EFM Capabilities with Plan 998

Performance analysis of the standard VDSL technology using spectral plan 998

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Supporters

- **Sabit Say, Todd Pett: Next Level Communications**
- **Danny Gur, Idan Alrod: Metalink**
- **Steven Haas, John Egan: Infineon**
- **Rami Verbin: Tioga Technologies**
- **Juri Sipila: VDSL Systems**
- **Ron McConnell: Telebyte**

Goal

Intensive analysis of spectral plan 998, aimed to:

- **Check compliance with the requirements indicated by service providers**
- **Find ways for improvement**

NOTE:

All presented results are based on the current standard single-carrier modulation (SCM) technology. It uses the worst-case description of the loop topology and noise environment, and considers all transmit signal limitations adopted for North American access networks.

Requirements

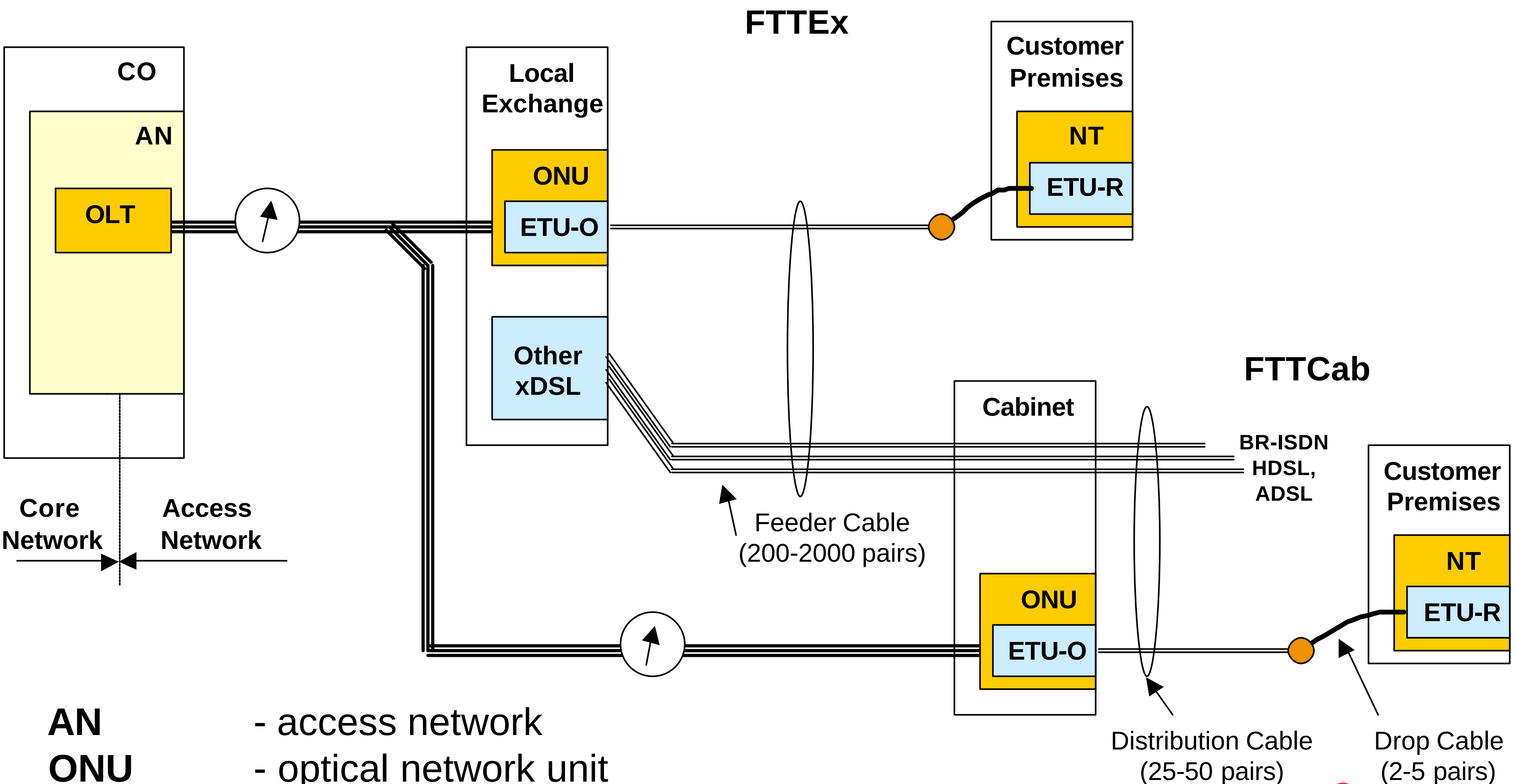
Analysis of extensive discussions on EFM reflector leads to the following conclusions regarding the copper EFM performance requirements

- **Reach:**
  Minimum**:** 2.5 kft with at least 10 Mb/s aggregate
  Maximum : up to CSA (9 kft @ 26AWG) and more

- **Main services:** 2-3 video channels (VoD and broadcast)
  high speed data
  high quality audio

- **Spectral compatibility**
  Environment: unbundled
  Compliance: T1.417, NRIC-V (spectral plan 998), ITU-T, ETSI
  Consideration: HPNA

