DROP SYSTEM AND COMPONENT PERFORMANCE: EMERGING REQUIREMENTS IN A HIGH BANDWIDTH, 64 QAM DIGITAL WORLD

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ABSTRACT

Digital modulation techniques and refined terminal devices are rapidly becoming available, paving the way for a whole new world of communications and entertainment services to the home. An unanswered question is whether existing drop components and systems are capable of effectively transmitting this digital superhighway traffic. This paper reports on the testing of 64 QAM modulated signals over typical and less-than-ideal drop systems. Also, from a joint Raychem/CableLabs sponsored indoor cabling project, important performance criteria, such as shielding effectiveness and return loss, are reported on for a variety of drop components. Sources of these components include electrical contractor distributors, consumer retail outlets, and typical CATV operator vendors. Digital signal transmitted through drops containing these products show significant Symbol Error Rate degradation, requiring the Carrier to Noise levels to be well maintained. Furthermore, many products being installed today can allow considerable levels of noise into the system, reducing any 'safety (fade) margin' in the Carrier to Noise ratio. Recommendations for insuring a reliable Residential Communications Network are offered.

INTRODUCTION

The CATV industry is rapidly bringing forth improved customer service, picture quality, and multiple service offerings as competition and the ability to fill a broad range of demands grows. Plans for new services and revenues, such as implementing high bandwidth networks and high symbol rate digitally modulated signals, are placing great demands on all parts of the CATV network. Much work has been concentrated in fiber and distribution portions of the network. Until recently, less attention has been placed on the drop. The time is rapidly approaching when the drop, consisting of all components of the system from the tap to the TV set, must meet minimum performance and reliability metrics to assure clean signal. Much can be done in the composition of the drop to improve the quality of CATV under existing AM transmission. Digital compression will further add to the technical considerations of the drop system and will require a substantial general increase in awareness of component performance and reliability.

In the outside area of the drop, the effects of improper installation and corrosion of components are well recognized problems. These problems can be addressed directly with proper component selection and training.

The indoor area of the drop has its own set of issues. Electrical performance requirements are similar to the outdoors, however, component selection and installation practices vary greatly. The operator has little control over these variables due to the wide range of purchasers and installers of equipment, including system operators, CATV contractors, home building contractors, and homeowners.

This paper addresses practices that should be considered for improved drop performance and reliability. There are concerns that the existing drops, particularly the indoor portion, will not always maintain a discernible signal to the TV set. Test results of 64QAM digital signal transmitted over typical and less-than-ideal drop systems are reported.

In addition, individual component performance is characterized to understand product impairments that can contribute to overall drop failure. Products analyzed consist of 'generic' and 'premium' types of cables, connectors, and splitters from retail, electrical supply outlets, and CATV industry vendors. The paper is organized as follows:

1) The magnitude of drop-related problems known in today's analog systems,

2) the technical considerations of an effective drop in a high bandwidth, digital world,

3) the performance of currently available products with respect to these characteristics,

4) actual test results of 64 QAM signal transmitted over drops, and

5) recommended practices for the Residential Communications Network, which should perhaps replace the 'drop' designation, which has connotations of lower levels of acceptable quality, service, and revenues.

STATE OF THE 'DROP' TODAY

The Drop Network

The drop, consisting of all components from the distribution multi-tap to the television set, can have many variations. The ideal drop would be one that has few components from tap to TV, minimizing reflections and cumulative leakage and interference. However, the operator has little control over the inside of the house and many subscribers purchase and install their own equipment. Drops can range from that shown in **Figure 1**, the typical CATV drop with few devices, to that in **Figure 2**, the less than ideal drop. It is not clear how typical the 'typical' drop actually is, as the data above suggest that a substantial number of subscribers install their own equipment.

For example, cables sold at retail outlets often do not have bonded foil and have very low braid counts. Connectors are often tool-less, yet craft sensitive to a degree that often results in poor shielding effectiveness. Splitters often have poor isolation and return loss, as will be shown below.

Problems in the drop

In recent years, the scope of indoor connector problems and service calls due to indoor versus outdoor drop problems has become better understood due to improved tracking and studies. Studies from several systems, performed within the last five years, show the magnitude of the problem as experienced today.

To get a sense of the scope of the indoor problems, one can refer to NCTA studies[1] conducted across three systems of varied geographic and demographic character. Upon examination of all trouble calls (217 total hardware-attributed problems), **Figure 3** shows a large percentage of calls (80%) were caused by drop hardware problems.

Within the drop, **Figure 4** shows that 60% of the problems were indoor related. [In a separate study[2], **Figure 6**, a CLI audit was conducted at an eastern seaboard location. Signal leakage problems were indoor related in 53% of the instances].

Outdoor problems either were due to loose connectors or were unspecified, both likely related to the actual installation of the connectors. This suggests that a connector or drop system that eliminates craft error, and reduces the number of accesses to the F-connector, would reduce outdoor trouble calls. Many of the remaining connector problems were likely corrosion related, a common connector design issue.

Figure 5 illustrates the proportions of the various types of service calls related to the drop. Of the indoor-related problems, a large portion (26%) were related to equipment purchased or installed by the customer. Implementation of programs that help to control subscriber purchases and installation practices have great potential for reducing trouble calls.

Of the in-home components not installed by the subscriber, but by the cable operator, the largest percentage of problems were connector related (25%)(**see Figure 5**). A substantial percentage of service calls (6%) were specifically due to loose connectors.

In a third study[3] of drop-related signal leakage, it was found that:

- 57% of indoor problems were connector related
- 43% of indoor problems were subscriber related
- 70% of indoor connectors were found loose.

The CableLabs Intra-Premises[5] study confirms these results and based on their broad industry survey, the two primary causes of in-home trouble calls are: 1) subscriber related equipment and 2) loose connectors.

Summary

The studies cited above yield different results, yet there are recurring trends in their findings:

1) Over half of the drop problems/service calls are related to indoor products.

2) Connectors account for between 25% and 60% of drop service calls and leakage.

3) Loose connectors are ubiquitous in systems, accounting for half of the connector-related problems.

There is a strong correlation between loose connectors and signal leakage in both the field and the lab. **Figure 7** shows the difference for in shielding effectiveness for standard swivel connectors when loose versus when tight.

The recurrence of loose connectors shows substantial opportunity for improvement in design. One potential solution to this problem is to use connectors that cannot be put on or behave in a 'loose' manner. The other is to train installers well and extensively.

TECHNICAL CONSIDERATIONS FOR FUTURE NETWORKS

The previous section outlined the state of the drop today and problems that require improvement. What are the future implications of sending digital signal down existing drop system.? First we must examine the nature of digital signal processing and potential drop component performance implications.

Nature of Digital Video Transmission and Compression

Proposed methods of digital transmission use two fundamental concepts to send information. The first, compression, uses redundancy elimination schemes to reduce the number of bits required to deliver quality video. The second, bandwidth efficient modulation, increases the bit rate for a given frequency spectrum using special modulation encoding schemes (e.g. QAM).

To increase the number of bits per hertz, digital signal processing must be specially modulated to allow fast data transmission and bandwidth efficiency. Many proposed systems are considering 64 Quadrature Amplitude Modulation (QAM). The RF carrier is digitally modulated with multiple states designated by discrete amplitude and phase combinations. As the QAM level rises, however, the immunity to noise and interference is greatly reduced, because the symbol states are closer together, and therefore more difficult to discriminate.

Figure 8a shows a 64 QAM 'Constellation', where each cluster represents a state. I and Q scales are used where the two axes are separated by 90 degrees. In a vector from the center point to any state, the amplitude is represented by the length of the vector and the phase by the angle made with the positive I axis.

For 64 QAM, each state and each symbol transmitted represents 6 bits of information. There are sixty four possible combinations of a six bit long series of 0's and 1's. Each of these 6-bit word combinations is represented by a state in the 64 state constellation. With 16 QAM, there are 4 bits per state. For 256 QAM there are 8 bits per state ($2^{(\text{bits per state})}$ = QAM level).

The constellation shows many symbols that pass through the I/Q plane over time. In the ideal case, each cluster would appear as a single dot, for clear distinction of symbol states. The greater symbols deviate from the decision state, the more likely the receiver is to make errors determining the transmitted state. This is known as a symbol error. Symbol errors due to reflections or multipath often distort the clusters into oval or diamond shapes.

Another way to look at the closing of cluster gaps, is to use the 'eye' diagram, **Figure 8b**. The constellation looks at symbol transmission in the phase-amplitude plane, whereas the eye diagram looks at the I or Q amplitude versus time.

To reduce the effects of these impairments, adaptive equalization, echo cancellation, and forward error correction can be incorporated into the system. At the receive end, adaptive equalization filters out many impairments, particularly those that are stable and unchanging. Echo cancellation, a bi-directional bit stream identification and cancellation scheme, is used to minimize reflection effects. To further reduce errors, Forward Error Correction addresses the presence of impulse noise and other transients. To the extent that these circuits cannot filter out impairments, the drop network must keep their effects to a minimum.

SER Versus C/N

One of the more informative measurements is the Symbol or bit Error Rate (SER). If plotted versus the Carrier to Noise ratio, as shown in **Figure 9**, the allowed external impairment level can be estimated. The power of this measurement is in its ability to estimate the robustness of a given system, representing the transmission capability, a function of electrical design, of components or systems. This information indicates the contribution that the unit under test is making on the degradation of SER, and the corresponding Carrier to Noise ratio needed to achieve a desired SER.

Today's transmission equipment operates effectively with 1×10^{-10} or better SER using Forward Error Correction (FEC). Performance is 'degraded' at 1×10^{-6} SER and is rendered 'unusable' at 1×10^{-3} SER. Interfering noises must not raise the noise so high as to break the C/N threshold corresponding to these levels. Threshold breaks come in the unpleasant form of cracking and popping in audio, and broken, frozen and/or total picture loss in the video.

IMPORTANT DROP PERFORMANCE CHARACTERISTICS IN A DIGITAL ENVIRONMENT

Component effects on the digital signal can be characterized in two ways. One is transmission effects, such as reflections, that are due to the electrical transmission character of the components. The second type includes those effects that decrease the actual Carrier to Noise level, such as attenuation and interference (signal ingress and impulse noise).

Transmission Effects

Transmission impairments often result in distortion of constellation cluster shapes. These are fairly steady (except for special cases such as 'channel surfing', see below). The SER curve is primarily a representation of the transmission effects, setting the benchmark for noise avoidance.

Reflections

Microreflections are typically measured in the CATV industry by the 'Return Loss' method. Reflections can result in the reflected signal interfering with forward signal causing standing waves, constellation cluster distortion, and increased SER.

Port to Port Isolation

Without good port-to-port isolation in splitters, interference of one downstream reflected signal can affect the other. This can combine with other microreflections to distort and enlarge constellation clusters, increasing SER further.

One such combination comes from the practice of 'channel surfing', a rapid changing of channels in search of the preferred program. Reflections received at a television set often come from an adjacent TV connected to the same splitter. As the adjacent set is being changed, the reflections that are not well isolated at the splitter may well travel toward the other terminal, causing an error burst.

Carrier-to-Noise Effects

Although the acceptable Carrier-to-Noise level based on SER versus C/N curves appears to be quite acceptable, there are often many sources of noise that components must be able to withstand.

