Reprinted with permission from the 1999 NCTA Technical Papers, pp. 67-78

Correlating Return-Band Impulsive Noise Measurements from Houses with Sheath Current Induction Test Results

Tom Williams

Holtzman Inc.
Longmont, Colorado

Abstract:
Sheath current induction is a method for finding shield breaks in coaxial cable by inducing a broadband test current onto the shield and receiving a center conductor signal when there is a shield break. This test method allows the range to a shield break to be measured, as well as a measure of the severity of the break. This paper correlates the sheath current induction test results for a house with the house's ability to generate impulsive interference with digital upstream traffic. The test method is to first create a known shield break at the ground block and characterize the break by the sheath current induction test. Next, impulsive interference is generated inside the house on the house's power wiring with a noisy 110 volt AC load. This impulsive interference is measured at the tap with a bandpass filter and a totaling counter. Finally, the known shield break is fixed and the test is redone. This test procedure was repeated on a number of different houses.

Background:
HFC (hybrid fiber coax) cable networks are widely expected to assume a major role as a transport medium for two-way high speed data including digital television, internet browsing, e-mail, cable telephony and a host of other new services. Many of the new digital services require a reliable two-way transmission capability, although the upstream bandwidth requirements are typically lower.

The downstream portion of the cable plant, which may extend from 50 to 750 MHz, is both highly evolved and well understood. The tree and branch architecture allows many high-quality copies of the composite downstream signal generated at the headend or hub site to be replicated and distributed to homes. Furthermore, the cable operator has tight control of both the signal level and the quality of the composite signal originating at the headend.

The upstream portion of the cable system, which typically extends from 5-40 MHz, is a different situation. The tree and branch architecture permits noise as well as signals from many locations to be combined into a common signal path. This well-known phenomena is known as "noise-funneling." As a net effect, a noise problem that is generated at any location affects signals from all locations that are supported by a common receiver. Typically a common receiver supports one to several nodes with 500-2000 homes passed in each node. Frequently encountered return problems are common-path distortion (CPD), broadcast ingress, and burst noise.

Burst Noise

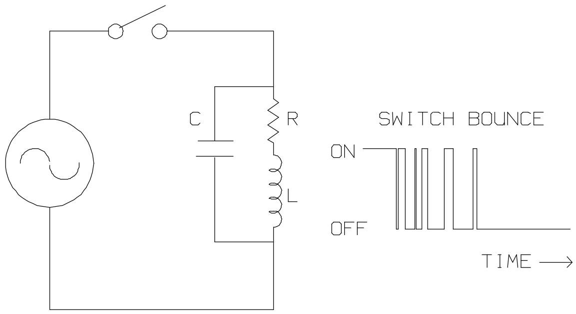

Fig. 1 A reference model for the generation of burst noise with an inductive load and switch bounce

Burst noise was found to be a prevalent return impairment in a number of studies [1] [2]. Burst noise is frequently created when switching off and on inductive loads with mechanical contacts or with electric motors with brushes. The burst energy is typically short in duration but high in energy. Solid-state power controllers also create impulses, usually with repetition rates that are at harmonics of the power line frequency.

Received burst noise typically has the characteristic of having most of its energy constrained to the frequency band below 15 MHz. Because of the high energy associated with burst noise, the energy below 15 MHz frequently has sufficient power to clip upstream active devices, especially Fabry Perot laser diodes. Clipping upstream active devices, although brief, is disruptive to signals in the entire upstream frequency band due to a third order distortion component called cross-compression. (Cross-compression is similar to the cross-modulation distortion that is sometimes observed on downstream cable systems.)

One theory about how burst noise is getting into upstream cable plant is via shield breaks. The burst noise traveling on the AC power line finds its way onto the cable sheath and travels on the sheath until a shield break is encountered. Shield breaks are frequently caused by corroded connectors, animal chews or other mechanical damage, and consumer electronic devices with poor shielding.

Fig. 1 is a reference model of a burst noise generator created by a mechanical switch that bounces multiple times as it opens and closes. The load has an inductance and a resistance associated with the windings as well as a winding-to-winding capacitance. When a current is flowing inside an ideal inductor, the current can only go to zero instantly with an infinite voltage. In practice, the switch arcs and the capacitor rapidly charges to a high voltage. When the switch bounce causes the contacts to re-connect, the capacitor dumps its charge into the power supply lines creating a noise burst. The exact nature of the noise burst depends on the instantaneous voltage on the AC power source when the switch is tossed and the manner in which the switch bounces as it is opened or closed. The spectrum of the burst energy contains significant energy up to the VHF television frequency band. Reference [3] describes the nature of electrical interference generated by arcing contacts.

Sheath Current Induction

The most commonly used method of finding sheath breaks is with signal leakage detection equipment. Unfortunately, signal leakage detection is less than ideal for finding breaks that allow upstream-band noise into the cable plant because conventional signal leakage test equipment uses a single carrier frequency, frequently 108-120 MHz, that is outside the upstream frequency band. Furthermore, a fast Fourier transform (FFT) of burst energy captured at the headend shows a frequency selectivity that can be missed by a single frequency test signal.

