Nonlinear Distortions Distribution in HFC Networks

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Abstract

This paper uses a new method to analyze the nonlinear distortions, CTB, CSO and CIN in the HFC Network.

Each carrier is treated as a vector, the amplitude, frequency and phase are set for each channel.

Both 550 MHz & 750 MHz all analog system and 750 MHz mixed analog and digital HFC system are analyzed. The level variations, random phase between channels and the output tilt of a real cable system are considered.

For the all analog systems, the distributions of CSO & CTB vs. tilt, the worst channels vs. tilt and the modulation effects are proposed.

For HFC systems with mixed analog and digital signals, the CIN noise distribution vs. tilt and worst channels vs. tilt are proposed.

This analysis provides some insight into the nonlinear distortions distribution in real cable systems.

Introduction

Cause of Distortions

The distortions are caused by nonlinear devices in the network, including amplifiers and AM fiber systems. [1], [2]

Distortion performance for the analog system includes Composite Second Order (CSO) and Composite Third Order Beat (CTB). Testing methods for these performance criteria, are well established. [3]

Distortion performance for the mixed analog and digital HFC system could be specified as Composite Intermodulation Noise (CIN), CSO and CTB. [4], [5]

Analysis method

The conventional "beat count" method results in the well-known beat tables for both CTB and CSO.[6] This "beat count" method only counts the beat number on the specified frequency locations relative to the video carriers. There is no consideration for level and phase variations among channels using the beat count method. The beat count method does not accurately characterize present day or planned cable systems which carry video modulated carriers, use tilted output or carry both analog and digitally modulated carriers.

A computer program was designed to analyze the CATV system with mixed analog and digital signals. The output tilt and modulation effects were also considered.

The program assumes that the nonlinear characteristic of any device is expressed by the transfer function. [7]

$$V_O(t) = K_1 * V_{in}(t) + K_2 * V_{in}(t)^2 + K_3 * V_{in}(t)^3$$

where

$V_O(t)$ is the output signal

$V_{in}(t)$ is the input signal

K1, K2 and K3 are the 1st, 2nd and 3rd coefficients

All the high-order terms are neglected. The time-variant input signal is assumed to be

$$V_{in}(t) = A1 * COS(W1 * t + \varphi_1) + A2 * COS(W2 * t + \varphi_2) + \ldots$$

Where

A1, A2 ... are the amplitudes

W1, W2... are the frequencies

φ_1, φ_2 ... are the phases

The amplitude, frequency and phase of every carrier can be set separately. Thus, the synchronized / non-synchronized carriers, flat/sloped output and CW/modulated carriers could be simulated by the program.

In order to analyze the relationships among all the discrete and composite beats in detail, all the beats within 0.25 MHz intervals in the 6 MHz NTSC channel are recorded. This feature can simulate the FCC frequency offset or count the total power in any interval just as the resolution bandwidth setting of spectrum analyzer.

The analyses are based on a hypothetical nonlinear device with specified nonlinear coefficients, K_2 and K_3. Any other device will have similar characteristics except the reference value.

In order to prevent confusion, the EIA Channel designation and the STD frequency allocation plan are chosen. CH-95 to CH-99 are not included in these analyses.

The tilt is defined as the level difference between the highest and lowest analog channels.

Detailed results of the analyses are shown in the following sections.

Analog System Results

CSO Distribution

The distribution of CSO vs. tilt and the worst case distribution CSO vs. tilt is shown in figures 1, 2 and 3.

There are two extreme groups, CH-5/CH-6 and the highest channel. In the case of CH-5/CH-6, the CSO distribution is caused by the special frequency assignment. In the case of the highest channel CSO distribution is due to the largest beat counts and the highest beat power.

There exists a transition point, about -6.5 dB tilt. Any tilt higher than this value, CH-5 is the worst channel. In this region, when the tilt is getting higher, the CSO is getting worse. When tilt changes, both the carrier power and the beat power of CH-5 decrease, but the carrier power decreases much faster than the beat power.

For the tilt lower than -6.5 dB, CH-78 (547.25 MHz) is the worst channel for 550 MHz system; CH-116 (745.25 MHz) is the worst channel for all analog 750 MHz system. In this region, when tilt increases from -15 dB to -6.5 dB, the CSO is getting better. That is because the carrier power of the highest channel increases faster than the CSO beat power accumulation.