Signal Ingress

Signal ingress is measured by Shielding Effectiveness. When the Shielding Effectiveness of components degrades, external RF interference decreases the Carrier-to-Noise ratio causing an increased potential for threshold crossing.

If signal ingress occurs, error bursts may result. Examples of strong transient RF sources are two-way radio, pagers, cellular signals, or multipath geographic reflections.

If the ingressive signal is due to multipath, the terminal receives a secondary signal that is slightly delayed relative to the primary signal. For analog, the result is ghosting. For digital the result is frequency-selective fading because of signal cancellation or inter-state interference due to time delay.

Impulse Noise

Impulse noise can be induced by electrostatic discharge, machinery, electrical arcing, lightning and other system transients. Effects of localized activation of electrical equipment near the drop has been shown to impress approximately 7 dB of additional noise across the drop frequency spectrum.[4] This is likely to vary significantly depending upon the situation. Significantly high field Impulse Noise measurements have been mapped by NYNEX for ADSL applications and were found to cause 50% receive errors for Telco applications.[9,10]

Attenuation

Though the Signal to Noise ratio can drop quite low in digital systems and still provide excellent quality, recommended operation levels should be strongly adhered to. Maintaining high carrier levels to the drop without inducing noise, will assure a higher 'safety margin', allowing ingress and impulse noise to be impressed upon the system without affecting picture quality. If the carrier is allowed to decrease, failures will not be as forewarning as the gradually degrading analog signal. A pictures will look fine until the threshold is met, at which time it is destroyed.

Implications of Higher Bandwidth

High bandwidth systems are being proposed at anywhere from 1 to 1.2 GHz. Both higher attenuation and greater signal leakage are experienced with increased bandwidth. Greater signal leakage occurs with higher frequency because the shorter wavelengths are more difficult to shield with decreasing wavelength interfaces. Reflections are also affected by high frequency, making maintenance of the impedance match more difficult with decreasing wavelength.

Due to the attenuation and tilt characteristics of most products at 1 GHz and the need for reduced actives in the distribution plant, it is important that the capabilities of drop components are understood. Most systems design or have taps in place with outputs of 10 +/- 5 dB. With FCC regulations requiring 0 dB to the video terminal, all products going into the home, regardless of source, should be the industry's concern. Estimates of the number of TVs per home vary, but 2 to 4 sets are common. The existence of multiple set homes requires that the indoor drop have good shielding to minimize cumulative leakage and low attenuation in order to serve all terminals with adequate levels.

PERFORMANCE OF TODAY'S DROP PRODUCTS

Considering the above implications, how well do existing components rate? Several of the existing products have been evaluated out to 1 GHz. The products were purchased from a cross section of CATV industry, electrical supply store, and retail outlet sources. The CATV products tested are those popular among Cable operators. The electrical supply sources are those from which electrical and home building contractors might purchase. Retail outlets are all chain retail stores tailoring to the hobbyist or 'do-it-yourself' customer. The tests performed, and the drop component tested is indicated in the table below.

COMPONENT	TEST
Cable	Shielding Effectiveness Signal Transmission (Attenuation)
Connectors	Shielding Effectiveness
Jumpers	Shielding Effectiveness
Splitters	Return Loss, Port to Port Isolation, Phase Shift vs Frequency

Splitters

A total of six splitters were tested for Return Loss, Port to Port Isolation, and Phase characteristics. Most of the splitters were specified for under 600 MHz. One premium CATV industry 1 GHz splitter was also evaluated. Though most splitters were rated for lower than 1 GHz, all were tested to the full spectrum to understand what they would be capable of if exposed to all frequencies. Two of the splitters were CATV industry products, while the other four were retail products. The construction and performance of the splitters placed them naturally into the following four groups:

1. Premium Retail
2. Standard Retail
3. 600 MHz CATV
4. 1 GHz CATV

Return Loss

The six splitters tended to naturally fall into the four categories of curves based on Return Loss results. Representative curves for each of these categories are plotted in **Figure 10.**

Return Loss Summary

Splitter	550MHz	1GHz
CATV 1 GHz	-22 dB	-25 dB
CATV 600	-21 dB	-5 dB
Premium Retail	-13 dB	-19 dB
Standard Retail	-7 dB	-5 dB

Performance varied over a wide range from approximately -5 dB to -25 dB. At 550 MHz, the CATV industry splitters (at -20+ dB) were approximately 7dB better than that for the premium retail splitters, and approximately 13dB better than that for standard retail splitters. The return loss of the CATV splitters over their specified frequency range was significantly better than that of the retail splitters. The 600 MHz rated CATV splitters rated as well as the 1 GHz up until the specified (600 MHz) frequency.

Port-to-Port Isolation

The port to port isolation of the splitters over their specified frequency range exceeded 20dB for all six splitters tested. There was no more than a few dB difference between the level of isolation for the retail splitters versus the premium versions. **Figure 11** shows all the results on one graph, as they all fall below 20dB.

A typical directional coupler demonstrated a return loss of approximately 20dB and a port to port isolation of approximately 30dB over a frequency range of 10MHz to 600MHz **(Figure 12)**. In cases where the isolation of existing splitters does not effectively isolate unwanted reflections and noise, a directional coupler should be considered. In homes where the indoor architecture is home run and the signals into the home are sufficient, this may be an approach worth considering. (That is, if improved splitter isolation is not available).

Phase Changes

The effect of phase noise can be significant with regard to QAM modulation schemes. Although not yet fully understood, phase related non-linearities and phase shifts through shared passives may be important. Though adaptive equalizers can accommodate a substantial degree of phase distortions and reflections, this data is included for reference purposes.

The phase shift for the CATV splitters, that is, the change in phase occurring as signal passes through the component, was close to a linear function of frequency. The retail splitters, on the other hand had a widely varying phase shift. Typical plots are shown for a premium CATV splitter **Figure 13** and a standard retail splitter **Figure 14.** All measurements were normalized to the reference standard, a cable sample with a Regal F-81. The F-81 was exchanged for the splitter in each test.

The other measurement regarding phase is the measurement of the phase shift of input to output versus the phase shift as signal passes into one output and out the other. This simulates the difference of signal phase that a television might see as a result of a forward signal that is coupled with reflections from an adjacent terminal, such as a TV or converter with poor return loss. Plots show very different phase change characteristics in this case, **Figures 15 and 16.**.

Connectors, Cable, and Jumpers: Shielding Effectiveness

The components tested and summary of shielding effectiveness testing are listed in **Table 1**. In all, 16 connectors, 12 cables, and 7 jumper products were evaluated.

Components were tested using the Transverse Electromagnetic Method (TEM) of shielding effectiveness testing (**Figure 17**). Three of each of the samples were tested. Each sample was measured and rotated 90 degrees in the chamber to achieve four measurements per sample.

Results summarized in **Figure 18,** are divided into connector, cable, and jumper categories. Connectors did not show as much variation in shielding as the other categories, although some variation occurred with values at 72 +/- 8 dB. Cable samples differed substantially more, measuring 84 dB +/- 16 dB. Jumpers, showed the highest variability and lowest performance as a group, measuring 52 +/- 19 dB.

For a given cable, various connectors showed little difference in shielding effectiveness, whereas cable shielding varied significantly. This shows that the effect of cable is far stronger than the effect of connectors on the F-interface shielding effectiveness. Again, the greatest variance and poorest performance category were the jumpers.

Connectors

Twist-on connector performance is comparable to the crimp connectors, depending upon design. Of the retail connectors, the two-piece crimp versions consistently performed as well or better than the one-piece versions. This was interesting, as there is a perception that the two-piece connector is of much lower quality. When these are installed properly, as done for this test, they perform quite well.

The problem lies in the substantial care to get that proper installation. None of the connectors were sold with crimping equipment. This is not a problem in a test lab but the homeowner is not likely to be as adequately equipped. The two piece connectors took extra care to get the crimp ring into place. Twist-on versions did not require tools but they did take extra care to assure that the dielectric of the cable was flush with the connector mandrel face.

Cables

Cable shielding, as mentioned above, varied significantly. There is some correlation in shielding to braid coverage, but other factors are involved. For example, the best performing cable, out-shielding even the CATV industry quad cable, was a 60% braided electrical supply house sourced cable. Also, a 9% coverage cable did shield better in this test than several cables ranging from 30 to 67% coverage. The 9% braid sample did have good aluminum tape coverage of the dielectric. The high percentage braid coverage cables tend to have better shielding, but the presence of tape and other factors may be of equal significance. This should be taken into accout when considering a construction-based standard.

Jumpers

The jumpers tested all had low braid counts and in two cases had no tape over the dielectric. Both cases where no tape was used had very poor performance. The other low rating performers had low braid count. It is suspected that, in part, poor shielding can be attributable to assembly techniques. Due to the high speed at which some low cost jumpers are manufactured, proper assembly may be compromised. Inspection is also difficult due to the over-molded construction used by many of the manufacturers.

Jumpers are sold for application after the set-top, typically for use between the VCR and television set. However, these are now found installed and will continue be installed between the wall plate or subscriber-installed splitter and the set-top.

Cable Signal Attenuation

Signal transmission tests revealed that the attenuation for the CATV products were substantially better than those from other sources, (**Figure 19**). Throughout the retail and electrical supply sourced products the 6 had lower attenuation than the 59 as expected. However, the CATV 59 was better than even the retail/electrical supply -6 products. In fact, at 1 GHz the CATV industry cable shows 8 dB attenuation as compared to a retail -6 cable attenuating almost 12 dB. Again, as with shielding characteristics, attenuation should not be based too readily upon the construction of the cable (in this case whether or not the cable is '59' or '6').

SUMMARY OF PRODUCT PERFORMANCE FINDINGS

The level of performance necessary for drop components will no doubt vary depending on ambient conditions. However, considerations of potential problem areas have been outlined. The data given here can serve as a reference to performance of existing products. The best way to determine component performance levels required is to conduct or refer to actual digital field studies and determine tolerance levels. Conclusions based on the product performance evaluations are listed below:

1. Extra precaution should be taken when purchasing jumpers. Workmanship and/or quality of construction affect the quality of the jumper shielding performance.

2. When properly installed, most connectors will shield comparably. Care must be taken to assure connectors are installed properly, as tools rarely are sold or recommended with retail connectors. All connectors tested in this study were carefully installed.

3. An unexpectedly wide variation in shielding effectiveness exists between various cable brands. If a minimum cable construction is to be specified, the tape construction as well as the percentage coverage should be included. The best standard would involve actually testing samples. Shielding cannot be accurately predicted based solely on the existence of tape or the braid coverage.

4. Cable attenuation, as with shielding effectiveness standards, will be substantially more reliable if based on actual measurements of products as opposed to construction. For example, some -59 CATV industry products attenuate less than -6 retail products.

5. Port-to-port isolation for all categories of splitters was better than 20 dB. For optimal port-to-port isolation, the use of the directional coupler (better than 30 dB) is recommended.

6. The return loss of retail products are significantly lower than the industry products. This may pose a threat to signal encoding, depending upon effectiveness of error correction, echo cancellation and adaptive equalization techniques..

DIGITAL DROP SYSTEM TEST RESULTS: 64QAM TRANSMISSION

Several drop configurations were tested to determine the range of digital signal impairment that may be expected. Constellation charts, eye diagrams and SER (Symbol Error Rate) versus C/N (Carrier to Noise) information were utilized.

