The Effect Of Digital Signal Levels On Analog Channels In A Mixed Signal Multiplex

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ABSTRACT

In a cable system carrying both analog and digital signals, the digital signals are typically run at –10 dB relative to the analog channels. This is done in order to minimize effects of digital third order distortion on the analog signals. Since distortions produced by digital signals are noise-like, their effect appears as a decrease in Carrier/Noise ratios in adjacent analog channels.

Selection of digital power levels is a compromise between minimizing effects of analog distortions (i.e.- burst errors) on the digital channels and maintaining an acceptable noise floor in the analog channels. This is of particular concern as the industry moves toward higher density modulation formats such as 256QAM. This paper will discuss the results of testing to determine optimum levels of digital signals added to a 77 channel analog multiplex.

BACKGROUND

In a typical cable system, analog channels are located in the lower portion of the spectrum and digital channels are appended to the high frequency end. In such a system, theory has shown that digital third order distortion produces a noise-like spectrum that extends into the lower adjacent analog channels. This phenomenon is known as Composite Intermodulation Noise (CIN) and has been described in earlier publications [1], [2]. The result is a decrease in the C/N ratio of the channels at the upper end of the analog spectrum. The decrease in C/N performance is proportional to the digital signal power as well as to the number of digital channels.

Although operating the digital signals at reduced power levels minimizes analog C/N effects, it makes the digital signals more susceptible to burst errors resulting from analog CSO/CTB peaking [3]. Therefore a series of laboratory tests were conducted to determine optimum digital/analog ratios for operation of a mixed signal multiplex.

TEST SYSTEM DESCRIPTION

Test Setup

The system configuration for the tests consisted of a 77 channel analog multiplex in the 55-550 MHz range combined with digital channels above 550 MHz. Tests were conducted with a total of 32, 16 and 8 digital channels. Digital power levels were varied from zero to –10 dB relative to peak analog carriers and C/(N+CIN) levels were measured throughout the analog spectrum.

A block diagram of the test system is shown in Fig. 1. A 77 channel analog headend was used to generate the analog signal multiplex. The analog channels were independently modulated by separate video test signals. The digital multiplex consisted of a maximum of 32 digital signals, received from various satellites and transcoded to 64QAM via a bank of Motorola IRT1000 Integrated Receiver/Transcoders. The IRT outputs were up-converted to RF using Motorola C6U up-converters and inserted into the combined signal multiplex starting at 552 MHz. The average digital power levels were adjusted in 2 dB increments from 0 to –10 dB relative to peak of analog sync. Regardless of the number of digital channels, the digital signals were always contiguous throughout the course of the testing.

reliable secondary indication of AGC effects on laser drive level and modulation. As the

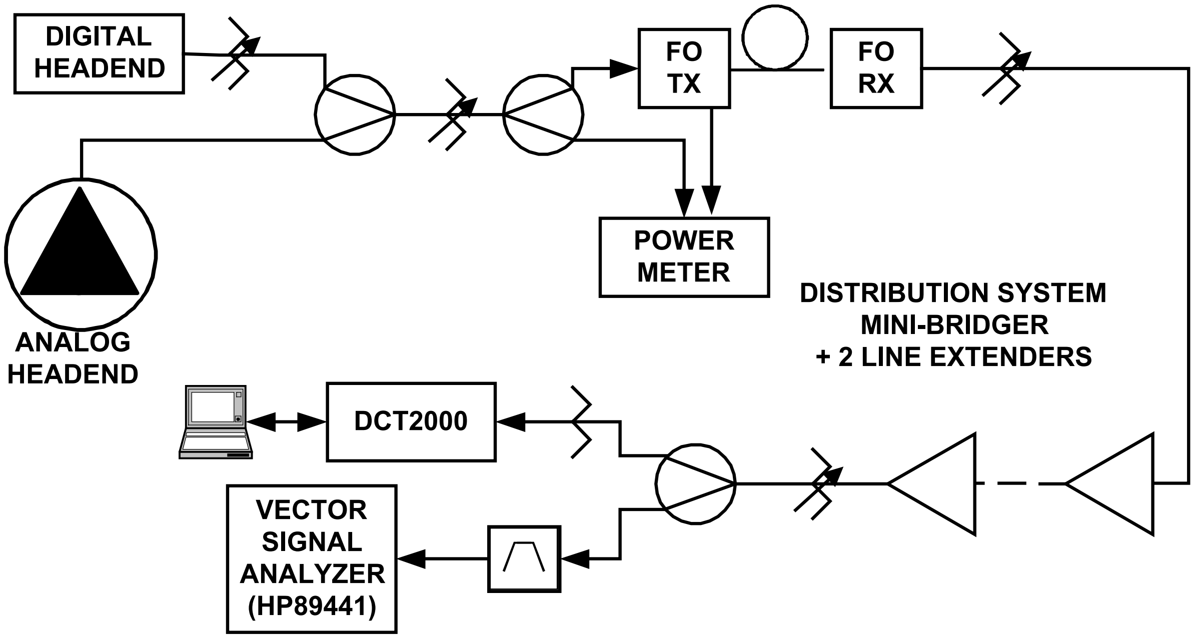

FIG. 1 - BLOCK DIAGRAM OF TEST SETUP

The distribution system used for the tests consisted of a 1310 nm laser transmitter driving a 20 Km fiber optic link with a 1.8 dB in-line optical attenuator followed by an RF system consisting of a Motorola MB-86SH/G mini-bridger, two Motorola BLE-86S line extenders and 21 taps. The RF distribution system was designed with 10 dB of tilt for 750 MHz spacing. The amplifiers were set up to be driven at their specified output levels for 77 NTSC carriers plus 200 MHz of compressed data (37/44/37 dBmV for 750/550/50 MHz, respectively).

