ORIGINAL

EX PARTE OR LATE FILED

FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

November 29, 2001

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
445 12th Street, S.W. TW-A325
Washington, D.C. 20554

RE: **CC Docket No. 98-147, Ex Parte Presentation**
CC Docket No. 96-98, Ex Parte Presentation
CC Docket No. 99-216, Ex Parte Presentation

Dear Ms. Salas:

On Tuesday November 27, and Wednesday November 28, 2001, Paul L. Marrangoni, of the Federal Communications Commission's Office of Engineering and Technology, attended a meeting of Focus Group 3 (FG 3) of the fifth Network Reliability and Interoperability Council (NRIC V) held at the Federal Communications Commission in Washington, D.C. The members of FG 3 in attendance were: Pete Youngberg (Sprint), John Unruh (Lucent), Philip Kyees (Paradyne), Massimo Saorbara (Globespan), Gary Tennyson (Bell South), Greg Sherrill (Verizon), Robert Beard (AT&T), Paul Donaldson (MCI Worldcom), Jamal Boudhauia (Qwest) , Kevin Schneider (Adtran) David Rosensien (COVAD), Thomas Maudox (Texas Instruments) and the Chair of FG 3, Ed Eckert (Catena Networks). Elizabeth Yockus and Arron Goldberger, the FCC's Common Carrier Bureau, and Jeffery Goldthorp of the FCC's Office of Engineering and Technology monitored the meeting.

NRIC V Focus Group 3 completed work on the white paper regarding the deployment of intermediate ADSL transceiver units (TUs) and related spectral compatibility issues regarding central office based DSL. Copy attached.

The group also discussed the parameters and values that should be used to ensure that a loop voice circuit is functioning properly.

There was also a discussion of effective working length (EWL) for copper loops.

In accordance with section 1.1206(b)(2) of the Commission's rules, 47 C.F.R. § 1.1206(b)(2), the original and 5 copies of this letter and attachment are being filed with for inclusion in the public record of the listed proceedings.

Sincerely,

Paul L. Marrangoni

Paul L. Marrangoni
Office of Engineering and Technology
Federal Communications Commission

No. of Copies rec'd 0+8
List A B C D E

Contribution

TITLE: **Updated DRAFT for the White Paper on Intermediate TUs**

SOURCE: **Editor* of Intermediate TUs White Paper**

TOPIC: **Intermediate TUs**

DISTRIBUTION: **Focus Group 3**

ABSTRACT

This contribution contains the final updated draft of the white paper including the editor's final edits without change marks. The contents are those agreed at the conclusion of the November 27-29, 2001 meeting.

---

* CONTACT: Massimo Sorbara; Email: msorbara@globespan.net; Tel: 732-345-7535; Fax: 732-345-7592

[This page left intentionally blank.]

Remote Deployed DSL: Advantages, Challenges, and Solutions

A publication of the Network Reliability and Interoperability Council (NRIC)

November 25, 2001

MSEE20011026

The following members of NRIC-V, Focus Group 3 dedicated their time and talent to the development of this white paper:

Edward Eckert, Catena Networks, Chairman Focus Group 3

Philip Kyees, Paradyne, Chairman FG3 SC1

Massimo Sorbara, GlobeSpan, Chairman FG3 SC2

Brad Beard, AT&T

Jamal Boudhaouia, Qwest

Jim Carlo, Texas Instruments

Paul Donaldson, WorldCom

Gene Edmon, SBC

Thomas Maudoux, Texas Instruments

Harry Mildonian, Lucent Technologies

David Reilly, Rhythms

David Rosenstein, Covad Communications

Kevin Schneider, ADTRAN

Greg Sherrill, Verizon

Patrick Stanley, Elastic Networks

Gary Tennyson, BellSouth

John Unruh, Lucent Technologies

Pete Youngberg, Sprint

The members of FG3 owe special thanks to the following members of the FCC staff for their assistance in the execution of FG3's tasks:

Young Carlson, FCC OET

Aaron Goldberger, FCC CCB

Kent Nilsson, FCC OET

Paul Marrangoni, FCC OET

Jessica Rosenworcel, FCC CCB

63 Elizabeth Yockus, FCC CCB

ABSTRACT

This paper addresses the wireline network spectral integrity challenge created when DSL transceivers are deployed at locations remote from the central office (CO) yet within the potential reach of CO-based DSL transceivers.[1] It discusses background, technologies, architectures and major issues surrounding the evolution of the telecommunications access network as they relate to remotely deployed DSL transceivers and wireline network spectral integrity.

The paper aims to assist the FCC and the industry in managing this very complex and difficult problem by promulgating a consistent understanding of the underlying issues. It offers options for possible solutions for deployment of CO-based systems in the presence of remote DSL transceivers. This paper does not address repeatered systems.

All of the members of NRIC-V Focus Group 3 agreed to the inclusion of all of the material in this paper. There is no consensus, however, on the extent to which any of the benefits, challenges or possible solutions will affect the industry's ability to provide the consumer with more advanced service choices (type and supplier) while maintaining wireline spectral integrity in a competitive, cost-effective, and business-driven manner.

[1] This problem has the potential to take on different forms as DSL transceivers are placed between RTs and the end user (e.g. FTTx, ONU or MTU architectures).

1. Introduction

1.1. Purpose and Scope

The purpose of this paper is to provide the FCC and the telecommunications industry a compendium of the background, technologies, architectures and major issues surrounding access network evolution as it affects, and is affected by, wireline network spectral integrity.

The white paper approach was taken due to lack of consensus in NRIC-V Focus Group 3 on a single solution to the problem created when DSL transceivers are deployed at locations remote from the central office (CO) yet within the potential reach of CO-based DSL transceivers.[2]

It was agreed that the facts surrounding this problem could be included in such a paper, along with many points of view (possibly conflicting) on options for possible solutions to the deployment of remote DSL transceivers. Such an approach would assist the FCC and the industry in managing this very complex and difficult problem by promulgating a consistent understanding of it.

This paper does not address repeatered systems.

1.2. The Big Picture

There is a fundamental conflict between two equally important, but opposing, interests: (1) exploiting the business opportunity of migrating DSL transceivers closer to the customer, and (2) protecting the viability of services provided by DSL transceivers located at the central office.

Deployment of remote DSL transceivers provides a service benefit to consumers and a business opportunity to service providers. When deploying from a remote location, a larger percentage of the residential customer base can be served by reaching customers that cannot be easily served directly from the CO and higher data rates can be provided to customers for richer and more advanced services.

While it is desirable to migrate DSL transceivers closer to the customer, there exists a potential threat to competition by doing so. When proposing possible resolutions to potential spectral compatibility problems, the current investment in CO-based DSL equipment must be considered and weighed against the benefits of the more robust and higher speed service offerings enabled by DSL transceiver migration.

When crosstalk from remotely deployed DSL transceivers is encountered, CO-based DSL transceivers may exhibit significantly reduced performance or be rendered completely inoperable. This crosstalk may be seen when customers, whose loops are in the same distribution cable, are served both from CO-based and remotely deployed DSL transceivers. The rate of occurrence of this condition is not yet fully known. Data from one region suggest that the rate of occurrence will be low; however, some are concerned that the rate of occurrence could be significant since the particular architecture used and the deployment plans going forward will have an impact on the rate of occurrence.

The foundations of wireline network spectral integrity are based on the premise that complete spectrum management guidelines, when properly implemented, will reduce the occurrence of service degradations to levels where such events can be remedied in a timely manner without requiring the dedication of excessive resources to remedy the problems. As of the date of this paper standards for spectral integrity

---

[2] This problem has the potential to take on different forms as DSL transceivers are placed between RTs and the end user (e.g. FTTx, ONU or MTU architectures).

[1] assume network-side transceivers collocated in the central office; they do not include any additional requirements associated with remote transceivers deployed to the same customer distribution area. Currently, an issue 2 of the spectrum management standard is being developed that will address remote deployment of network-side transceivers.

In summary, there is consumer value in CO-based DSL transceiver deployment as well as in migrating DSL transceivers closer to the customer. In order for both to succeed, a framework must be established to provide the consumer with more advanced service choices (type and supplier) while maintaining wireline spectral integrity in a competitive, cost-effective, business-driven manner.

2. Access Architecture and Remote DSL Transceivers

Historically, the predominant access architecture involved the use of paired metallic cables. Starting in the 1970's, loop carrier systems began to be deployed. These systems multiplex many customer services onto a small number of transport lines. In the 1980's these carrier systems started employing digital technology, and are denoted Digital Loop Carrier (DLC) systems. Please see Annex A for more details on both DLC and metallic cable design practices and Annex B for loop architecture models.

