ELASTIC
NETWORKS

Fast Robust Ethernet in the First Mile

Ethernet end-to-end

End Points are Ethernet

- 90% of LANs are Ethernet
- Ethernet Used at Desktop
- Ethernet Used at Servers

Ethernet is the most efficient way to carry IP traffic

- TCP/IP Stack fits naturally on top of Ethernet
- Internet Protocol (IP) is driving today's internet
- Multiservice IP will drive the emerging applications :
  VoIP, Interactive TV, Presence, Chat, etc.

Ethernet is the most cost effective network

- Optical Ethernet exploding in MAN/WAN
- Much Cheaper than ATM
- QOS continues to improve – Traffic Shaping, Policy Manager, Priority Queuing, etc.

Copper Based EFM Bridges
LAN to MAN

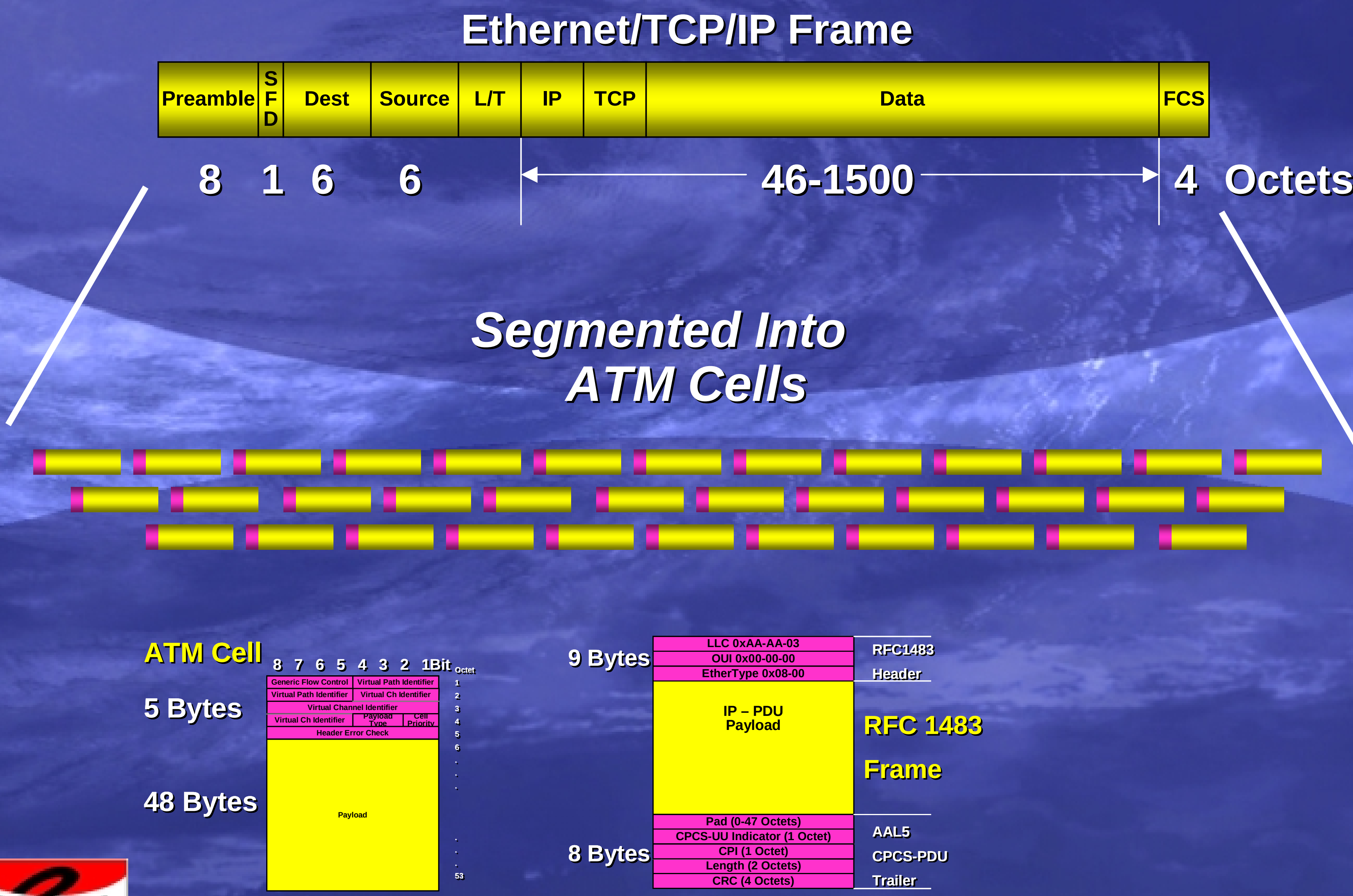
Ethernet in the First Mile

- Interfaces should be 802.3 compliant
- No SAR - One solution is to encapsulate Ethernet Frames in HDLC

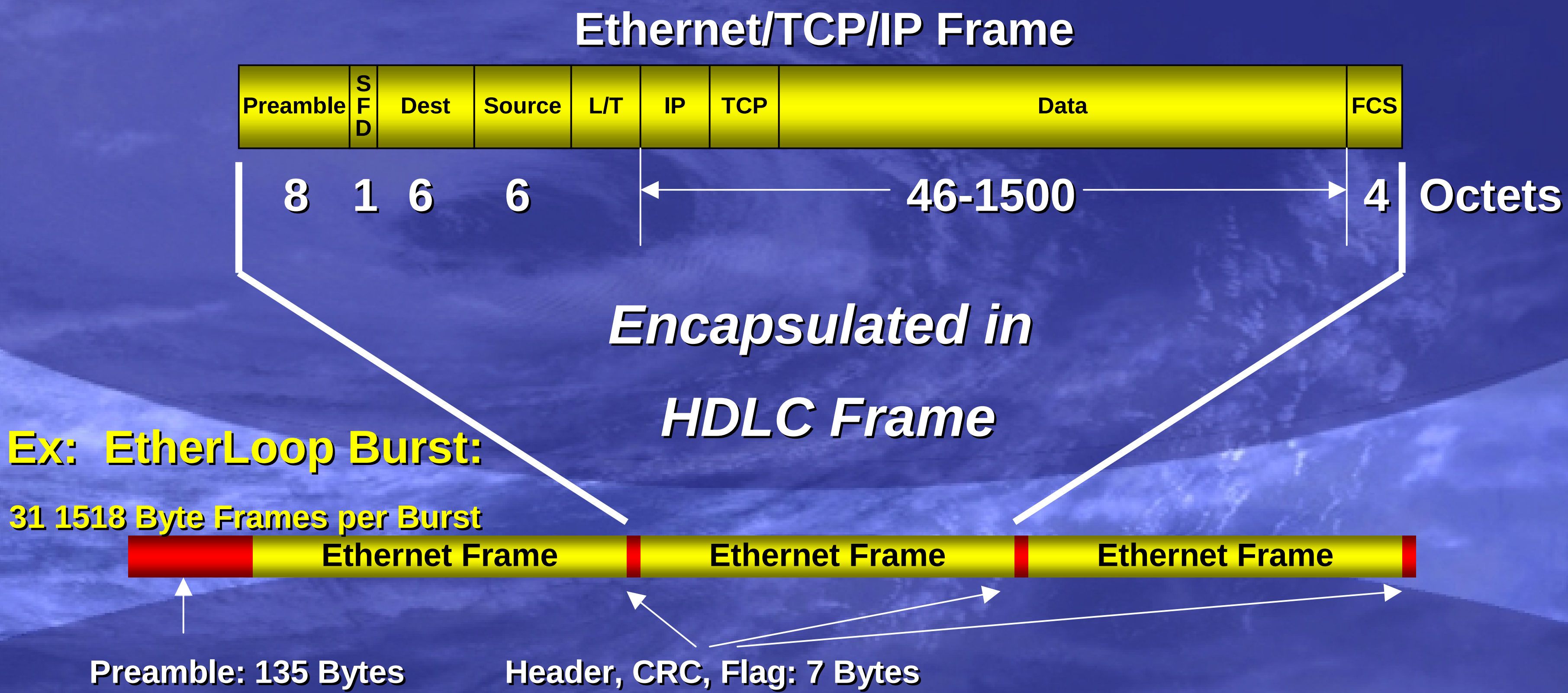
Should Leverage Existing Copper Infrastructure

- The future is fiber (greater bandwidth, lower BER)
- Fiber deployment is growing, new builds often include fiber at the start
- BUT… far more consumers are served today by twisted pair than by fiber
  - YANKEE Group estimates 5-7% of market served by fiber
- Cost of building fiber infrastructure is significant.
- Copper Loop based EFM can cost effectively provide bandwidth today

Ethernet Over ATM



Ethernet encapsulated in HDLC



Packet Size (Bytes)	EtherLoop	ATM
1518	0.7%	11.0%
64	0.7%	30.0%

Transport Overhead

Modeling the Copper Loop

Copper Loop Environment

- Requires a solution beyond today's DSL
  - Must adapt to frequency slope
  - Must equalize effects of bridged taps
  - Should continuously adapt to environment
    - Maintain maximum possible throughput
    - Ensure Spectral Compatibility

