MIGRATION TO FULL DIGITAL CHANNEL LOADING ON A CABLE SYSTEM

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ABSTRACT

Present day cable systems run a mix of both analog and digital signals. As digital services evolve, HDTV becomes reality, and competition from fully digitized direct satellite services increases, migration toward a full digital spectrum is inevitable. Moving to a full digital multiplex raises some concerns with regard to distribution and signal quality. Digital signals produce noise-like distortions that extend throughout the spectrum. Full digital channel loading will decrease the measured C/N (Es/No) in the QAM channels. This paper will present the results of lab tests to determine optimum levels for digital signal distribution and the effect of a full digital multiplex on a modern cable plant. Digital signal quality issues are also investigated.

BACKGROUND

With the rollout of HDTV and competition from fully digital home satellite systems, increasing the number of digital channels in a cable system is the next step in digital deployment. Increasing digital services will attract new subscribers, provide higher quality services and minimize existing subscriber turnover.

Typical cable systems are currently running a mixture of both analog and digital channels with the digital signals appended to the higher frequency edge. Due to distribution system non-linearities, it has been shown that digital distortion produces a noise-like spectrum that extends into the lower adjacent analog channels [1]. This phenomenon is known as Composite Intermodulation Noise (CIN) and has been described in earlier publications [2].

Systems evolving to a full digital multiplex will also need to concern themselves with the effects of CIN throughout the distribution system. Full digital loading will produce noise-like distortions that extend throughout the spectrum. Characterization of digital second order intermodulation products shows that they always fall outside the frequency range of the digital signals that generate the products. Third order intermodulation products fall into several distinct categories. These distortion products have components that fall outside the frequency range of the source signals and also components that fall within the signal bandwidth. Second and third order distortion products (those falling outside the generating signal's bandwidth) are statistical in nature, additive, and uncorrelated in time with respect to the active signals [3]. This will decrease the measured C/N or Es/No in the digital channels, with the greatest degradation occurring near the center and edges of the frequency range. The effect will be proportional to the number of digital channels present and their overall power level [1].

A third order distortion product that falls within the bandwidth of the signal that generates the product is classified as a cross-modulation product and has a multiplicative effect. These products are correlated with the generating signal and cannot be measured using spectral analysis [3]. Therefore, the measured Es/No values presented in this paper exclude the cross modulation effect.

Operating the digital signals at reduced power levels through the distribution system minimizes the effects of intermodulation products. A balance between noise and distortion products must be achieved in order to optimize Bit Error Rate (BER) performance. Tests were conducted with the objective of determining optimum levels for digital signal distribution, consistent with avoiding fiber optic clipping and minimizing CIN. Es/No ratios and digital signal quality were measured as a function of frequency throughout the spectrum. Digital signal quality in the test channels was gauged according to Bit Error Rate (BER) and Modulation Error Ratio (MER).

TEST SYSTEM DESCRIPTION

The system configuration for the tests consisted of a 133 digital channel multiplex in the 55-860 MHz range. Tests were conducted on 9 channels spaced throughout the spectrum. A block diagram of the test system is shown in Figure 1. The digital multiplex was generated using a platform of 49 independent digital signals received from various satellites and transcoded to 64 QAM via a Headend consisting of Motorola IRT1000 and IRT2000 Integrated Receiver/Transcoders.

To generate the full multiplex, the spectrum was broken up into 4 distinct frequency groups as follows: 55.25 to 97.25 MHz (Group 1), 97.25 to 349.225 MHz (Group 2), 355.25 to 601.25 MHz (Group 3), and 607.25 to 853.25 MHz (Group 4). Group 1 channels were received from 7 IRT's and independently upconverted using Motorola C6U upconverters. The IF outputs of 42 IRT's were split with each leg feeding two separate C6U upconverters that covered groups 3 and 4. Group 4's RF spectrum was split with one leg down-converted using a mixer to generate the signals in Group 2. Group 2 and 3 were de-correlated from the original signals using two fiber optic links with delays of 1 km and 2 km, respectively. All 4 groups were then combined to form a contiguous spectrum of uncorrelated digital channels.

A notch filter was used to reject noise contributions prior to the distribution system for each channel under test. The filter was inserted after the combined output of a frequency group and prior to the group's introduction into the combined multiplex. This provided better than 50 dB of noise rejection in the channel under test. The channel that originally occupied the space in the multiplex was turned off and a 64/256 QAM signal transmitting a Pseudo-Random Bit Stream (PRBS) was inserted in order to make BER and MER measurements. Once the test on the channel was completed, the filters were removed and the original channel reinserted. Filters were available for all channels except EIA Channel 134. The Carrier to Noise ratio measured on this channel was better than 49 dBc and the measurement error due to the absence of the notch filter was assumed to be negligible.