In some cases, all of the circuits in an area are 'cut-over' to the DLC. There is no metallic path, of whatever length, available to directly connect a potential user to the CO. In other instances, the DLC transport parallels existing copper feeder cable. In these cases, a Feeder Distribution Interface (FDI, sometimes referred to as a Serving Area Interface (SAI)) provides for connection to either the copper feeder cable or the feeder circuits provided via DLC. This arrangement allows the service provider to provide service to the customer via the copper plant or via the DLC remote terminal. Figure 1 portrays this arrangement. Note that the FDI and the DLC remote terminal are often co-located.

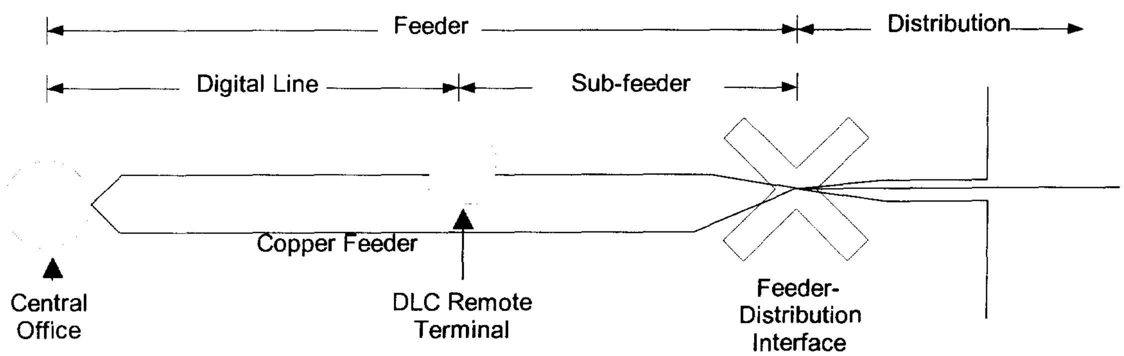

Figure 1: Dual Loop Architecture Reference Diagram

The above architecture — involving both DLC and copper feeding the same FDI — permits DSL to be deployed from the RT (remote DSL) or, if the copper feeder is short enough, from the central office. Due to the difference in signal level between the two DSL transceivers, spectral compatibility issues may arise when remote DSL is used to serve areas that can also be served via the copper feeder. This problem is accentuated on longer loops when remote DSL transceivers are placed closer to the customer. This can be the case when a remote DSL transceiver is placed in a Multi-Tenant Unit or in a curbside pedestal.

This Spectral Compatibility Issue will be defined further in Section 5.

3. Benefits of Deploying Remote DSL Transceivers

3.1. Loop Limitations

It is well understood that many customers cannot obtain Digital Subscriber Line (DSL) service. Assuming that a DSL service provider is offering service from the Central Office (CO) from which the potential DSL customer would be served, the reason that DSL is not available is in fact due to local loop limitations. These limitations include the following:

- DLC deployments that preclude direct metallic access to the CO.
- The use of load coils, i.e., inductors spliced in series at periodic intervals on the loop in order to maintain acceptable voice-grade quality.
- The loop over which the potential customer is served, although not loaded, is judged by the potential service provider to be so long that there is a significant likelihood that the DSL circuit will not operate successfully.

Each of these is explored in more detail below.

3.1.1. Digital Loop Carrier

DLC technology is often used to provide feeder facilities to an area. In some cases, all of the circuits in an area are 'cut-over' to the DLC. There is no direct metallic path available to connect the potential DSL customer to the CO. In this case, a remote DSL transceiver is the only means of providing the service.

In other cases, DLC technology is used to supplement the existing metallic feeder pairs. In these cases, some or all of the existing metallic feeder pairs are left available, but 'growth' is served via the DLC-provided feeder. In many of these cases, the area served is so far from the CO that DSL cannot be supported on the metallic paired cable. Again, in such a case, deployment of a remote DSL transceiver is the only means of providing the service.

3.1.2. Loading

Annex A provides a definition of loading. Most DSL systems cannot operate over loaded loops. Note that loading coils generally exist only in the feeder portion of the loop. Where loops are short enough such that loading is not required to ensure adequate voice grade performance, the load coils may be removed to enable DSL service. Otherwise, a remote DSL transceiver connected to the FDI (hence, beyond the last loading coil) is generally the only means of providing the service.

3.1.3. Long, Non-Loaded Loops

Successful DSL transmission, like any digital transmission scheme, requires that the DSL 'receiver' enjoy some minimum Signal-to-Noise Ratio (SNR). This metric consists of two components, i.e., the received signal level, and the noise level. As the loop gets longer, the received signal level drops. The received noise is assumed to be due to crosstalk from systems on other cable pairs. The pair-to-pair coupling provided by the crosstalk, though, is non-deterministic, i.e., some pair-combinations provide for greater coupling than do other combinations.

Given that the noise coupled via crosstalk is an unknown, it can be seen that, as a loop gets longer, the probability that a specific DSL system will enjoy some minimum SNR (and thus be capable of providing an acceptable grade of service) diminishes. This factor, coupled with the variables in the wiring in a customer's premises and the desire to maximize the ratio of successful installations, has resulted in a decision by some service providers to 'disqualify' longer non-loaded loops.

Again, in such a case, deployment of a remote DSL transceiver is generally the only means of providing the service.[3]

3.2. Greater Data Rates

In addition to providing DSL service to those customers that could otherwise not obtain service, remote DSL platforms provide a means to evolve broadband capabilities. Although DSL service might be available, for instance, to a customer on a loop consisting of 14 kft of 26 AWG (American Wire Gauge) cable, the resultant data rate may not prove to be satisfactory as the broadband access market matures. While a customer might initially be satisfied with something less than 1 million bits per second (Mbps), that data rate might not be satisfactory in a few years.

Because remote DSL transceivers are located at a point much closer to the customer (than from the CO) the DSL service from the remote platform can be arranged to operate at a significantly greater data rate, relative to that data rate that could be achieved from the CO. The data rate could be achieved through exploiting the entire capacity of the mature Asymmetric Digital Subscriber Line (ADSL) technology, or through the use of an evolving technology, such as Very-high-bit-rate Digital Subscriber Line (VDSL).

3.3. Summary of Remote DSL Advantages

In summary, remote DSL platforms provide the following two benefits:

- DSL service to those customers who could not otherwise obtain the service, and
- Higher data rates, relative to the data rate that could have been obtained via metallic paired cable from the CO.

4. Challenges of Deploying Remote DSL Transceivers

The environment into which remote DSL transceivers are deployed presents several unique challenges to service providers, including the following:

- Space – Remote cabinets and enclosures have space limitations that are not generally encountered in Central Offices.
- Variety of services – Because remote locations do not have the size and scalability of Central Office locations, the variety of DSL services that can be economically offered by multiple service providers is limited.
- Backhaul of data – In some cases, there is insufficient data capacity between the CO and the RT to adequately serve remote DSL deployments.
- Power – Remote locations are less likely to have excess reserve dc powering and battery backup than Central Office locations.
- Craft access – Unlike Central Office equipment, Remote equipment is generally not in open racks that can be easily accessed.

[3] Some proprietary DSL implementations may provide for greater loop reach in this case than does standards-based ADSL. However, such implementations may not provide the data rate afforded by a remote DSL transceiver, or meet other service provider requirements.

- Environmental requirements – Remote locations often require the use of environmental vaults or temperature hardened equipment that is not needed for Central Office deployments.
- Economics – The smaller number of customers typically served by a remote location (as compared to a CO) presents a challenge to the service provider's business case.
- Competitive access – Collocation space is generally less abundant in remote locations than in CO locations.
- Voice switch access – It may be difficult to wire DSL equipment to voice switches and splitters in a remote environment.
- Competitor's ease of connectivity - Cross-connection access to the incumbent's facilities may not be readily available to competitors in a remote environment.

Another significant challenge to deployment of remote DSL transceivers is maintaining spectral compatibility between the remote DSL and CO-based DSL. This spectral compatibility challenge is discussed in detail in Section 5.

5. Wireline Network Spectral Integrity Issues

While there are advantages of delivering DSL service via remote platforms, there are some instances where the remote DSL can cause significant interference into DSL being served from the CO. The problem will primarily be seen when remote and central office deployments of ADSL serve customers using the same distribution cable and the total loop length from the CO to the customer premises is short enough (e.g. 15.5 kft EWL, or Equivalent Working Length, according to T1.417-2001[1]) to support the affected DSL (namely ADSL).