Typical installation



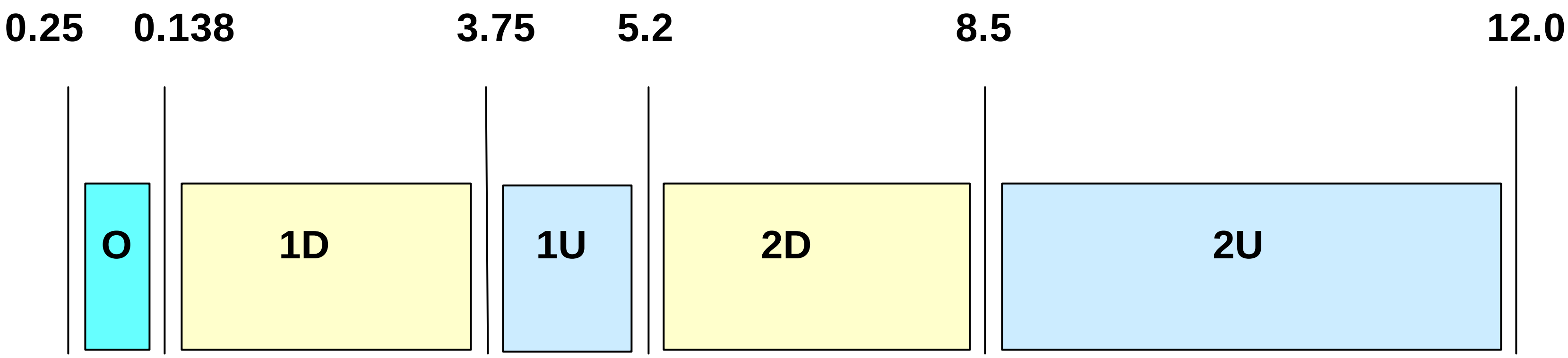
AN - access network
ONU - optical network unit
ETU - EFM transmission unit

Plan 998: Background

- **Plan 998 was proposed by international group of operators (FSAN) in 1999 to accommodate the most popular services**
- **Plan 998 was accepted by T1E1.4 and NRIC-V as the only spectral plan above 1.104 MHz to be used in North America**
- **Plan 998 is currently proposed to ITU-T as a U.S. position to be internationally recognized for only use in North America**
- **Plan 998 was accepted by ETSI as a regional plan for Europe**
- **Japan requested ITU-T to consider 998 as the national spectral plan**

Plan 998: Overview

- **Five bands of 998 allow accommodation of symmetric and asymmetric services over loops of different length**

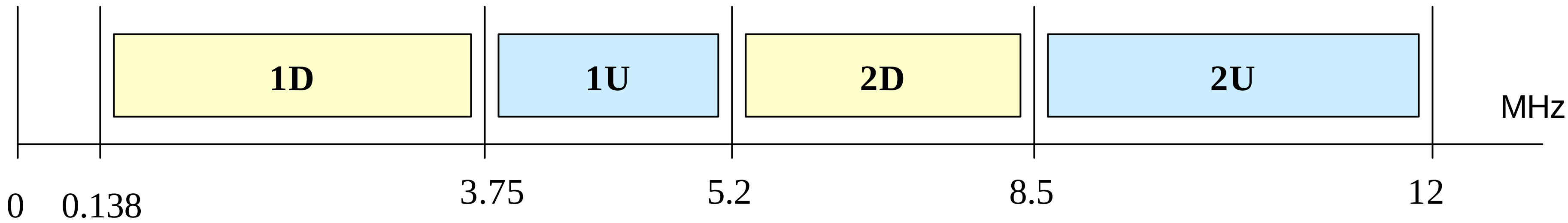


- **1.** Band "O" is optional and could be used for either upstream or downstream transmission

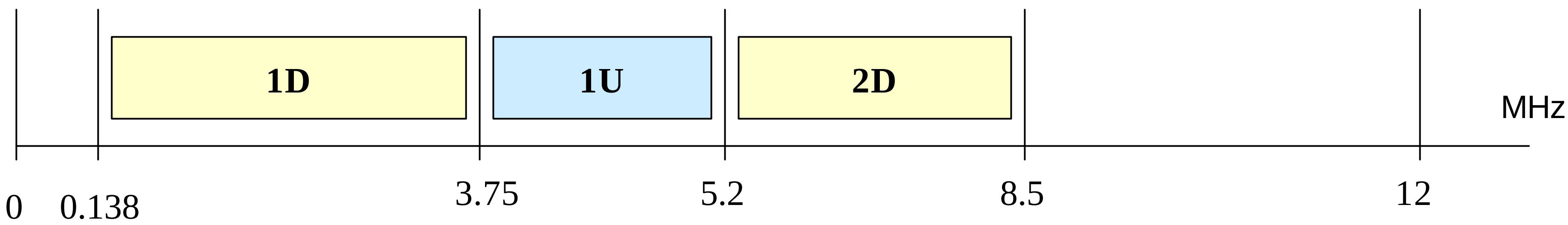
- **2**. Band "O" can't be used if EFM shares the same pair with BR-ISDN

