ANALYSIS OF TWO-WAY CABLE SYSTEM TRANSIENT IMPAIRMENTS

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Abstract

This paper presents an analysis of the effects and potential sources of transient impairments found in field testing of two-way cable systems currently supporting trials of digital transmission equipment for two-way services. Data on the characteristics and statistics of impairments that have been captured over extended time periods using a device known as the CW Tester™ are presented. This device demodulates a test carrier wave into in-phase (I) and quadrature (Q) baseband signals. When a transient impairment is sensed, the device triggers a digital oscilloscope to acquire the demodulated impairment. The impairment data is stored on a computer for subsequent analysis using a data browsing software analysis tool for detailed inspection of individual impairments, as well as for longer term statistical analysis and transmission performance characterization. The results of laboratory experiments designed to replicate and thus identify the source of some impairments are compared with similar characteristics observed in the field.

INTRODUCTION

Successful deployment of interactive two-way services on the existing HFC cable systems requires an in-depth characterization of the return transmission medium[1]. Such a characterization seeks to determine the nature of transmission channel impairments as well as limitations imposed on transmission capacity[2]. Characterization should be done for both stationary impairments (e.g., thermal noise, intermodulation distortion, frequency response) and for transient impairments (e.g. impulse noise, RF ingress, signal clipping). An extensive study of cable channel characteristics for stationary impairments has been previously reported [3]. This paper focuses only on the transient impairments for the cable return channel due to the predominance of transient disturbances in this portion of two-way cable systems.

Diagnostic hardware and software tools to facilitate cable system characterization are under development. These tools are useful for plant certification, real time status monitoring, deduction of impairment sources, and prediction of transmission system performance of vendor equipment in the two-way cable environment.

TEST SYSTEM DESCRIPTION

A transient impairment capturing system

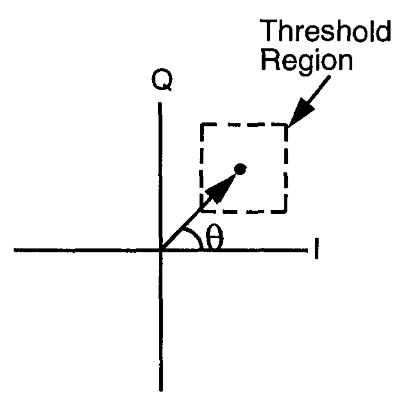


Figure 1. I-Q Constellation of CW Tester™

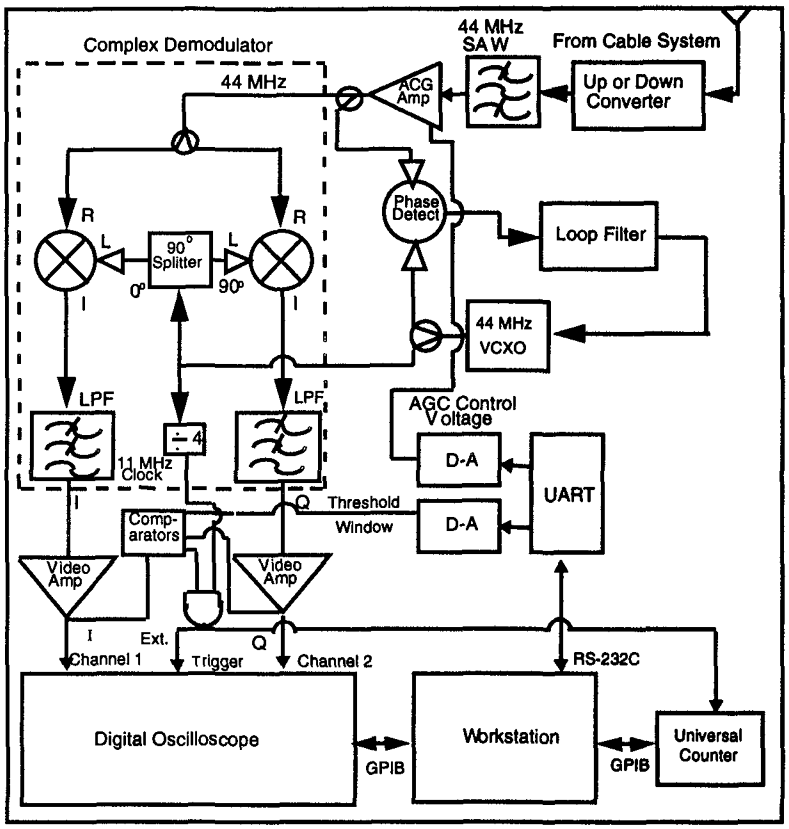


Figure 2. CW Tester™ block diagram

called the CW Tester™ has been developed by CableLabs. This system currently allows for testing of a cable channel in up to a 6 MHz bandwidth. This tester works by placing a carrier wave (CW) in a vacant channel, and may be used on either the forward or return cable system.

Figure 1 is a constellation diagram of a CW carrier. By way of comparison, a 16-QAM signal demodulated into I and Q components and sampled each data symbol interval would produce a 16 point constellation. An unmodulated CW carrier has a single point constellation with some static magnitude and phase angle. A threshold region is established around the static carrier. The power level of the carrier and the size of the threshold region are chosen for the appropriate bandwidth and transmission modulation format respectively. The results reported here assume a 6 MHz QPSK carrier. If the carrier trajectory wanders outside of the threshold region, the oscilloscope is triggered and the demodulated carrier components are downloaded from the oscilloscope into the computer. The amount of time the carrier spends outside of the threshold region is also measured with a gated counter.

A block diagram of the CW Tester™ is shown in Figure 2. A CW carrier is transmitted through the system under test, and either up or down converted to an IF frequency of 44 MHz at the receiver input of the CW Tester. After IF filtering by a SAW filter, automatic gain control (AGC) is applied to the received carrier under computer control to monitor and compensate for cable plant gain fluctuations. A phase-locked loop (PLL) tracks the signal using a voltagecontrolled crystal oscillator (VCXO). The VCXO output is divided with a quadrature splitter and applied to a complex demodulator to provide in-phase (I) and quadrature (Q) outputs. The I and Q signals are amplified and supplied to a digital oscilloscope. The I and Q outputs are also provided to comparators which drive an "and" gate. The "and" gate's other input is an 11MHz clock. The output of the "and" gate drives a universal counter and triggers the digital oscilloscope. Once an event triggers the oscilloscope, 5000 I and Q channel samples are collected in about 0.5 millisecond, and the oscilloscope memory contents and the digital counter value are transferred to the workstation. About 2 second are required for this operation. The purpose of the counter is to provide an estimate of the amount of time that the carrier spends outside the threshold region, independent of the oscilloscope signal acquisition. This estimate gives an indication of whether the event captured by the oscilloscope was of a short or long duration. The data captured by the oscilloscope are useful for evaluating the nature and severity of the impairment that triggered the data capture, and can also be Fourier transformed to provide information about the spectral content of the interferer.

