# Cable System Transient Impairment Characterization

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## ABSTRACT

*CableLabs is performing a field study of transient disturbances occurring in cable systems to evaluate the impact of nonstationary impairments on high speed, band-limited transmission of digital information. This paper describes the design and operation of a system which has been built to determine the nature of non-stationary impairments that interfere with digital signal transmission.*

*The system inserts a CW (carrier wave) signal at the headend in the center of a vacant channel. At the receive site, the carrier is quadrature demodulated to baseband. Dual triggers are set for the in-phase and quadrature channels. When triggered by a disturbance, a digital oscilloscope captures data from both channels for later time and frequency domain analysis.*

*The type of transient disturbance, duration, and inter-arrival statistics are derived from the accumulation of events over a significant time period (weeks to months). This system can also be used for reverse system characterization. Samples of test data captured and analyzed are presented.*

*At this time, the system has been built and some preliminary testing on a cable system in Boulder, Colorado has been done.*

## INTRODUCTION

Interference is a ubiquitous property of the environment in which a multiplicity of communication systems and man-made noise sources coexist with the cable transmission medium. The ingress of these (possibly spurious) sources of interference introduce impairments to digital transmission over the cable plant. Also, non-ideal mechanisms present in the equipment used in the communication process can introduce transient interference and distortion.

Interference of a transient or impulsive nature can occur via two distinct mechanisms: ingress of external interference energy from cochannel signals or nonstationary (man-made) noise sources, and dynamic impedance or return loss changes due to time-varying terminations or signal path components.

The characterization of these types of impairments does not lend itself to a simple, elegant model. Thus a time-domain transient representation of such observed phenomena with duration and inter-arrival statistics would seem to be the best approach.

## IMPAIRMENT CHARACTERIZATION METHODOLOGY

Figure 1 is a constellation diagram of a 16-QAM modem used for carrying data over an RF

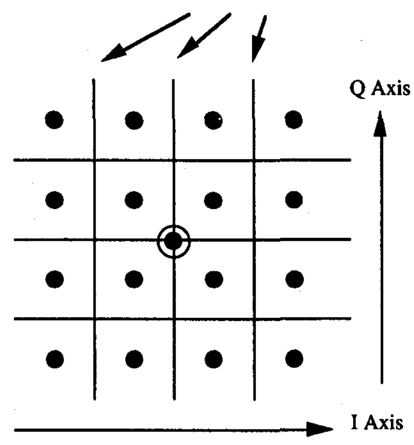


*Figure 1:*
*Modem Testing*

channel. Each of the 16 constellation points is identified as the modulated phase and amplitude that a carrier voltage may be at the correct sampling instant. Also shown in Figure 1 are decision thresholds. When the modem is carrying random data, the modem switches between states at the symbol rate. Any particular state out of 16 possible states can be identified from the voltage of the demodulated carrier on the I (in phase) axis, along with the corresponding voltage on the Q (quadrature) axis. At RF frequencies, the channel is occupied with uniformly distributed energy from the random carrier modulation.

If an impairment, such as Gaussian noise, is added to this channel, each constellation point will be moved from its nominal position. If the impairment is strong enough to move a received constellation point across the decision threshold, errors will occur. Testing with this energy present in a channel is very difficult because the energy masks the impairment. About the only type of testing that can be done is bit-error measurement, which requires that the channel be taken out of service for the test. Bit error testing is useful, but gives results that are a mixture of channel performance and modem performance. The cause of the bit errors is not apparent, only their presence and (possibly) duration.

This diagram can be contrasted with the constellation in Figure 2, which consists of only a single point. This single constellation point is generated by a CW signal. The distance from the point to the origin is the magnitude of the carrier. A rectangular threshold region is established around the point. If the level of impairment is sufficiently weak so that the point is continuously within this region, then the impairment is sufficiently benign so that an equivalent modem would operate error-free. If an impairment drives the constellation point outside of the threshold region, the event is detected and recorded for later examination. Impairments that can be identified by this technique are shown in Table 1 along with the characteristic appearance. In addition, Fourier analysis of the captured time waveforms could identify the nature of the impairment.

