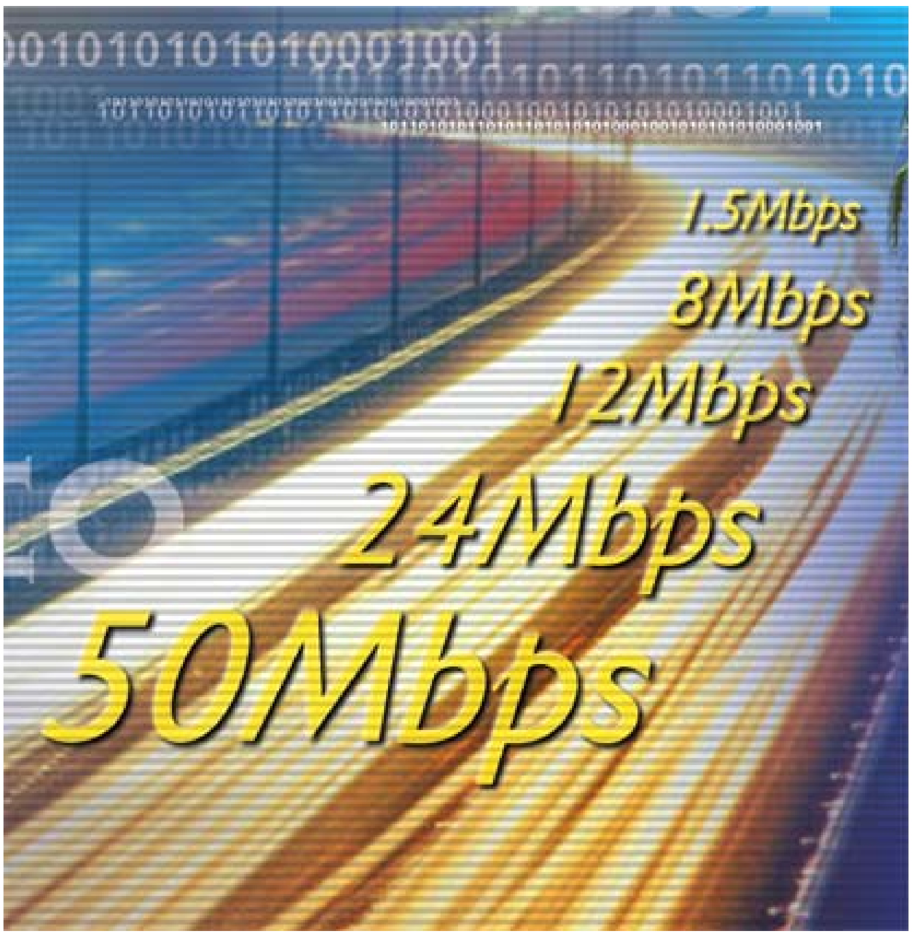
CENTILLIUM COMMUNICATIONS

eXtremeDSL^{MAX}
Technology and Applications



Team Centillium
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1 Overview

eXtremeDSL^{MAX} is a unique technology designed and developed by Centillium Communications intended to enable DSL services that require very high bit rates. This technology, along with newly standardized capabilities such as ADSL2 and ADSL2plus, is offered in the form of a chipset and software to equipment manufacturers. As the natural progression to ADSL2plus, Centillium will introduce eXtremeDSL^{MAX} into standards bodies later this year (2003).

eXtremeDSL^{MAX} includes the following characteristics and advantages

- Downstream transmission band is extended to 3.75 MHz
- PSD mask is a compatible with standard ADSL/ADSL2plus and VDSL masks
- Optional support for extended upstream (up to 276 kHz)
- Delivers up to 50 Mbps downstream and up to 3 Mbps upstream
- Backward compatible with all existing ADSL standards
- Compatible with all new standardized ADSL2 and ADSL2plus (G.992.3 and G.992.5)
- Designed for price parity with standard ADSL chipsets for cost effective high speed services

The high bit rate capability of eXtremeDSL^{MAX} would undoubtedly create an intriguing question. How does VDSL compare to eXtremeDSL^{MAX}? In general, standard ADSL has certain overlap of applications with VDSL. On the other hand, the higher we push the bit rate capability of the ADSL, the more overlap is created in applicability of ADSL type transceivers for high speed services compared to their VDSL counterparts. The picture below makes an attempt to show this visually. This scenario does not render VDSL useless or ineffective but simply points to the fact that with a large overlap of functionality between eXtremeDSL^{MAX} and VDSL, the service providers would have a larger set of DSL options to satisfy their high speed service needs. This paper is intended to provide a technical analysis of eXtremeDSL^{MAX} performance vs. VDSL and draw conclusions on applicability of the eXtremeDSL^{MAX} in comparison to VDSL.

