Analysis of Cable System Digital Transmission Characteristics

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ABSTRACT

CableLabs has performed an evaluation of cable channel characteristics to statistically quantify the cable environment for high speed, band-limited transmission of digital information in a study conducted in cooperation with several of our member cable system operators. Approximately three hundred subscriber home sites in twenty cable systems were measured and analyzed over a wide range of channel frequencies.

The range of channel characteristics, degree of impairment, and relative frequency of occurrence in a statistical distribution of both the cable plant and the subscriber home wiring is presented. These results provide the purveyors of digital cable modem equipment with valuable design information which can be used to determine the receiver interference mitigation techniques required, the complexity and performance characteristics of a demodulator design, and the relative percentage of cable subscribers who can satisfactorily receive a digital transmission utilizing a specific demodulator implementation.

Various measurements of relevant channel characteristics provide useful information needed for both cost and performance optimization of the digital demodulator, as well as the cable system transmission equipment.

INTRODUCTION

The range of channel characteristics, degree of impairment, and relative frequency of occurrence in a statistical distribution of both the cable plant and the subscriber home wiring is needed to determine the receiver interference mitigation techniques required, the complexity and performance characteristics of a demodulator design, and the relative percentage of cable subscribers who can satisfactorily receive a digital transmission utilizing a specific demodulator implementation. Thermal noise level, carrier power level, channel frequency response (or alternatively impulse response) and interference due to ingress characterized by a statistical distribution of stationary disturbances in the cable environment provide useful information needed for both cost and performance optimization of the digital demodulator, as well as the cable system transmission equipment.

CableLabs has completed a digital channel characterization project that quantifies these stationary impairments on a multiplicity of cable systems across the U.S. and Canada. A number of geographically separated cable systems of varying size, age, and technology were investigated. Within each cable system, multiple distribution tap and home locations on as diverse a set of system branches as possible were measured. This data is available to provide the purveyors of digital cable modem equipment with valuable design information.

METHODOLOGY

The Digital Transmission Characterization project conducted field measurements of both cable television transmission channel and subscriber home distribution characteristics. The field measurements were performed using computer automated instrumentation installed in a vehicle integrated into a self-powered mobile laboratory testing environment. The data acquired at each location within each cable system was compiled into a database for generation of a statistical distribution of cable plant and subscriber home wiring transmission characteristics including frequency response, shielding effectiveness, ingress, thermal noise level, carrier power level, time domain reflection response, and composite triple beat intermodulation distortion level. This measured data can be linked to a description of relevant cable system design parameters obtained and catalogued for each cable system prior to measurement.

At each cable system subscriber location tested, a series of ten automated measurements were performed for assessing these cable system performance characteristics. All measurements were performed in the upper frequency region of each cable system where spectrum was available but not utilized for conventional analog signals (usually in a recently upgraded system prior to deploying expanded channels). These measurements are as follows:

1) Headend to Home Outlet Amplitude Flatness and Group Delay
2) Headend to Tap Amplitude Flatness and Group Delay
3) Cable System Signal Spectrum at the Tap
4) Cable System Noise Spectrum at the Tap
5) Cable System Ingress Spectrum at the Tap
6) Composite Triple Beat Level at the Tap
7) Local FM Field Strength
8) Home Wiring Shielding Effectiveness
9) Home Wiring Amplitude Flatness and Group Delay
10) Home Wiring Time Domain Reflection Response

An easy to use menu driven software program for instrument control and data acquisition had been developed to control various instruments and catalogue measurement data via a GPIB board connected to a DOS computer. All ten measurements are available in the measure menu. In addition, instrument states and calibration data are saved and restored to the instrument.

Instrument control parameters were provided in input script files that were easily edited on site for local cable system parameters. Because of the diversity of each cable plant, this script file scheme allows changing a given measurement by editing the input script files at each measurement site. This greatly simplifies data collection in the field which is much less controllable and predictable than laboratory measurement. In addition, no changes to the control program are necessary from one site to another.

After starting a measurement, instrument settings can be readjusted and data re-acquired. This process can be repeated until valid measurement data is obtained. The software has great flexibility by allowing complete control over the measurement process. Measurement data is stored into output data files along with instrument settings in the header information in the computer database for later analysis.

