HDSL Basics

Introduction

Providing T1 service is a competitive race, and High-bit-rate Digital Subscriber Line (HDSL) is quickly emerging as the ideal solution to remain a step ahead. Currently touted as "repeaterless T1", HDSL enables T1 service to travel up to 12,000 ft. on copper cable without regeneration. When used with a single HDSL doubler, service can be extended to 24,000 ft. By eliminating T1 line repeaters and fault locate pairs, HDSL can provide service in as little as 24 hours over two existing POTS lines. This enables established service providers to meet the demands for quicker turn-ups and improved service quality over the installed base of copper cable. The increase in efficiency comes without sacrificing service quality as HDSL features several enhancements that eliminate the common problems associated with standard T1 transmission. HDSL enables established service providers to remain competitive while reducing operational costs.

This ***Technical Note*** provides an overview of HDSL technology, a detailed discussion of how HDSL works, and recommended test procedures that can guarantee consistent performance.

HDSL Overview

The standard HDSL loop architecture, shown in ***Figure 1A***, is a point-to-point circuit that consists of two HDSL transmission units (HTUs). The HTU-C [HTU at the central office (CO)] replaces the T1 office repeater and fits easily into any standard 220 office repeater bay. The HTU-R (remote HTU) can be installed with, or replace, the network interface unit (NIU) at the customer demarcation point. The HTUs are then connected by two non-loaded copper cable pairs. If the local loop exceeds 12,000 ft., a HDSL doubler can be installed, as shown in ***Figure 1B***, on the next page, to extend service up to 24,000 ft.

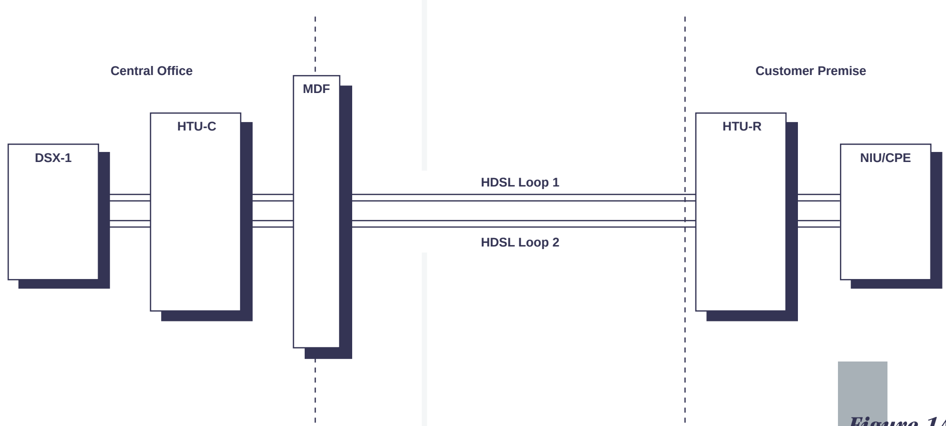

Figure 1A
Point-to-point circuit.

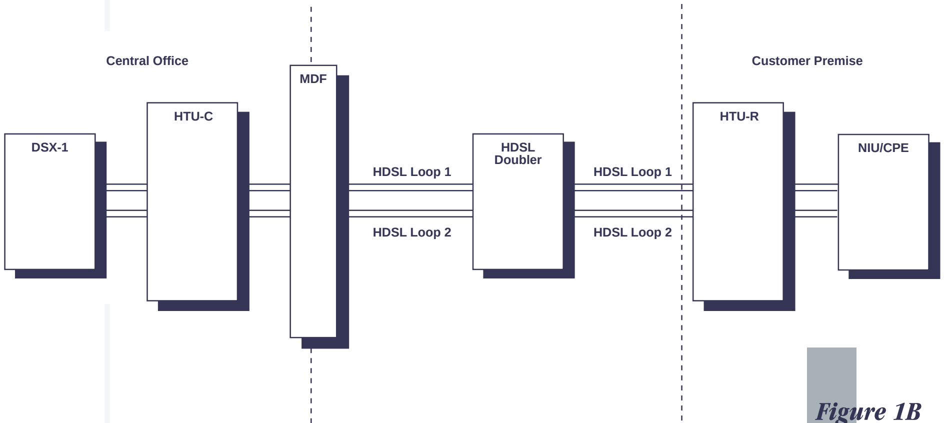

Figure 1B
Extending service with a HDSL doubler.