Figure 2 Shows the HFC distribution system. The digital multiplex was input to a medium sized HFC distribution system. The optics consisted of an ALM-11 1310 nm laser transmitter, 20 kilometers of fiber, and an SG-2000 Fiber optic node. The RF system consisted of two Motorola BLE-87S/G GaAs line extenders and 21 taps. The RF distribution system was designed with 11.5 dB of tilt for 860 MHz spacing. The SG-2000 and Line Extenders were operated in manual mode with the AGC disabled. A characteristic of this particular distribution system displayed a slight flattening of the frequencies above 700 MHz originating from the SG-2000 node. This propagated through the distribution system to the 2nd line extender.

The level of the digital multiplex was adjusted to provide an input level that is near optimal for the fiber optic transmitter. A power meter was used at the laser's RF test point to monitor AGC effects on laser drive level and provide an indication of modulation. The transmitter's AGC works on average power and maintains a constant drive level to the laser. Motorola's Headend Control Software (HCS) was used to monitor and control the transmitter's laser drive level, optical output power, and the laser Depth of Modulation (DOM). With AGC enabled, the average power at the laser test point varied according to the laser DOM between -23.5 to -25 dBm.

Digital C/N (Es/No) ratios were measured using a HP89441 Vector Signal Analyzer. 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. The digital 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. Two Motorola DCT2000's, modified to run Broadcom QAMLink™ software, were used to monitor the Pre and Post FEC BER, and MER of the digital channel under observation. A constant signal level of 0 dBmV (±2dB) was maintained at the set top input throughout the test.

TEST RESULTS

Tests were performed with the laser's AGC enabled in both Preset and Set Modes. The AGC maintains the laser DOM in both factory set and user offset levels. Preset Mode allows the laser AGC to maintain the Depth of Modulation (DOM) at factory-default level. This level is optimized for a full load of 110 NTSC channels. Set Mode allows the DOM to be incremented or decremented from factory set levels by 0.25 dB increments. For a typical analog system, reducing the laser DOM by 1 dB degrades the C/N ratio by approximately the same level and improves intermodulation distortion products by approximately 2 dB and 1 dB for CTB and CSO, respectively. Test results for the different modes of operation are given below. All MER and short-term BER tests were performed using a PRBS source for both 64 and 256 QAM on all test channels.

Testing was also performed with a reduced channel loading of 91 digital channels. The amplifier drive level was adjusted to meet the same Carrier/Noise ratio and C/CTB and C/CSO ratios as with the full digital multiplex.

Preset Mode

Initial link analysis was performed with 133 CW carriers to adjust the distribution systems operating level with respect to a full analog spectrum. The number of NTSC channels specifies the input level (total power or power per channel) to the laser transmitter. The nominal level specified for 133 NTSC channels is approximately 12.5 dBmV/Channel. The laser was operated in the preset-CW mode for performance testing which increases the drive level to the laser by 3 dB. Output of the distribution system was set to typical C/N, C/CTB and C/CSO operating levels when running a fully loaded modulated NTSC spectrum. Table 1 shows the performance of the HFC distribution system with full analog loading measured at the node and line extender 2 (BLE #2) outputs. The optimum output level of the distribution system was found to be 32.5 and 43.5 dBmV for 55.25 and 853.25 MHz, respectively, to achieve typical performance parameters.

For preset testing in video mode, the Laser Depth of Modulation (DOM) is held constant by the AGC at 0 dB and the Laser Drive Level at 5.75 dBm. The average power of each digital signal was set according to analog specifications described above. Initial tests were run to find the effects of amplifier cascade drive level changes on the distribution system. To find the optimal levels for running the RF cascade, the input level to the transmitter was held constant and the SG-2000 RF output level was varied around the optimum NTSC operating point of 32.5/43.5 dBmV. This optimum operating point represents the average power level that would be seen with a fully loaded NTSC system. Figure 3 shows the results of 64 QAM Es/No Ratio versus Frequency performance for different RF cascade operating levels.

Higher levels of distortion are seen on the higher frequency channels as the power level of the RF section is increased. This can be attributed to the positive tilt in the distribution system, which causes increased amplifier distortion at the higher frequency channels. The low Es/No ratio levels at the lower frequency edge can be attributed to second order intermodulation distortion.

Figure 3 shows that, when the amplifier section is run into compression, digital third order distortions are reduced approximately 1.5 dB by a 1 dB decrease in amplifier drive level. This decrease in the noise floor extends to an operating level approximately 2.5 dB above the distribution system's optimum setting of 32.5/43.5 dBmV. This effect is predominant in the higher frequency range. Below this level, a 1 dB decrease in output level shows less than a 1 dB decrease in Es/No ratio performance throughout the spectrum. Operating the RF section for improved distortion performance as opposed to optimum C/N ratio improves overall system performance. The recommended Es/No ratios are 28 dB and 34 dB for 64 QAM and 256 QAM, respectively. From the figure, the worst-case recorded Es/No ratio of 38.2 dB exceeds the minimum recommended Es/No ratio operating level for both modulation schemes.

