THE EFFECTS OF SINGLE ENDED, PUSH-PULL, AND FEEDFORWARD DISTRIBUTION SYSTEMS ON HIGH SPEED DATA AND VIDEO SIGNALS

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ABSTRACT

Field testing was conducted to investigate the effects of cable television system electronics on downstream video and high speed data transmission. Three system configurations were used for the testing: a 15 year old single ended 12 channel plant; a 3 year old 35 channel push-pull plant; and a 1 year old 54 channel feedforward plant. Various RF, video, and digital tests and measurements were performed to determine if a relationship exists between typical cable television system operating characteristics and the performance of video and high speed data signals on these systems.

INTRODUCTION

Cable television systems have provided operators with an excellent means of delivering entertainment services to subscribers for over 30 years. The nature of the coaxial cable distribution network lends itself to being much more than an entertainment delivery system. This "electronic pipeline" can just as easily move information.

As the industry evolved, technology kept pace to accomodate the increased number of services carried on cable systems. Additional video signals, and now even data communications, are rapidly filling the cable spectrum. But are these signals being affected by the systems carrying them?

The effects of noise, cross-mod, composite triple beat, and other distortions are well documented. Modern cable system electronics incorporate phase inversion circuitry, delay lines, error amplification, and other complicated circuits. Video signals are themselves inherently complicated, using amplitude and phase modulation techniques to transmit a large amount of information that includes fast risetime waveforms, pulses, high frequency energy, and phase sensitive signals. High speed data also includes fast risetime waveforms and high frequency energy, and digital transmission schemes such as PSK (phase shift keying), QASK (quadrature amplitude shift keying), and QPSK (quadrature phase shift keying) are very sensitive to phase distortions.

Do different types of cable television distribution electronics -- single ended, push-pull, and feedforward -- have any effect on video or high speed data signals in the downstream path? Are video signals and high speed data signals affected similarly by cable system characteristics such as frequency response, noise, channel loading, and signal levels?

To address these questions, several tests and measurements were performed in cable systems operating with single ended, push-pull, and feedforward distribution electronics. Measurements were made to determine the extent of video delay and phase distortions, data errors, and data waveform envelope distortions in the three types of distribution systems. Analog RF tests and measurements determined the effects of frequency response, carrier to noise, channel loading, signal amplitude and signal amplitude variations on video and data transmission performance.

THE CABLE SYSTEMS AND TEST LOCATIONS

Cable System #1

Cable system #1 is a classic rural system serving approximately 1200 subscribers in a small Colorado mountain community. The system is 15 years old, and is a 12 channel single ended configuration with some push-pull equipment located in newer areas. The plant is one-way capable only, and operates with 11 downstream television channels and one midband pilot carrier. Built originally with non-integral sleeve type connectors, the plant is 88% aerial and 12% underground.

Cable System #2

Cable system #2 is located in the metropolitan Denver area, and serves approximately 5700 subscribers in Denver's southwestern suburbs. It is a 3 year old 35 channel push-pull two-way capable system, operating with 30 downstream television channels and 1 upstream television channel. The plant is 85% underground and 15% aerial, and was built using integral sleeve type connectors. Diplex filters have been installed in all amplifiers.

Cable System #3

Cable system #3 is located in the metropolitan Los Angeles area, providing service to approximately 7500 subscribers. The system is between 1 and 2 years old, and is a 54 channel feedforward two-way capable system operating with 42 downstream television channels. Built with integral sleeve type connectors, the plant is 55% underground and 45% aerial. Diplex filters have been installed in all amplifiers, but the upstream path has not been activated.

System Test Locations

In each of the cable systems, the headend and two field locations were used for the various tests and measurements performed.

TABLE 1

SYSTEM	LOCATION	TRUNK CASCADE	BRIDGER	L.E.
	Headend	N/A	N/A	N/A
#1	Field #1	6 S.E.	1 S.E	1 P.P.
	Field #2	6 S.E., 2 P.P	1 P.P.	1 P.P.
	Headend	N/A	N/A	N/A
#2	Field #1	14 P.P.	1 P.P.	0
	Field #2	10 P.P.	1 P.P.	0
	Headend	N/A	N/A	N/A
#3	Field #1	8 F.F.	1 F.F.	0
	Field #2	9 F.F.	1 F.F.	1 F.F

S.E.-single ended; P.P.-Push-pull; F.F.-feedforward

Measurements were made at the output of the headend combining network. The results were used to establish a baseline reference to allow determination of actual system contribution to signal degradation. The two field locations in each of the systems were subscriber drops located at amplifier cascade extremities varying from 6 to 14 trunk amplifiers. The cascades also included a bridger, and, depending on the location, a line extender.