Industry Standard Models Exist

- ANSI T1E1.4
- ETSI
- FSAN

T1.417 Spectrum Management Standard Published

T1.417-2001 Spectrum Management for Loop Transmission Systems Standard published on 2/28/01

- Two Methods of Proving Spectral Compatibility
  - Membership in 1 of 9 Spectrum Management Classes
  - Standardized Analysis – Method B
- Some of the symmetric SM Classes have deployment restrictions
- Short-Term Stationary (Burst) Conformance Criteria
  - Elastic Networks was a principal author
  - Ensure Spectral Compatibility

Contains Standardized Models for Loop environment

- Loop Insertion Gain Models
- NEXT and FEXT Models
- Mixed Crosstalk Models

Standardized Curve Fit Loop Model

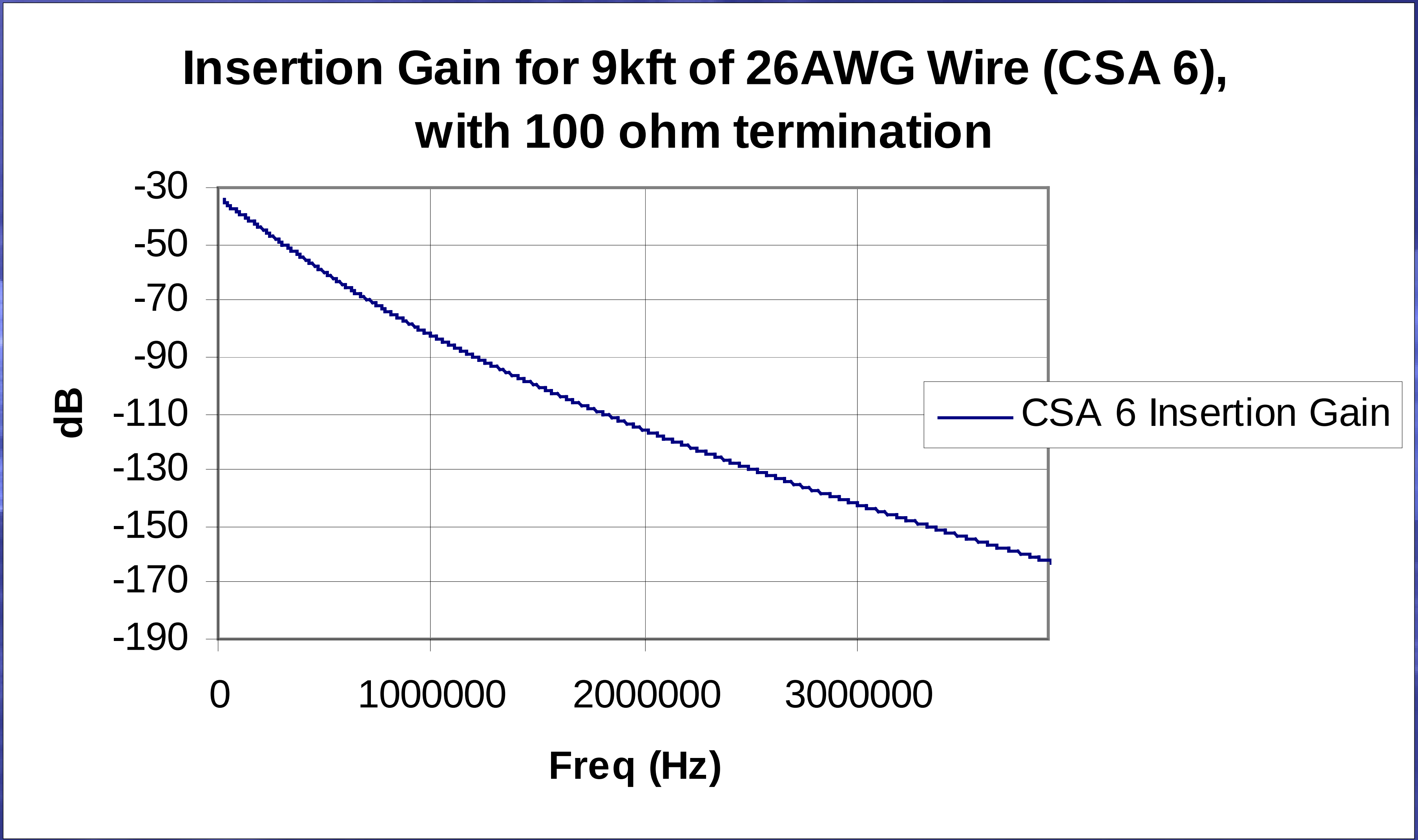
$$R(f) = \frac{1}{\dfrac{1}{\sqrt[4]{r_{OC}^{4} + a_{C} \cdot f^{2}}} + \dfrac{1}{\sqrt[4]{r_{OS}^{4} + a_{S} \cdot f^{2}}}}$$

$$L(f) = \frac{l_{0} + l_{\infty} \left(f / f_{m} \right)^{b}}{1 + \left(f / f_{m} \right)^{b}}$$

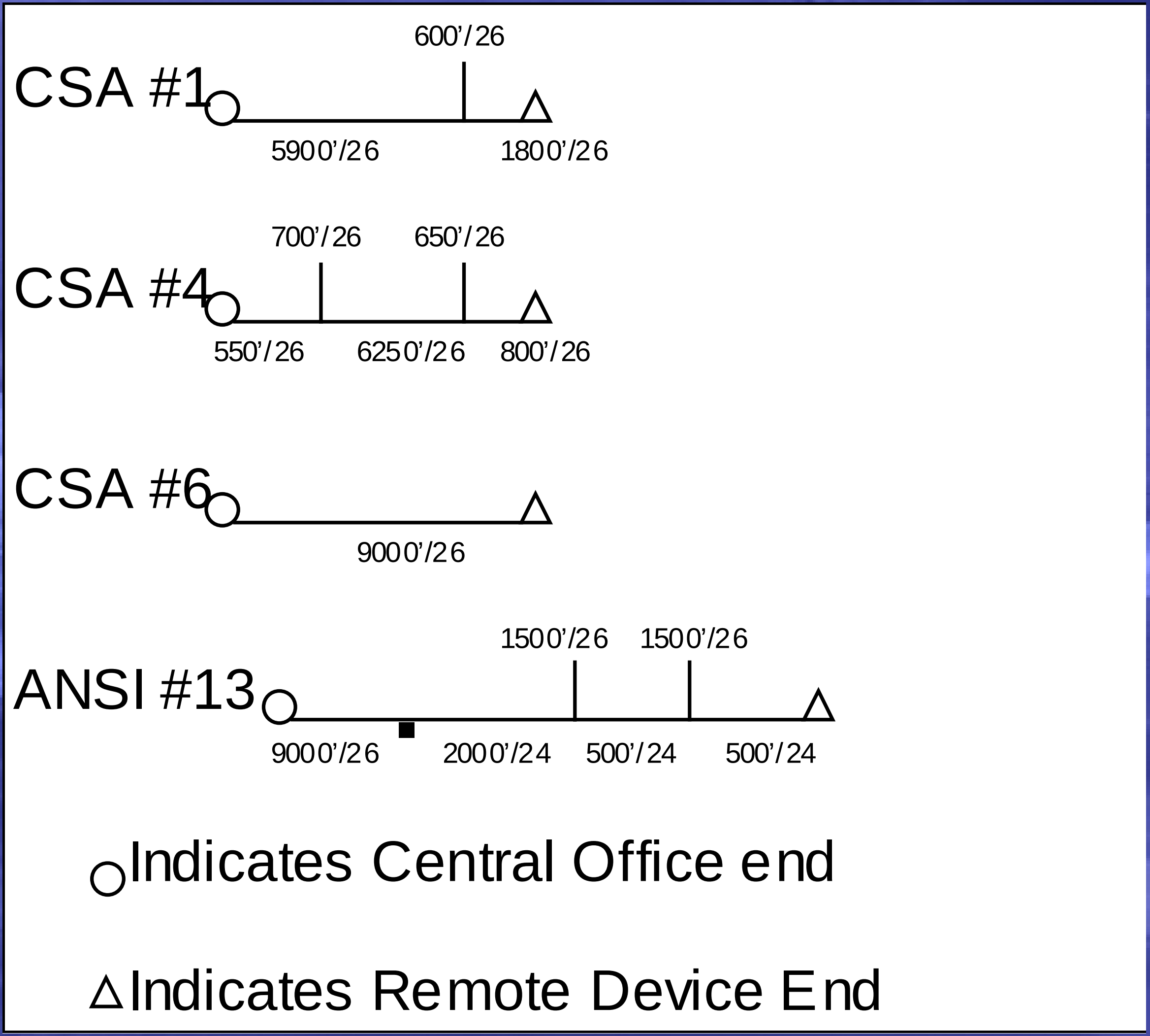
$$C(f) = c_{\infty} + c_{0} \cdot f^{-c_{e}}$$