Test data in Table 2 and Table 3 show MER and short term Pre-Reed-Solomon (Pre-RS) BER performance for both 64 and 256 QAM. Pre-RS BER is measured after Trellis Decoding in the QAM decoder. Note that the Pre-RS bit error rates for all short term tests were well within acceptable levels of operation. Test data on Pre-RS BER performance for 64 QAM signals indicate no errors occurring in the test channels. Improvement should be seen in the 256 QAM Pre-RS BER rate as the time duration is increased as shown in long term BER testing. No burst errors were recorded and the Post-FEC BER for all tests was recorded at zero errors. MER values for both 64 and 256 QAM test channels are also reasonable. An improvement in MER for both 64 and 256 QAM is seen as the amplifier drive levels are reduced.

Measurements were made to determine the Es/No ratio degradation at various depths within the RF section under the optimum amplifier drive level. Figure 4 shows the Es/No ratio versus Frequency for the RF section of the distribution system. Table 4 shows test data for both 64 and 256 QAM MER. Data shows that digital signal degradation is minimal through the different amplifier stages as long as the bandwidth and minimal operating conditions for the distribution system are met.

Set Mode

Since the laser is optimized for 110 NTSC channels in preset video mode, the transmitter was changed to set-mode in order to control and change the Depth of Modulation.

Figure 5 shows the effect of changes in DOM on noise performance. The transmitter shows approximately a 1 to 1 dB change in Es/No ratio degradation versus a decrease in DOM. This demonstrates that the laser transmitter can effectively be run in the preset video mode and is virtually transparent to the digital signals with full digital loading. Table 5 shows 64 QAM MER measurements as a function of DOM. No advantage is gained by decreasing the DOM with full digital loading. It can be seen from Figure 3, Figure 4 and Figure 5 that the RF section of the distribution system is the major contributor to digital distortions in the link.

Laser Clipping

The Laser Drive Level (LDL) was adjusted to measure the system's laser clipping margin with full digital loading. RF amplifier compression was considered to be negligible for the increase in node level variations covered in this test. To measure this effect, the Pre-RS BER was monitored while the LDL was manually increased. Laser clipping produces burst errors in the digital signal that cause large bit error counts during testing. Clipping can also cause the digital demodulator to momentarily lose synchronization. MER is a time-averaged measurement and does not effectively capture periodic clipping events; therefore, BER testing must be used to capture such events.

Bit error rate (BER) measurements were made on the test channels located throughout the digital multiplex. Short-term test results shown in the tables above demonstrated no clipping events. The LDL for 64 QAM was increased by 6 dB with no Pre-RS BER events recorded. A Pre-RS BER increase from 10E-9 to 10E-7 was recorded for 256 QAM signals at this same level. Since the Pre-RS BER is measured after Trellis decoding, some errors will be corrected and remain undetected.

Reduced Digital Loading

Reduced digital channel loading shows similar results. The decrease in the number of channels allows for the RF section to be run at a higher output level to achieve the same performance. Figure 6 and Table 6 show test data for a 91 digital signal multiplex.

Long Term BER Testing

Long-term BER tests were performed at random using the two laser modes. The tests were conducted using a PRBS 256 QAM signal located on the higher frequency channels. Table 7 presents long term bit error rate test data for different configurations of the distribution system. Note that the Pre-RS BER rate for all long term tests were on the order of 10E-9 and well within acceptable levels of operation. No burst errors were recorded and the post-FEC BER for all tests was zero errors. The MER remains constant under the different loading conditions.

CONCLUSIONS

Cable plants will soon need to transition to a fully digital multiplex due to the advent of terrestrial HDTV and the demise of analog services along with increased competition from fully digitized satellite services. Transition to full digital operation may come sooner than expected.

Amplifier reduced rebuilds in cable distribution systems typically run at levels with a C/N ratio near 49 dB and C/CSO and C/CTB ratios greater than 53 dBc. Test data show that implementing a full digital spectrum can be realized on modern distribution systems as long as system bandwidth and performance specifications are met. Test results show that digital distortion can be regarded as an additional noise source that adds to system AWGN to produce an increase in the noise floor throughout the active spectrum. Test data show that this effect remains relatively flat in the spectrum as long as the RF section is operated within reasonable limits. Minimizing the generation of digital distortion in the distribution system will improve the Es/No ratio and optimize digital signal robustness. Test data show that operating the distribution amplifiers slightly below specified operating levels can reduce system noise due to digital distortion. The worst-case recorded Es/No ratio of 38.2 dB exceeds the minimum recommended Es/No ratio operating level for both 64 and 256 QAM signals.

Current amplifier stages rely on a peak power AGC that derives its control information from an analog signal. The strategy of using peak power in the RF amplifier AGC section needs to move towards an average power type detector. This will provide stable levels due to temperature changes in the distribution system.

Transition to a full digital multiplex will soon become a necessity for cable operators.