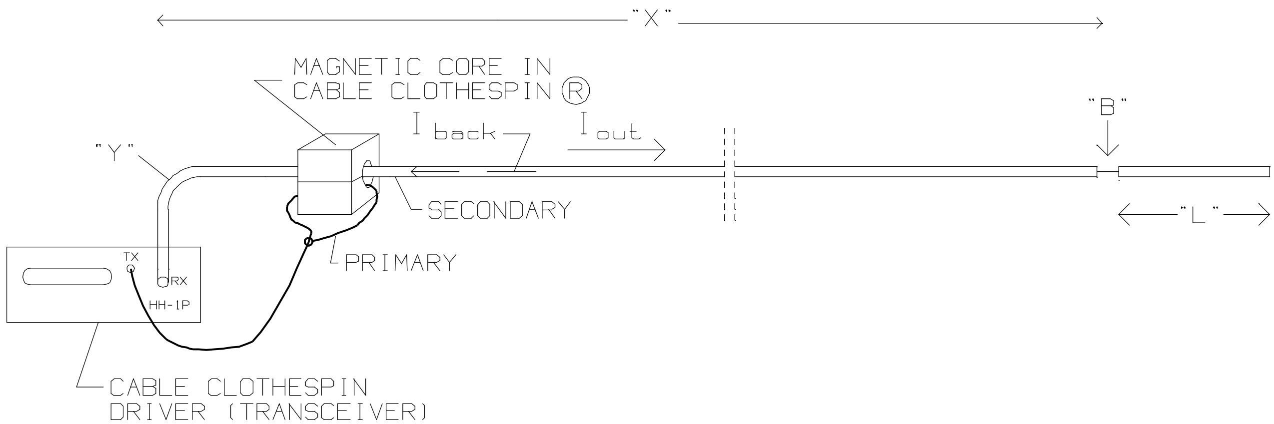

Fig. 2 The principle of testing a shield break via sheath current induction

Figure 2 is a block diagram of a sheath current test on a coaxial cable with a shield break. A technician creates a transformer by clamping a split magnetic core around a coaxial cable. Also included with the coaxial cable inside the center hole of the magnetic core is a wire connected to a reference signal transmitter which generates a broadband test signal. The technician creates a transformer with the wire forming a one-turn primary winding, and the drop sheath forming a secondary winding. The transmitter transmits a reference test signal which is measured by a receiver attached to the center conductor of the coaxial cable signal. If there is a shield break, some of the test signal will enter the inside of the coaxial cable and propagate to a receiver.

The received test signal can be analyzed to determine which frequencies are preferentially allowed into the cable, the total returned energy in the test signal, and an approximate distance to the shield break.

With sheath current induction, there are several methods for transmitting, receiving, and analyzing the test signal. The test method used for this paper was to determine the impulse response between the transmitter and receiver by transmitting a pseudonoise (PN) sequence, and performing a cross-correlation between the transmitted and received signals. A device called the Cable Clothespin® contains the magnetic core that is attached around the cable. A hand-held transceiver called a Cable Clothespin driver contains both the transmitter and receiver (transceiver). This equipment is illustrated in Photo 1. The Cable Clothespin driver may be attached to a personal computer (PC) to download the impulse response. The time delay between correlation samples is 20 ns. giving a resolution of 2.5 meters to a shield break. The PC performs a fast Fourier transform on the impulse response to show a frequency response associated with the shield break.

Photo 1.
Sheath current induction test at a tap

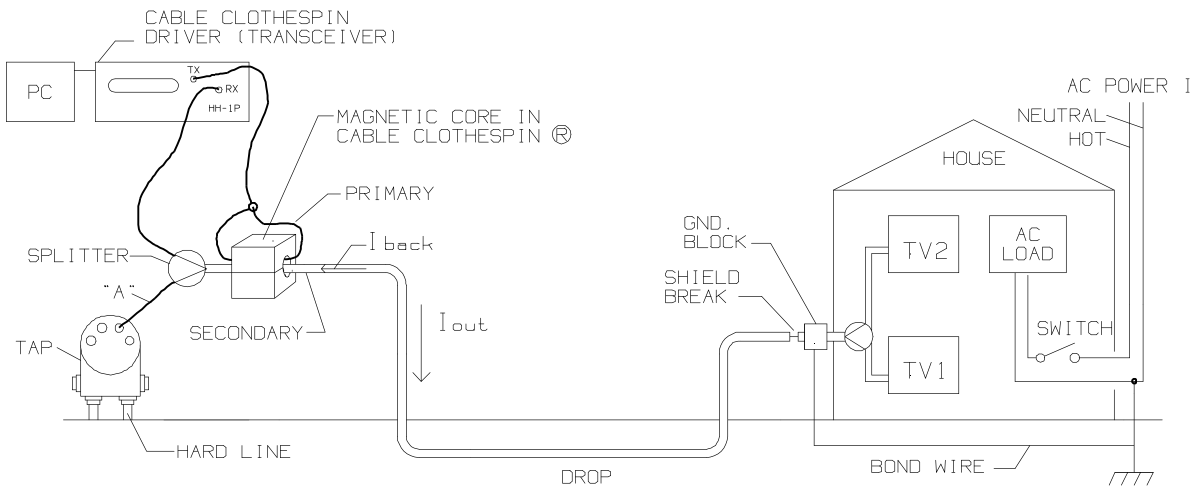

Fig. 3 Sheath current induction test for a house from a tap location

Reference [4] is an early paper written on field experiences with sheath current induction. The tester used to gather data for this earlier paper was a DSP-based complex frequency response measuring device called a Cable Scope® that employs a separate transmitter and receiver.

The Question

The question that this paper attempts to answer is: "Are the shield breaks that are typically found by the sheath current induction technique actually capable of causing packet errors in upstream data services?"

Test Method

The technical approach used to assess the capability of shield breaks to cause a disruption to upstream data was as follows. First, a known shield break near the ground block was created by inserting a 30 cm. piece of coax with a 3 mm. section of its shield removed.

Second, the shield break was characterized with the sheath current induction method using the wiring diagram shown in Fig. 3. The sheath current was injected at the tap location and the results were recorded on the laptop PC. A splitter at the tap was used to supply signals to the subscriber while the test was being performed.

Third, one operator went inside the house and created an interference on the AC power line while another operator at the tap measured the interference heading upstream. The block diagram for this process is illustrated in Fig. 4. This test utilizes a bandpass filter and a totaling counter with an accurately set threshold. Its operation will be described later in this paper. The level of the interference was measured for successively higher threshold levels.

