TWO-WAY PLANT CHARACTERIZATION

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ABSTRACT

An array of new telecommunication services that encompasses video, voice, and data offers the cable television industry a tantalizing opportunity that can be capitalized by taking advantage of the broadband nature of the CATV networks. Although most cable systems can be upgraded to full bi-directional capability, the amount of experience and knowledge on the upstream or the reverse portion of the networks are inadequate relative to those on the traditional, forward direction. This paper describes two-way test procedures, equipment package, and field test results and experiences obtained from five cable testbeds.

INTRODUCTION

The broadband nature of the CATV networks fortified with fiber deployment and digital technologies uniquely position the cable industry as a full or universal telecommunications provider. The next generation cable network architecture envisioned by Cable Television Laboratories[1] describes a regional hub interconnecting groups of fiber headends, which in turn feed fiber hubs, and finally to fiber nodes. Each fiber node serves about 200 homes passed which are connected via existing coaxial tree-and-branch network.

The typical coaxial reverse bandwidth of 5 to 30 MHz is considered by CableLabs to be only an interim solution until other methods are made available such as mid-split, passive, and parallel coaxial networks. However, the existing sub-low reverse network may continue to thrive for an extended period of time, and this network asset is the critical element in realizing the full potential of the cable network. Consequently, the reverse portion's noise characteristic and transmission capability must be better understood and controlled if the myriad of new services are to be successfully deployed in the absence of fully segmented, digital cable network.

In order to better study this problem, the CableLabs Telecommunications Subcommittee commissioned a subset of its members to participate on the Network Integrity/Ingress Working Group. The participants of the working group were Mike Stone and Ray Fournier of Continental Cablevision, George Hart and Albert Kim of Rogers Engineering, Larry Langevin of Greater Media, Bill Gast of Crown Cable, and George Stickler and Paul Schauer of Jones Intercable. The working group was chaired by Paul Schauer. The purpose of this working group was to direct a two-way field test measurement and analysis program. The main objectives of the test program were to:

- characterize the two-way CATV plant analog impairments;
- determine the impact of these impairments on the performance of the digital transmission;
- recommend guidelines to the member companies of CableLabs as to appropriate network topologies and operations methods to guarantee reliable digital transmission.

To support the working group's efforts in meeting the test program objectives, the services of three separate companies were contracted by CableLabs. These companies were AT&T Bell Laboratories, GT Communications, and Rogers Engineering. AT&T contributed to the digital portion of the test platform, Rogers Engineering consolidated the digital portion with the analog testing segment and developed the automated test equipment control and data collection software, and GT Communications retrieved the field data and performed preliminary analysis.

The first section of the paper describes the two-way test procedures, test platform, and data analysis methodology. The second portion provides the testbed system details and field test results from the five test locations. Finally, lessons learned from the field efforts are discussed to highlight the necessary steps required to attaining reliable two-way plant.

TEST PROCEDURES

The basic premise of this undertaking was to ascertain what CATV system elements affect digital transmission and how they can be managed or controlled given a "generic" digital communication system. The digital transmission system utilized in the test was a QPSK modulated, T1 rate channel with no error correction. The intent was not to derive the necessary modulation technique and error correction scheme to properly operate in a given CATV system; rather the intent was to determine the principal sources of impairments existing in CATV plants and educe corrective measures. Following this axiom, the two-way plant characterization effort was divided into three broad areas:

1. collect valid test data over sufficient time period to properly characterize the baseline two-way digital performance for each test system ("valid" in the sense that the proposed test equipment package is set up properly and the procedures are followed correctly; "sufficient" period in the sense that enough samples are collected to derive statistically valid analysis);
2. identify primary symptoms that produce digital transmission impairments, infer potential causes of the identified symptoms, and conduct controlled plant variations to ascertain the casual agents;
3. derive a set of recommendations or guidelines to achieve optimum CATV plant and digital equipment configuration and desired signal quality and reliability.

The analog and digital testing were conducted in parallel to permit correlation of digital error occurrences to the changes in the analog parameters such as ingress and impulse noise levels. Other factors contributing to digital error performance and availability were also accounted for to supplement the correlation effort such as cable maintenance practices, plant equipment failures, power outages, and environmental conditions. The analog and digital parameters comprised the core set of data and were measured and recorded by the control software program automatically.

The core analog and digital data measurement technique defined in the two-way test procedures[2] took a broad perspective on the cause-and-effect relationships between different cable systems and the digital performance. The classical transfer function definition of the cable channel was not addressed with these test procedures. Efforts to define the cable channel characteristics to such detail has been undertaken by CableLabs to evaluate complex modulation techniques for the transmission of compressed digital video information[3]. Results from this experiment will yield valuable insights for modem designers in developing appropriate cable terminal equipment.

A comprehensive and consistent set of data is a necessary prerequisite to draw valid and useful conclusions and recommendations. The test procedures enable a consistent collection of field data across a variety of plant design, topology, operation, and environmental conditions. The consistent plant characterization methodology provides a foundation upon which to compare and assess the effectiveness of various plant improvement techniques in enhancing the cable plant transparency to digital transmission. Such techniques will attain wide adaptability and high confidence level if all test participants realize similar improvements. Hence, the test procedures provide a powerful method of vetting improvement measures and thus enhancing the utility of the overall test efforts. The conclusions reached through this process will lead to guidelines for cable operators wishing to implement digital data services on their cable networks.

Analog Performance Parameters

Prior to any digital transmission tests, the forward and reverse cable plant analog parameters need to be recorded. The parameters are divided into static and dynamic categories, and the latter category has two subdivisions between fast-varying and slow-varying types. The parameters under the static category are not expected to vary significantly over time, and include the following:

- amplitude-frequency response;
- group delay response;
- visual carrier-to-noise (CNR);
- distortions (CTB, CSO);
- hum modulation;
- return loss.