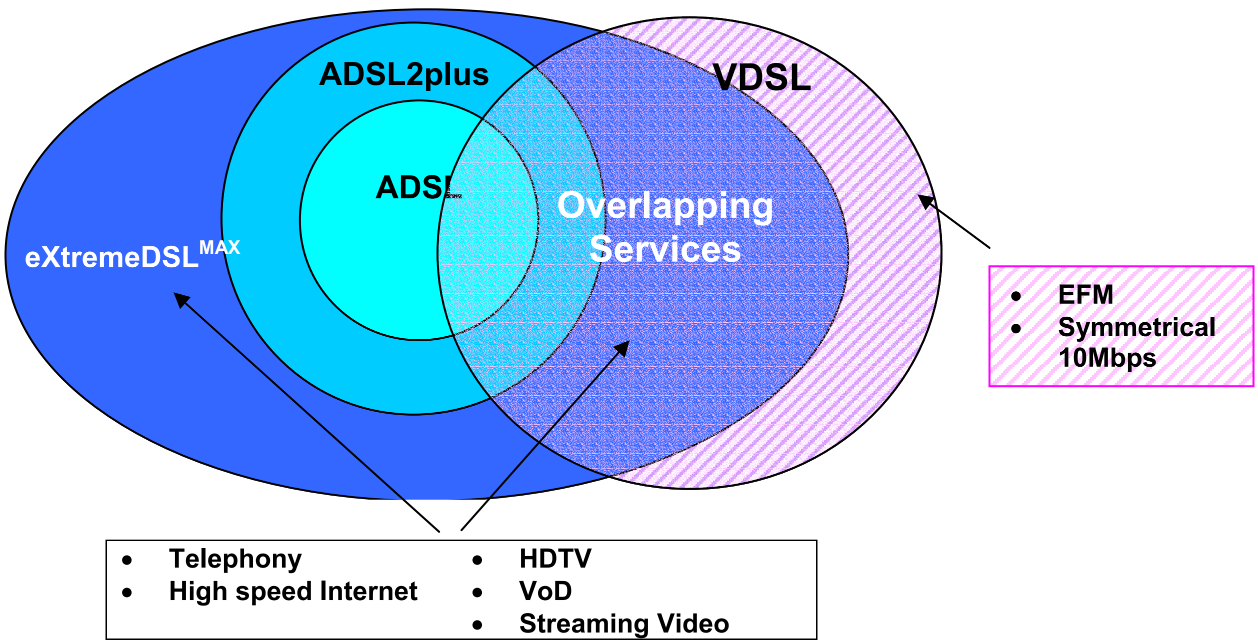


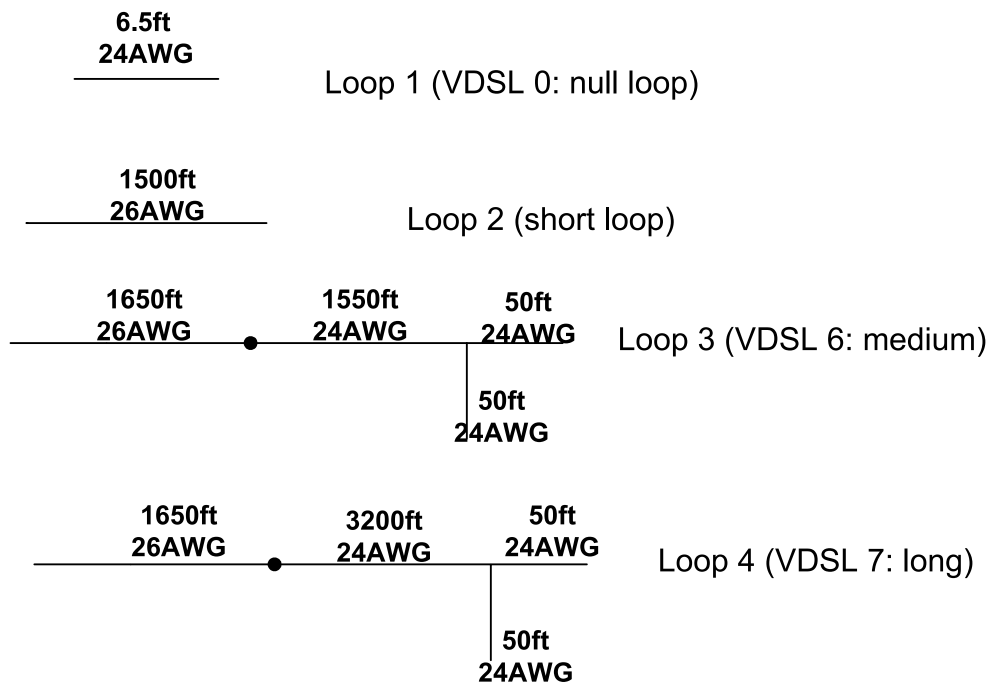
Figure 1 – eXtremeDSL^{MAX} and VDSL overlapping services

2 Assumptions

For comparison purposes, we will show the performance of eXtremeDSL^{MAX} and VDSL on straight loops using various noise models. We will also select 4 loops from VDSL specification to complete the analysis.

2.1 Selected VDSL Loops

We have chosen the loops below that are derived from the VDSL (plan 998) standard. These loops are meant to cover the entire range of VDSL's target customers (loop lengths below 4900 feet.)



2.2 Noise models

We will apply four different noise models to each loop and calculate the overall system capacity for eXtremeDSL^{MAX} and VDSL. These four noise models are as below:

- **Noise 1:** Only AWGN (–140 dBm/Hz)
- **Noise 2:** 10 ADSL + 16 ISDN + 4 HDSL + AWGN
- **Noise 3:** 10 Echo Cancelled ADSL + 16 ISDN + 4 HDSL + 2 T1 + AWGN
- **Noise 4:** 20 VDSL + AWGN

2.3 PSDs

Figure 2 depicts the assumed upstream and downstream PSD for eXtremeDSL^{MAX} and VDSL. The eXtremeDSL^{MAX} PSD is based on T1.424 FTTex M2, adjusted to keep the total power within 20dbm. VDSL PSD is based on Plan 998, adjusted down to keep the total power limited 14.5dbm, as defined in VDSL standards G.993.1 and T1.424.

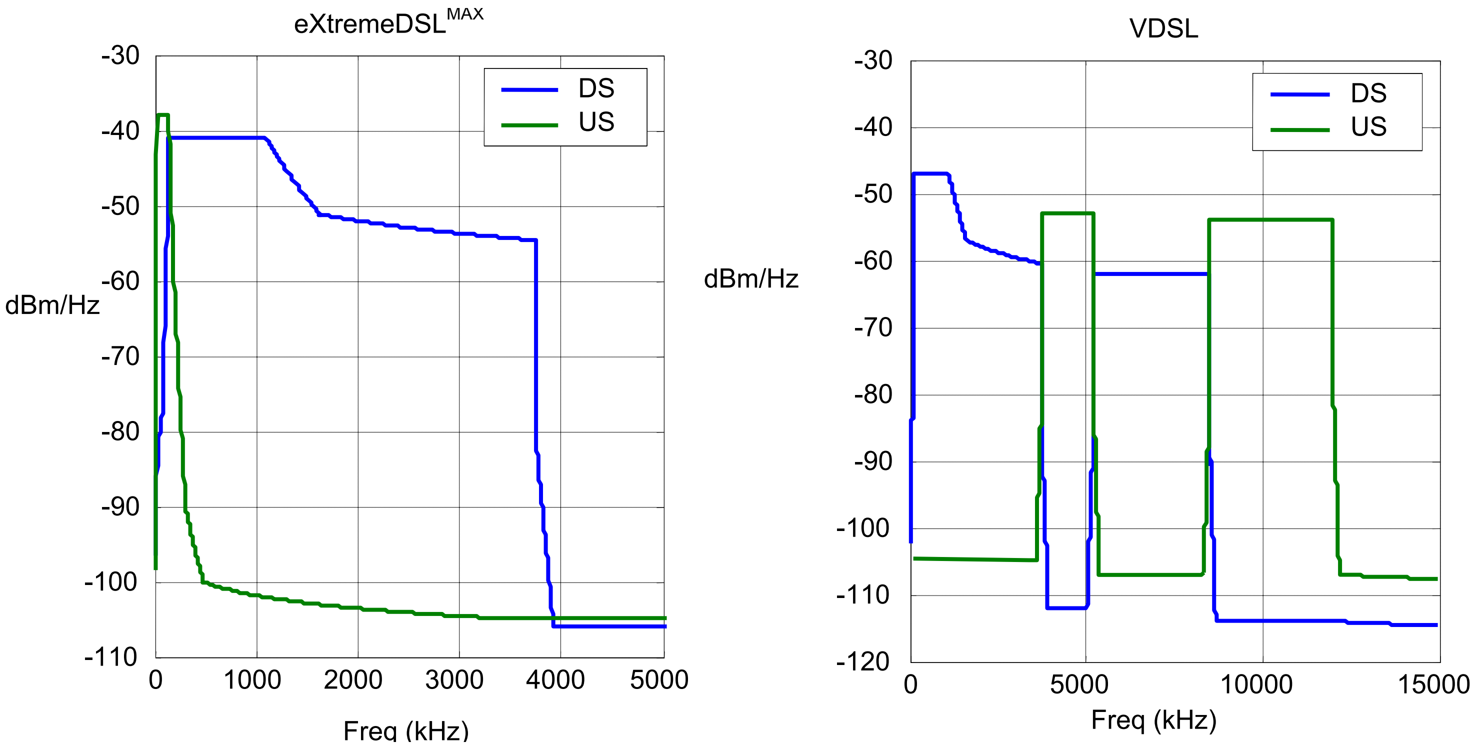


Figure 2 – eXtremeDSL^{MAX} and VDSL PSD

2.4 Other assumptions

We have made the following assumptions in calculating the performance numbers in both eXtremeDSL^{MAX} and VDSL cases:

- SNR Gap = 9.8 dB
- Margin = 6 dB
- Coding Gain = 0 dB
- Maximum number of bits per bin = 15
- Minimum number of bits per bin = 2
- Total power for VDSL is limited to 14.5 dBm per VDSL specifications
- Total power for eXtremeDSL^{MAX} is limited to 20 dBm

3 Performance Numbers

3.1 Performance graphs

The following section provides loop reach graphs for various noise environments (Noise 1 – Noise 4).

3.1.1 Downstream

The next four figures comprise downstream performance results for the noise cases mentioned in section 2.2 on straight loops.