Plan 998 for short and medium loops

Case 1: Short loops: < 2.5 kft @ 26 AWG



Case 2: Medium loops: 2.5 - 3.5 kft @ 26 AWG



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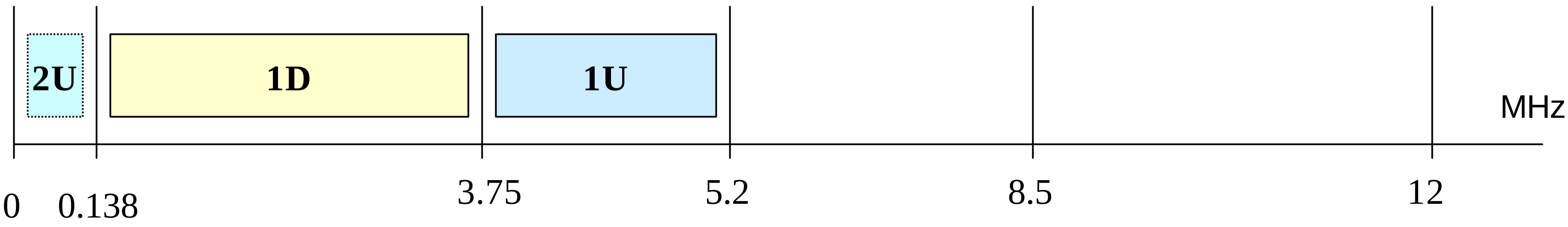
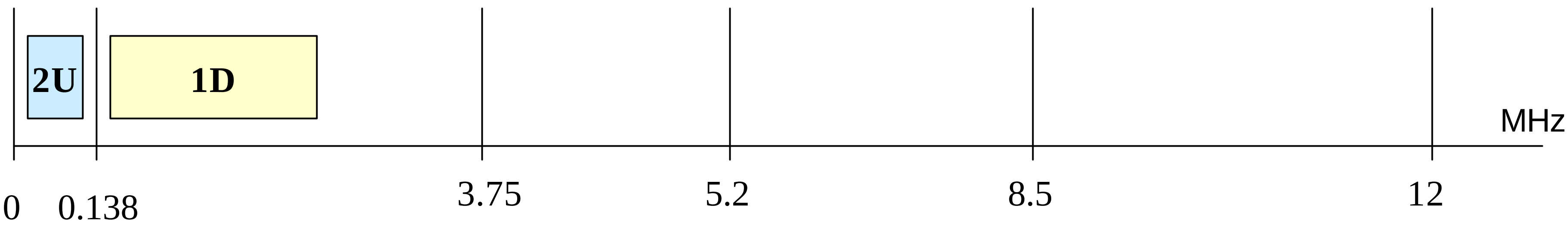
Plan 998 for medium and long loops

Case 3: Medium loops: 3.5 - 4 kft @ 26 AWG



Case 4: Long and very loops: 4 - 15 kft @ 26 AWG



Method of performance evaluation

Performance of any loop of length ***L*** in both upstream and downstream direction is evaluated by its channel capacity ***C:***

$$C(L) = \int_{\Delta F} \log_2 \left[1 + \frac{SNR(f,L)}{G} \right] df \,,$$

- ***SNR(f,L)*** - receiver signal-to-noise ration
- ***G*** - SNR gap

$$SNR = \frac{S(f) H^2(f,L)}{FEXT(n,f,L) + BGN(f)} \,,$$

- ***S(f)*** - PSD of the transmit signal
- ***H(f,L)*** - module of the loop transfer function
- ***FEXT*** - self-FEXT PSD from ***n*** EFM disturbers
- ***BGN*** - background noise PSD, includes WGN, quantization noise, and crosstalk from other xDSL.

Noise environment

- **Self-FEXT of 20 EFM disturbers**

  - FEXT coupling function for the 99% worst case:

$$FEXT = 8 \cdot 10^{-20} \cdot L \cdot f^{2} \cdot \left(\frac{n_{fext}}{49} \right)^{0.6} \cdot H^{2}(f, L)$$

