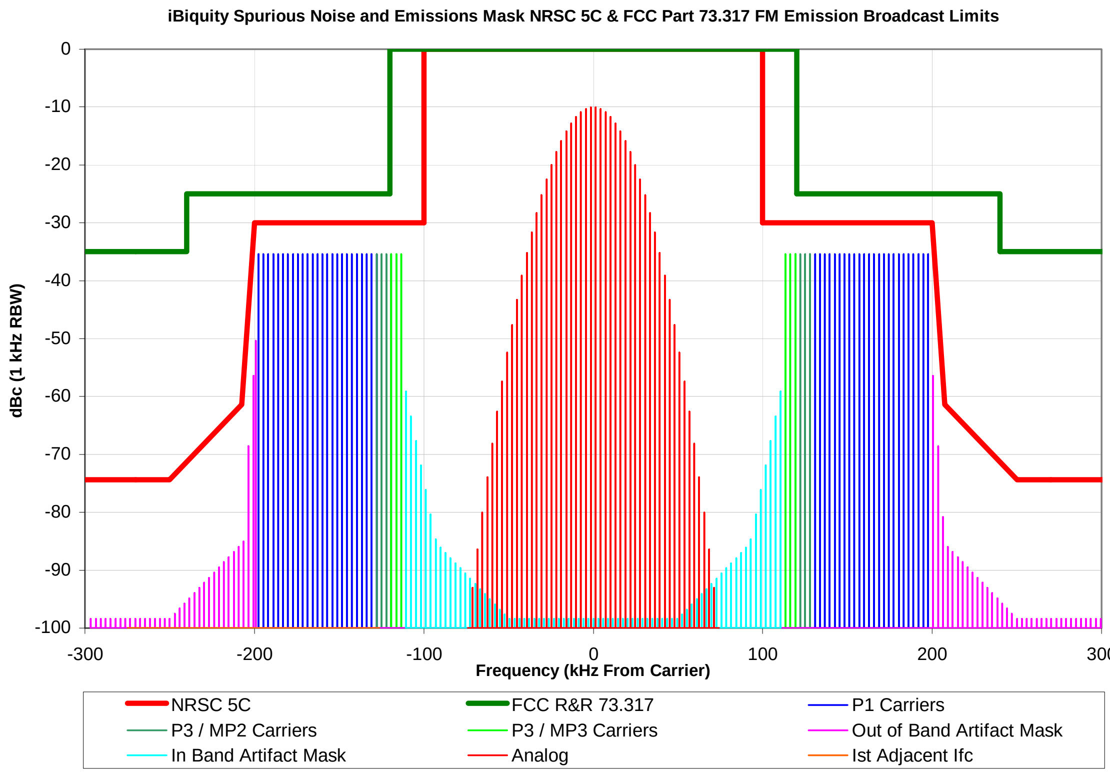

Figure 6-3: LSB @ -17 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

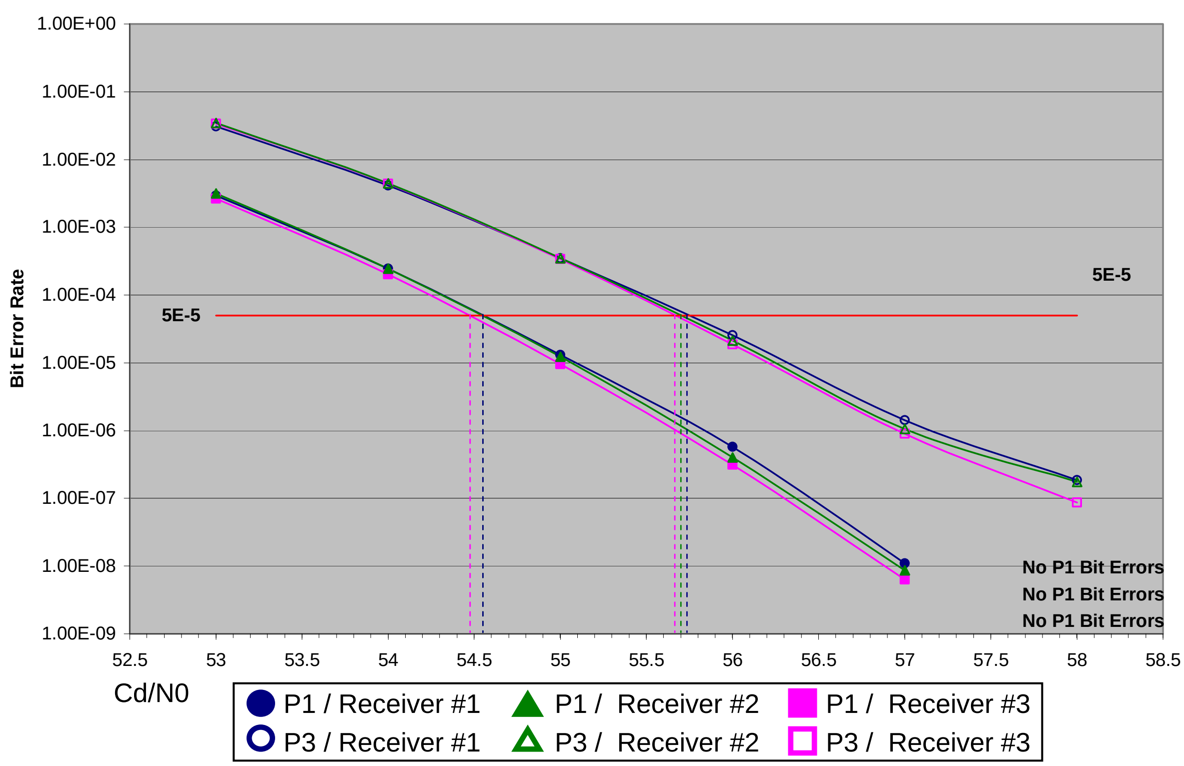

Figure 6-4: LSB @ -17 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

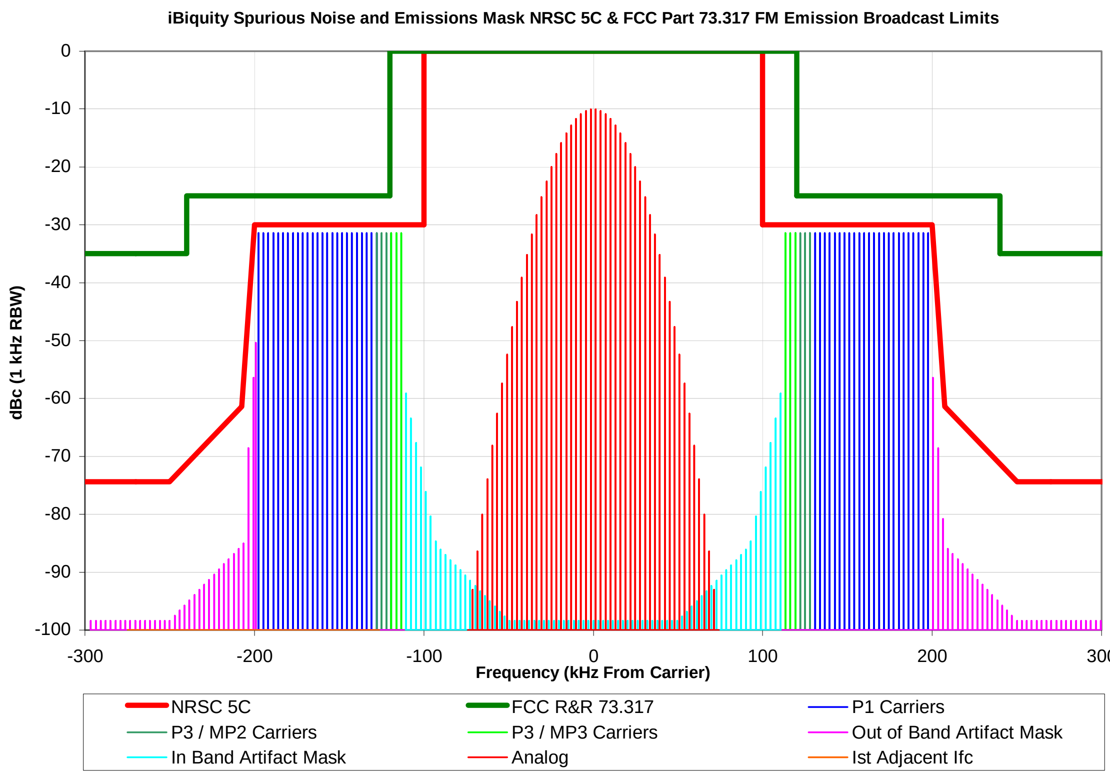

Figure 6-5: LSB @ -13 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

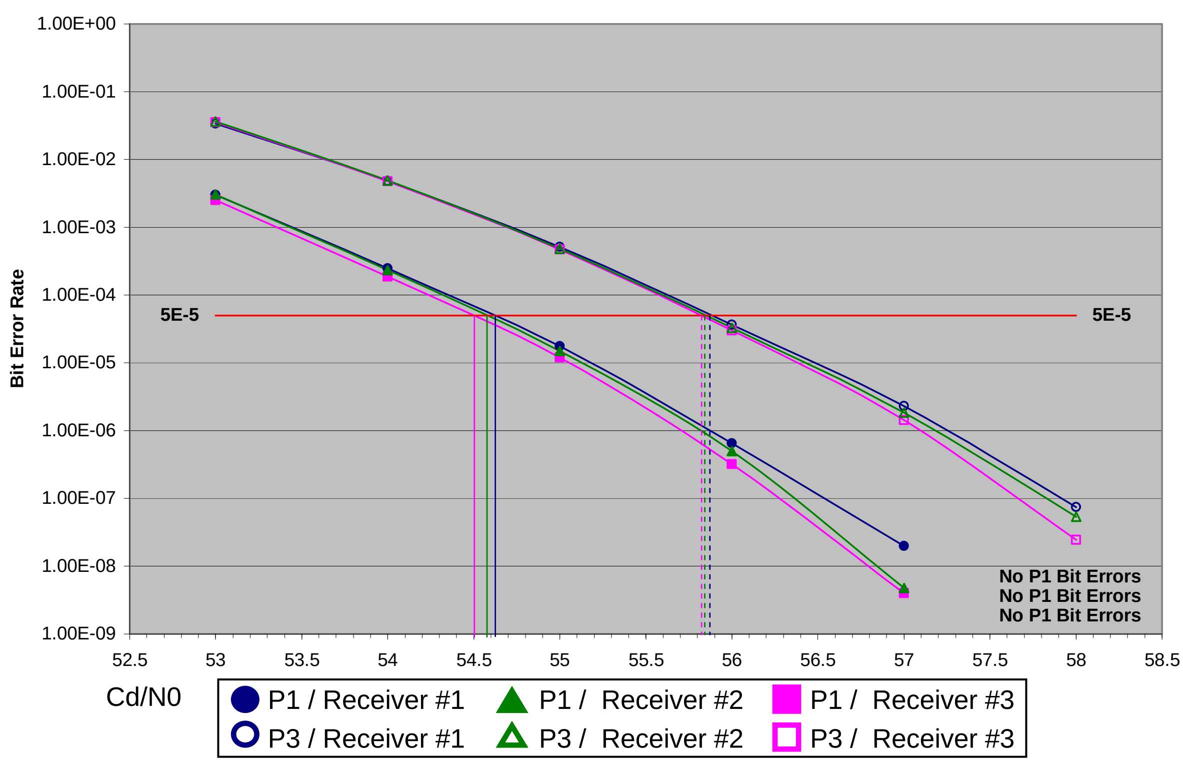