Impairments are stored on a computer disk for later data analysis. A data reduction algorithm regulating the interval between event samples from a minimum of two seconds to an arbitrarily long duration will prevent a continuous impairment from overflowing available disk storage with redundant oscilloscope data. However, the counter continuously monitors the error inducing effects of all impairments during any interval.

Figure 3 shows a high level flow diagram explaining the control software and data acquisition process. Three daily files are created each day and are used to record data. The first file stores the bulk of the data. The second file is a separate log file used to store a summary of each event. The third daily file is an AGC file to

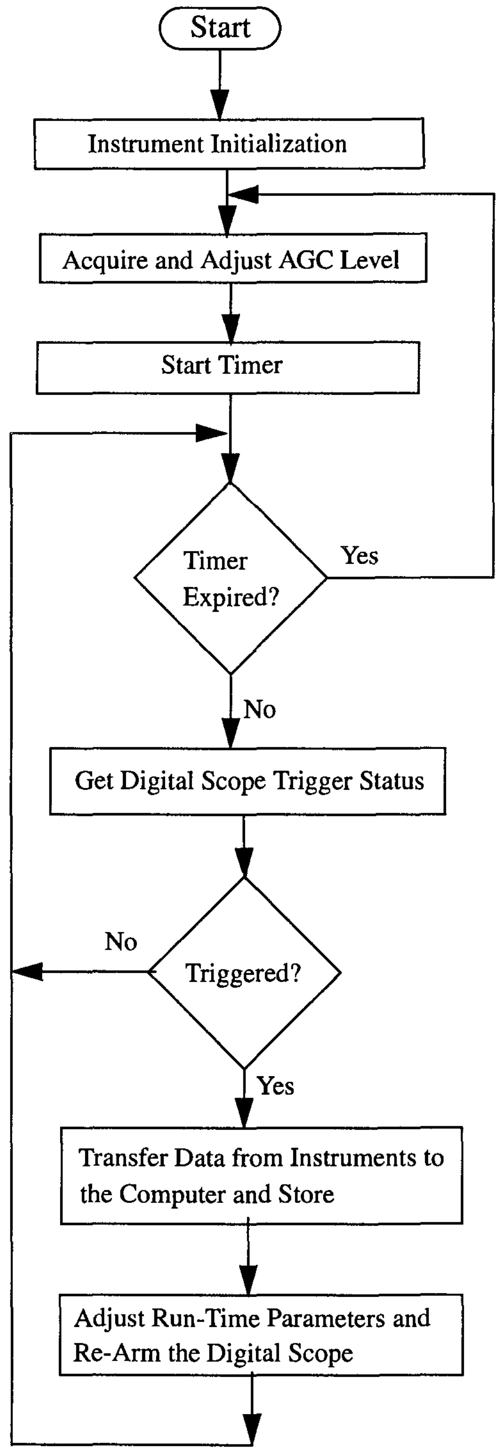


Figure 3. CW Tester™ software control program high level flow diagram

record signal level variations during the day on a minute-by-minute basis. In addition to AGC level, carrier-to-noise ratio is measured each minute and recorded in this file. A unique file format for each daily file identifies date, time, counter value, count interval, and instrument settings so that the captured impairment waveforms can be correctly interpreted.

Besides using the computer for data acquisition control and storage, the control program will initialize various instruments and monitor for abnormalities. This is accomplished through fault tolerant and error recovery software routines included in the control program. Furthermore, a number of flexible features are added to allow for reconfiguring the control environment by reading an input parameter file. The daily files contain actual instrument settings in case the operator changes the default values in the input parameter file. These parameter changes will become effective immediately upon restarting the control program.

DATA BROWSING TOOL

The CW Tester™ can capture a large amount of data making individual observation of each captured event impractical. The data browsing tool developed at CableLabs simplifies the analysis of captured impairment statistics and provides overall channel performance metrics while identifying important and interesting impairment characteristics in detail. This tool provides both long and short term data analysis. A summary of several important digital transmission performance characteristics with a hierarchical structure that can quickly point the user to the individual events of interest for direct inspection.

The LabVIEW software package from National Instruments implements the tool with an interactive graphical user interface (GUI). LabVIEW provides a rich class of ready to use graphical modules for a variety of applications, including tools for signal processing, statistical analysis, and data manipulation. In addition, waveform plotting tools (widgets) are supported for presentation of individual impairment events.

The data browsing tool calculates several layers of performance characteristics pertinent to digital transmission systems providing more data reduction and performance summarization at each level. Thousands of channel impairment events are analyzed with data reduction algorithms providing statistics on captured impairments on a second by second basis, a longer interval of interest (e.g. 1 minute, 15 minutes, 1 hour etc.), a daily basis, and global performance statistics over the entire duration of testing.

The CW Tester™ captures a half millisecond demodulated sample of an impairment that exceeds the trigger threshold in addition to a gated two second count for each time stamped transient event. The duration the impairment forced the test carrier outside of the threshold region is determined for each demodulated sample, as well as for the longer count interval. This data is used to calculate several channel characteristics and performance metrics.

The time that the CW carrier spends outside the threshold region in the demodulated sample determines the *burst duration* of the transient impulsive noise burst. The counter value determines the number of such burst events in the two second (or longer) interval, which in turn provides a short term estimate of the average time separation between impulsive disturbances or *interarrival time*. The proportion of time the CW carrier spends outside of the threshold region in the two second count interval defines the *symbol error rate*. Each second containing symbol errors defines an *errored second* at the symbol error rate so determined. Thus an *unavailable second* at a specified symbol error rate exceeds that error rate during that second. The percentage of errored seconds above a specified symbol error rate in a given time interval (e.g. 15 minutes) defines the *percentage unavailability* at that symbol error rate during that time interval. The unavailability at any error rate over any time interval for one minute, one hour, one day, or the entire test epoch could be

