A NEW TECHNIQUE FOR MEASURING BROADBAND DISTORTION IN SYSTEMS WITH MIXED ANALOG AND DIGITAL VIDEO

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I. ABSTRACT

Several proposals have been made to augment the channel capacity of existing or proposed CATV systems by adding compressed digital video signals to conventional analog VSB signals. Such a proposal brings with it the difficulties of quantifying the degradation of broadband distortion performance (CTB, XMOD, DSO and CSO) associated with the additional loading caused by the new digital signals. Conventional techniques that measure device and system distortion performance by modeling the digital signals with CW carriers at the picture carrier frequencies of conventional analog VSB channels will give extremely disappointing results.

A new technique is described that models the digital signals in a manner that accurately represents the digital channel energy spectral density. Measurements using this technique are given that accurately predict distortion performance that is far better than that predicted by conventional CW carrier techniques.

A simple means of generating this signal is described. Test results are given that compare the performance of test devices when loaded with only conventional analog VSB signals to the performance of the test devices when loaded with mixed analog and digital signals.

II. CONVENTIONAL DISTORTION TECHNIQUES

It is a primary goal in the electronic processing of CATV signals to minimize any corruption of these signals. This design goal, as it interplays with economic considerations, has set the practical limits for performance of the system components (whether they be program supplier studio electronics, satellite delivery systems, headend electronics, distribution plant or subscriber electronics). In the case of broadband electronics, the principle technical trade-offs have been between broadband distortion and noise limitations.

Well established techniques have been used throughout the industry for several years in order to characterize the broadband distortion performance of conventional CATV electronics. Composite triple beat, discrete second order, composite second order and crossmodulation have historically been used as figures of merit for system performance. These techniques are closely linked with the types of signals used in conventional CATV applications.

In the United States, Canada, Mexico, Japan and several other countries, NTSC-M is the standard for color television transmission. As we are all aware, this system utilizes vestigial sideband modulation with a 6 MHz channel bandwidth. The picture carrier contains the most significant amount of channel energy, from a distortion standpoint, and is located 1.25 MHz from the lower channel edge. Another significant characteristic is the horizontal line frequency of 15734.264 Hz. The distortion techniques mentioned above utilize this characteristic in order to quantify system performance.

Knowing that the majority of the energy in an NTSC-M television signal is located at or very near the picture carrier leads to the understanding that the majority of the distortion in a CATV system results from that energy. In many laboratory or test applications the modulated video signal is replaced with a CW carrier at the picture carrier frequency. In a CATV system with a standard frequency line-up (not HRC or IRC) the frequency characteristics of these carriers have the useful property that third order distortion products fall at or very near to the picture carrier frequencies of affected channels. A simple examination of the possible linear combinations of an odd number of picture carrier frequencies will demonstrate this fact (for example: Channel 7 + Channel 8 - Channel 37 = 175.25 MHz + 181.25 MHz - 301.25 MHz = 55.25 MHz = Channel 2). This is the driving factor in the definition of CTB (composite triple beat). Note that the name CTB is somewhat of a misnomer as this distortion product is composed of not only third order beats, but also many higher odd-order distortion products.

A similar examination of the linear combination of the frequencies of any two picture carriers will result in a frequency that falls at 1.25 MHz above or below the picture carrier frequency of an affected channel in a standard system. The result is of course discrete second order distortion. A simple extension of this phenomena to any combination of an even number of carrier frequencies results in an explanation of composite second order, a phenomena that grows significantly as the broadband system bandwidth exceeds 450 MHz.

Crossmodulation is closely linked to the frequency components contained within the modulating signal of the RF spectrum. In the case of NTSC-M, there is a significant spectral content at 15.734 kHz. In a test environment, the modulating waveform is simplified to a 15.734 kHz square wave. Under these test conditions, it is relatively easy to quantify the parasitic modulation impressed upon an unmodulated carrier when included in a broadband spectrum where all other carriers are modulated and then passed through a device that can create nonlinear distortion. The ratio of the amplitude of that parasitic modulation to the modulation generated by 100% modulating that carrier with a 15.734 kHz square wave is defined as the crossmodulation.