Finally, the cable break was fixed and the test procedure was repeated.

Unfortunately, no one simple set of test conditions can be found that apply equally well to all possible upstream field situations. Significant variables are:

a. the nature of the AC power load and switching creating an interference on the power line
b. the type of upstream modulation that will be contending with the interference
c. any forward error correction that the upstream modulation will be using
d. whether the drop is aerial or buried

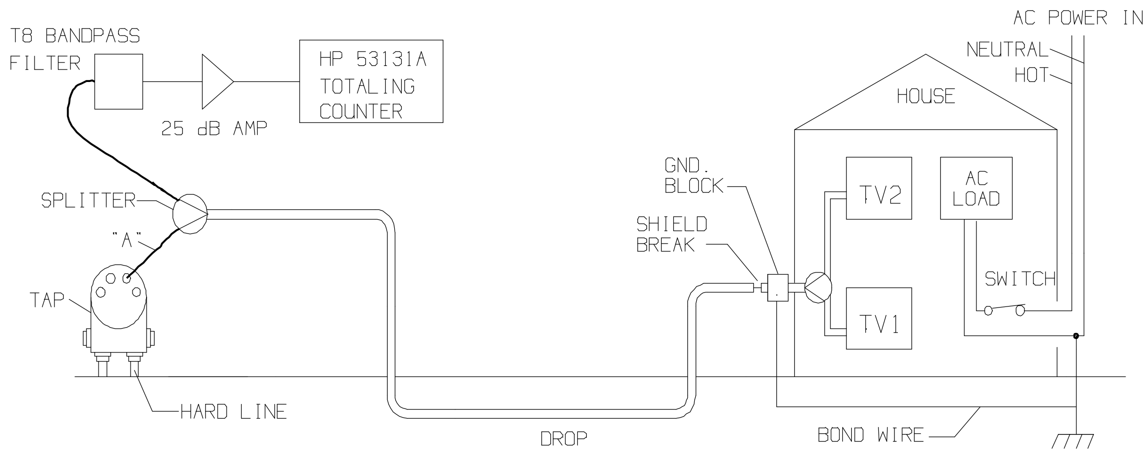

Fig. 4 Impairment test with a bandpass filter and a totaling counter

e. the frequency that the return carrier will be using
f. the bandwidth of the return carrier
g. the transmit level of a return carrier which is influenced by system design as well as the value of the tap at a given location.

For the sake of this test, a power relay with 30 amp contacts and a 110 volt AC 60 Hz coil was wired to "flutter". This was accomplished by routing the AC power supply through the relay's normally-open contact and then to the coil. As the relay energizes and starts to break the normally-open contact, the coil is temporarily de-energized. This causes the relay's spring to pull back, re-connecting the coil. The noise-generating load was plugged into a kitchen duplex power outlet in each house under test.

For the sake of this investigation it was assumed that the modulation that will be used is QPSK (quadrature phase shift keying) occupying a bandwidth of 6 MHz. QPSK is used for MCNS-DOCSIS modems and is a commonly-used modulation on upstream cable systems. The frequency chosen was T8 (11.75-17.75 MHz.) because this frequency was low enough to experience burst noise energy but high enough to be considered for use by an upstream data transmission service.

Since the transmit level of a home terminal device was unknown, a curve of symbol error rate versus the transmitter's output power was generated.

Measuring the Level of Interference
The method used to measure the level of interference heading upstream from the house is based on a bandpass filter with a known bandwidth connected to a high-speed totaling electronic counter. The sensitivity of the counter was set to increment the count value when the instantaneous input voltage level was sufficient to have caused a QPSK signal to make an error. Patents are applied for on this technology and on sheath current testing.

A qualitative description of how this technique operates is as follows. Fig. 5 has four views. View A shows four QPSK constellation points on an I-Q (in-phase, quadrature) diagram. This constellation diagram is made by demodulating a QPSK signal to DC as a baseband I signal and a baseband Q signal and sampling the signals at the correct time. An error can be made in reading a symbol if an impairment, such as the continuous wave impairment or the impulsive impairment illustrated push a constellation point across a decision threshold. The information that is desired for impairment testing is an estimate of the amount of time a signal spent over a threshold line.

Fig. 5 View B is the same as View A but the underlying QPSK signal has been removed, so the origin (I=0 volts and Q=0 volts) is the expected position without any additive impairments. A threshold region can be established at appropriate voltage, "R", and what is now of interest are any threshold crossings. Fig 5 View C shows what the impulse impairment in View B would have looked like if it had not been demodulated to baseband. The spinning rate of the impulse is approximately the center frequency of a