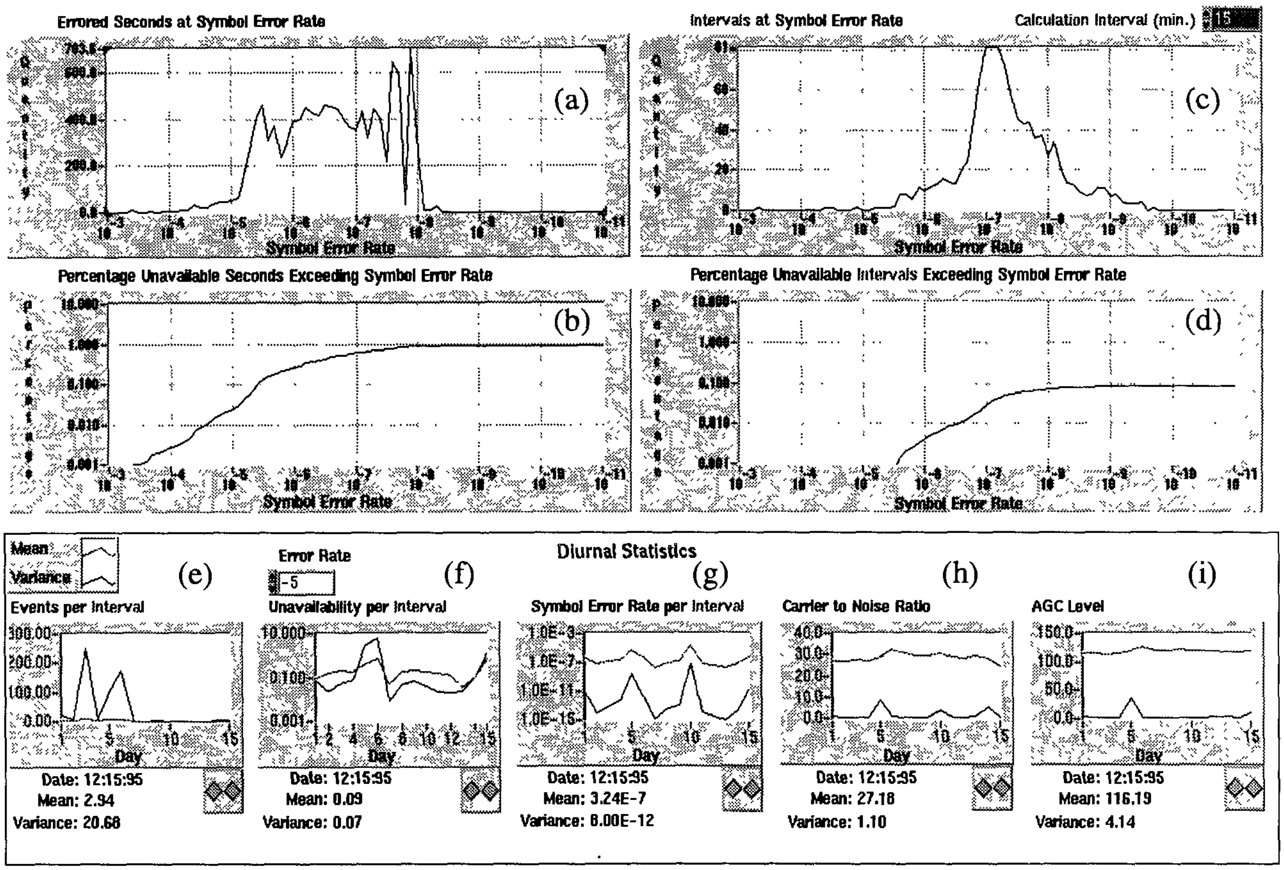


Figure 4.

calculated from the errored seconds statistics.

The CW Tester™ data browsing tool performs a hierarchical analysis of the CW Tester™ daily data files for an extended period of time. The features of the data browsing tool are illustrated in the presentation of field test results obtained from a two-way cable television system in the following section.

PRESENTATION OF RESULTS

The architecture for the field tested system consisted of a two-way express feeder upgrade with a maximum cascade of three amplifiers passing 600 subscribers from the node. The node tested consisted of all newly connected drops.

Figure 4 summarizes the return path performance of the node appropriate for QPSK transmission in a 6 MHz bandwidth centered at 26.75 MHz. The data for this analysis was acquired over approximately a two week test period. Figures 4a through 4d plot several histograms of statistics as a function of the symbol error rate. Figures 4e through 4i show the daily mean and variance of several statistics.

Figure 4a shows a histogram of the number of errored seconds as a function of symbol error rate for the entire test period. Figure 4b is a cumulative distribution of the percentage of unavailable seconds exceeding a given error rate, calculated as the normalized integral of figure 4a. For example, 1.0 percent of all seconds during the entire two week test period exceeded an error rate of 10^{-8}, and less than 0.1 percent exceeded 10^{-5}.

Figure 4c shows the number of 15 minute intervals as a function of symbol error rate. The