Under the dynamic category, ingress and impulse noise comprise the slow-varying and fast-varying parameters, respectively. Ingress is the level of unwanted ambient signals leaking into the cable plant, and is a direct result of imperfect shielding of the cable plant. Ingress mechanisms include loose connectors, cracked cables, broken multitap spigots, and other plant defects. On the reverse plant, sources of off-air ingress include short-wave broadcasts, HAM band transmissions, and CB traffic. The short-wave broadcasts originate from distant transmitters, thus subjecting the cable plant to a uniform field. In contrast, the HAM and CB transmissions are localized and will affect a small portion of the plant near these HF energy origination.

The ingress spectral contents are confined to narrow frequency ranges; however, the impulse noise energy occupies a continuum of frequency spectrum with decreasing spectral energy density as frequency increases. Impulse noise occurrences are sporadic and their causes are not well understood. However, these broadband noise bursts have been linked to electrical discharges (AC arcing) which materialize when intermittent connections along the transmission path are encountered such as improperly installed or deteriorated connectors and splices, and cracked/eroded cables. Other common causes of impulse noise are lightening, powerline arcing, arc welding, and industrial machinery.

The test participants should ensure that their cable testbeds meet minimum analog performance requirements. For the forward direction, the minimum performance is tied to the FCC Rules and Regulations document, Part 76, as amended through the Cable Act of 1992. However, no equivalent industry standards or regulatory specifications exist for the reverse plant static parameter performance and for the dynamic variables. The two-way test efforts will attempt to fill this gap by measuring the intensity and incidence rate of ingress and impulse noise for various plant configurations. These measurements will define the baseline performance of a given test site. All analog parameters are measured with HP 8590/91E Spectrum Analyzer.

This initial cursory examination of the cable plant for two-way testing may uncover the need for repairs and realignment. Proper plant alignment according to individual operator's design guidelines must be verified prior to digital testing. To ascertain plant shielding integrity, CLI radiation patrols or CB "sweeps" can be performed. However, the repair activities should be confined to what each operator considers as "normal maintenance" for its plant. Disproportionate amount of repairs before conducting the digital testing may lead to misleading results which do not correspond to a "typical" CATV plant. Various improvement techniques will be exercised in a controlled manner under the direction of the working group after initial or typical digital performance is recorded for each test site.

Digital Performance Parameters

The basic metric used to determine digital link performance is bit errors or bit error ratio (BER). The telecommunication industry characterizes the digital transmission performance on the basis of statistical information derived from received bit error counts and received bit counts at 1-second intervals. Additional digital performance parameters are defined based on the bit error counts:

- availability;
- errored seconds (ES);
- severely errored seconds (SES);
- degraded minutes (DM).

There are numerous standards available from which to measure and characterize the digital link performance such as ANSI, AT&T Accunet T1.5, and CCITT Recommendation G.821. Each standard allocates different performance requirements to the digital parameters listed above. One of the most widely used digital performance measure is the CCITT G.821 recommended performance objectives. The two-way test procedures include HP37701B T1/Datacom Tester to measure and record G.821-compatible digital parameters.

The G.821 recommended error performance objectives are defined for an end-to-end transmission encompassing the low, medium and high grades, and each grade is allotted a proportion of the total end-to-end objectives. The digital services carried on the cable plant should at a minimum meet the recommended performance for local exchange carrier (LEC) access which constitutes low grade performance. Connection between LEC and an interexchange carrier (IXC) constitutes medium grade performance, and between IXCs as high grade. The two-way testing will determine if this objective can be achieved with existing cable plants, and establish the effectiveness of various plant improvement techniques in meeting higher digital performance objectives. Exhibits 1 and 2 list the G.821 end-to-end error performance objectives and the apportionment among the three grade levels.

Classification	Objectives
Errored Seconds	Fewer than 8% of one-second intervals to have any errors
Severely Errored Seconds	Fewer than 0.2% of one-second intervals to have a BER worse than 10^{-3}
Degraded Minutes	Fewer than 10% of one-minute intervals to have a BER worse than 10^{-6}

Exhibit 1: G.821 End-to-End Objectives

Grade	ES (%)	SES (%)	DM (%)
Local	1.2 (X2)	0.015 (X2)	1.5 (X2)
Medium	1.2 (X2)	0.015 (X2)	1.5 (X2)
High	3.2	0.04	4.0