For many remote DSL deployments, either because of the distance of the deployment from the CO or because there are no copper facilities between the CO and the customer, this interference is not an issue. In addition, when all of the service providers' DSL transceivers are deployed at the same remote location, the existing spectrum compatibility requirements and assumptions from T1.417-2001 [1] apply.[4] However, there are currently no standards (i.e. Committee T1/T1E1.4) or regulations, which prevent deployments where interference could be a significant problem. Given that remote deployments of DSL are ongoing, it is important that the issues are understood and appropriate action taken. This section provides a technical background of the issues involved.

5.1. Crosstalk and DSL performance

Figure 2 shows a DSL deployment with multiple pairs in a single binder group. Two of the pairs, A and B, run from the CO DSL transceiver to the customer located DSL transceiver while the third pair, C, runs from a remotely deployed DSL transceiver to the customer located DSL transceiver.

[4] This was proposed in T1E1.4/2001-060 [2] and agreed in T1E1.4 as new text for the next issue of T1.417-2001 [1].

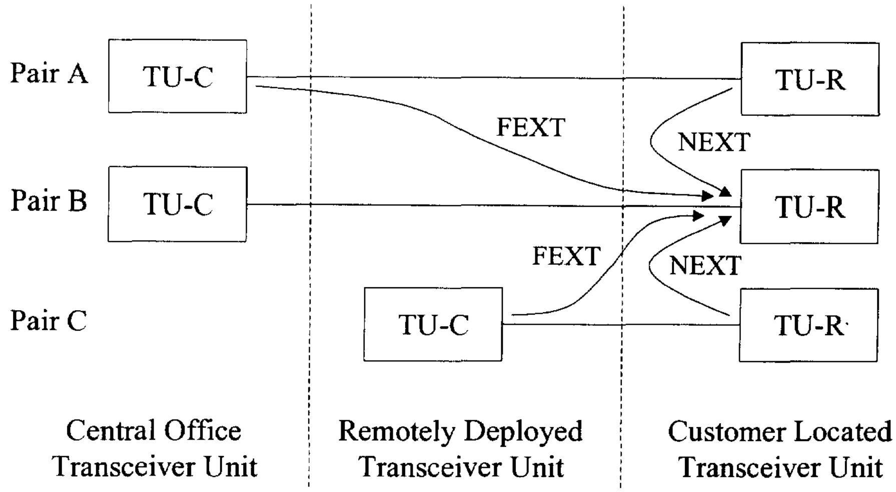

Figure 2: Model of remotely deployed transceiver units in a multi-pair cable.

The quality of the signal at the receiver limits the performance of DSL systems. Both the absolute strength of the signal at the receiver, and the strength of the desired signal relative to the noise seen at the receiver are critical to reception. The cable length and attenuation, along with the transmitter power, largely determine the strength of the signal at the receiver. When multiple DSLs coexist in the same binder group, crosstalk between pairs in the binder is a major source of noise, and a major limiter of performance.

Crosstalk caused when the signal transmitted from the (CO and/or remotely deployed) TU-C of one pair appears at the far end of another pair is called Far End crosstalk (FEXT). In Figure 2, the crosstalk caused by the TU-C transmitters of pair A and pair C create noise which limits the ability of the customer located TU-R receiver at the end of pair B to detect the signal intended for it.

Similarly, crosstalk caused when the signal transmitted from the (customer located) TU-R of one pair appears at the near end of another pair is called Near End crosstalk (NEXT). In Figure 2, the crosstalk caused by the TU-R transmitters of pair A and pair C create noise which limits the ability of the customer located TU-R receiver at the end of pair B to detect the signal intended for it. NEXT can also occur between TU-C's, for example between the TU-C's of pairs A and B in Figure 2.

DSL systems can be classified as frequency division duplex (FDD), echo cancelled (EC), and hybrid. FDD DSL systems use different frequency bands for upstream (TU-R to TU-C) and downstream (TU-C to TU-R) traffic. Echo cancelled systems use the same upstream and downstream frequency bands and have echo cancellers to eliminate interference from the echo generated at the far end of the pair. Hybrid systems have partially overlapping frequency bands in the upstream and downstream directions. Frequency division duplex system performance is typically limited by FEXT, while echo cancelled system performance is typically limited by NEXT.

5.2. Effect of DSL Transceiver Location

The effect of NEXT and FEXT on ultimate performance depends on the construction of the cable, the relative location of the DSL transceivers, and on the type of DSL. Cable design can change both the attenuation and the inter-pair coupling. As coupling between pairs increases, so does the crosstalk experienced at the receiver. In Figure 2, the downstream DSL transmitter for pair C is much closer to the receiver for pair B than the downstream transmitter for pair B. The cable for pair B attenuates the signal from the Central Office located DSL transmitter to the customer located DSL receiver much more than the cable for pair C attenuates the signal from the remotely deployed DSL transmitter to the customer located DSL receiver. Subscriber C may have better performance than subscriber B because of the reduced attenuation and resulting stronger signal. Unfortunately, the crosstalk induced in pair B by the downstream transmitter for pair C has similarly reduced attenuation. More FEXT is detected at the receiver on pair B from pair C than is detected at the receiver on pair B from pair A. In some deployments, the FEXT from pair C detected at the receiver from pair B may be nearly as strong as the desired signal from the transmitter at the far end of pair B. In this case, the customer on pair B experiences service that may have significantly reduced performance or may be rendered completely inoperable.

5.3. The CO-RT crosstalk model

When customers served from remotely deployed DSL transceivers (hereafter simply referred to as RTs) using the same distribution cable as customers served from the Central Office (CO), the crosstalk models[5] are different than when all DSL transceivers are collocated. Compared to the case where all service providers' DSL transceivers are deployed from the same location, the DSL transceivers at the customer sites experience greater far-end crosstalk (FEXT) from the remote DSL transceivers than from the CO-based DSL transceivers. See Annex C for a more complete description of FEXT and near-end crosstalk (NEXT). Increased FEXT may occur when customers whose loops are in the same distribution cable are served both from CO-based and remote DSL deployments.

5.4. Influence of DSL technology specific characteristics

The effect of the RT crosstalk coupling is quite different depending on the spectral properties of the DSL technologies that are involved. The increased FEXT coupling from the RT-based signals can significantly reduce the level of performance (either in data rate capacity or bit error ratio) in the downstream (CO-to-customer) direction for systems that are designed to have their performance limited by the level of FEXT that is present. ADSL and VDSL are deployed as self-FEXT limited systems because they use different transmit frequencies in each direction, a technique known as frequency division duplexing. As a result, CO-based DSL transceivers may exhibit significantly reduced performance or be rendered completely inoperable when significant FEXT coupling from RT-based ADSL systems is present. This reduced performance has been documented in several T1E1.4 contributions, including T1E1.4/2000-302 [7] and T1E1.4/2000-336 [8].

Relatively unaffected by the increased FEXT coupling from remotely deployed DSL transceivers are full-duplex DSL systems that use identical transmit spectra from both the service providers' and customers DSL transceivers; it is self-NEXT that limits the performance of these systems.[6] Because the performance of these systems is limited by self-NEXT, the increased level of FEXT only slightly reduces their performance. The NEXT coupling is still stronger than the increased FEXT coupling for most loop lengths). This has been documented in T1E1.4/2000-240 [11] and T1E1.4/2001-081 [12].

---

[5] A model showing the crosstalk coupling functions of interest is included in Annex L of T1.417-2001[1]. This model assumes that the pairs from the CO and RT share a binder group the entire distance from the RT to the customer. This assumption is a bit pessimistic. As shown in LA#5 of Figure 3 in Annex B (and in Figure 1 of Section 2), the FEXT from the RT-based TU-C is attenuated by the loss of the sub-feeder. The new model, which does include the effects of the sub-feeder, is shown in Annex C.

[6] Examples of such systems include Basic Rate ISDN, IDSL (T1.601 [3]), HDSL (G.991.1 [4]), SDSL, and the versions of SHDSL with symmetric spectra (G.991.2 [5], T1.422 [6]).

Affected to a greater degree than classical self-NEXT limited systems, but still less than ADSL, are the full-duplex DSL systems, which use transmit spectra that are different in each direction but overlapped in frequency.[7] Remote deployment of these systems also affects the performance of CO-based ADSL more than the classical self-NEXT limited systems.

Documentation of the effect that RT-based ADSL has on HDSL2 has been provided in T1E1.4/2001-081 [12].

5.5. Influence of loop plant design (or architecture) on expected rate of incidence

The expected rate of occurrence of CO and RT-based xDSL sharing the same distribution cables is dependent on loop architecture. Since the affected distribution area must be served from both the remote location and the CO, the problem is more likely to be seen where the remote platform has been added to reinforce the loop plant originally served from the CO.