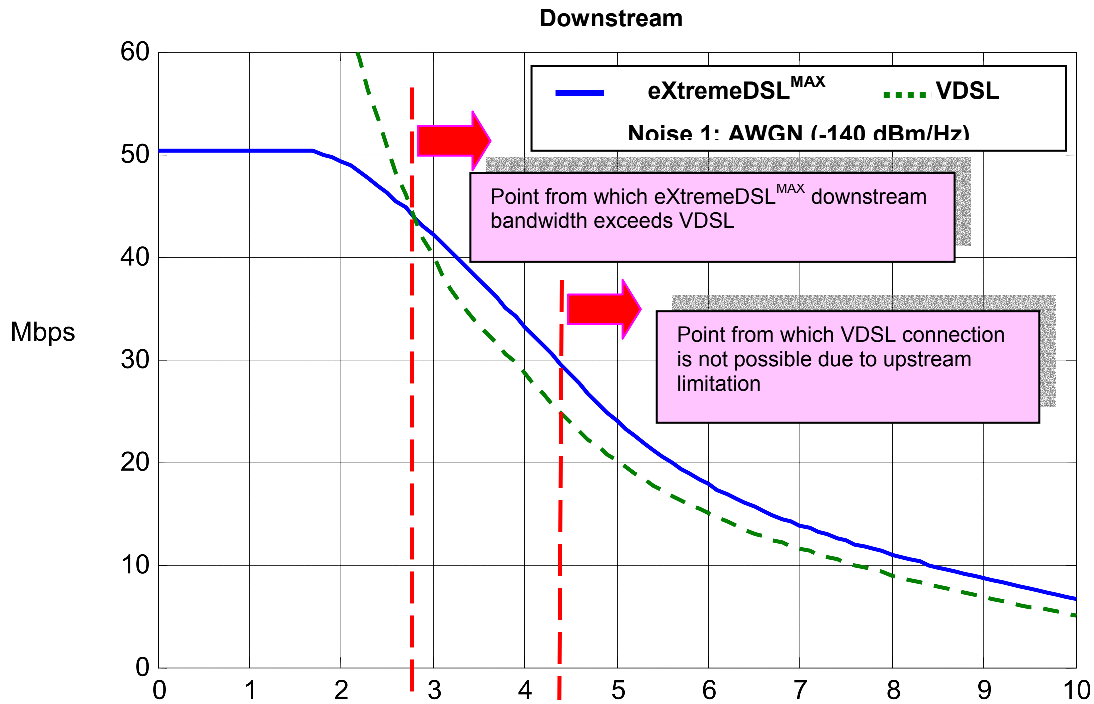


Figure 3- Downstream eXtremeDSL MAX vs. VDSL comparison (Noise 1: AWGN -140 dBm/Hz)

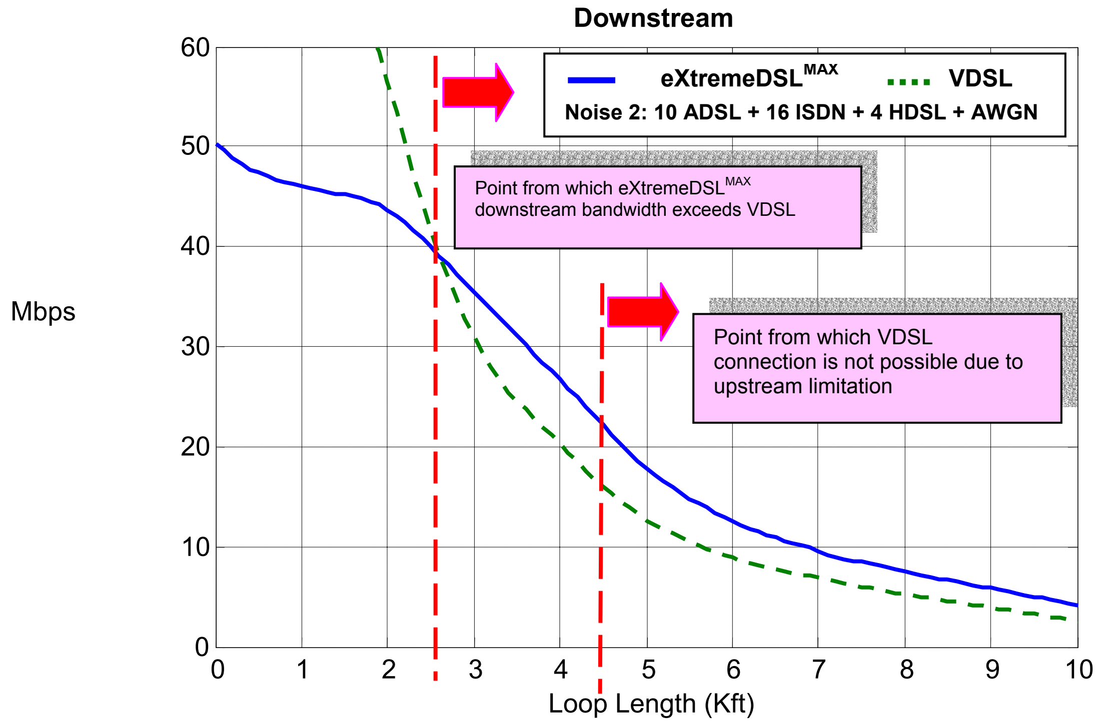


Figure 4- Downstream eXtremeDSL^MAX vs. VDSL comparison (Noise 2: 10 ADSL + 16 ISDN + 4 HDSL + AWGN)

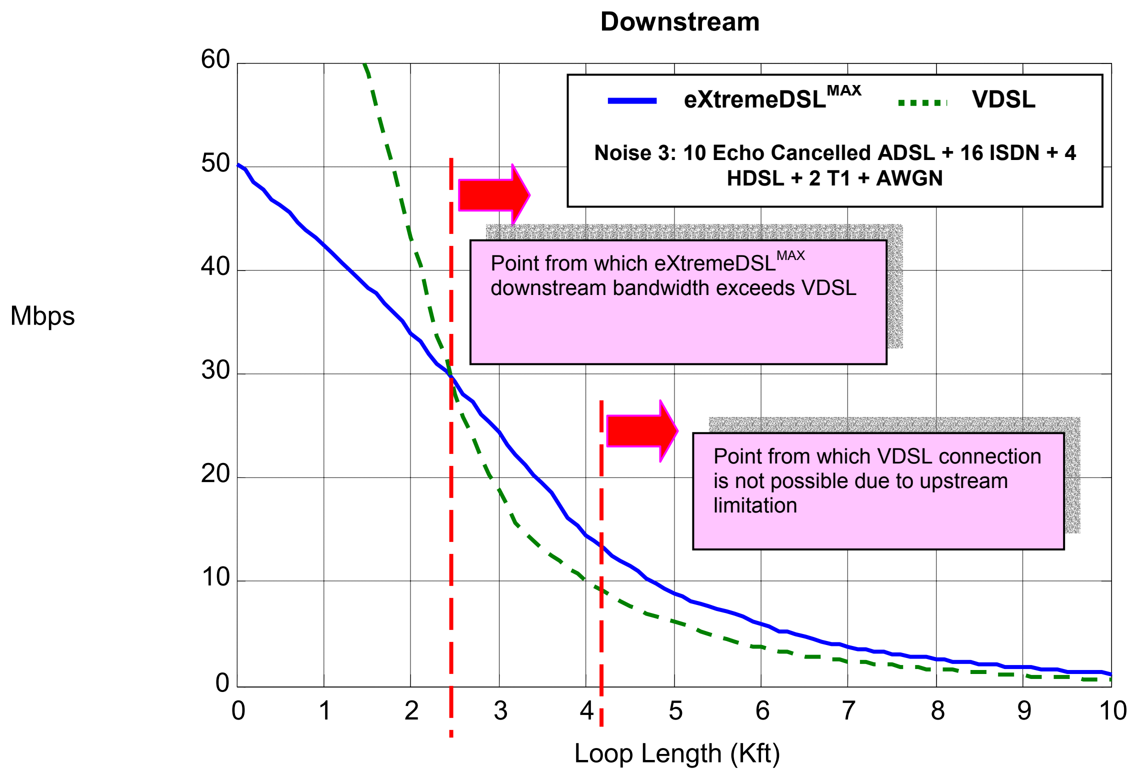


Figure 5- Downstream eXtremeDSL^MAX vs. VDSL comparison (Noise 3: 10 Echo Cancelled ADSL + 16 ISDN + 4 HDSL + 2 T1 + AWGN)