Exhibit 2: G.821 Apportionment

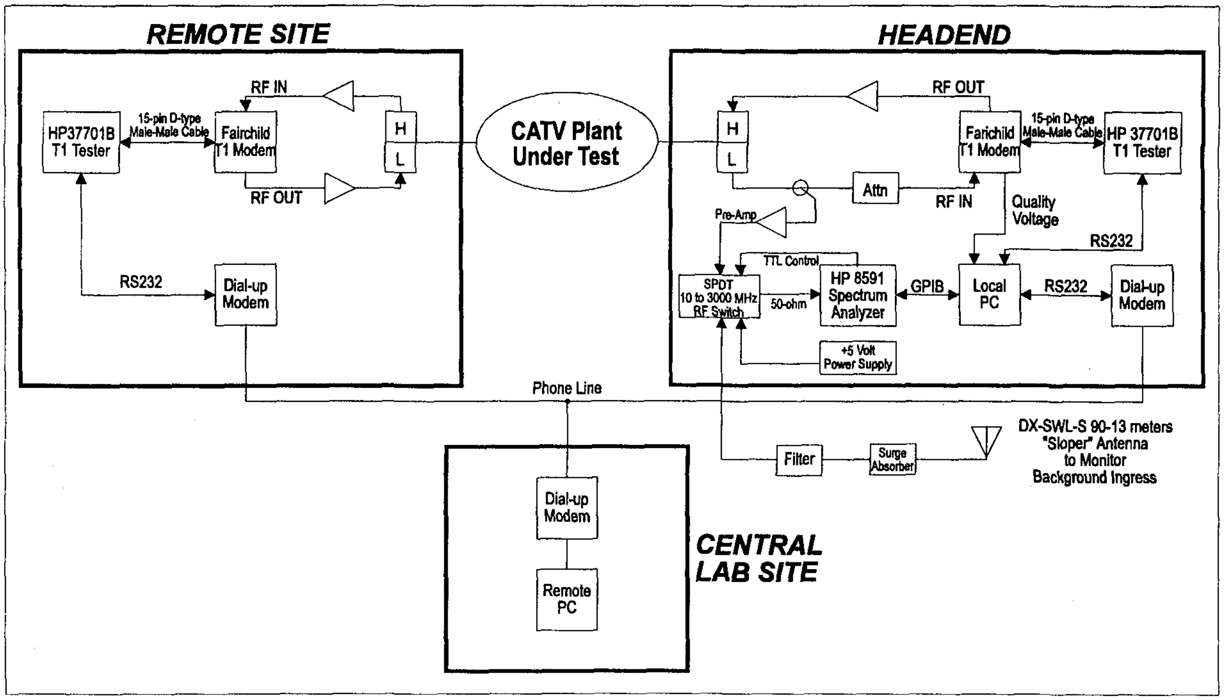


Exhibit 3: Two-Way Test Platform

TEST PLATFORM

Exhibit 3 illustrates the two-way test platform. The equipment control software (written in QBASIC) residing on an IBM-PC compatible computer at the headend manages and directs the activities of two principal test equipment: the spectrum analyzer and the T1 tester. Another element controlled by the program is an RF switch to select between the local HF antenna feed and the reverse frequency spectrum feed from the testbed. The T1 tester at the remote site is not controlled by the QBASIC program; instead, the forward T1 tester is controlled remotely using a communications software package (Procomm Plus).

Two T1 testers are used, one at the headend or hub and the other located at the remote site to measure the reverse and forward digital performances, respectively. The T1 testers generate 1.544 Mbps pseudo random T1 data streams and perform data signal analysis as per CCITT Recommended G.821. Two Fairchild M505 Broadband Modems modulate the T1 streams in QPSK format onto RF carriers: between 5 to 42 MHz for the reverse path and between 50 to 400 MHz for the forward direction. No error correction mechanism is utilized by the modems. The T1 testers are configured to record error activities and alarm conditions in 1-minute samples. At the end of a test run, the tester provides the summary digital performance (BER, ES, SES, DM, and availability) and the 1-minute resolution sample results.

The QBASIC program collects several different types of raw data from the spectrum analyzer in both frequency-domain and time-domain. Changes to the method of collecting and measuring data or test procedures are implemented easily by downloading a modified QBASIC program to the appropriate test site computer. Since the program is written in Basic and operates on a PC, the test software is easy to use and maintain. The program has operated effectively in the beta test sites for over several months which is indicative of the stability of the test hardware and software. Explanations for each raw data type and measurement methods are described below.

HF Antenna & Ingress Files

The antenna trace file captures the ambient high frequency band energy activity; the reverse band frequency trace file captures the ingress and noise levels present in the reverse portion of the cable plant. Both traces are swept from 5 to 35 MHz. The antenna and ingress traces are created every 30 minutes, one immediately after the other to allow for time correlation. The antenna/ingress subroutine sets the spectrum analyzer instrumentation to RBW of 100 kHz and VBW of 300 Hz. The resulting sweep time is 3.0 seconds.

The ingress monitoring allows full visibility over the entire sub-low band, revealing amount of useable frequencies (either in slots or contiguous), availability (depending on service definition), and carrier level required to meet specified service quality and reliability. Because the reverse carrier level has a limitation due to equipment and design, the intensity and incidence of ingress levels observed broadly highlights the level of effort required to improve the plant integrity before a variety of services can be supported reliably. In addition, the ingress monitoring routine also provides an account of the plant's transmission integrity and problems such as amplifier failures, power supply failures, amplifier by-pass, and signal interruptions (voluntary or involuntary). The measured ingress and noise levels on the reverse plant are processed with respect to frequency, percentiles (deciles, quartiles, median), and time (diurnal). The profile of ingress activity is cross-correlated to the following:

1. plant size;
2. number and type of subscribers served (SFU, MDU);
3. construction type (aerial, buried).

Additional correlation to specific plant portions (trunk, distribution, drop, home wiring) can be conducted by focusing on one specific bridger area.

The antenna monitoring, in conjunction with the ingress monitoring, provides a reference base to compare relative shielding effectiveness of the testbed. The shielding effectiveness derived will not be in absolute terms since the HF antenna employed is not calibrated, but the ambient levels measured can be used to calculate the relative shielding effectiveness of a specific testbed germane to different serving sizes, maintenance activities, and repair efforts.

Error-Triggered Power Time Sweep Files

The error-triggered power time sweep file (TR file) captures the interference energy that has caused bit errors on the digital carrier. The error occurrences are appraised via a quality voltage signal level available from a test point on the receive section of the Fairchild M505 T1 Broadband Modem, and the voltage level is used to trigger the power time sweep subroutine. The DC quality voltage provides an indication of the amount of noise on the demodulated in-phase (I) data carrier. The voltage level is sampled through a 12-bit A/D card residing on the local computer. When this voltage exceeds a preset threshold level saved in the subroutine, the current time sweep trace is captured in a file. The spectrum analyzer is set to zero-span mode with RBW of 1 MHz, VBW of 1 MHz, and sweep time of 100 ms for the power time sweep traces.

Regardless of where in the sweep the threshold violation trigger is detected, the current sweep is commanded to complete the 100 ms trace. Once the sweep is completed, the entire 100 ms trace information is uploaded into a file consisting of date, time, threshold preset level, quality voltage level, and the 401 data points of the spectrum analyzer trace (fixed resolution of the HP8591). The zero-span center frequency is selected ± 3 MHz away from the digital carrier frequency. This particular frequency offset is chosen to be close enough to the digital carrier's skirt to have visibility on the carrier but at the same time far enough away to have sufficient dynamic range in capturing the interference energy.

One disadvantage with this method arises from the indirect measurement technique—the actual interference energy that causes the bit errors may not always be captured because visibility underneath the digital carrier is not possible with this method. However, by placing the reverse digital carrier at an ingress-free spectrum, there is high probability that majority of interference causing logic errors is due to impulse noise. The choice of analyzer settings and location of the center frequency of the zero-span provide visibility on the short-duration impulse activity in terms of incidence and intensity. There are recognizable energy patterns captured by the traces and thus can be catalogued according to severity of error hits, coarse causes of interference, duration, plant construction, and plant size. Unfortunately, processing the impulse noise by energy patterns is time-consuming and does not answer what the root causes of the interference are. Nonetheless, the traces do provide indirect clues as to where to look for the causes of impulse noise interference.