In all of the cases mentioned above, the distortion measurements, by definition, are linked closely to the baseband video format and RF modulation techniques. An easy extension of these concepts may be used to quantify broadband distortion in the case of HRC or IRC frequency line-ups. It is also possible to extend these concepts to apply to other video formats, such as PAL and SECAM as well as their various RF spectrum formats, such as I, B, G, N, etc.

III. INITIAL STUDIES OF LOADING OF CATV DEVICES FOR DIGITAL VIDEO

A popular scenario for expanding the capabilities of a CATV plant is based on the inclusion of digital video in the upper part of the CATV broadband spectrum. Digital video promises to greatly increase the capability of this spectrum by permitting digital compression of the analog video signal. This compression will allow the carriage of up several times the number of channels in a given block of spectrum as would be possible using conventional VSB techniques. For example, one scenario might be to include conventional analog signals in the spectrum from 54 MHz to 550 MHz in order to serve the existing base of CATV subscribers. Additional digital video services could be included from 550 MHZ to 750 MHz. However, it is not clear how the inclusion of this potentially large number of video signals would affect the overall system distortion performance.

Initial testing of typical equipment was performed by Scientific-Atlanta in order to quantify the performance of 550 MHz CATV electronics when loaded with video carriers from a Matrix signal generator from 54 MHz to 750 MHz. This is the natural extension of the existing art of distortion measurements. Under these test conditions it was shown that distortion deteriorates significantly when conventional video carriers between 550 MHz and 750 MHz are included in the spectrum. These results were initially somewhat discouraging.

IV. AN EXAMINATION OF DIGITAL VIDEO SIGNAL CHARACTERISTICS

As one might expect, the RF characteristics of the compressed digital video spectrum are substantially different from those of the conventional VSB analog signal. For the purposes of this discussion, we will examine the characteristics of the 4-level VSB modulation technique employed by Scientific-Atlanta. However, the significant characteristics as described herein may be applied to most other compressed digital video RF modulation systems. Most of the conclusions drawn are easily extended to all systems.

Upon examining the RF spectrum of the digital video, the most striking characteristic is the uniform distribution of the energy as a function of frequency. There are no discrete high level carriers that result in the concentration of the RF energy at particular frequencies. The distribution of the energy is further homogenized by various multiplex techniques that allow the inclusion of several video programs within one 6 MHz slice of spectrum. A final smoothing of the energy is accomplished by the various encryption techniques that allow conditional program access. In the case of the S-A 4-level VSB technique, there is a suppressed pilot carrier at the very low end of the spectrum, but its impact upon the overall energy distribution is negligible.

Another significant difference in the signal characteristics is level. The average level of the signal is reduced with respect to the level of a conventional analog signal. The average level of the power in the channel is 10 dB below the peak envelope power (sync tip power) of a conventional analog channel. There are instantaneous peak powers that are higher than the average power but because of the multiplex and encryption techniques mentioned above, it is virtually impossible to relate the frequency components of these peaks to any characteristics of the original video waveforms.

Finally, a performance advantage is obtained with the compressed digital video that allows it to be more robust with respect to undesirable interference. Excellent bit error rates (BER) may be obtained with average channel power to interference ratios of only 20 dB. This results in a required channel dynamic range of 30 dB (resulting from operation at a level of -10 dB with respect to the peak carrier power of the analog video and the the requirement for a 20 dB signal to interference ratio), as compared with the dynamic range required by conventional analog video of 57 dB.

These characteristics result in a channel energy distribution that very closely resembles Gaussian noise at an average channel power that is -10 dB with respect to a peak power of a conventional analog signal.

V. DISTORTION TESTING TECHNIQUES

A new distortion measurement technique was developed that allowed the simulation of a mixed system containing both conventional analog channels and compressed digital channels. For the purposes of this test it was proposed that the device under test (DUT) would be loaded with conventional analog carriers from 54 MHz to 550 MHz and loaded with simulated digital channels from 550 MHz to 750 MHz. The device chosen to be tested in this experiment was the Scientific-Atlanta Model number 9504 four-port interdiction unit.