TESTS AND MEASUREMENTS

RF

- Visual and aural carrier amplitudes were measured on all channels
- Separation between visual and aural carrier amplitudes was measured and recorded
- Visual carrier to noise ratios were measured and corrected for 4 MHZ bandwidth on selected channels at all field locations
- Visual carrier amplitude variations were monitored over a 24 hour period to verify headend processor and system AGC performance
- Full spectrum swept frequency response and in-channel frequency response (on one selected reference channel) were measured at each location

Video

- Chrominance-luminance delay, differential phase distortion, chrominance non-linear phase distortion, and ICPM (incidental carrier phase modulation) were measured on one selected reference channel

Digital

- A data carrier transmitting a 1.544 Mb/s QPSK pseudo-random data stream was monitored at each location for bit errors over periods ranging from 1 to 17 hours
- A 5.72 Mb/s eye test data pattern was observed for distortion of the overlaid clock and data pattern

TEST EQUIPMENT CONFIGURATION

Headend (Refer to Fig. 1)

The sweep transmitter was connected to the headend combiner sweep input and was adjusted for normal operation per the manufacturer's instructions.

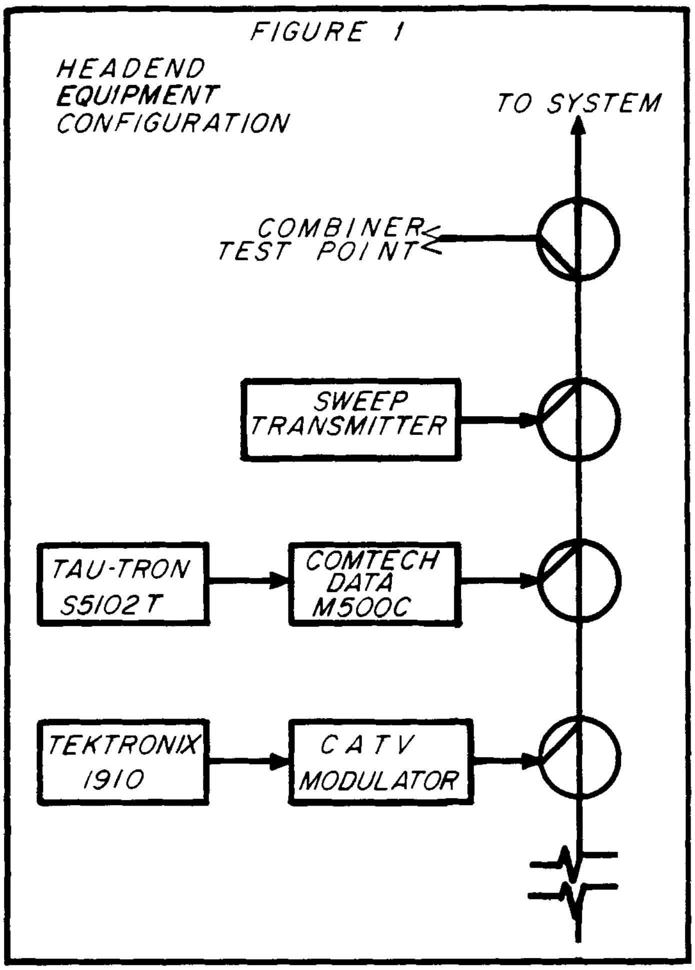


FIGURE 1

HEADEND EQUIPMENT CONFIGURATION

To accomodate bit error rate measurements, a Tau-Tron S-5102-T Error Rate Test Set Transmitter was configured for a 1.544 Mb/s pseudo-random data output and connected to the data input port on the Comtech Data M500C RF modem. The modem RF output was connected to a spare headend combiner input port, and the modem RF level was adjusted to approximately 15 dB below system visual carrier levels.

One of the headend modulators was chosen to be the reference channel for all the video testing. The aural carrier on that modulator was turned off, and the Tektronix 1910 Digital Video Signal Generator full field output was connected to the modulator video input. Video depth of modulation was adjusted to 87.5%, as required. Proper modulator RF output level was verified.

An individual remained in the headend during field tests to select video signals on the Tektronix 1910, and to turn the sweep and data signals on and off as necessary.