Reverse and Forward Digital Files

The reverse and forward digital files provide all the information related to the digital transmission performance during the test run. The digital files contain the summary digital results, the 1 minute resolution digital records, and a host of alarm flags.

The forward digital carrier level is set -20 dBc relative to the adjacent video carrier level, and the frequency is set at 1.5 MHz below the adjacent video frequency. Similarly, the reverse digital carrier level is set -10 dBc relative to reverse video carrier level as specified by the design of the return plant. Note that not all test participants have followed the -10 dBc setup on the reverse due to noise and ingress levels present at the associated test site. Some carriers are set at reverse video level or higher. The carrier level is adjusted with attenuators such that its input to the spectrum analyzer is at a fixed level of 10 dBmV (in 1 MHz RBW). The frequency of the reverse carrier varies between test participants, ranging between 17.0 MHz to 26.5 MHz.

The digital performance measurement is the fundamental metric in the two-way characterization effort. The digital results provide a direct visibility on impulse noise activity, plant maintenance, interruptions, and power failures. By placing the reverse digital carrier at known ingress-free frequency ("clear" spectrum), the causes of errors can be confined to those causes listed above. The HP37701B T1/Datacom Tester is configured to record digital performance information in 1 minute increments, providing a suitable resolution of error and alarm occurrences.

The individual 1 minute records are processed into BER histogram and into error occurrence in time. The former process provides the distribution of errors in the data set and the latter shows when errors occurred in time. Both processed results are used to isolate or highlight large error occurrences in order to conduct further investigation with the local operators in determining possible causes. The forward and reverse error occurrences are compared in time to ascertain if correlation exists.

The summary and individual 1 minute records furnish a means to gauge the behavior of error occurrences: low logic error counts arising steadily versus very large error counts but only sporadically. The ingress and error-triggered traces supply additional, supporting intelligence in analyzing the digital error performance and behavior.

TEST SITE DESCRIPTION

Five test participants were involved in the two-way plant characterization effort: four beta testbeds (Site A to D) and one alpha testbed (Site E). Pertinent testbed information for each site is summarized in Exhibit 4. The testbeds encompass a wide range with regards to number of subscribers served, types of subscribers served, number of active elements, plant construction, and geographical dispersion (northeast, midwest, southeast continental US). It is worth noting that all test participants have had several years of experience with reverse plant operations, notably in supporting impulse pay-per-view (IPPV) services and status monitoring communications systems.

Site A testbed is the smallest test area with respect to number of subscribers fed, serving a total of 1329 subscribers of which 94% of them are multiple dwelling unit (MDU) customers. Majority of the MDU buildings are low-rise complexes. Approximately 25% of the customers in the test area subscribe to IPPV service, and the reverse IPPV carrier is located at 8.9 MHz. Site A also has status monitoring (SM) carrier at 29.5 MHz.

Parameters	Site A	Site B	Site C	Site D	Site E
No. of Subscribers SFU MDU	83 1,246	3,821 472	1,700 2,000	2,000 1,000	4,962 2,987
Fiber Link Length (mile)	6.95	3.0	5.27	3.0	All Coax
Return Laser Type	Jerrold	ALS	Texscan	Scientific Atlanta	N/A
Trunk Plant (mile)	1.48	23.0	30.0	3.0	17.4
No. of Trunk Amps.	8	55	56	9	87
Maximum Trunk Cascade	5	9	13	9	25
Digital Modem Cascade	3	9	5	9	25
No. of Distribution Amps	32	178	156	1	396
Maximum Dist. Cascade	2	2	2	1	3
% Aerial	63.1	75	97	10	50
% Buried	36.9	25	3	90	50
Bridger Switching Support	Yes	No	No	N/A	Yes
Return Plant Applications	SM @ 29.5 MHz IPPV @ 8.9 MHz	IPPV @ 8.5 MHz	IPPV @ 11 MHz Modem @ 6.2 MHz	None	SM @ 18.0 MHz
Home Terminal Equipment	Jerrold	Jerrold	Zenith	N/A	Zenith
Reverse Video Level	25 dBmV	20 dBmV	17 dBmV	20 dBmV	20 dBmV
Reverse Digital Level	15 dBmV	10 dBmV	19 dBmV	10 dBmV	20 dBmV
Average Plant Age	7 years	12 years	5 years	10 years	15 years

Exhibit 4: Testbed System Information

Site B testbed is the second largest test site with a total of 4293 subscribers of which 89% of them are single family units (SFU), and majority of the plant is aerial. Similar to Site A, the reverse spectrum includes an IPPV carrier at 8.5 MHz; no other services on the reverse spectrum is carried. The reverse digital carrier was carried at 10 dBmV referenced to the reverse trunk input, which is 5 dB lower than that of Site A. This particular cable system utilizes HRC channel lineup in the forward direction.

Site C testbed size is similar to that of Site B in terms of number of subscribers, trunk amplifiers and line extenders. Total number of subscribers served in the testbed is 3700 of which 54% of them is MDU. This system utilizes 11.0 MHz for its IPPV service and a modem carrier at 6.2 MHz. The reverse digital carrier is injected into the plant 2 dB higher than the reverse trunk input level of 17 dBmV instead of being -10 dBc. Higher level was required to overcome noise present on the sub-low and to acquire modem synchronization, which was surprising in light of the relatively new plant.

Site D's testbed has the lowest number of active distribution amplifiers with only one line extender conducting sub-low energy along with the plant portion between the trunk bridger ports and the first line extenders. However, the area being served is very dense with a total of about 3000 subscribers. Almost all of the testbed's plant is buried.

Site E's testbed is the largest test system with close to 90 trunk amplifiers and almost 400 line extenders. The testbed serves nearly 8000 subscribers of which 62% of them are SFU. The plant construction is evenly distributed between aerial and buried types. There is no return fiber optic link included in the reverse transmission path. Note that the reverse digital carrier was injected into the plant at reverse video trunk input level of 20 dBmV (0 dBc). Moreover, the average age of the plant was the oldest, with some portions of the plant exceeding 25-plus years.