The test set-up for this experiment is shown in figure 1. The conventional analog carriers were supplied from a matrix generator. A conventional distribution equalizer was cascaded with the matrix generator in order simulate the typical tilt encountered in a conventional feeder leg of a distribution plant. The optional video generator, optional modulator, and optional directional coupler will be discussed in detail later. The conventional analog signals are combined with the output of the digital video signal simulator.

For the purposes of this test, the digital video is simulated with band limited gaussian noise. The noise was generated by amplifying thermal noise in a cascade of two high gain indoor distribution amplifiers. The noise must be band limited to the 550 MHz to 750 MHz band in order to match the desired test conditions. It was determined that a very complex and high order band-pass filter would be required to meet the shape factor requirements of limiting the noise to this band.

A simpler approach was identified that utilized a series of low-pass filters that produce a noise spectrum occupying the band from approximately 3 MHz to 100 MHz. This spectrum is then mixed with a 650 MHz LO to produce band limited noise spectrum from 550 MHz to 750 MHz. The SBL-1X type mixer used gave adequate LO rejection at the output to ensure that the LO content would not significantly affect the distortion measurements. Finally a 550 MHz high-pass filter is included to ensure that any inadequacies in the mixer isolation would not degrade the distortion measurements by masking distortion products in "leaked" noise. An added benefit of this technique is the ability to "turn-off" the digital channels by simply removing the LO from the mixer. Comparisons could therefore be easily made between performance with and without the additional loading of the digital video signals.

The resulting total RF spectrum is shown in figure 2. Note that in the simulated digital portion of this spectrum, the average level is -12.5 dB with respect to the peak analog carrier level. This apparent discrepancy with respect to the normal operating conditions described above is due to the resolution bandwidth of the spectrum analyzer. The widest available resolution bandwidth was 3 MHz. Correcting this for 6 MHz and compensating for the equivalent noise bandwidth of the analyzer filter, the resulting observed average power level is -10 dB with respect to the analog carriers, as described above.

Also note the relatively low level of the mixer LO leakage and the narrow gap of noise introduced around 650 MHz by the inability of the indoor distribution amplifiers to amplify the noise all the way to DC. It was decided that these characteristics would cause negligible effects on the measured