- **Self-NEXT is not considered (FDD duplexing)**

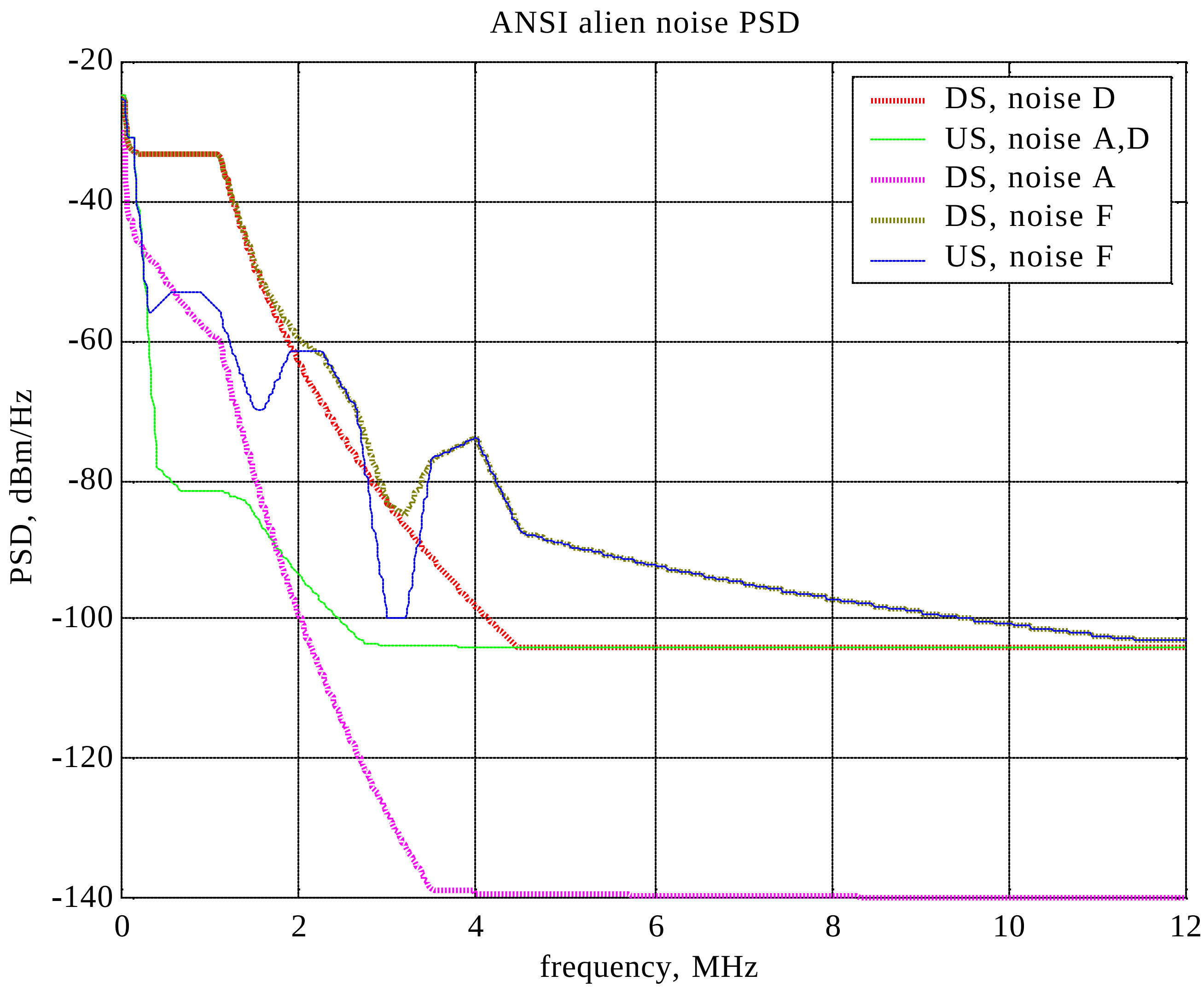
- **Background noise**
  - WGN of -140 dBm/Hz
  - Quantization noise of -146 dBm/Hz
  - Alien crosstalk (NEXT and FEXT from other xDSL)

Alien crosstalk

It was adopted in standard bodies to specify alien crosstalk by noise models

- **T1E1.4 specifies two models: A and F. Additional model D was also considered in this analysis**
- **Model A - applied for cabinet-based deployments (FTTCab)**
  - crosstalkers: 16 BR-ISDN, 10 EC-ADSL, 4 HDSL
  - 3 kft minimal distance from the exchange
- **Models D,F - applied for exchange-based deployments (FTTEx)**
  - crosstalkers D: 16 BR-ISDN, 10 EC-ADSL, 4 HDSL
  - crosstalkers F: 16 BR-ISDN, 10 EC-ADSL, 4 HDSL, 2 T1
  - T1 only in the adjacent binders