Another distinguishing aspect of the Site E testbed was the utilization of the remote bridger switching to alter the testbed configuration. The bridger switching is separated into two bands: 5-18 and 21-33 MHz (18-21 MHz is the cross-over band) which can be exercised independently, and status monitoring system carrier operates at 18 MHz. Seven different configurations were exercised at Site E of which five of them are described in Exhibit 5 (designated CONFIG 1 to 5); the other two configurations are "Trunk Only" and "All On". The reverse energy contribution from various distribution areas were controlled via the bridger switched to artificially alter the test plant; however, the entire trunk portion of the testbed is reverse active for all test configurations. The number of trunk amplifiers shown in Exhibit 5 indicates the number of bridger switches that were activated to conduct reverse energy from the distribution plant.

When a trunk transponder is polled, its 5-18 MHz band switch is activated temporarily to communicate, and the polling takes place continuously. Therefore, ingress level measurements in the 5-18 MHz band for the six test configurations (excluding the "All On" case) include some energy from plant areas outside the specified configuration. However, the duration of the switch activation is very short and do not materially affect the results.

System Variables	CON-FIG 1	CON-FIG 2	CON-FIG 3	CON-FIG 4	CON-FIG 5
#SFU	751	1032	1426	1489	1296
#MDU	0	55	0	55	2932
# Trunks	18	15	25	50	19
% Aerial	16.7	70.4	34.4	65.4	75
% Buried	83.3	29.6	65.6	34.6	25

Exhibit 5: Site E Test Configuration Parameters

TEST RESULTS & ANALYSIS

The field testing was divided into three phases: first, an initial two-way measurement was conducted at the alpha site (Site E) to confirm the proper operation of the test platform and programs, and to make any required modifications; second, baseline performance results were obtained from all five testbeds, and principal symptoms for each testbeds were diagnosed; and third, controlled variation testing was conducted to substantiate the postulated casual agents identified in the second phase. Test results and analysis of the baseline and controlled variations testing phases are discussed below.

Baseline Performance Results

After completing preliminary testing at Site E, the refined test platform was installed at the four beta test locations (Site A to D). The data and analysis presented in this section is based on test results collected over at least 27 consecutive days for the four beta test sites and one week per test configuration at Site E. Moreover, the data sets were collected after all problems associated with the test equipment package were corrected and confirmed for proper operation; hence, these data sets constitute valid baseline performance measurements.

The summary results for the five participating cable operators are presented below under anonymous names. The digital summary results are presented along with examples of reverse spectrum energy levels, BER histograms, and error-triggered power traces. Exhibit 6 lists the baseline digital summary results for Sites A to D, and Exhibit 7 shows the results from Site E for seven different test configurations. An example of reverse ingress DQM (decile-quartile-median) level chart is depicted in Exhibit 8, Exhibit 9 presents the BER histograms for Site E, and examples of error-triggered traces are presented in Exhibit 10.

Digital Summary Parameters	Site A		Site B		Site C		Site D	
	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward
Total Test Duration (minutes)	36750	37811	26298	28621	22311	36966	22862	24493
Weighted Average BER	1.8E-5	1.7E-7	5.9E-5	3.3E-7	1.6E-5	2.7E-7	1.3E-6	4.9E-7
Weighted Average %Avail.	99.978	99.971	99.771	99.997	99.997	99.999	99.591	99.867
Weighted Average %ES	0.215	0	10.893	0.011	2.745	0.004	0.170	0.111
Weighted Average %SES	0.026	0	0.172	0.001	0.048	0.001	0.006	0.003
Weighted Average %DM	2.624	0	31.404	0.140	13.963	0.027	0.831	0.703
Wght. Average %BER $\leq 10^{-6}$	97.329	99.971	63.930	99.856	84.247	99.971	98.754	99.162

Exhibit 6: Sites A to D Baseline Summary Digital Performance Results

Digital Summary Parameters	Trunk Only	CONFIG 1	CONFIG 2	CONFIG 3	CONFIG 4	CONFIG 5	All On	Forward Digital
Total Test Duration (minutes)	11574	9203	8041	11887	8845	6712	6374	64269
Weighted Average BER	1.8E-6	4.5E-7	1.4E-7	4.7E-7	7.5E-7	2.2E-5	1.3E-4	1.4E-6
Weighted Average %AVAIL	100	100	100	97.911	100	99.867	97.929	100
Weighted Average %ES	3.557	1.560	0.853	1.150	1.821	11.724	14.812	0.048
Weighted Average %SES	0.002	0.005	0.001	0.002	0.003	0.072	0.155	0.001
Weighted Average %DM	6.169	5.101	2.301	3.266	6.004	38.601	41.444	0.187