$$G(f) = g_{0} \cdot f^{+g_{e}}$$

Copper Environment: Attenuation Slope



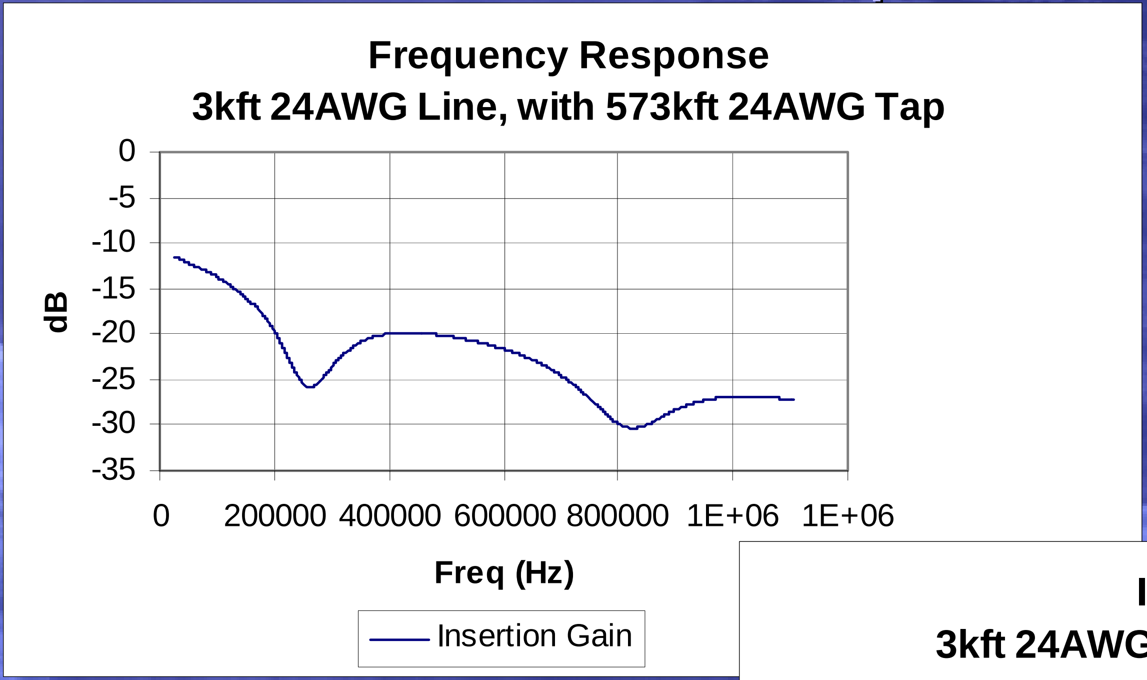
Loop Topologies

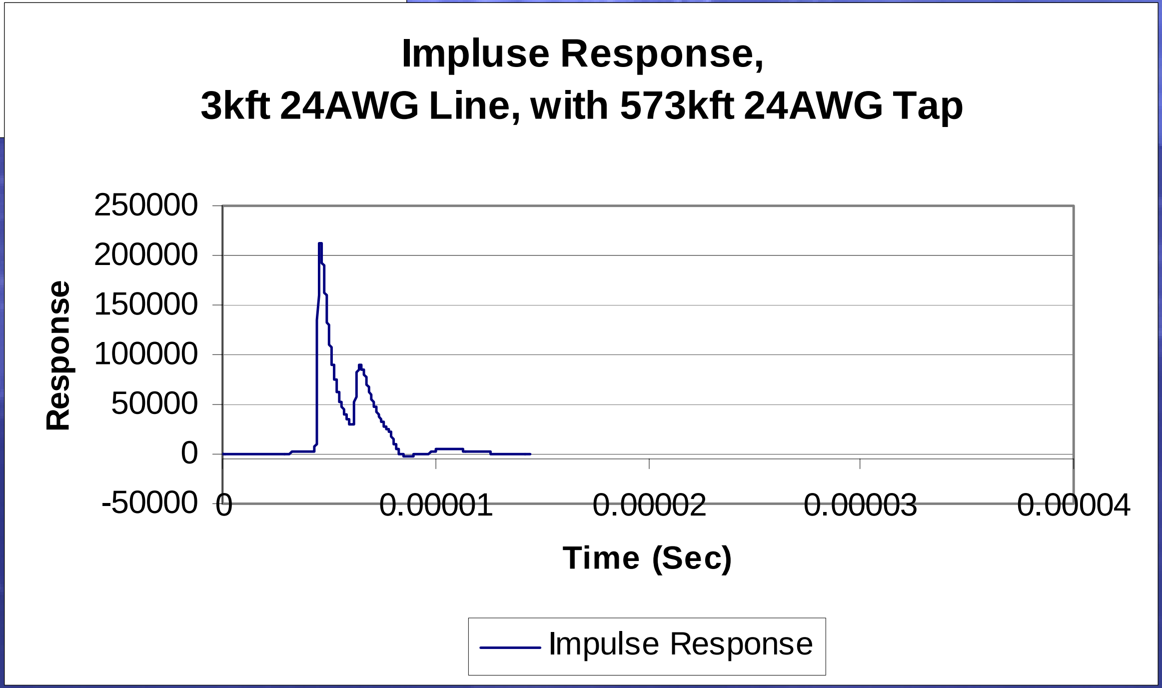


Complex Topologies modeled by cascading 2-port ABCD models of segments with different gauges and lengths, and 3-port ABCD models of bridged taps

Some CSA & ANSI Loops

Copper Environment: Bridged Tap Echos





NEXT models

Two Piece Unger Model

- Typically used for baseband signals
- Uses one slope below 20kHz, and another slope for higher frequencies.
  - For one disturber, the Unger model uses a slope of 6dB per decade below 20kHz, and 15 dB per decade above 20kHz