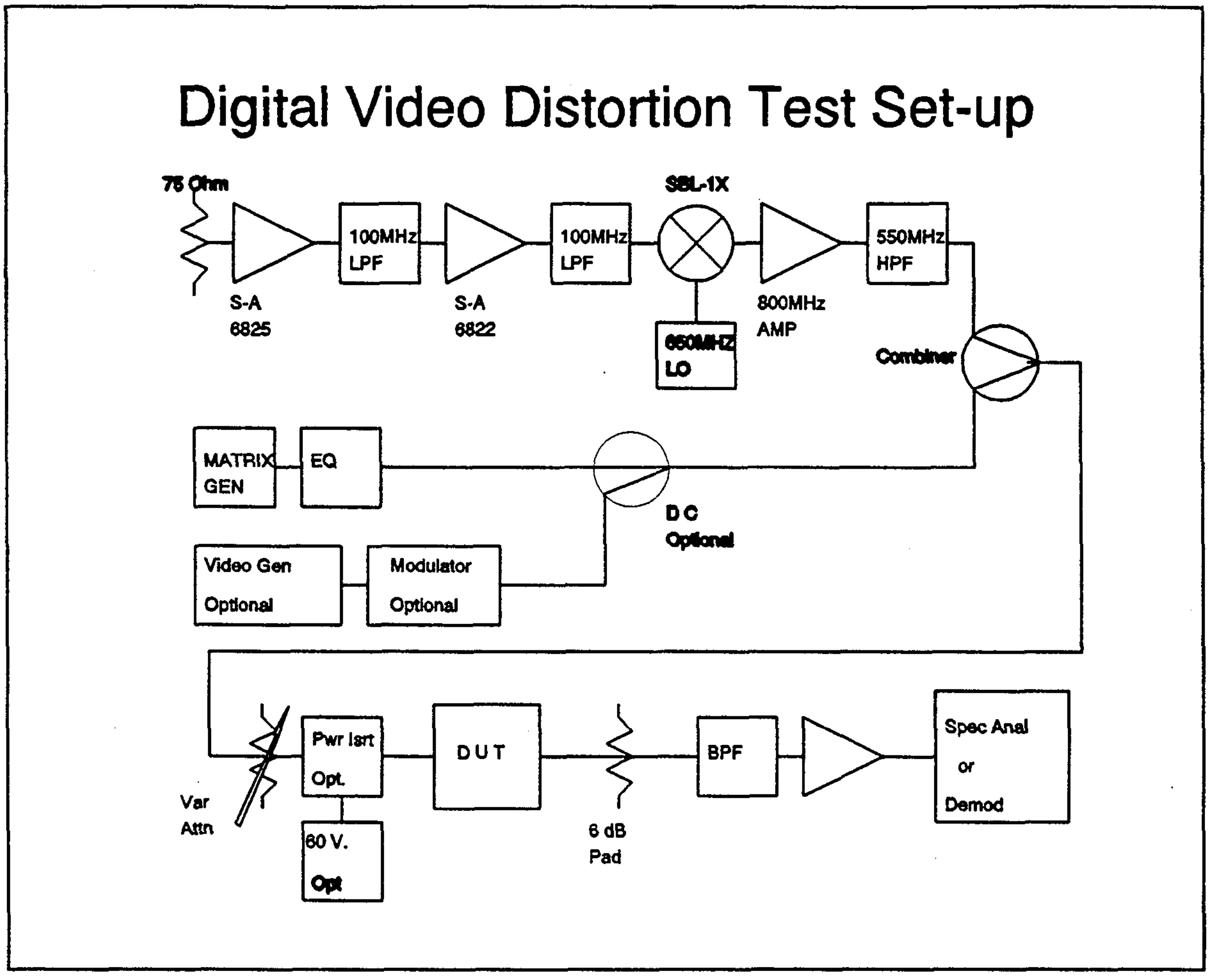

Figure 1

distortion performance.

VI. MEASURED DISTORTION RESULTS

Conventional distortion techniques were utilized to quantify the distortion performance on the analog channels with and without the loading of the digital video. The distortion results were initially measured on a total of 4 different subscriber ports. Distortion was measured at five different frequencies spaced throughout the 54 MHz to 550 MHz band. CTB, CSO, and XMOD were measured. The data from this initial experiment is given in figure 3.

In general, the additional noise loading of the simulated digital video signals causes a deterioration of the distortion performance of only a few tenths of a dB. In no instance does the addition of the noise degrade the signal by more than 1 dB (note that in a few cases the signal appears to actually get better with the addition of the noise, but these measurements are limited by the measurement system noise floor).

To further confirm the results, an additional 20 ports were measured for CTB at elevated output levels to ensure that system noise would not mask the results. A summary of this data is shown in figure 4. Note again, that the performance, though clearly deteriorated by the higher levels and now clearly above the system noise floor, shows distortion performance impacts of only tenths of a dB when the