Figure 6-6: LSB @ -13 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

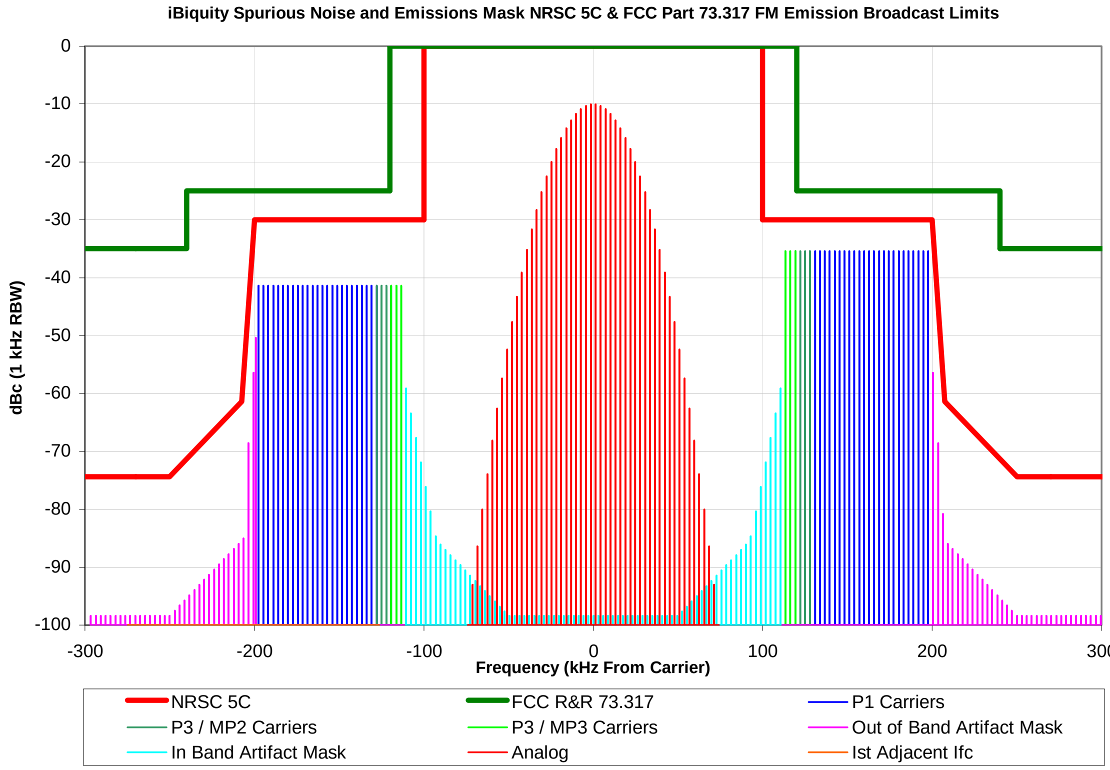

Figure 6-7: LSB @ -23 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

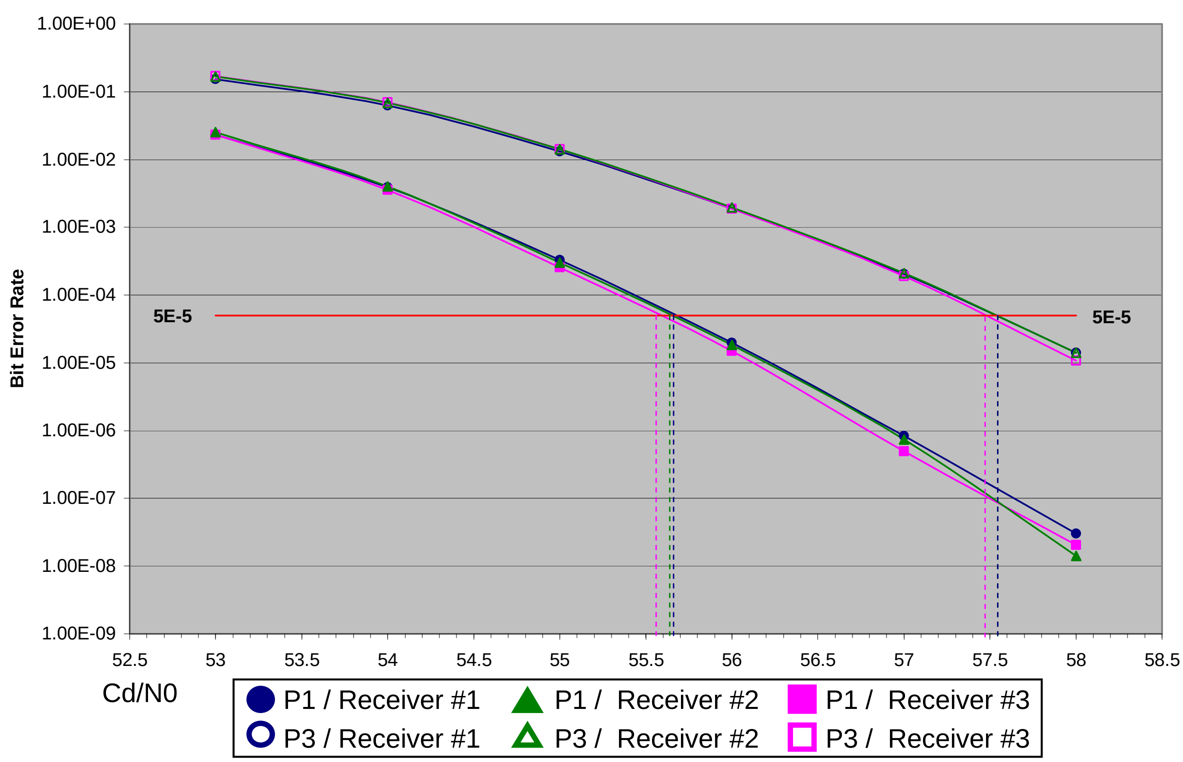

Figure 6-8: LSB @ -23 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

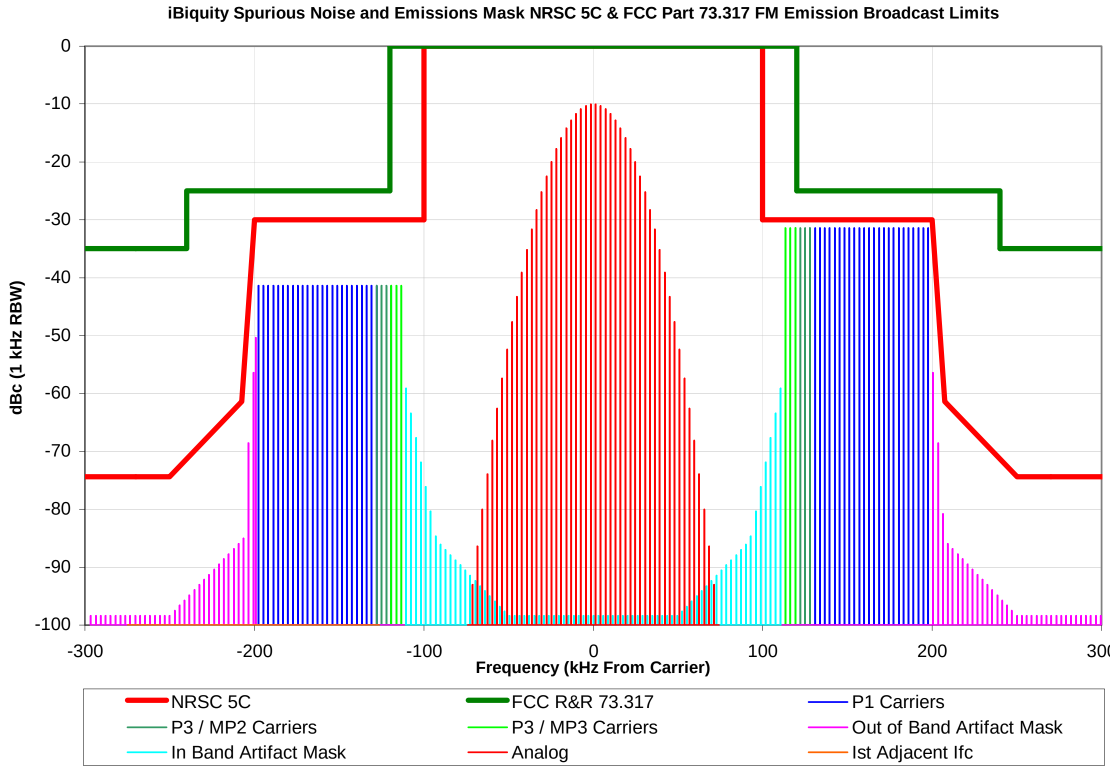

Figure 6-9: LSB @ -23 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