Combined PSD of alien crosstalk



Upstream power back-off

- **The standard (T1E1.4/ITU-T/ETSI) UPBO method used**

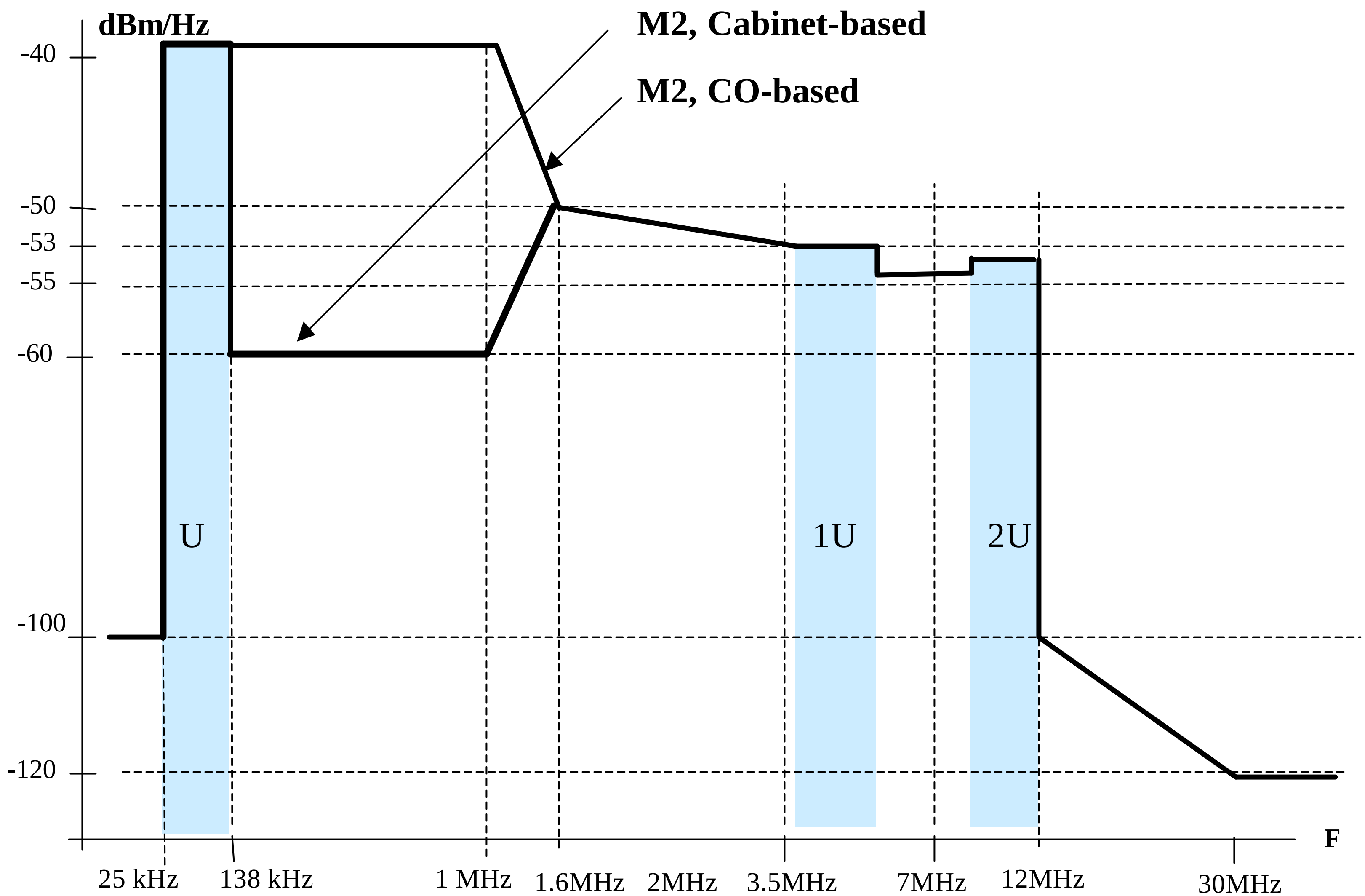
The transmit PSD in the upstream direction set by estimation of the electrical length l_e of the loop as:

$$TxPSD = \min\{\, PSD\_REF + k l_e \sqrt{f}\ ,\ PSD_0 \},\ \text{dBm/Hz}$$

- **The used standard value of Reference PSD (PSD_REF) is optimized for service bit rates between 3 to 9 Mb/s**

- **The worst case loop topology considered for upstream performance (concentrated topology)**