A Line Diagram of the test setup is shown in **Figure 20.** Signal generation and analyzer equipment operated at 50 MHz. Frequency was upconverted to 850MHz to simulate levels that may be expected in future networks. The symbol rate was 5MHz, hence a 30 Mbit/s transmission rate. Baseband filters were not used in order to be able to attribute impairments to the drops under test. Results are therefore probably slightly worse in actual practice, for it is likely these would be used.

The reference SER vs C/N curve, **Figure 8**, shows the effects of transmitting through the test equipment alone. The lower level curve represents the theoretical ideal, where the right curve is the actual. At 1×10^{-6} SER the there is little (2 dB) discernible additional requirement, or 'implementation margin', in the Carrier to Noise ratio.
Two models, encompassing a broad range of conditions that the signal will experience, are reported on here. One is the best case, with the so called typical drop architecture shown in **Figure 1,** utilizing higher grade products. The other is the worst, 'less-than-ideal' case, modeled after the drop in which the subscriber has installed several retail products, **Figure 2.** The drop components used in each model are listed below. 'CATV grade' represents products which are popular among system operators. 'RL' represents approximate Return Loss at 850 MHz.

Best Drop

Cable, 150 feet CATV grade -6
Ground Block, 17-18 dB RL rated
Cable, 5 feet CATV grade -6
Splitter, 1 GHz rated, 23 dB RL
Cable, 30 feet CATV grade -6
Wall Plate, 15 dB RL rated
Cable, 5 feet CATV grade -59

Worst Drop

Cable, 150 feet CATV grade -59
Ground Block, 12 dB estimated RL
Cable, 5 feet CATV grade -6
Splitter, 600 MHz rated, 10 dB RL
Cable, 30 feet CATV grade -59
Wall Plate, 15 dB RL
Cable, 3 feet retail
Splitter, standard retail, 6 dB RL
Cable, 25 feet retail -59

Note: The carrier in the worst drop case attenuated almost 20 db from the tap to the TV set.

In the ideal drop case, the SER vs C/N graph, **Figure 22,** shows very little implementation margin (1 dB), versus the test equipment reference. The Carrier-to-Noise ratio thus required is approximately 26 dB at 10^{-3} SER and 29 dB at 10^{-6} SER. From the Constellation and Eye Diagrams, **Figures 23 and 24**, we see that in this ideal case, the drop has a constellation with very tight clusters.

In the worst case, 'less-than-ideal drop', deviation from theoretical is about 5 dB, which is substantial (See **Figure 25**). Thus for an error rate of 10^{-3}, almost 30 dB C/N is required, and for 10^{-6}, 37 dB C/N is needed! Though significant, drop signal *usually* reaches the TV set well above this. Note the constellation diagram, **Figure 26**, showing the more scattered nature of the state clusters. The diamond shape of the clusters show that the increased distortion is due to reflections. In the eye diagram for this case (**Figure 27**), ripple in the left side of the eye opening reduces the time and degree of symbol state separation, and is due to reflection perturbations.

To determine the cause of the reflection and impaired signal, attenuation pads were placed between the two splitters. The effect of doing this was that it not only attenuated the carrier, but also the reflection. As a result, the reflected signal is reduced into the noise floor and the carrier is lowered. The eye diagram in **Figure 28** shows that ripples were no longer discernible. The signal versus time proves to be noisy but it is ripple free (a constant width, yet noisy trace). The difference in results, due to attenuation between splitters, suggests the problem is with standing waves between these two low-grade passives.

When the splitter ports were terminated with 50 feet of cable and a Television set, SER increased significantly, depending on the channel. The phase of the reflected signal changed as a function of the channel setting. Receivers would ideally be able to correct for fast-changing, multi-reflections.

Effects that can close the Carrier-to-Noise safety, or 'fade' margin, include impulse noise and ingress. As shown above, the effect of loose connectors can greatly decrease the shielding effectiveness of the connector and hence close the threshold margin. Impulse noise, which can give a wide range of hits to that margin[4,9], could add to the ingressive noise due to the loose connector combined with strong ambient RF.

With the effect of attenuation, especially at high frequencies, the carrier degrades substantially, directly effecting C/N. Low attenuation cable will reduce low carrier problems, as will proper engineering of the feeder-line-to-drop transition.

CONCLUSIONS

Digital transmission through the cable drop network looks very promising, though care must be taken to assure positive results. The following findings, regarding the state of cable systems and components today, should be understood and addressed.

1. Indoor cabling practices are a major cause of existing trouble calls, primarily due to
   - Loose connectors (also a major problem outdoors)
   - Subscriber installed products

2. Indoor component performance is substantially lower than that of outdoor. Shielding and return loss performance of many of the products that are likely to be in homes are extremely poor compared to the CATV operator products. Specifically,
   - Jumper shielding effectiveness is consistently very poor.
   - Cable shielding is varies widely.
   - Cable attenuation is varies widely.
   - Retail splitter return loss is poor.
   - Construction of the cable, such as braid coverage and 59/6-designation, is not always a reliable indicator of performance quality.

3. Based on tests of random bit generated 64 QAM digitally modulated signal, the drop does not appear to pose a major barrier to compression based services.
   - In the worst case, the drop will likely need a Carrier to Noise level of 30-37 dB to assure adequate signal (for 10^{-3} and 10^{-6} SER, respectively).
   - Although 64 QAM is very promising, in-home practices may pose a threat in cases where sufficient Carrier-to-Noise is threatened, especially if

     1. Engineering precautions are not taken to assure consistently adequate carrier levels.
     2. Retail splitters and other passives are used excessively, causing extreme reflections and carrier degradation
     3. Connectors are not tightened, especially in high ingress areas.
     4. Impulse noise is excessive. Combinations of the above scenarios will increase the chances of exceeding the threshold.

RECOMMENDATIONS

Based on test results and the many variables to consider, (none of which is insurmountable), the following recommendations are offered.

I. Work to control practices and products used in all areas of the drop. Standards must be rapidly implemented in the industry. The In-Home Cabling Sub-committee of the SCTE, CableLabs, and the NCTA are currently addressing quality practices. The SCTE, for example, has a three phase approach that should be supported:

   1) Publish a consumer guide for the electrical contractor and homeowner, to be provided by the CATV operator.
   2) Publish a comprehensive technical manual of practices.
   3) Create a 'Stamp of Approval' process for retail products.

   A comprehensive plan for awareness building in all industries is included in the CableLabs Intra-premises Study.[5]

II. Avoid splitting in the home. Home Run Architectures should be used whenever possible. All unused ports should be terminated to 75 ohms.

III. Sufficiently high carrier levels should be maintained. This is important to do proactively, as there will likely be little warning based on picture quality that will alert the operator that signal is degrading.

IV. Appropriate components should be used.
- Connectors should ideally:
  1. Eliminate craft sensitivity and be designed in a way that they can not be put on in a 'loose' manner.
  2. Rarely be connected/disconnected, perhaps permanent where practical (mostly outdoors), to statistically reduce the chance of a loose connector installation
  3. Be sealed, as this will reduce the chance of ingress due to corrosion.

- High bandwidth, low Return Loss splitters, splices, and passives should be phased into the drop network.

- In the home, circuit protection should be considered to reduce the chance of impulse noise problems.

V. Consider utilizing decompression and analog conversion at a Demarcation Box/Residential Gateway. This could do some or all of the following:

- Keep digital signal from entering the home
- Assure robust signal into the home through simple, low bandwidth amplification
- Remove unwanted set-tops from the home and share electronics cost of boxes
- Provide controlled security.

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REFERENCES

1. "The Indoor Challenge: The Rising Trend Toward Problems With In-home CATV Wiring and Connectorization", 1990 NCTA Papers, Lemaire J., Smith B., Drumm M.

2. Raychem Field Trial and Audit Archives, Audit No. CBU92-10.1-A, Bauer B., Mathis M.

3. "Drop Related Leakage Sources". Communications Technology, September 1992.

4. "CATV - Cable Systems Digital Characterization Utilizing 16 and 64 QAM 45 Mb/s Telecommunications Modems". Summers B., Nash B. Tele-communications, Inc., Engineering Technical Paper No. 92-11-01. 1993 SCTE Conference on Emerging Technologies.

5. Cable Television Industry Intra-Premises Cabling Practice and Strategy, 1992.

6. Digital Radio Theory and Measurements, Hewlett Packard Application Note 355A.

7. "Installation of Drop Systems in the Era of Full-Service Communications". Bauer B., Habeck B., Communications Technology, February.1993.

8. "Estimating Symbor Error Rate vs. Carrier to Noise Ratio in Modulated Systems Based on Digitization of Constellation and Statistical Models". Klein, Matt, Hewlett Packard.

9. "Asymmetric Digital Subscriber Line (ADSL): Technology and System Considerations", Bellcore Communications Research, Special Report, Issue 1, June 1992.

10. "NYNEX Impulse Noise Study", NYNEX Publication NIP-74015, Issue 1, January 1988.