RESULTS

A major cause of digital signal degradation at the receiver results from corruption by intersymbol interference caused by a deviation from the ideal (i.e., Nyquist) channel response required for high speed data transmission over band-limited channels. The intersymbol interference introduces time dispersion, causing each received data symbol pulse response to overlap with many adjacent symbols in a destructive manner. The deviation of the channel characteristics from the ideal are caused by signal reflections due to impedance discontinuities in the transmission path(s).

Examples of amplitude flatness and group delay responses at one subscriber test location are shown in Figures 1 and 2 respectively. The degradation due to intersymbol interference is most easily assessed in the impulse response as reduced amplitude, delayed versions of the main impulse. The frequency response data is inverse Fourier transformed from the previous measured data into the impulse response of Figure 3. An echo approximately 24 dB down delayed 100 nanoseconds is apparent in the figure.

As a very large number of responses were measured, a statistical representation of the impulse responses is calculated using a two-dimensional histogram depicting the relative frequency (or probability) of a given echo amplitude attenuation at a given delay time. This result for the cascaded cable plant plus inside home wiring is shown in Figure 4. The echoes of more significant amplitude (20 dB attenuation or less) occur at delays of less than 500 nanoseconds. Longer delay echoes are more attenuated. More densely packed modulation formats with a larger number of states are more susceptible to echoes; hence even very weak echoes may be significant as data capacity is increased.

By projecting the data onto either the amplitude or delay axis of Figure 4, a relative frequency of each echo parameter is obtained independently. The distribution of echo amplitudes is shown in Figure 5. The distribution of echo delay times is shown in Figure 7. A useful characterization of the measured echo distributions would depict the total percentage of sites with either echo amplitudes or delays larger than a given value. This is available from the cumulative distributions obtained by integration of the relative frequency distributions. The cumulative relative frequency of echo amplitudes is shown in Figure 6. The cumulative relative frequency of echo delay times is shown in Figure 8. One may ascertain by inspection of the cumulative distributions shown in Figures 6 and 8 that 90 percent of the home sites measured had echo amplitudes less than -27 dB below the desired signal and delay times less than 570 nanoseconds.

The shielding effectiveness of the home wiring was measured in the FM radio frequency band. The strength of the local FM field was measured with a dipole antenna at the test site. The home wiring was disconnected from the cable plant and terminated. The terminated home wiring replaced the antenna and the FM field strength measured again. The shielding effectiveness is calculated as the ratio of these two measurements averaged over all the local FM stations received at that location. The relative and cumulative distributions of home wiring shielding effectiveness are shown in Figures 9 and 10 respectively. Although the average as well as the median shielding over all sites is greater than 58 dB, a small but significant number of homes (about 5 percent) provided less than 36 dB shielding. These homes are much more susceptible to ingress from external RF signals.

The carrier-to-noise ratio relating the received signal energy to the thermal (additive white Gaussian) noise level is a fundamental performance parameter in determining the received bit error rate. The carrier power relative and cumulative distributions are shown in Figures 11 and 12 respectively. The noise power relative and cumulative distributions are shown in Figures 13 and 14 respectively. The carrier-to-noise ratio relative and cumulative distributions are shown in Figures 15 and 16 respectively.

The spurious power measured indicates the total non-thermal peak noise power due to intermodulation components and the ingress of external RF signals into the cable system. The spurious power relative and cumulative distributions are shown in Figures 17 and 18 respectively.

The specific spurious component generated as the composite triple beat (CTB) located 12 MHz above the last analog channel was measured separately. The CTB relative and cumulative distributions are shown in Figures 19 and 20 respectively.

A summary derived from the cumulative distributions of all the previously described impairments tabulates the maximum impairment values for the 50 (median), 90, 95, and 99 percent relative number of test sites measured. The results for microreflection impairments are shown in Table 1. The results for noise and interference impairments are shown in Table 2.

MicroReflection Impairments	50%	90%	95%	99%
Delay (nano sec.)	230	570	730	1280
Amplitude (dB)	-37	-27	-24	-19
System Delay (nsec.)	230	640	860	1520
System Amplitude (dB)	-37	-29	-26	-19
Home Wiring Delay (nano sec.) 50 - 200 MHz.	140	350	430	640
Home Wiring Amplitude (dB) 50 - 200 MHz.	-37	-26	-22	-16
Home Wiring Delay (nano sec.) 200 - 560 MHz.	130	330	440	1250
Home Wiring Amplitude (dB) 200 - 560 MHz.	-37	-28	-25	-19

Table 1. MicroReflection Delay and Amplitude Impairments Summary.