Several T1E1.4 contributions have addressed the issue of how likely this is to occur. In T1E1.4/2001-069 [13] and in contributions to NRIC-V FG3, BellSouth reported that in their loop plant, less than 7% of the loops working through a Feeder-Distribution Interface (FDI) and within 15 kft of the CO are served via DLC. For this particular loop plant, this number represents an upper bound on the percent of loops that have the potential to see this problem. T1E1.4/2001-179 [15] provides a similar analysis, using data from a 1990 survey of 126 wire centers in five regions (T1E1.4/2001-132)[14], finding 12 to 18% of loops eligible for remote DSL deployments are within 15.5 kft, and thus candidates for the crosstalk problem. When presented, several expressed concern that, since the data was 10 years old, quite a small sample, and did not include the impact of recent DSL deployments such as SBC's "Project Pronto", the analysis was not necessarily reflective of the current loop plant. These studies may not necessarily represent the impact of all future loop plant deployment architectures. For example, VDSL (which is very likely to be deployed from a remote location) has not been considered.

6. Possible Solutions to the Spectrum Compatibility Challenge of Remote DSL

In the previous sections, we detailed the problem created when DSL transceivers are deployed at locations remote from the central office (CO) yet within the potential reach of CO-based DSL transceivers. In this section, we discuss possible solutions to this problem.

Within NRIC-V FG3 there was unanimous agreement that where spectral compatibility problems occur due to the presence of remotely deployed DSL transceivers, a resolution to the problem needs to be available. However, there was disagreement on whether these solutions would be employed as a reaction to reported problems (reactive), or whether, as in the guidelines of T1.417-2001 [1], these solutions would be employed in a proactive manner, with the intent to keep spectral compatibility problems to a minimum. In this context, we define the following:

- Proactive means taking steps to assure that agreed-to analytical performance targets, such as those in T1.417, can be met on a CO-based DSL circuit such that the CO-based DSL circuit is unlikely to become impaired by crosstalk originating from the remote DSL transceiver.
- Reactive means taking steps to mitigate the effects of crosstalk from the remote DSL platform, after these effects have resulted in degradation below the agreed-to performance targets of the CO-based DSL circuit.

---

[7] Examples of such systems include HDSL2 (T1.418 [9]), HDSL4 (T1.418 issue 2 [10]) and the versions of SHDSL with asymmetric spectra (G.991.2 [5], T1.422 [6]).

Note that both proactive and reactive approaches could be applied on an "as needed" basis.

There was also no consensus on which party should be responsible for implementing solutions in either case.

Because of the wide variety of loop architectures and their impact on the spectrum compatibility problem, NRIC-V FG3 was unable to reach consensus on a one-size-fits-all solution. This section outlines pros and cons of the potential technical solutions that were discussed within the group.

Note that the solutions described below should not be considered an exhaustive list; other solutions may be possible.

6.1. Technical Solutions using PSD-Based Approaches

The spectrum compatibility problem we have been discussing is caused by the presence of greater FEXT from the remotely deployed DSL transceiver than the FEXT-limited CO-based DSL transceiver was expecting. Because the characteristics of the cable cannot be changed, a solution to this problem involves adjusting the power and/or power spectral density of the DSL transceivers in such a way so that the power of the signals at the RT are all approximately the same. This can be done with one of two basic approaches (also referred to as categories):

(a) Set the power of all signals at the RT (or equivalent points in the feeder) at standard transmit-levels. This can involve amplifying CO-based signals and/or moving the appearance of all ADSL[8] transceivers to the RT via RT collocation or derived logical circuits. This approach is applicable in either a reactive or proactive manner.

(b) Lower or Alter the PSD of RT based systems so that they do not adversely affect CO-based ADSL systems. While this approach may be used in both reactive and proactive approaches, the reactive approach is most likely.

6.1.1. Discussion on category (a)

Solutions that fall into category (a) either involve competitive access at the RT site or some sort of amplification of the CO-based ADSL signals at or near the RT so that the signal is of the same strength as the RT-based ADSL. Possible solutions to competitive access at RT sites include the following:

- Traditional physical collocation (namely using the loop providers enclosure)
- Separate cabinets or enclosures
- The concept of "Open backplane" or line card collocation
- Unbundled virtual circuit

In general, amplifiers introduce additional spectrum management concerns. However, for the particular case of resolving spectrum management issues at the RT, amplifiers may be attractive. Amplifiers provide the RT-deploying service provider a way to "fix" any affected CO-based ADSL circuits, without getting involved in the actual modem signal processing, and the associated interoperability difficulties. There is a concern that such a solution is not scaleable. Difficulties related to this solution include finding a suitable location for the amplifiers and providing power to this location, which in many cases is

[8] ADSL is commonly referred to in this context, since it is a well-known and understood FEXT-limited DSL transceiver technology. Other FEXT-limited DSL transceiver technologies, including, but not limited to, VDSL, would be treated in a manner similar to ADSL.

not located at the RT-site, but rather at an equivalent spot on the CO-FDI feeder route. (See Annex B, Figure 3, loop architecture LA#5).

The solutions in this category provide an opportunity for RT-deploying service providers to accommodate the affected CO-based circuits of other service providers, without affecting the performance of their own deployments. Much of the discussion concerning these solutions revolved around who would pay for the solution and whether it would have to be provided for only existing affected ADSL circuits, or future CO-deployments as well (i.e. circuits that might be turned up in the future using equipment already deployed, or even new deployments of equipment in the COs). This last item was a subject of much disagreement and was the downfall of a proposed agreement.

There was also discussion concerning a different idea that has been adopted by the Australian network. The idea here is that spectral compatibility for all DSL deployments would be determined from a defined "deployment reference point" (DRP). In Australia, the DRP could be at any feasible interconnection point along the loop. It is believed that when a service provider desires to deploy DSL at an intermediate interconnection point (e.g. at a RT site), some form of policy exists which enacts a defined set of procedures to move the DRP to that remote deployment closest to the customer. Once a deployment has been made at an RT site, FEXT-limited systems deployed from "upstream" locations are deployed at their own risk; all attempts at being spectrally compatible with them are ended. Concerns about this approach include:

- How service providers would be notified about the change in DRP,
- Whether service providers would have input into the decision to change the DRP,
- How much time service providers would have to modify their deployments to operate in the new environment,
- How effectively competitors could deploy in progressively smaller service areas as the DRP moves closer to the customer, and
- Additional stranded investment at RT(s) behind the DRP, as well as at the CO.

6.1.2. Discussion on category (b)

Several solutions that fall into category (b) have been investigated and the results presented in T1E1.4. They have involved lowering of the entire power spectral density (PSD) mask (T1E1.4/2000-321 [16]), lowering portions of the PSD mask (T1E1.4/2000-321, 2001-080, -159, -160, -161 [16] through [20]) and limiting the maximum excess noise margin of deployed ADSL systems. (T1E1.4/2001-136, -137 [21] and [22])

All of these methods have been shown to reduce the amount of FEXT from RT-deployed ADSL into CO-deployed ADSL circuits. However, most of the techniques cannot be implemented using the currently deployed RT-based ADSL transceivers. Also, interoperability with the multitude of ADSL CPE modems appears to be problematic. More technical work is required to determine if viable solutions can be developed.

6.2. Alternate Technology Solutions

DSL service from the CO to the customer could also be provided through the use of an alternate DSL technology that is relatively insensitive to the increased crosstalk due to the RT deployment (see 5.5).

This capability could be provided at the CO through the use of interworking devices[9]. Solutions of this type could be applied in either a proactive or reactive manner.

Solutions that fall into this category include:

- Those that employ a pair of interworking devices (one at the CO and one at the customer location) to digitally transport both the POTS signals and DSL payload to the customer location where the CO-based interfaces are re-created, and
- Those that employ a dual-mode customer modem (ADSL plus alternative DSL technology) and a single CO-based interworking device (alternate DSL technology), operating in the frequencies above the voice band, to transport the ADSL payload using the alternate DSL technology.

These solutions can be implemented quickly when deployed on a line-by-line basis. However, while these solutions reliably provide broadband service, the data rates provided may not be as high as those offered by CO-based ADSL in the absence of RT deployments. Therefore, these solutions may only be of value on longer CO-based loops, where the alternate DSL technology can accommodate the lower ADSL target rates. There are concerns about costs and operational issues; there are also concerns with who would pay for the solution and whether it would have to be provided only for existing affected ADSL circuits, or future CO-deployments as well.

7. Summary

This paper has provided information on the background, technologies, architectures and major issues surrounding telecommunications access network evolution as it affects, and is affected by, wireline network spectral integrity. It specifically addressed the wireline network spectral integrity challenge created when DSL transceivers are deployed at locations remote from the central office (CO) yet within the potential reach of CO-based DSL transceivers.[10] It also offered options for possible solutions to the deployment of remote DSL transceivers.