Figure 1
Today's Typical/Ideal Drop System

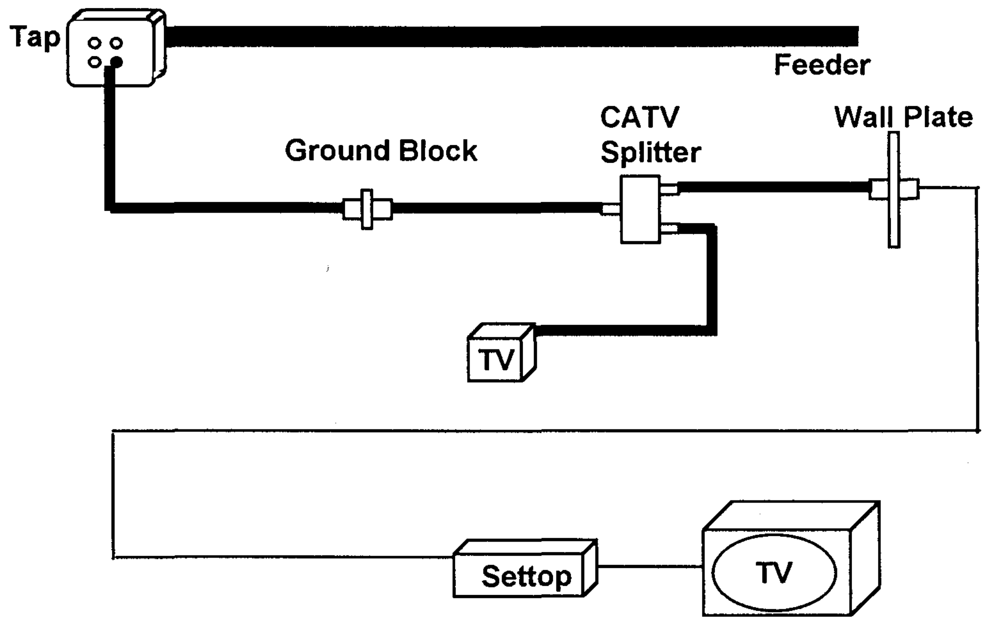


Figure 2
The Less-Than-Ideal Drop System

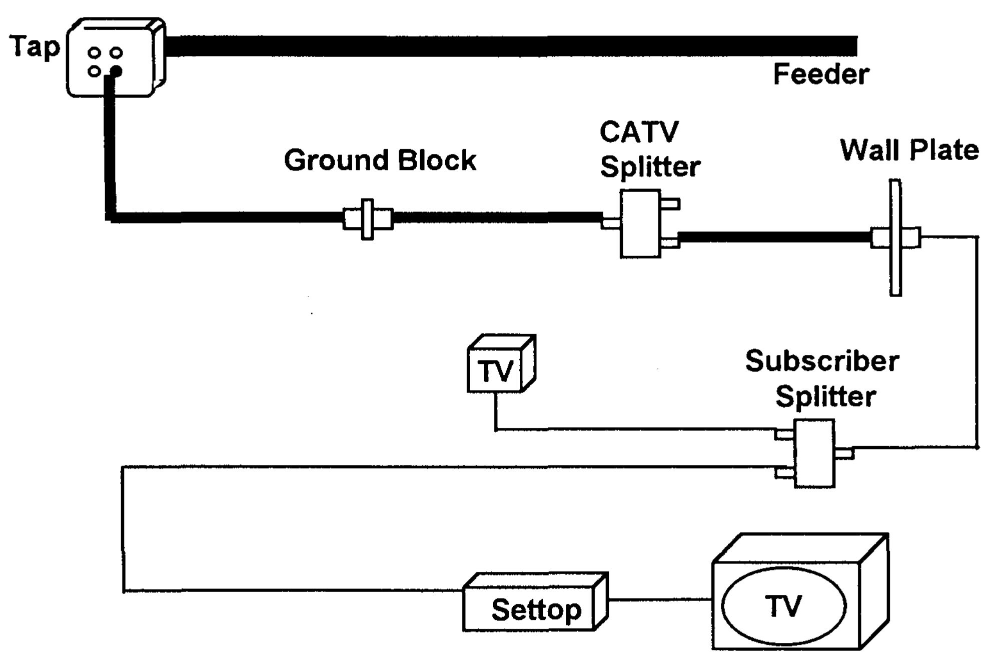


Figure 3
Summary of All Service Calls

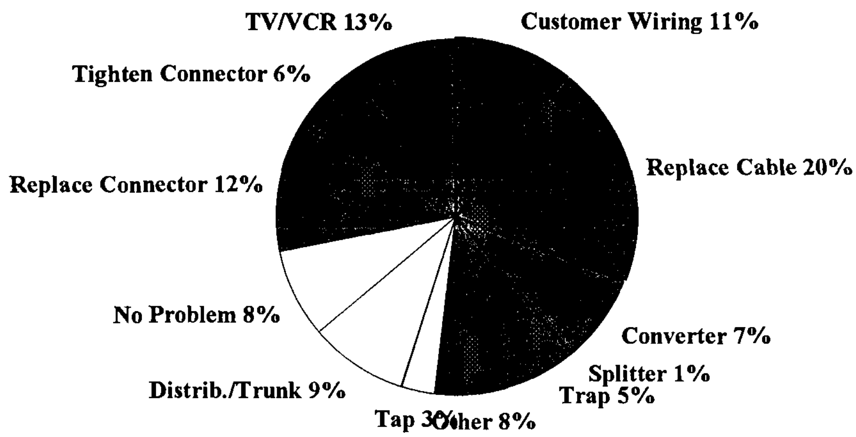


Figure 4
Drop Service Calls Only

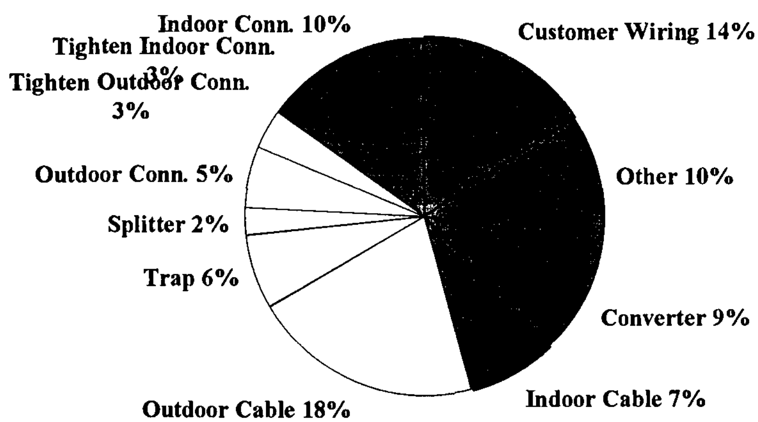


Figure 5
Indoor Service Calls Only

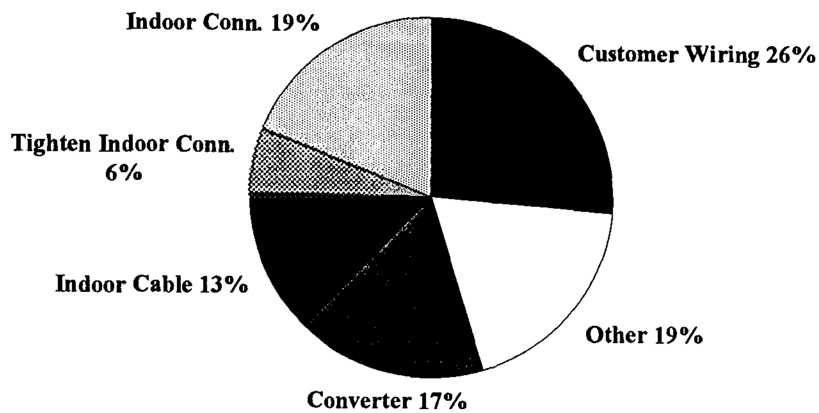


Figure 6
CLI Audit Study

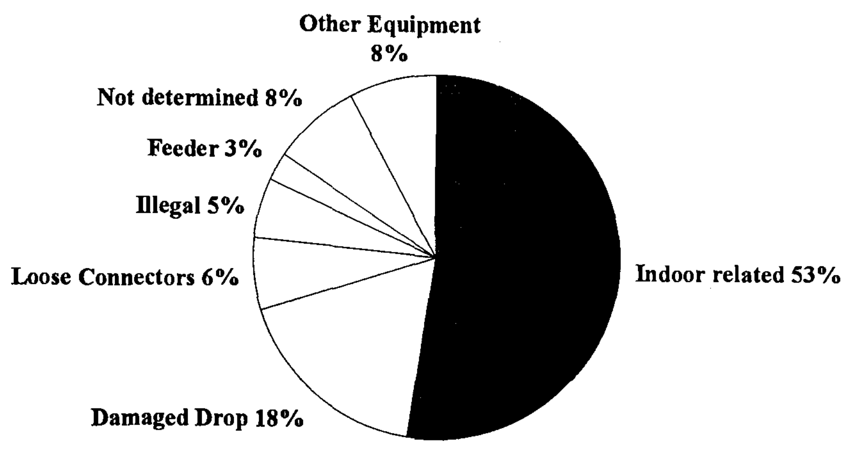
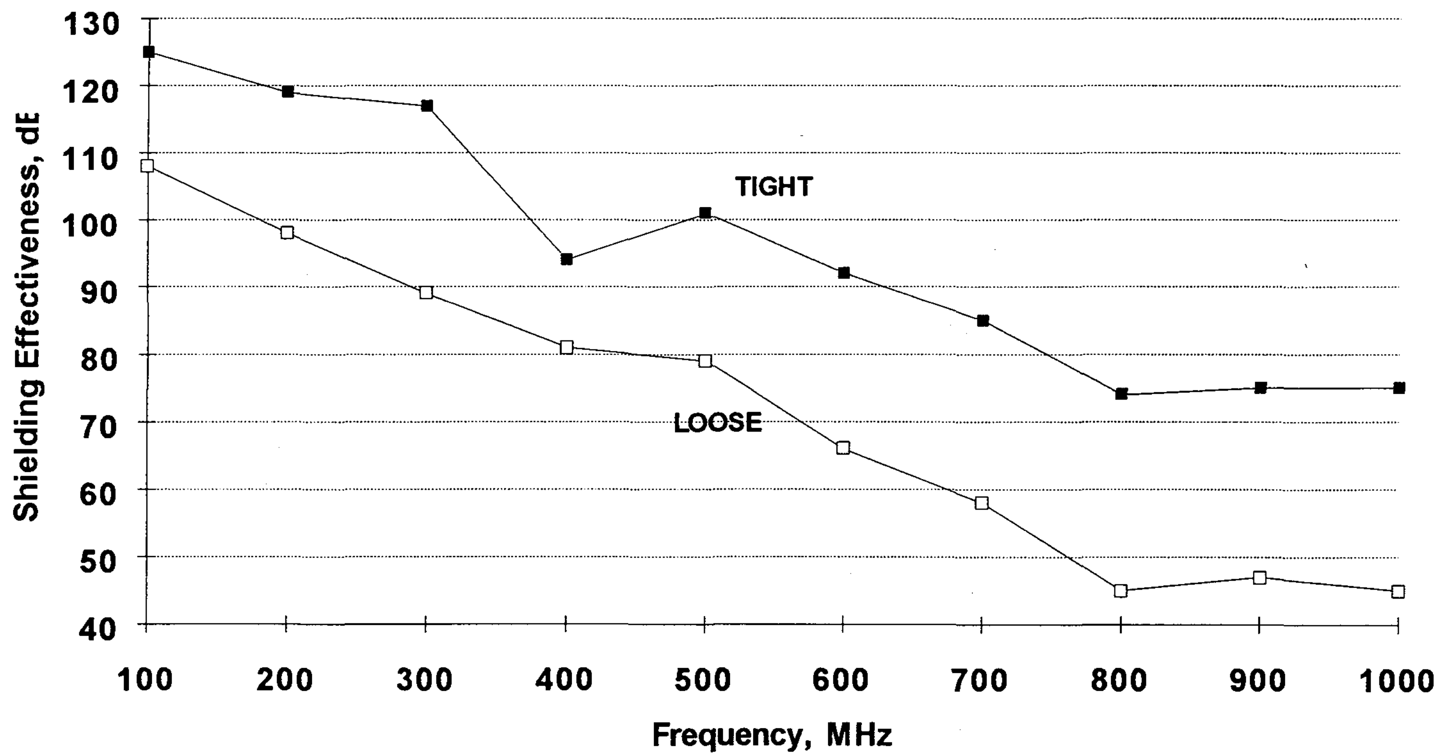


Figure 7
Shielding Effectiveness
Standard Swivel Connector



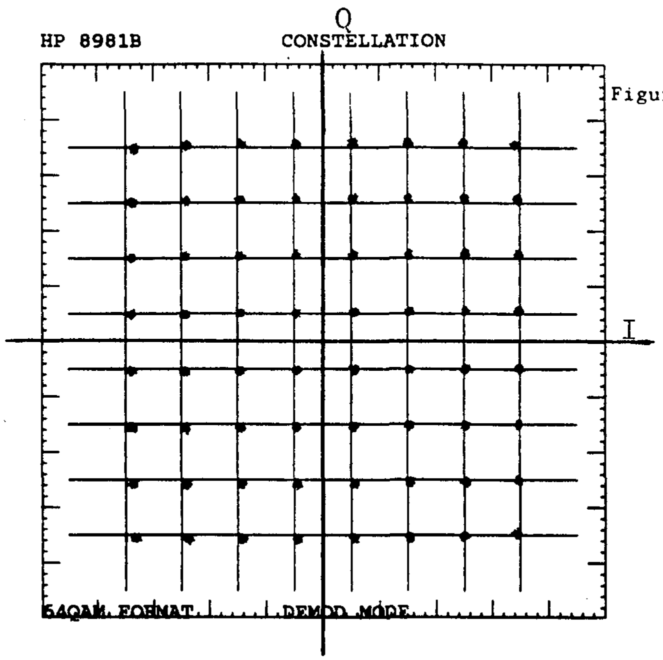


Figure 8a.