The level of the combined analog/digital multiplex was adjusted to provide an input signal level that is near optimal for the fiber optic transmitter. With full channel loading, the fiber optic link was monitored for clipping effects and found to be several dB away from clipping according to Motorola BCS's laser clipping test procedure. A calibrated RF test point is mounted on the front panel of the laser transmitter module. This point was monitored via a power meter to provide a channel loading varies, the transmitter's microprocessor controlled AGC maintains a constant drive level to the laser and adjusts the total input power accordingly.

Analog C/N ratios were measured using a HP89441 Vector Signal Analyzer. The analog test signal was monitored after the second line extender throughout the test. This test point provided a signal that was greater than +25 dBmV per channel for accurate C/N measurements. A DCT2000 set top terminal was used to monitor digital signal quality during the course of the testing. The monitored digital channel was always located at the center of the digital spectrum.

Test Procedure

Unless otherwise specified, all measurements were performed in accordance with NCTA recommended practices and procedures.

Analog and digital signal levels were adjusted to provide a flat spectrum at the input to the distribution system. The peak analog power levels were set at +15 dBmV per channel. The average digital power levels were adjusted from 0 to –10 dBmV per channel relative to the analog carriers. The total average input power to the laser, after AGC, was approximately -17 dBm.

All C/(N+CIN) measurements were made at the first tap after the second line extender. The HP89441 Vector Signal Analyzer was used to measure RF analog C/N ratios and digital Es/No ratios. The peak level for the channel under test was maintained at a constant +25 dBmV at the input to the HP89441. A tunable bandpass filter, centered on the test channel, was used for all measurements to eliminate saturation and distortions at the input to the test equipment. In-band ripple of the tunable channel filters did not exceed 0.5 dB in a 6 MHz bandwidth.

A Motorola DCT2000, modified to run Broadcom QAMLink™ software, was used to monitor Bit Error Rate (BER) and Modulation Error Ratio (MER) of the digital channel under observation. The digital test channel was always located in the center of the digital spectrum.

TEST RESULTS

Tests with 32 Digital Channels

Test data are shown in Table 1. Table 2 presents the contributions of CIN to the analog noise floor. Plots of C/(N+CIN) and C/CIN are shown in Figs. 2 and 3, respectively. CIN was calculated by treating it as an additional noise source and subtracting the effect of Additive White Gaussian Noise (AWGN) (i.e. – the system noise measured with no digital channels present) as shown by Equation (1).

$$CIN=10*Log(10^{0.1*(AWGN+CIN)} - 10^{0.1*AWGN}) \quad (1)$$

Where CIN is expressed in dBc and AWGN is the system noise floor (dBc) with no digital channels present.

From Figs. 2 and 3 it is seen that the analog channels adjacent to the digital multiplex are affected most severely by the increase in the analog noise floor due to digital third order distortion. This is in accordance with theory [1].

Although FCC requirements [4] specify a minimum system C/N of 43 dB, most cable systems are designed to meet more stringent requirements – typically 49 dB at the end of the system. When digital channels are added to an analog multiplex, the effect of CIN must be treated as an additional noise source to be added to the system AWGN. Therefore system C/N design goals must include the effect of CIN as well as AWGN. Table 3 shows the system C/AWGN requirements for a 49 dB C/(N+CIN) design goal. The system C/AWGN values are calculated as follows:

$$C/AWGN = -10*Log(10^{-4.9} - 10^{0.1*CIN}) \quad (2)$$

Where C/AWGN is the system Carrier/AWGN in dB that must be maintained to meet the required C/(N+CIN) (49 dB in this case) and CIN is expressed in dBc.

The blank entry in Table 3 for channel 78 at 0 dB is indicative of a value for which the CIN is too large to meet a 49 dB design goal. That is, equation (2) yields the log of a negative number. The blank entries in Table 2 at the lowest frequencies are indicative of negligible CIN values (i.e. – no measurable difference between CIN and the system noise floor).

In practice, system C/AWGN values greater than the low 50’s are difficult to achieve. An inspection of the data in Table 3 shows that in a cable system with a C/(N+CIN) target of 49 dB, the digital channels would have to be operated at power levels of –6 dB or lower relative to the analog channels in order to maintain desired C/(N+CIN) performance.

Tests With 16 Digital Channels

Test results are shown in Table 4. Table 5 presents the contributions of CIN to the analog noise floor. Plots of CIN plus system noise vs. frequency are shown in Fig. 4. Fig. 5 presents a plot of CIN vs. frequency. The blank entry in Table 5 indicates a negligible CIN value. Table 6 shows the C/AWGN values required to meet a 49 dB system C/(N+CIN) design goal.

As is the case with 32 digital channels, a 49 dB system C/(N+CIN) target would require that the digital signals be operated at –6 dB or lower relative to the analog carriers. It should be noted, however, that the CIN generated by 16 digital channels at equal power to the analog signals decreases more rapidly than the CIN for 32 channels in most of the channels immediately adjacent to the digital spectrum. This corresponds to theoretical predictions for an octave band decrease in the number of digital channels [1].

Tests With 8 Digital Channels

Test data and CIN contributions are presented in Tables 7 and 8, respectively and shown graphically in Figs. 6 and 7. Table 9 shows the system C/AWGN requirements needed to meet a design goal of 49 dB for C/(N+CIN).