Within NRIC-V FG3 there was unanimous agreement that where spectral compatibility problems occur due to the presence of remotely deployed DSL transceivers, a resolution to the problem needs to be available. However, there was disagreement on the following issues:

1) Whether these solutions would be employed
   - ❑ In a reactive manner, which implicitly assumes that the probability of a spectral compatibility problem is low, or
   - ❑ In a proactive manner, where solutions would be employed per the guidelines of T1.417-2001 [1] for CO-based DSL transceivers with the intent to keep spectral compatibility problems to a minimum.
2) Given the impact of the reactive solution on the customer of the CO-based service provider, what probability of a spectral compatibility problem is "low enough" to make the reactive solution broadly acceptable?

---

[9] An interworking device translates between ADSL (possibly along with voice) and an alternative DSL technology.

[10] This problem has the potential to take on different forms as DSL transceivers are placed between RTs and the end user (e.g. FTTx, ONU or MTU architectures).

3) If the reactive approach is taken, would the service provider deploying the remote DSL transceivers (RT) be required to accommodate (i.e. ensure no disruption of service to) only those CO-based DSL transceivers installed at the time of the RT deployment, or would that party be responsible for all CO-based DSL transceivers, including those installed at any time after the RT deployment?

4) Which party would be responsible for the costs involved in providing proactive or reactive measures, either at the time of deployment or at any time after the deployment?

Because of the wide variety of loop architectures and their impact on the spectrum compatibility problem, NRIC-V FG3 was unable to reach consensus on a one-size-fits-all solution.

The paper aims to assist the FCC and the industry in managing this very complex and difficult problem by promulgating a consistent understanding of it.

8. References

[1] T1.417-2001 "Spectrum Management For Loop Transmission Systems: January, 2001"

[2] T1E1.4/2001-060 "T1.417 provides compatibility for RT-Based xDSL systems" – Verizon: Trone Bishop (trone.t.bishop.jr@verizon.com (301) 236-3754)

[3] T1.601 "ISDN Basic Access Interface for Use on Metallic Loops for Application at the Network Side of NT, Layer 1 Specification: July, 1999"

[4] ITU-T Recommendation G.991.1 "High bit rate Digital Subscriber Line (HDSL) Transceivers" October 1998

[5] ITU-T Recommendation G.991.2 "Single-Pair High-Speed Digital Subscriber Line (SHDSL) Transceivers" Approved, publication pending.

[6] T1.422 "Single-Pair High-Speed Digital Subscriber Line (SHDSL) Transceivers: publication pending"

[7] T1E1.4/2000-302 "Performance of CO Deployed ADSL due to Crosstalk from RT Deployed ADSL" - Rhythms, Copper Mountain: David Reilly (dreilly@rhythms.net 303 476-5717), Jack Yang (jyang@coppermountain.com 858-812-8107)

[8] T1E1.4/2000-336 "Impact and Performance of Reduced Power RT-deployed ADSL" – Verizon: Dale Veeneman (dale.veeneman@verizon.com 781 466-2467)

[9] T1.418-2000 "High Bit Rate Digital Subscriber Line - 2nd Generation (HDSL2): April, 2000"

[10] T1.418-200x "High Bit Rate Digital Subscriber Line - 2nd Generation (HDSL2): publication of 2001 revision pending"

[11] T1E1.4/2000-240 "Simulation of ADSL with Crosstalk from Remotely-Deployed SDSL" – Verizon: Dale Veeneman (dveeneman@gte.com 781 466-2467)

[12] T1E1.4/2001-081 "Spectral Compatibility of RT-Based ADSL with Everything Except ADSL" – Telcordia: Kenneth Kerpez (kkerpez@telcordia.com (973) 829-4747)

[13] T1E1.4/2001-069 "Data Relating to the Spectral Compatibility of Remote ADSL with CO-fed ADSL" – BellSouth: Gary Tennyson (gary.j.tennyson@bridge.bst.bls.com (205) 985 6087)

[14] T1E1.4/2001-132 "Statistical Variables for Evaluating Compatibility of Remote Deployments" - Telcordia Technologies: Kenneth Kerpez (kkerpez@telcordia.com (973) 829-4747), Craig Valenti (cvalenti@telcordia.com (973) 829-4203)

[15] T1E1.4/2001-179 "The Probability of RT-based ADSL Disturbing CO-based ADSL" - Telcordia Technologies: Kenneth Kerpez (kkerpez@telcordia.com (973) 829-4747)

[16] T1E1.4/2000-321 "Spectrally Compatible RT-Based ADSL" - Telcordia Technologies, pursuant to work supported by BellSouth and SBC; Kenneth Kerpez (kkerpez@telcordia.com 973 829-4747)

[17] T1E1.4/2001-080 "More Work on Spectrally Compatible RT-based ADSL" - Telcordia Technologies: Kenneth Kerpez (kkerpez@telcordia.com (973) 829-4747)

[18] T1E1.4/2001-159 "Spectrally Compatible RT-based ADSL using Tone Masking and Flat Power Backoff" – Alcatel: Lane Moss (John.L.Moss@usa.alcatel.com (919) 850-1251)

[19] T1E1.4/2001-160 "RT-fed ADSL: Examining mix crosstalk" – Alcatel: Lane Moss (John.L.Moss@usa.alcatel.com (919) 850-1251)

[20] T1E1.4/2001-161 "Limitations on ADSL Notching and Power Backoff in G.992.1 and G.994.1" – Alcatel: Lane Moss (John.L.Moss@usa.alcatel.com (919) 850-1251)

[21] T1E1.4/2001-136 "Performance related to reduction in NMR" – SBC: Clifford Yackle (cyackle@tri.sbc.com (512) 372-5654)

[22] T1E1.4/2001-137 "Reduction in NMR" – SBC: Clifford Yackle (cyackle@tri.sbc.com (512) 372-5654)

NOTE:

- Published and pre-published T1 Standards may be obtained at: http://www.t1.org/html/standard.htm
- Contributions to Working Group T1E1.4 are public documents however the readers attention is called to the "NOTICE" at the bottom of each contribution. These documents may be obtained at: http://www.t1.org/filemgr/filesearch.taf
- Published versions of ITU-T Recommendations may be obtained at: http://www.itu.org

Annexes

A. Evolution of the Loop Architecture

A.1. Overview

The access network consists of the outside plant cable infrastructure and the drop that connects the cable to the premises wiring. Historically, outside plant cabling has been designed to support the transmission of voice grade signals with a useful bandwidth of between 3 and 4 kHz. The transmission path historically consisted of metallic paired cable. In the past decade, use of optical fiber has become a significant means of providing for new growth and for new services.

Metallic cable consists of pairs of solid copper conductors that are twisted together into units called pairs. During manufacturing, several pairs, usually in 25 pair complements (also called binders), are twisted together as separate bundles and the bundles are twisted together and wrapped in a polyethylene and aluminum jacket. When signals are transmitted across a pair, an electromagnetic field is created around the pair that is induced into other pairs in the same cable. As a result, a portion of the signal appears on neighboring pairs. This effect is called crosstalk. The greatest effect of crosstalk is within the same bundle. The twisting of the pairs and bundles tends to minimize coupling. However, the cable design was intended to minimize crosstalk around voice frequencies. DSL technologies use frequencies above the voice band. As the signals in copper cables increase in frequencies, crosstalk between pairs also increases. Simulation models that characterize this phenomenon are used to evaluate the effect of crosstalk on other services.

Optical fiber cable is also increasingly being used in place of metallic cable. Fiber is used because of its generally lower cost per line, greatly increased bandwidth capability, and lower maintenance costs than traditional copper plant. DSL applications generally permit much higher data rates when provided over facilities that include fiber.

The design of telephone cables between the local wire exchange and the customer is referred to as Outside Plant Design. Over the years, several sets of design rules for metallic cable have evolved. Many of the rules were developed before divestiture of AT&T in 1983, so there is a fair degree of consistency in their application throughout the country. Some variations will be noted in this document. This description is not exhaustive but is intended to cover the most common designs that are still in use today. It also describes some of the ramifications of using DSL bandwidths over voice-grade cable.