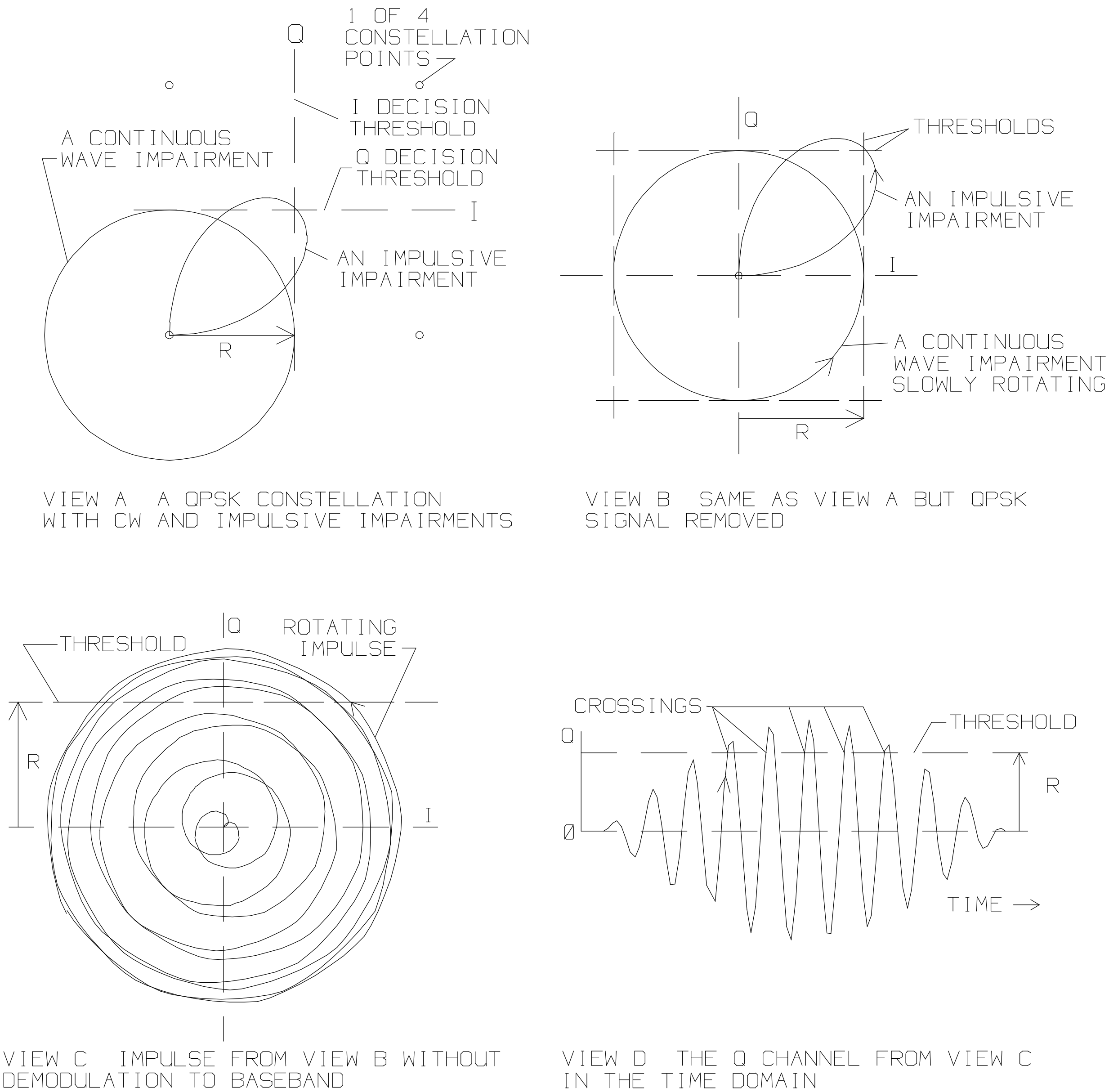

Fig. 5 I-Q Diagrams Illustrating how impairments can be characterized with a bandpass filter and a totaling counter.

bandpass filter that passed the impulsive impairment. View D is a temporal plot of the Q component of the signal in View C. By setting up a high-speed totaling counter with an accurate trigger level "R", the threshold crossings can be counted. In turn the threshold crossings can be used to estimate the amount of time an impairment spends over a decision threshold. The two variables that are important for meaningful results are the accuracy of the threshold voltage and the bandwidth of the bandpass filter that passes the impulsive energy. The bandpass filter's bandwidth should be the same as the bandwidth of the data service being tested, and the center frequency of the bandpass filter should be the center frequency of the data carrier.

This technique can also be used to test vacant downsteam channels.

Results of Sheath Current Testing

Five homes were tested for sheath current. The subdivision in which all 5 homes were located requires underground drop cable. The system was not 2-way active. House 1 was connected to the tap via a drop laying on the surface of the ground. House 2 deviated from the test plan in that the shield break was supplied by a pair of Labrador retrievers that liked to dig and chew. The homeowner did not want the damage repaired, so there is no data on how the wiring would have performed with the break fixed. Houses 3 and 5 were tested twice, once with the buried drop cable and once with a temporary aerial drop cable strung through the foliage. The dual testing was done to compare differences in sheath current results due to the presence of soil around the drop line. Table 1 lists the gross power readings for the 5 houses with and without shield breaks. The gross power was computed from the impulse response. The dB readings are relative, but absolute gross attenuation can be computed by subtracting each reading from eighty-five. Eighty-five is the effective reading obtained with a direct connection between the transmitter and receiver.

House Number	Reading Shield Broken	Reading Shield Fixed
House 1 (drop on gnd.)	48.0 dB	5.2 dB
House 2 (dog chews)	61.2	N.A.
House 3 (buried drop)	29.2	4.4
House 3a (aerial drop)	56.5	27.5
House 4 (buried drop)	37.4	-6.3
House 5 (buried drop)	47.2	11.5
House 5a (aerial drop)	60.1	23.0

Table 1 Sheath Current Gross Power Results

The impulse responses for each house with the shield broken and the shield fixed are shown in Figs. 6-12 . The vertical scale on each plot should be noted. The most striking observation is that burying a long drop produced a large reduction in the gross power readings, primarily because the high frequency portion of the burst energy is attenuated. A break at the end of a long aerial drop typically produces a lower gross power reading than a break at the end of a short drop because of skin-effect and radiation which attenuate the high frequency test signals traveling on the outside of the cable. However, this characteristic is exaggerated by burying the drop in soil, possibly because of soil conductivity. Another observation is that house 5 had non-trivial shield breaks beyond the intentional break introduced at the ground block. The homes in this neighborhood are large and typically have multiple splits feeding multiple television sets.

Unfortunately, signal leakage equipment was not available, so no correlation could be made between signal leakage and sheath current induction results.