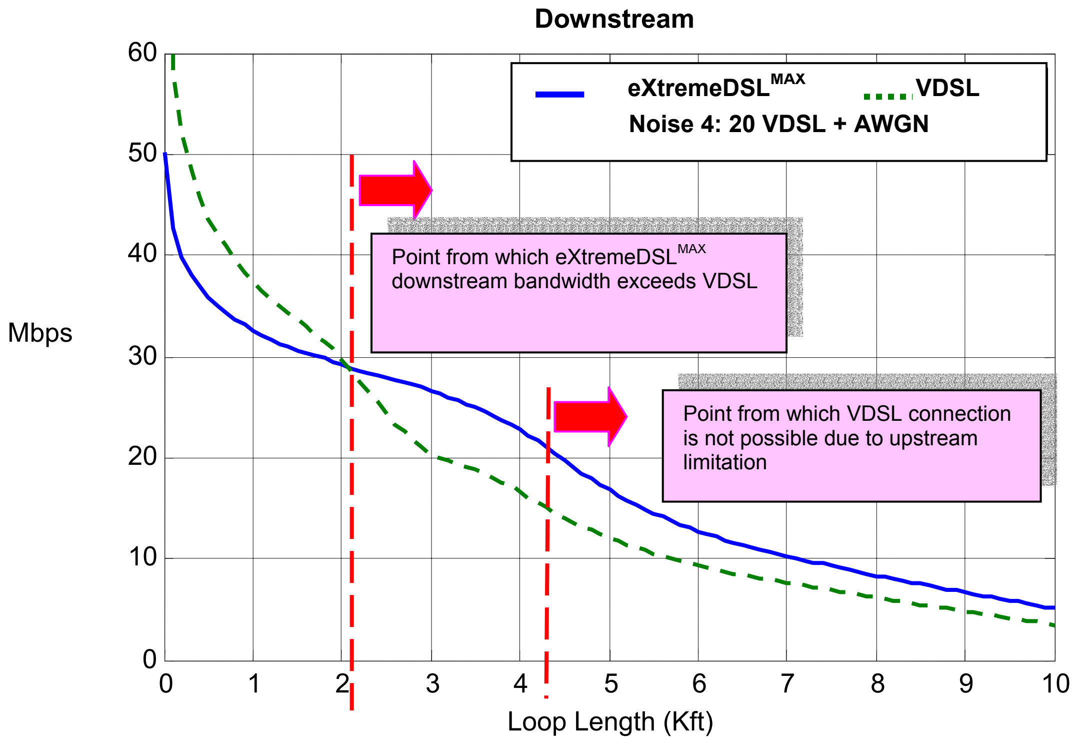


Figure 6- Downstream eXtremeDSL^{MAX} vs. VDSL comparison (Noise 4: 20 VDSL + AWGN)

3.1.2 Upstream

The next four figures comprise upstream performance results for the noise cases mentioned in section 2.2. Since eXtremeDSL^{MAX} is capable of extending the upstream band beyond bin 31, we have simulated the eXtremeDSL^{MAX} upstream performance utilizing extended spectrum up to bin 63.

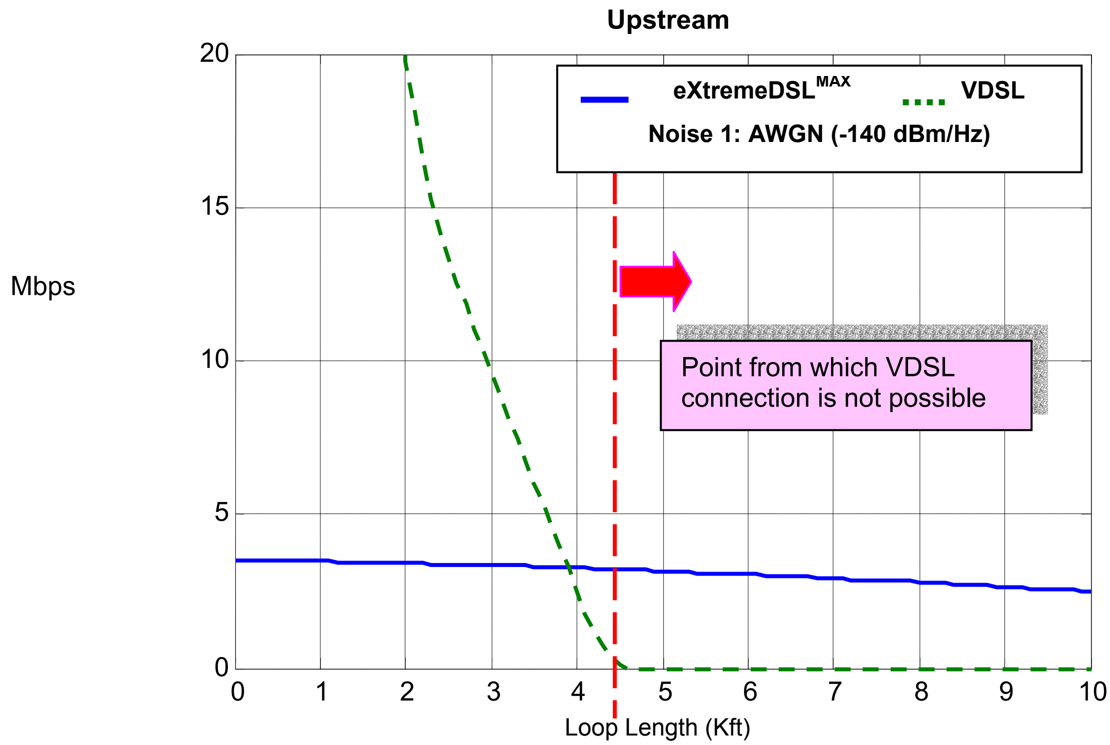


Figure 7- Upstream eXtremeDSL^{MAX} vs. VDSL comparison (Noise 1: AWGN -140 dBm/Hz)