Field Locations (Refer to Fig.2)

Signal from the subscriber drop fed the Comtech Data RF modem through the tap leg of a directional coupler. The data output from the modem was connected to the Tau-Tron S-5102-R Error Rate Test Set Receiver. After configuring the receiver for the 1.544 Mb/s pseudo-random data stream, the internal timer on the receiver was set for the desired test duration. Bit error counts were displayed directly on the Tau-Tron.

One port of the two way splitter was connected to a 75 to 50 ohm matching adapter at the input of the Tektronix 1450-1 Television Demodulator. The demodulator was tuned to the reference channel, and the video output connected to the vectorscope and waveform monitor. After setting the demodulator to its measurement mode, video delay and phase measurements were made on the vectorscope and waveform monitor.

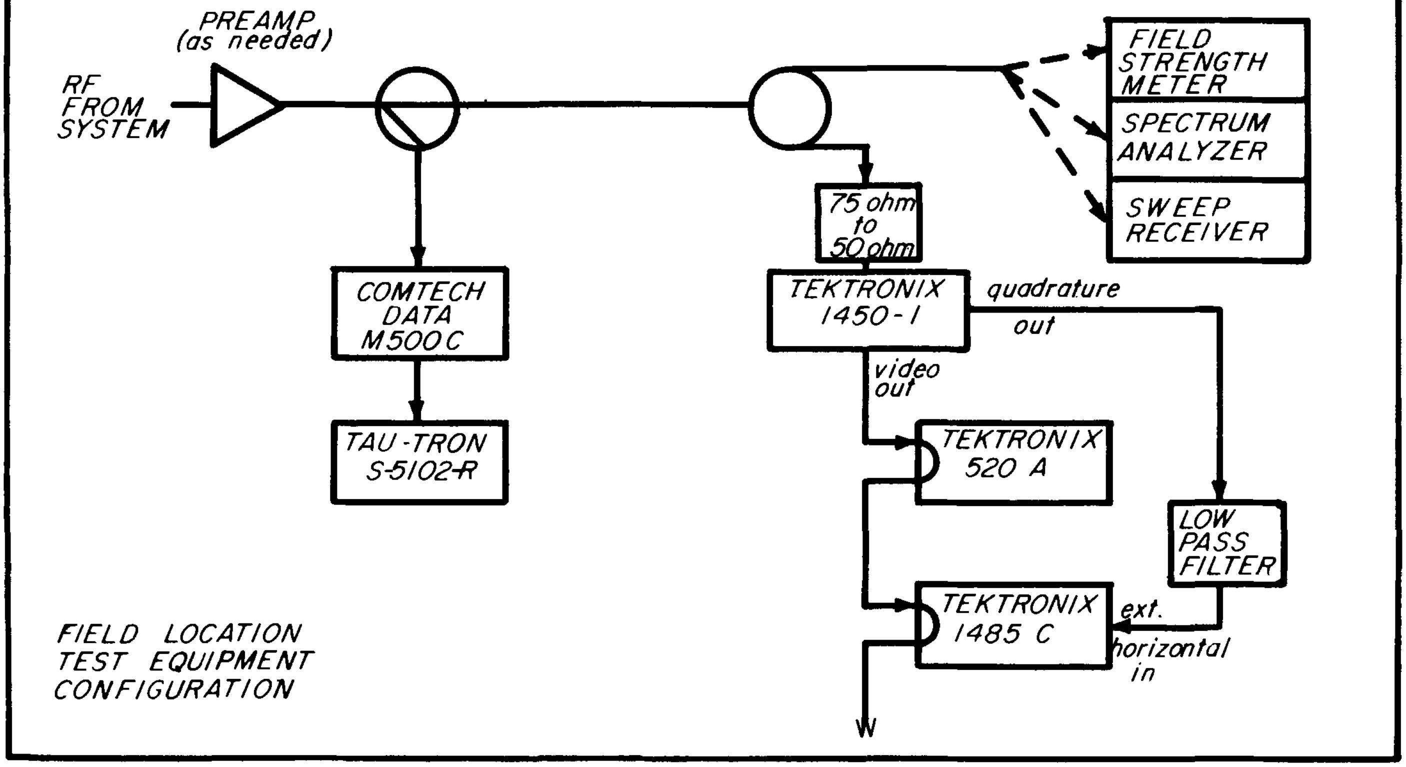
To perform the ICPM test, the demodulator quadrature output was connected to the waveform monitor external horizontal input through a 250 KHZ low pass filter. This test required the use of a special graticule (Tektronix P/N 331-0393-12) on the waveform monitor, which allowed direct indication of ICPM on the waveform monitor CRT.