ACKNOWLEDGMENTS

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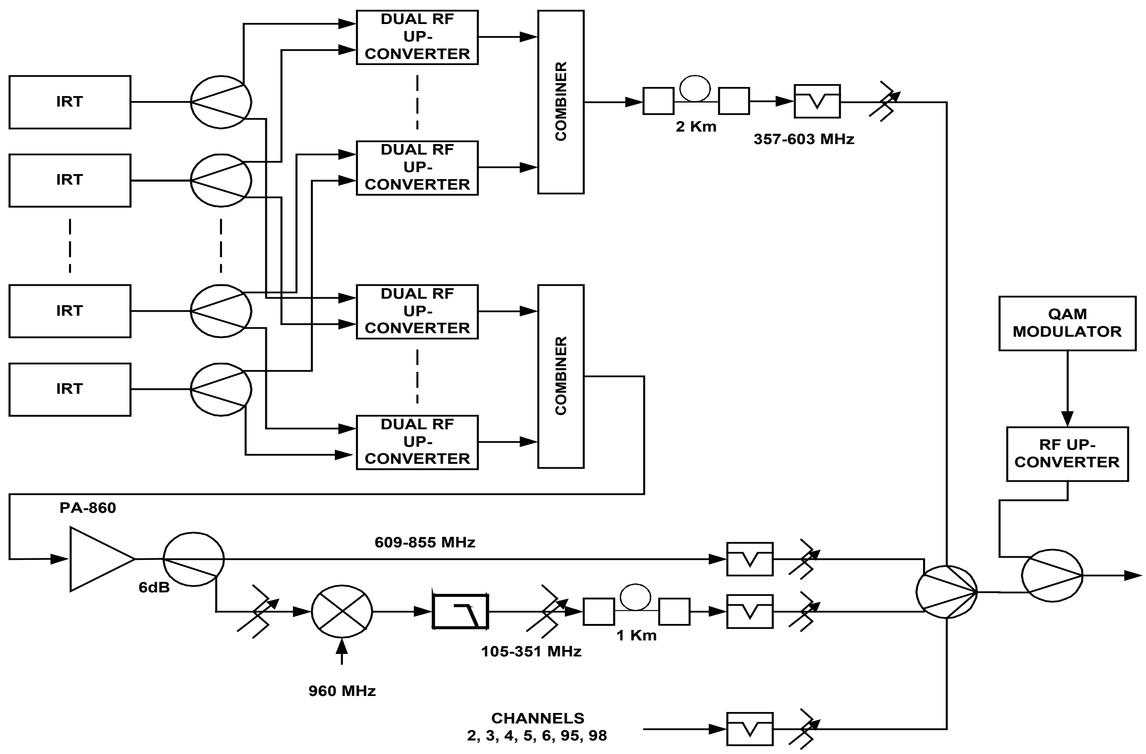

Figure 1 – Headend Configuration

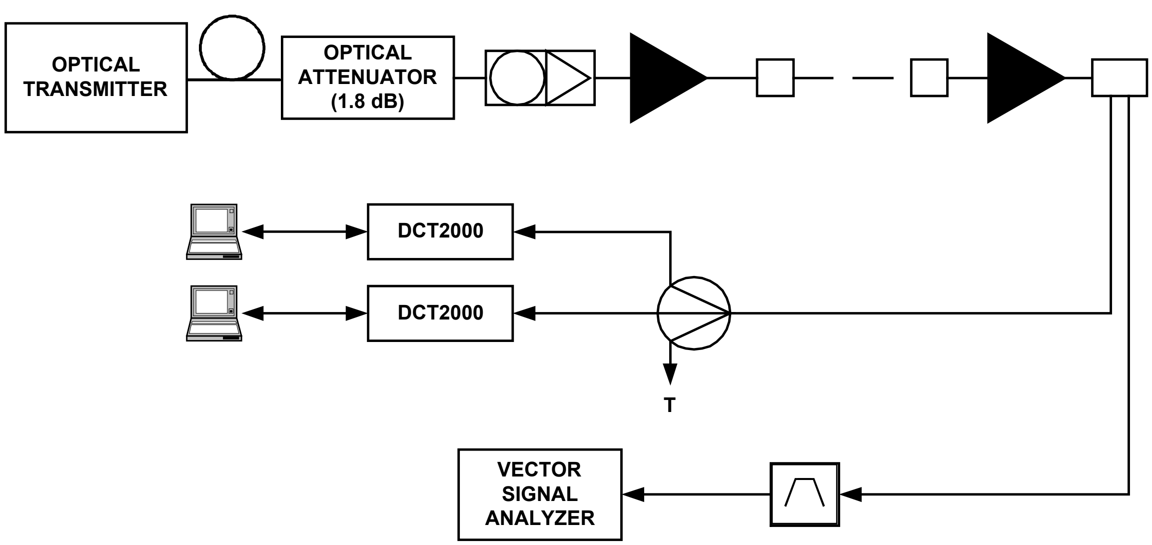

Figure 2 – HFC Configuration

Table 1 – 133 Channel CW Performance Summary

CW Performance						
Test Frequency (MHz)	C/N (dB)		C/CTB (dBc)		C/CSO (dBc)	
	Node	BLE #2	Node	BLE #2	Node	BLE #2
55.25	50.8	50.1	59.7	63.0	60.4	56.6
325.25	51.1	50.3	55.7	53.2	71.4	78.2
649.25	51.3	50.6	79.8	54.9	72.9	71.0
745.25	52.5	51.5	62.4	54.0	67.3	64.1
853.25	51.5	49.6	60.8	54.2	61.9	61.5