The block diagram of the test instrumentation is given in Figure 3. The down converter mixes the CW carrier down to an IF frequency of 44MHz with a very low phase noise local oscillator, which may be either an inexpensive crystal oscillator, or an expensive agile signal generator. For testing the reverse band, this block will be an up converter. The bandwidth of the SAW (surface acoustic wave) filter determines the width of the channel, and has been chosen to be

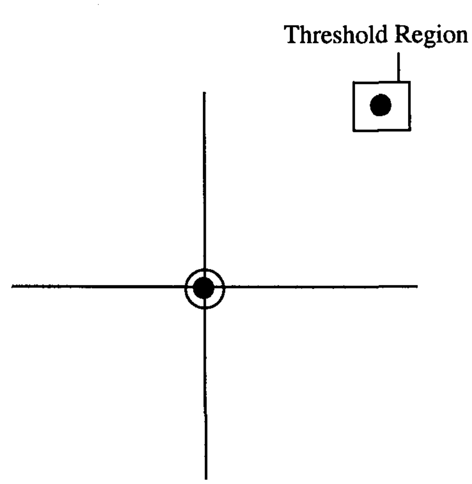


*Figure 2:*
*Carrier Wave Testing*

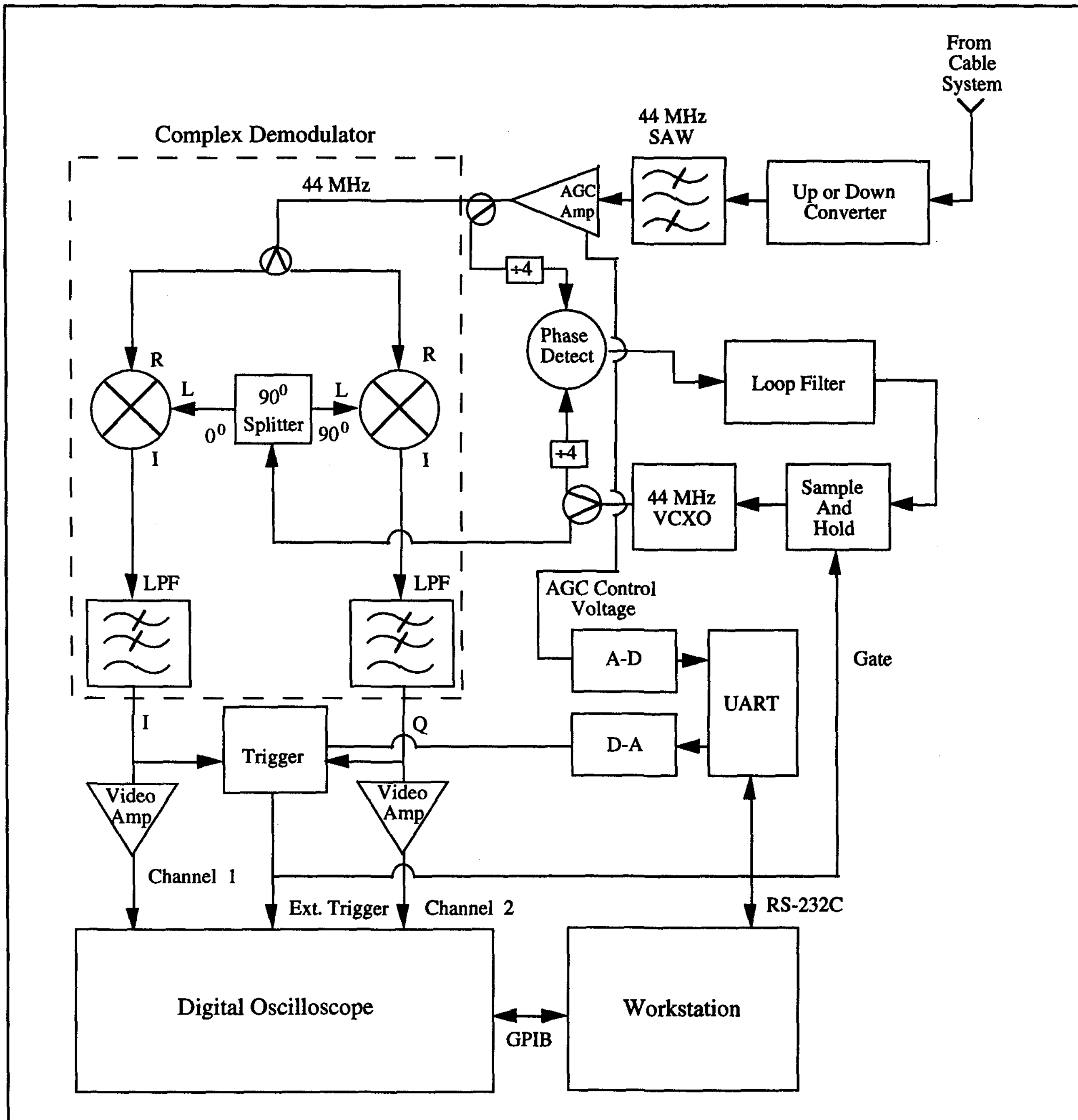


*Figure 3: CW Tester Block Diagram*

about 5MHz wide, so that the test may be carried out in a single 6MHz channel. The AGC amplifier serves to hold the constellation point at a constant distance from the origin as the strength of the received carrier varies slowly, due to the cable plant experiencing temperature variations. The AGC does not need to have a large dynamic range, but it does have a slow time constant and has been designed to have low phase shift with attenuation changes. A phase locked loop, based on a MC4044 type IC phase detector operating at 11MHz, keeps the voltage controlled crystal oscillator (VCXO) in lock with the incoming carrier.

The carrier is demodulated by a conventional complex demodulator that yields both I and Q components. The low pass filters in the demodulator have a 5MHz cutoff frequency. This frequency was chosen to be wide enough to pass the energy through the SAW filter (+/- 2.5MHz), but narrow enough to reject spurious components.

The trigger circuit consists of 4-AC coupled high speed comparators. Comparators establish the upper and lower trigger points for both the I channel and the Q channel. The OR'ed trigger outputs from the CW tester is supplied as an external trigger input to the digitizing oscilloscope. After triggering, a one-shot circuit opens the phase locked loop long enough to allow the data to be captured without responding to the phase error. This is accomplished through the control line labeled "gate."