Under normal operation, the HTU-C receives a standard T1 signal on Side 1 from the DSX-1. The HTU-C derives timing and converts the T1 into two HDSL signals, each representing half the T1 bandwidth. The HDSL signals are then transmitted on Loop 1 and Loop 2. The HTU-R receives the HDSL signals, reconverts them to a single T1 signal, and sends it to the customer on Side 1. The process is then reversed on Side 2, toward the CO. The HTU-R receives a standard T1 on Side 2 from the channel service unit (CSU) at the customer premises. It derives timing and converts the T1 into two HDSL signals, each representing half the T1 bandwidth. The HDSL signals are then transmitted on both loops. The HTU-C receives the signals, reconverts them to a single T1 signal, and sends it to the DSX-1 on Side 2. In order to transmit and receive on the same pair, the HTUs utilize transceivers rather than the separate transmitter and receiver used by standard T1 equipment. ***Figure 2*** depicts this process.

The HDSL Conversion Process

Upon receiving a standard T1 from the DSX-1, the HTU-C completes its conversion to HDSL in four steps: timing recovery, mux/demux, data scrambling, and applying overhead.

Like most other local loop equipment, the HTU-C recovers timing from the network. The HTU-C receives the incoming T1 signal, and the signal is sent through a phase-locked loop circuit. This enables timing to be recovered from the T1 signal itself. This process requires the signal to have a minimum pulse density. ANSI T1.403 defines this requirement with two rules: the incoming signal must contain at least 12.5% ones density, and the signal must contain no more than 15 consecutive zeros.

After the HTU-C has derived timing, it divides the incoming T1 into two HDSL signals, as shown in ***Figure 3***. The T1 is demultiplexed into 24 DS0s and re-multiplexed into two separate HDSL signals. Each HDSL signal contains 12 of the 24 DS0s and represents 768 kb/s of T1 bandwidth. The DS0s are typically regrouped with DS0s 1-12 in one HDSL signal and DS0s 13-24 in the other. Some vendors, however, allow users to prioritize each DS0. This enables the 12 highest-priority DS0s to remain up and running, if one of the two HDSL loops is dropped.

A pseudorandom data scrambling algorithm is applied to both HDSL signals to control ones density. Each signal contains an optimum ones density, regardless of the incoming T1 data. This ensures the HTU-R at the far-end will easily maintain synchronization with the HTU-C.

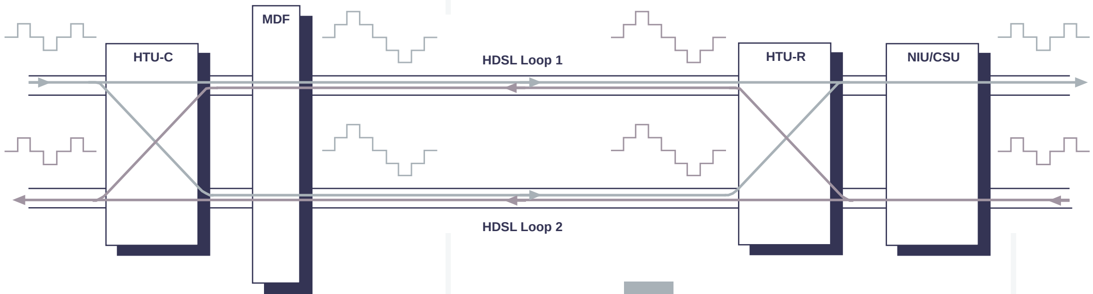

Figure 2
Transmitting HDSL signals.