Transmit PSD mask

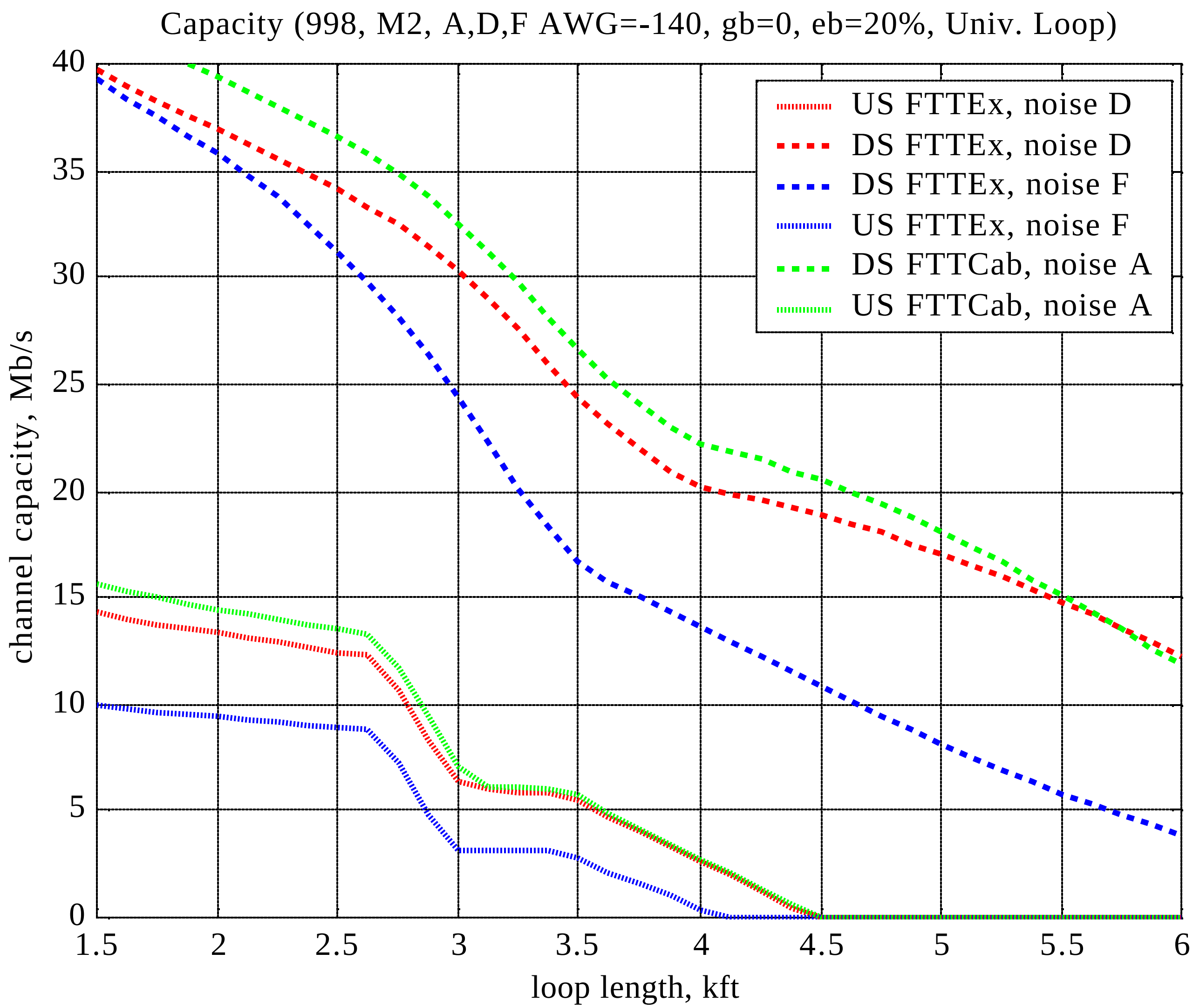


Other simulation data

Transmit PSD	Standard T1E1.4 Mask M2
Transmit power	14.5 dBm, except 11.5 dBm for FTTCab downstream
Shaping	Square-root raised cosine (Tx and Rx)
Excess bandwidth	20%
Coding gain	3.8 dB
Noise margin	6.0 dB
Shannon gap	9.8 dB
SNR gap	9.8 - 3.8 + 6 = 12 dB

Loop type	Universal loop – model of mixed TP1 (26AWG) and TP2 (24AWG), CSA=10.3 kft
Bridged taps	NO

Plan 998: Short and medium loops



Note: no optional band used

Observation 1

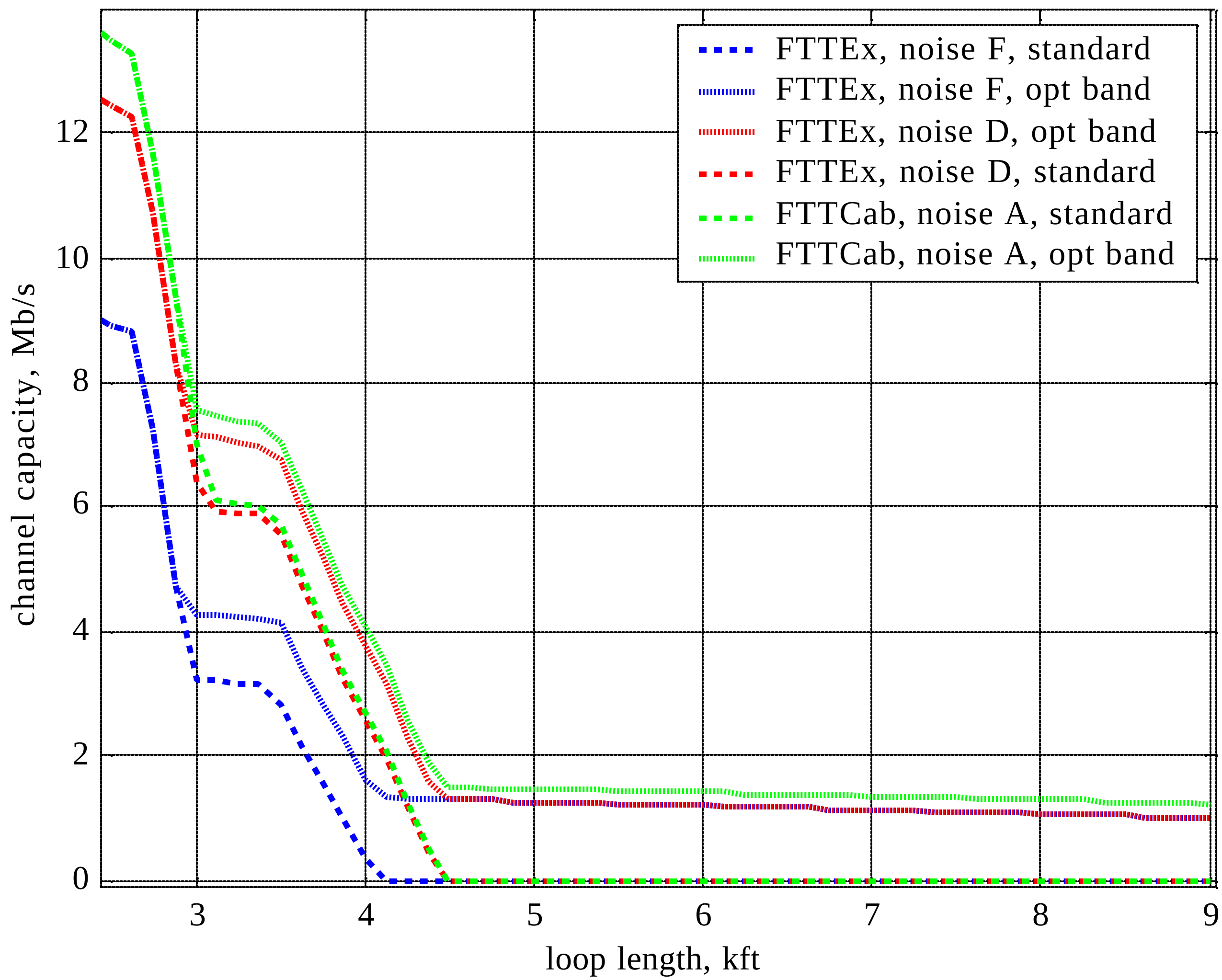
- **Plan 998 allows**
  - downstream bit rates greater than 22 Mb/s (three video channels) with upstream bit rates more than 3 Mb/s for distance of about 3.5 kft