From Table 9 it is seen that, in a typical cable system with a C/(N+CIN) target of 49 dB, the digital channels could be operated at a power level of –6 dB or lower relative to the analog channels. This would depend on how well the system AWGN could be controlled.

Since the analog channel most affected by CIN is the highest channel (i.e. – the lower adjacent channel to the digital spectrum), maintaining a desired C/(N+CIN) design goal in this channel should assure that the design goal would be met in the remainder of the analog spectrum. Fig. 8 presents plots of system C/AWGN vs. A/D ratio required to achieve a 49 dB C/(N+CIN) ratio in the worst case analog channel (EIA channel 78). From Fig. 8 it is seen that an A/D ratio of 6 dB or greater would be required to operate with a realistic C/AWGN level. Lower A/D ratios may be achievable, depending on the number of digital channels and the extent to which a system operator can control system AWGN.

CONCLUSIONS

Test results have shown that digital third order distortion may be regarded as an additional noise source that adds to system AWGN to produce an increase in the noise floor of the adjacent analog channels. Test data show that this effect is worst in the highest analog channel and decreases with decreasing analog channel frequency. Since digital signals are affected by CSO and CTB peaks, setting digital signal levels is a compromise between generation of digital distortion in the analog multiplex and optimizing digital signal robustness. To date, it has been a practice to set levels for 64QAM signals at –10 dB relative to analog carriers. As 256QAM is deployed, these levels may have to be increased. Test data show that a level of –6 dB relative to analog signals can be attained without generating objectionable CIN levels. The choice of an acceptable operating level is dependent on the number of digital channels in the system, the current C/AWGN performance and the extent to which the operator is able to control system AWGN.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Bill Otto, Chris Lynch and Lenton Jones for their assistance in conducting the tests.

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[4] FCC Regulations, Part 76

EIA Channel	2	16	7	12	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	57	135	177	207	273	327	393	459	513	519	525	531	537	543	549
A/D Ratio (dB)	System Additive White Gaussian Noise + CIN (dBc)														
0	-53.5	-52.8	-52.5	-51.9	-53.1	-52.1	-52.0	-52.5	-49.9	-49.6	-49.7	-50.3	-50.4	-49.8	-48.1
2	-54.1	-53.7	-53.5	-53.4	-54.6	-54.0	-54.0	-54.7	-53.3	-53.0	-53.1	-53.5	-53.7	-53.2	-50.9
4	-54.6	-54.0	-53.7	-54.0	-55.3	-55.0	-55.1	-56.2	-55.2	-54.7	-54.8	-55.4	-55.5	-55.2	-52.7
6	-54.7	-54.3	-54.1	-54.4	-55.7	-55.7	-55.7	-56.7	-56.2	-55.5	-55.7	-56.3	-56.4	-56.2	-54.5
8	-55.1	-54.4	-54.3	-54.5	-55.9	-56.0	-55.9	-56.9	-56.6	-56.0	-56.1	-56.6	-56.9	-56.7	-55.1
10	-55.2	-54.6	-54.4	-54.5	-56.0	-56.0	-56.0	-57.3	-56.8	-56.3	-56.5	-56.9	-57.1	-56.9	-56.2
No Digital	-55.2	-54.5	-54.3	-54.6	-56.3	-56.2	-56.4	-57.4	-57.3	-56.8	-56.9	-57.3	-57.6	-57.7	-57.3

Table 1 – System AWGN + CIN for 32 Digital Channels

EIA Channel	2	16	7	12	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	57	135	177	207	273	327	393	459	513	519	525	531	537	543	549
A/D Ratio (dB)	CIN (dBc)														
0	-58.4	-57.7	-57.2	-55.3	-55.9	-54.2	-54.0	-54.2	-50.8	-50.5	-50.6	-51.3	-51.3	-50.6	-48.7
2	-60.6	-61.4	-61.2	-59.7	-59.5	-58.0	-57.7	-58.0	-55.5	-55.3	-55.4	-55.8	-56.0	-55.1	-52.0
4	-63.5	-63.6	-62.6	-62.5	-62.2	-61.2	-61.0	-62.4	-59.4	-58.9	-59.0	-59.9	-59.7	-58.8	-54.5
6	-64.3	-67.8	-67.6	-68.3	-64.6	-65.3	-64.0	-65.0	-62.7	-61.4	-61.9	-63.2	-62.6	-61.5	-57.7
8	-71.5	-70.8		-71.2	-66.5	-69.5	-65.5	-66.5	-64.9	-63.7	-63.8	-64.9	-65.2	-63.6	-59.1
10				-71.2	-67.8	-69.5	-66.6	-73.7	-66.4	-65.9	-67.1	-67.5	-66.7	-64.6	-62.7

Table 2 – CIN Contribution to Analog Noise Floor for 32 Digital Channels

EIA Channel	2	16	7	12	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	57	135	177	207	273	327	393	459	513	519	525	531	537	543	549
A/D Ratio (dB)	System C/AWGN (dB)														
0	49.5	49.6	49.7	50.2	50.0	50.5	50.7	50.6	53.7	54.3	54.1	52.9	52.8	54.2	
2	49.3	49.3	49.3	49.4	49.4	49.6	49.6	49.6	50.1	50.1	50.1	50.0	50.0	50.2	52.0
4	49.2	49.2	49.2	49.2	49.2	49.3	49.3	49.2	49.4	49.5	49.5	49.4	49.4	49.5	50.4
6	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.2	49.3	49.2	49.2	49.2	49.2	49.6
8	49.0	49.0	49.0	49.0	49.1	49.0	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.2	49.4
10	49.0	49.0	49.0	49.0	49.1	49.0	49.1	49.0	49.1	49.1	49.1	49.1	49.1	49.1	49.2