Exhibit 7: Site E Baseline Summary Digital Performance Results

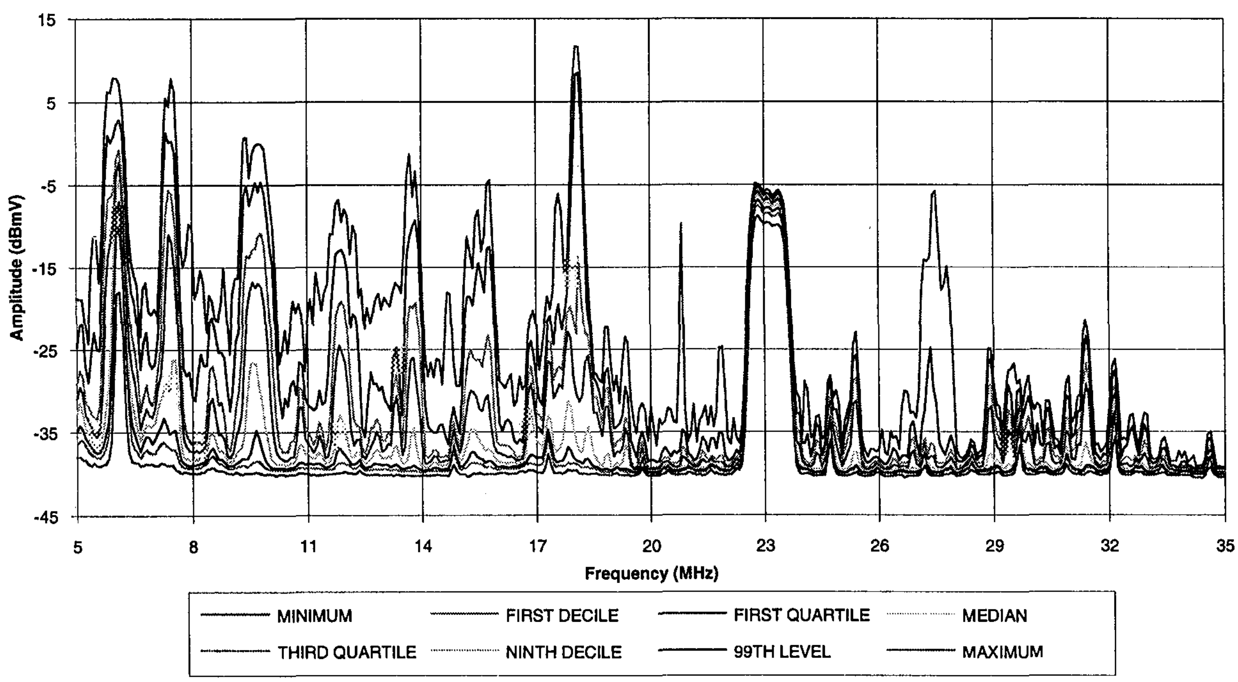


Exhibit 8: Site E CONFIG 1 Consolidated Ingress DQM Levels

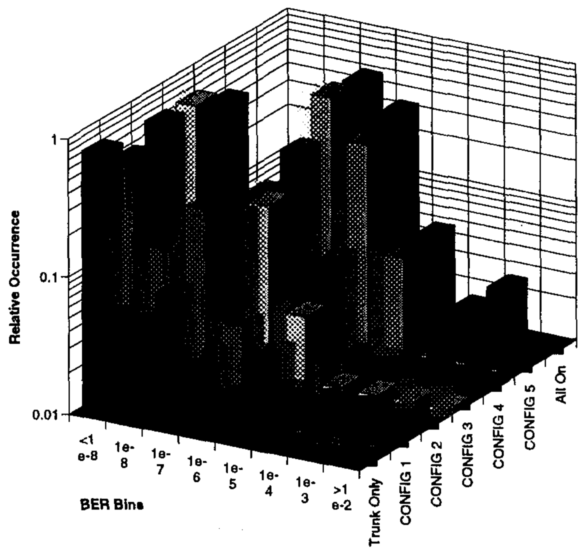
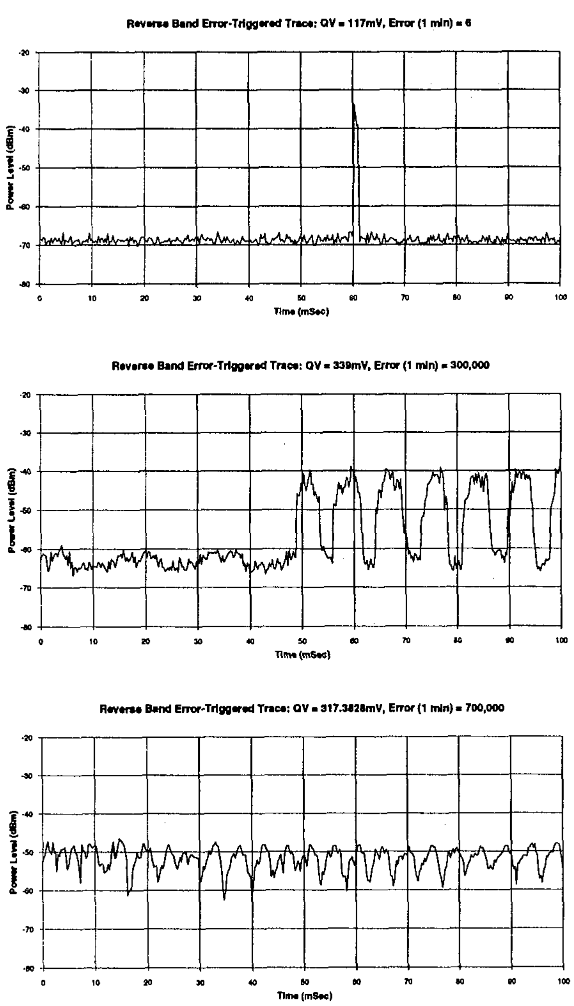


Exhibit 9: Site E Summary Reverse Digital BER Histogram



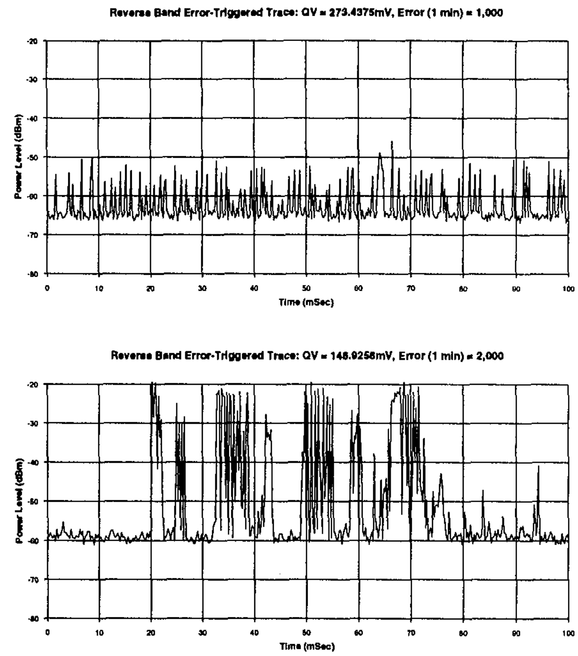


Exhibit 10: Examples of Error-Triggered Traces

Diagnosis

The various types of test results collected during the baseline phase were consolidated to surmise sources of impairments. For some sites, the presence of poor weighted average BER in conjunction with low %ES and %SES suggested that errors occurred infrequently for short duration but inflicted high error counts. The occurrences of these large errors at very specific times with high regularity pointed toward some preprogrammed activity. In other sites, 60/120 Hz types of impulse noise dominated the digital performance, leading to suspect either internally or externally generated electrical problems. Improper reverse gain alignment and/or excessive reverse input levels were also witnessed, resulting in amplifier compression and/or laser clipping. In addition, the effects of weather—more specifically, thunder storms—were observed and correlated to digital impairments. Lastly, plant interruptions such as plant disconnections or amplifiers going into by-pass mode occurred very infrequently but their impact was substantial with respect to overall BER and availability.