A.2. Resistance Design

The conductors in metallic cable vary in thickness, or gauge. They typically range from 26 and 24 AWG (American Wire Gauge) for shorter cables to 22 and occasionally 19 AWG for the longest cables. Use of the minimum gauge necessary, to control the voice band loss to an acceptable level, results in the most economic design. Use of finer gauges for customers close to the central office is economical, allowing lower cost per loop and allowing higher densities of customers served in the same cable and over the same infrastructure of underground conduit, public and private easements, and pole lines. A simple way to implement this efficiency was through the use of Resistance Design rules. These rules allow a maximum of 1300 Ohms loop resistance[11]. For 26 AWG, this equates to about 15 kft, assuming a cable temperature of 90 degrees F. For longer loops, combinations of gauges are used that keep the total resistance within the 1300-Ohm limit. For non-loaded loops, the embedded base generally consists of 26 AWG out to about 15 kft and consists of a combination of 26 and 24 AWG from 15 kft out to the non-loaded loop limit. Resistance design also includes rules for permitting bridged taps. A bridged tap is any portion of the loop that is not in the direct path between the customer and the central office. For example, if a loop serving a particular home also extends beyond the home to the end of the street, that extension would be called a bridged tap. Bridged taps are commonly not limited to a single loop, but are consistent throughout the binder. An exception is noted for situations where the extension of a single loop beyond a customer terminal is sometimes removed to control bridged tap. In resistance design, any number of bridged-taps is allowed with a maximum combined bridged-tap length of less than 6 kft. According to loop surveys, most bridged taps are relatively short. In general, longer bridged taps have the greatest impact on voice frequency while shorter bridged taps have the greatest impact on ADSL frequencies.

Even with control of cable gauge and bridged-tap length, losses increase with frequency. For this reason, loops over 18 kft require inductors, commonly called load coils[12,13]. To reduce this loss near the telephony voice upper-band edge, inductors can be inserted in series with the loop at periodic intervals to reduce and flatten the voice-band loss. The first coil is placed at 3 kft from the central office and additional coils are placed every 6 kft thereafter. A minimum of 3 kft (12 kft maximum) is required between the last load coil and the customer. While load coils flatten the voice band attenuation response, it is at the expense of increasing attenuation above 3 kHz. This increase in attenuation makes DSL transmission over loaded loops difficult, if not impossible for most technologies. Loading coils are placed on cables in increments of 25 pair binders.

A.3. Outside Plant Infrastructure

Most cable plant designed in the last few decades is divided into feeder and distribution plant. Feeder plant extends from the wire center to a location that permits cross-connects to the distribution plant. Feeder cable is usually pulled through underground conduit in urban locations. Splice locations are accessible to permit splicing unused segments of one cable to other cables that need additional capacity. Bridged taps appear only occasionally on feeder cable. Distribution plant extends from the cross-connect box to the premises. It is not designed to be as flexible for rearrangements as feeder plant. This is because distribution plant is near the customer and must accommodate placement under sidewalks, fences, driveways and foliage. Rearrangements are usually disruptive and expensive. For this reason, distribution cable is sized so customers can order more than one line without need to rearrange the cable. Typically, this flexibility is enabled by use of bridged taps. Since the loop provider does not know how many lines a particular customer premises will require, bridged taps permit the same loops to pass by

---

11 Many service providers use a set of rules called Revised Resistance Design (RRD) to determine loop gauge. While rules have changed over time, the current rules allow a maximum of 1300 ohms loop resistance for nonloaded loops and a maximum of 1500 ohms for loaded loops.

12 In the past loading rules for some services, such as PBX trunks, required the application of two load coils on some loops less than 18 kilofeet in length.

13 Additionally, single load coils are occasionally found on loops that were originally properly loaded, but at sometime in the past were re-arranged to serve an area closer to the CO. Apparently, for whatever reason, some of the load coils were not removed at the time of re-arrangement.

several homes so that additional lines are available to whoever needs them. A Feeder-Distribution Interface (FDI) is used to connect feeder and distribution loops to form a working line between the wire center and the customer. In certain kinds of outside plant construction, the FDI is denoted as a Serving Area Interface (SAI).

A.4. Carrier Serving Area Design

In the early 1980s, Carrier Serving Area (CSA) rules were written for the design of distribution cable. CSA rules were originally written to enable the deployment of certain types of services without having to condition the loops. These services included voice grade specials, Digital Data Service, and switched 56 kb/s services. CSA rules allow a maximum of 9 kft for loops that contain any 26 AWG and allow a maximum of 12 kft for loops that contain only 24 AWG or coarser. A maximum of two bridged taps are allowed. A single bridged tap cannot exceed 2 kft and the combination of both bridged taps cannot exceed 2.5 kft. CSA bridged tap rules were intended to maximize voice-band performance; they do not address those bridged tap lengths that have the most impact on ADSL performance.

With the advent of DSL technologies, these rules were used to define performance objectives in the standardization process. Specifically, High-bit-rate Digital Subscriber Line (HDSL) (and its later versions) was designed to work on CSA loops. Performance objectives were also established for ADSL operating over CSA loops.

A.5. Digital Loop Carrier

In the 1980s, loop providers began provisioning access lines using a technology called Digital Loop Carrier (DLC). DLC was provisioned in place of new copper cables to provide for subscriber line growth. DLC entails the provisioning of channelized T-1 lines from the central office to a remote location near the FDI. A Central Office terminal (COT) is placed at the central office end and a Remote Terminal (RT) is placed near the FDI. The T-1 lines are repeatered every few kft. The length between repeaters varies with cable gauge and whether the upstream and downstream channels are in the same binder, adjacent binders, or non-adjacent binders. They carry time division multiplexed channels that carry voice grade (up to 3.4 kHz bandwidth) traffic. The terminals at each end multiplex and demultiplex traffic.

The DLC system described above is called a Universal DLC system. Later improvements replaced the T-1 lines with optical fiber and integrated the COT into the central office switch. In the 1990s, another improvement called Next generation Digital Loop Carrier (NGDLC) was deployed that uses time slot interchange (TSI) to make more efficient use of the channels during quiet periods. More recently, advances have been made to permit both DSL and voice over the DLC.

A.6. Enclosures

DLC systems typically employ battery backup. Early RT's (and their associated batteries) were typically deployed in pedestals and pole-mounted cabinets. As the demand for larger systems developed, RT's were deployed in huts and Controlled-Environment Vaults (CEV's). As the deployment of fiber moves closer to the customer, e.g., in Fiber To The Curb (FTTC) systems, the number of customers served via one remote site is smaller, thus resulting in smaller enclosures. These enclosures are designed to house the equipment that is planned for a specific forecast period, and thus there is often no space to accommodate unplanned equipment additions.

A.7. Dual Provisioning with DLC and copper

In some instances, DLC transport parallels existing copper feeder cable. At or near the RT, an FDI provides for connection to either the copper feeder cable or the feeder circuits provided via DLC. This arrangement allows the service provider to provide service to the customer via the copper plant or via the DLC remote terminal. This architecture permits DSL services to be served from the RT or, if the copper feeder is short enough, from the central office. Spectral compatibility issues may arise when remote DSL is used to serve areas that can also be served via the copper feeder.

See Figure 1 in Section 2 and LA#5 in Annex B for pictorial representations of this arrangement.

As loop architectures continue to evolve, concerns for wireline spectral integrity will continue.

B. Loop Architectures

This Annex describes the various DSL loop architectures, including remote TUs and repeaters. The loop architectures described include DSLs deployed

- Using direct metallic access from the CO
- With repeaters or amplifiers in the loop
- In or near RT cabinets at intermediate points in the loop plant, and
- At fiber ONUs at intermediate points in the loop plant or near the customer premises.

Figure 3 shows the different possible loop architectures.