Noise / Interference Impairments	Ave.	50%	90%	95%	99%
Carrier / Noise (dB)	48	43	35	33	25
Carrier Power (dBm)	-32	-37	-48	-53	-60
Noise Power (dBm) in a 6 MHz. Bandwidth	-72	-82	-72	-68	-60
Spurious Power (dBm) in a 6 MHz. Bandwidth	-68	-78	-66	-62	-56
CTB Power (dBm) in a 30 kHz. Bandwidth	-93	-107	-90	-86	-80
Home Wiring Shielding (dB) in FM Band	67	58	42	36	27

Table 2. Noise / Interference Impairments Summary.

CONCLUSION

A statistical characterization of cable system impairments to digital transmission has been presented. Three hundred home sites in twenty diverse cable systems have been measured and analyzed. The relative percentage of the total measured population exceeding a given level of impairment has been derived from a statistically significant number of cable subscriber homes.

The range of cable channel characteristics, degree of impairment, and relative frequency of occurrence in a statistical distribution of both the cable plant and the subscriber home wiring presented may be used to determine the receiver interference mitigation techniques required, the complexity and performance characteristics of a demodulator design, and the relative percentage of cable subscribers who can satisfactorily receive a digital transmission utilizing a specific demodulator implementation. This data provides the manufacturers of digital cable modem equipment with valuable design information as well as insight into the existing cable environment.

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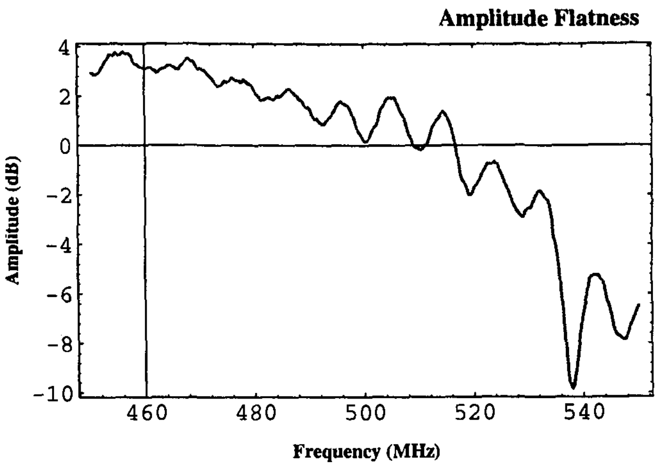

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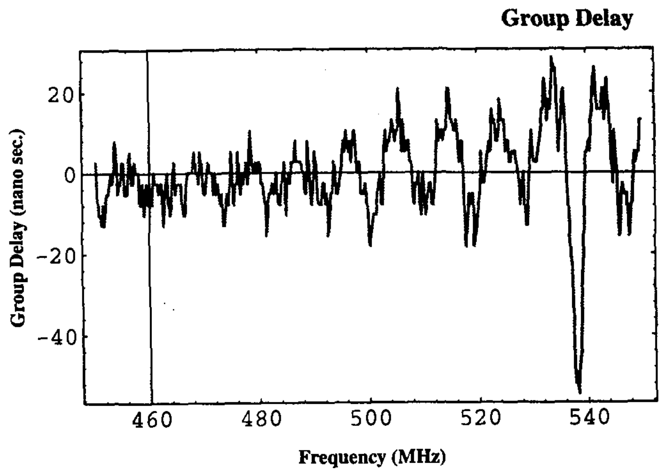