For comparison, the results of sheath current testing in other systems is presented in Fig. 13A and Fig. 13B. These plots are histograms of gross power readings without introducing any intentional breaks on the cable sheaths. Sheath current injection was performed at the taps in Oct. 1998.

What is concluded is that all of the introduced breaks are visible on the impulse response plots, all of the gross power readings are much lower with the introduced break fixed, and a long buried drop cable attenuates the sheath current.

Results of Impulsive Noise Testing

Fig. 14 is a plot of symbol error rate versus transmitted signal level with shield breaks in place. It can be seen that for an uncorrected symbol error rate of 10^{-4} a transmit level from the houses of between 28 and 39 dBmv will be required. Fig. 15 shows what the curves looked like when the intentional break was fixed and table 2 tabulates the improvement. Note that house 5 still had a break. A symbol error rate of 10^{-9} indicates no errors.

	Improvement
house 1	>44 dB
house 3	39 dB
house 4	33 dB
house 5	22 dB

Table 2. Improvement when the intentional shield break is fixed

Observations

One observation that was made is that common path distortion was frequently observed on the hard line, and the splitter had to be disconnected from the tap at some locations to keep the return-band noise in the hard line from contaminating the test results.

Conclusions

This paper shows that the intentionally introduced sheath break at the ground block can be seen by the sheath current test method, although the sheath current test signal is diminished by a long buried drop. It also shows that the sheath break can be responsible for impairments in upstream data traffic coming from the tested home, or any other home connected to the common upstream receiver for that matter. If the home terminal transmit power levels are low, the symbol error rates will be higher.

References

[1] Two-Way Cable Television System Characterization, Cable Television Laboratories Technical Report, 1995, pp. 123-126

[2] Results of Return Plant Testing, 1997 NCTA technical Papers, by R. Prodan, M. Chelehmal, and T. Williams, pp. 142-165

[3] Noise Reduction Techniques in Electronic Systems, 2nd edition, Henry W. Ott, pub. John Wiley and Sons, Chaper 7

[3] A Method to Locate Nodes with High Return Band Ingress, by T. Williams, CED Magazine, Nov. 1997

[4] Testing Coaxial Shielding Integrity by Sheath Current Induction, by T. Williams and D. Bell, Cable-Tec Expo. Proceedings Manual, 1998

contact: tom@holtzmaninc.com
303-444-6140 (ph.)
303-444-7698 (fax)