Table 3 – System C/AWGN Required to Meet a 49 dB C/(N+CIN) Design Goal in a System with 32 Digital Channels

Fig. 2 - System AWGN + CIN for 32 Digital Channels

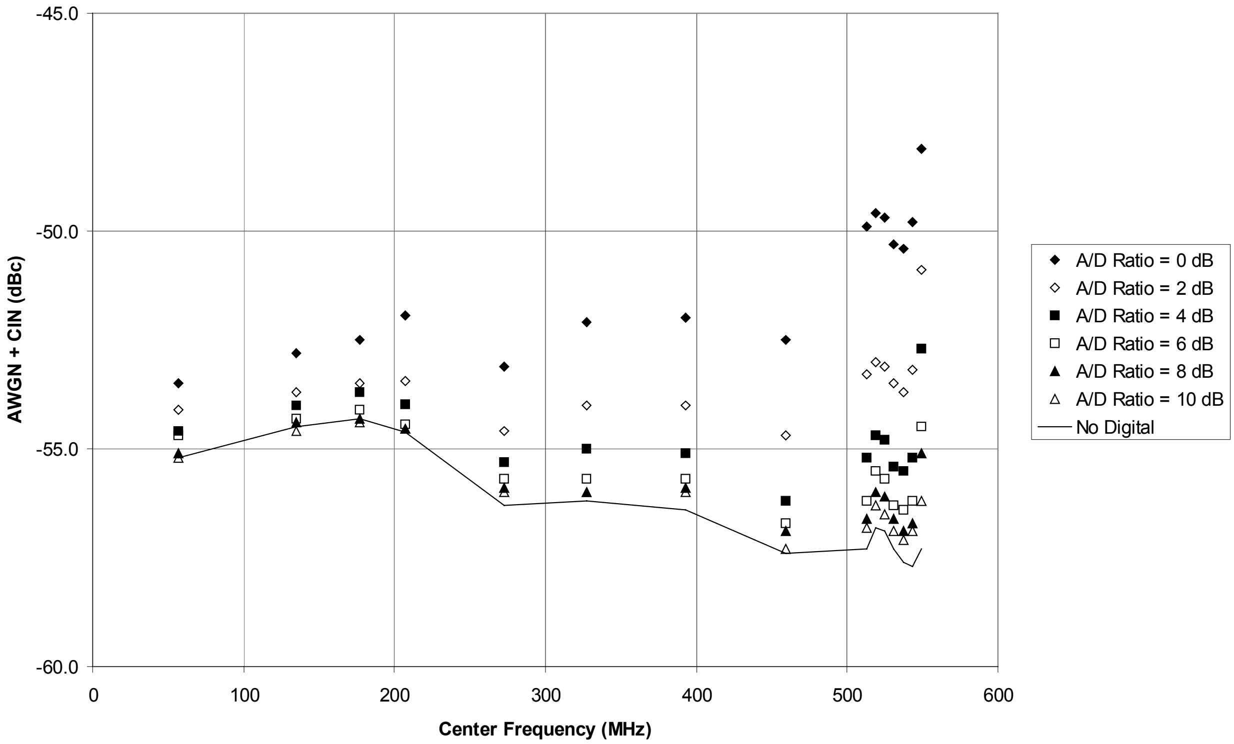
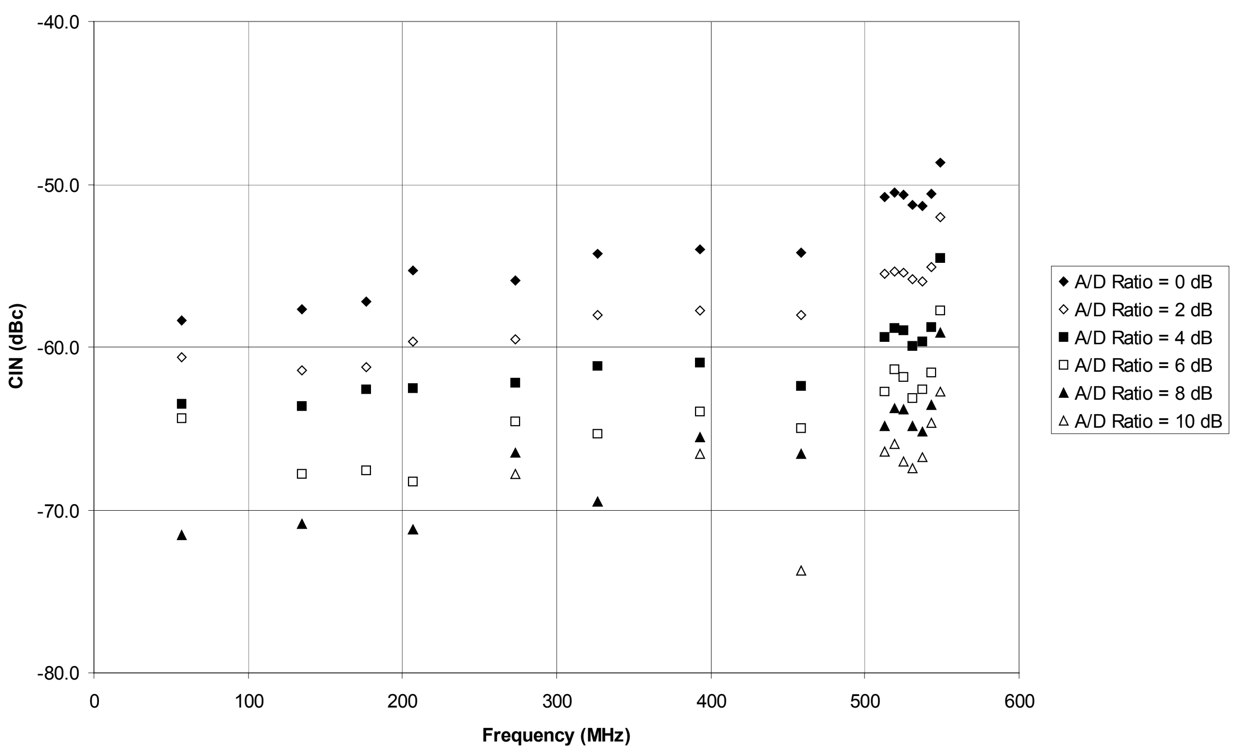