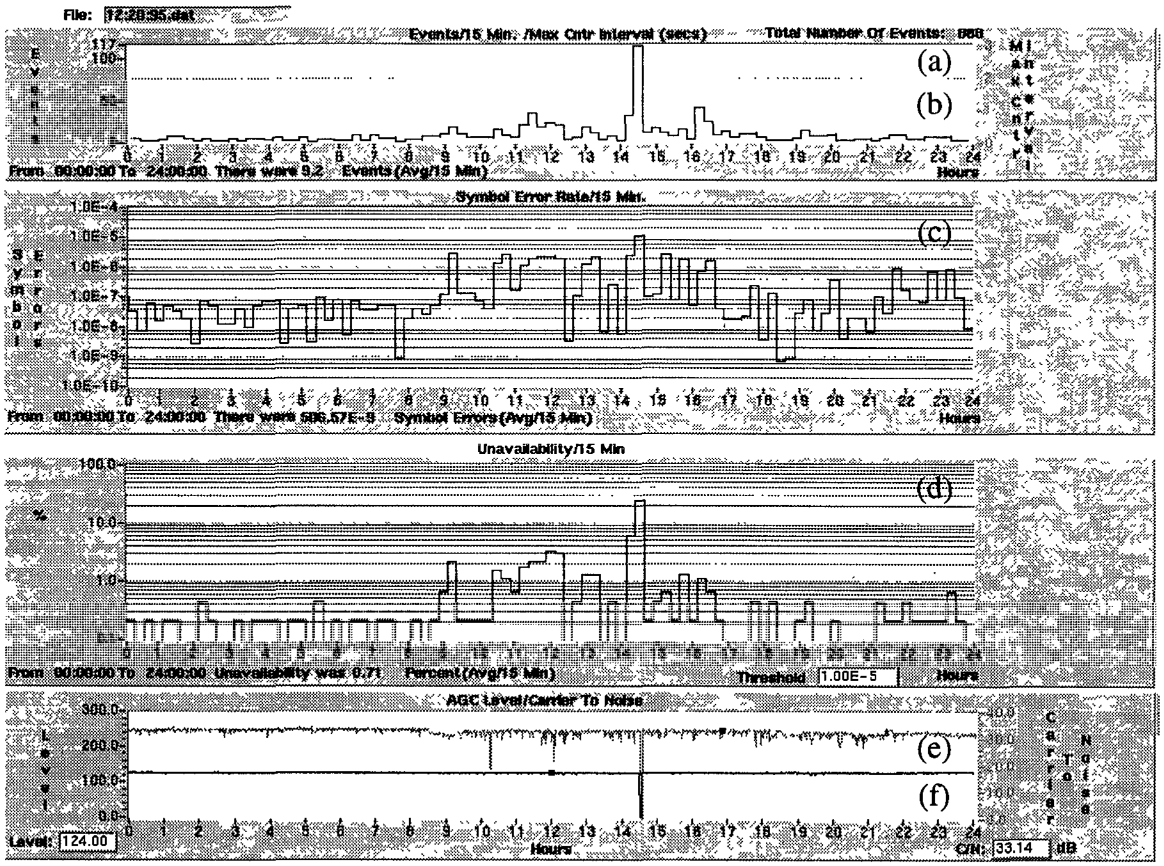


Figure 5.

interval over which errors are accumulated is increased to every 15 minutes in figure 4c from every second in figure 4a. The interval can be varied from 1 minute to 24 hours. Figure 4d is a cumulative distribution of the percentage of unavailable 15 minute intervals exceeding a given error rate, calculated as the normalized integral of figure 4c. For example, 0.1 percent of all 15 minute intervals during the entire two week test period exceeded an error rate of 10^{-8}, and less than 0.001 percent exceeded 10^{-5}.

Figures 4e, 4f, 4g, 4h, and 4i display the daily mean and variance of several interesting statistics. Figure 4e shows the daily mean and variance of the number of burst impairment events per 15 minute interval. Figure 4f shows the daily mean and variance of the percent unavailable 15 minute intervals exceeding 10^{-5} error rate. Figure 4g shows the daily mean and variance of the symbol error rate per 15 minute interval. Figure 4h shows the daily mean and variance of the carrier-to-noise ratio sampled every minute. Figure 4i shows the daily mean and variance of the received CW carrier AGC level, which is proportional to the received carrier level, sampled every minute.

A fluctuation in the mean or a large variance indicates significant time variability in the measured statistic during a 24 hour period. Thus the individual days with significant variation in plant performance can be readily identified for analysis over a single day from the top level of the browsing tool.

Figure 5 illustrates the next lower level of the browsing tool, which shows a representative output of a 24 hour analysis selected from the top level of the browsing tool. A comprehensive report of the transmission performance during

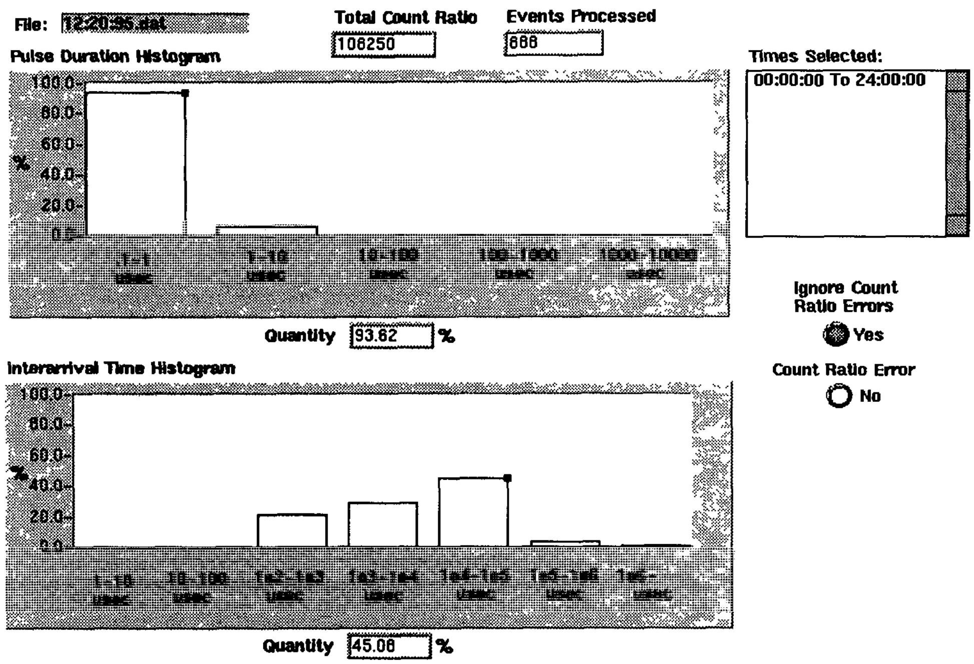


Figure 6.

each 15-minute period in a single day is displayed using several graphs. Figure 5b is a plot of the number of impairment events that triggered the oscilloscope in each 15 minute period. Since a minimum of 2 seconds is required to reset the oscilloscope for another trigger, this number is limited to a maximum of about 450 per 15 minute interval. However, if the impairments are continuous, the system has a data reduction algorithm that increases the minimum time interval between event samples preventing overflow of available disk storage. Figure 5a shows the maximum count interval time in seconds during each 15 minute period.

The counter value is used to estimate the relative amount of time the carrier spent outside of the threshold region. This can be expressed as a symbol error ratio and is shown as figure 5c. The percentage of unavailability for a given symbol error rate over a 15 minute period may be read on figure 5d. In this example, a symbol error rate of 10^{-5} is shown. Other functions that are available are the carrier-to-noise ratio and the AGC level. The carrier-to-noise ratio is obtained by periodically triggering the oscilloscope every minute and computing the ratio. The carrier-to-noise ratio is shown as figure 5e. Since an 8-bit A-D converter is used, the quantization noise limits the measurement range to about 40 dB. The AGC level, which is updated once per minute, is an indication of carrier level drift or an outage if the value is zero. The AGC level is shown in figure 5f.

The burst error duration and interarrival time statistics for the impairments for the entire 24 hour period is shown in figure 6. The predominant number of bursts occur with a duration of less than 1 microsecond, and average interarrival time of about 10 milliseconds. This is typical for most days. A portion of the day may also be selected for analysis of burst error statistics.