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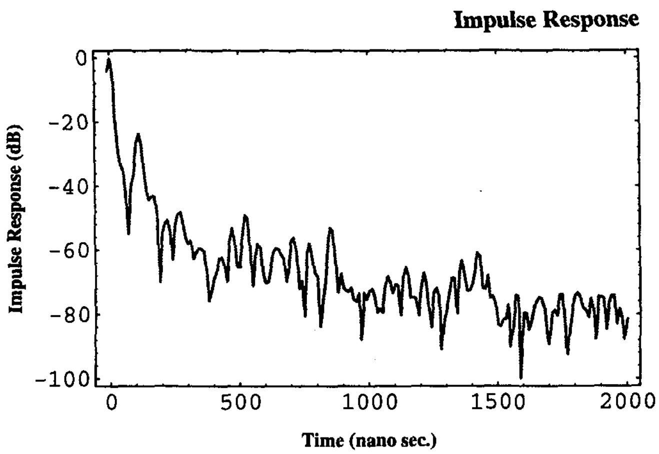

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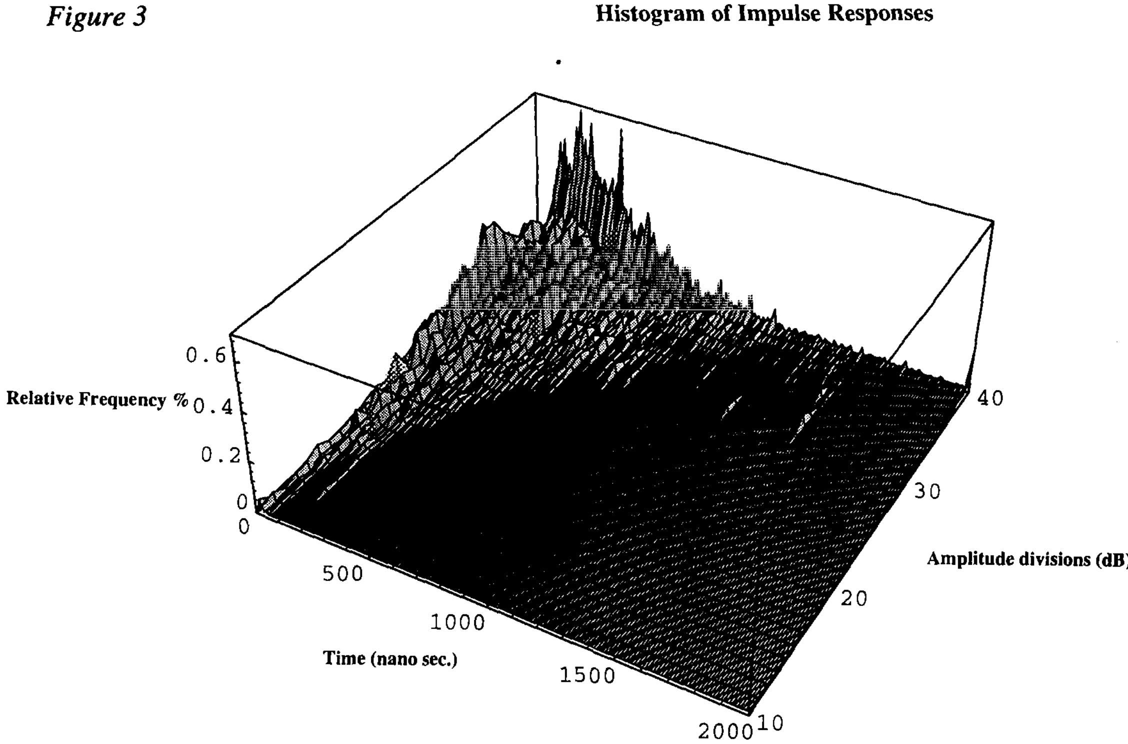

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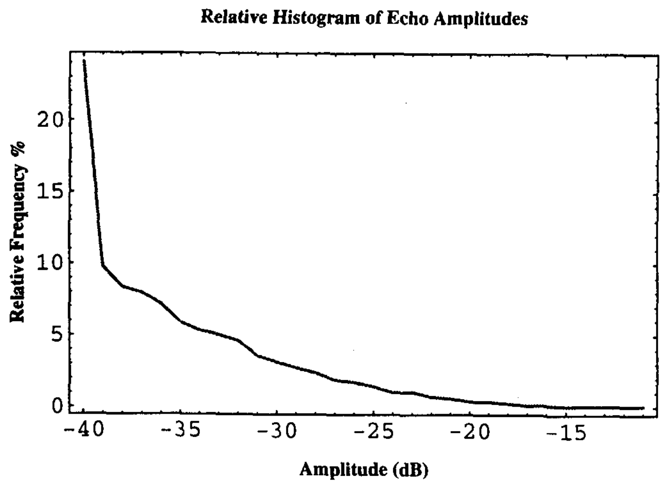