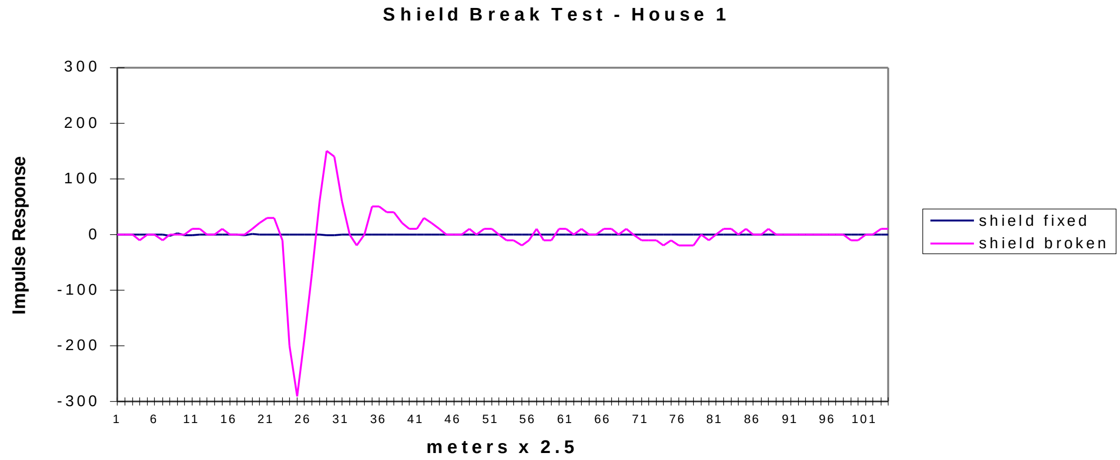

Fig. 6 Drop laying on ground. Gross power = 48 dB broken, =5.2 dB unbroken

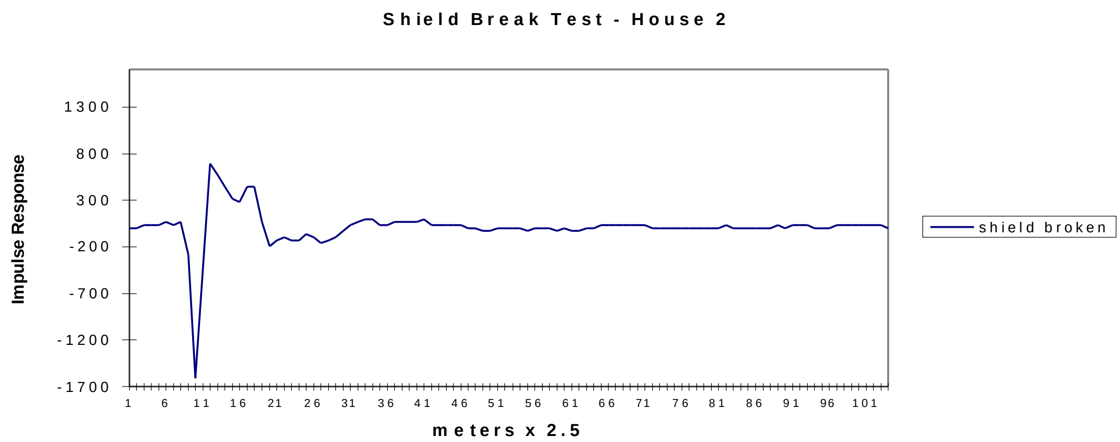

Fig. 7 Dog-chewed drop cable. Gross power =61.2 dB broken, N.A. unbroken

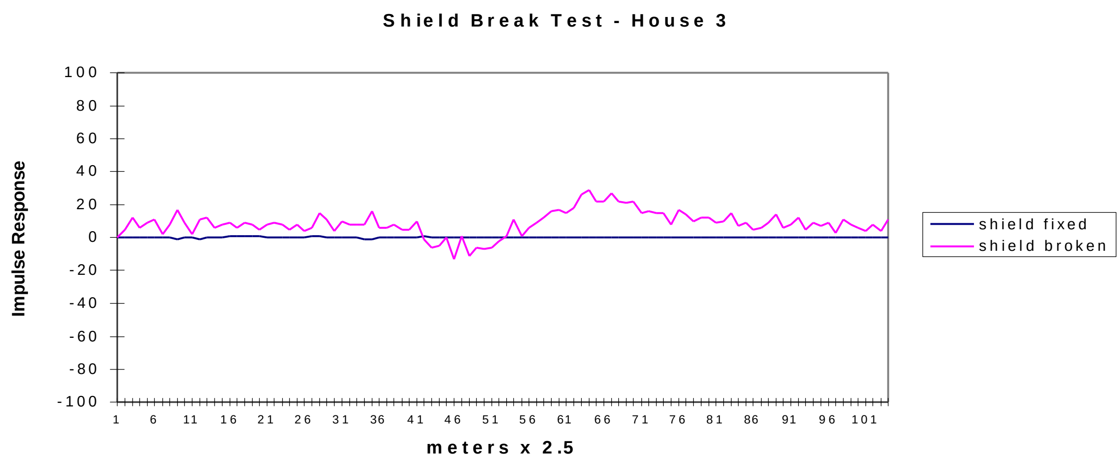

Fig. 8 Long buried drop (142 ft.). Gross power =29.2dB broken, =4.4 dB unbroken
Noise on plot caused by ingress from shield break.

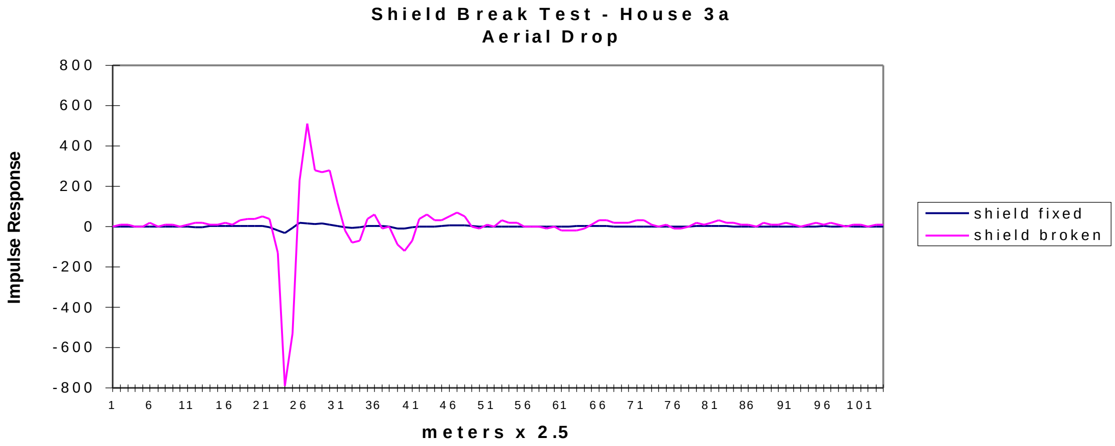

Fig. 9 Repeat of Fig. 8 with an aerial drop. Gross power =56.5 dB broken, =27.5 unbroken. Note large increase in readings over buried drop readings.