Fig. 3 - CIN Contribution to Analog Noise Floor for 32 Digital Channels



EIA Channel	2	16	7	12	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	57	135	177	207	273	327	393	459	513	519	525	531	537	543	549
A/D Ratio (dB)	System Additive White Gaussian Noise + CIN (dBc)														
0	-54.0	-53.3	-53.5	-54.0	-54.0	-54.7	-54.7	-55.0	-54.0	-53.0	-53.7	-53.9	-54.0	-53.5	-49.6
2	-54.3	-53.6	-54.0	-55.0	-54.8	-55.4	-55.4	-56.0	-55.0	-55.0	-55.2	-55.5	-56.0	-55.2	-51.7
4	-54.5	-54.0	-54.2	-55.0	-55.4	-56.0	-56.0	-56.6	-56.0	-56.0	-56.0	-56.0	-56.0	-56.1	-53.2
6	-54.8	-54.2	-54.3	-55.0	-55.7	-56.4	-56.4	-56.9	-56.0	-56.0	-56.4	-56.5	-57.0	-56.6	-54.6
8	-54.9	-54.2	-54.6	-56.0	-55.7	-56.5	-56.5	-57.0	-57.0	-56.0	-56.6	-56.8	-57.0	-56.9	-55.4
10	-54.9	-54.4	-54.6	-56.0	-55.7	-56.6	-56.6	-57.2	-57.0	-56.0	-57.1	-56.9	-57.0	-57.1	-56.4
No Digital	-55.2	-54.4	-54.7	-56.0	-55.8	-56.8	-56.8	-57.4	-57.0	-57.0	-57.2	-57.2	-58.0	-57.6	-58.3

Table 4 – System AWGN + CIN for 16 Digital Channels

EIA Channel	2	16	7	12	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	57	135	177	207	273	327	393	459	513	519	525	531	537	543	549
A/D Ratio (dB)	CIN (dBc)														
0	-60.2	-59.8	-59.7	-58.7	-58.7	-58.9	-58.9	-58.7	-56.3	-55.7	-56.3	-56.6	-56.8	-55.6	-50.2
2	-61.6	-61.3	-62.3	-61.7	-61.7	-61.0	-61.0	-61.6	-59.9	-58.9	-59.5	-60.4	-59.8	-58.9	-52.8
4	-62.8	-64.6	-63.8	-63.4	-66.0	-63.7	-63.7	-64.3	-62.4	-61.4	-62.2	-62.2	-62.5	-61.4	-54.8
6	-65.4	-67.7	-64.9	-64.1	-72.1	-67.0	-67.0	-66.5	-64.6	-63.7	-64.1	-64.8	-65.1	-63.5	-57.0
8	-66.7	-67.7	-71.0	-69.1	-72.1	-68.3	-68.3	-67.6	-67.2	-65.9	-65.5	-67.4	-66.6	-65.2	-58.5
10	-66.7		-71.0	-69.1	-72.1	-70.1	-70.1	-70.7	-70.3	-67.0	-73.5	-68.7	-69.0	-66.7	-60.9

Table 5 – CIN Contribution to Analog Noise Floor for 16 Digital Channels

EIA Channel	2	16	7	12	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	57	135	177	207	273	327	393	459	513	519	525	531	537	543	549
A/D Ratio (dB)	System C/AWGN (dB)														
0	49.3	49.4	49.4	49.5	49.5	49.5	49.5	49.5	49.9	50.0	49.9	49.8	49.8	50.1	55.1
2	49.2	49.3	49.2	49.2	49.2	49.3	49.3	49.2	49.4	49.5	49.4	49.3	49.4	49.5	51.4
4	49.2	49.1	49.1	49.2	49.1	49.1	49.1	49.1	49.2	49.3	49.2	49.2	49.2	49.3	50.3
6	49.1	49.1	49.1	49.1	49.0	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.2	49.7
8	49.1	49.1	49.0	49.0	49.0	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.1	49.5
10	49.1	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.1	49.0	49.0	49.0	49.1	49.3

Table 6 – System C/AWGN Required to Meet a 49 dB C/(N+CIN) Design Goal in a System with 16 Digital Channels