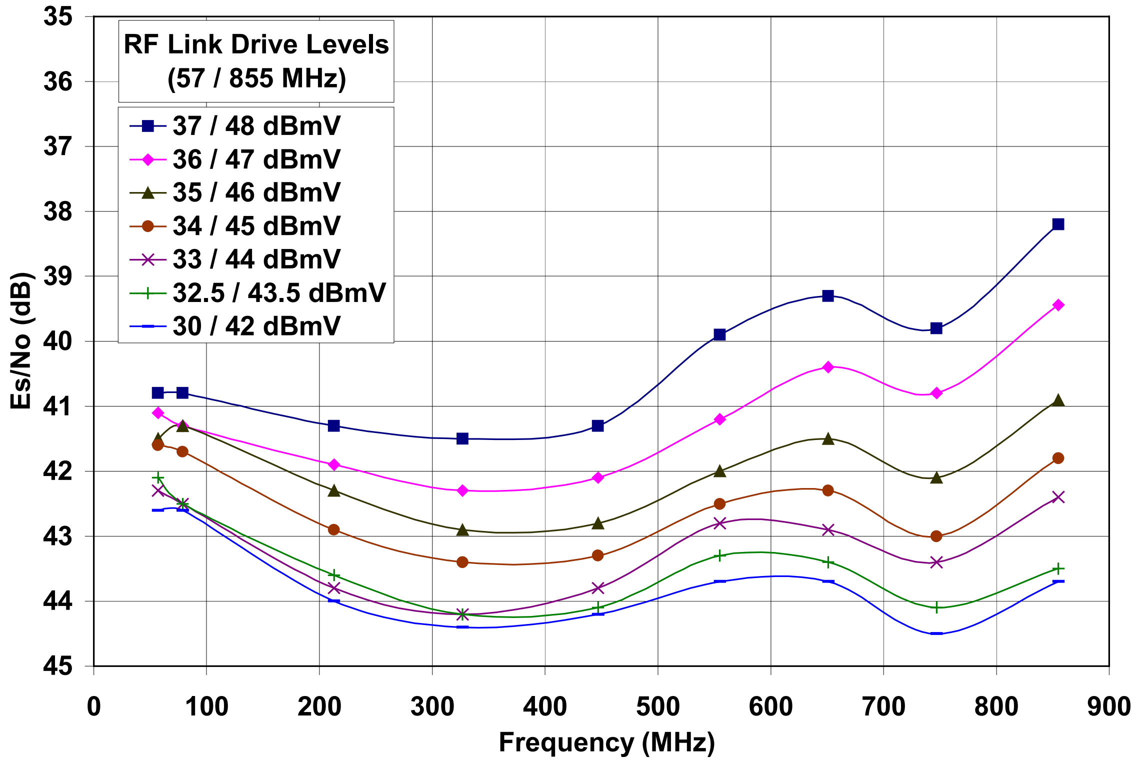

Figure 3 – SG-2000 RF Amplifier Output Level Variation for 64 QAM

Table 2 - 64 QAM Data for Variouse RF Amplifier Drive Levels

64 QAM - Laser Preset Video Mode														
Center Frequency (MHz)	SG-2000 RF Output Level 55 / 855 MHz (dBmV)													
	37 / 48		36 / 47		35 / 46		34 / 45		33 / 44		*32.5 / 43.5*		30 / 42	
	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER
57	34.3	0	34.2	0	34.4	0	34.4	0	34.5	0	34.6	0	34.6	0
79	34.4	0	34.6	0	34.4	0	34.6	0	34.7	0	34.7	0	34.7	0
213	34.1	0	34.3	0	34.7	0	34.6	0	34.9	0	34.8	0	34.9	0
327	34.3	0	34.5	0	34.6	0	34.6	0	34.7	0	34.8	0	34.8	0
447	34.6	0	34.7	0	34.8	0	34.8	0	35.0	0	34.9	0	34.9	0
555	34.1	0	34.6	0	34.6	0	34.9	0	35.0	0	34.9	0	35.0	0
651	33.9	0	34.4	0	34.6	0	34.8	0	34.8	0	35.0	0	34.9	0
747	34.2	0	34.6	0	34.8	0	34.9	0	35.0	0	35.2	0	35.1	0
855	33.6	0	33.9	0	34.5	0	34.5	0	34.8	0	34.9	0	34.8	0