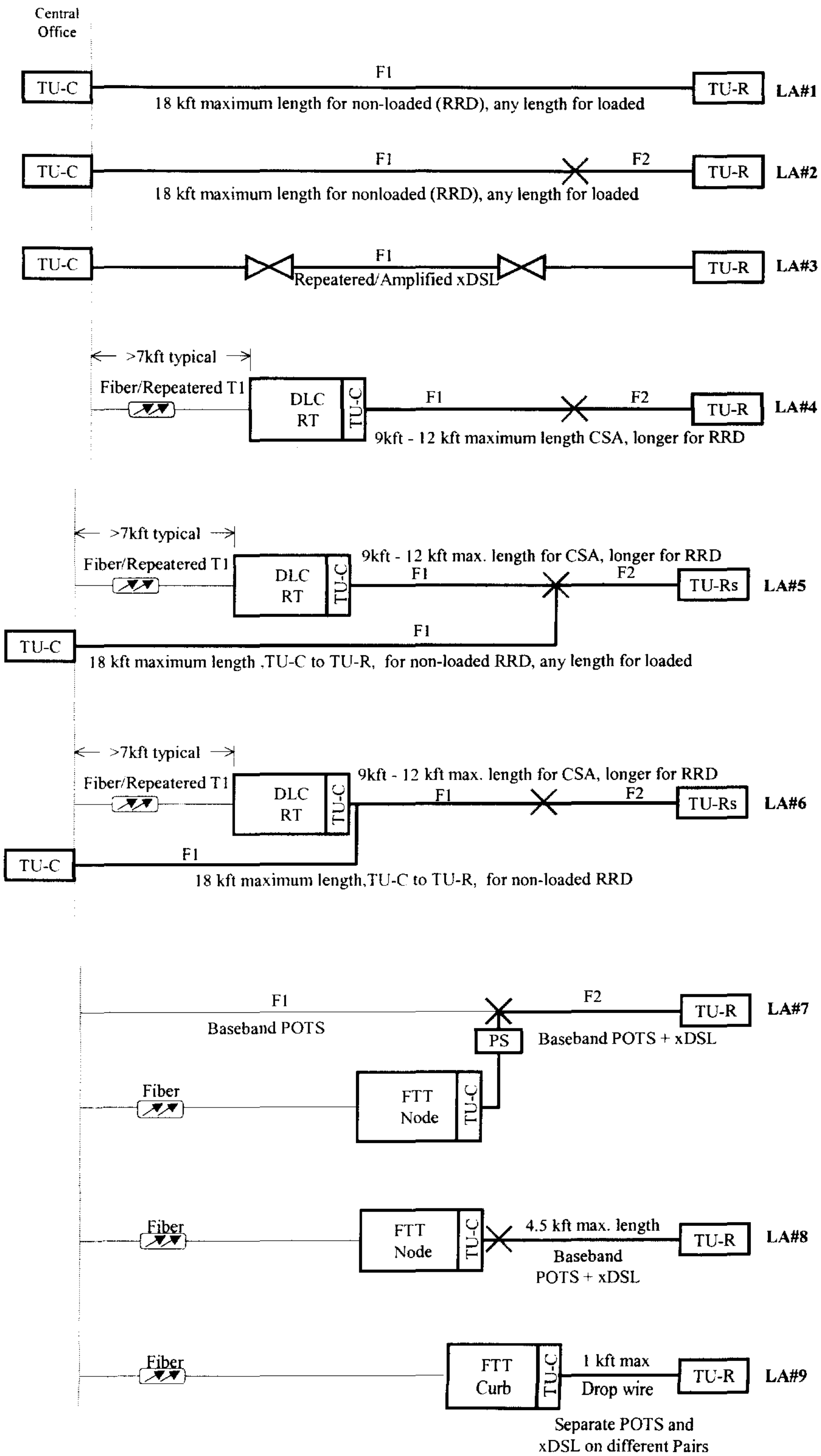

Figure 3: DSL Loop Architectures (LA).

C. Crosstalk Simulation Models

C.1. Crosstalk in the Loop Plant

Crosstalk generally refers to interference that enters a communication channel, such as a twisted wire pair, through some coupling path. The diagram in Figure 4 shows two examples of crosstalk generated in a multi-pair cable. On the left-hand side of the figure, signal source $V_j(t)$ transmits a signal at full power on twisted wire pair j. This signal, when propagating through the loop, generates two types of crosstalk into the other wire pairs in the cable. The crosstalk that appears on the left-hand side, $x_n(t)$ in wire pair i, is called near-end crosstalk (NEXT) because it is at the same end of the cable as the cross-talking signal source. The crosstalk that appears on the right-hand side, $x_f(t)$ in wire pair i, is called far-end crosstalk (FEXT) because the crosstalk appears on the end of the loop opposite to the reference signal source. In the loop plant, NEXT is generally far more damaging than FEXT because NEXT has a higher coupling coefficient and, unlike far-end crosstalk, near-end crosstalk directly disturbs the received signal transmitted from the far-end after it has experienced the propagation loss from traversing the distance from the far-end down the disturbed wire pair.

In a multi-pair cable, relative to the wire-pair the desired receive signal, all of the other wire pairs are sources of crosstalk. For DSL systems, the reference cable size for evaluating performance in the presence of crosstalk is a 50 pair cable [2]. So by reviewing the example shown in Figure 4, we see that relative to the received signal on wire pair i, the other 49 wire pairs are sources of crosstalk (both near-end and far-end).

C.1.1. Near-end Crosstalk Model

As described in references [2,3,5 and 6], for the reference 50 pair cable, the near-end crosstalk *coupling* of signals into other wire pairs within the cable is modeled as

$$\left|H_{NEXT}(f)\right|^2 = \chi_{49} \times \left(\frac{N}{49}\right)^{0.6} \times f^{\frac{3}{2}}$$

where $\chi_{49} = 8.818 \times 10^{-14}$ is the coupling coefficient for 49 NEXT disturbers, N is the number of disturbers in the cable, and f is the frequency in Hz. Note that the maximum number of disturbers in a 50 pair cable is 49. A signal source that outputs a signal with power spectral density $PSD_{Signal}(f)$ will inject a level of NEXT into a near-end receiver that is

$$PSD_{NEXT}(f) = PSD_{Signal}(f) \times \left|H_{NEXT}(f)\right|^2$$

So as illustrated in Figure 4, if there are N signals in the cable with the same power spectral density $PSD_{Signal}(f)$, the PSD of the NEXT at the input to the near-end receiver on wire pair i is $PSD_{NEXT}(f)$.

Note from the above expressions that the crosstalk coupling is very low at the lower frequencies and the coupling increases at 15 dB per decade with increasing frequency. For example, at 80 kHz, the coupling loss is 57 dB for 49 disturbers. The loss (in dB) for 49 disturbers at other frequencies may be computed using the following formula:

$$L_{49} = 57\,\mathrm{dB} - 15 \cdot \log\left(\frac{f}{80\,\mathrm{kHz}}\right),$$

where L_{49} is the near-end crosstalk coupling loss in dB and f is the frequency in kHz.

C.1.2. Far-end Crosstalk Model

Correspondingly, in the same 50 pair cable, the far-end crosstalk coupling of signals into other wire pairs is modeled as

$$|H_{FEXT}(f)|^2 = |H_{channel}(f)|^2 \times \left(\frac{N}{49}\right)^{0.6} \times k \times l \times f^2$$

where $H_{channel}(f)$ is the channel transfer function, $k = 8 \times 10^{-20}$ is the coupling coefficient for 49 FEXT disturbers, N is the number of disturbers, l is the coupling path length in feet, and f is the frequency in Hz.

Note that the coupling is small at low frequencies and large at higher frequencies. The coupling slope increases at 20 dB/decade with increasing frequency.

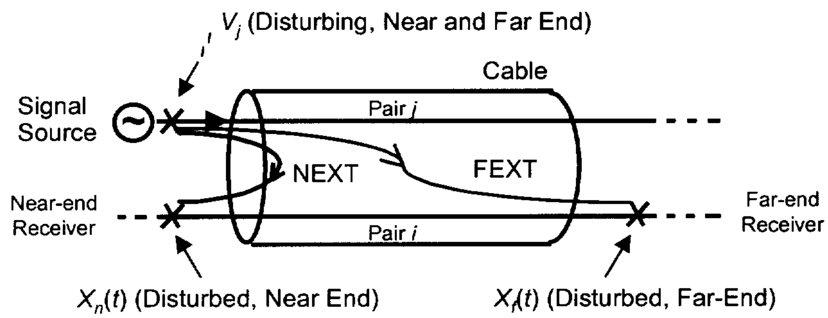

Figure 4: NEXT and FEXT in a multi-pair cable.

C.2. Applications that use Intermediate TU Devices

In some instances it may be desired to evaluate the effect of interference from systems that use intermediate (TU-I) devices between the CO and CI to another system. In these cases, the TU-I is integrated in to the same binder at some intermediate point between the CO and the CI such as may be the case in DLC deployments. In this case, crosstalk from the intermediate TU system will and affect the CO based system. The reverse is generally not of concern because the intermediate TU system benefits from higher signal levels as a result of the shorter path for the signals in the intermediate TU system.

The configuration in Figure 5 shows the sources of the crosstalk that are represented in the simulation model for the basis system downstream receiver.

C.2.1. Interference into the Basis System Downstream Receiver

The model in Figure 6 should be used when performing a computer simulation of the effect of the new technology intermediate TU-I system NEXT and FEXT interference into the basis system downstream receiver.