  - symmetric bit rates greater than 10 Mb/s (20 Mb/s aggregate) for distance of about 2.7 kft

- **Performance of a standard 998 with no optional band used is limited by the upstream capacity**

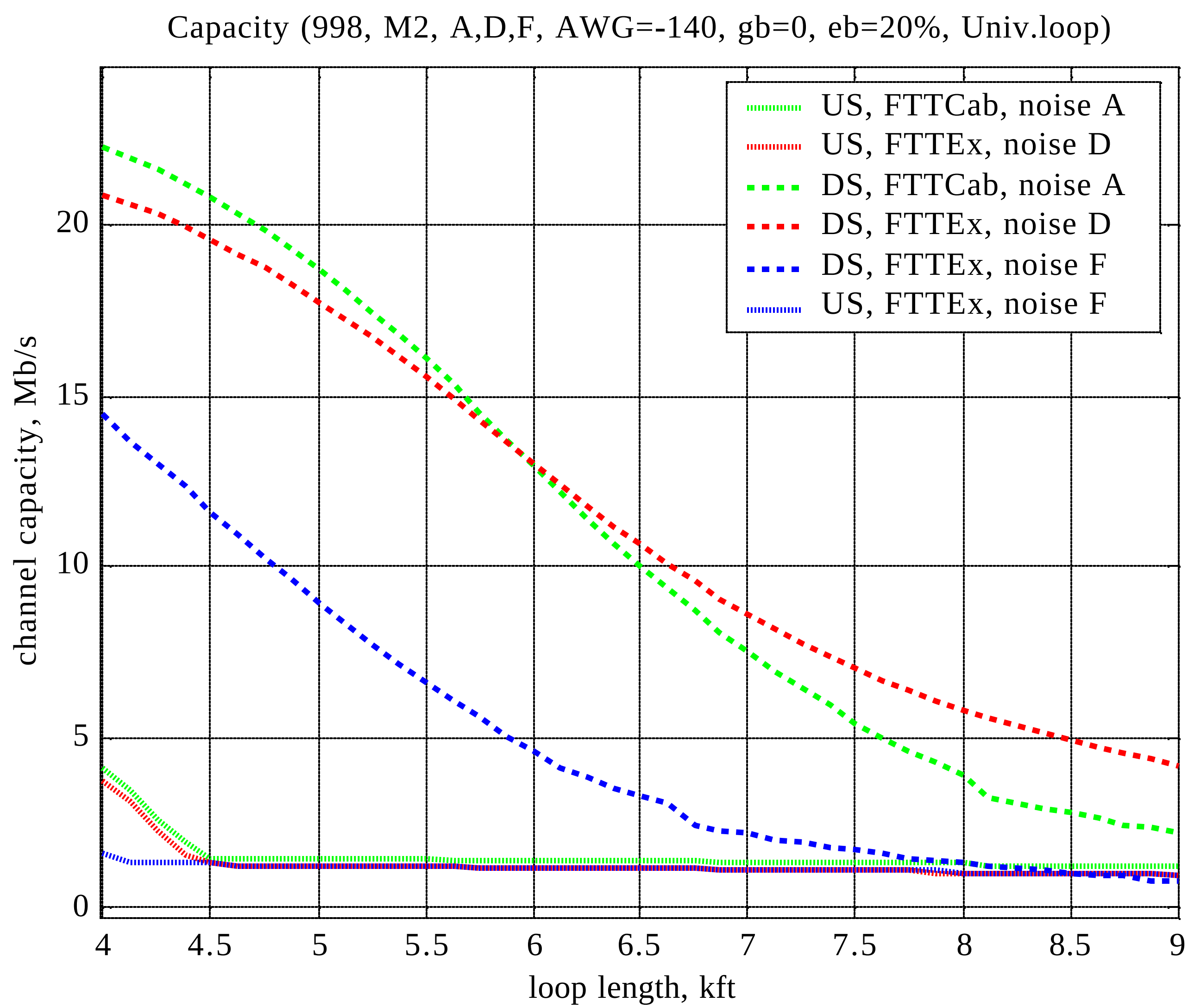
Optional band for more upstream

Upstream capacity (998, M2, A,D,F, AWG=-140, gb=0, eb=20%, Univ.loop)