Video amplifiers boost the signal level for input into the digital oscilloscope. A Unix workstation controls the threshold levels for the trigger circuit via a UART (universal asynchronous receiver/transmitter) interface to a digital-to-analog converter. The threshold levels are operator selected for a test. The UART also gathers the control voltage of the AGC circuit through an analog-to-digital converter. This information can be translated into the incoming carrier strength. The UART circuit communicates with the workstation via the RS-232C port.

The digital oscilloscope (TEK TDS 420) samples both the I and Q channels at 10M samples per second for up to a maximum of 60,000 samples on each channel. This sample rate is above the Nyquist limit for the channel. After an event is captured, the data is extracted from the oscilloscope via a GPIB (general purpose instrumentation bus) interface for storage on the work station's hard disk drive.

Effective shielding is necessary to avoid capturing interference that is actually originating locally.

A workstation was chosen to allow the apparatus to operate over an extended period of time in an unattended mode. The controlling software stores data in three types of files. The first is an AGC file that periodically monitors and logs, once each minute, the current AGC voltage. The second is an event log file containing the event time of day, the trigger voltage threshold, the event number, and the current AGC voltage. The third file contains the number of points and the actual demodulated I and Q time waveforms triggered by an event. The system is designed to prevent overflowing the hard drive should pernicious interference be experienced. This can occur when sweeping a system, causing an event to be logged every few seconds. Although in this case, the data from every event would not be stored, all events would be logged with time information, thereby capturing the event total duration with samples of the interference.