If the same active device is used, when the tilt is higher than -6.5 dB, the CSO of 550 MHz system is about 4 dB better than that of the all analog 750 MHz system. When tilt is lower than -6.5 dB, the CSO of 550 MHz system is about 3 dB better than that of all analog 750 MHz system.

Typically, for typical cable systems, the negative tilt will not happen in the trunk lines, but in the distribution network and the input stage of the settop box negative tilt is likely.

CTB Distribution

The distribution of CTB vs. tilt and the worst CTB vs. tilt are shown in figure 4, 5 and 6.

When tilt increases, the CTB performance becomes better. At the same time, the worst CTB channel moves toward the low frequency band. For example, in the 550 MHz, 0 dB tilt system, the worst CTB happens on CH-41. In the 550 MHz, 9 dB tilt system, the worst CTB channel moves to CH-25, but the CTB performance improves about 7 dB.

When tilt increases, both carrier power and beat power decrease, but the carrier power decreases much faster on the low band than that of high band. So the worst case CTB channel will move toward the low band.

As the worst case channel moves toward the low band, the composite beat power of the worst channel becomes lower because the beat counts and the power of each beat decrease. Though the carrier power decreases when the tilt increases, the carrier to composite beat ratio continues to improve.

If the same active device is used, the CTB of 750 MHz all analog system is about 6.5 dB worse than that of all analog 550 MHz system.

Modulation Effects

Several papers discuss the modulation effects on system performance. [8], [9]&[10]

When the carriers are modulated, the CSO and CTB performance will be better because the average carrier power is about 6 dB down from the peak value. A 6 to 7.8 dB CSO improvement factor is reported and a 10 to 12.8 dB CTB improvement factor is reported as well.

In the analysis, the video information are assumed to be in Gaussian distribution.

The simulated modulation effects on CSO and CTB are shown on figure 7, 8, 9 and 10. Note that all these modulated curves follow the trends of the non-modulated (CW) curves.

For CSO curves, because the beat counts are very small, compared with that of CTB, the modulation effects are much more apparent. It follows the ***Law of Large Number*** of statistics.

Mixed Analog & Digital System Results

In mixed signals system, the digital carriers do not contribute any new CSO or CTB beat as the analog carriers. Instead, the beating process within digital carriers and between digital carriers and analog carriers generate the new impairment, Composite Intermodulation Noise, CIN. [5]

For convenience, 4 MHz is chosen as the noise bandwidth just as that in the analog channels.

CIN3 Distribution

CIN3 is the third order composite intermodulation beat noise. The beats involve at least one digital carrier.

The CIN3 Distribution vs. channel number and tilt is shown in figure 11. The worst CIN3 channel vs. tilt is shown in figure 12.

While CIN3 is distributed within both the analog and digital bands, most of the CIN3 is located in the digital band and the high channels of the analog band.

The impact of CIN3 to analog channels is greater than the impact to the digital channels.

In the digital band, the CIN3 performance is almost the same with either tilt or level difference changes. In the analog band, for increasing slope, the digital carriers will increase as well, same as the power of CIN3. But the analog carriers will decrease; thus, the CIN3 in the analog band will be worse for increasing slope.

When the level difference

increases, i.e. the digital levels decrease, the CIN3 in digital band remains the same because the composite beat noise decreases about the same amount. But in the analog band, CIN3 becomes better because the beat noise from digital band decreases. The limitation to the level difference will be the BER performance and the system noise level.

CIN2 Distribution

CIN2 is the composite of all the second order beats involving at least one digital carrier.

Compared with CIN3, CIN2 is about 20 dB lower than CIN3, the total CIN is almost the same as CIN3.

The total CIN should be considered in the analog band CNR calculation.

Conclusion

For all analog systems, CSO has two extremes, CH-5/CH-6 and the highest channel. If tilt is higher than the transition value, -6.5 dB, CH-5 is the worst channel. On CH-5, when the tilt becomes higher, the CSO becomes worse. With tilt lower than -6.5 dB, the highest channel is the worst channel for CSO and as the tilt decreases, the CSO will become worse.

The CTB performance for all analog systems will be better and the worst channel will move toward the lower frequency channels as the tilt increases.

For the mixed digital and analog signals system, the CIN noise in the digital band remains almost the same as the level difference or slope changes. But in the analog band, the CIN performance becomes worse when the slope increase, and improves when the level difference increases. The limiting factors of the level difference will be the system noise floor or desired noise performance and the BER performance requirement.