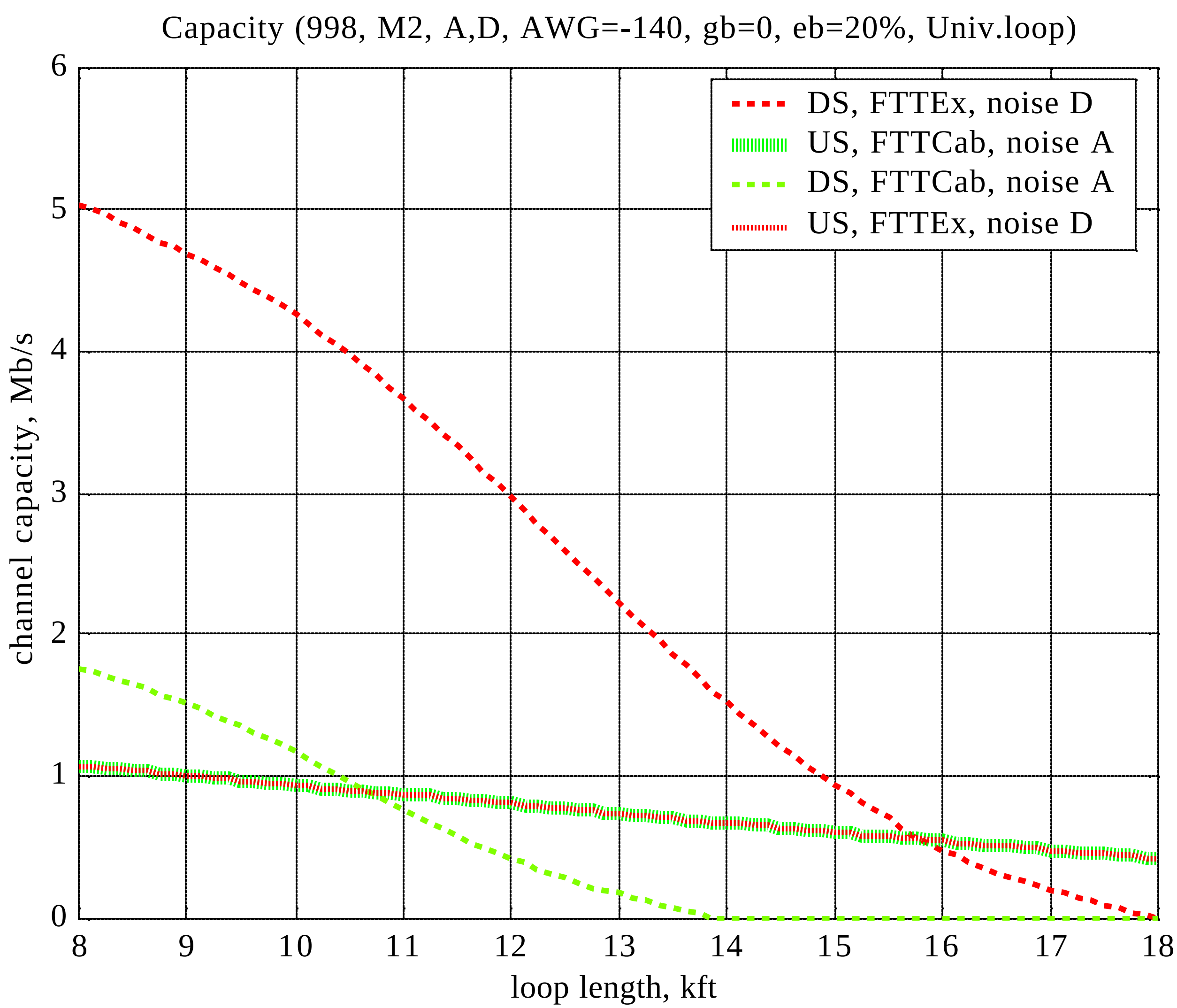


Note: No restrictions on signal constellation applied for the optional band

Plan 998: Long loops



Plan 998: Very long loops



Observation 2

- **With optional upstream band used plan 998 allows:**

  - reach of up to 10 kft with at least 1/1 Mb/s capacity

  - reach of up to 16 kft with at least 0.5 Mb/s capacity for Exchange-based deployments

  - reach of up to 12 kft with at least 0.5 Mb/s capacity for Cabinet-based deployments

- **Performance of 998 with optional upstream band used is limited by the downstream capacity**

Plan 998: performance summary

Service (channel capacity)	Maximum reach (no T1) kft
3 video channels and data (~ 22 Mb/s)	3.8
2 video channels and data (~ 16 Mb/s)	4.2
Data (10/10 Mb/s)	2.7
Data (16/1 Mb/s)	4.2
Maximum reach with no optional band	4.4
Data (1/1 Mb/s)	10
Maximum reach (data 0.5/0.5 Mb/s)	16

How to improve it?

- **Upstream performance for long loops can be improved by extending the upstream band up to 300-500 kHz. The improvement of the upstream performance, however, comes on the account of downstream performance. Expected to be good for 4-7 kft loops.**

Conclusion

- **Standard plan 998 demonstrates excellent performance characteristics for video and data transmission for deployments with loop length below 4 kft**
- **For longer loops performance is limited by the upstream, however usage of optional upstream band extends the reach up to 10 kft with channel capacity of at least 1 Mb/s**
- **The absolute maximum reach is limited by the downstream to 16 kft with channel capacity of at least 0.5 Mb/s**
- **Further improvement for long loops may be achieved by extending the optional upstream band over 138 kHz**