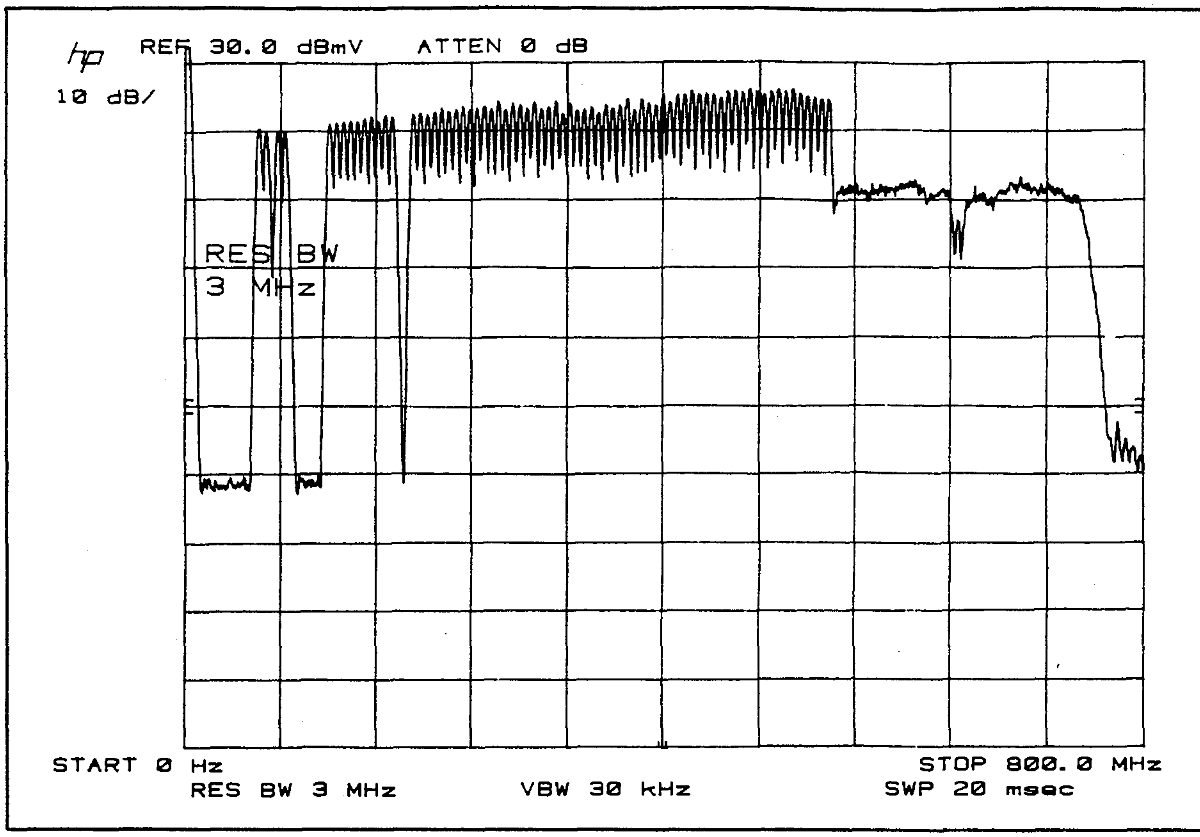

Figure 2

additional noise loading of digital video is added. This encouraging result implies that the additional loading of compressed digital video at frequencies above the conventional analog channels will have a minimal impact on system performance.

VII. EXPLANATION OF RESULTS

As described above, the energy in a conventional NTSC-M VSB channel is primarily concentrated around the frequencies of discrete RF carriers. Therefore the loading of a DUT with these types of signals results in discrete distortion products or beats that fall at easily predicted discrete frequencies (CTB, DSO, CSO, XMOD). In the case of compressed digital video signals, however, the energy is at a much lower average level and evenly distributed across the entire 6 MHz channel.

The distortion products from such a signal do not lie on discrete frequencies, but rather spread themselves across the entire 6 MHz of an affected channel. Fortunately, as the energy is spread, its impact on perceived picture quality is minimized. It was theorized that the result would appear as a slight degradation of the video signal to noise on the affected channel.

VIII. VIDEO S/N EFFECTS

The S/N effects were quantified using the optional video generator, optional modulator and optional directional coupler mentioned above. To use these devices, a single carrier of the matrix generator was turned off. The modulator was then used to replace that carrier with modulated video. An S-A agile modulator was used to allow the modulated carrier to be moved throughout the 54 MHz to 550 MHz band, and specifically to the frequencies where the distortion had been measured earlier.