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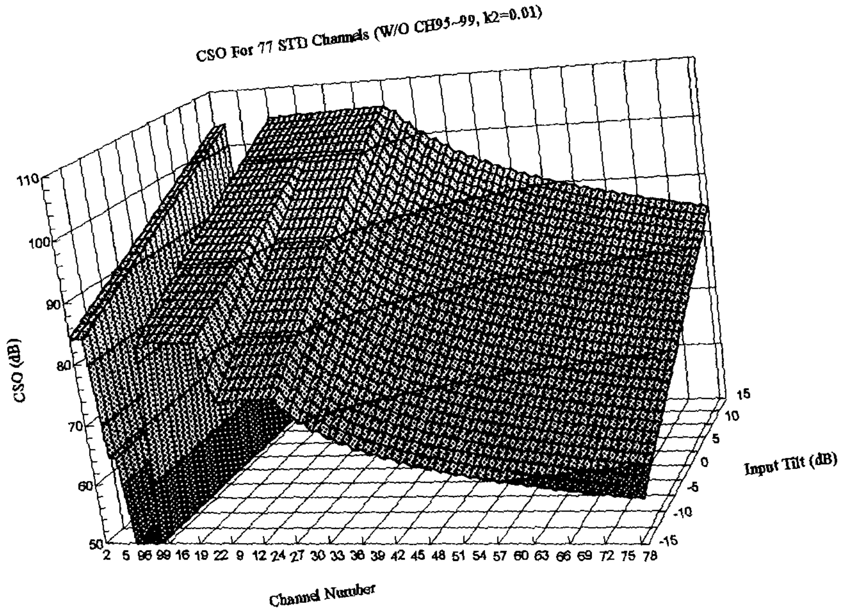
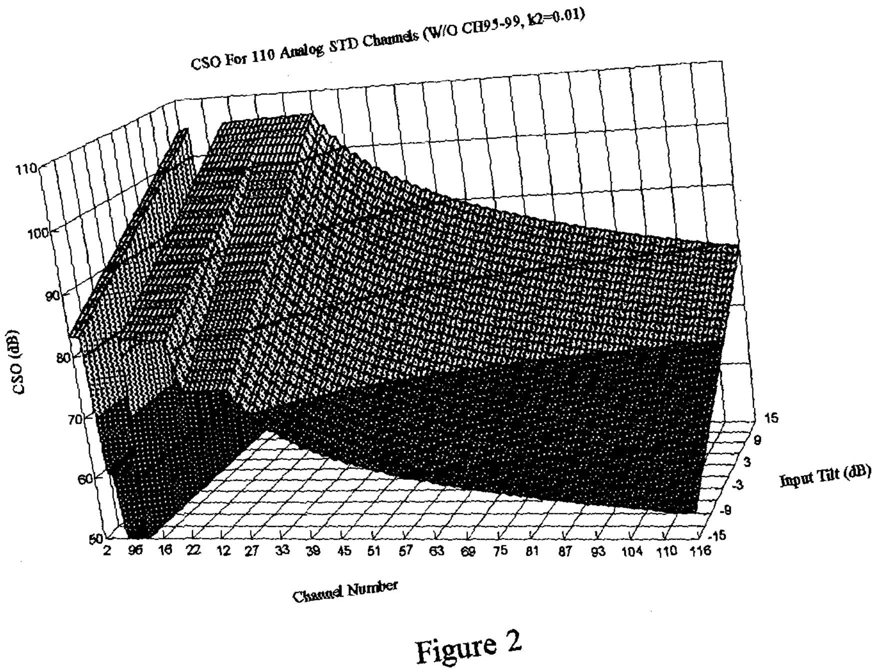