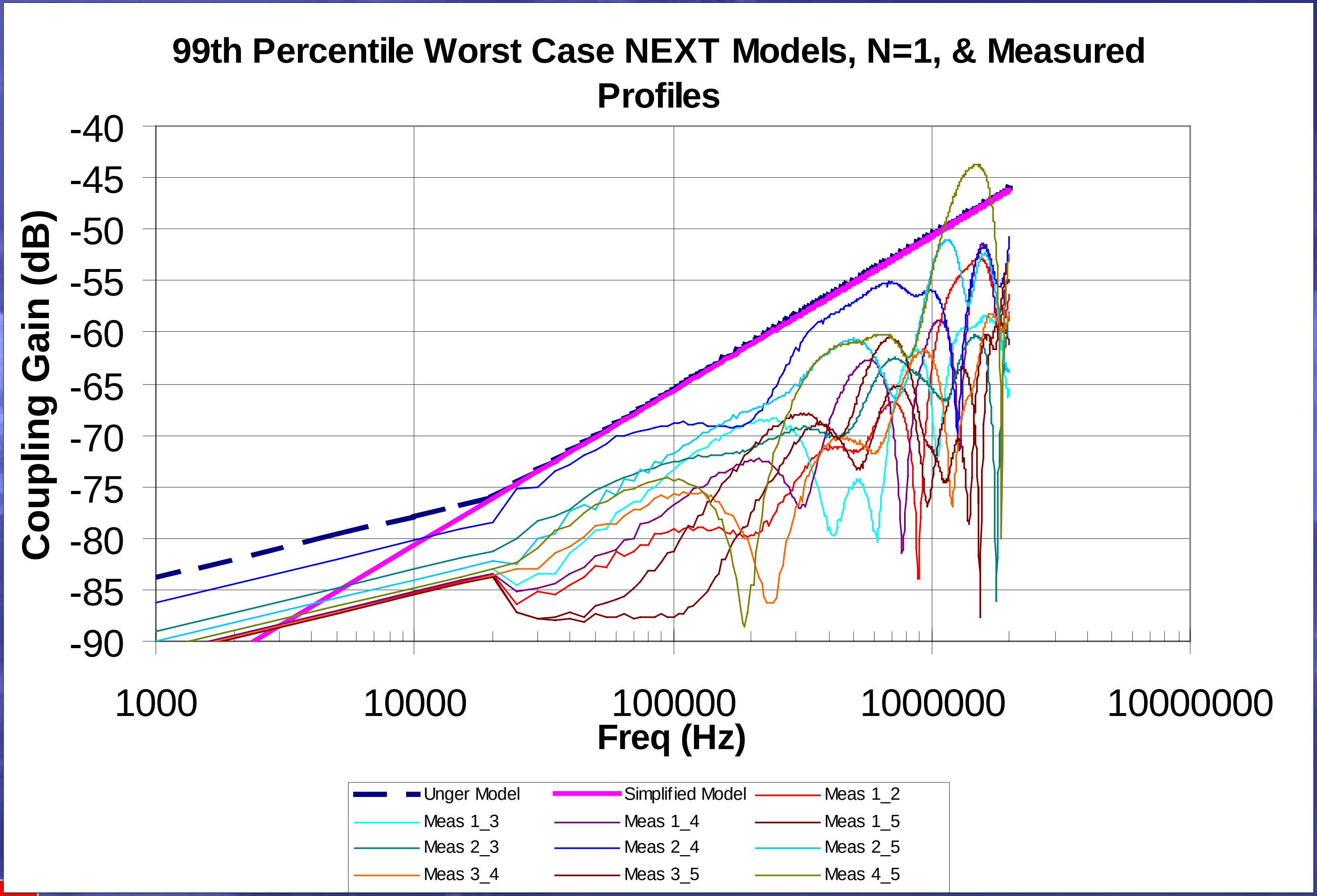
Simplified T1E1 Model

$$NEXT_n = x_n \times f^{3/2}$$

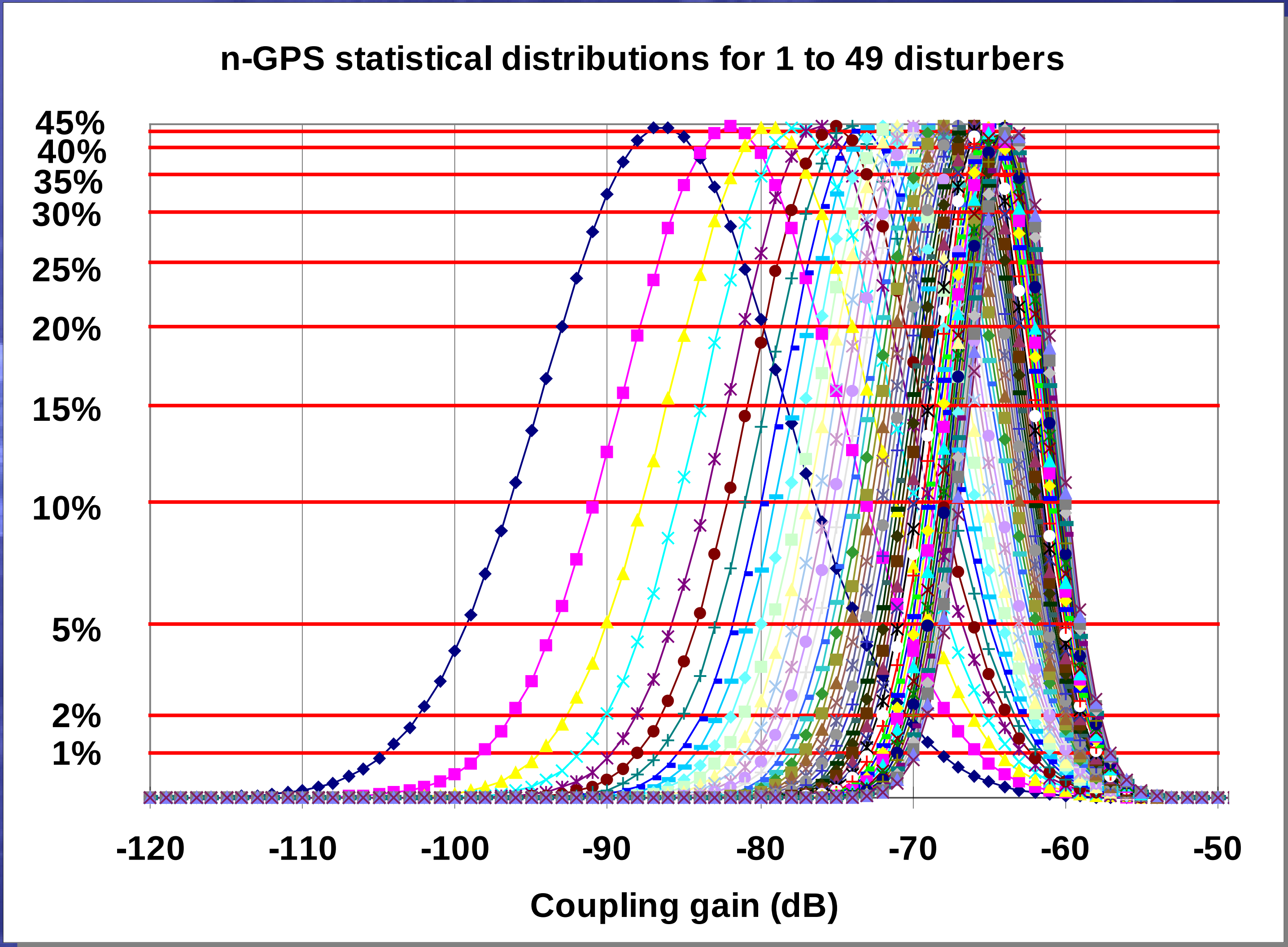
$$x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$$

n is the number of disturbers, and f = the frequency in Hz.

NEXT measurements



NEXT Statistics



FEXT Model

$$FEXT_n = \left|H_{channel}(f)\right|^2 \times klf^2$$

$$k = 8 * 10^{-20} * (n/49)^{0.6}$$

n = number of disturbers, l = the loop length in feet, and f = frequency in Hz.

$\left|H_{channel}(f)\right|^2$ is the channel insertion gain

FSAN Mixed Disturber Model

$$Next\,[f] = \left(\left(S_1[f]\, X_N\, f^{3/2}\, n_1^{0.6} \right)^{1/0.6} + \ldots + \left(S_i[f]\, X_N\, f^{3/2}\, n_i^{0.6} \right)^{1/0.6} \right)^{0.6}$$

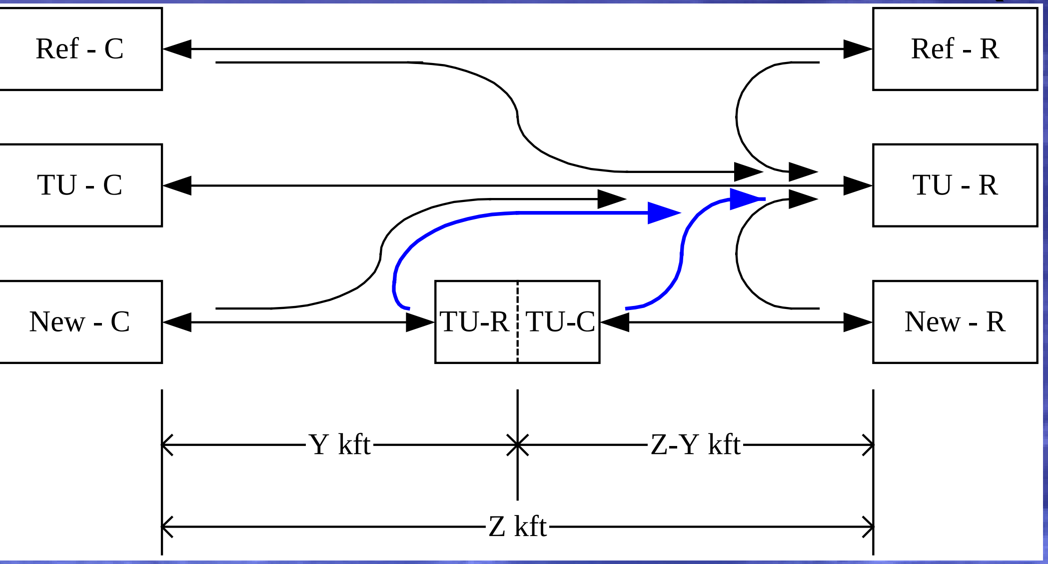
$$Fext[f] = \left(\left(S_1[f]\, H_1^{2}[f]\, X_F\, f^{2}\, l_1\, n_1^{0.6} \right)^{1/0.6} + \ldots + \left(S_i[f]\, H_i^{2}[f]\, X_F\, f^{2}\, l_i\, n_i^{0.6} \right)^{1/0.6} \right)^{0.6}$$

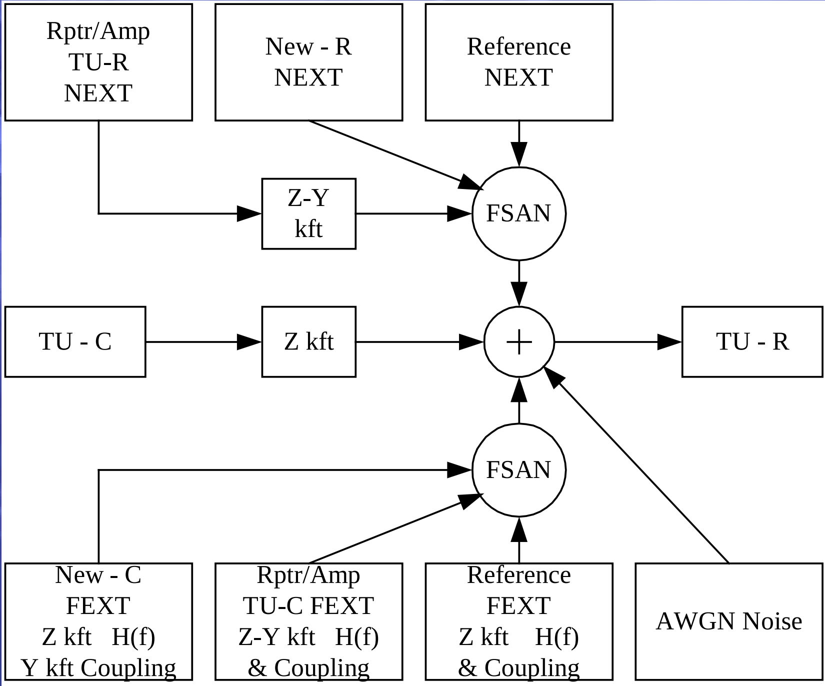
$S_i[f]$ is the PSD of the disturber, and $H_i[f]$ is the insertion gain of the loop

- No physical significance to this model
- Analytical tool, with these characteristics:

1. Reduces to the identical disturber equation for disturber type j, if $S_i = 0$ or $n_i = 0$ for all $i \neq j$.
2. Reduces to the identical disturber equation if $S_i = S_j$ for all $i \neq j$.
3. Generates nondecreasing crosstalk power as more disturbers are added.
4. Treats all disturbers equally.