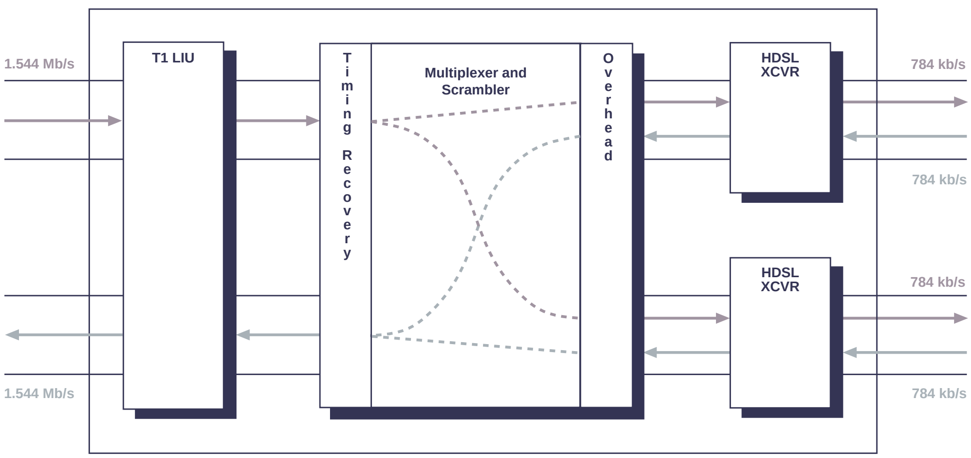

Figure 3
Dividing the incoming T1.

Finally, 16 kb/s of overhead is applied to each HDSL signal producing a total bit rate of 784 kb/s. This overhead includes framing, CRC error checks, and a proprietary embedded operations channel.

HDSL Signal Encoding

HDSL transmission utilizes a 2-Binary 1-Quaternary (2B1Q) signal encoding scheme, which is also used by Basic Rate ISDN. 2B1Q represents two bits with each pulse, as ***Figure 4***, on the next page, shows. Each pulse can be any of four possible signal levels.

Once encoded, the HTU-C transmits HDSL Signals 1 and 2 on HDSL Loops 1 and 2, respectively. Each of the signals are received by the HTU-R, re-converted into a standard T1 by reversing the above process, and sent to the customer. The use of HDSL technology to deliver T1 service is, therefore, transparent to the customer.

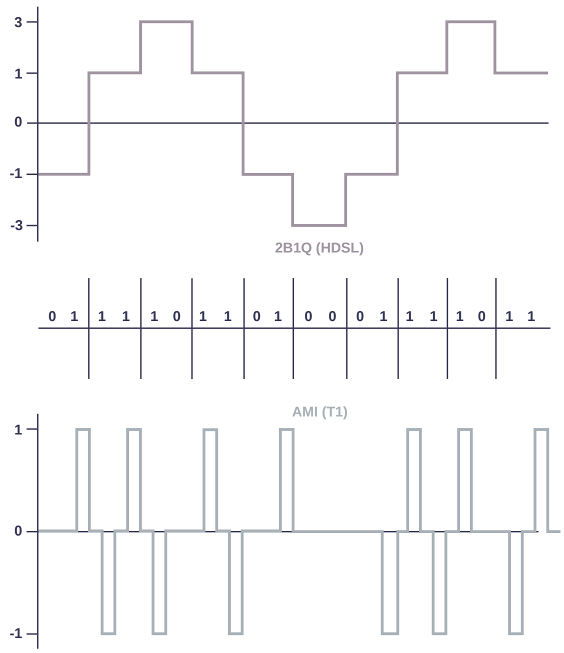

Figure 4
2B1Q signal encoding.

This process is repeated when transmitting from the customer to the network. Upon receiving the standard T1 from the customer premises, the HTU-R completes the same conversion process. Both HDSL signals are encoded with a 2B1Q format and transmitted on both loops.

How Does HDSL Improve Performance?

A decreased frequency of operation and several enhancements that correct for common problems inherent in standard T1 transmission help HDSL to provide superior service. Some of these problems are repeater reliability, pulse density, bridged taps, and degrading splices.

Lower Frequency

The conversion process from T1 to HDSL centers on a basic transmission theory that relates a signal's frequency to the distance of transmission: the lower the signal's Nyquist (center) frequency, the greater the distance it can travel. For example, a 56 kb/s signal, having a Nyquist frequency of 28 kHz, can travel much further than a T1 signal having a Nyquist frequency of 772 kHz.

As previously described, HDSL splits the incoming T1 into two separate data streams reducing the overall bit rate from 1.544 Mb/s to 784 kb/s per loop. Decreasing the overall bit rate – and encoding with 2B1Q – combine to reduce the Nyquist frequency of HDSL transmission from the 772 kHz of standard T1 to 196 kHz, see ***Table 1***. The lower Nyquist frequency enables HDSL to travel up to 12,000 ft. as opposed to 6,500 ft. with standard T1. This additional range enables service providers to reach approximately 80% of their customers without deploying line repeaters.