Table 3 - 256 QAM Data for Variouse RF Amplifier Drive Levels

256 QAM - Laser Preset Video Mode														
Center Frequency (MHz)	SG-2000 RF Output Level 55 / 855 MHz (dBmV)													
	37 / 48		36 / 47		35 / 46		34 / 45		33 / 44		*32.5 / 43.5*		30 / 42	
	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER	MER (dB)	Pre-RS BER
57	33.1	2.1E-09	33.2	0	33.3	0	33.3	0	33.4	3.2E-09	33.4	4.2E-09	33.5	0
79	33.4	0	33.4	0	33.5	0	33.6	6.4E-09	33.6	5.7E-09	33.7	7.9E-09	33.8	1.2E-08
213	33.3	3.7E-08	33.4	0	33.5	5.0E-09	33.6	4.1E-09	33.7	0	33.6	4.8E-09	33.4	0
327	33.1	0	33.2	0	33.3	8.4E-09	33.3	1.5E-08	33.5	0	33.7	2.7E-08	33.6	0
447	33.4	0	33.5	0	33.6	1.1E-09	33.6	1.2E-09	33.7	0	33.5	5.6E-09	33.6	4.4E-09
555	33.2	0	33.5	0	33.6	2.9E-09	33.7	0	33.8	0	33.8	0	33.9	0
651	33.0	4.7E-09	33.3	4.2E-09	33.6	0	33.7	5.7E-09	33.8	0	33.9	0	33.9	0
747	33.3	1.3E-09	33.7	1.2E-08	33.9	0	33.9	6.9E-09	34.2	0	34.2	0	34.1	6.9E-09
855	32.6	5.1E-08	33.0	1.7E-08	33.4	3.7E-08	33.5	1.1E-08	33.6	0	33.7	4.8E-09	33.7	0