Intermediate Transmission Unit (TU-I)



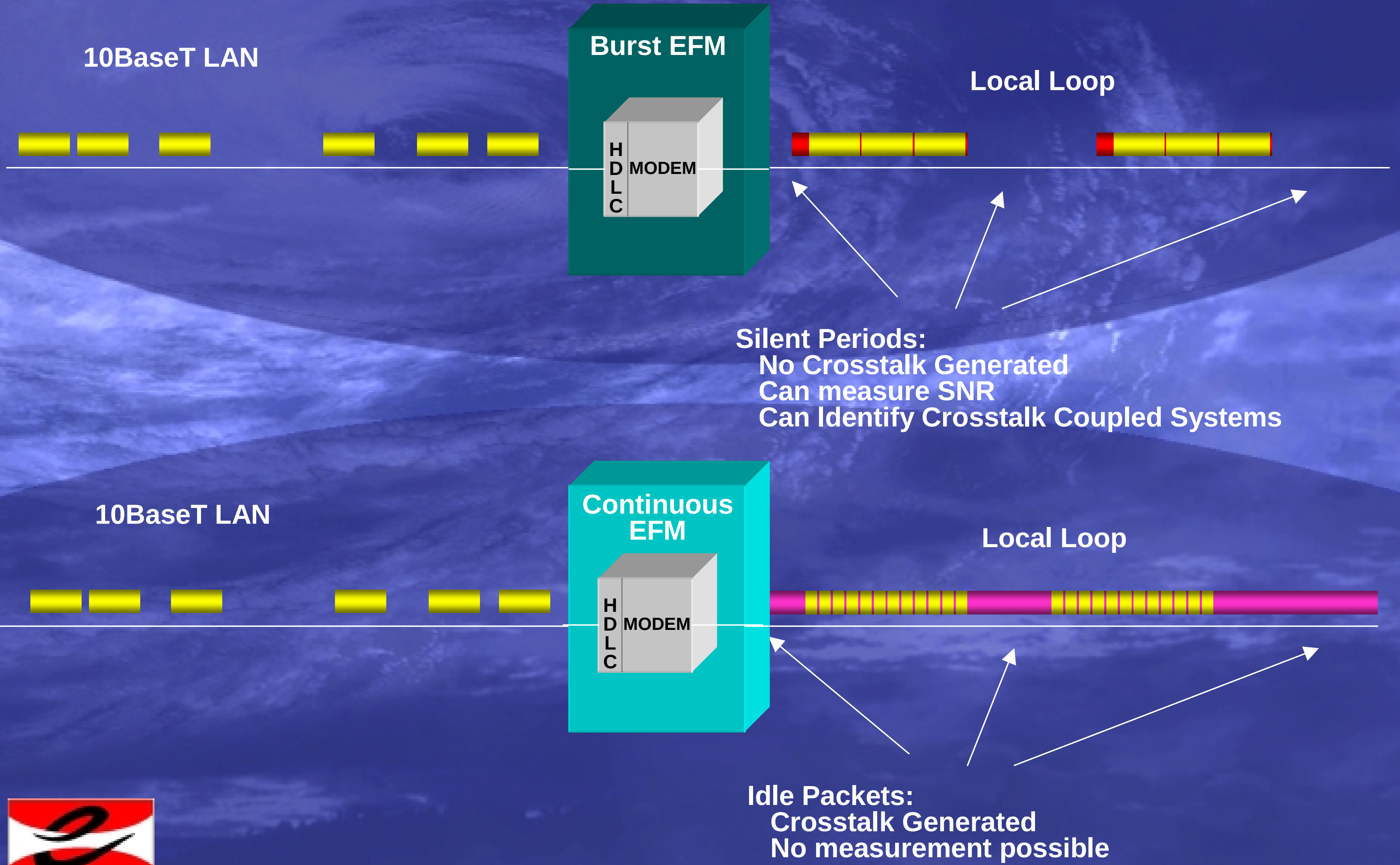


Crosstalk Model for NEXT & FEXT from a repeater

Directional Multiplexing Choices

- ~~SINGLE BAND, FULL-DUPLEX~~
  - ~~NEXT-LIMITED~~
- ~~FREQUENCY DIVISION, FULL-DUPLEX~~
  - ~~CONSTRAINS TRAFFIC SYMMETRY~~
  - ~~UPPER FREQUENCY BAND HAS SHORTER REACH~~
- TIME DIVISION, HALF-DUPLEX
  - BURST TRANSMISSION
  - SINGLE BAND, REDUCED NEXT
  - SYMMETRY AGILE
  - FREQUENCY AGILE

Burst Mode vs. Constant Transmissions



Spectrum Manager™

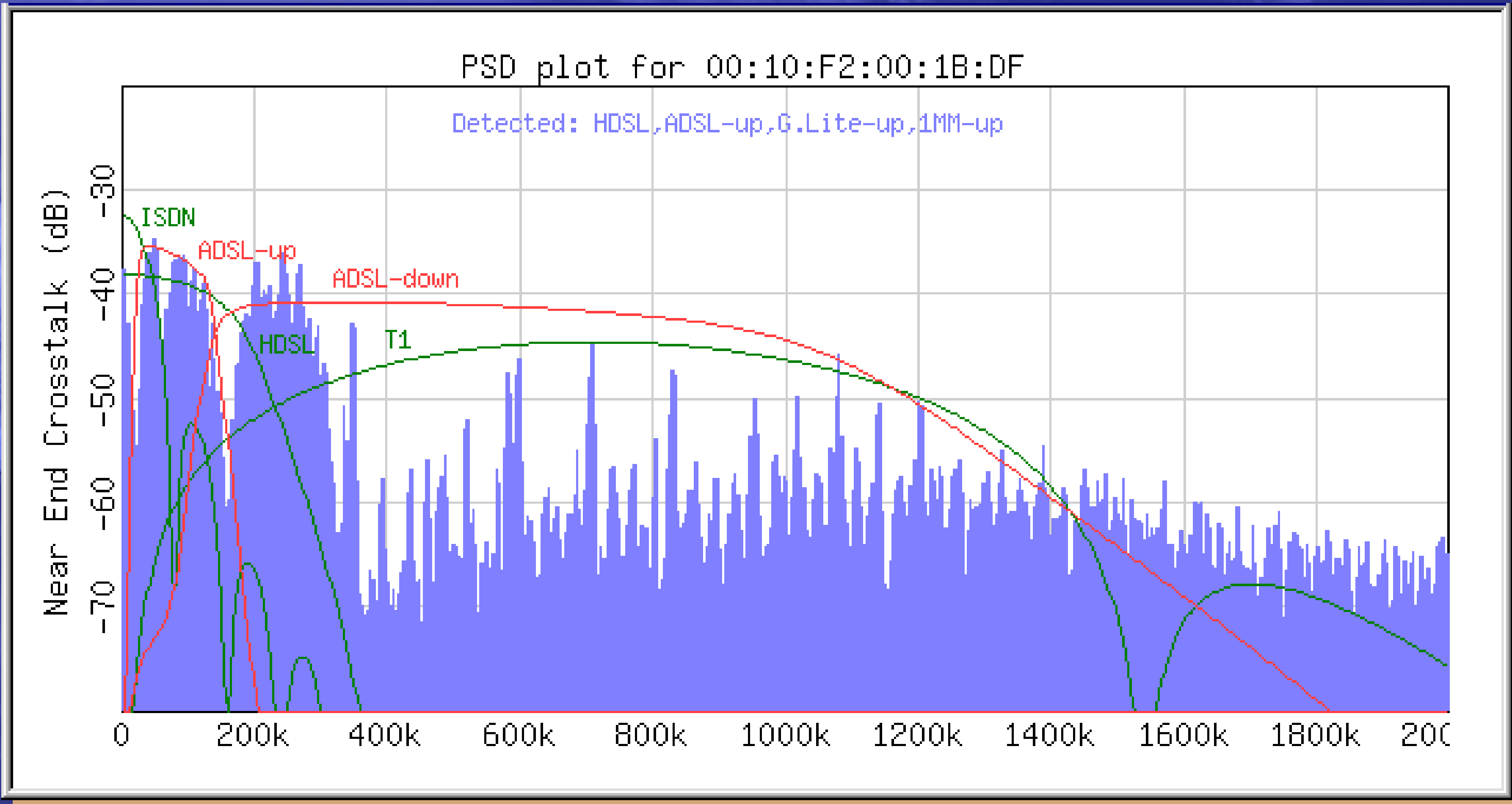
Patented Spectral Compatibility Method

- Don’t need to design for worst case – continuously measures actual coupling on every loop
- No Deployment restrictions, automatically ensures spectral compatibility
- Allows remote monitoring of Spectrum, while in service