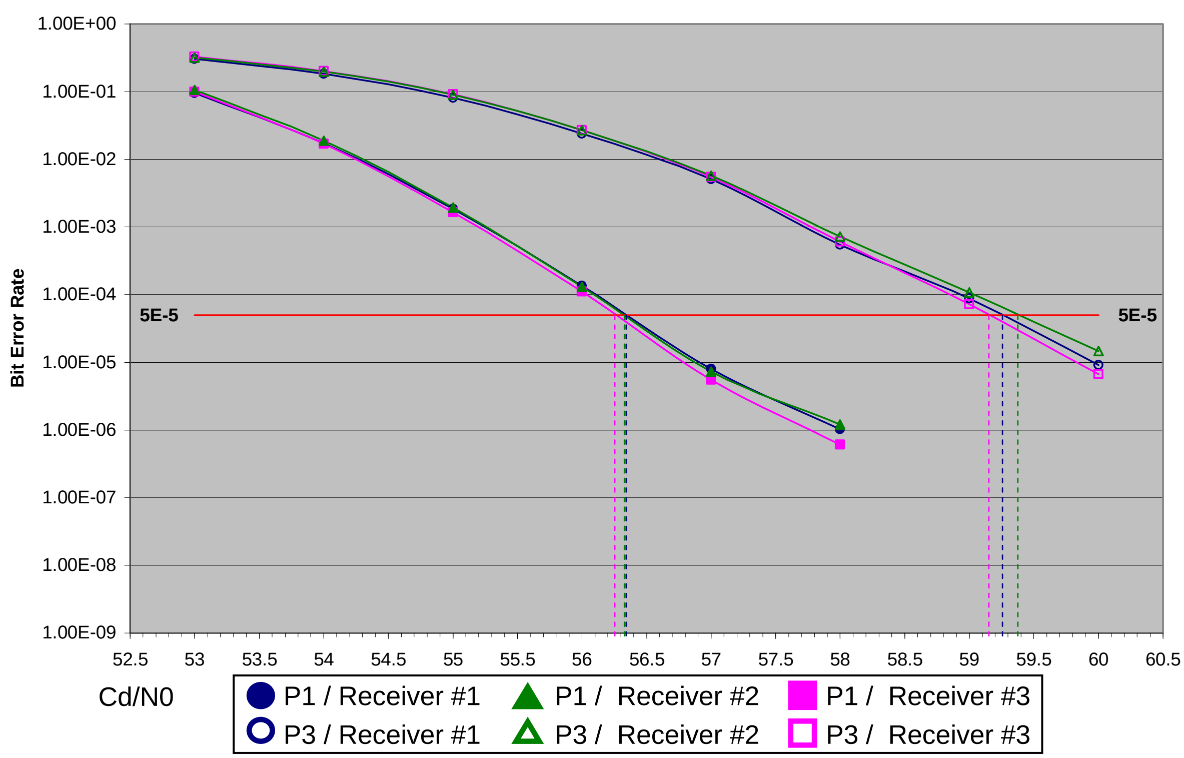

Figure 6-10: LSB @ -23 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

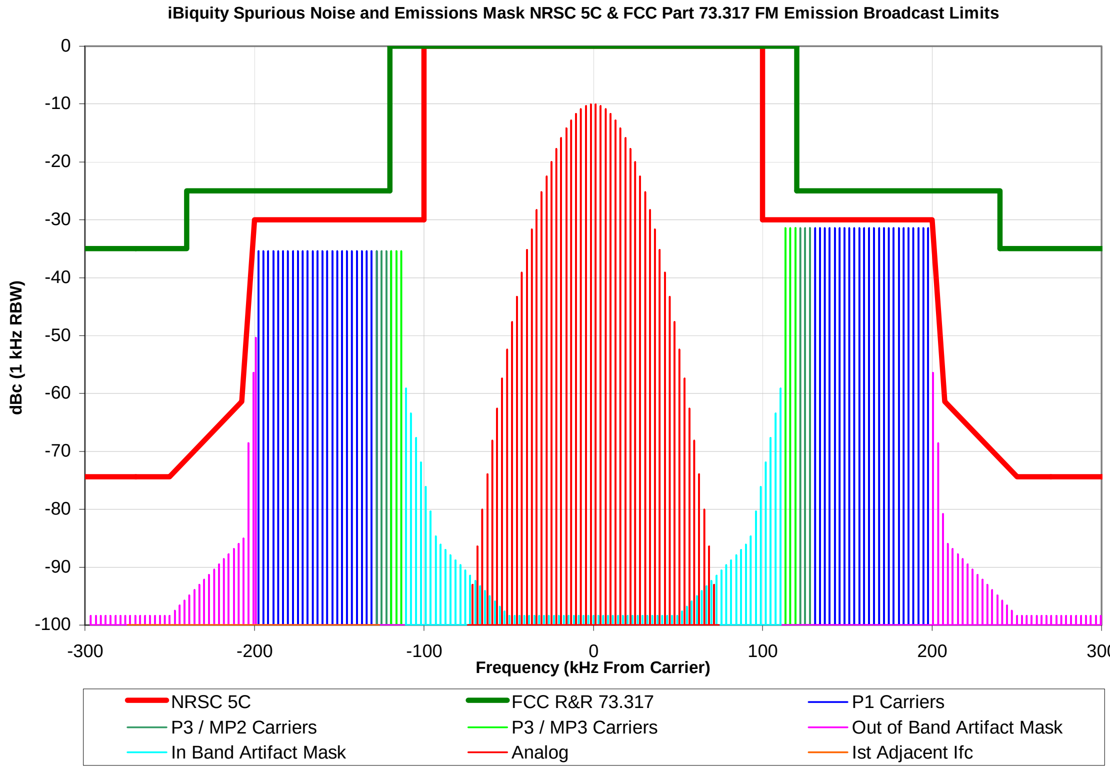

Figure 6-11: LSB @ -17 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

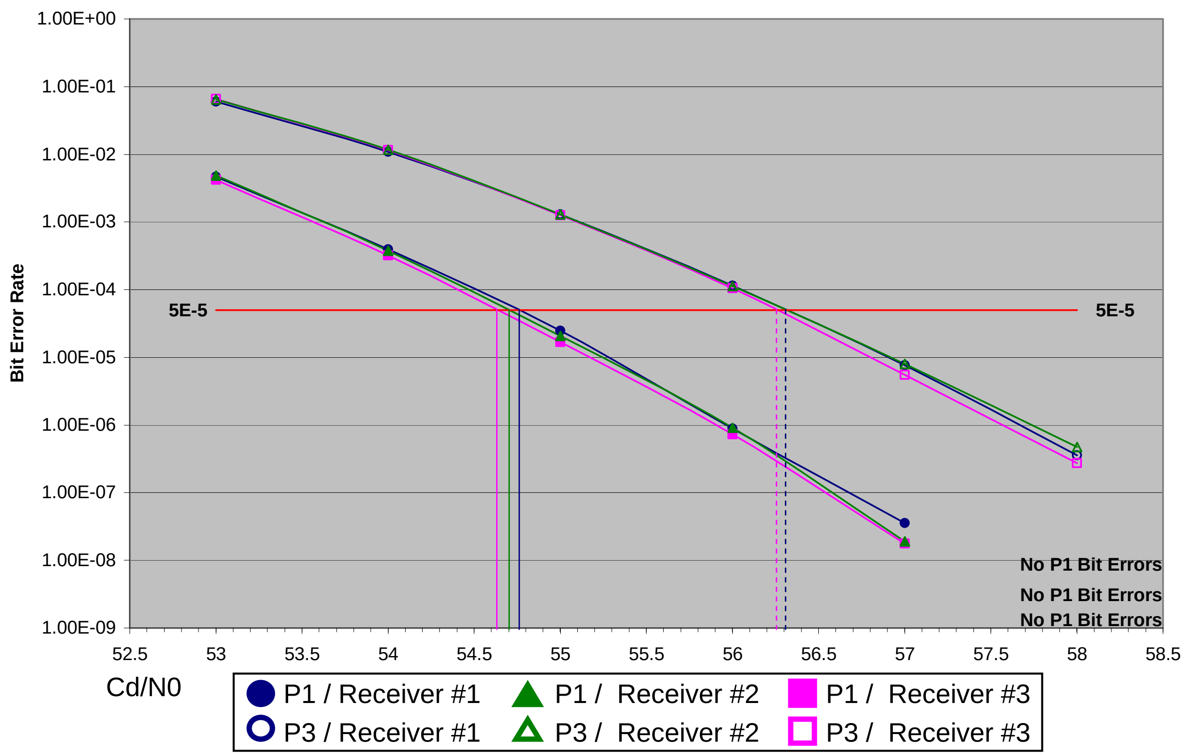

Figure 6-12: LSB @ -17 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / No Interference