Fig. 4 - System AWGN + CIN for 16 Digital Channels

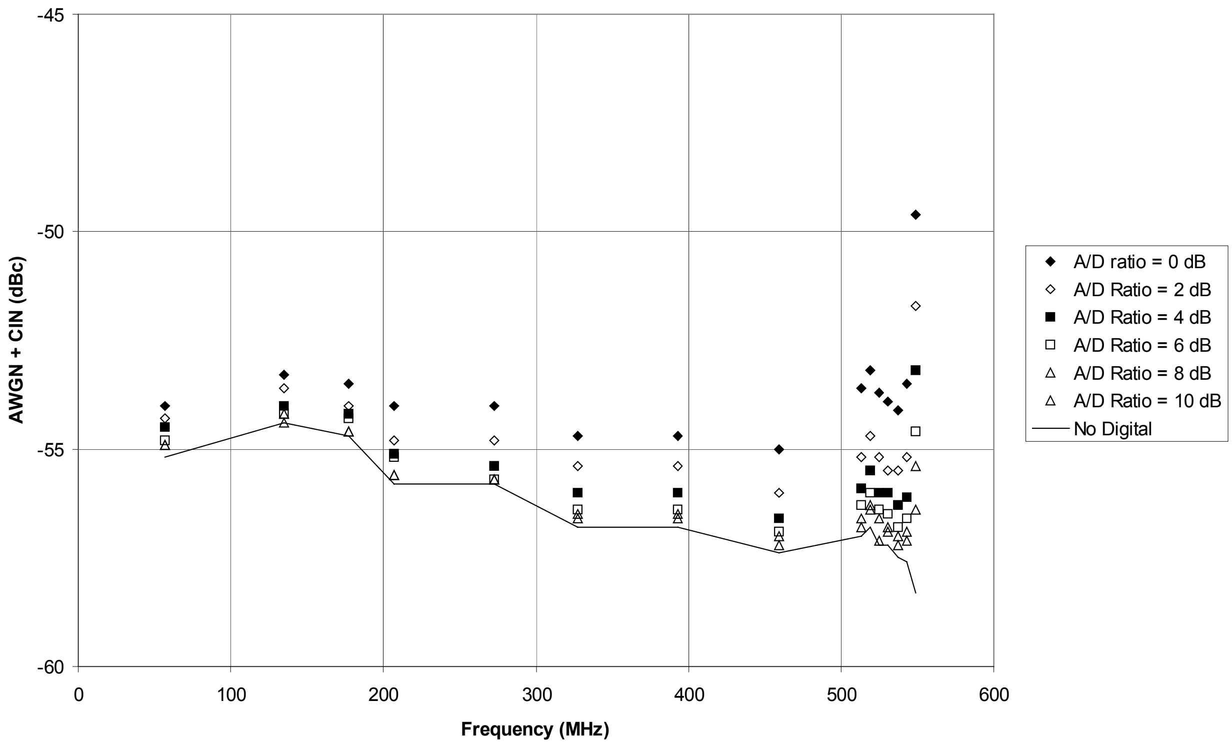
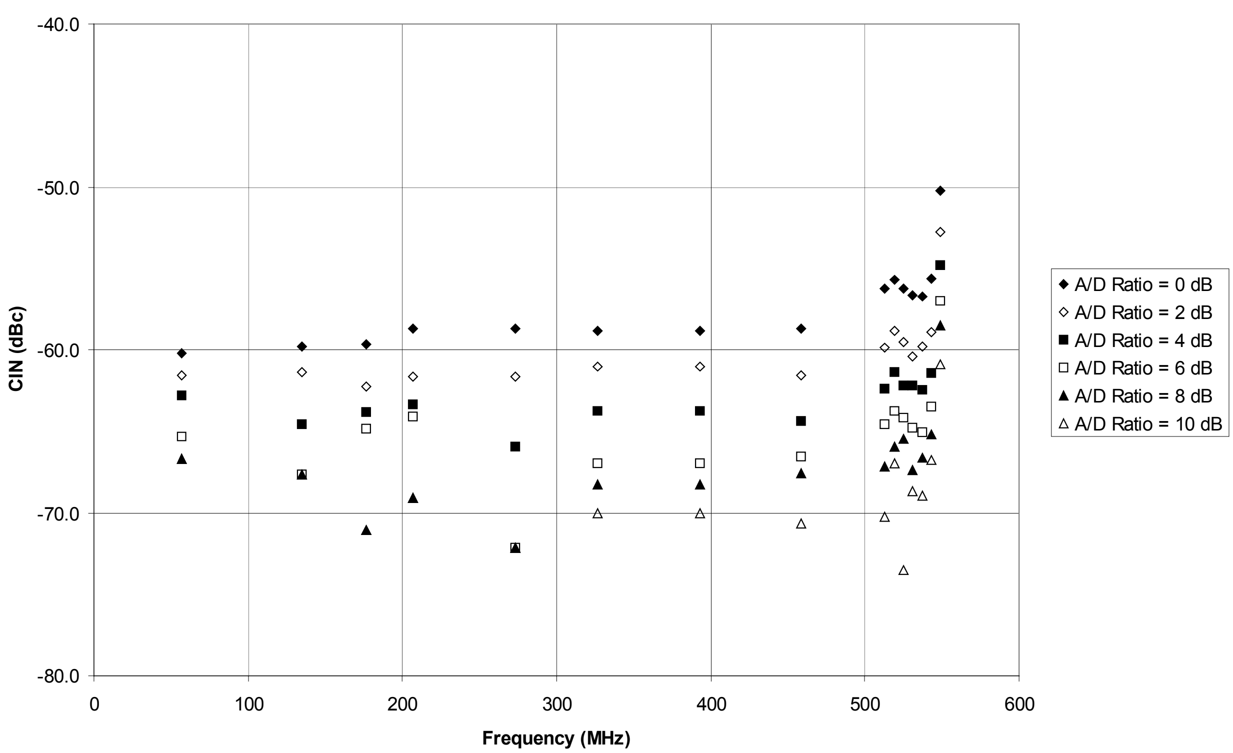