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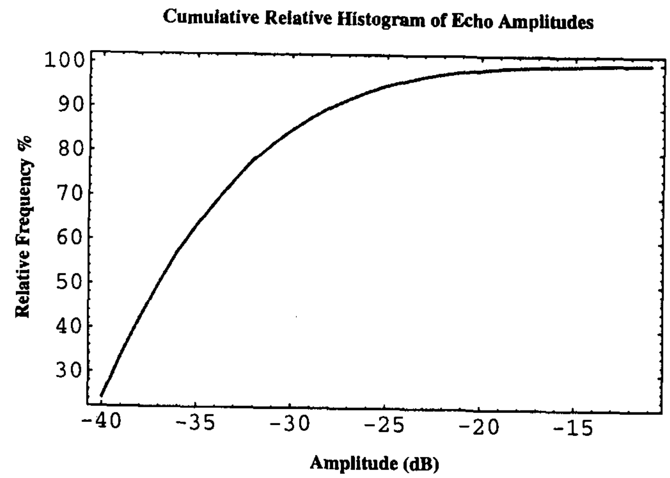

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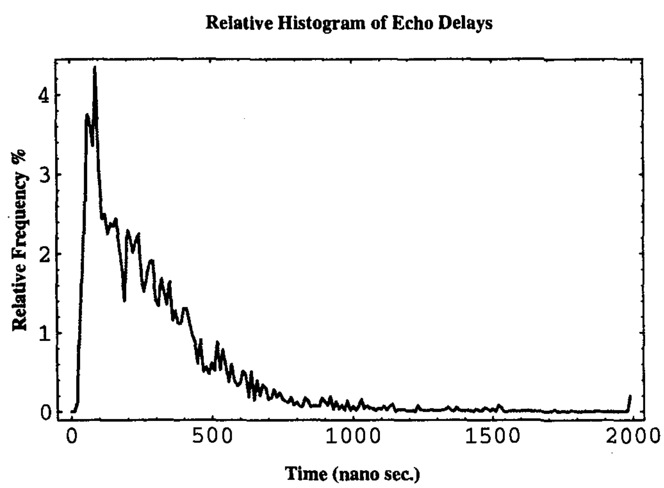

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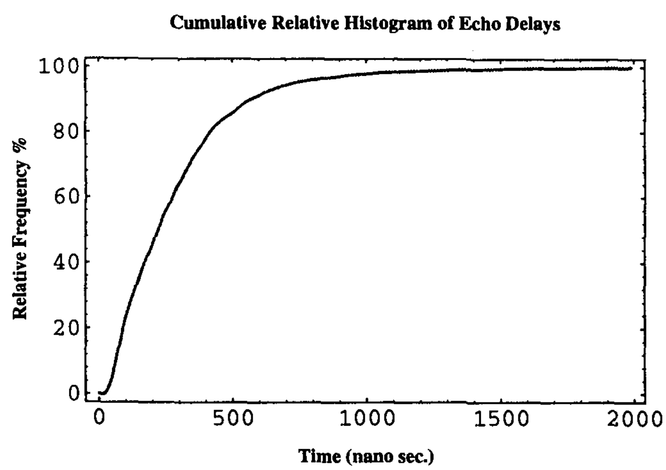

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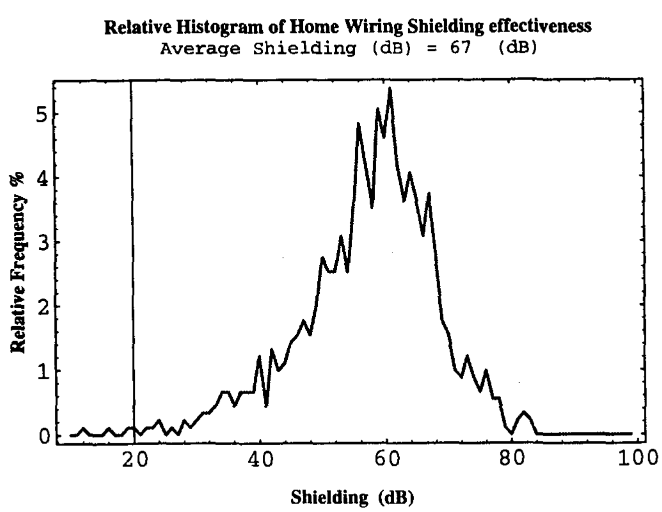