Controlled Variations

Based on the analysis and diagnosis performed on the baseline results, site-specific controlled variations were constructed to authenticate the postulated causal agents of impairments. Individualized controlled variations were particularly chosen to yield the greatest potential impact and improvement to the reverse digital performance. However, common variations for all test sites were implemented such as segmenting the testbeds to isolate and repair trouble spots.

Examples of site-specific controlled variation involved realigning the reverse plant, sweeping the reverse plant, deactivating existing reverse applications (IPPV carrier), selecting different IPPV carrier levels, selecting different reverse T1 digital carrier levels and frequencies, and installing high-pass filters at the tap. Each controlled variation test run constituted a 48-hour test duration. Several dozens of such test runs were conducted over a three-month period. Instead of showing the results of every single controlled variation test run, an overall discussion of the impact of the proactive changes and some hard lessons learned from the field trial are presented below.

LESSONS LEARNED

Fundamental Lessons

At a macro level, the size of the testbed certainly had a prominent role in determining the overall performance of the digital link. Strong correlations were found between the reverse digital measurements and the cable plant system parameters such as the number of trunk amplifiers and line extenders in a given testbed. Intuitively, such correlation was expected and the test data confirmed this supposition. The correlation also provided assurance that increasing plant segmentation will not only support increased system capacity but provide manageable network segments.

However, the very nature of the reverse plant, where all return signals share the same medium, does not guarantee a reliable reverse transmission just based on plant segmentation size. Only one plant defect can make the entire reverse spectrum unusable—in deed, several instances of field maintenance efforts confirmed this acute weakness of the CATV sub-low architecture where a single poorly aligned amplifier or loose/corroded connector adversely affected the reverse digital performance.

The meticulous care needed to maintain a reliable reverse plant with the combining and funneling effect was prominently highlighted during the course of the field testing. Maintaining proper operation for the forward channels alone was not a sufficient assurance for a dependable reverse spectrum operation. Many instances of asymmetrical impairments on the forward and reverse channels were witnessed; for example, impulse noise affecting the reverse band was effectively filtered out due to its decreasing power density with respect to frequency. In addition, the wide differential in digital link performance for the two directions from all testbeds further established fundamental differences of the forward and reverse links.

The numerous iterations of plant segmentations and plant maintenance efforts performed on the beta testbeds did not totally eliminate all sources of impairments—in some cases, reverse digital link performance could not be materially improved even after isolating and repairing some of the plant faults. However, such lack of success does not imply that the reverse sub-low operation is hopeless; rather, the field testing simply emphasized the critical importance of conducting a comprehensive and thorough plant hardening effort and maintaining precise gain alignment. **The necessity of accomplishing these two fundamental steps cannot be emphasized enough.** Although these steps seem too logical and self-evident to warrant such attention, the reality of the sub-low operation dictates such painstaking measures—in effect, there are no short cuts in acquiring and maintaining dependable reverse communication channel.

OSS & Training

All levels of the organization must be involved and committed to realistically achieve a full two-way CATV communication network. The resources necessary to properly train the personnel and equipping them with requisite test equipment to deal with the sub-low spectrum must be expended in conjunction with the design and rebuild efforts that are primarily focused for the forward channel delivery. Nothing short of complete dedication will be needed to successfully achieve reliable reverse operations.

As stated previously, the increased penetration of fiber optic systems will mitigate the scope of reverse plant problems through smaller coaxial networks. But unless the segmentation process has reached down to very small networks, for example, each fiber receiver serving only tens of subscribers, many of the reverse plant problems witnessed during these field trials will continue to haunt cable operators. Having well trained and well equipped field personnel will be a key asset in sustaining reliable two-way plant; however, the value of possessing a comprehensive status monitoring and control system was also accentuated during the tests. Such troubleshooting aid was found to be very valuable and powerful in systematically characterizing individual bridger areas for isolating and uncovering faults.

Coupled with individually controllable reverse-band switches on every bridger amplifier, the network management system greatly improved the efficiency and effectiveness of field personnel by quickly isolating and directing problems for the technicians to handle. A comprehensive network management system will need to be adopted as network complexity increases in the migration of all-coaxial plants to a hybrid fiber-coax (HFC) architecture. Such adoption should include necessary switching and appropriate telemetry to monitor and control not only the forward plant but the reverse plant as well. The availability of remote monitoring and switching system for the reverse will be an essential tool in maintaining reliable interactive and transactional services.

The efforts expended to harden the reverse plant not only improved the shielding effectiveness by uncovering leakage points but also exposed potential transmission discontinuities that generated internal impulse noise, or AC arcing. Discontinuities such as loose/corroded connectors, splices and terminators; cracked cable sheath; water migration; poor grounding; and other plant defects severely affected the reverse digital performance. For some beta testbeds, the internally generated impulse noise was the dominate source of impairment, being much more harmful than ingress.

Plant Integrity

Efforts to track down the sources of impulse-generating plant defects proved to be very time-consuming as each and every connections and splices in the testbed had to be scrutinized. Cursory physical inspection did not always uncover the faults since the problems were intermittent. Increased impulse noise activity were observed with cold temperatures, high wind conditions, increased precipitation (including thunder storms), and combinations of all of these weather variables. The integrity of the transmission path was affected with adverse weather conditions, resulting in increased errored seconds, severely errored seconds, and poor availability.