For the RF measurements, the second port of the two way splitter was connected to the remaining test equipment. Signal levels were read directly on the field strength meter. Carrier to noise measurements were made through a tunable bandpass filter connected to the field strength meter.

Full spectrum swept frequency response was read directly on the sweep recovery receiver display; in-channel frequency response on the reference channel was measured on the spectrum analyzer by observing the frequency domain display of the SIN X/X test signal.

A preamplifier was used in some cases to provide suitable signal level for carrier to noise measurements and any other tests requiring additional signal.

FIGURE 2



FIELD LOCATION
TEST EQUIPMENT
CONFIGURATION

TEST AND MEASUREMENT PROCEDURES

RF Measurements

Visual and aural carrier amplitude, carrier to noise ratio, 24 hour signal amplitude variation, full spectrum swept frequency response, and in-channel frequency response measurements conformed to cable and broadcast industry accepted practices. (1,4)

Video Distortions

Table 2 outlines the video test signals used and their application. All of these test signals were generated by the Tektronix 1910 Digital Video Signal Generator. (2,3)

TABLE 2

VIDEO TEST SIGNAL	APPLICATION
SIN X/X	In-channel frequency response
FCC Composite (12.5 T Pulse)	Chrominance-luminance delay
5-Step Staircase	ICPM (Incidental carrier phase modulation)
80 IRE Modulated Ramp	Differential Phase Distortion
Modulated Pedestal	Chrominance Non-Linear Phase Distortion
Eye Test Data Pattern	Expanded waveform observed for distortion of overlaid clock and data pattern

Digital Testing

The 5.72 Mb/s eye test data pattern was expanded horizontally on the waveform monitor and the clock and data patterns overlaid. Any distortions occurring to the data pattern envelope were displayed on the waveform monitor CRT.

Bit errors occurring in the 1.544 Mb/s QPSK data stream were counted by the Tau-Tron receiver and displayed directly on the receiver LED readout. (5) This unit also provided a count of total error seconds during the measurement periods.

RESULTS

The cable systems in which the tests were conducted were not "tuned up" beforehand. RF levels varied considerably from test point to test point: the lowest visual carrier level measured was -9.5 dBmV, and the highest was +19.5 dBmV. Aural carrier amplitudes ranged from 9 to 21.5 dB below visual carrier amplitudes.

Corrected visual carrier to noise ratios ranged from 40.5 to 50.5 dB, with the majority from 47 to 50 dB.

System full spectrum swept frequency response was anywhere from 2 to 8.78 dB P-V (peak to valley), with the average being about 5 dB P-V at system cascade extremities. In-channel frequency response was in the 1 to 2.5 dB P-V range, with the average being about 1.5 dB. In some cases, in-channel response did not change from measurements at the headend.

Video phase distortions -- differential phase distortion, chrominance non-linear phase distortion, and ICPM -- did not change in any of the systems from what was measured in the headends. Chrominance-luminance delay did change in some instances, but only when the in-channel frequency response changed from that measured in the headend. The eye test data pattern also changed in some cases, paralleling changes in the in-channel frequency response and chrominance-luminance delay. When in-channel frequency response did not vary from the headend reference, chrominance-luminance delay did not change, nor did the eye test data pattern.

The 1.544 Mb/s QPSK data signal carrier to noise ratio varied from 30.5 to 40 dB during field tests, with actual data modem RF input levels ranging from -10 dBmV to +17 dBmV. It was observed that the data modem would not provide data output when the RF input level dropped below about -12 dBmV. This was found to be a function of the modem circuit design.

During the measurement periods, bit errors did not occur at any of the test locations in System #2 and #3. Bit errors were recorded at both field locations in System #1; however, none occurred in the headend. The bit errors occurred randomly in bursts of 10 to 20 errors at a time. The measured bit errors were 2.52×10^{-8} and 2.63×10^{-8} respectively.

During equipment setup at one of the field locations in System #2, a single static discharge to the grounded metal case of the error test set receiver (caused by walking across the carpet and touching the unit's case) resulted in a single burst of 93 bit errors.

DISCUSSION

The results of these tests and measurements indicate cable television distribution electronics are transparent to video and high speed data. Limited research has been conducted in this area, much of it under laboratory conditions. This testing has used "real world" operating cable systems to take the research one step further.