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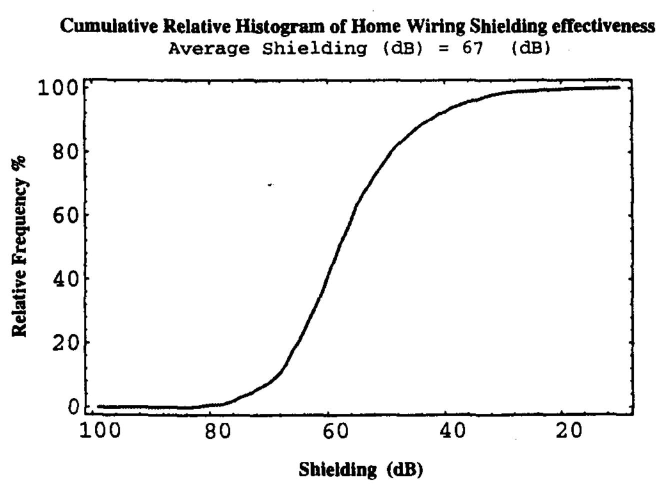

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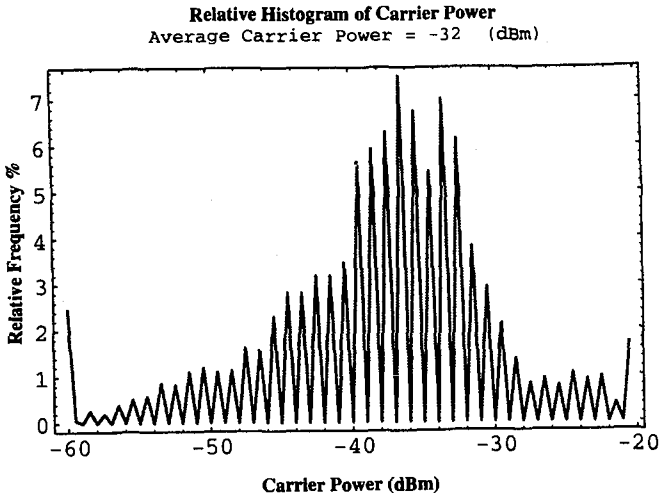

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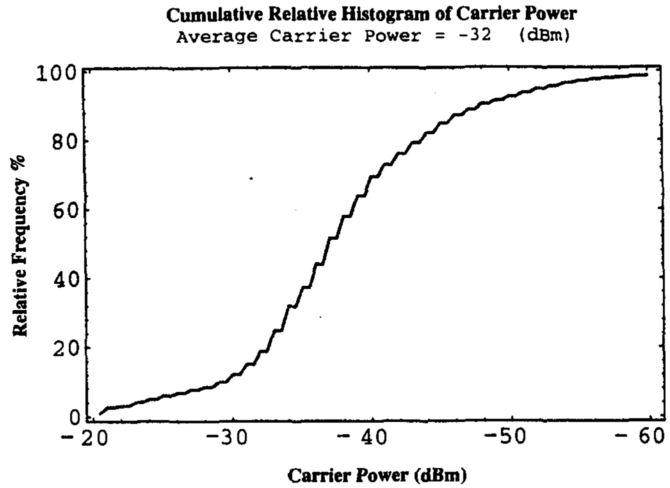