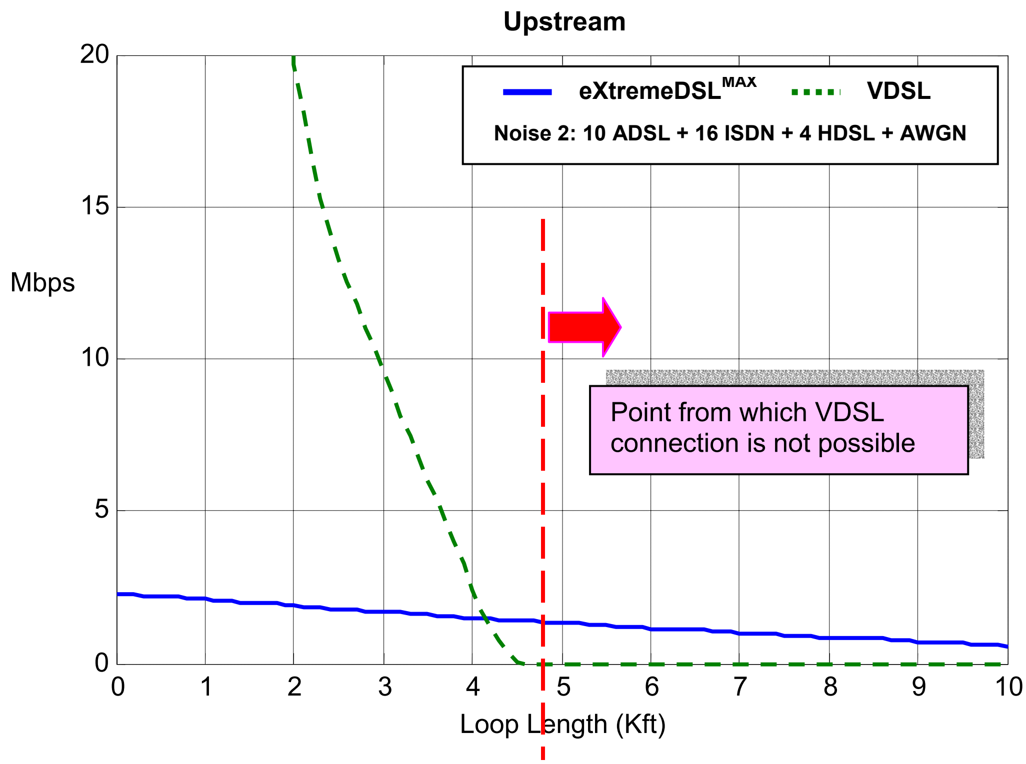


Figure 8- Upstream eXtremeDSL^{MAX} vs. VDSL comparison (Noise 2: 10 ADSL + 16 ISDN + 4 HDSL + AWGN)

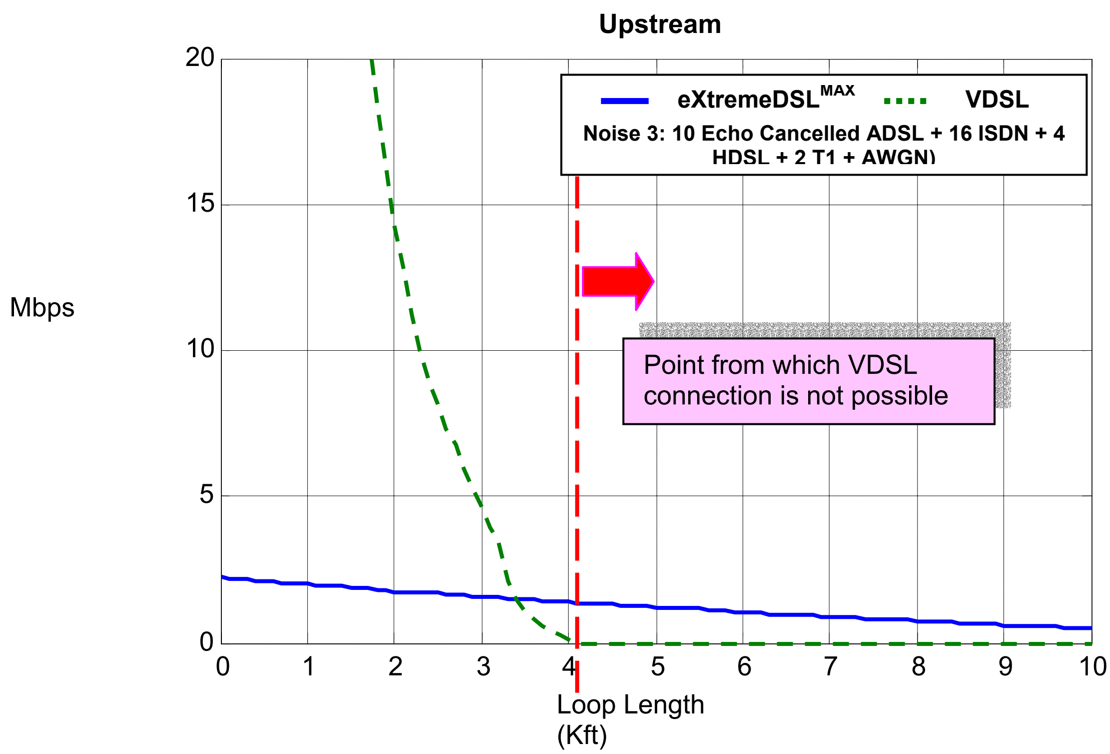


Figure 9- Upstream eXtremeDSL^{MAX} vs. VDSL comparison (Noise 3: 10 Echo Cancelled ADSL + 16 ISDN + 4 HDSL + 2 T1 + AWGN)

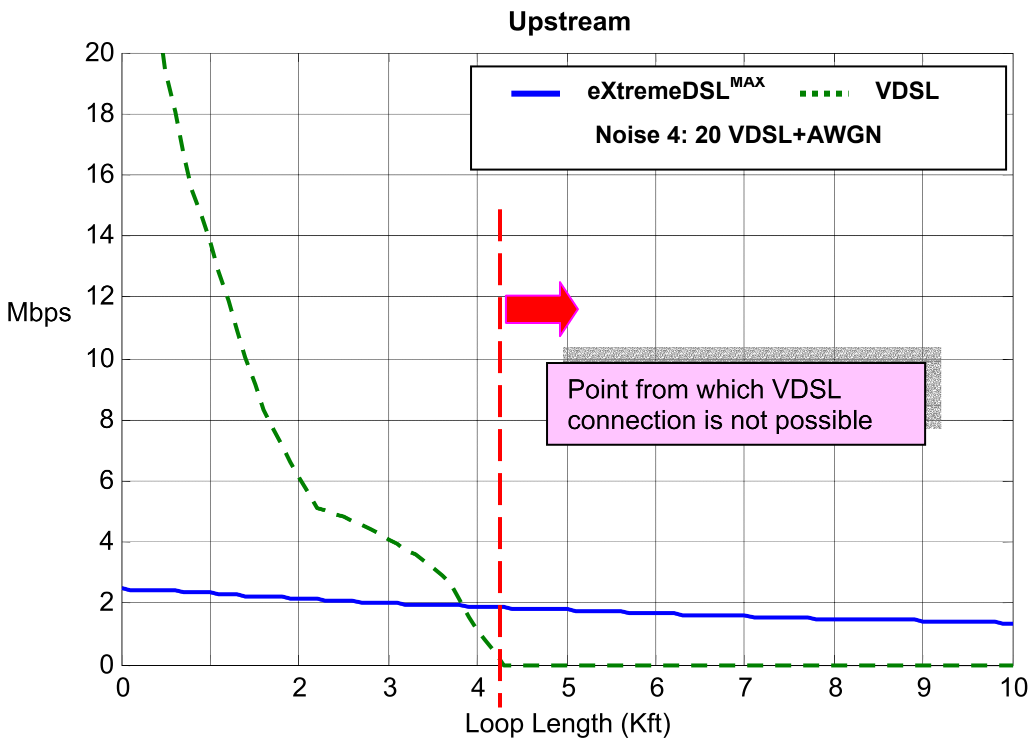


Figure 10- Upstream eXtremeDSL^{MAX} vs. VDSL comparison (Noise 4: 20 VDSL + AWGN)

3.2 Results on loops 1-4

3.2.1 Downstream

The following tables comprise downstream results on loop 1 to loop 4

	Noise 1	Noise 2	Noise 3	Noise 4
Loop 1	50.2	50.1	50.1	50.0
Loop 2	50.0	45.0	38.1	30.4
Loop 3	37.4	30.6	19.6	24.3
Loop 4	26.7	19.9	10.7	18.3

Table 1 - Downstream eXtremeDSL^{MAX} (Mbps)

	Noise 1	Noise 2	Noise 3	Noise 4
Loop 1	96.0	95.9	94.7	80.5
Loop 2	79.2	71.2	58.9	33.7
Loop 3	36.1	27.0	15.1	18.6
Loop 4	23.5	15.1	8.0	13.7

Table 2 - Downstream VDSL (Mbps)

The following figures are provided to better visualize the above numbers and to compare eXtremeDSL^{MAX} vs. VDSL (Note: To enhance graph clarity we have limited the displayed rates to 50 Mbps).