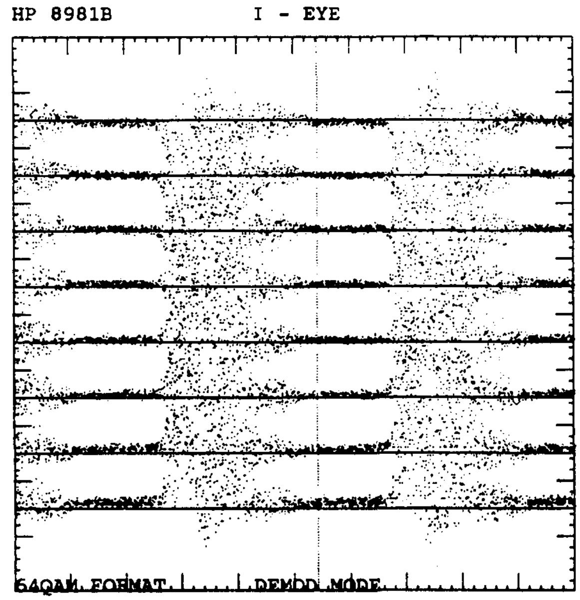


Figure 8b.

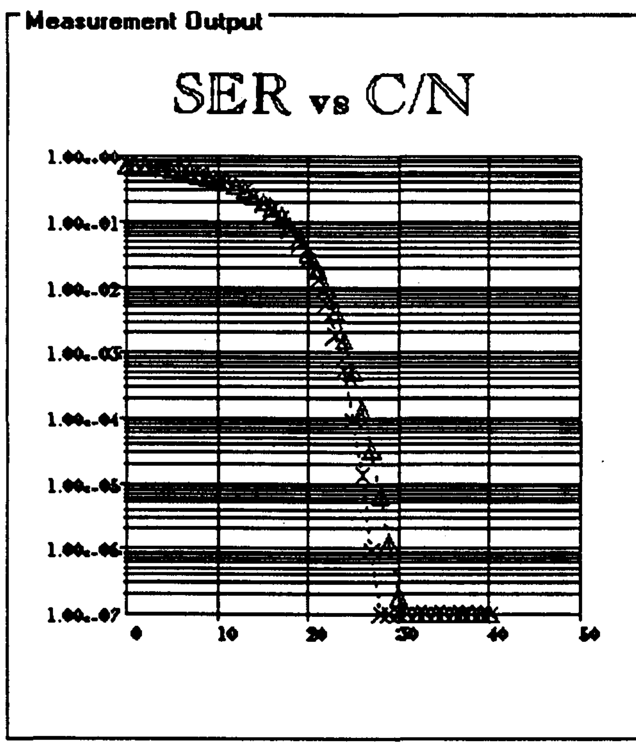


Figure 9

FIGURE 10
RETURN LOSS

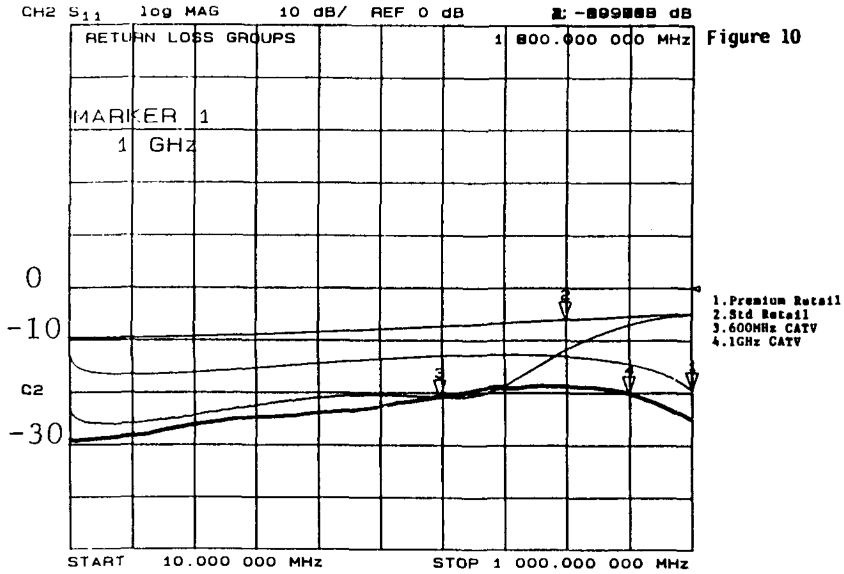


Figure 10

FIGURE 11
SPLITTER PORT TO PORT ISOLATION

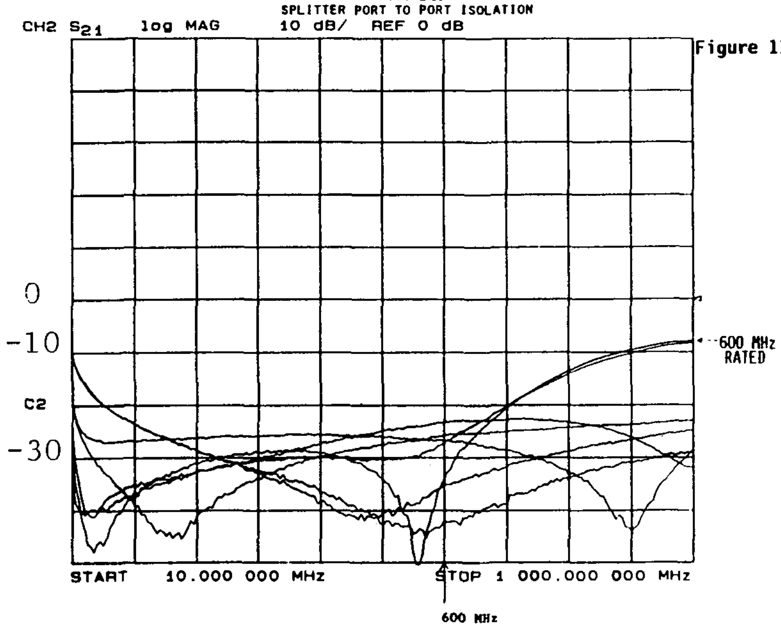


Figure 11

FIGURE 12
DIRECTIONAL COUPLER PORT TO PORT ISOLATION

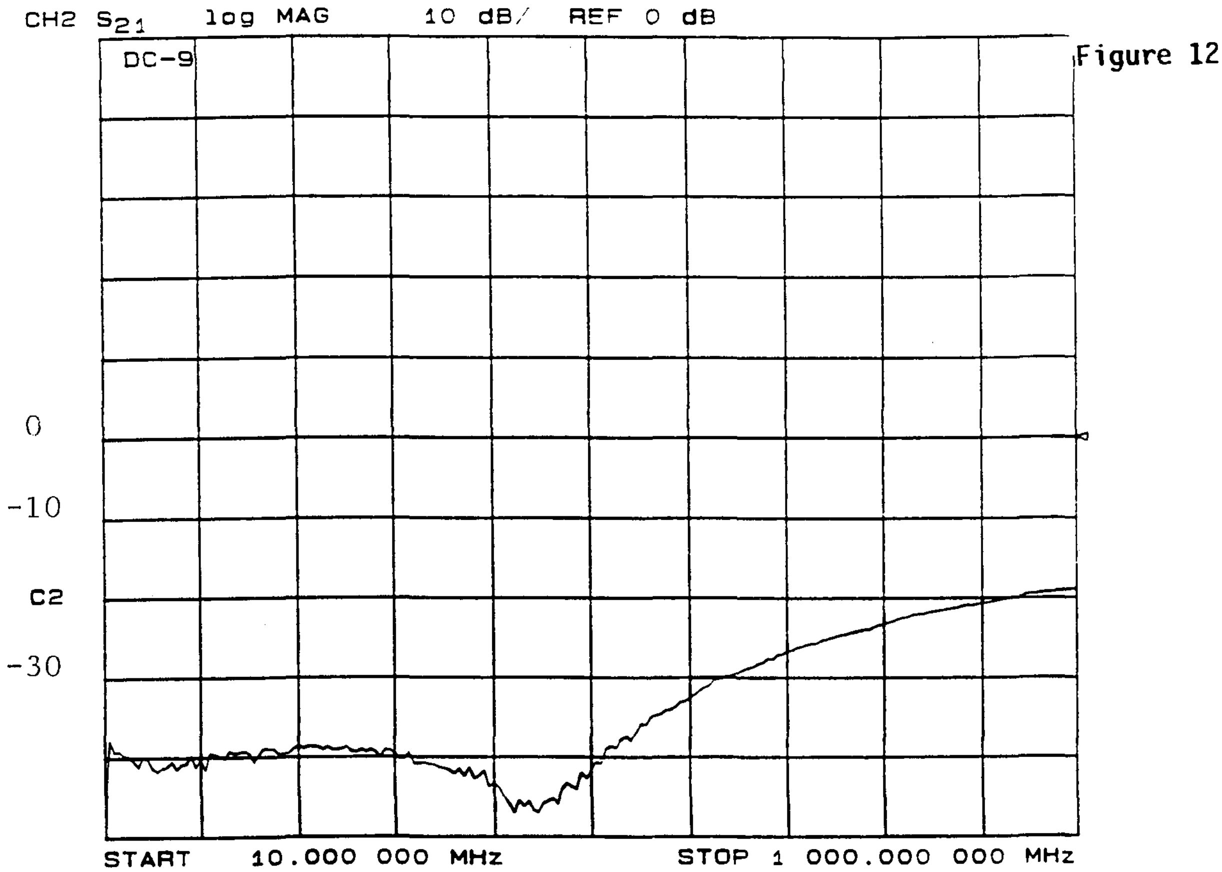


FIGURE 13
PHASE SHIFT THROUGH SPLITTER
PREMIUM CATV PRODUCT

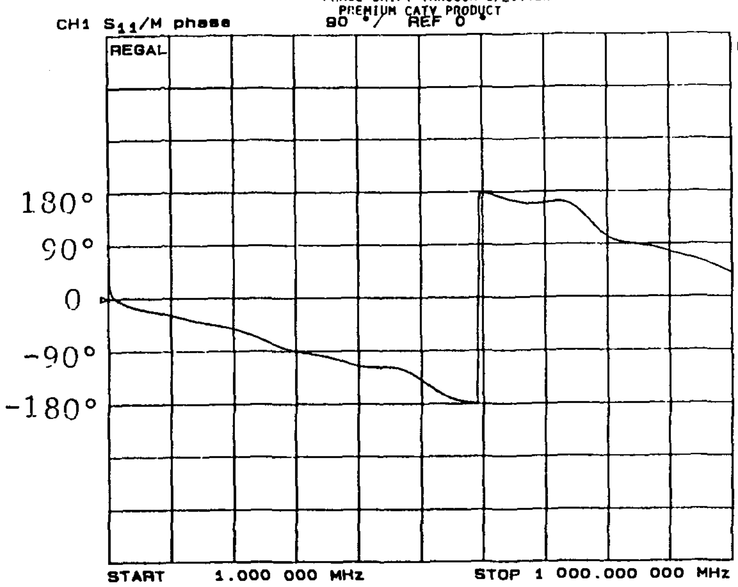


Figure 13

FIGURE 14
PHASE SHIFT THROUGH SPLITTER
RETAIL PRODUCT

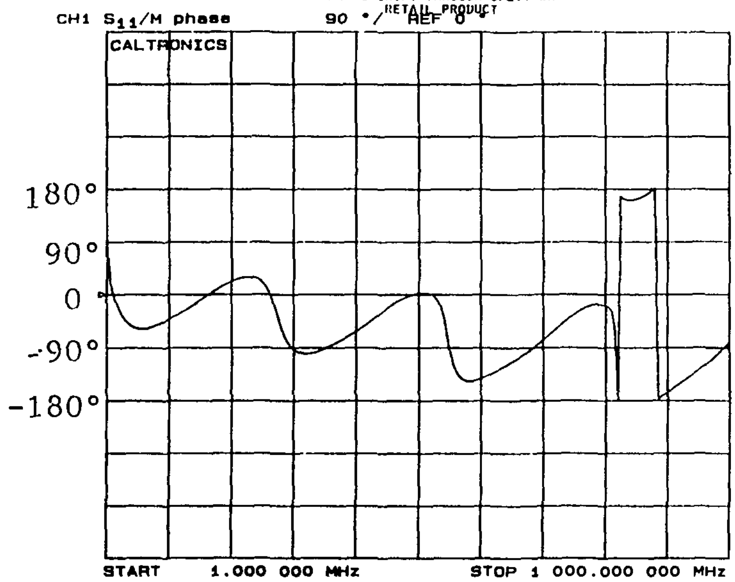


Figure 14

Figure 15
Retail Splitter Input Phase vs "Reflected" Adjacent Port Phase

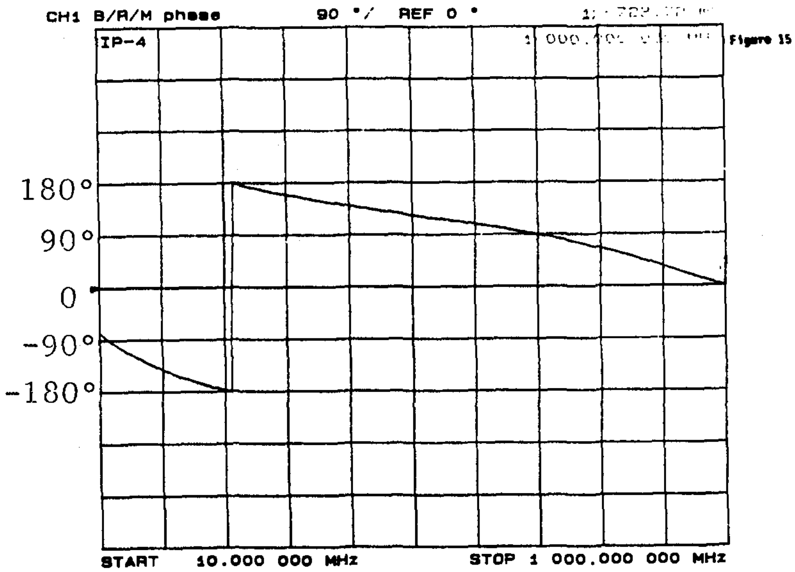


Figure 16
Low Grade CATV Splitter
Input Phase vs "Reflected" Adjacent Port Phase

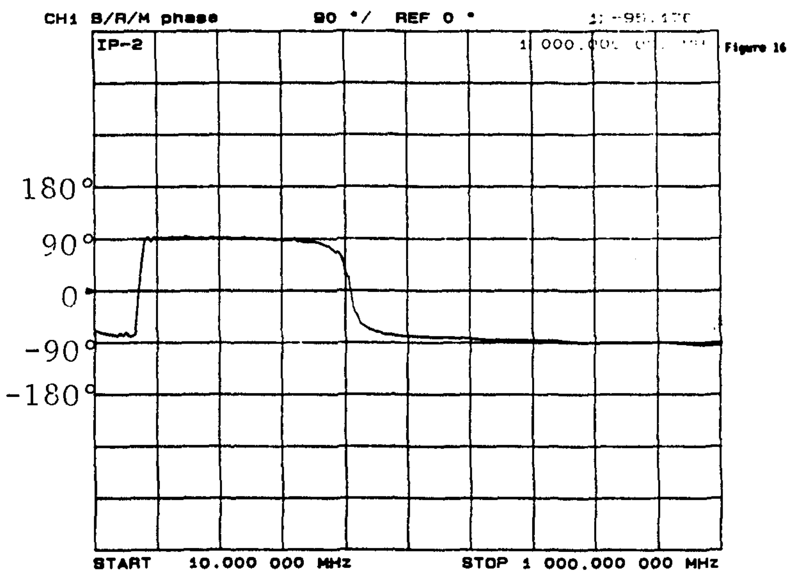


TABLE 1

Summary of Products Tested	
Source	**Style**
CONNECTORS	
Retail A	59 Crimp, Two Piece
Elect. Supply A	59 Twist on
Retail B	59 Crimp, Two Piece
CATV A	6 Crimp, 1 Piece Universal
Elect. Supply B	59 Crimp, Two Piece