Fig. 5 - CIN Contribution to Analog Noise Floor for 16 Digital Channels



EIA Channel	2	16	7	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	**57**	**135**	**177**	**273**	**327**	**393**	**459**	**513**	**519**	**525**	**531**	**537**	**543**	**549**
A/D Ratio (dB)	**System Additive White Gaussian Noise + CIN (dBc)**													
0	-54.3	-54.6	-53.9	-55.1	-54.4	-55.5	-56.7	-55.8	-55.3	-55.9	-56.2	-56.4	-55.7	-50.5
2	-54.6	-54.8	-54.2	-55.4	-54.7	-55.9	-57.2	-56.5	-55.8	-56.4	-56.9	-57.2	-56.6	-51.9
4	-55.0	-55.1	-54.4	-55.6	-55.0	-56.2	-57.5	-56.8	-56.3	-56.8	-57.2	-57.5	-57.2	-53.5
6	-55.1	-55.3	-54.5	-55.8	-55.1	-56.5	-57.5	-57.1	-56.6	-57.0	-57.5	-57.7	-57.5	-54.7
8	-55.1	-55.3	-54.7	-55.9	-55.2	-56.6	-57.7	-57.2	-56.7	-57.1	-57.7	-57.8	-57.8	-55.8
10	-55.2	-55.3	-54.7	-56.0	-55.4	-56.6	-57.8	-57.5	-56.7	-57.3	-57.7	-58.0	-57.9	-56.5
No Digital	-55.4	-55.4	-54.7	-56.1	-55.6	-56.8	-57.8	-57.6	-57.1	-57.5	-58.0	-58.2	-58.4	-58.3

Table 7 – System AWGN + CIN for 8 Digital Channels

EIA Channel	2	16	7	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	**57**	**135**	**177**	**273**	**327**	**393**	**459**	**513**	**519**	**525**	**531**	**537**	**543**	**549**
A/D Ratio (dB)	**CIN (dBc)**													
0	-60.8	-62.3	-61.6	-62.0	-60.6	-61.4	-63.2	-60.5	-60.0	-61.0	-60.9	-61.1	-59.0	-51.3
2	-62.3	-63.7	-63.8	-63.7	-62.0	-63.2	-66.1	-63.0	-61.7	-62.9	-63.4	-64.1	-61.3	-53.0
4	-65.6	-66.9	-66.2	-65.2	-63.9	-65.1	-69.3	-64.5	-64.0	-65.1	-64.9	-65.8	-63.4	-55.2
6	-66.9	-71.7	-68.0	-67.6	-64.7	-68.3	-69.3	-66.7	-66.2	-66.6	-67.1	-67.3	-64.8	-57.2
8	-66.9	-71.7		-69.4	-65.8	-70.1	-74.1	-67.8	-67.3	-67.7	-69.5	-68.4	-66.7	-59.4
10	-68.7	-71.7		-72.4	-68.9	-70.1		-73.9	-67.3	-70.8	-69.5	-71.5	-67.5	-61.2

Table 8 – CIN Contribution to Analog Noise Floor for 8 Digital Channels

EIA Channel	2	16	7	32	41	52	63	72	73	74	75	76	77	78
Center Frequency (MHz)	**57**	**135**	**177**	**273**	**327**	**393**	**459**	**513**	**519**	**525**	**531**	**537**	**543**	**549**
A/D Ratio (dB)	**System C/AWGN (dB)**													
0	49.3	49.2	49.2	49.2	49.3	49.3	49.2	49.3	49.4	49.3	49.3	49.3	49.5	52.9
2	49.2	49.1	49.1	49.2	49.2	49.2	49.1	49.2	49.2	49.2	49.2	49.1	49.3	51.2
4	49.1	49.1	49.1	49.1	49.1	49.1	49.0	49.1	49.1	49.1	49.1	49.1	49.2	50.2
6	49.1	49.0	49.1	49.1	49.1	49.1	49.0	49.1	49.1	49.1	49.1	49.1	49.1	49.7
8	49.1	49.0	49.0	49.0	49.1	49.0	49.0	49.1	49.1	49.1	49.0	49.1	49.1	49.4
10	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.1	49.0	49.0	49.0	49.1	49.3

Table 9 – System C/AWGN Required to Meet a 49 dB C/(N+CIN) Design Goal in a System with 8 Digital Channels