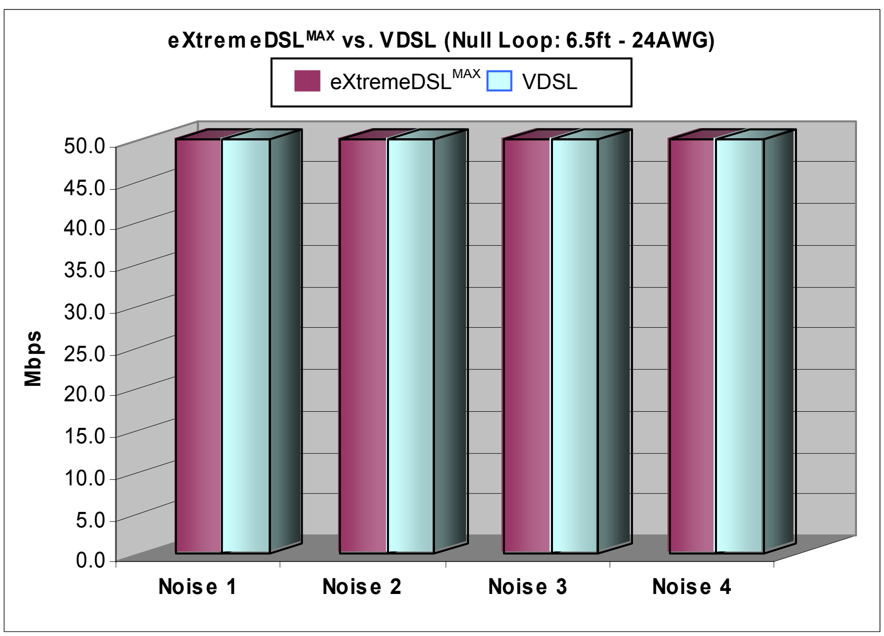


Figure 11- Downstream eXtremeDSL^{MAX} vs. VDSL; Loop1: Null loop 6.5ft - 24AWG

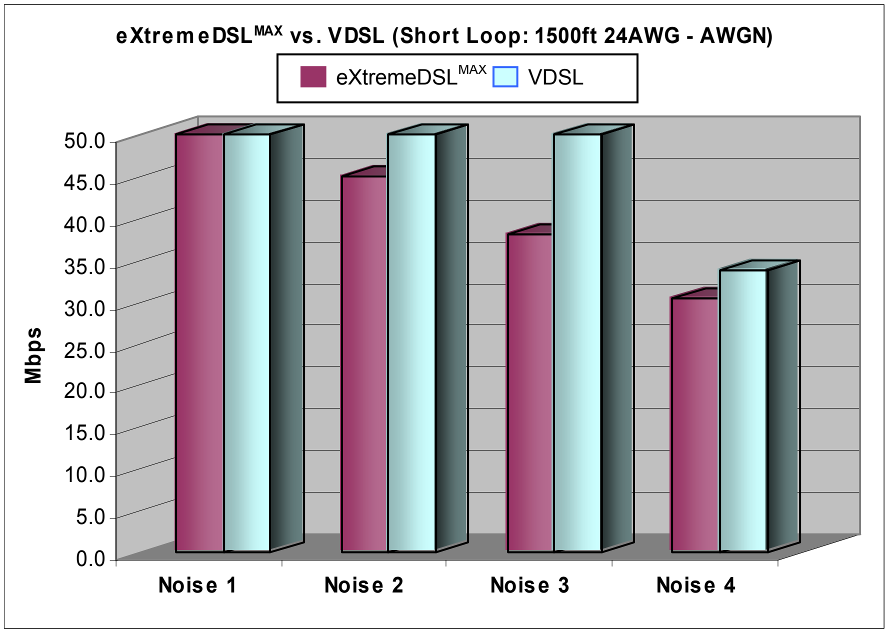


Figure 12- Downstream eXtremeDSL^MAX vs. VDSL; Loop2: Short loop: 1500ft - 24AWG

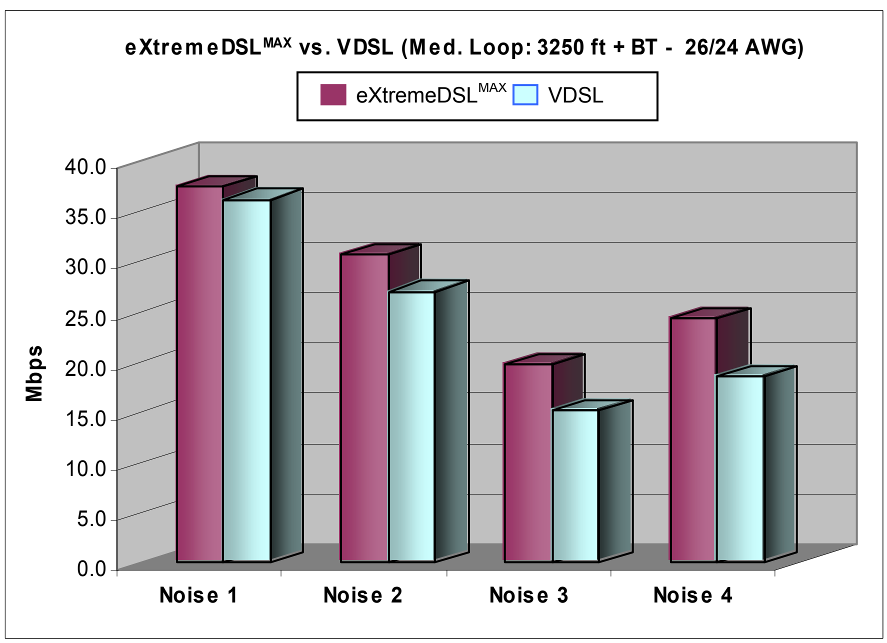


Figure 13- Downstream vs. eXtremeDSL^MAX vs. VDSL; Loop3: Medium loop: 3250 ft + BT – 26/24AWG

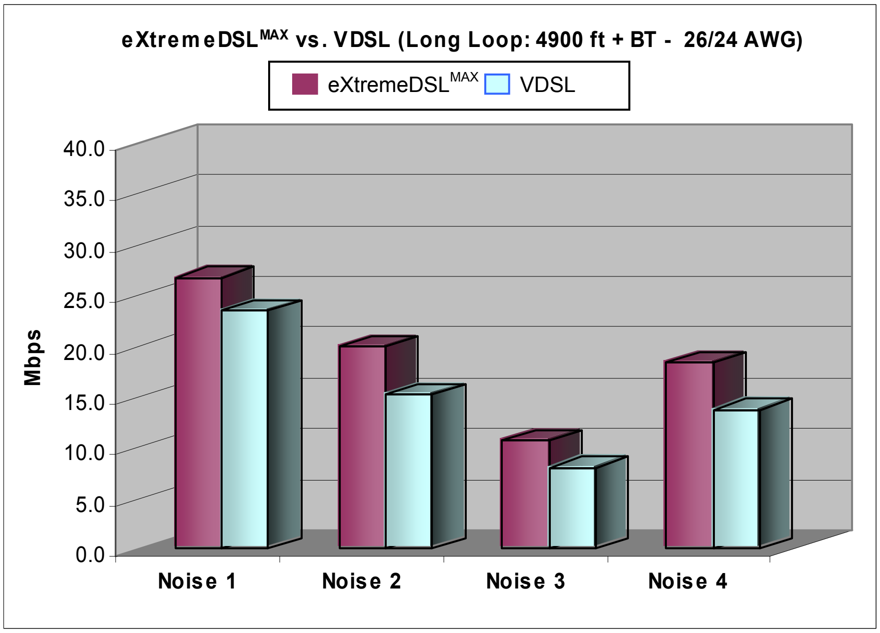


Figure 14- Downstream eXtremeDSL^{MAX} vs. VDSL; Loop 4: Long loop: 4900 ft + BT – 26/24AWG