The lowest level of the browsing tool allows an operator to set cursors selecting interesting periods of time and inspect the individual impairments that caused the errors. For example, the cursors select 14:30 hours and the impairment shown in figure 7 is a typical scope trace. The I and Q voltages are shown on the

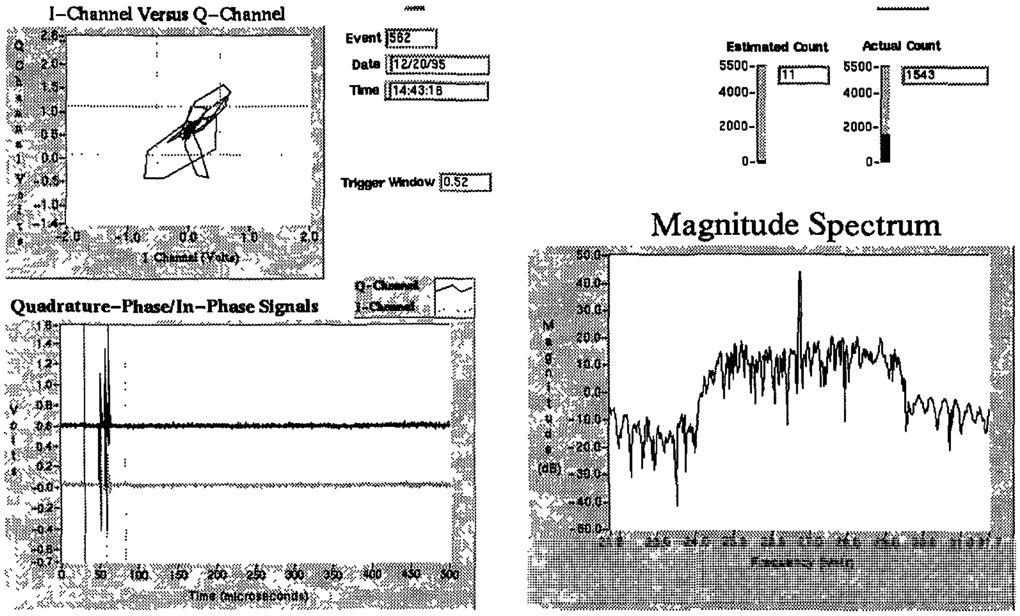


Figure 7.

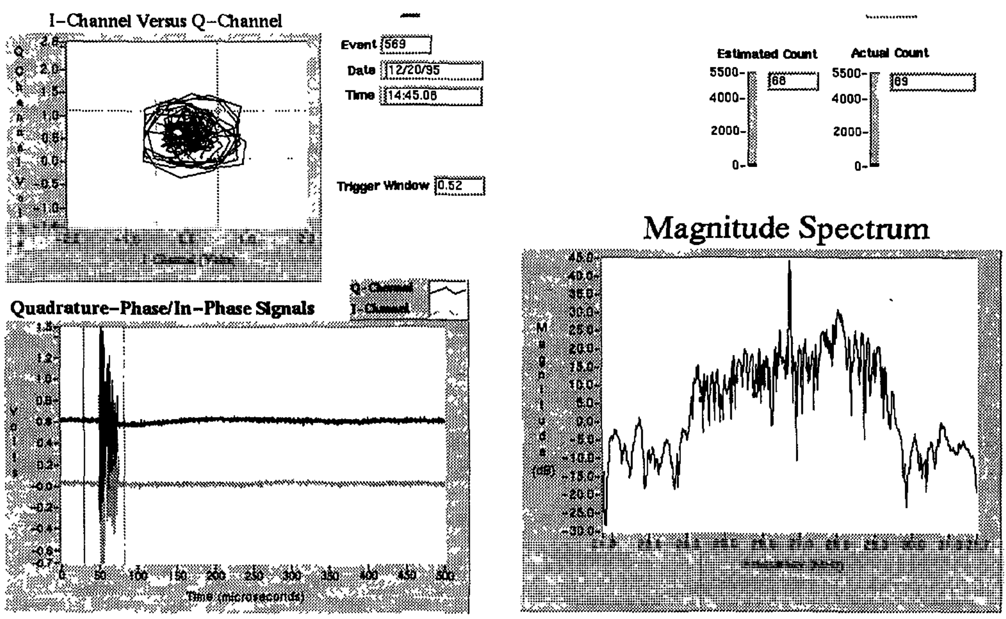


Figure 8.

lower left graph. The vector I-Q voltage is shown on the upper left graph, and a Fourier transform of the time domain data is displayed in the lower right graph. Note that the impulse is brief. This is collaborated in the estimated count box which shows a value of 11. This value is obtained by computing what counter value would have been obtained during the 500 microsecond scope trace time. The total time for this count is 1 microsecond for an 11 MHz clock. However, the counter totaled for 2 seconds, and a count of 1543 was actually received. This strongly suggests that this scope impairment was only one of many that were received during the 2 second period. If the estimated count is close in value to the actual count, the entire impairment was captured by the scope within the 500 microsecond scope trace as

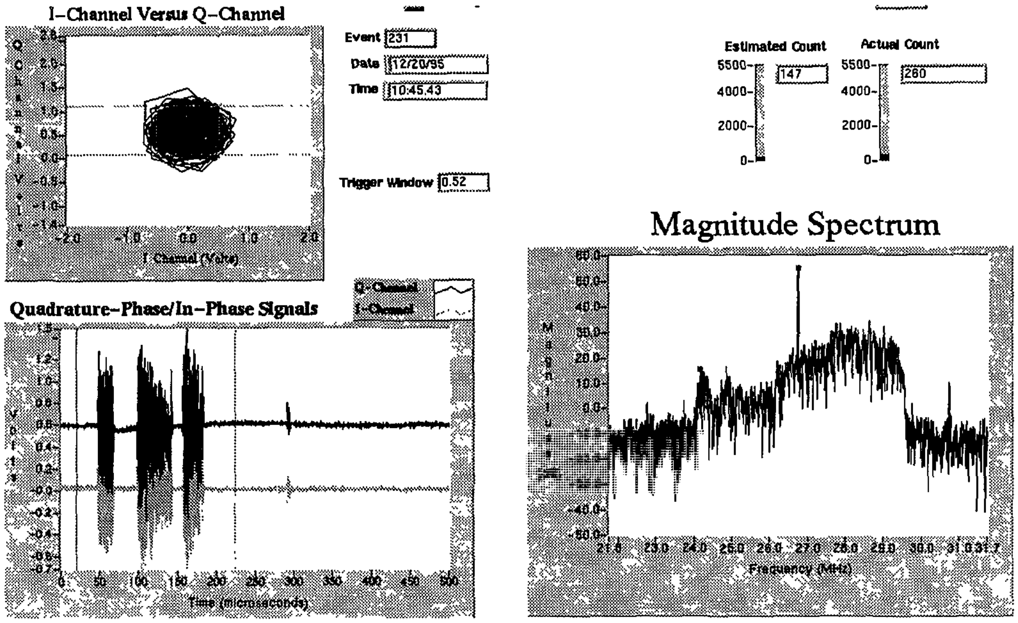


Figure 9.

shown in figure 8. The total time for this isolated event with a count of 68 is 6 microseconds.