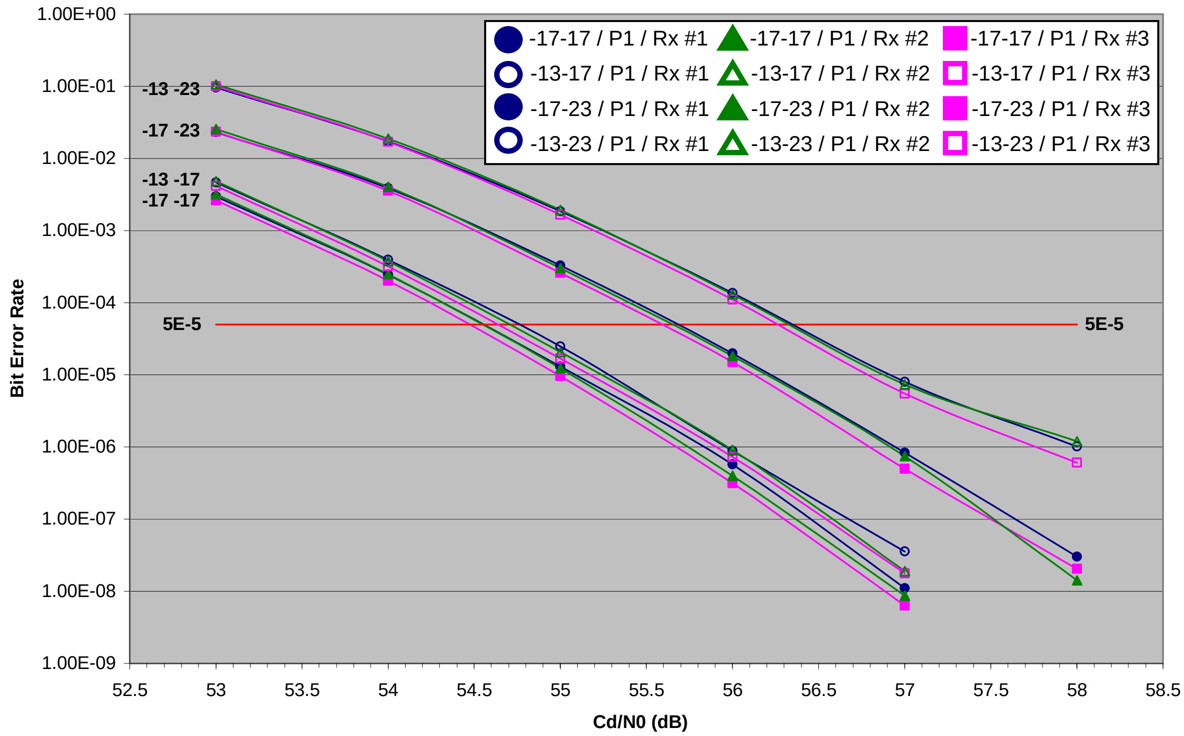

Figure 6-13: P1 BER's at Various Asymmetries / PAR v.2 Mask Offset at -24 dB / No Interference

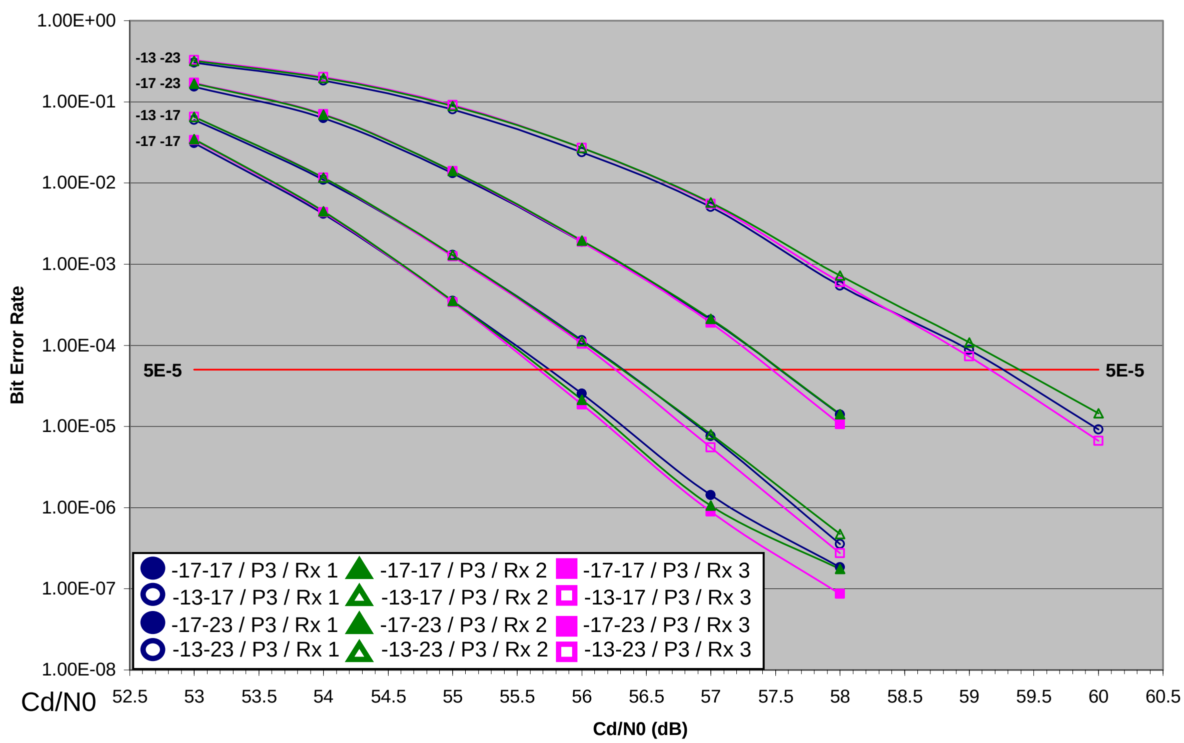

Figure 6-14: P3 BER's at Various Asymmetries / PAR v.2 Mask Offset at -24 dB / No Interference

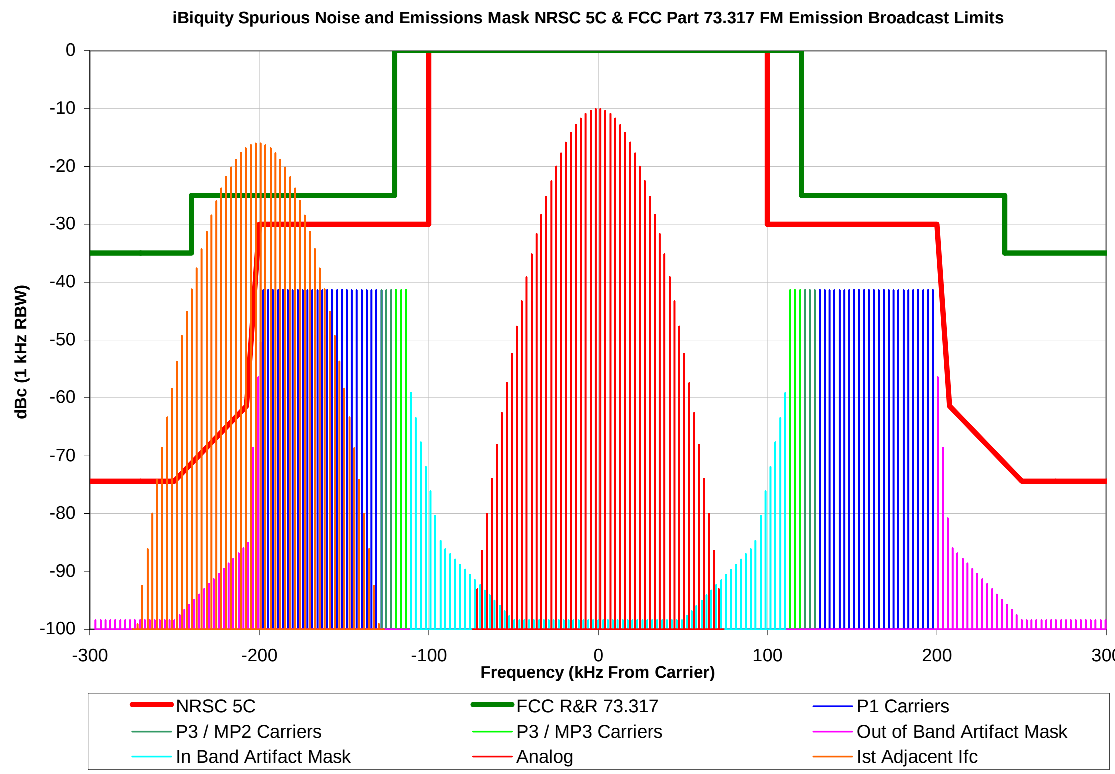

Figure 6-15: LSB @ -23 dBc & USB @ -23 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