Assumptions:

- The TU-I will integrate with the CO based binders at an intermediate point between the CO and the CI, such as at the FDI (or SAI).
- The head-end transmitters (TU-Cs) for the two systems are not co-located.
- All customer premises transmitters (TU-Rs) for both systems are co-located.
- The binders are contiguous for the purposes of demonstrating spectral compatibility with the exception of the TU-I integration

The first cable section is adjusted to cover the distance from the CO based TU-C to the intermediate TU-I, (Z-D ft), and the second cable section is adjusted to cover the remaining length (D ft) of the test loop under consideration. The new technology New TU-I FEXT noise is equivalent to the New TU-I output signal passed through the FEXT coupling loss, using a coupling length equal to the second cable section (labeled Z - Y - A + D ft). The resulting FEXT coupling equation for this second cable section is expressed by

$$|H_{FEXT}(f)|^2 = |H_{L1}(f)|^2 \times \left(\frac{N}{49}\right)^{0.6} \times k \times L2 \times f^2$$

where $H_{L1}(f)$ is the transfer function of the cable section from the New TU-I to the New TU-R, N is the number of disturbers, $k = 8 \times 10^{-20}$ is the coupling coefficient for 49 FEXT disturbers, $L2 = D = Z - Y - A$ is the coupling path distance in ft, and f is the frequency in Hz.

C.2.2. Interference into the Basis System Upstream Receiver

The model in Figure 7 should be used when performing a computer simulation of the effect of the intermediate TU-C system new technology NEXT and FEXT interference into the basis system upstream receiver.

Assumptions:

- The intermediate TU-I will integrate with the CO based binders at an intermediate point between the CO and the CI.
- The head-end transmitters (TU-C) for the two systems are not co-located.
- The customer premises transmitters (TU-R) for both systems are co-located.
- The binders are contiguous for the purposes of demonstrating spectral compatibility with the exception of the TU-I integration.

The first cable section is adjusted to cover the distance from the CO based TU-C to the TU-I, and the second cable section is adjusted to cover the remaining length of the test loop under consideration. The new technology NewTU-R FEXT noise is equivalent to a NewTU-R output signal passed through the FEXT coupling loss, using a coupling length equal to the second cable section. The NewTU-R FEXT noise is attenuated by the first cable length. The new technology New TU-C NEXT noise is determined by the New TU-C output signal. The New TU-C NEXT noise is attenuated by the first cable length.

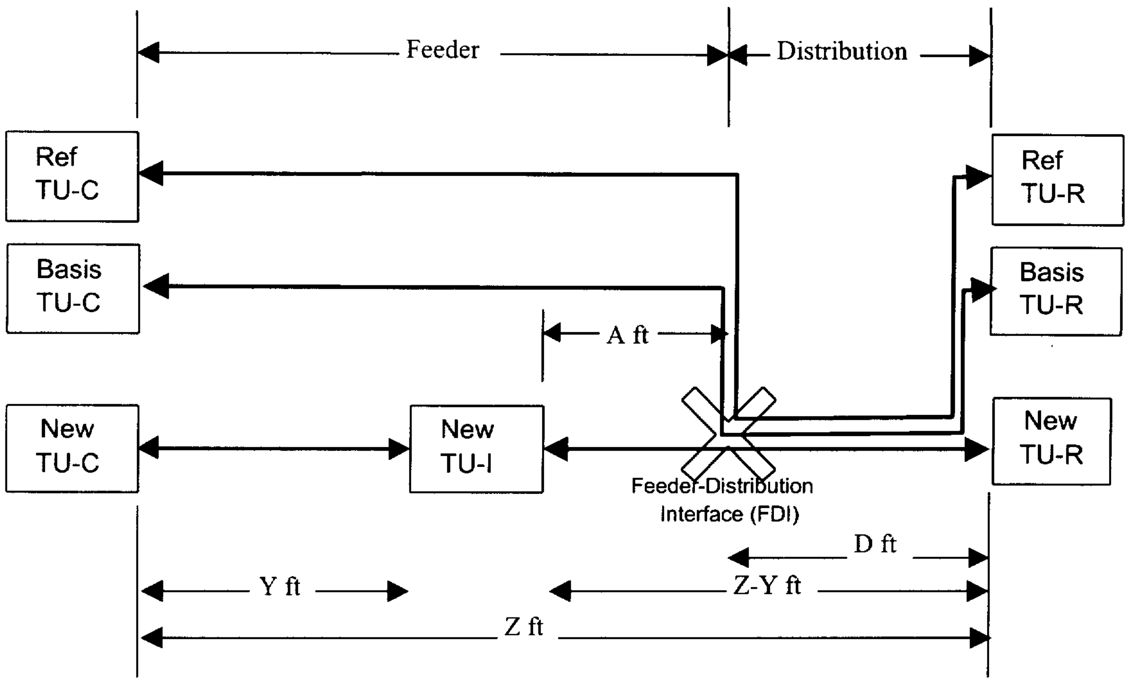

Figure 5: NEXT & FEXT from Remote TU-C into TU-R.

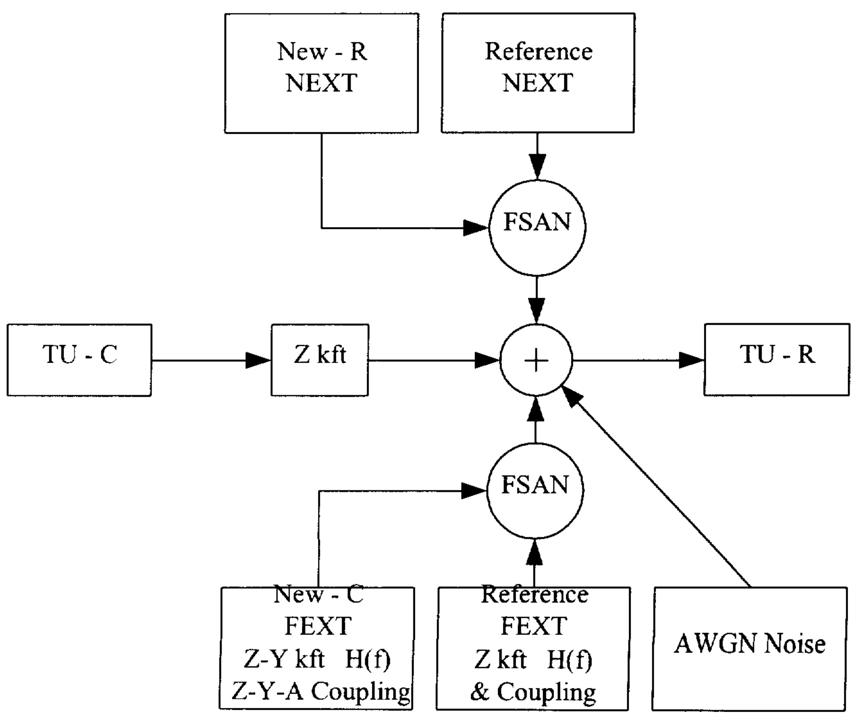

Figure 6: Model for Reference and New Crosstalk into TU-R with Remote TU-C Device.

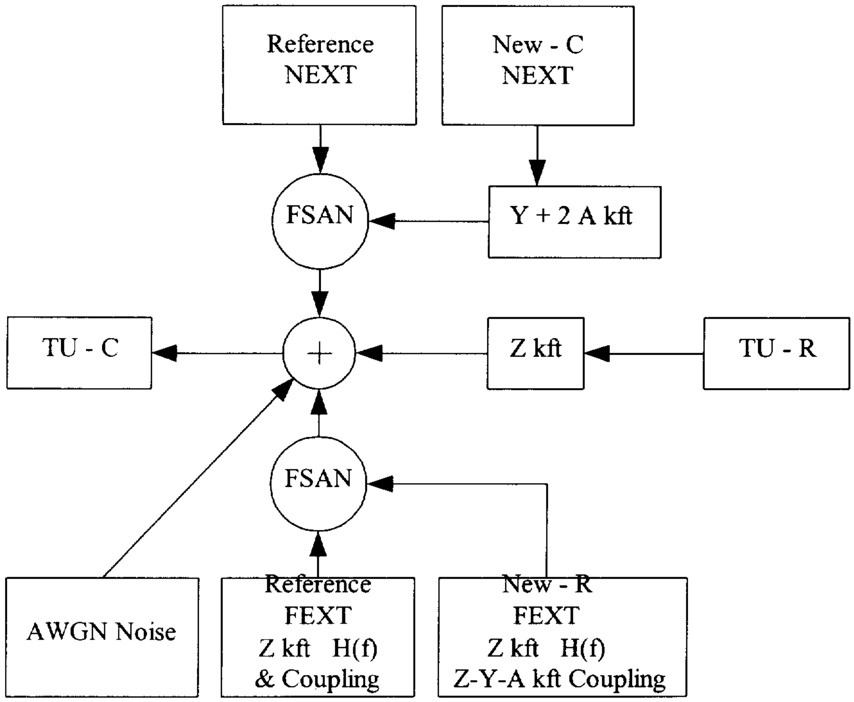

Figure 7: Model for Reference and New Crosstalk into TU-C with Remote TU-C Device.