LABORATORY VERIFICATION

Some of the impairments captured in the field possessed distinctive characteristics which were repeated in several test sites where the CW Tester™ system was installed. These observations revealed some patterns that suggested experimental replication of these impairments by duplicating the impairment sources and mechanisms in the laboratory. An inspection of the oscilloscope traces from field data inspired two laboratory experiments to determine the probable cause of several observed impairments.

One very prevalent burst type impairment known as impulse noise is similar in appearance to the data shown in figure 9. Switching of electrical devices in homes such as TV sets, VCRs, hair dryers, vacuum cleaners, washers and dryers, etc. could be the source of these types of impairments. Furthermore, the majority of impulse noise ingress originating from inside of the subscriber home enters the cable network through the drop cable connection. The question arises as to the mechanism by which this impairment enters the cable plant. One possible mechanism injects this noise from the public utility neutral wire into the cable system at the common bonding point at the side-of-home ground block.

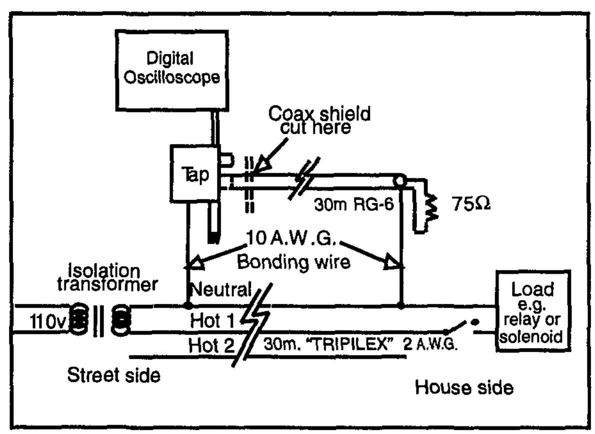
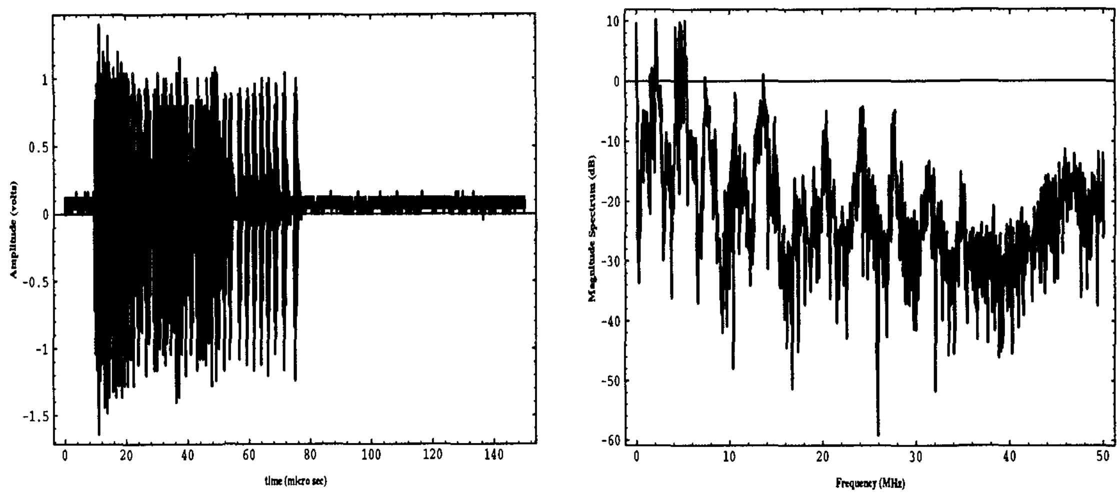


Figure 10. Lab experiment 1 simulating home wiring

Figure 10 is a wiring diagram of the lab experiment attempting to recreate this situation. The point of the experiment was to determine if devices in the home, when they are switched on and off, can create impulsive energy in the return band, if there is a mechanism to conduct the



(a) (b)

Figure 11. Lab unshielded drop cable time and frequency responses.

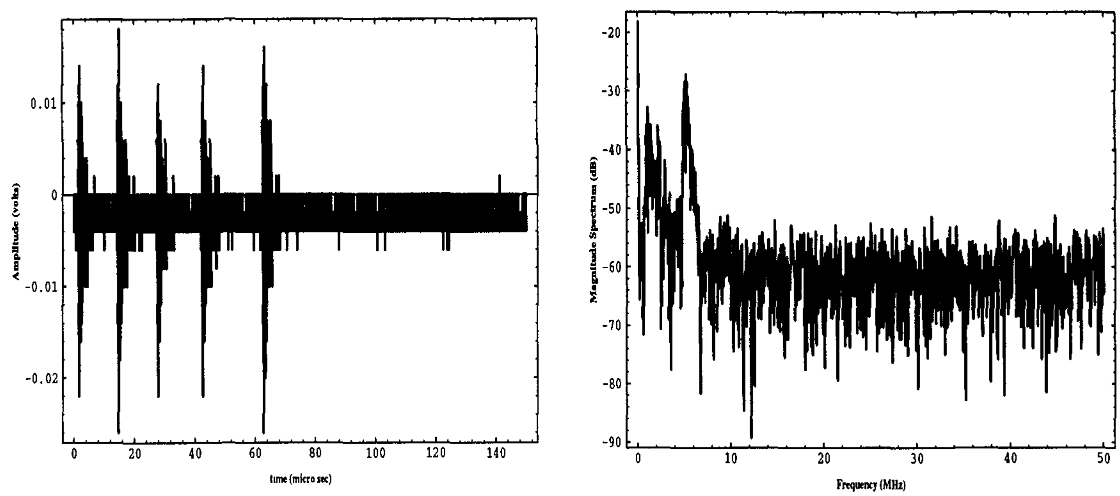


Figure 12. Shielded humidifier load time and frequency responses.

energy from the AC power lines into the cable plant, and if the impulsive energy had similar characteristics to what was recorded in the field. About 30 meters of 2 AWG "triplex" aerial house wiring was bonded on the neutral wire at both ends to a 30 meter piece of RG-6 coaxial cable. The RG-6 coax was applied to an 8 dB tap port, and the output of the tap was connected to an oscilloscope and to a CW Tester™. An isolation transformer provided power to the home wiring at the "street side" and in the "home" a motor starter relay was powered on and off by means of a switch.