Distributed Processing

- Scalable – each modem performs capture and identification
- Centralized Management – NOC server queries modems
- Allows remote monitoring of Spectrum, while in service

Spectrum Manager Analysis



Spectral Compatibility

Safe Mode

If significant coupling is present with FDD system, then Robust EFM emulates the FDD bandplan

National Reliability and Interoperability Council V (NRIC5)

Chartered to advise FCC on Spectrum Management Issues

Has made recommendation on use of spectrum above 1.1MHz:

NRIC5 Recommendation

For frequencies from 1.1 MHz to 12 MHz:

1. T1E1 has selected a single high- frequency band plan (known as FSAN 998) for frequencies from 0.138 to 12 MHz for use in the VDSL draft trial use standards, after substantial efforts to optimize it for multipleservice types. FG3 acknowledges the selection of this plan and recommends that this good work be recognized and supported by the FCC as the default high- frequency band plan for use in the United States.

2. We recommend that T1E1 define PSD levels, transmit power limits, and spectral compatibility criteria for signals that support this default band plan (FSAN 998). These parameters should be specified for both the central office and customer premises locations.

3. FG3 further recommends that T1E1 include the determined PSD levels, transmit power limits, and spectral compatibility criteria in the second issue of the SM standard for protecting systems using frequencies 1. 1 MHz to 12 MHz from harm. The development of the spectral compatibility criteria should assume that only Plan 998 systems utilize frequencies 1.1 to 12 MHz.

4. The following pertains to systems that do not follow the default band plan (FSAN 998) in the frequencies from 1.1 to 12 MHz.

* **a) Frequency agile technologies may deviate from this plan if they continuously monitor monitor and default to the FSAN 998 plan if they are coupled to technologies adhering to the plan.**

b) Systems not complying with the default band plan must show spectral compatibility per a compliance criteria (see #3 above) determined for the default plan. This requires that Annex A in the next issue of the SM standard contain the compatibility criteria of item #3 to show spectral compatibility in the frequencies of 1. 1 to 12 MHz.

5. FG3 is evaluating the use of an alternative band plan under controlled or limited deployment scenarios.

EtherLoop Speeds

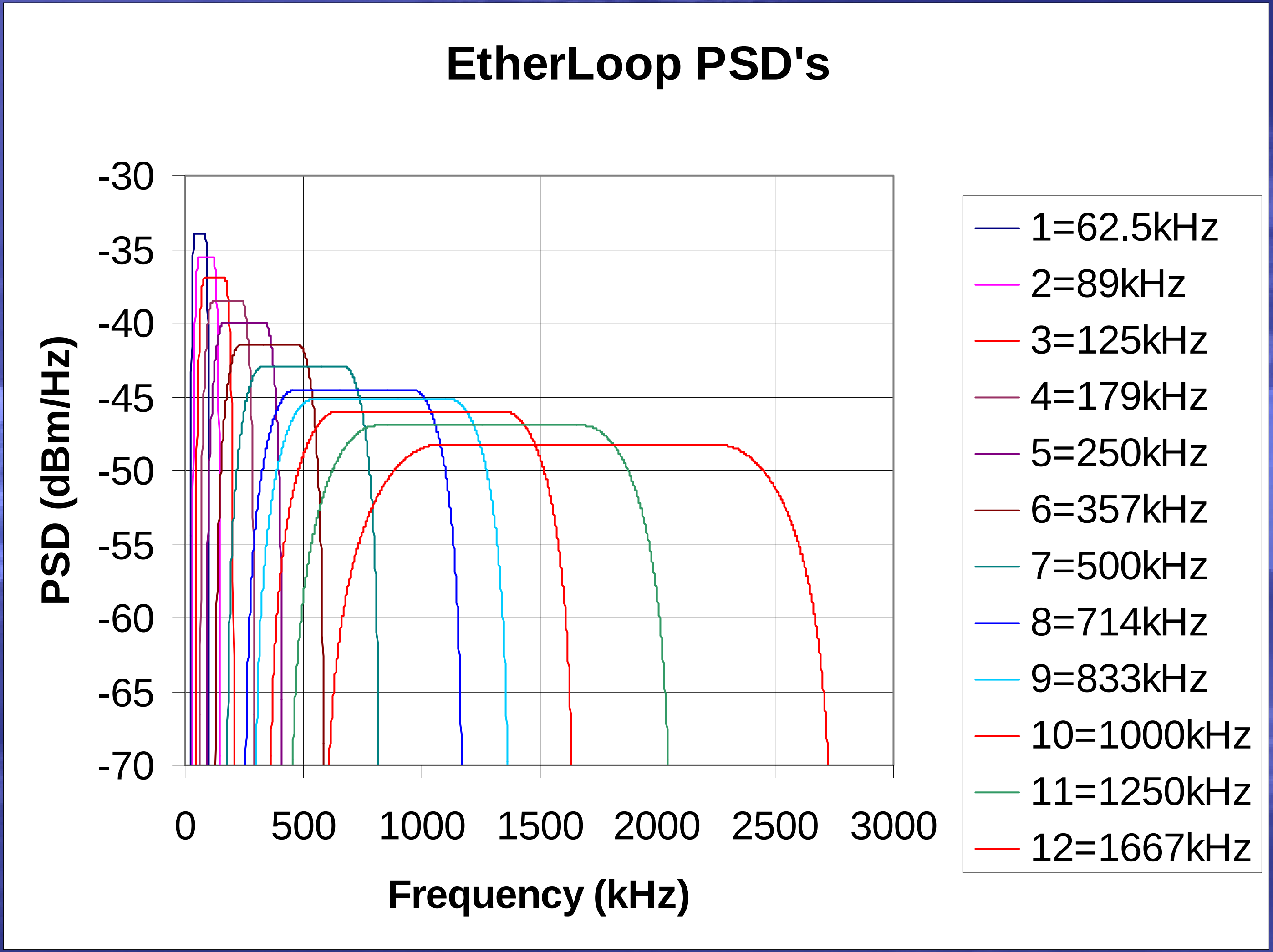
EtherLoop has 36 possible speeds

- Speed is a combination of center frequency and modulation
- Total of 12 center frequencies from 62.5kHz to 1.667MHz
- Total of 3 modulation levels: QPSK,Q16,Q64