3.2.2 Upstream

The following tables comprise upstream results on loops 1 to 4:

	Noise 1	Noise 2	Noise 3	Noise 4
Loop 1	3.5	2.2	2.2	2.5
Loop 2	3.4	2.0	1.9	2.2
Loop 3	3.4	1.7	1.6	2.0
Loop 4	3.3	1.5	1.4	1.9

Table 3 - Upstream eXtremeDSL^{MAX} (Mbps)

	Noise 1	Noise 2	Noise 3	Noise 4
Loop 1	68.7	68.7	68.7	47.6
Loop 2	31.0	31.0	26.1	9.2
Loop 3	8.7	8.7	3.5	3.7
Loop 4	0.0	0.0	0.0	0.0

Table 4 - Upstream VDSL (Mbps)

The following figures are provided in order to better visualize the above numbers and to be able to compare eXtremeDSL^{MAX} vs. VDSL (Note: To enhance graph clarity we have limited the displayed rates to 10 Mbps).

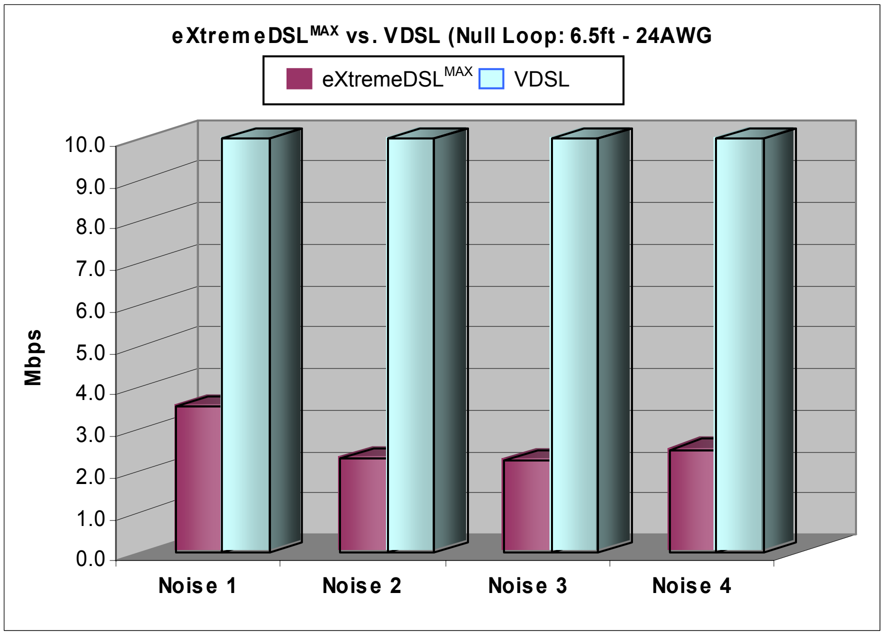


Figure 15- Upstream eXtremeDSL^{MAX} vs. VDSL; Loop1: Null loop 6.5ft - 24AWG

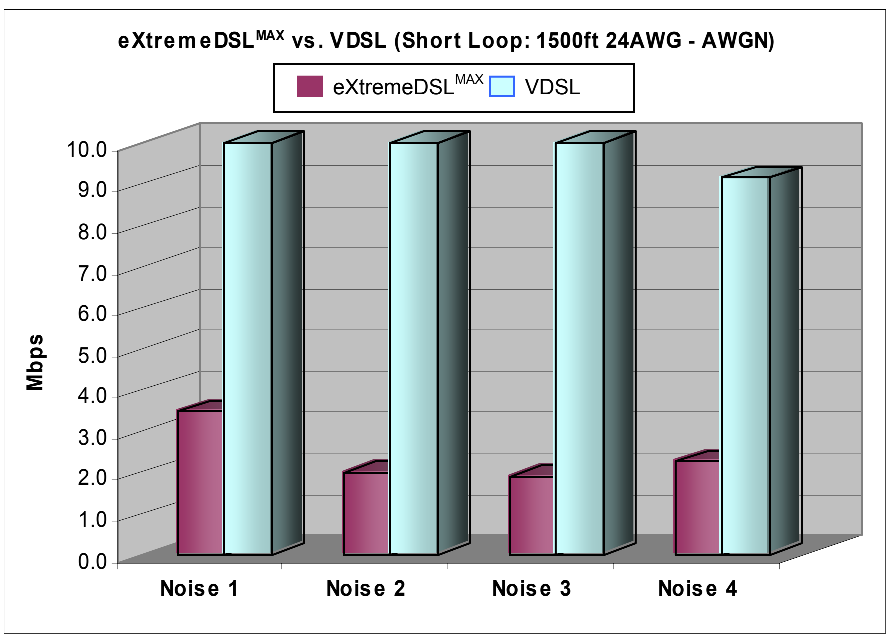


Figure 16- Upstream eXtremeDSL^{MAX} vs. VDSL; Loop2: Short loop: 1500ft - 24AWG

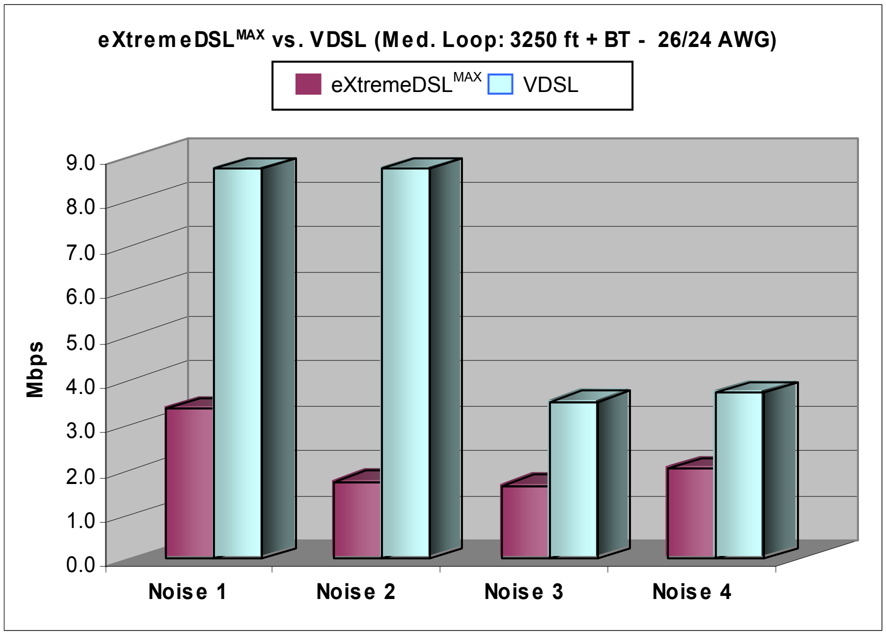


Figure 17- Upstream eXtremeDSL^{MAX} vs. VDSL; Loop3: Medium loop: 3250 ft + BT – 26/24AWG