A small amount of impulsive energy was coupled into the cable return path. However, when the shield of the coaxial cable was cut on either end, the magnitude of the impulsive energy increased dramatically (about 20 to 30 dB) as shown in figure 11a. A Fourier transform

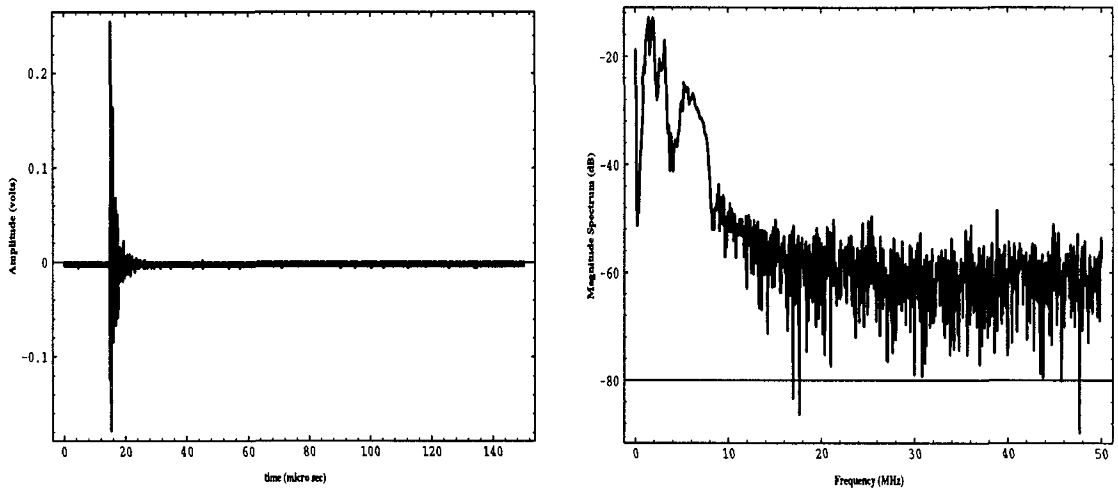


Figure 13. Shielded static electricity discharge time and frequency responses.

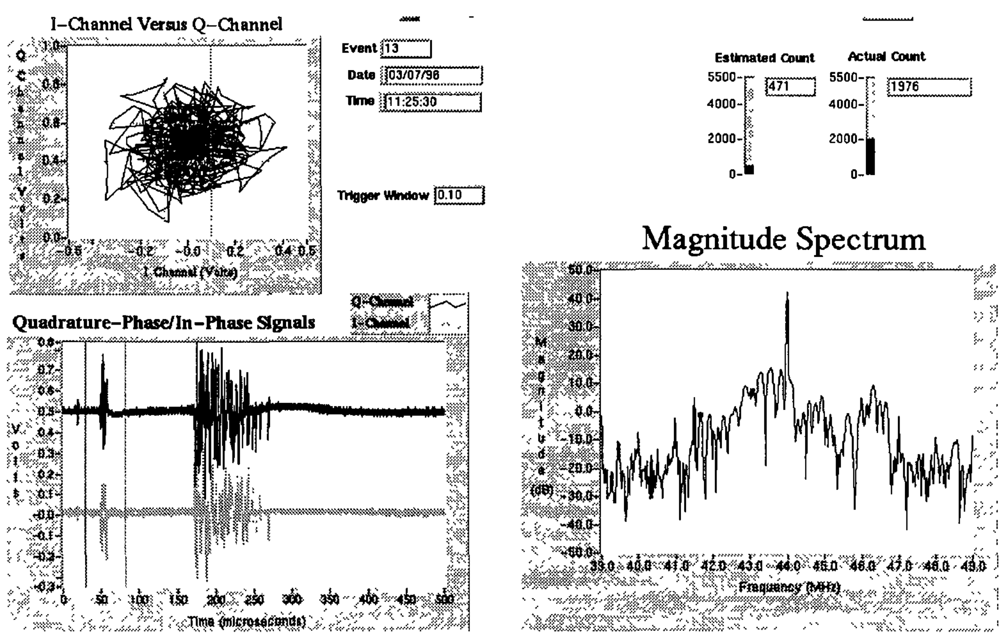


Figure 14.

of the signal indicated that significant energy is available in the entire return band as shown by the spectrum plot in figure 11b.

Similar impulsive events were observed from a randomly chosen home with underground utilities. In this home, the cable was grounded with a ground rod at the entry point, not directly connected to the power ground. The impairment in figure 12 was caused by a humidifier load. Another observation was that static electricity from walking across a carpet being discharged on a wall switch plate could also cause an impairment as shown in figure 13. This home proved to be quite capable of generating impairments with its own appliances without being supplied special loads and switches from CableLabs. When the drop coax shield was

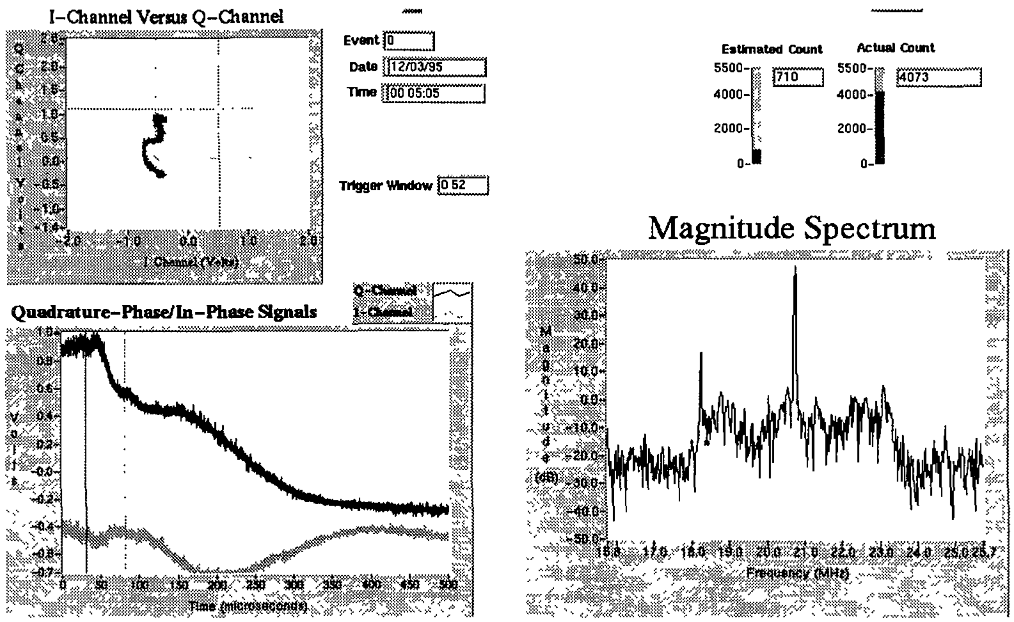


Figure 15.

severed at the tap, the impairments increased in amplitude by 20 to 30 dB.