Figure 1



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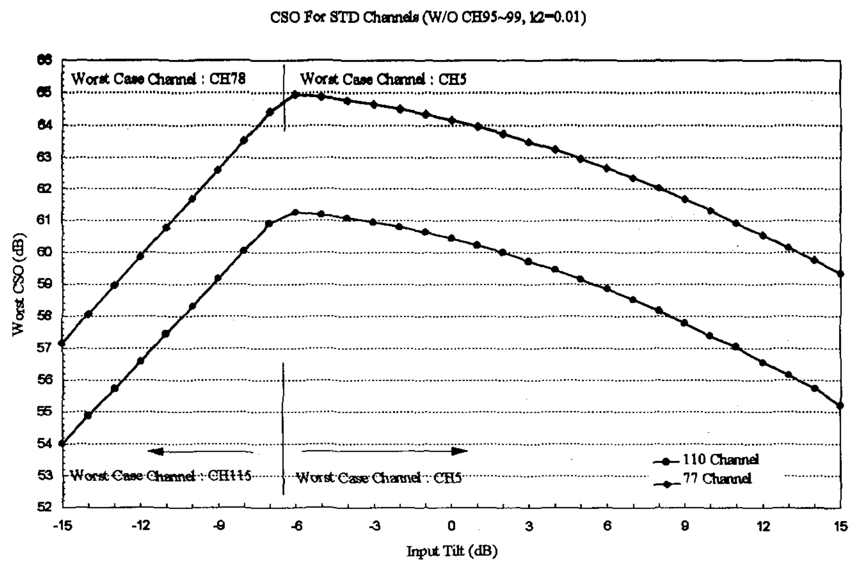

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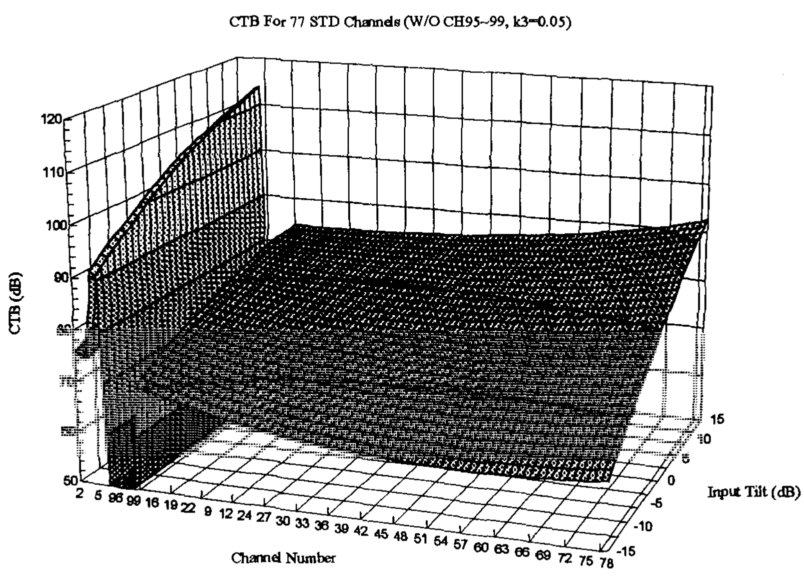

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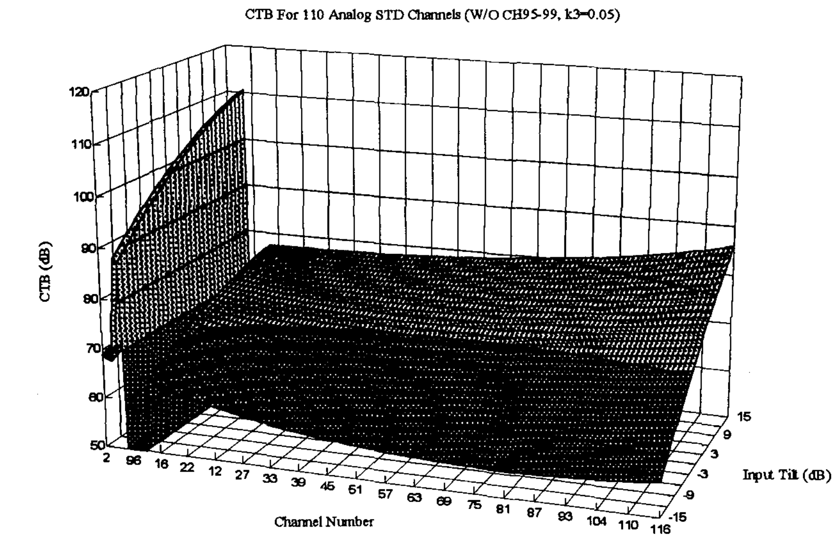