CATV B	59 Crimp, One Piece Universal
CATV C	59, One Piece Universal
Elect. Supply C	6 Twist on
Retail C	59 Crimp, Two Piece
Retail D	59 Crimp, Two Piece
CATV E	6, One Piece Universal
Retail E	59 Crimp, One Piece
Retail F	59 Twist on
Elect. Supply D	6 Crimp, One Piece
Elect. Supply E	59 Crimp, One Piece
Retail G	59 Twist on
CABLES	
ElctSup A 6-60%	6, 60 %
CATV A 6-Quad	6-Quad
Retail A 59 33%	59, 33%
CATV B 6-60%	6-60%
Retail B 59-59%	59, 59 %
Retail C 59-35%	59, 35 %
CATV C 59-Quad	59-Quad
ElctSup B 59-9%	59, 9%
Retail D 59-30%	59, 30%
Retail E 59-33%	59, 33 %
CATV D 59-67%	59-67%
Retail F	6
JUMPERS	
Retail A	59
Retail B	59 Gold
Elect. Supply A	59
Retail C	59 Regular
Retail D	59
Retail E	59 Gold
Elect. Supply B	59
SPLITTERS	
Elect. Supply, IP1	2 way splitter
CATV, IP2	2 way splitter
CATV, IP3	2 way splitter
Retail, IP4	2 way splitter
Retail, IP5	2 way splitter
Retail, IP6	2 way splitter
CATV, IP7	3 way splitter

Figure 17

Line Diagram
Measurement of Shielding Effectiveness, TEM Method

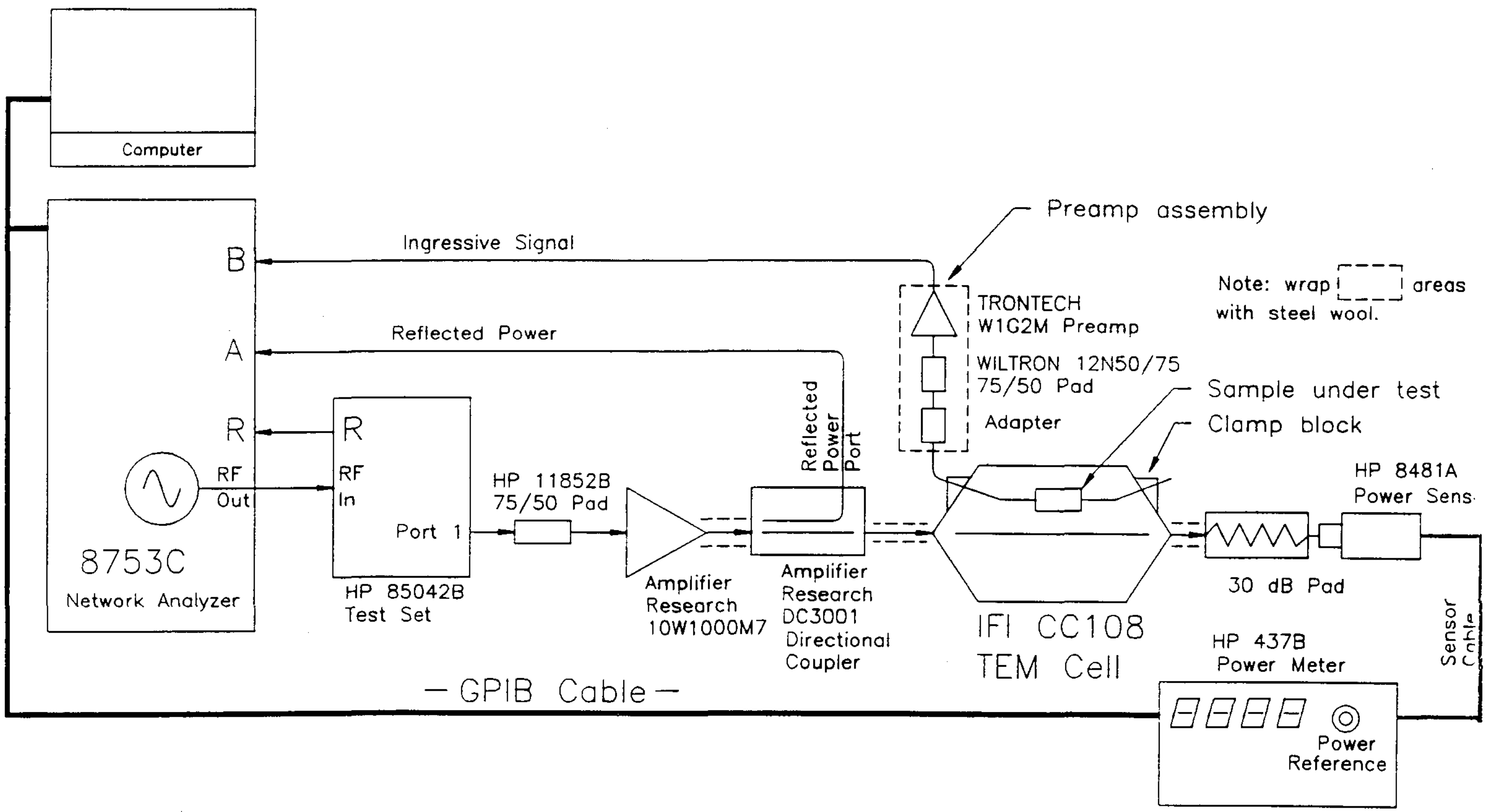
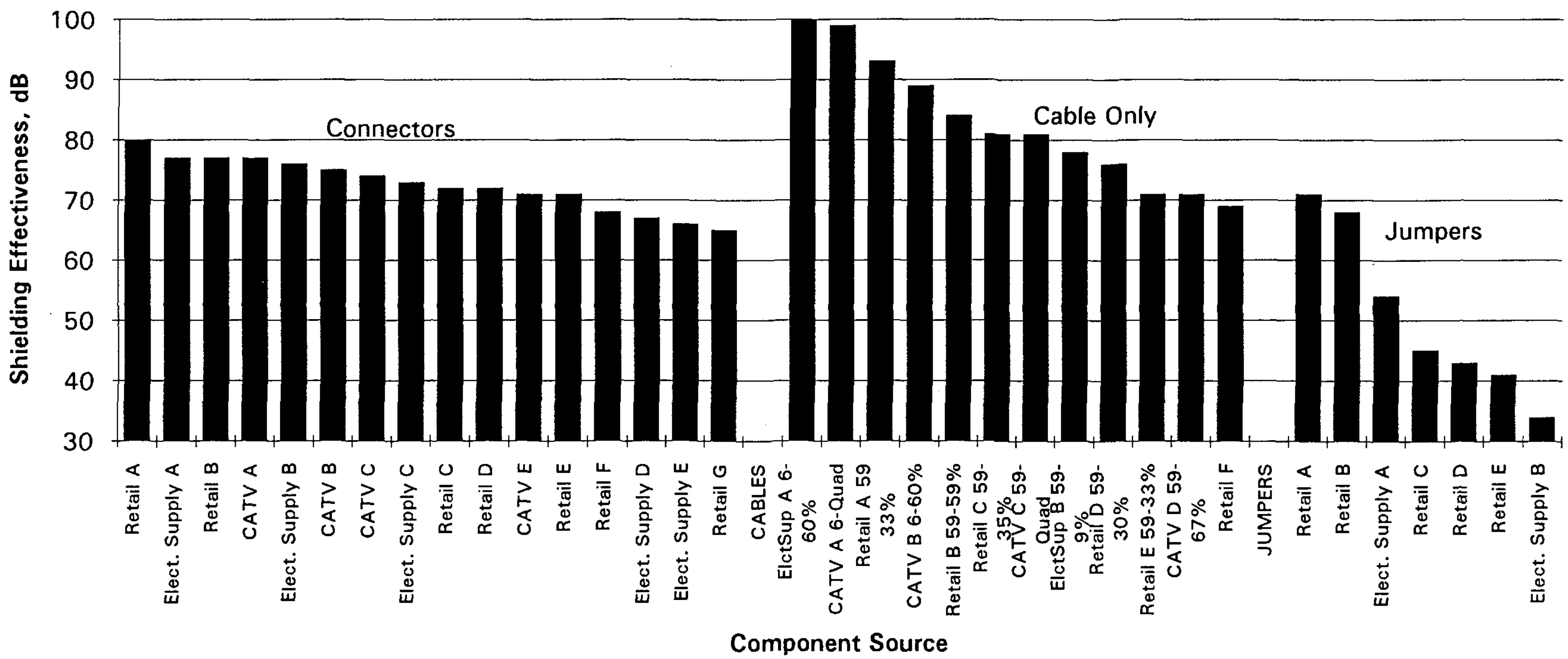