The spectrum of the impairment indicated that much of the high energy from the house was attenuated relative to the lower frequency energy. This characteristic was not as evident in the lab results. Apparently, high frequency roll-off of the energy may be a general trend of house wiring.

The CW carrier transmitted through the home simulated wiring was connected to the CW Tester™. The result is shown in figure 14. Note the burst characteristics similar to the field results previously shown in figures 7 through 9.

Another type of impairment that was found in the field with the CW Tester™ is illustrated in figure 15. This impairment was much less common than the impulsive impairments and was most easily found in plant with no drops attached. The characteristics of this impairment include a low frequency disturbance of the demodulated carrier. This impairment was also observed in downstream channels. One possible cause could be that the ferrites in the cable plant were being saturated by current from the power grid.

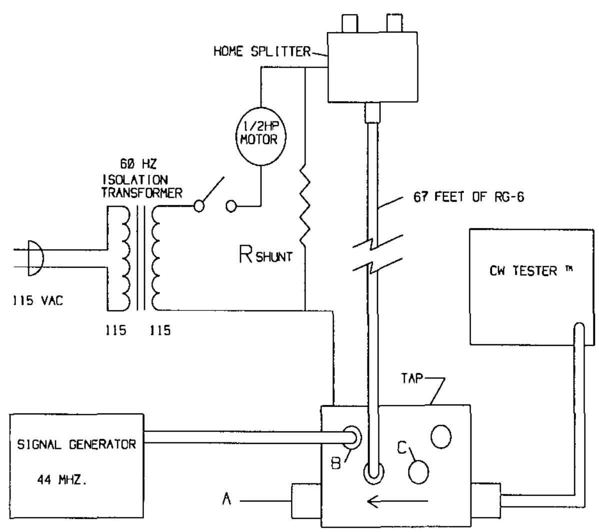


Figure 16. Lab experiment 2 simulating ferrite saturation in the tap.

Figure 16 is the wiring diagram of a lab experiment to replicate this phenomenon. A tap without a blocking capacitor on the tap port was connected through a long piece of RG-6 cable. The cable was connected to a splitter that provided a path between the shield and the center conductor. The coax was used as a

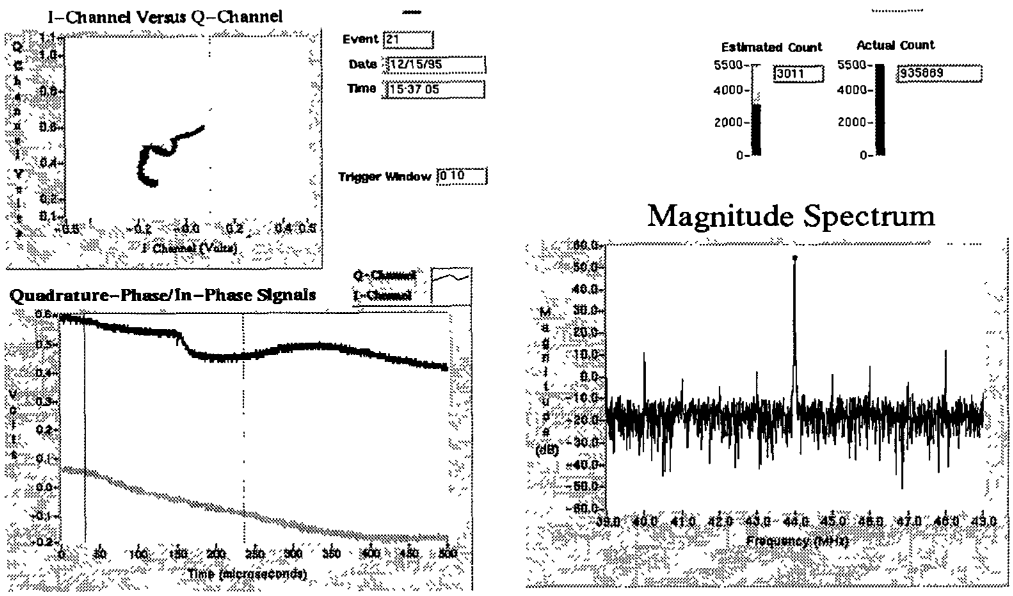


Figure 17.

conductor for a 1/2 h.p. motor. The current was shared between the center conductor and the shield. When the motor was started, a surge of about 36 amps flowed for several hundred milliseconds, after that it went to a steady-state value of 8 amps. The signal for the CW Tester™ was passed through an adjacent port and was attenuated by ferrite saturation as shown in figure 17. Although it is difficult to state if the impairment that was seen in the field was caused by ferrite saturation, the results are similar.

CONCLUSIONS

The CW Tester™ transient impairment data acquisition system and the companion data browsing software analysis tool provides a comprehensive transmission channel performance evaluation system for two-way cable systems. The utility of the hierarchical data analysis features allowing overall global performance evaluation of a two-way cable system (primarily the return path) over a significantly long duration has been described.

The results provided by the CW Tester™ channel characterization and transmission performance evaluation system presented here allows a transmission system designer to evaluate the requirements for modem performance at any desired level of service availability defined in terms of both short and long term channel error rate and burst error characteristics.

The evaluation of transient impairment data acquired over a two week period in the field on a typical 600 home passed node was presented. The error rate measured over successive 15 minute intervals was observed to vary significantly (many orders of magnitude) over a 24 hour period. Some days showed a higher average error rate as well as more variation in error performance.

Several characteristics of typical impairments were illustrated. A potential cause of these impairments was hypothesized. Laboratory and field experiments and results were presented to verify the sources and effects of these transient impairments. Common bonding of the cable plant with power lines apparently provides an entry point for electrical impulse noise generated by electrical appliances in homes.

As demonstrated in the lab and verified in the field, maintaining the integrity of cable shielding is extremely important. A compromised shield on a single drop could produce a hundred-fold increase in interference level from a single home connected to the common return path serving several hundred subscribers. In this situation, locating the individual drop responsible can be extremely difficult due to the time-varying nature of the impairment source.

The two-way cable system return path requires consistent attention to properly maintain a high level of performance. Diagnostic tools for cable plant proof of performance verification, problem isolation, and real-time status monitoring are needed for the operational success of two-way cable services. The CableLabs CW Tester™ system is an embodiment of one such tool for assisting cable operators in the successful deployment and operation of these services.

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