Data Rate = Symbol Rate * Bits/Symbol of Modulation

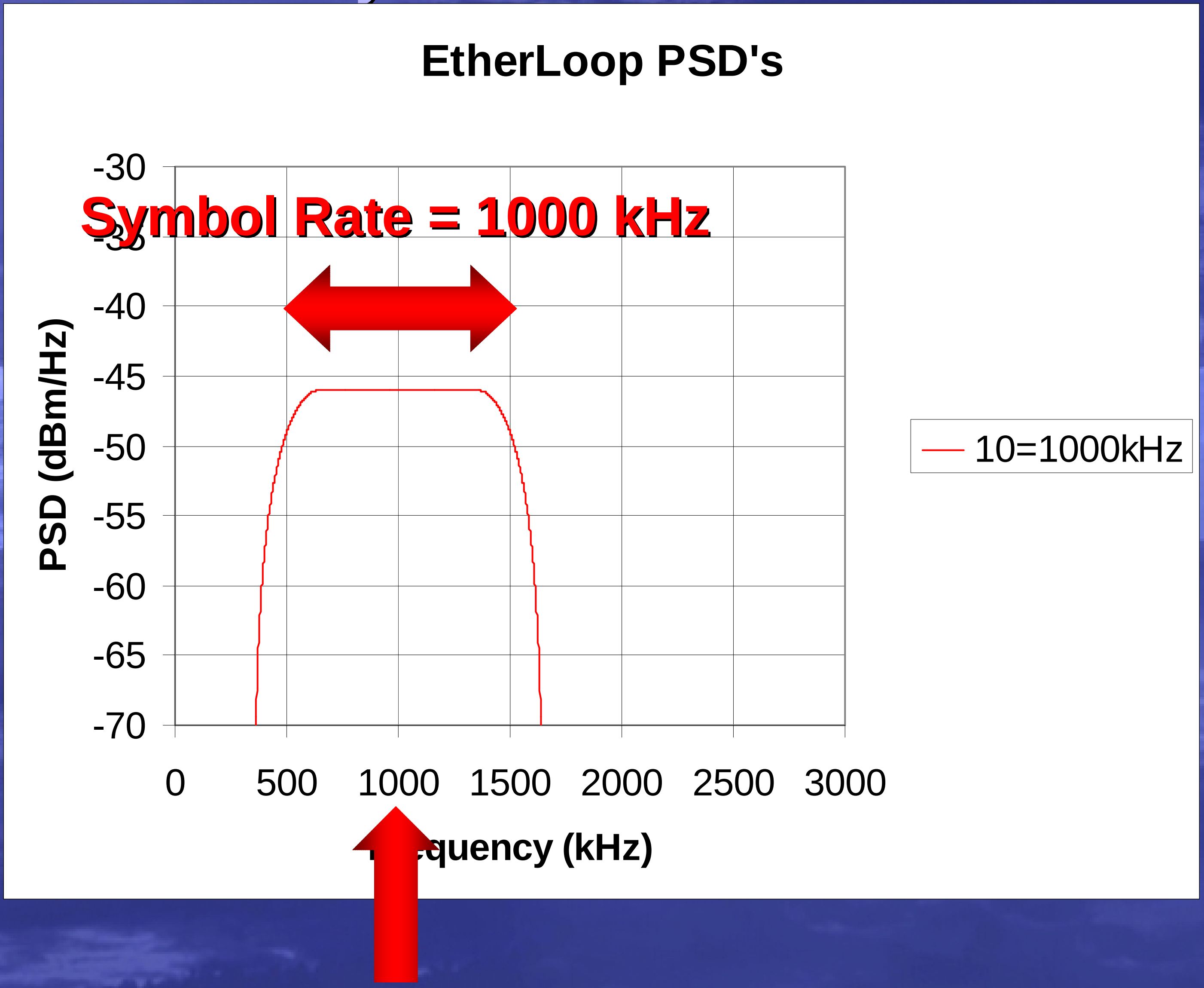
- QPSK = 2bits/symbol
- Q16 = 4 bits/symbol
- Q64 = 6 bits/symbol