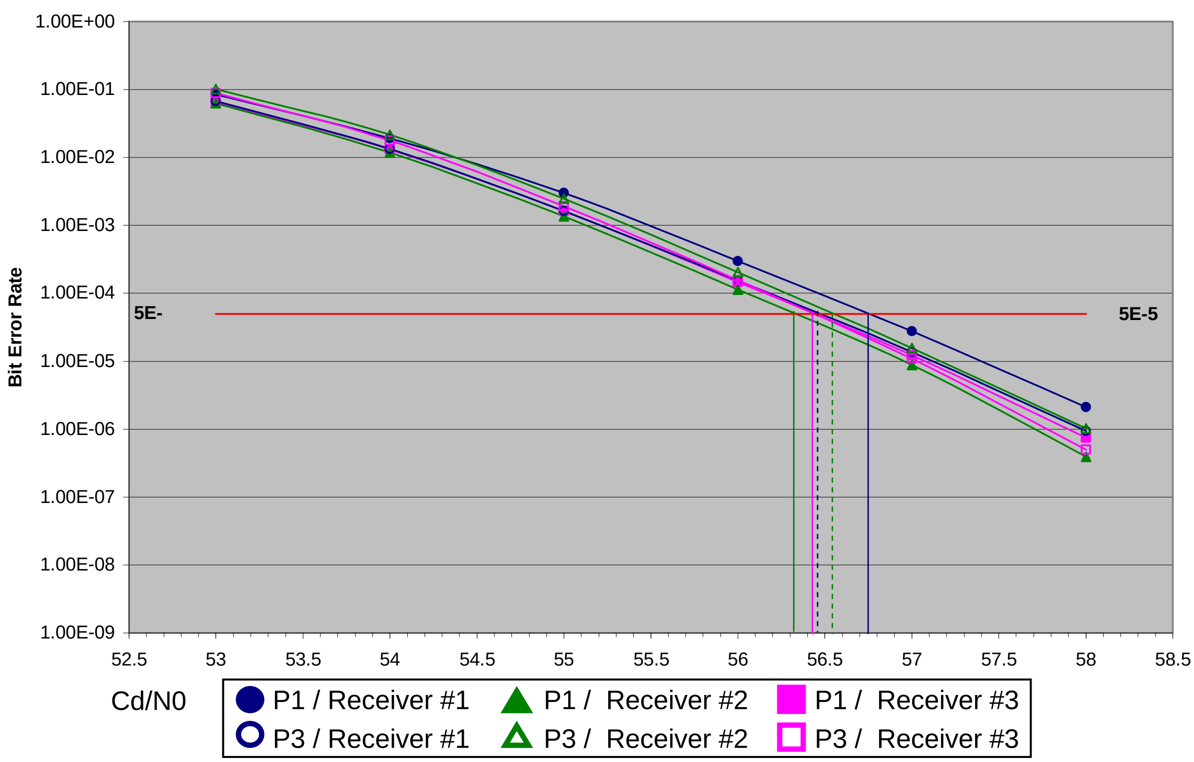

Figure 6-16: LSB @ -23 dBc & USB @ -23 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