Figure 5

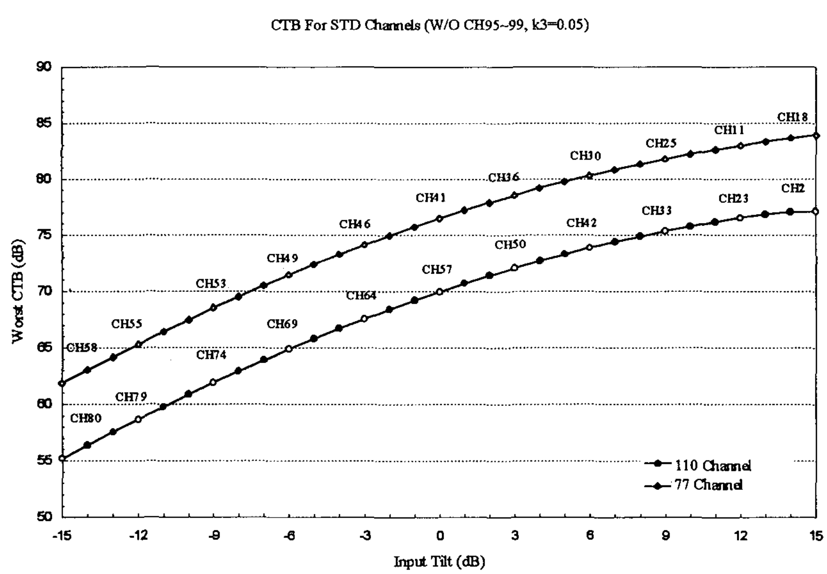


Figure 6

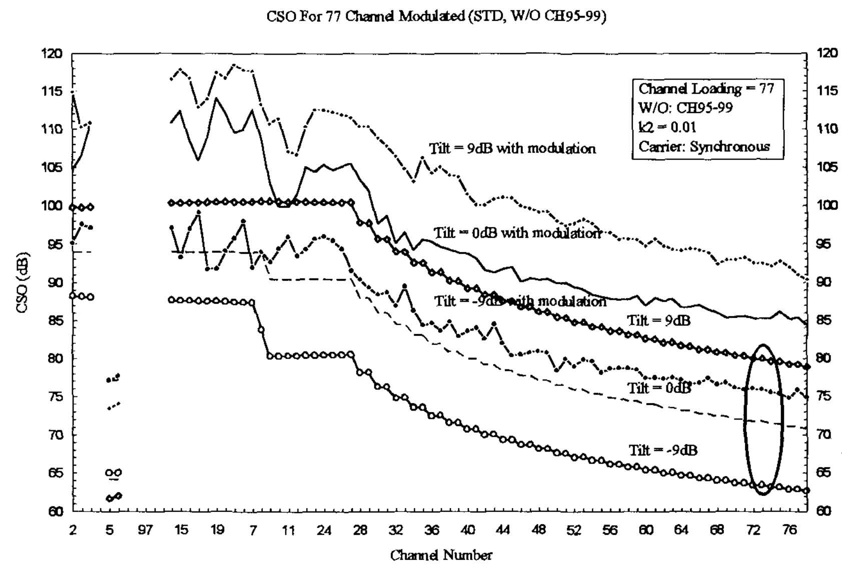


Figure 7

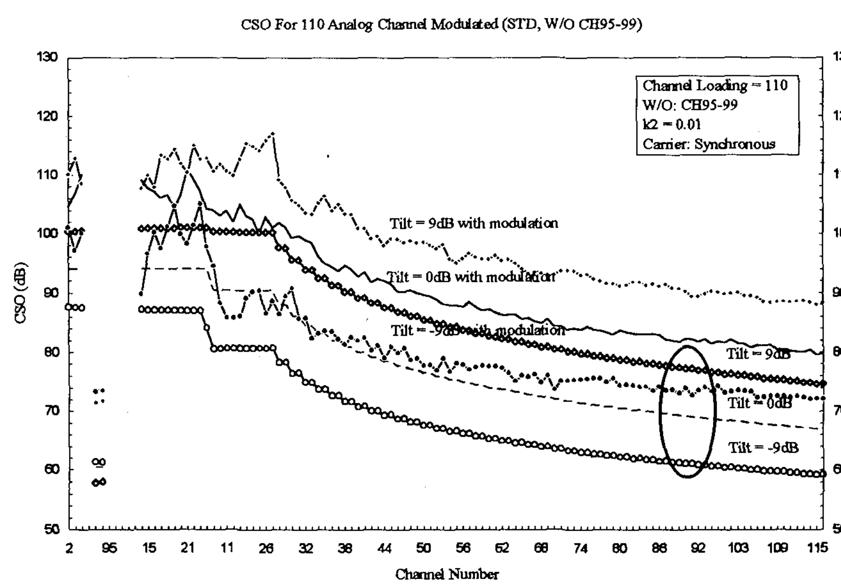


Figure 8

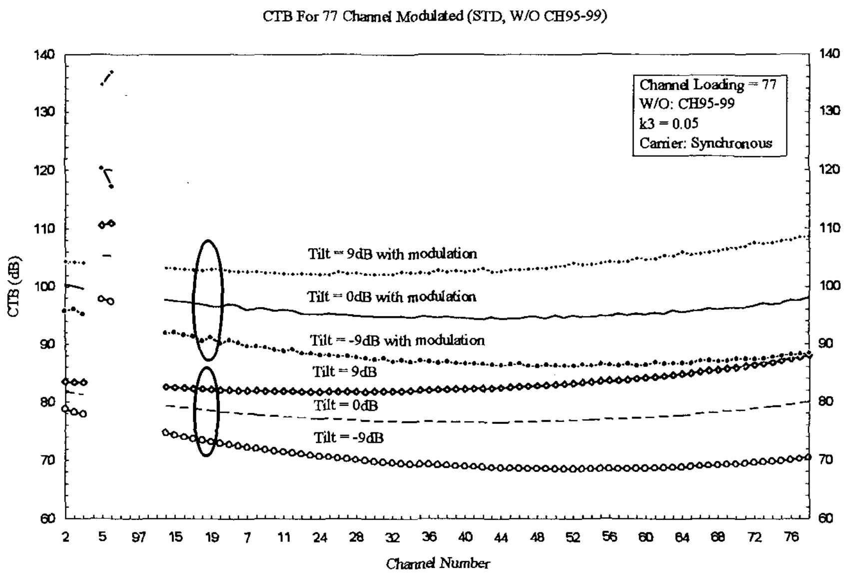


Figure 9