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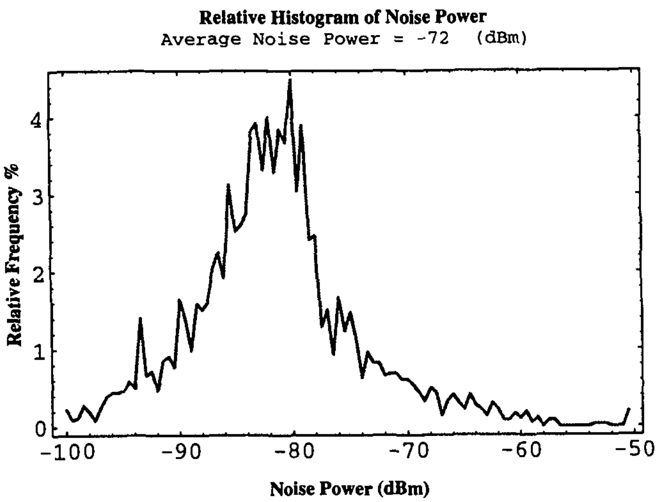

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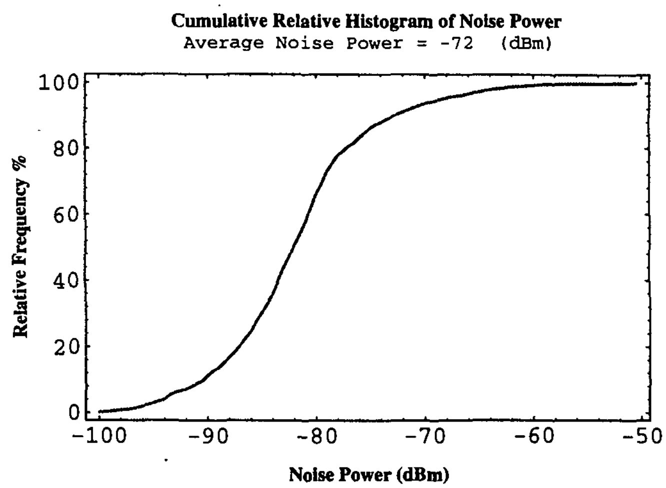

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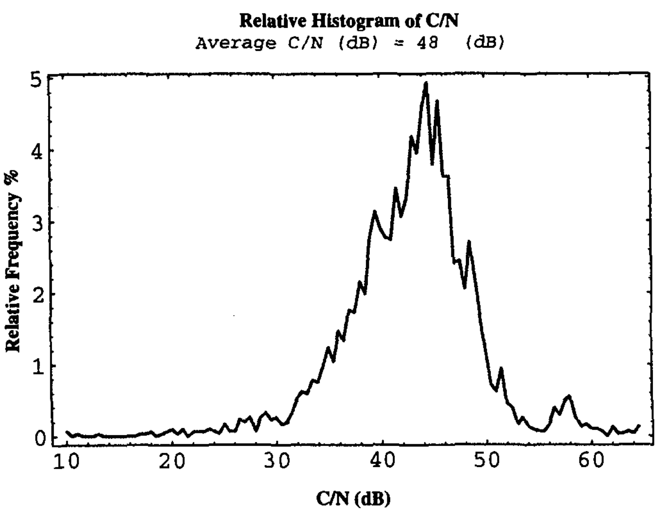

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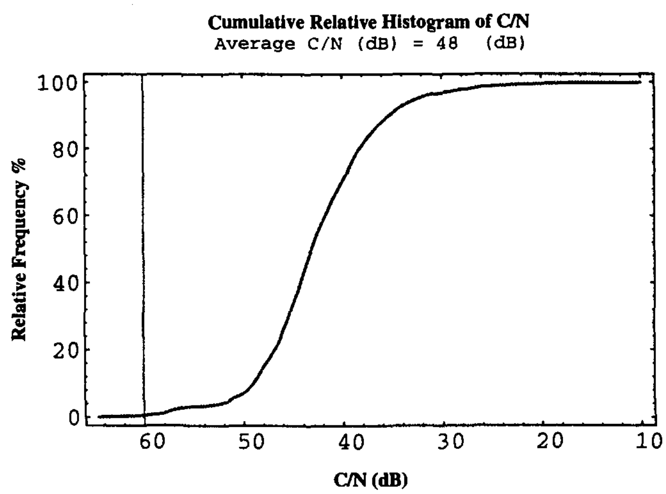