Concerns voiced in the Introduction of this paper regarding video and high speed data transmission do not seem to be a problem. Testing indicates that video and high speed data are not affected by the types of amplification techniques used in cable television signal delivery.

Several video distortion measurements were performed as part of the overall testing, and it was found that video phase distortions did not increase in the CATV distribution system. The phase distortions observed were generated in the headend modulators, and remained unaffected by the performance of the cable systems. Two video signals that did change in the distribution systems were the 12.5 T pulse and the eye test data pattern. The 12.5 T pulse was used to measure chrominance-luminance delay, which was observed to change with variations in the in-channel frequency response of the reference channel under test. The envelope of the eye test data pattern also changed with variations in the in-channel frequency response. But when in-channel frequency response did not change in the distribution system, the 12.5 T pulse and eye test data pattern did not change either.

This suggests that in-channel frequency response variations have a parallel effect on video distortions and data signals: as frequency response worsens, the video chrominance-luminance delay degrades, and the data envelope distorts.

Envelope delay and in-channel frequency response variations can be reduced by locating data channels away from the extreme ends of a system's transmitted spectrum. This would avoid problems associated with diplex filter cutoff response, equalizer response, and amplifier rolloff. Maintaining system swept frequency response to closer tolerances would also reduce in-channel response problems.

As far as system sweeping is concerned, high level sweep equipment should be used with caution in systems transmitting data. The high level sweep in system #2 had to be shut off during bit error rate testing and video distortion measurements. It was observed that the high level sweep caused between 13 and 33 bit errors every time the signal swept through the spectrum. Later measurements resulted in a bit error rate of 4.9×10^{-6} with the high level sweep in operation. The high level sweep also affected the AGC circuitry in the demodulator, causing poor clamping action in the test equipment. The low level sweep used in System #1 and #3 did not cause bit errors, nor did it affect the test equipment.

A partial solution to this is to trap out the high level sweep at critical frequencies; however, this precludes frequency response measurements at those frequencies.

As mentioned earlier, a static discharge to the case of the error rate test set receiver caused a single burst of 93 bit errors. This points to the need for designing consumer oriented data equipment in static-proof enclosures.

Video distortions varied with each modulator used in the system testing. As with broadcast transmitters, many cable television headend modulators incorporate delay predistortion circuitry for color transmission (F.C.C. §73.687 a.5) which "artificially" introduces a chrominance-luminance delay of -170 nanoseconds (advanced chroma) into the video signal. The modulators in System #1 and #2 both exhibited the effects of delay predistortion circuitry (as per manufacturer's specs), but neither met the -170 nanosecond specification. The reference channel modulator in System #3 apparently did not incorporate delay predistortion, since the demodulated 12.5 pulse had no measurable chrominance-luminance delay. These variations may preclude "blanket" compensation for delay predistortion in data equipment, if cable television modulators are to be used for high speed data transmission. Modulators used in this capacity may have to be ordered without delay predistortion circuitry installed or have the circuitry bypassed to avoid potential problems with envelope distortion of the data.

Signal levels and channel loading did not appear to affect the video and data test signals. Measured carrier to noise ratios were suitable for data transmission, even with a reduced amplitude data carrier. Depending on the circuit design of the RF data modems used, low signals can affect modem operation. However, operating levels encountered in the testing presented no problems and did not affect the outcome of the testing.

The results of the bit error rate tests at the field locations in System #1 support previous research: data transmission is degraded in "loose" cable systems. Intermittent connections, impulse noise, ingress, and other problems common to "loose" systems definitely increase data errors. Measurements in System #1 indicated that the physical condition of the 15 year old plant, particularly the lack of integral sleeve type connectors, contributed to data errors. While the bit error rates were on the margin of being acceptable, they would very likely have been much worse in a metropolitan area subject to higher levels of ingress and impulse noise, than in the rural mountain community where this system is located.

CONCLUSIONS

The three types of distribution electronics used in cable television -- single ended, push-pull, and feedforward -- do not affect video and high speed data transmission. Video and data signals are affected similarly by cable system characteristics such as frequency response.

Cable television -- the electronic pipeline -- can be used as an efficient transmission medium for high speed data and other information. While many systems will have little trouble carrying relatively error-free data signals, others will have to be "tightened up" and "fine tuned." Improving system reliability through better maintenance procedures, equipment alignment, and physical integrity will ensure the coaxial cable network is recognized for its capability to deliver entertainment and information.

REFERENCES

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5. "Data Communications Testing" (Hewlett-Packard Manual Part No. 5952-4973; 1981)