Figure 18
Shielding Effectiveness Summary
Shielding at 1 GHz, TEM Method



Retail: Retail Outlet
Elect. Supply: Electrical Supply, likely home contractor source
CATV: Major CATV MSO Vendor

FIGURE 19
Cable Attenuation
At 550 MHz and 1 GHz

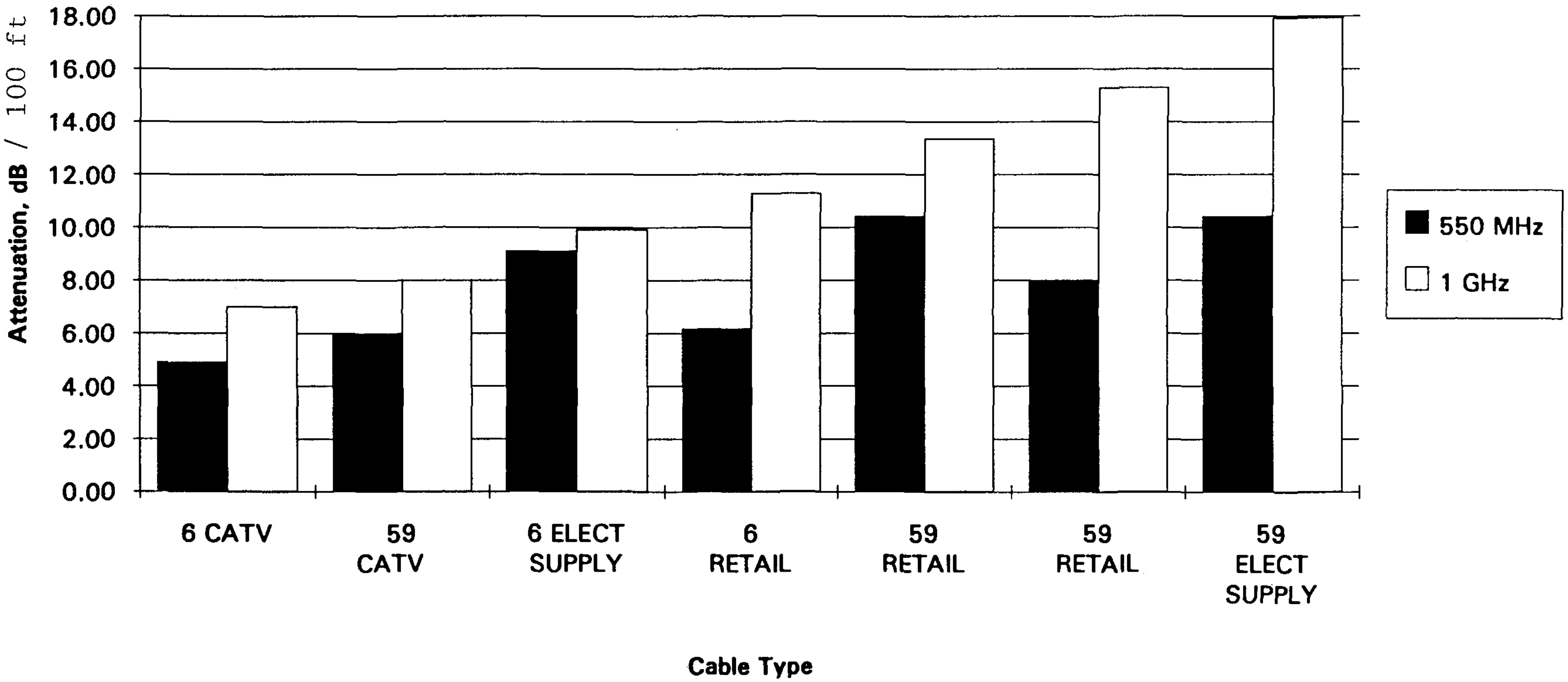


Figure 20
Digital Modulation Test
Line Diagram

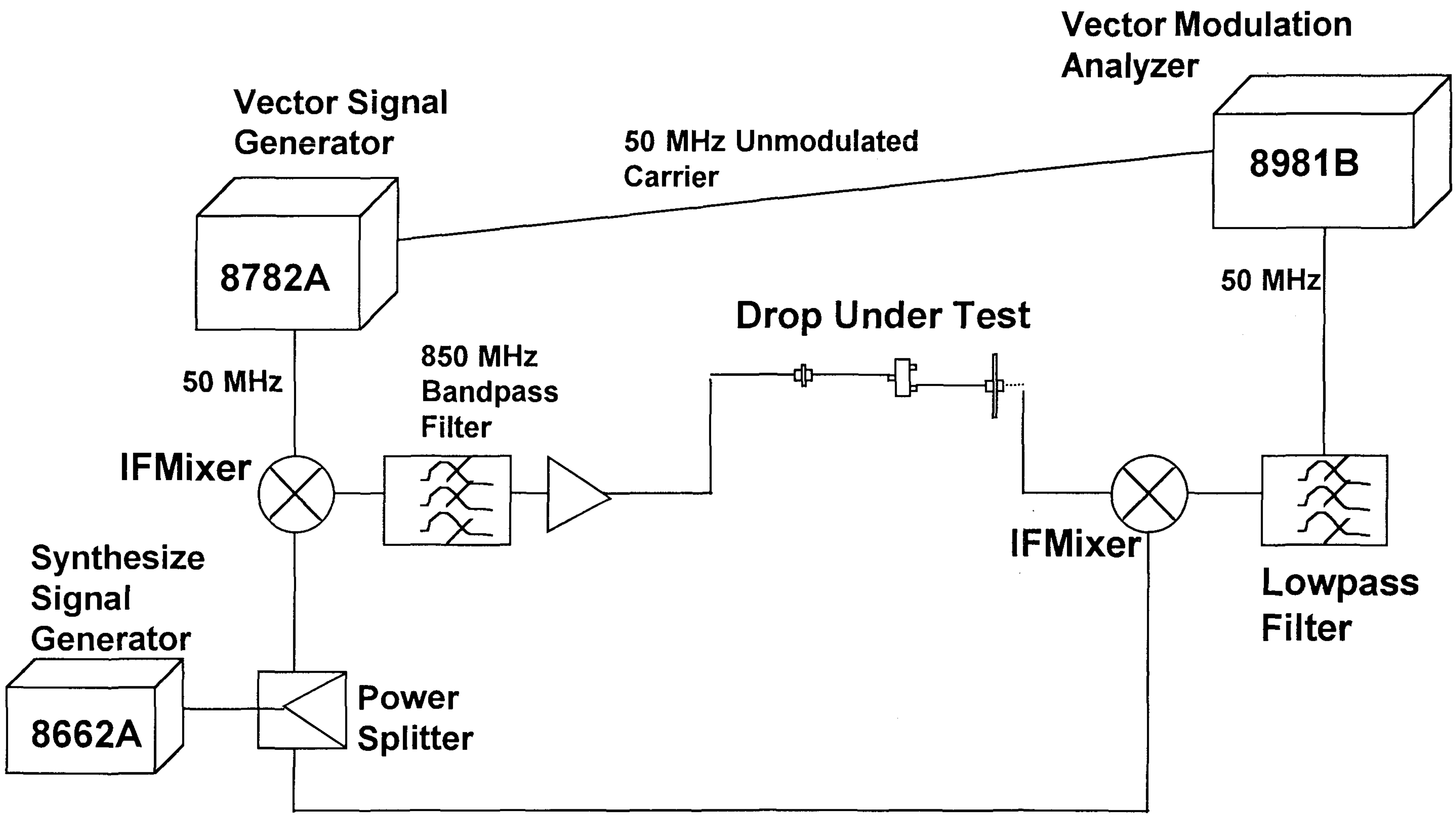
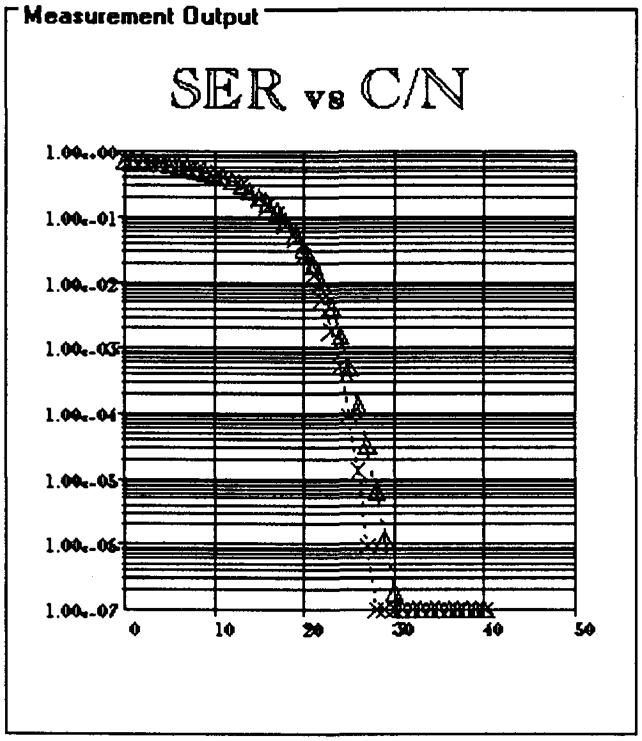
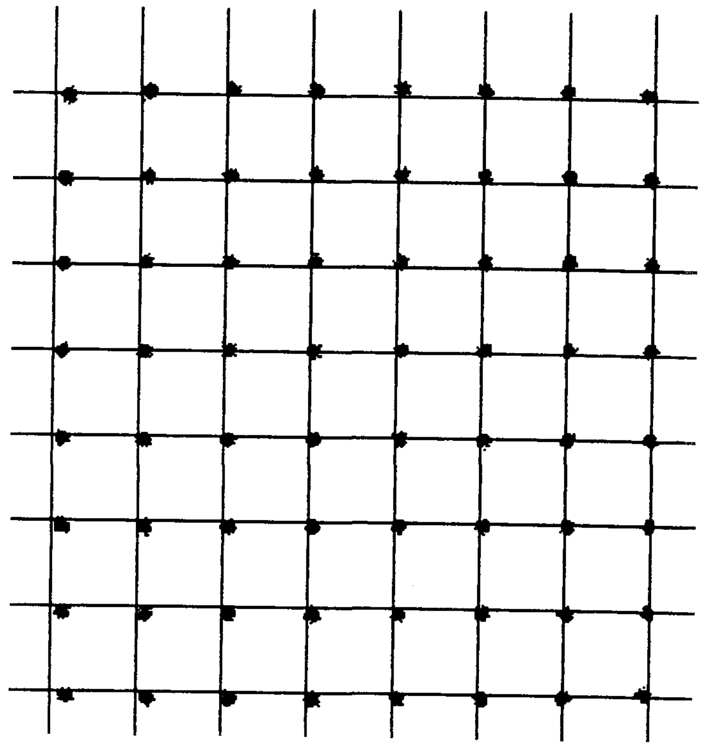