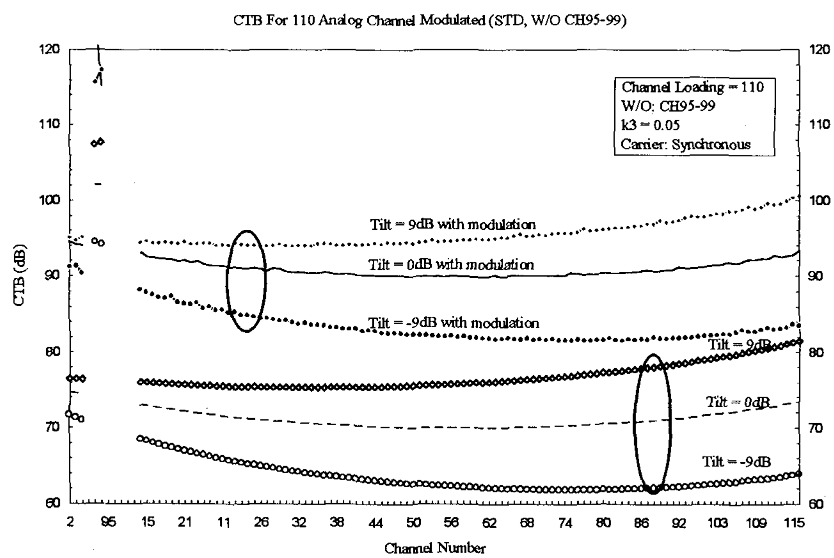


Figure 10

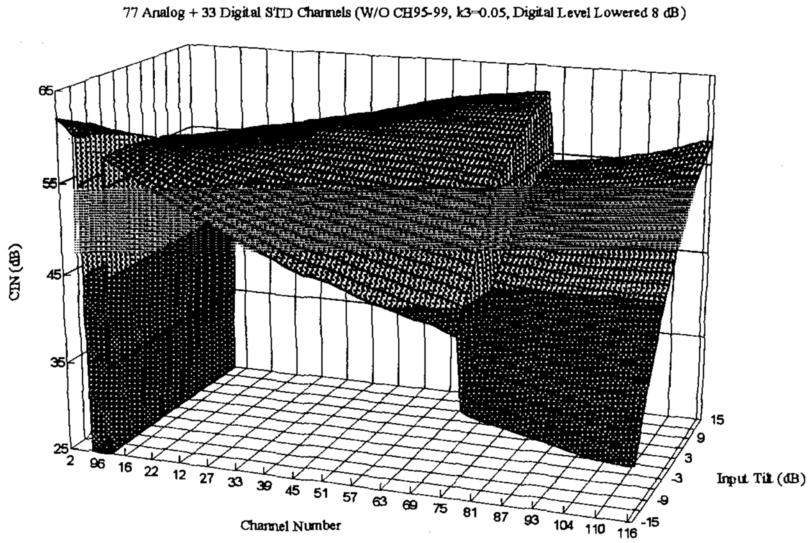
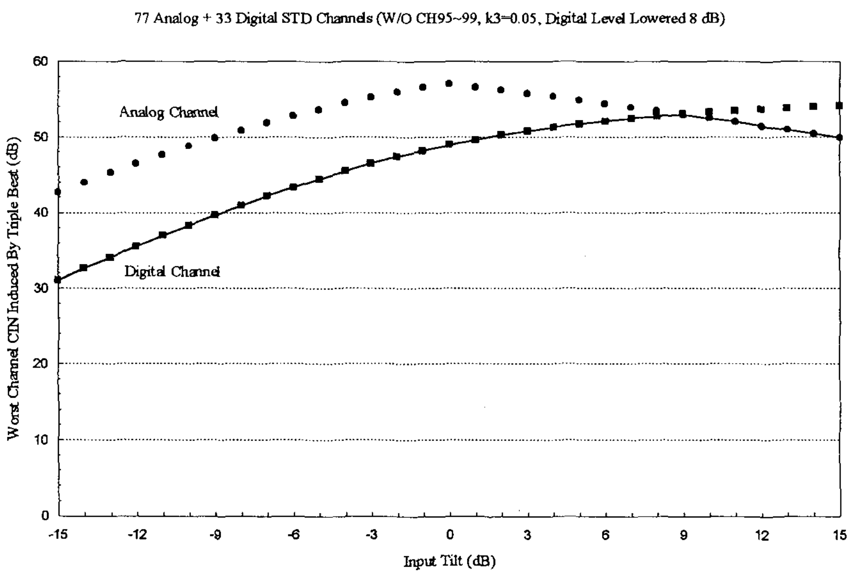


Figure 11



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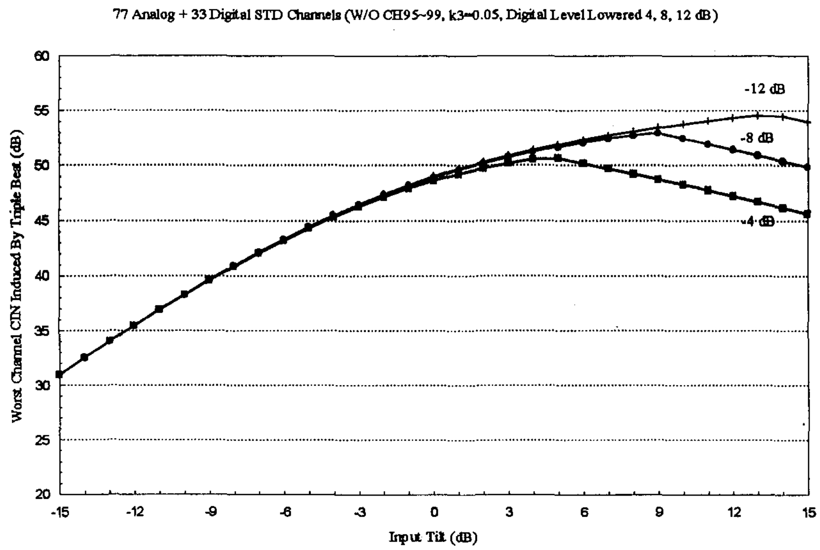
77 Analog + 33 Digital STD Channels (W/O CH95~99, k3=0.05, Digital Level Lowered 4, 8, 12 dB)
Worst Channel C/N Induced By Triple Beat (dB)
Input Tilt (dB)
-12 dB
-8 dB
-4 dB
60
55
50
45
40
35
30
25
20
-15
-12
-9
-6
-3
0
3
6
9
12
15

Figure 13