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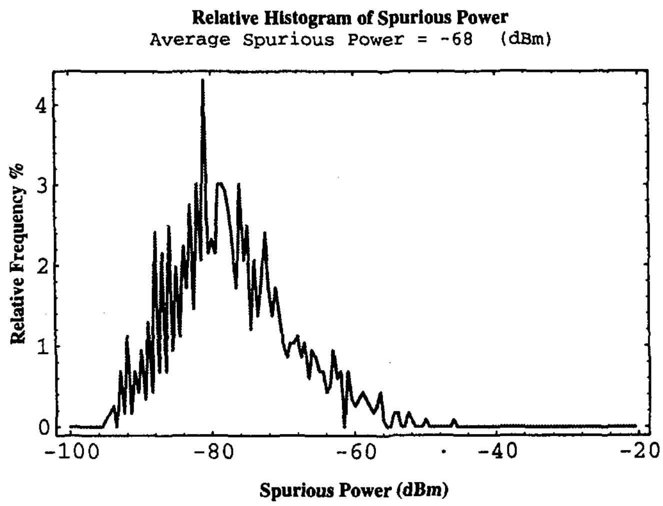

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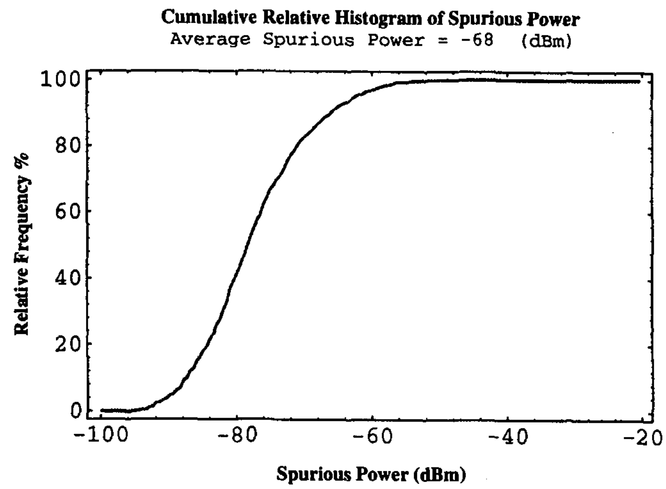

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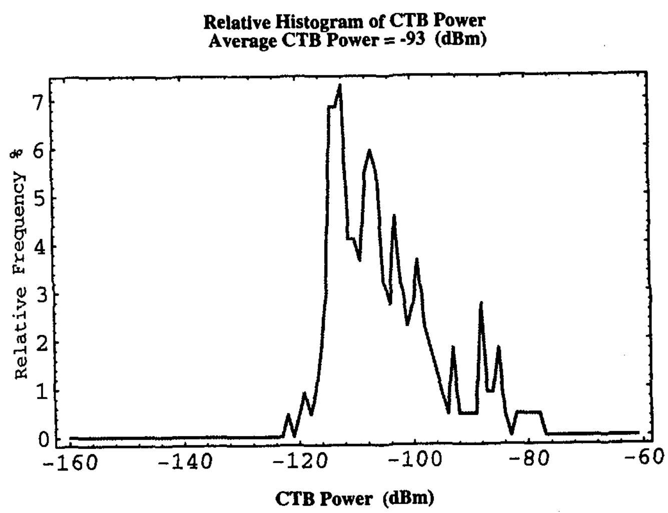

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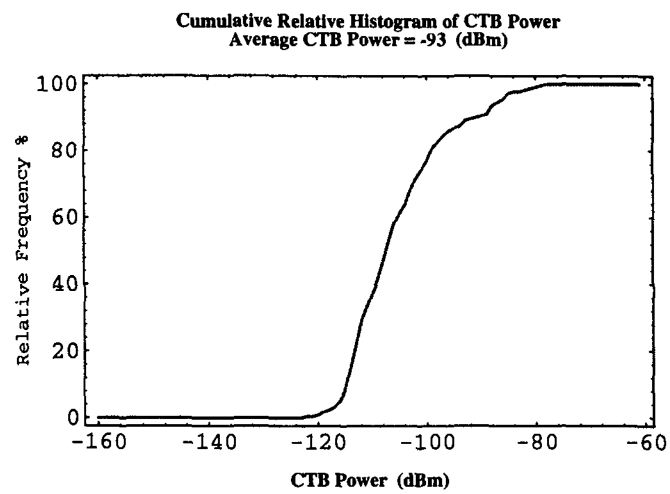

Figure 20