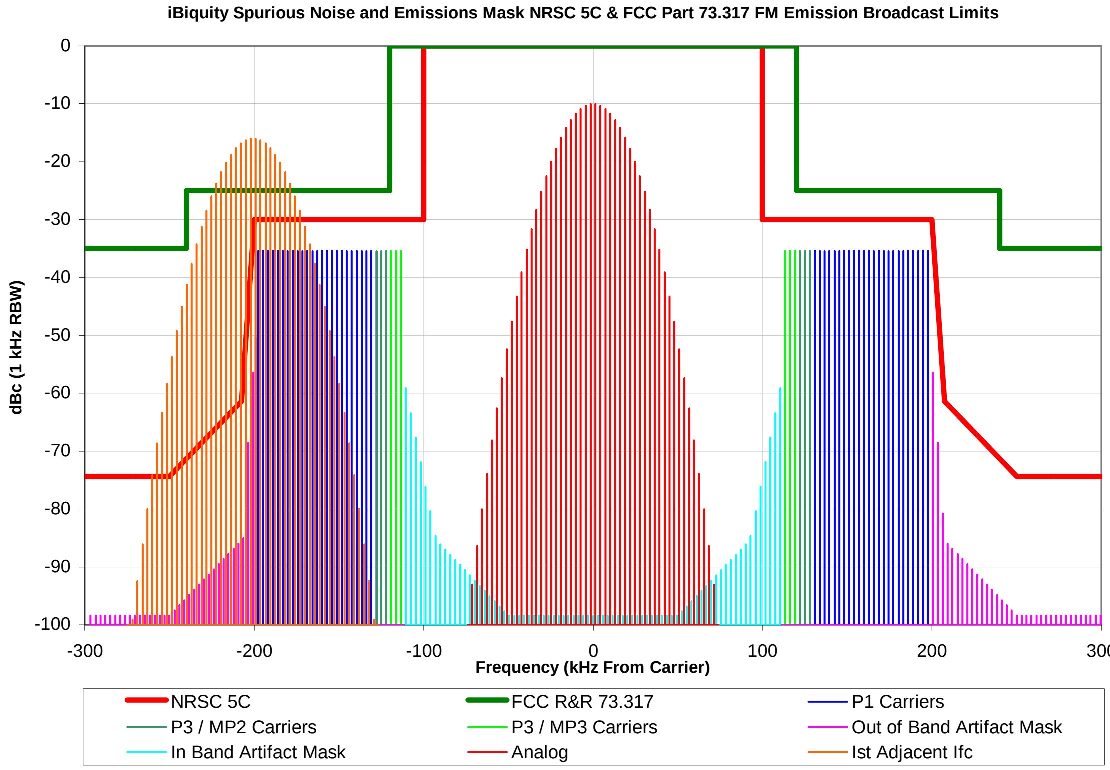

Figure 6-17: LSB @ -17 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

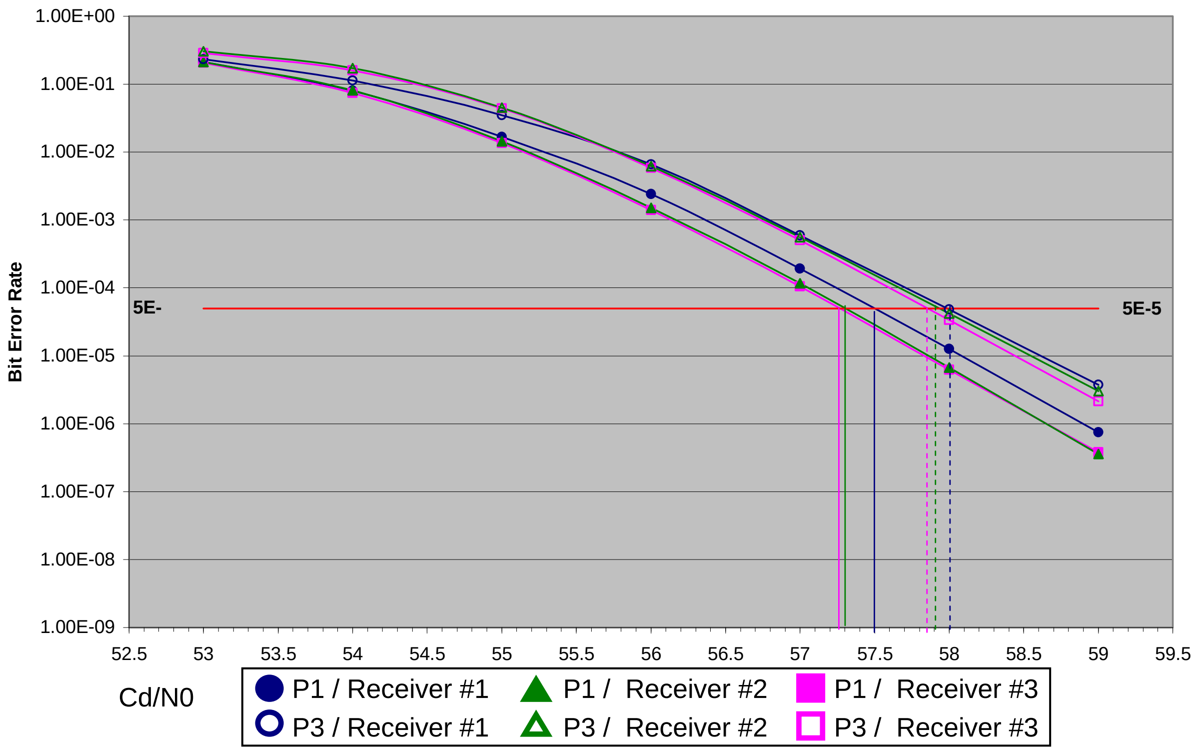

Figure 6-18: LSB @ -17 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

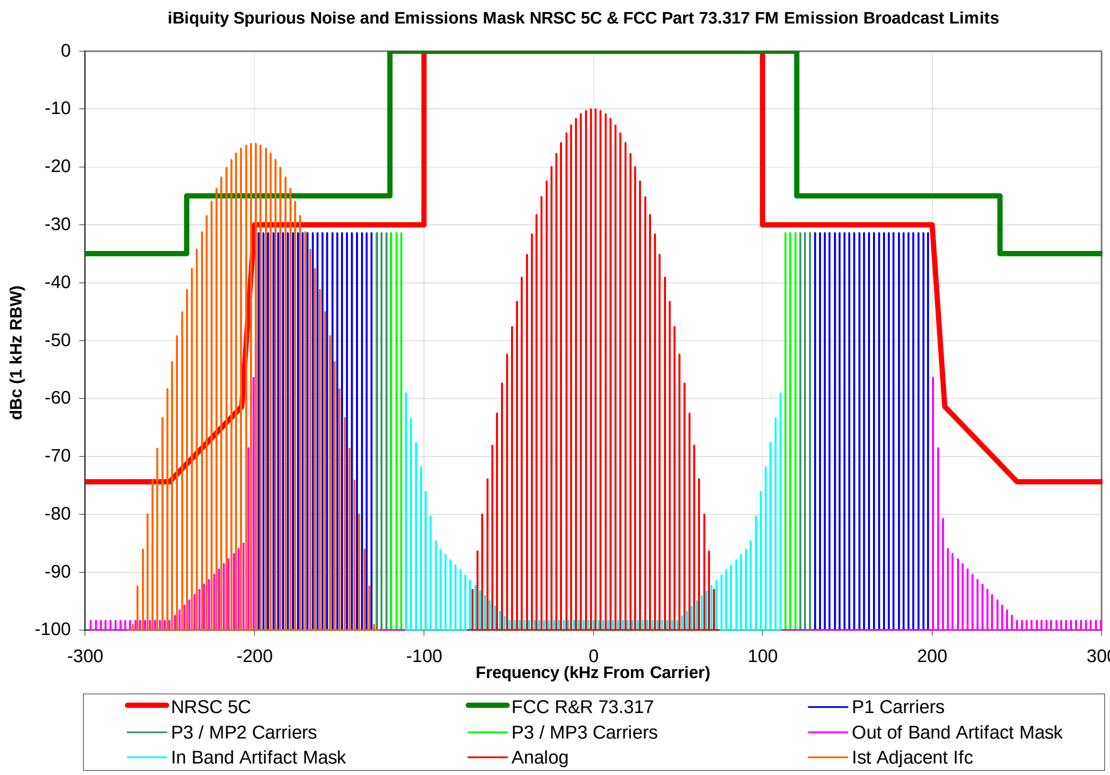

Figure 6-19: LSB @ -13 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

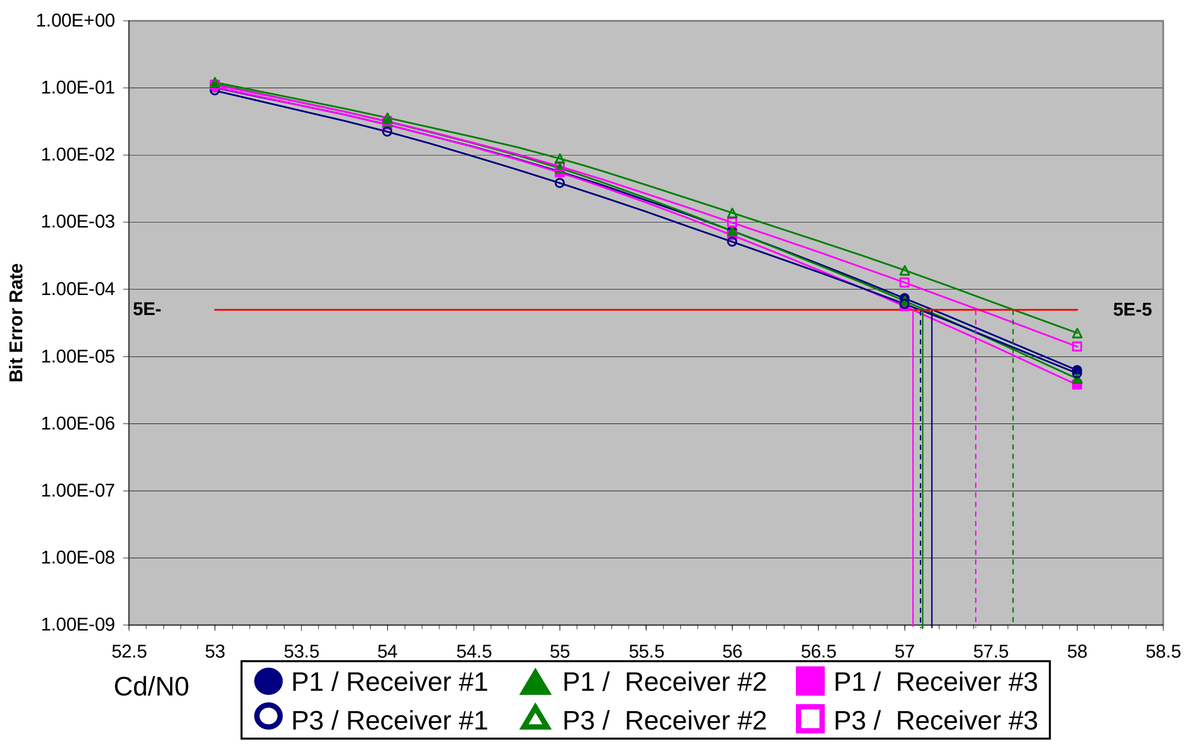

Figure 6-20: LSB @ -13 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

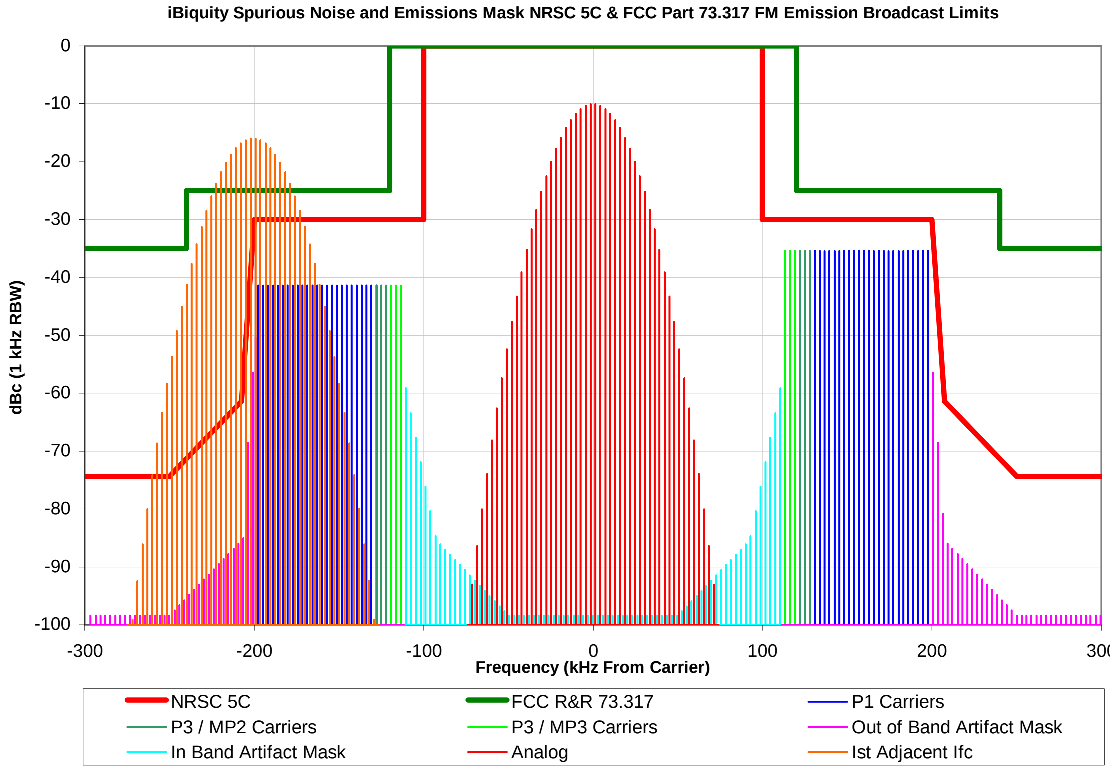

Figure 6-21: LSB @ -23 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

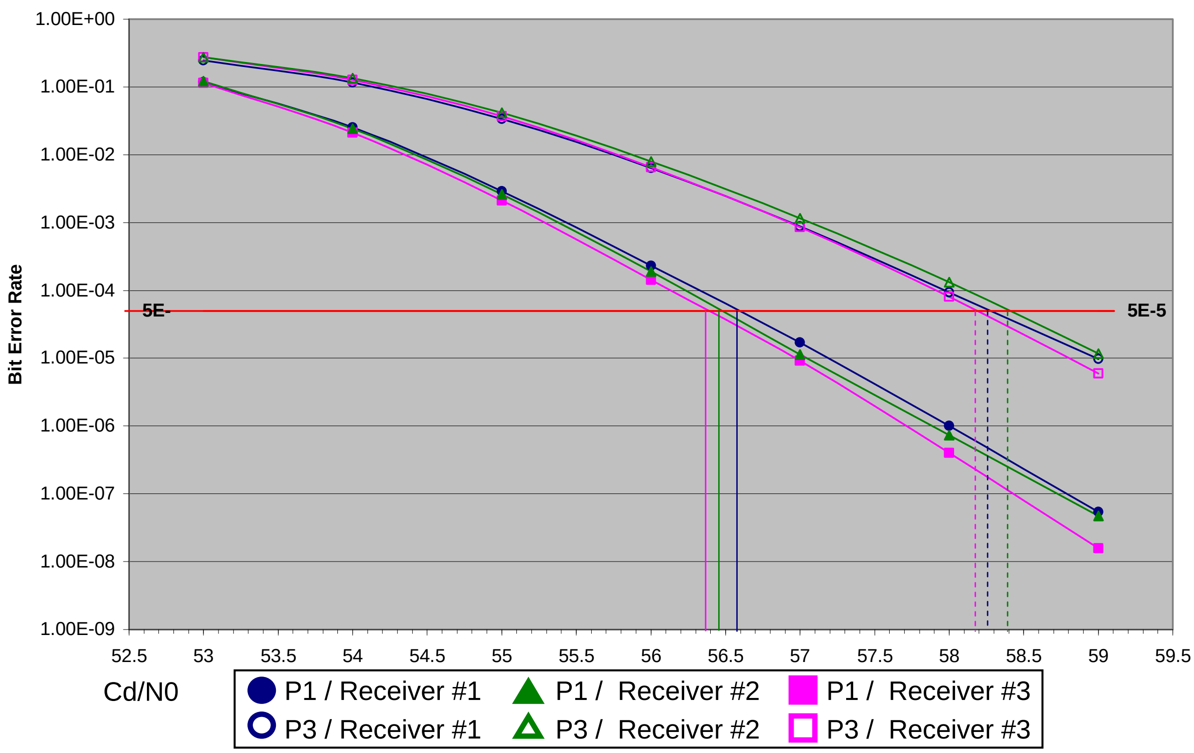

Figure 6-22: LSB @ -23 dBc & USB @ -17 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