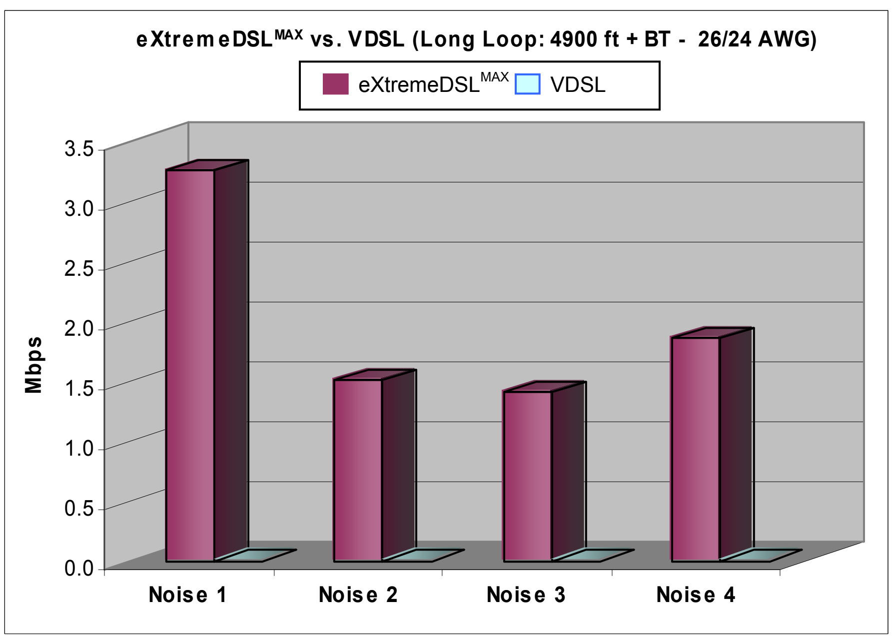


Figure 18- Upstream eXtremeDSL^{MAX} vs. VDSL; Loop 4: Long loop: 4900 ft + BT – 26/24AWG

3.3 Conclusions on performance graphs and VDSL Loop 1-Loop 4 rates

3.3.1 Performance over straight loops

Downstream
As depicted in figures 3-6, downstream performance of eXtremeDSL^{MAX} surpasses VDSL at the 2-3 Kft range depending on the noise case:

- Noise Case 1: 2.8 Kft is the range after which downstream eXtremeDSL^{MAX} ≥ downstream VDSL
- Noise Case 2: 2.6 Kft is the range after which downstream eXtremeDSL^{MAX} ≥ downstream VDSL
- Noise Case 3: 2.5 Kft is the range after which downstream eXtremeDSL^{MAX} ≥ downstream VDSL
- Noise Case 4: 2.1 Kft is the range after which downstream eXtremeDSL^{MAX} ≥ downstream VDSL

The reason for the above is that eXtremeDSL^{MAX} downstream transmit power is higher than VDSL hence allowing downstream eXtremeDSL^{MAX} connections with higher line speed compared to VDSL. eXtremeDSL^{MAX} downstream rates can be up to 7-8 Mbps higher than VDSL depending on the noise case and loop length.

Upstream
As depicted in figures 7-10, upstream performance of eXtremeDSL^{MAX} surpasses VDSL at the 3.5-4.2 Kft range depending on the noise case:

- Noise Case 1: 3.9 Kft is the range after which upstream eXtremeDSL^{MAX} ≥ upstream VDSL
- Noise Case 2: 4.2 Kft is the range after which upstream eXtremeDSL^{MAX} ≥ upstream VDSL
- Noise Case 3: 3.4 Kft is the range after which upstream eXtremeDSL^{MAX} ≥ upstream VDSL
- Noise Case 4: 3.9 Kft is the range after which upstream eXtremeDSL^{MAX} ≥ upstream VDSL

The reason for the above is that eXtremeDSL^{MAX} upstream transmission can utilize the 26 kHz – 276 kHz range whereas VDSL (Plan 998) utilizes the 3.75 MHz – 5.2 MHz frequency range. As the loop length increases, the available SNR is reduced at higher frequencies. Depending on the loop length and noise model, there is a point where there is no available SNR on the upstream band of VDSL as can be seen in figures 7-10. These are the points where VDSL connectivity is not possible due to lack of upstream capacity.

- Noise Case 1: 4.5 Kft is the range after which VDSL connection is not possible
- Noise Case 2: 4.5 Kft is the range after which VDSL connection is not possible
- Noise Case 3: 4.1 Kft is the range after which VDSL connection is not possible
- Noise Case 4: 4.3 Kft is the range after which VDSL connection is not possible

3.3.2 Performance over VDSL-specified loops

Downstream

Downstream rates of VDSL are higher than eXtremeDSL^{MAX} for the Loop 1 (Null loop: 6.5 ft) and Loop2 (Short loop 1500 ft). This is due the higher number of bins that VDSL utilizes for downstream transmission than eXtremeDSL^{MAX}. However, in cases of Loop 3 (Medium loop: 3250 feet + bridge tap) and Loop 4 (Long loop: 4900 ft + bridge tap), downstream line rates of eXtremeDSL^{MAX} exceed VDSL in all 4 noise cases and depending on the loop and noise case, this difference can be up to 4.8 Mbps, 31.7 % increase. This difference is due the higher transmit power of eXtremeDSL^{MAX} and the fact that at longer loop lengths, there is not enough SNR on the downstream VDSL bins above 5.2 MHz.

Upstream

VDSL (Plan 998), due to its utilization of the 3.75 MHz – 5.2 MHz frequency range for upstream transmission, can provide higher upstream rates than eXtremeDSL^{MAX} in case of Loop 1, Loop 2 and Loop 3. However, the difference diminishes with increasing the loop length and reduction of SNR on the higher frequencies. As seen on figure 18 (Long loop: 4900 feet + bridge tap), VDSL is not able to deliver any upstream rate regardless of the noise case, whereas eXtremeDSL^{MAX} upstream rates can be as high as 3.3 Mbps and better than 1.4 Mbps depending on the noise case.

4 Conclusions

The information provided in the preceding sections point out to the conclusion that eXtremeDSL^{MAX} makes possible deployment of a new set of services that require very high data rates not possible utilizing ADSL and ADSL2plus. As such, these services may overlap with certain services that VDSL was designed to deliver such as multi-channel video broadcast or HDTV. Given that eXtremeDSL^{MAX} technology is backwards compatible to ADSL and ADSL2plus, it does provide for a more orderly transition of currently deployed ADSL -based services such as high-speed internet access, to higher speed services like video. Backward compatibility also implies that the mid range and long loop (24Kft of 26AWG) connectivity of ADSL is still maintained despite the higher data rates on short loops. In addition, the transition to eXtremeDSL^{MAX} can be done with a cost structure in parity with standard ADSL since eXtremeDSL^{MAX} would enjoy the volume market created by standard ADSL.

As indicated, eXtremeDSL^{MAX} and VDSL are both capable of delivering high-speed asymmetrical physical layer connectivity such as Video-on-Demand and HDTV. VDSL on the other hand, is capable of providing high data rates in both upstream and downstream directions for short loops, which eXtremeDSL^{MAX} is not able to match. There are obviously specific applications requiring symmetrical high-speed connectivity that VDSL is able to satisfy such as EFM and symmetrical 10 Mbps.

In summary, eXtremeDSL^{MAX} and VDSL technologies are both capable of delivering ultra high-speed data rates (50 Mbps downstream). VDSL would be the transceiver of choice if the intended service is 10 Mbps symmetric (EFM). On the other hand, eXtremeDSL^{MAX} does offer a more graceful and cost effective transition to asymmetrical high-speed services intended for residential and small businesses.

5 Contact Information

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