The lower frequency of HDSL transmission provides additional benefit by being less susceptible to cable impairments. In general, the higher a signal's frequency, the more vulnerable it is to cable faults. As in the previous example, the Nyquist frequency of a 56 kb/s signal is only 28 kHz, while T1 is 772 kHz. If the above theory holds true, then a 56 kb/s circuit should have fewer testing restrictions placed on it than a T1… and it does.

Controlled Pulse Density

HDSL also proves superior to T1 by reducing the concerns related to pulse density in the outside plant. ANSI T1.403 requires that standard T1 bandwidth contain a minimum of 12.5% ones density and no more than 15 consecutive zeros to ensure that common trans-

	Standard T1	HDSL
User Bandwidth/Overhead	1.544 Mb/s	1.544 Mb/s
Transmission Rate	1.544 Mb/s	784 kb/s (2 loops)
Pulse Level Combinations	2 (AMI)	4 (2B1Q)
Nyquist Frequency	772 kHz >>	196 kHz

Table 1
Reducing the Nyquist frequency of T1.

mission equipment will receive adequate pulse density to recover timing from the network. In addition, low pulse density reduces a T1 signal's ability to pass physical faults such as one-side opens and degrading splices. Conversely, high pulse densities stress the power output of common equipment and occasionally induce cross-talk noise on adjacent pairs. Commonly used stress patterns (e.g., 3 in 24, 1:7, and ALL ONES) have been developed to proactively locate such problems and are often used during span qualification.

HDSL compensates for these inherent problems by introducing the incoming T1 to a pseudorandom data scrambling algorithm within the conversion process. This algorithm ensures a healthy pulse density within the outgoing signals regardless of the incoming T1 data.

Echo-cancellation

Bridge taps, a frequent nemesis of T1, also play a role in impairing HDSL transmission. Bridge taps can impose signal problems at specific frequencies. These frequencies vary with each bridge tap. They are defined by the distance to the tap, the length of the tap, and the termination of the drop. Each HTU includes echo-cancellation circuitry that corrects for the effects of bridge taps. Upon transmitting a frequency that activates a bridge tap, the tap impairs the signal by introducing reflections of energy (known as echoes) back toward the source. The purpose of echo-cancellation circuitry is to detect such echoes and adjust itself to cancel them out, thereby reducing their effects on live traffic.

Adaptive Digital Filtering

Adaptive digital filtering is also useful in reducing the effects of physical faults in the outside plant. Environmental elements such as water and humidity can cause copper cable and splices to degrade. Over time, this degradation introduces signal noise to the service that the cable supports. Adaptive digital filtering corrects for this process by routinely monitoring the HDSL signals for unwanted noise and adapting itself to filter it out. This reduces the need to perform periodic testing on high-priority cable pairs to detect degradation.

The Requirements for HDSL Loops

If HDSL transmission is superior to T1, what are its limitations? The physical requirements of the HDSL loops are defined by Carrier Serving Area (CSA) specifications which describe total loop length, bridge tap length, and gauge changes.

CSA specifications state that the total loop length must be less than or equal to 12,000 ft. for 22/24 AWG cable and less than or equal to 9,000 ft. for

26 AWG cable. This total cable length also includes the length of any bridge taps on the loop. For example, a loop of 11,730 ft. with a 1,000 ft. bridge tap does not meet CSA requirements, as the total loop length exceeds 12,000 ft.

In addition, the total length of all bridge taps on the span must total less than 2,500 ft. with no single tap exceeding 2,000 ft. A span containing eight 60 ft. bridge taps is CSA compliant while a loop containing one 2,400 ft. bridge tap is not. Finally, the loop must be non-loaded and contain a maximum of two gauge changes.

Special attention should be paid to bridge taps that are extremely close to each HTU. For example, a bridge tap within 100 ft. of a HTU-R can impair the HDSL signal even if the loop meets CSA requirements. The closer the bridge tap is to the HTU, the more likely it is to return reflections that contain more energy than the incoming data pulses from the other HTU. If this occurs, the echo-cancellation circuitry will be unable to distinguish between data and unwanted reflections.

Testing HDSL

What happens if the HTUs are inserted into their respective slots; their test sequence is initiated; and it fails? This section defines some recommended testing techniques to enable you to quickly identify and locate why the HTUs would fail. As with most other digital services, HDSL loops can be tested by performing two basic tests: testing the physical cable pairs and determining the actual signal quality.