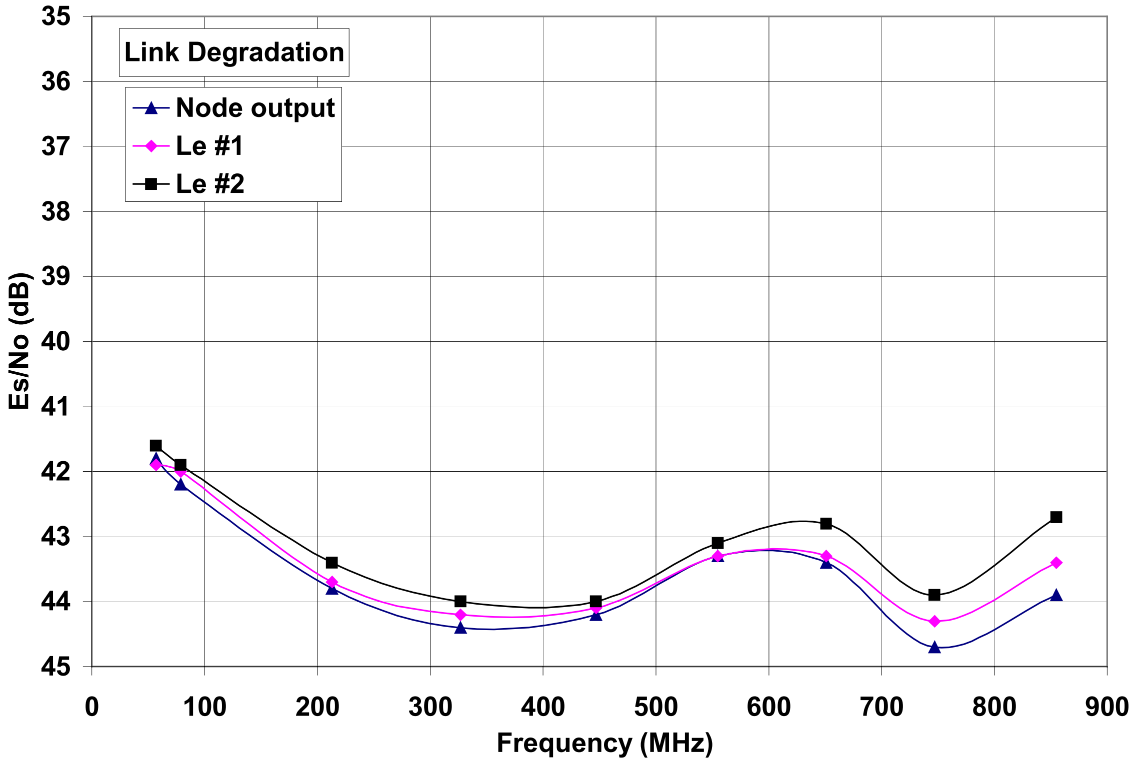

Figure 4 – Es/No versus Frequency for Distribution Depth

Table 4 – Distribution System Depth Effect on MER

ALM-11 Preset - Video Mode							
EIA Channel	Center Frequency (MHz)	SG-2000 MER (dB)		Line Extender 1 MER (dB)		Line Extender 2 MER (dB)	
		64 QAM	256 QAM	64 QAM	256 QAM	64 QAM	256 QAM
2	57	34.7	33.6	34.6	33.4	34.4	33.3
5	79	34.6	33.5	34.6	33.6	34.6	33.6
13	213	34.3	33.6	34.8	33.8	34.8	33.7
41	327	34.8	33.8	34.9	33.7	34.7	33.4
61	447	35.1	33.9	34.9	33.7	34.9	33.7
79	555	34.9	33.8	34.9	33.8	34.8	33.8
100	651	34.9	33.7	35.0	33.8	34.8	33.9
116	747	35.0	33.9	35.0	34.0	35.2	33.9
134	855	35.0	33.9	34.8	33.6	34.9	33.6

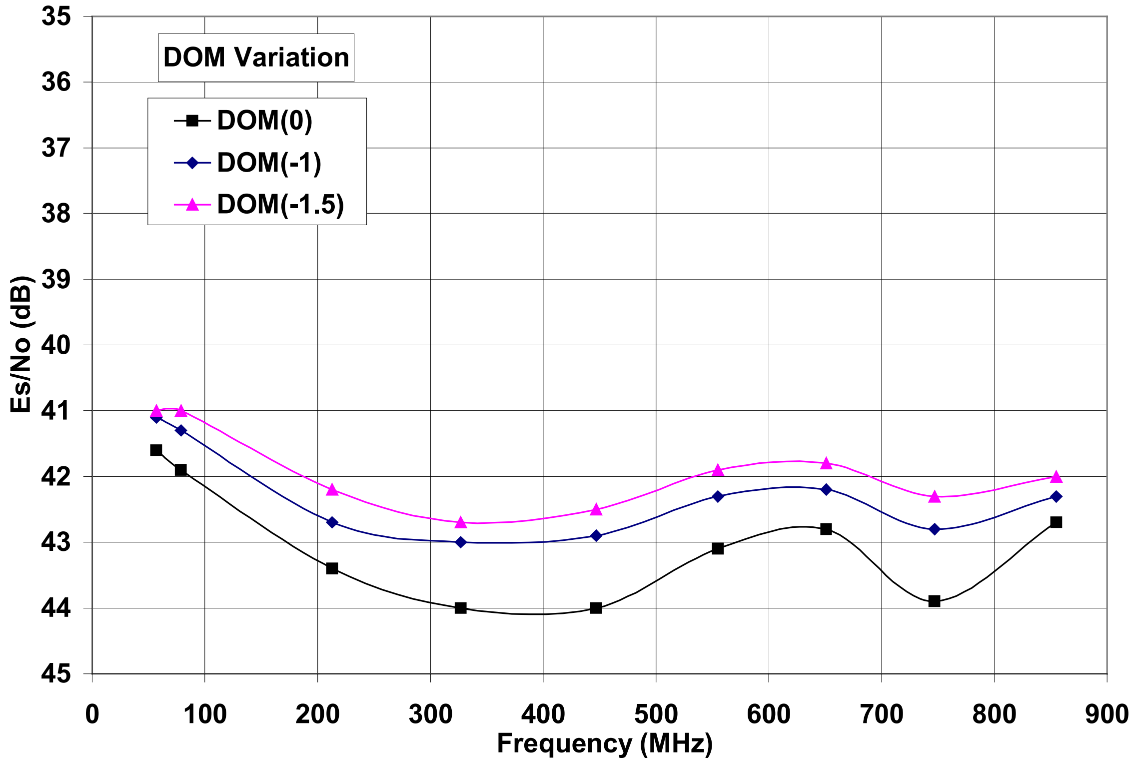

Figure 5 – 64 QAM Es/No versus Frequency for DOM Variations

Table 5 – DOM Variations on 64 QAM MER

64 QAM							
EIA Channel	Center Frequency (MHz)	DOM (dB) / LDL (dBm)					
		0 / 5.75		-1 / 4.75		-1.5 / 4.25	
		MER (dB)	Pre-FEC BER	MER (dB)	Pre-FEC BER	MER (dB)	Pre-FEC BER
2	57	34.4	0	34.4	0	34.2	0
5	79	34.6	0	34.5	0	34.4	0
13	213	34.8	0	34.7	0	34.3	0
41	327	34.7	0	34.6	0	34.7	0
61	447	34.9	0	34.8	0	34.8	0
79	555	34.8	0	34.7	0	34.6	0
100	651	34.8	0	34.7	0	34.7	0
116	747	35.2	0	34.7	0	34.8	0
134	855	34.9	0	34.7	0	34.7	0