| Impairment | Characteristic Appearance |
|---|---|
| Gaussian noise | fuzzy ball on I-Q plot |
| Phase noise | arc shape on I-Q plot |
| Signal drop | point drops to origin on I-Q plot |
| Sweep interference(Wavetek) | chirp on I-T and Q-T plots |
| Sweep interference(Calan) | burst on I-T and Q-T plots |
| Sudden change in echo | a change in point position on I-Q plot |
| CW interference | sine wave on I-T, and a circle on I-Q plot |
| AM hum | a line heading towards origin on I-Q plot |
| Impulse noise | "flower petals" on I-Q plot |
| CTB or CSO | interference with large peak excursions |

*Table 1*

## EARLY RESULTS

Preliminary testing was done with an downstream CW signal at 445.25MHz using a signal carried at video level originating at a cable system headend. Data was captured at CableLabs, which was one fiber link and one line away, and one home site that was one fiber link and 18 amplifiers away. Figure 4 is a sweep-like interference that was captured. It was probably a piece of agile headend equipment that was turned on and passed through the test channel on

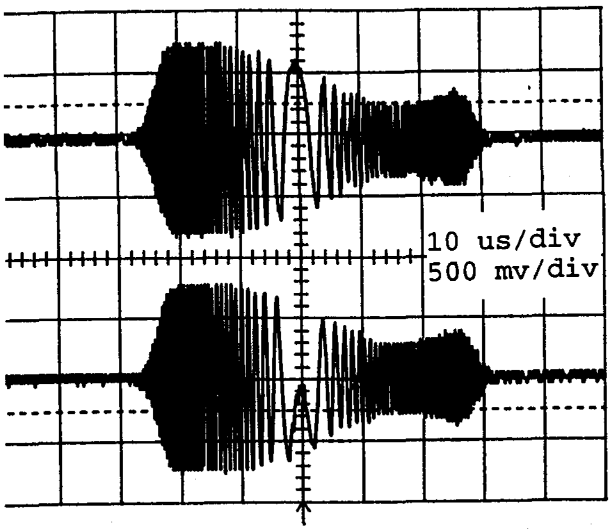


*Figure 4*

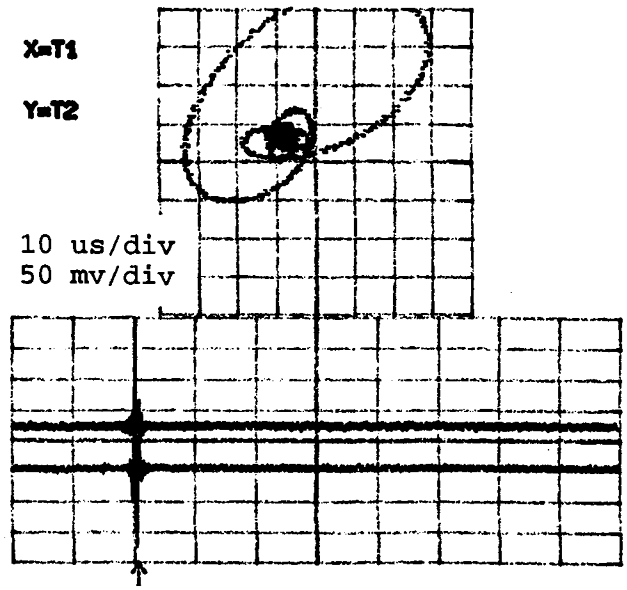


*Figure 5*

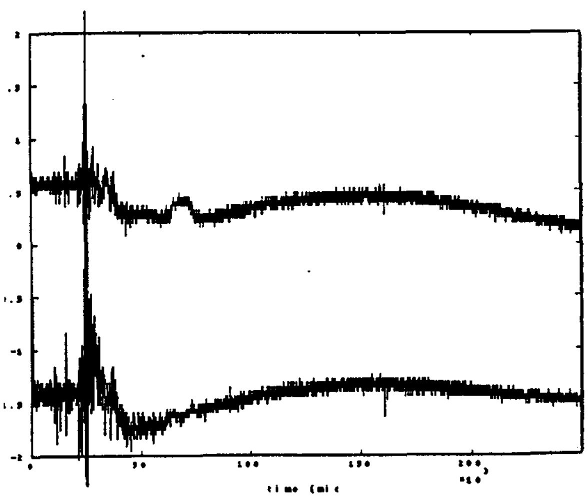

*Figure 6*

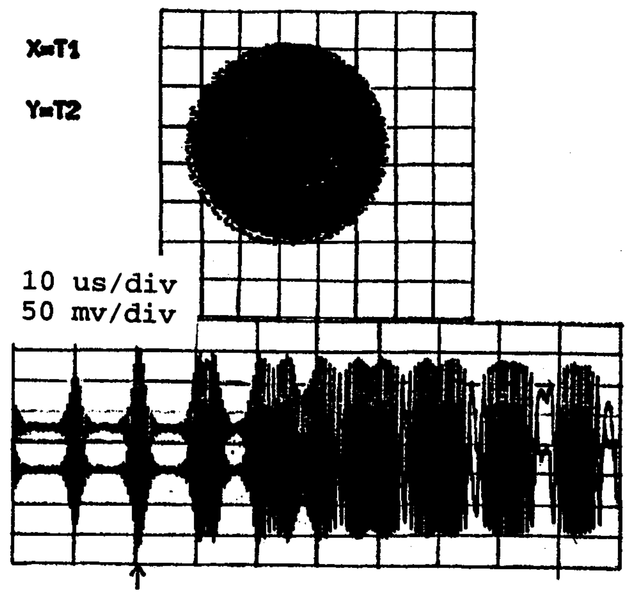


*Figure 7*

its way to its final frequency. Figure 5 is an impulse. Figure 6 is a nearby lightning strike that got into the phone system on the test home as well as the cable system. This particular lightning strike destroyed a home computer that was connected to the phone line through a fax-modem board in the test home. The cable equipment was not harmed. Figure 7 is interference of unknown origin. This data indicates that signals may not get out of headends unscathed unless special care is taken.

## FUTURE WORK

Two impairments not characterized by this test method are (possibly dynamic) channel frequency response and group delay distortion. This can be remedied by sending an in-phase only reference signal from the headend intermittently, perhaps once an hour. One good reference signal to use would be the standardized ghost cancellation reference (GCR) waveform currently used on line 19 of many NTSC broadcast signals. This signal possesses high energy, compact duration, and a flat frequency spectrum. This signal would trigger the CW receiver, and be automatically captured by this equipment for later analysis.