One common technique for testing the physical cable pairs is performing an end-to-end loss test at the service's Nyquist frequency, as shown in ***Figure 5***. This measurement assures proper signal level at the customer demarcation point and approximates signal performance. The Nyquist frequency of HDSL is 196 kHz and most HTU equipment cannot withstand greater than -36 dB of loss. This test requires two transmission impairment measuring set (TIMS) test instruments. Although these sets do an adequate job of approximating signal performance, they provide very little, if any, information about the type or location of a fault. Efficient fault location requires additional test equipment to complement a TIMS, such as a time domain reflectometer (TDR).

Another common method of testing for physical faults on HDSL loops is to first measure the total loop length, including bridge taps, and then measure the total loop length without bridge taps. The total loop length, including bridge taps, can be approximated by measuring loop capacitance and referring to a conversion table. Some products will complete the conversion for you and simply display a result in feet. Note that making an accurate measurement in either case requires an open at the far-end of the loop. Total loop length without bridge taps is best approximated by mea-

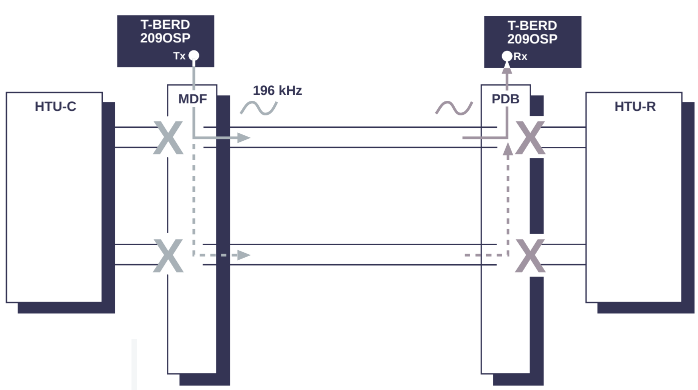

Figure 5
Nyquist frequency for HDSL.

suring the resistance between tip and ring and referring to a conversion table. This measurement requires a short at the far-end of the loop. Upon completing these two measurements, you can verify the total loop length and total bridge tap length meet CSA specifications. If CSA requirements are not satisfied, a TDR can be used to locate any applicable bridge taps, shorts, opens, or load coils. Since this method requires only one test set, it proves to be more efficient. ***Figure 6*** describes measuring loop length.

Upon verifying the cable pairs, a bit error rate (BER) test should be performed between the DSX-1 and the customer demarcation point. Although stress patterns have little effect on HDSL transmission, ANSI T1.403 requires the service provider to adequately qualify the circuit, as it is still a T1 service being delivered to the customer. In addition, each HTU's T1 receiver actually derives timing from the incoming pulses; therefore, patterns such as 3 in 24 can prove quite useful in locating faulty equipment. Each HTU responds to a variety of loopback codes, so these tests can be completed with a single T1 test set.

To properly qualify a T1 service, ANSI T1.403 recommends testing the ALL ONES pattern for five minutes, 3 in 24 for five minutes, and the QRSS pattern for 15 minutes.

With the recent emergence of HDSL doublers, it is often a requirement to test for signal quality prior to installing the CO equipment. This test is typically performed in order to verify the doubler is working and installed properly. When completing this test, it is common to access the span at the main distribution frame (MDF) and emulate the HTU-C with a BER test set. It is important to recognize this test set must also be able to provide loop current to power the doubler. Once connected, the test set can loop up the doubler and qualify its proper operation by means of a BER test. ***Figure*** 7, on the next page, depicts this test application.

A final issue in HDSL testing is crosstalk noise measurements. The signal spectrum for HDSL, as shown in ***Figure 8*** on the next page, ranges from approximately 40 kHz to 390 kHz. Although this range doesn't contain the Nyquist frequency of any other common services, it does overlap with 56 kb/s, 64 kb/s, Basic Rate ISDN, and T1 signal spectrums. This fact implies that near-end crosstalk (NEXT) from these servies may induce noise upon live HDSL traffic or vice versa. For example, if the HTUs report a consistently high S/N ratio during normal operation, the problem might very well be NEXT. Conversely, most physical faults will typically cause fluctuating S/N readings due to the adaptive digital filtering. Isolating this trouble requires taking the HDSL circuit out-of-service and measuring the noise power residing on the pair induced from other signals in the same bundle. The T1/E1 group has defined the F bandpass filter for performing this measurement. A TIMS set equipped with the F filter is able to measure only the noise power that resides within the HDSL signal spectrum, providing a true measurement for the presence of relevant NEXT.