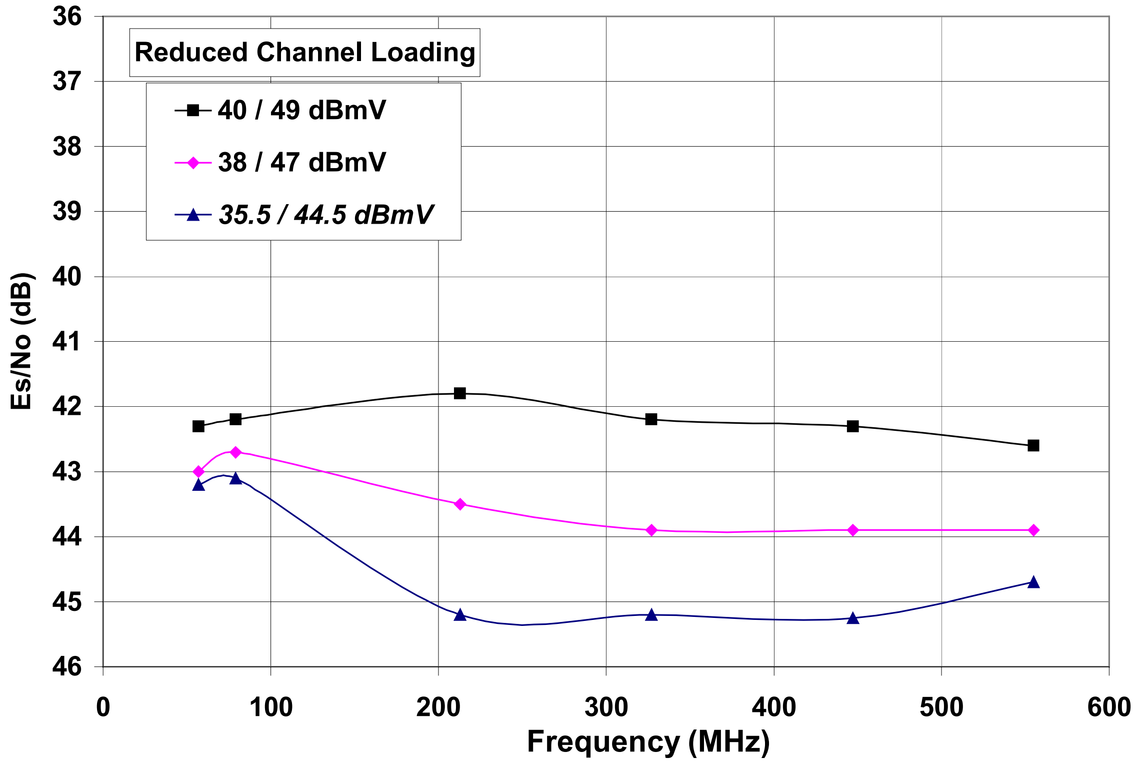

Figure 6 – 64 QAM Es/No versus Frequency for Reduced Channel Loading

Table 6 – 64 QAM MER for Reduce Loading on the Distribution System

Laser Preset Video Mode - Reduced Loading												
	SG-2000 RF Output Level 55 / 603 MHz (dBmV)											
	40 / 49				38 / 47				*35.5 / 44.5*			
Center Frequency (MHz)	256 QAM MER (dB)	256 QAM Pre-RS BER	64 QAM MER (dB)	64 QAM Pre-RS BER	256 QAM MER (dB)	256 QAM Pre-RS BER	64 QAM MER (dB)	64 QAM Pre-RS BER	256 QAM MER (dB)	256 QAM Pre-RS BER	64 QAM MER (dB)	64 QAM Pre-RS BER
57	33.4	0	34.6	0	33.5	0	34.7	0	33.5	0	34.6	0
79	33.6	0	34.5	0	33.7	0	34.8	0	33.8	0	34.7	0
213	33.4	0	34.1	0	33.6	0	34.7	0	33.7	0	35.0	0
327	33.2	0	34.5	0	33.4	0	34.9	0	33.4	0	34.9	0
447	33.5	0	34.8	0	33.8	0	35.0	0	33.8	0	35.1	0
555	33.8	3.5E-08	34.8	0	33.9	0	34.9	0	33.9	4.8E-09	35.2	0

Table 7 – 256 QAM Long Term Bit Error Testing

256 QAM - Long Term BER				
LDL (dBm)	5.75	5.75	4.25	5.75
DOM (dB)	0	0	-1.5	0
Loading	55 – 855 MHz	55 - 855 MHz	55 - 855 MHz	55 - 603 MHz
LE #2 Output Level (dBmV)	32.5 / 43.5	35 / 46	32.5 / 43.5	40 / 49
EIA Channel	134	100	116	79
MER (dB)	33.6	33.64	33.8	33.73
Pre-RS BER	1.80E-09	2.68E-09	3.00E-09	3.64E-09
Post-RS BER	0	0	0	0
Error Seconds	0	0	0	0
BER	0	0	0	0