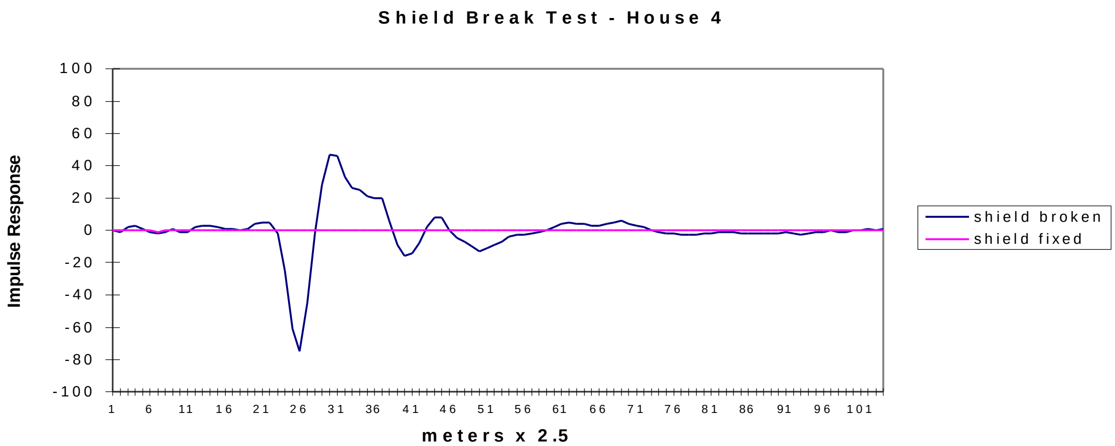

Fig. 10 Gross power =37.4 dB broken, =-6.3 dB unbroken

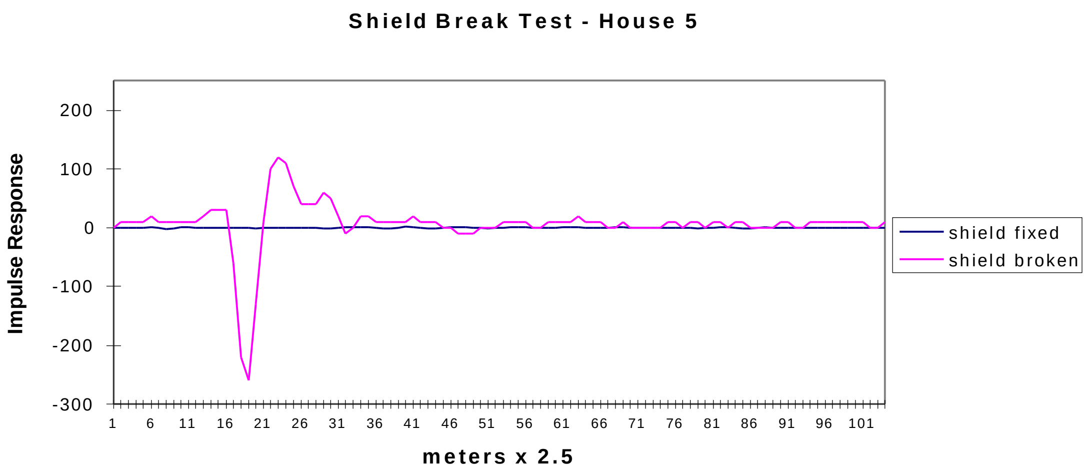

Fig. 11 Buried drop (50 ft.). Gross power =47.16 dB broken, =11.54 unbroken

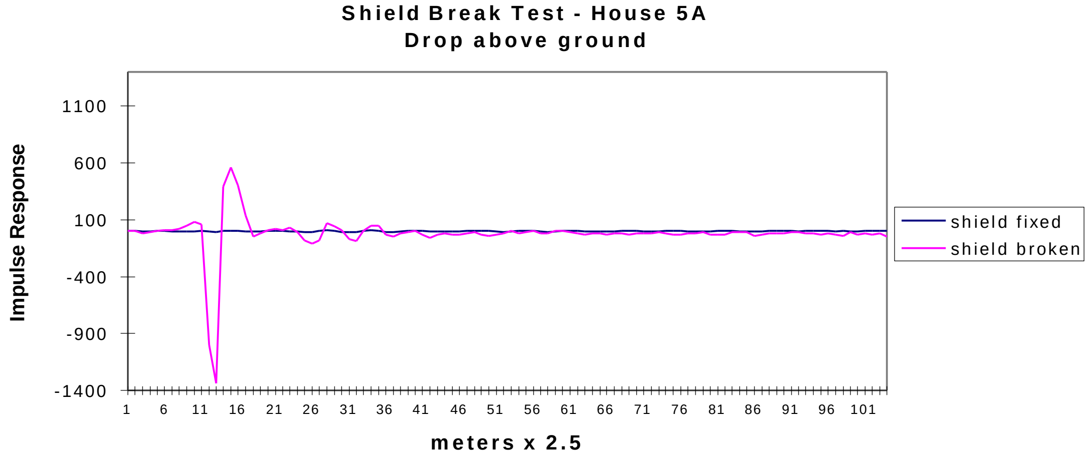

Fig. 12 Re-test of Fig. 11 with an aerial drop. Gross power =60.1 dB broken, =23.0 dB unbroken

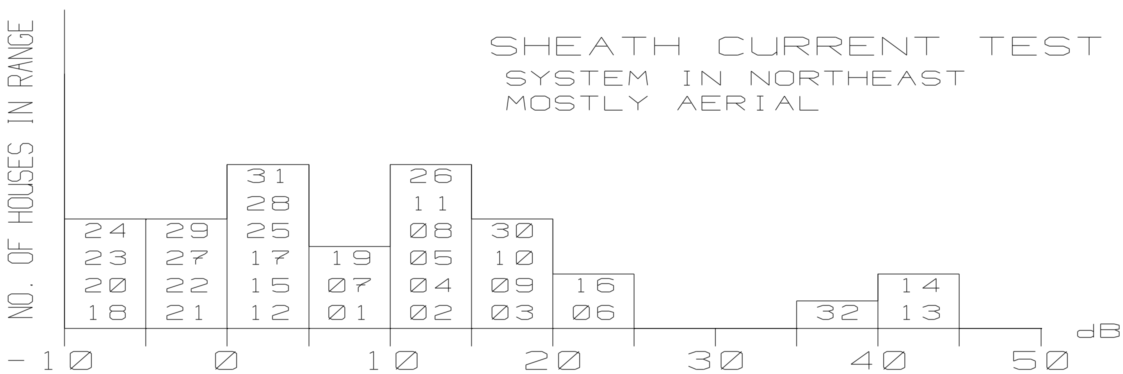

Figure 13A

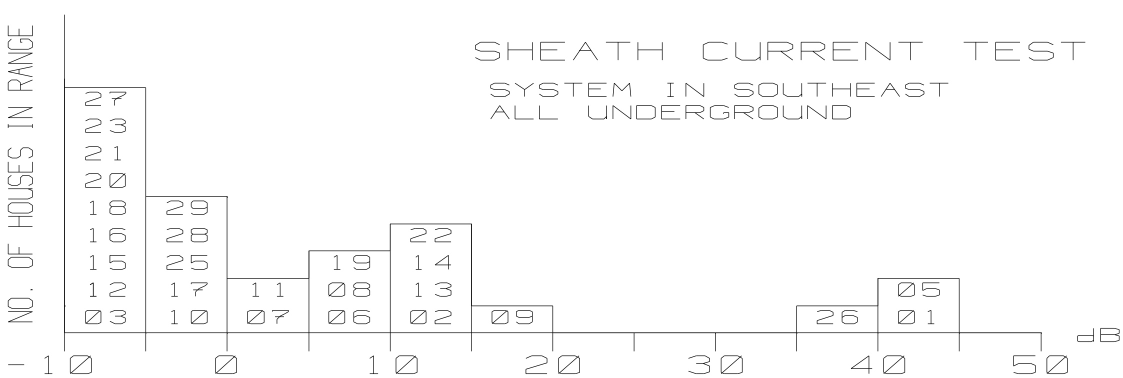

Figure 13B

Fig. 13 Histograms of sheath current induction tests done in other cities. Shield breaks were not induced.