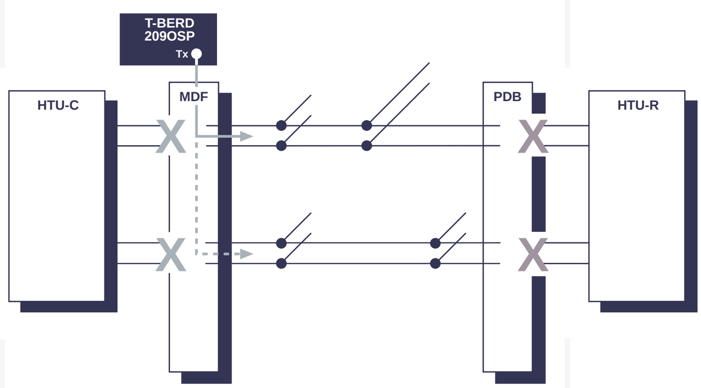

Figure 6
Measuring loop length.

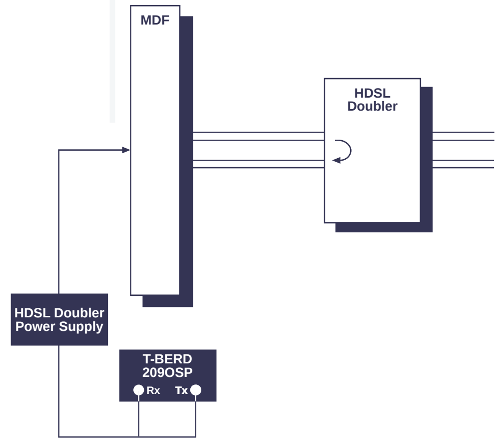

Figure 7
BER testing with a doubler.

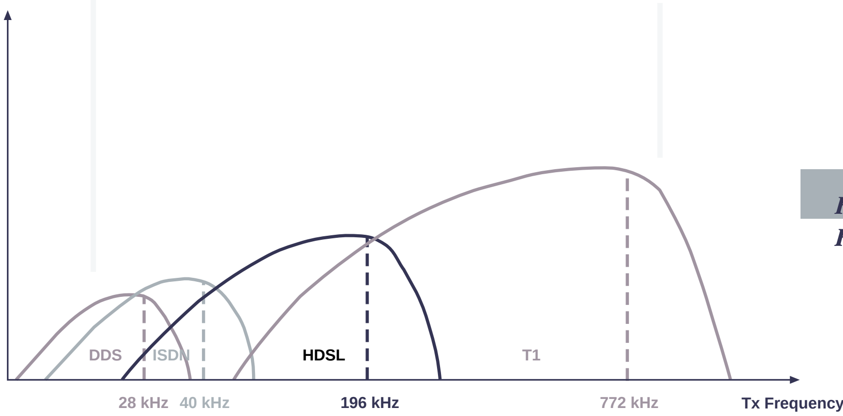

Figure 8
HDSL signal spectrum.

These quick qualification tests will guarantee the cost savings and service benefits that HDSL offers. However, HDSL is a very cost-driven technology and the advantages begin to dwindle if service providers must spend upwards of $20,000 to purchase a TIMS set, TDR, and T1 test set for each applicable technician. A solution to this predicament is the T-BERD 209OSP and the T-BERD HDSL Doubler Power Supply, which meet all the above requirements for a much lower price.

Conclusion

HDSL provides the unique ability to extend the life of copper cable while providing distinct improvements in service quality. This implies that HDSL will prove to be a strategic tool in the increasingly competitive T1 service market… but only for those who can support it effectively.

NOTE: Specifications, terms, and conditions are subject to change without notice.