The channel availability lost due to errors in fixed time intervals is a useful parameter for estimating transmission reliability. An approximation of this number can be found by modifying the CW tester circuit in the following fashion.

Remove the one-shot trigger circuit that breaks the phase locked loop. The loop will now remain locked. Add a gate circuit that is open whenever the constellation point is outside the threshold region. This gate will pass a clock oscillator to an event counter. Set the threshold region to be the same as the distance between adjacent constellation points on the simulated modem. Over a time interval, the counter will contain a number of pulses from which error duration can be estimated. For example, if the clock is a 10MHz square wave (100ns between pulses) and the counter contains 10,000 pulses, then the duration of the disturbance is one millisecond. Very long disturbance durations could be quantified this way, along with short time samples of the actual interference, as previously described.

The data will later be analyzed to determine the frequency and duration of transient impairments that would affect a given modulation and/or forward error correction scheme. A short time Fourier analysis can determine if the interference originated from a transient impedance change (changing reflection), ingress of a narrow-band interferer, or a wide-band impulsive noise spike.

## CONCLUSION

A method for characterization of transient impairments on cable systems has been proposed. A system developed at CableLabs for evaluating the nature and effect of these impairments on digital transmission using this methodology has been described. Analysis techniques on the captured impairment data were outlined.

Many types of impairments may be recognized by analyzing the actual disturbances captured by this system. Also, a characterization of the duration and inter-arrival statistics of the transient disturbances are available. Channel availability and related statistics such as errored seconds may be derived. These test results can be used to design burst error mitigation schemes such as error-correction coding with interleaving for any desired type of single carrier modulation for digital data transmission over cable systems.