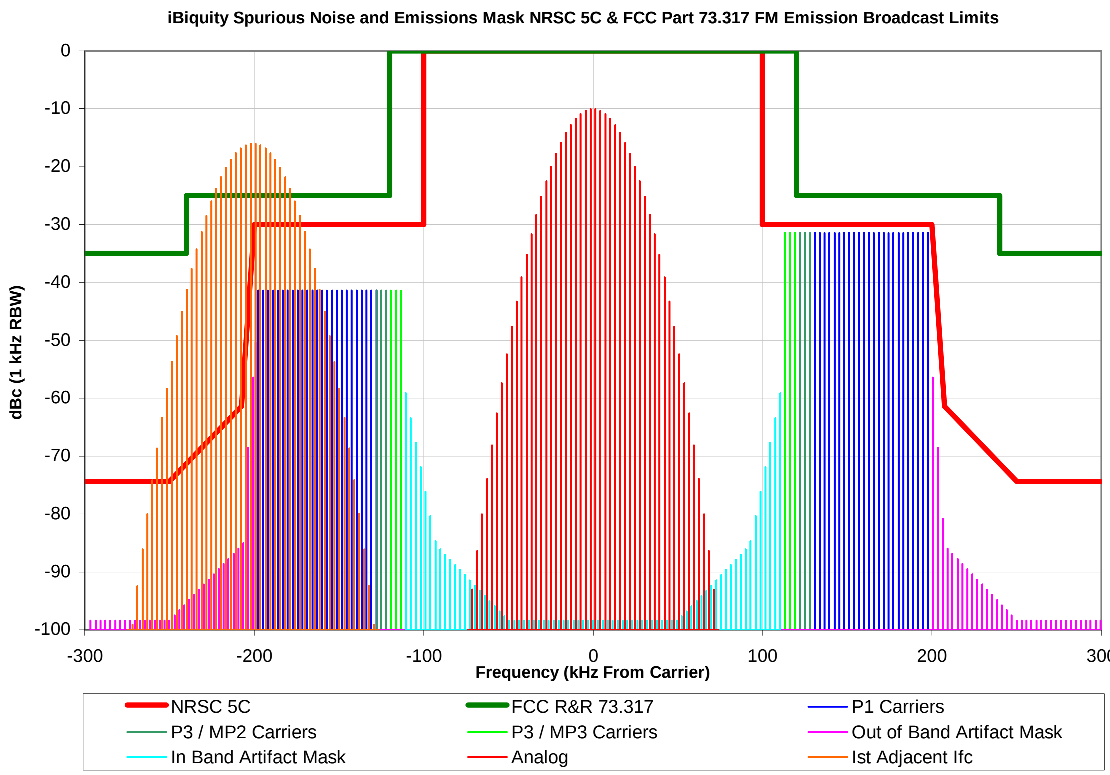

Figure 6-23: LSB @ -23 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

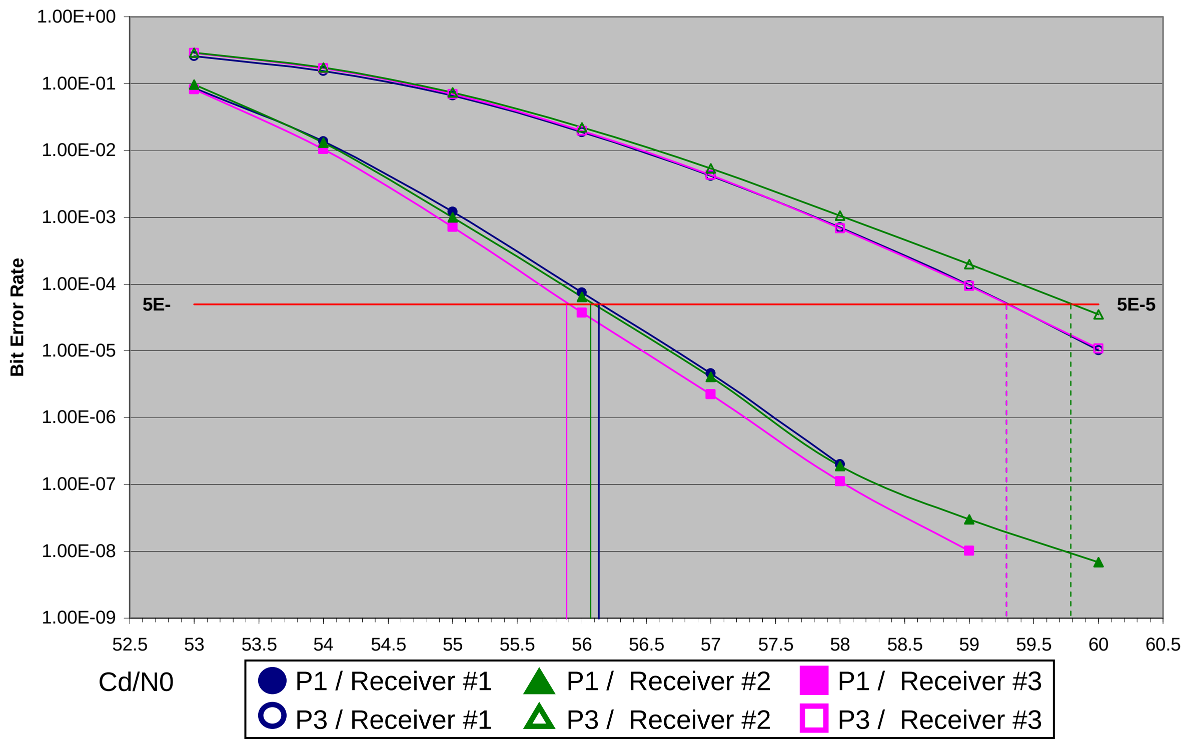

Figure 6-24: LSB @ -23 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

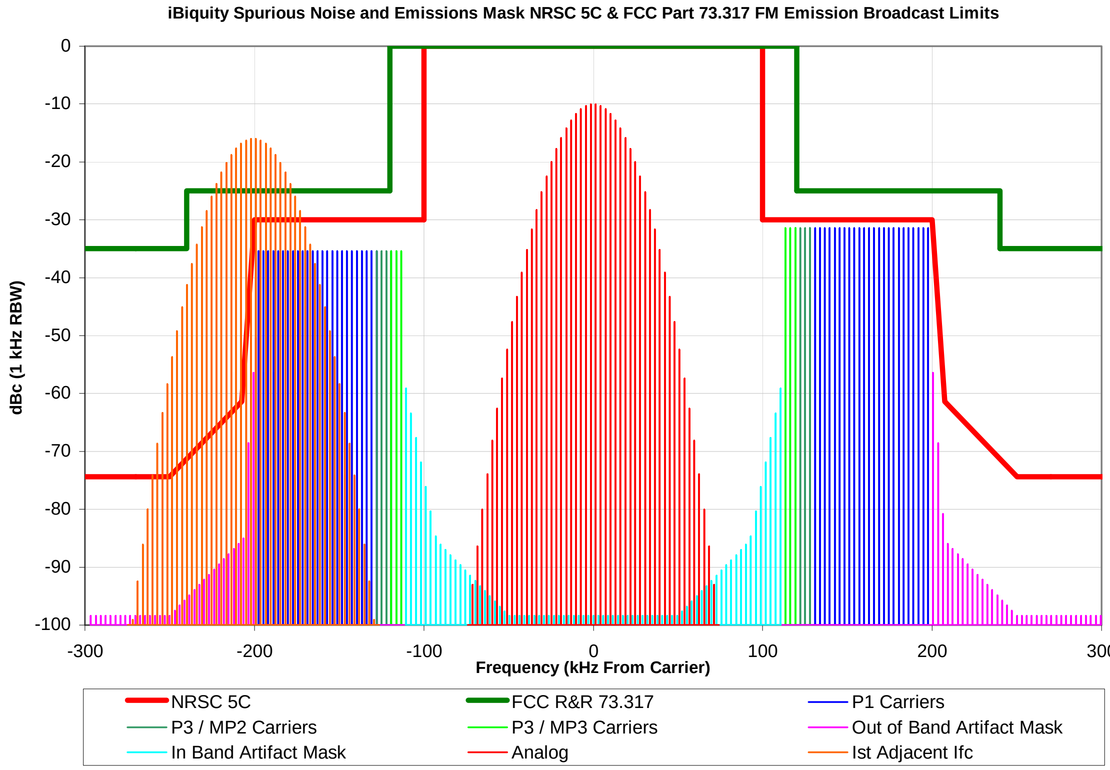

Figure 6-25: LSB @ -17 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

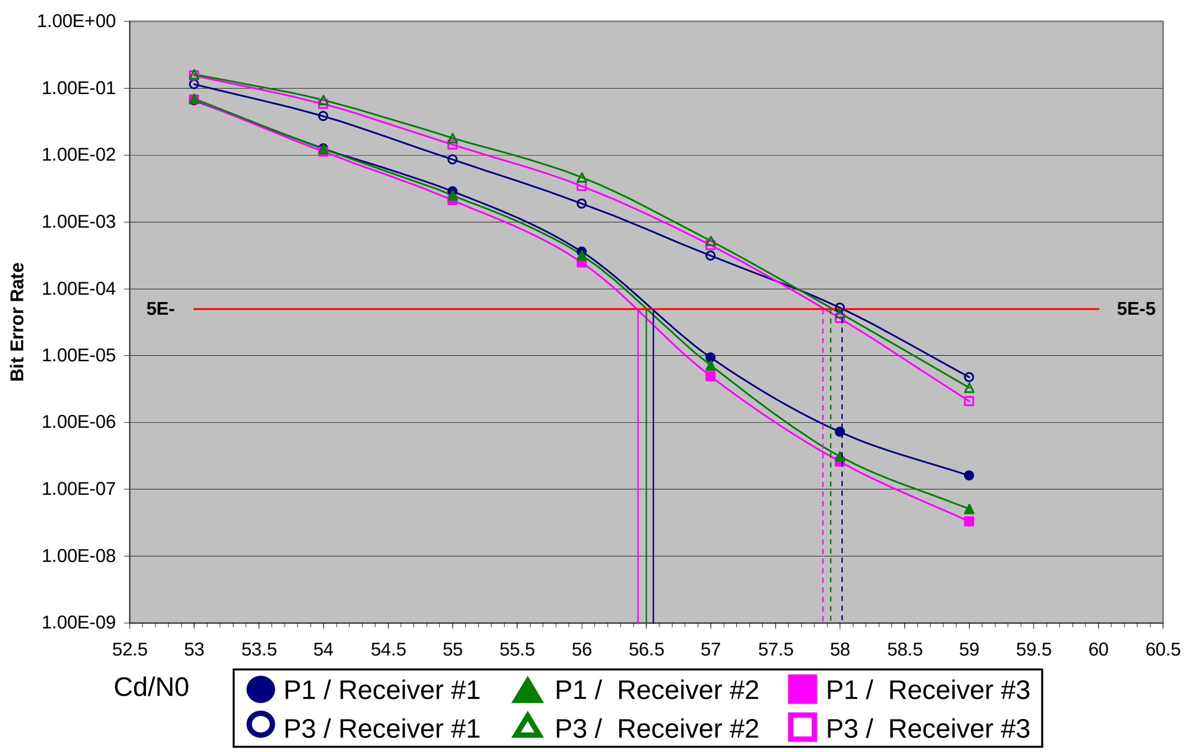

Figure 6-26: LSB @ -17 dBc & USB @ -13 dBc / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 dB DU

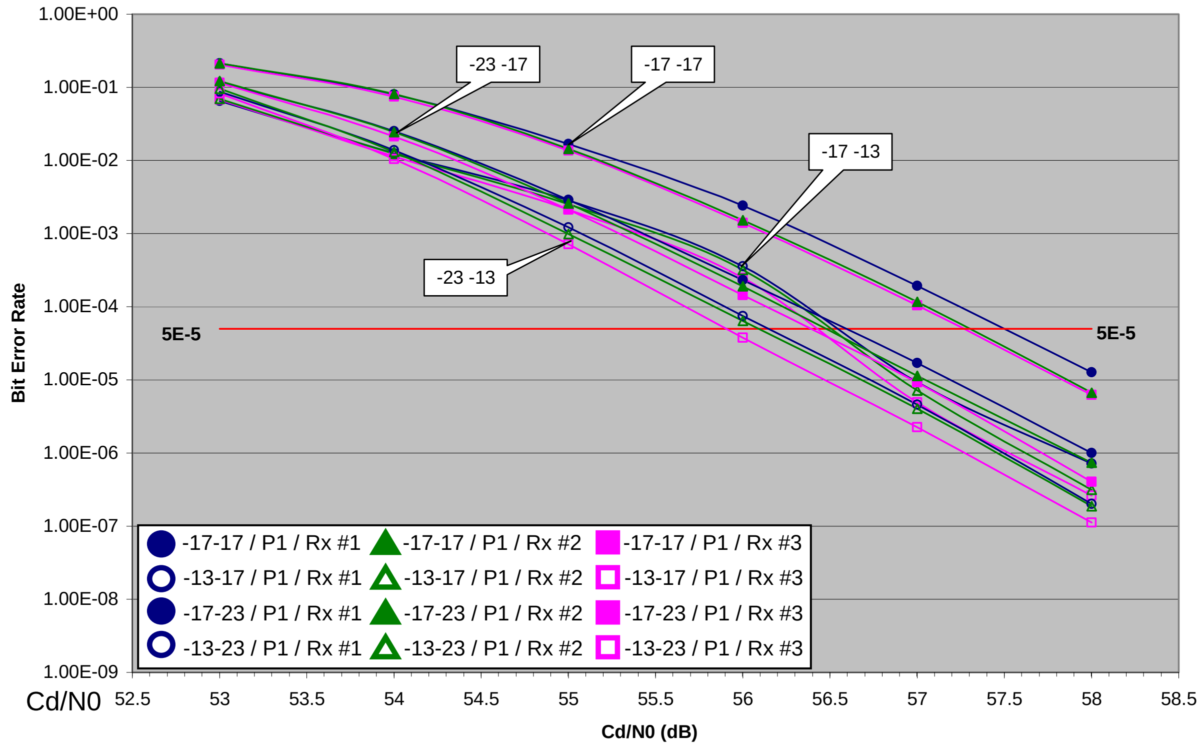

Figure 6-27: P1 BER's at Various Asymmetries / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 DU

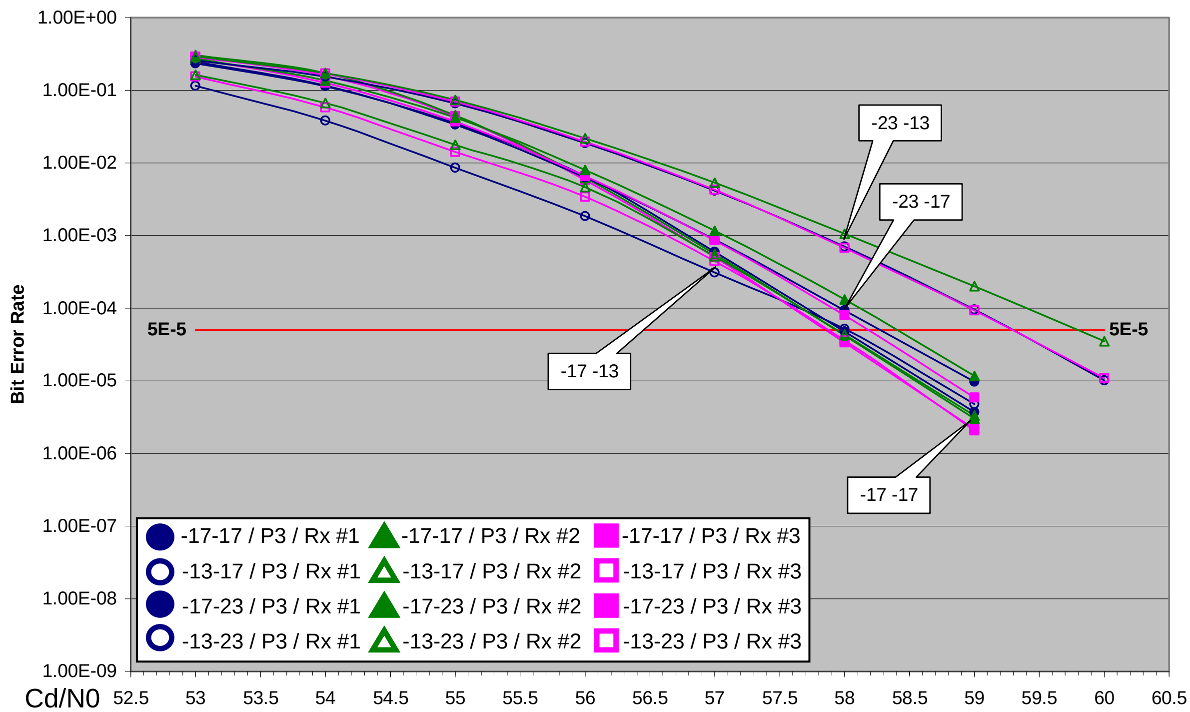

Figure 6-28: P3 BER's at Various Asymmetries / PAR v.2 Mask Offset at -24 dB / 1st Adj. @ 6 DU

7. Summary

Prior to April, 2010, the upper and lower digital sidebands of an HD Radio signal were transmitted at equal power, for a total integrated digital power that was limited by the FCC to 1 percent of the analog power (-20 dBc). After extensive testing by iBiquity (funded by NAB FASTROAD), National Public Radio and others, the FCC determined that all FM stations in the U.S. could increase their digital power four fold, (to -14 dBc), without significant interference to first-adjacent stations, and adopted an Order detailing this determination. This across-the-board power increase has been shown to augment a station's digital coverage to be on par with the analog.

In the same Order, the Commission also allowed stations to increase their digital power to 10 percent of the analog power (-10 dBc), provided that certain 1st adjacent protection requirements are satisfied. Testing has shown that an increase to -10 dBc not only fills in "holes" at edge of coverage, but also greatly improves the digital signal's building penetration, enabling in-office listening and data services.

Most stations have different 1st adjacent protection requirements for their upper and lower digital sidebands. In many cases, one sideband may be limited to the newly authorized -14 dBc, and the other has no limitation at all, with a potential increase to the full -10 dBc. With the legacy symmetric power limitation, a station had to maintain <u>both</u> sidebands at the lower level, dictated by worst-case interference.

This report shows the improvement in digital SNR that can be realized with the use of asymmetric sideband operation. A previous Asymmetric Sideband Field Test Report showed the digital signal coverage improvement that can be realized by increasing the power of the non-limited or differently limited digital sideband.[1]

iBiquity's IRSS 4.4.x software load now allows stations to tailor their digital power asymmetrically to meet different upper and lower sideband 1st adjacent interference limitations. The new software load also allows the incorporation of the analog signal's characteristics into a new peak to average ratio reduction algorithm and distributes clipping artifacts more widely under the NRSC emissions mask, improving transmitter efficiency. Provided that a station's digital transmitter has the power capability, this asymmetric power increase is as simple as entering the desired signal levels into the exciter's Signal Configuration GUI.

[1] See *FM HD Radio™ Field Performance With Unequal Digital Sideband Carrier Levels (Preliminary) Revision 01.03*, iBiquity Digital Corporation, February 22, 2011.