Distortion Data		55.25 MHz		199.25 MHz		295.25 MHz		379.25 MHz		499.25 MHz	
		w/o dig	w/ dig	w/o dig	w/ dig	w/o dig	w/ dig	w/o dig	w/ dig	w/o dig	w/ dig
CTB (dB)	Port 1	73.6	73.6	72.7	72.8	74.3	74.1	72.7	72.5	75.5	75.2
	Port 2	74.4	74.0	72.9	72.6	74.5	74.5	72.5	72.4	75.5	75.3
	Port 3	73.5	73.4	72.3	72.6	73.7	73.8	70.6	70.3	74.2	74.4
	Port 4	73.4	73.4	72.3	72.3	72.5	72.7	70.7	70.6	75.3	75.2
CSO- (dB)	Port 1	64.8	65.0	64.0	64.0	62.9	63.3	63.5	63.5	77.1	77.3
	Port 2	64.0	64.0	63.0	62.8	62.8	62.8	62.8	62.9	77.5	77.6
	Port 3	64.5	64.6	64.2	64.0	63.8	63.8	63.5	63.4	75.7	75.5
	Port 4	64.0	64.6	64.0	63.8	63.6	63.2	63.2	63.1	76.5	76.4
CSO+ (dB)	Port 1	74.8	75.0	76.8	76.6	71.7	71.5	66.7	66.6	64.2	65.0
	Port 2	75.5	75.6	76.7	76.9	71.5	71.3	66.2	66.3	64.3	64.2
	Port 3	74.6	74.8	74.7	74.6	71.1	70.9	66.8	66.8	66.7	66.6
	Port 4	74.6	74.7	74.7	74.7	71.1	71.1	66.1	65.9	64.0	63.8
XMOD (dB)	Port 1	65.1	65.1	66.1	66.4	66.8	66.4	65.3	65.6	66.2	68.9
	Port 2	67.1	66.4	64.9	65.5	66.6	67.5	65.7	65.8	67.0	67.0
	Port 3	69.8	69.3	65.1	67.6	67.1	67.6	65.0	65.2	66.7	66.2
	Port 4	68.5	68.6	66.6	66.5	66.8	66.0	64.2	64.0	65.5	67.4

Figure 3

COMPOSITE TRIPLE BEAT (dB)
Measured at elevated operating levels

Analog Video Only					
	55.25 MHz	199.25 MHz	295.25 MHz	379.25 MHz	499.25 MHz
Minimum	53.5	55.0	51.1	49.8	48.0
Mean	54.5	55.2	51.7	50.8	49.0
Maximum	55.5	55.4	52.0	51.8	49.8
Analog And Digital Video					
	55.25 MHz	199.25 MHz	295.25 MHz	379.25 MHz	499.25 MHz
Minimum	53.3	54.4	50.4	49.4	47.4
Mean	54.3	54.6	51.1	50.2	48.7
Maximum	55.3	54.8	51.4	51.1	49.6

Figure 4

Reduction of Unweighted Video S/N
With the Addition Of Digital Video Signals
In the 550 MHz to 750 MHz Band

Frequency	55.25 MHz	199.25 MHz	295.25 MHz	379.25 MHz	499.25 MHz
Average Change of S/N	0.3 dB	0.4 dB	0.5 dB	0.5 dB	0.3 dB

Figure 5

During this test, the spectrum analyzer was replaced with a video demod and a Tektronix VM-700 video analyzer. The VM-700 was then used to measure the video S/N on that channel. Care was taken to ensure that adequate pre-selection filtering was placed in front of the demod so that additional distortion was not generated by that demod. The results of these measurements are summarized in figure 5.

The Video S/N degradation resulting from the loading of the simulated compressed digital video was typically less than 0.5 dB.

IX. CONCLUSIONS

It has been analytically shown that band-limited Gaussian noise is a good simulation for compressed digital video. Testing with noise of this type may be used for quantification of distortion performance of broadband devices. This method easily allows the simulation of mixed systems with partial analog video and partial compressed digital video.

Additional study of this subject is required. However, based on the preliminary data presented, the distortion performance impact of system or device loading with compressed digital video should be substantially less than the effect of loading the same amount of spectrum with conventional analog signals. In particular, the Scientific-Atlanta model 9504 4-port interdiction device shows very little distortion deterioration (less than 1 dB) with the additional loading of simulated digital video from 550 MHz to 750 MHz. The deterioration of the video signal to noise ratio resulting from this loading is typically less than 0.5 dB.

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