Higher integrity seizing mechanisms and better weatherproof connectors and splices will certainly help in reducing ingress and impulse noise impairments. Although existing components do have good shielding and connection integrity, their performance limitations with respect to outdoor environment must be better understood in the reverse direction. The capacitance-coupling effect observed during the tests suggests that transmission integrity on the forward may mask impairments on the reverse direction, and that failure of transmission integrity occurs more quickly on the reverse direction than on the forward direction.

Along the same vein, the traditional method of measuring plant shielding effectiveness with leakage index did not successfully uncover specific problems affecting the reverse plant. The frequency of the leakage carrier does not accurately reflect the conditions of the sub-low band; a more appropriate and useful method is to use a CB radio to measure the level of leakage. Such testing must be done in accordance with governing radio transmission guidelines. Hence, much greater scrutiny must be applied to the overall plant transmission integrity than just on the forward direction.

Drop Plant

Some solace was provided with the observation of relatively clean trunk and distribution plants in comparison to the drops. Some of the controlled variation testing revealed that very little ingress was leaking within the hardline plants, which was not too surprising. Consequently, a thorough plant hardening exercise can be done once for the hardline portion and have sufficient assurance that this portion's integrity will be maintained for a certain length of time. Other advantages of the hardline plant are its accessibility and relatively limited number of connections. In contrast, the drop plant opens up a whole host of operational issues and poses a serious threat to the overall reverse plant viability. The drop plant possesses all the uncontrollable elements that cause nightmares for CATV operators: cables with poor shielding, difficulty in accessing connections, unknown illegal extensions, unterminated connections, poor connectors and splitters, improper installations, and micro-reflections.

Such uncontrolled additions to the CATV network were recognized in the past but were allowed to exist due to limited resources in tracking down all the culprits and their limited impact on the forward analog services. However, with the advent of digitally compressed signals, these unauthorized elements cannot be tolerated anymore. Equivalently, new services on the reverse plant cannot be successfully introduced unless the drop plant can be controlled and maintained at a much higher degree of discipline than is currently viable. For example, installing high-pass filters is not a viable long-term solution if equal-access services are to be provided.

New methods of consolidating and terminating the services offered by the CATV operator at outside/inside the home are being developed to address this issue, but technology alone will not alleviate the problems associated with the drops. New procedures and policies must be constructed for dealing with problematic subscribers and drop installations to regain control over the cable network. Tackling the drop plant may prove to be the most challenging and difficult of all problems mentioned so far. However, similar to the adaptation of network monitoring and control system with the evolution of HFC networks, the delivery of digitally compressed channels will provide the impetus in making the required changes in the drop plant which will be beneficial for the reverse services as well.

Reverse Services

After all the hard work is done to obtain a reliable and tight reverse plant, introducing ill-behaved reverse channels can totally jeopardize the entire sub-low spectrum. Such affliction was witnessed in couple of the beta testbeds involving the IPPV order system. The IPPV carrier only provided a narrowband service, several times a day, but the RF signature from the set-top boxes were so dirty that all of the reverse band was severely impaired when the carrier was activated. Understandably, the IPPV carrier was the only return signal in operation at some of the beta test sites prior to the two-way testing, and hence, the test participants did not have any visibility on its harmful effects.

However, the implications brought out by the IPPV effects were clear: that all services planned to be provided on the reverse spectrum must conform precisely to their technical performance specifications, and that intelligent control systems be developed to monitor individual carrier performances and to automatically shut down problematic carriers before they affect other services. Resembling the tight conformance of forward carriers, the reverse services also have to be maintained at a high degree of performance. Of course, the number of subscriber terminal equipment will far exceed the forward complement of equipment which will constrain the economic justifications for expensive, high performance home terminal devices. But as one beta participant summarized very succinctly, "You get what you pay for."

CONCLUSIONS

A comprehensive two-way CATV plant characterization was undertaken under the auspices of CableLabs. The field test program jointly prepared by Rogers Engineering and AT&T Bell Laboratories was deployed successfully at five beta test sites. Valid and sufficient data was collected over a duration of approximately four weeks from all of the sites which represented the baseline performance levels. Principal symptoms for each testbed were diagnosed based on the analysis of the baseline test results, and a list of recommended controlled variations were derived. The baseline data was used as a yardstick in evaluating the controlled variations' impact on analog and digital performance.

After performing a considerable amount of field testing, many new insights into the CATV plant's viability of transporting digital services were obtained. The principal knowledge acquired from the testing efforts was the simple reality that the reverse sub-low spectrum is a very hostile environment. Although it's generally known that the reverse band suffers from the vagaries of HF broadcast, amateur, and citizen-band signal leakages, the two-way testing unveiled a much more complex and troublesome channel than previously recognized. In addition to ingress, impulse and common-path noise played significant roles in affecting the digital performance. In fact, ingress is benign compared to impulse noise; the former interference can be avoided with judicious selection of operating frequencies away from the known interferences, but it is difficult to avoid the latter type of impairment in which the entire reverse band can be affected.

The overall two-way CATV plant characterization effort represents the first step in examining the viability of the reverse sub-low spectrum in supporting digital services. The anticipated problems based on limited reverse plant experience and speculation were confirmed; in fact, the reverse plant proved to be much worse than expected in some respects, revealing a very hostile environment. The limited impact of ingress and the dominance of impulse noise on the digital link performance shed new light on the reverse spectrum, highlighting a different set of issues and problems that need to be resolved by potential modem designers. Of course, the burden of dealing with impulse noise must be carried by the system operators as well in reducing the incidence and intensity of broadband impairments.

Meticulous plant hardening and precise gain alignment efforts are required to obtain any semblance of long-term reverse transmission reliability—there are no short cuts. Such endeavor will not succeed without full commitment from all levels of the organization, and the necessary resources must be expended in providing the needed training, and providing requisite equipment and tools. However, these tangible, capital elements only comprise a subset of changes that are necessary; the attitudes of all organizational members must also be challenged and altered to properly reflect the changing definition of the CATV industry. The increasing competition and greater focus on customer satisfaction, customer service, and network reliability will compel such changes in attitudes to take place.

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