Figure 22 - Best Case Drop





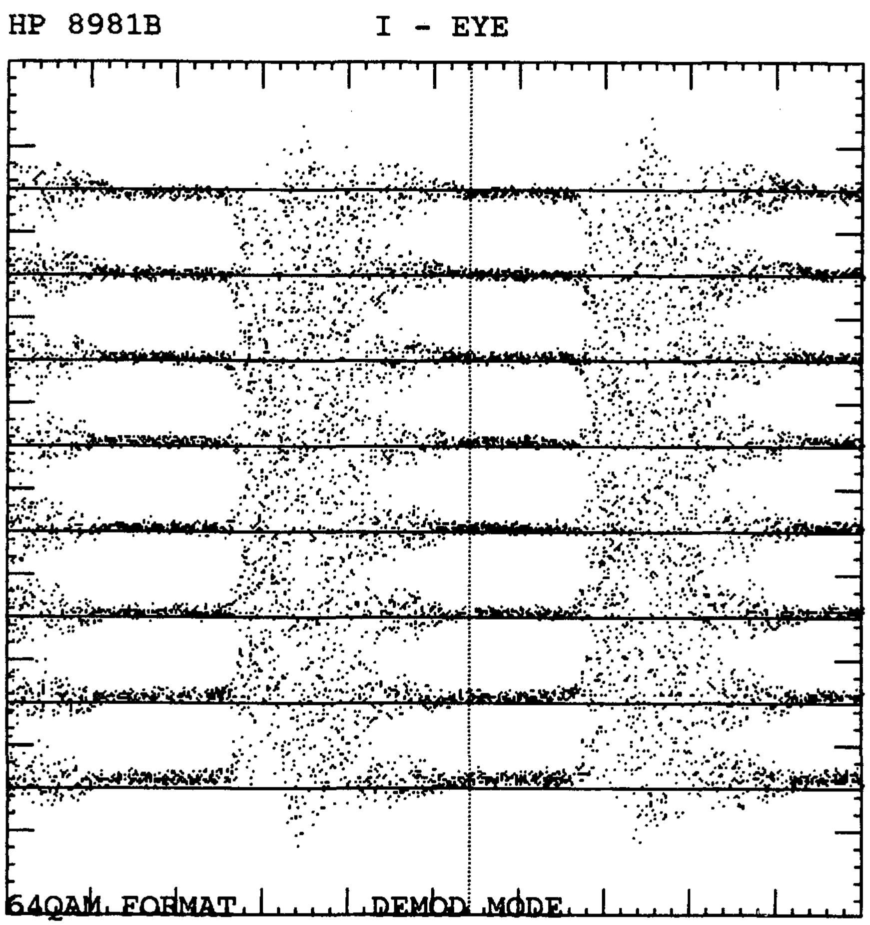
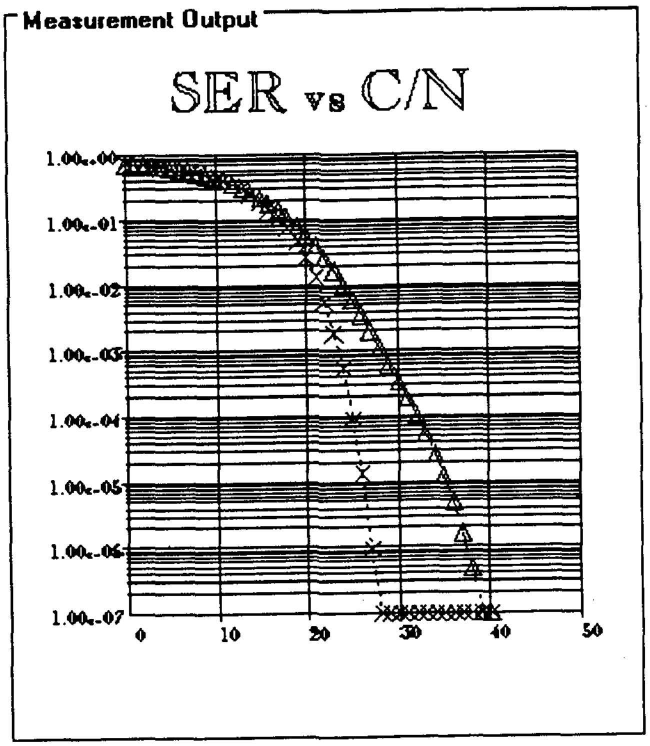


Figure 23
Constellation

Figure 24
Eye Diagram

Figure 25 - Worst Case Drop



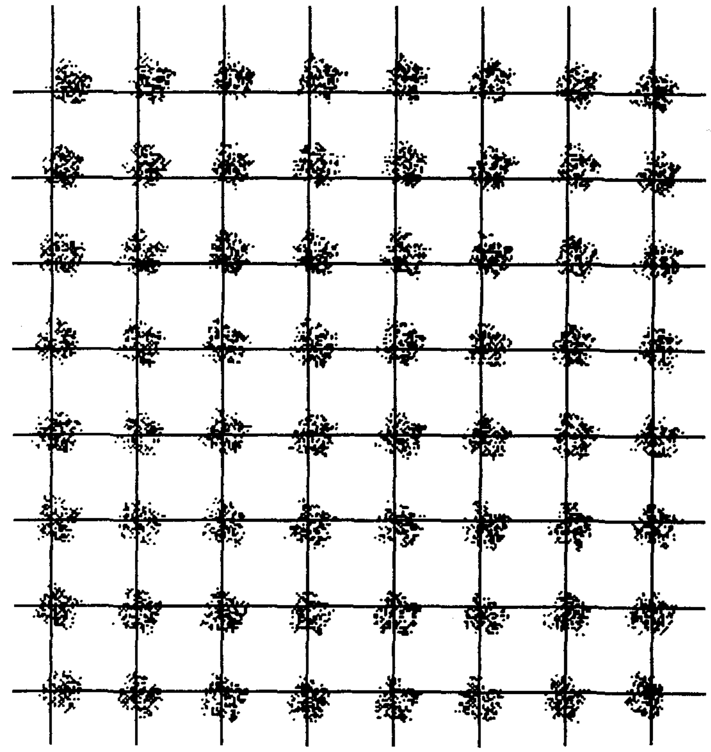


Figure 26
Constellation

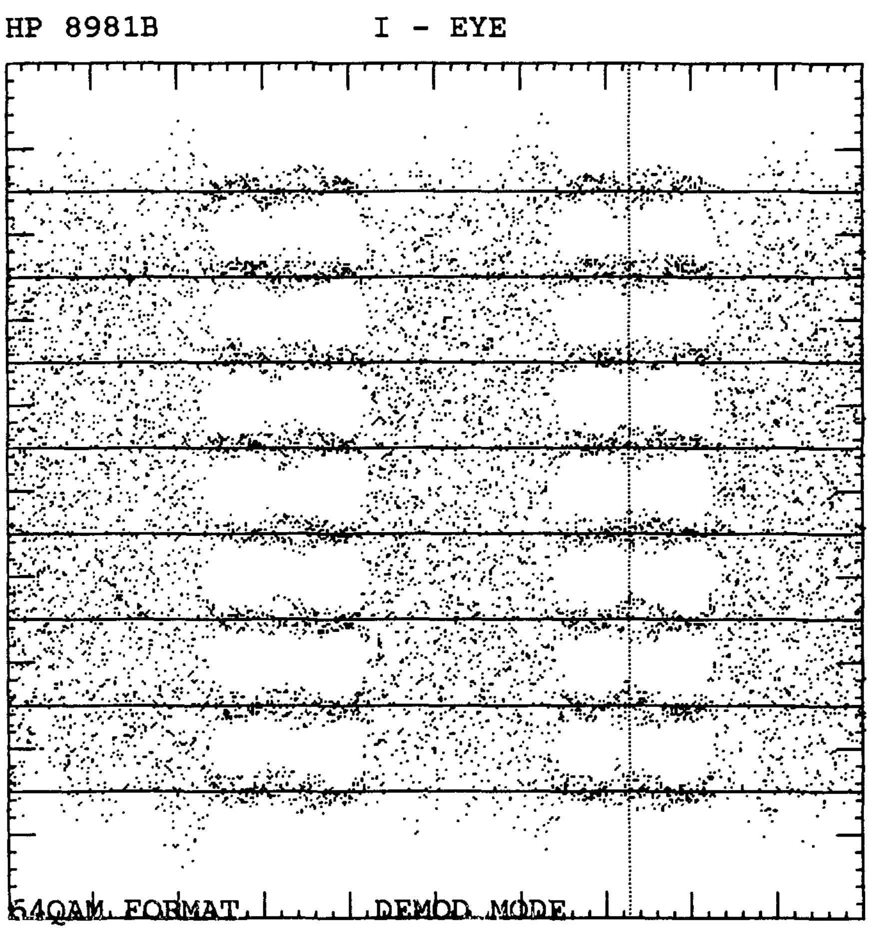


Figure 27
Eye Diagram

Figure 28

Worst Case
Attenuated Between Splitters
Note wider eye opening from attenuated reflections