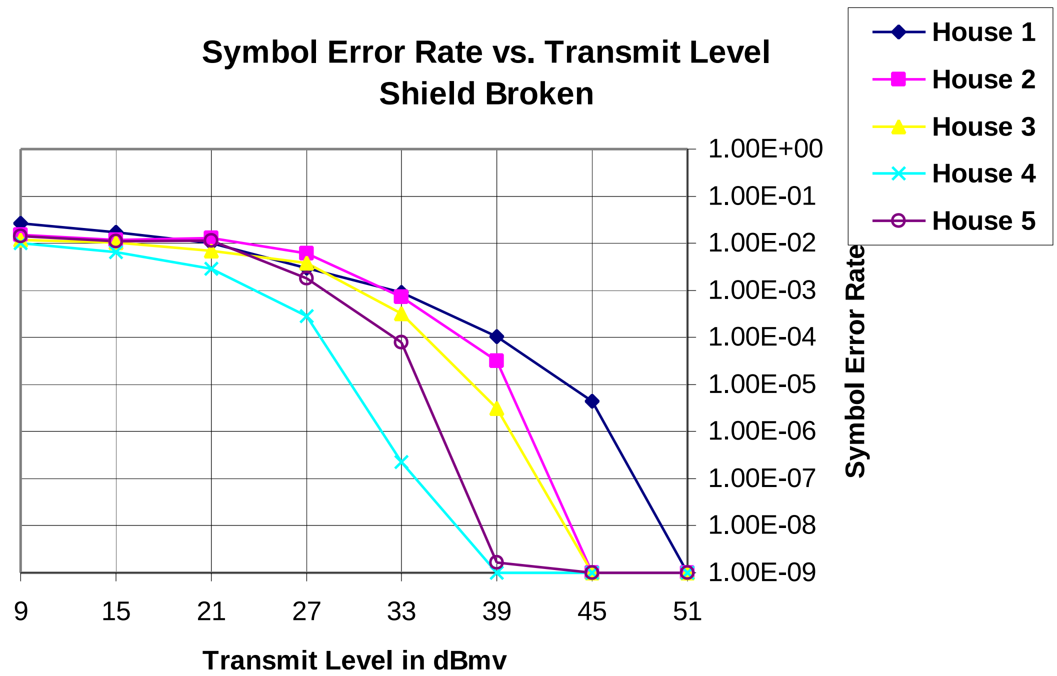

Fig. 14 Required QPSK transmit level at a tap port for a given symbol error rate in the presence of burst noise generated on house's AC power wiring. Shield intentionally broken at the ground block.

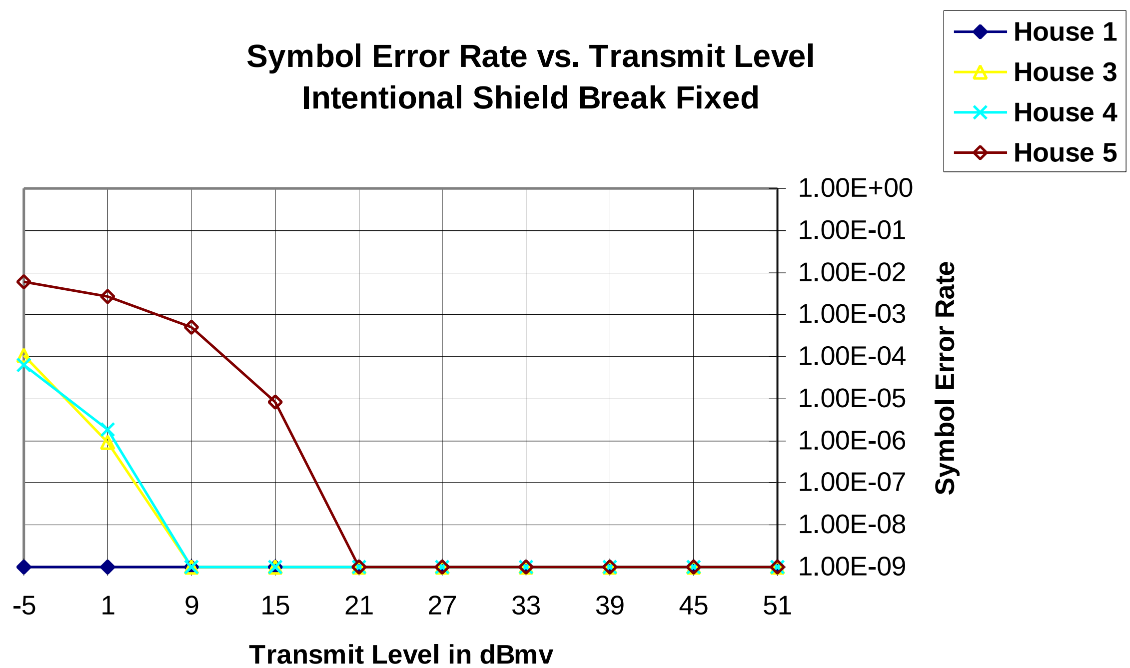

Fig. 15 Required QPSK transmit level at a tap port for a given symbol error rate in the presence of burst noise generated on house's AC power wiring. The intentional shield break at the ground block is repaired.