Fig. 6 - System AWGN + CIN for 8 Digital Channels

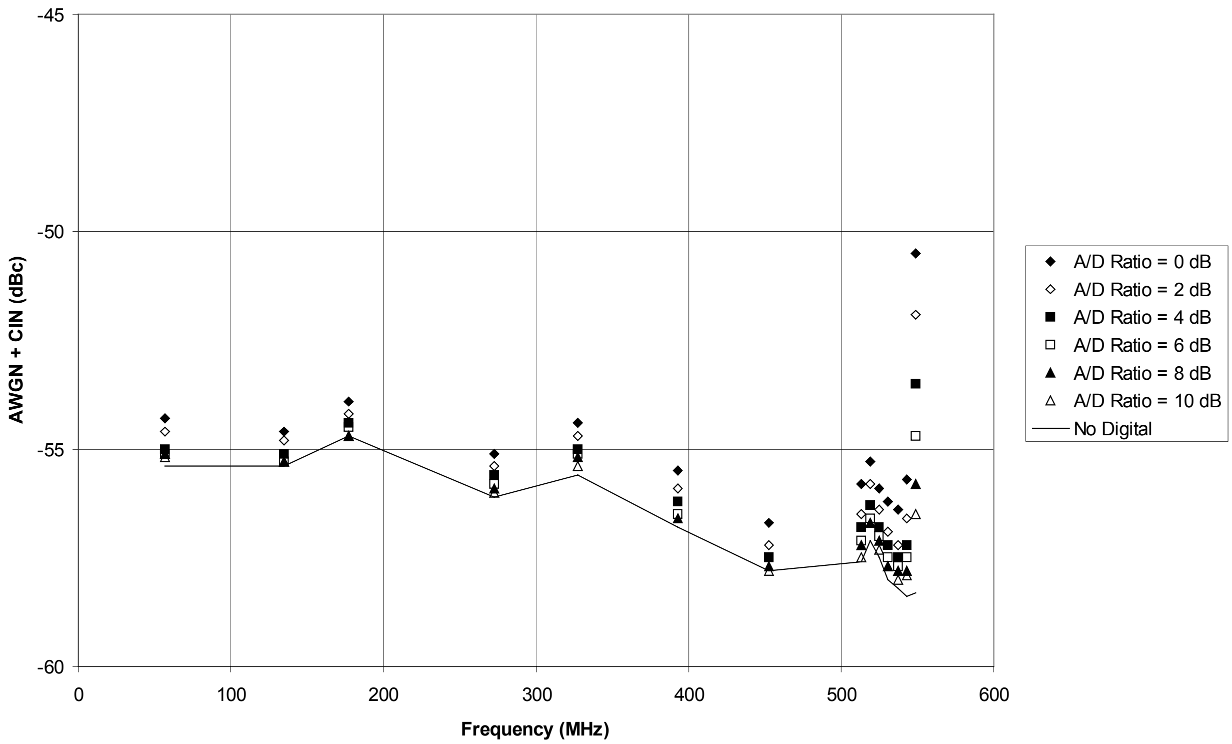


Fig. 7 - CIN Contribution to Analog Noise Floor for 8 Digital Channels

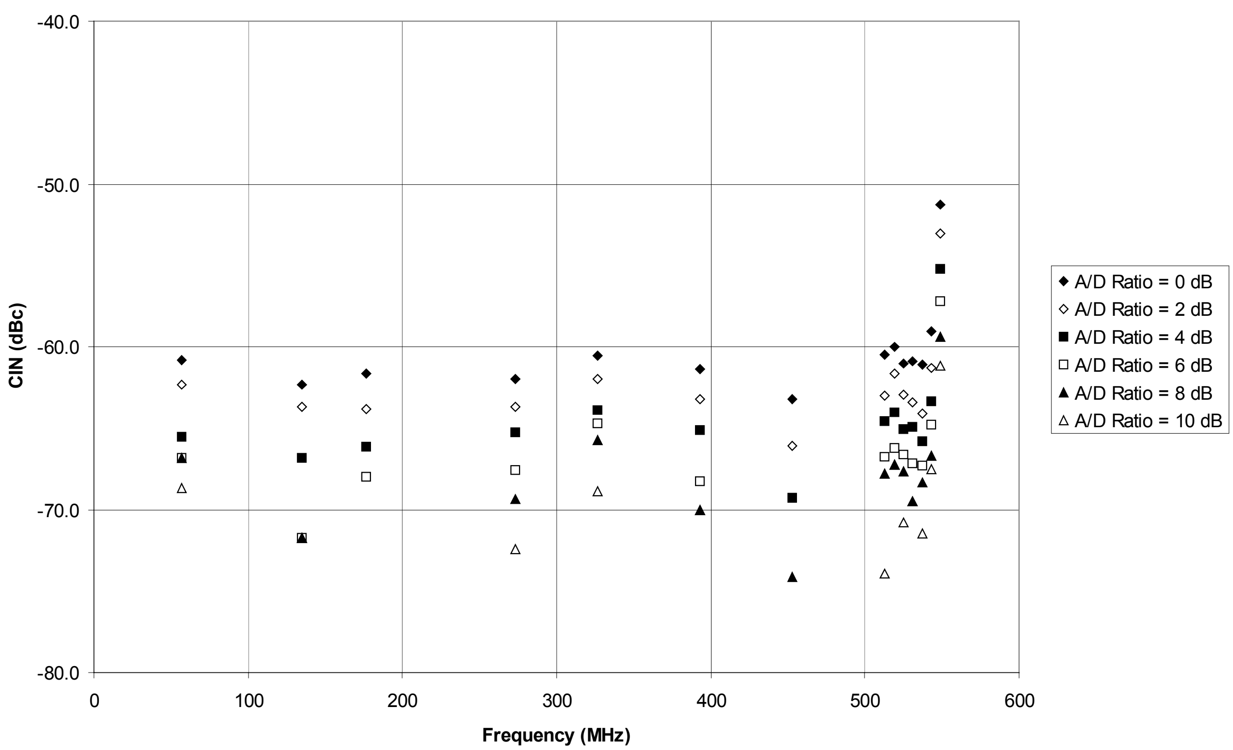


Fig. 8 - System C/AWGN Required to Meet 49 dB C/(N+CIN) in Channel 78