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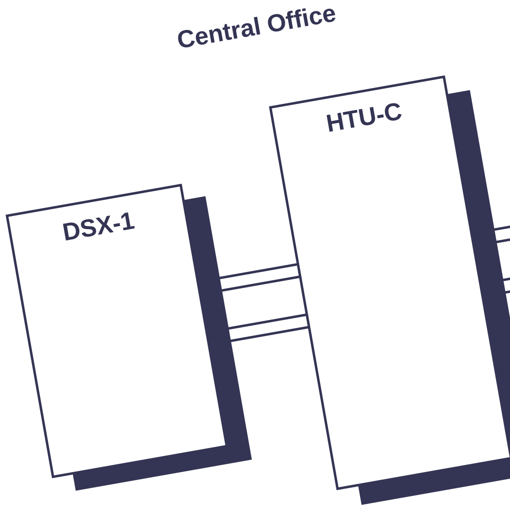

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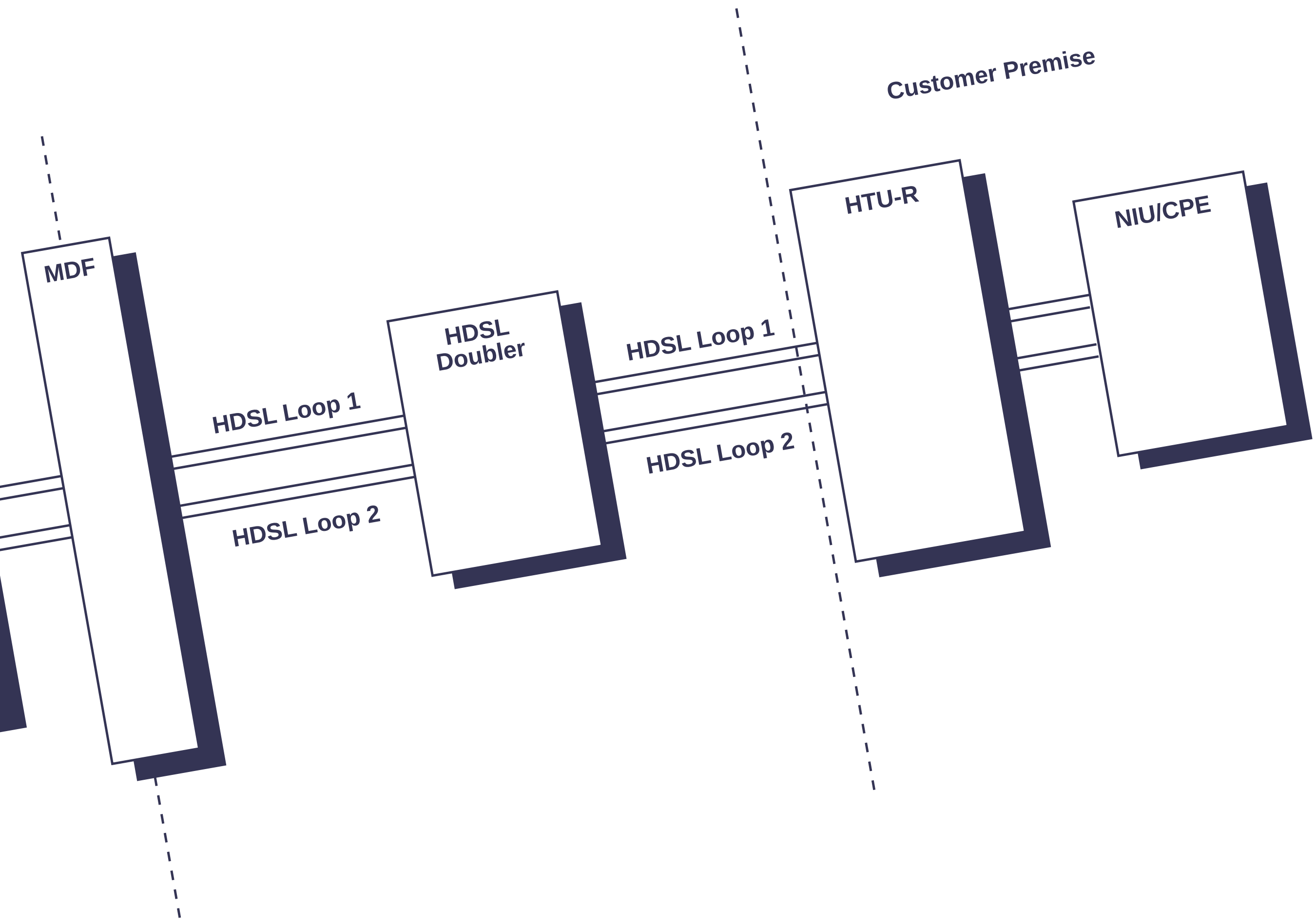

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