EtherLoop PSDs



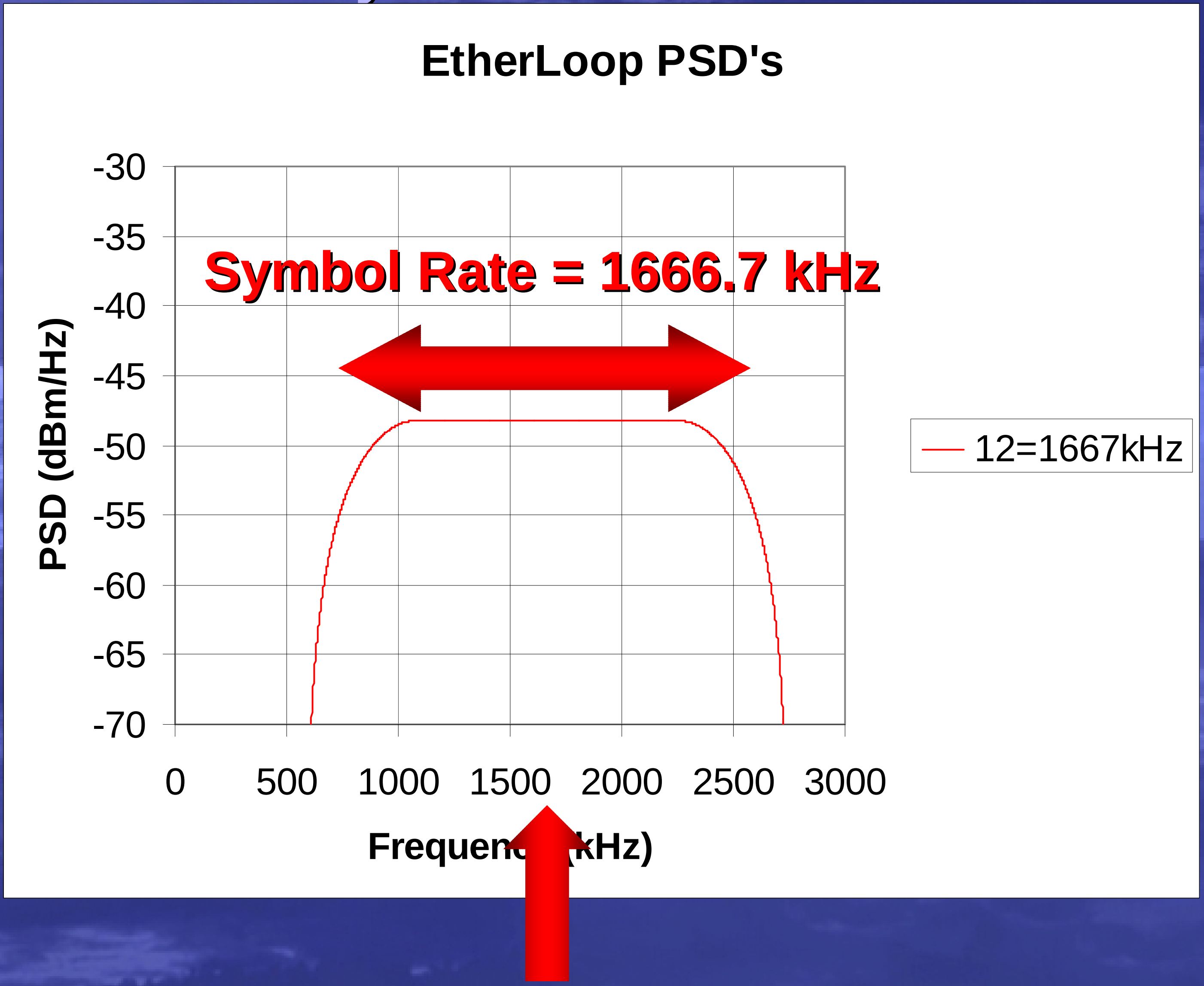
12 Possible Symbol Rates

EtherLoop: Center Frequency = Symbol Rate



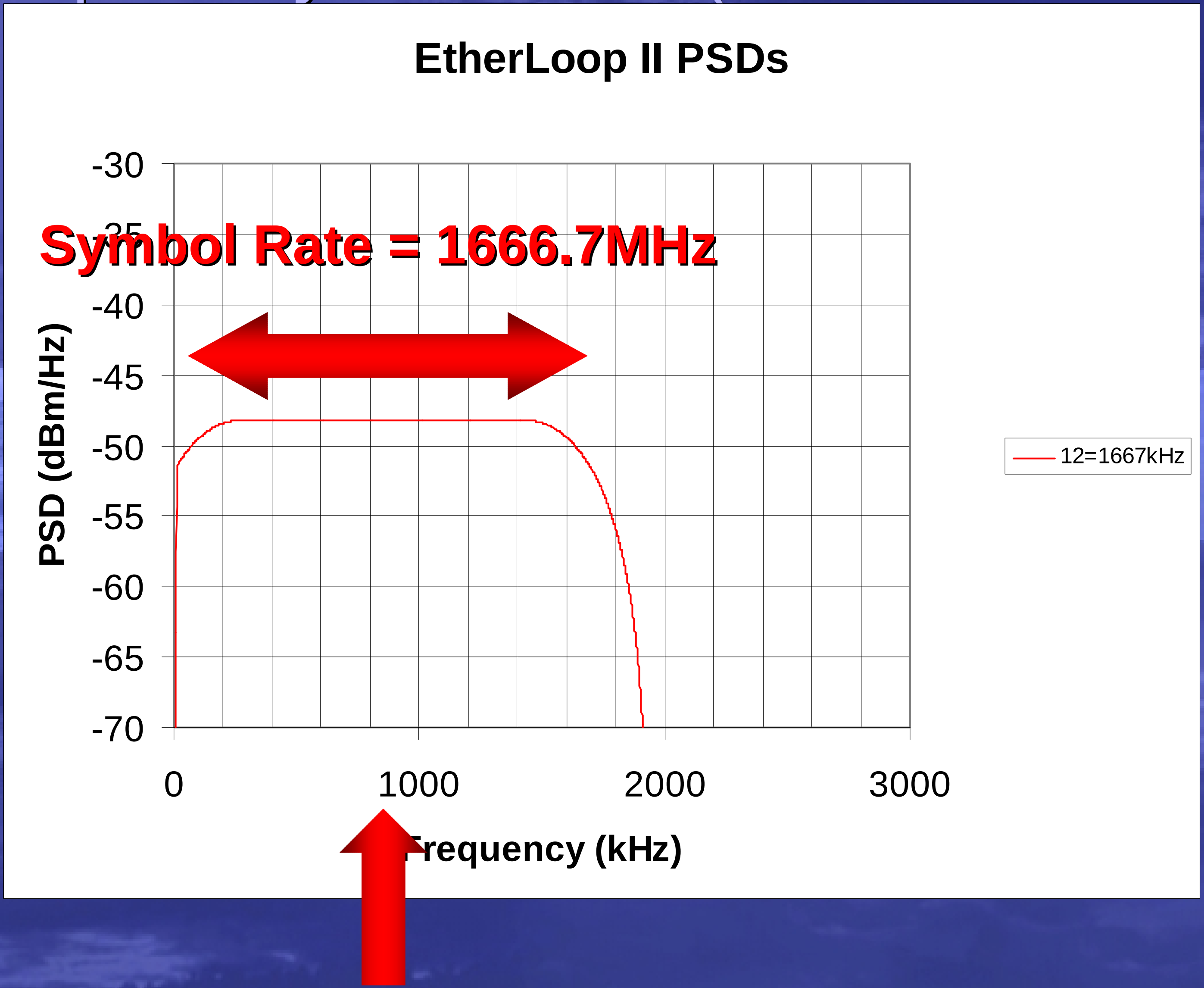
Center Frequency = 1000 kHz

EtherLoop: Center Frequency = Symbol Rate



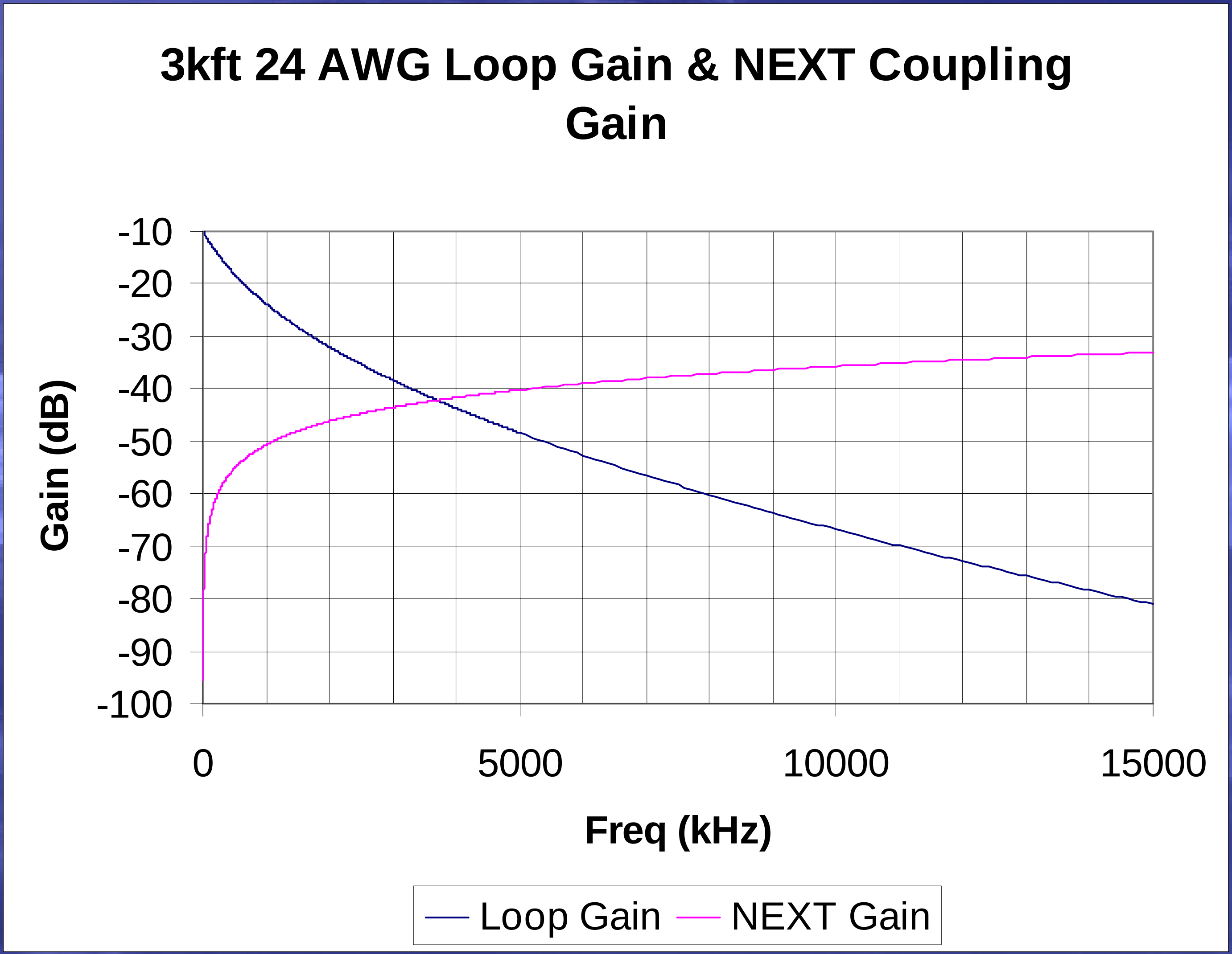
Center Frequency = 1666.7 kHz

Fast Robust EFM: Lower Corner Frequency is Fixed (Patent Pending)



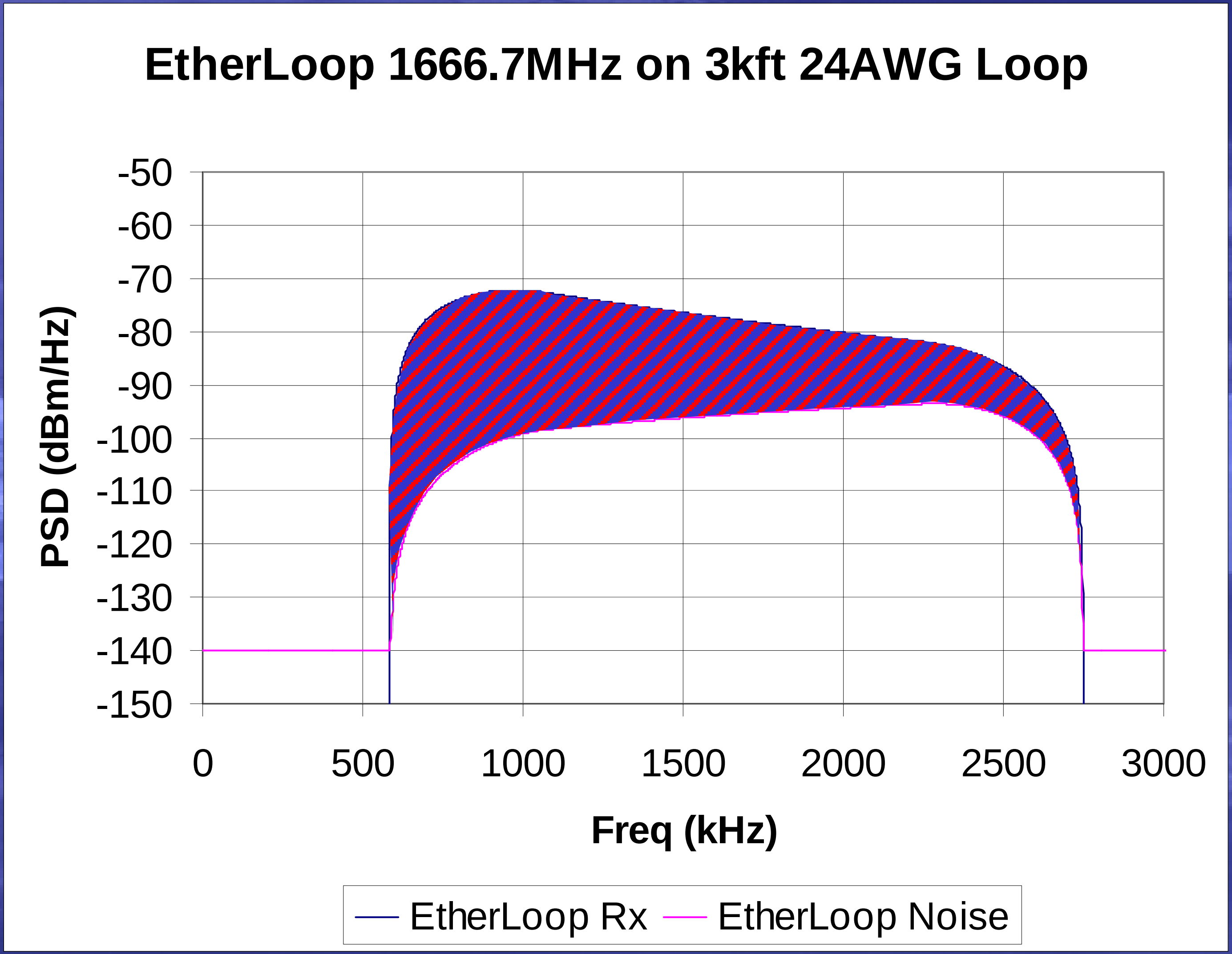
Center Frequency = 1666.7kHz/2 + 20kHz = 853.3kHz

Why use a fixed lower Corner Frequency?



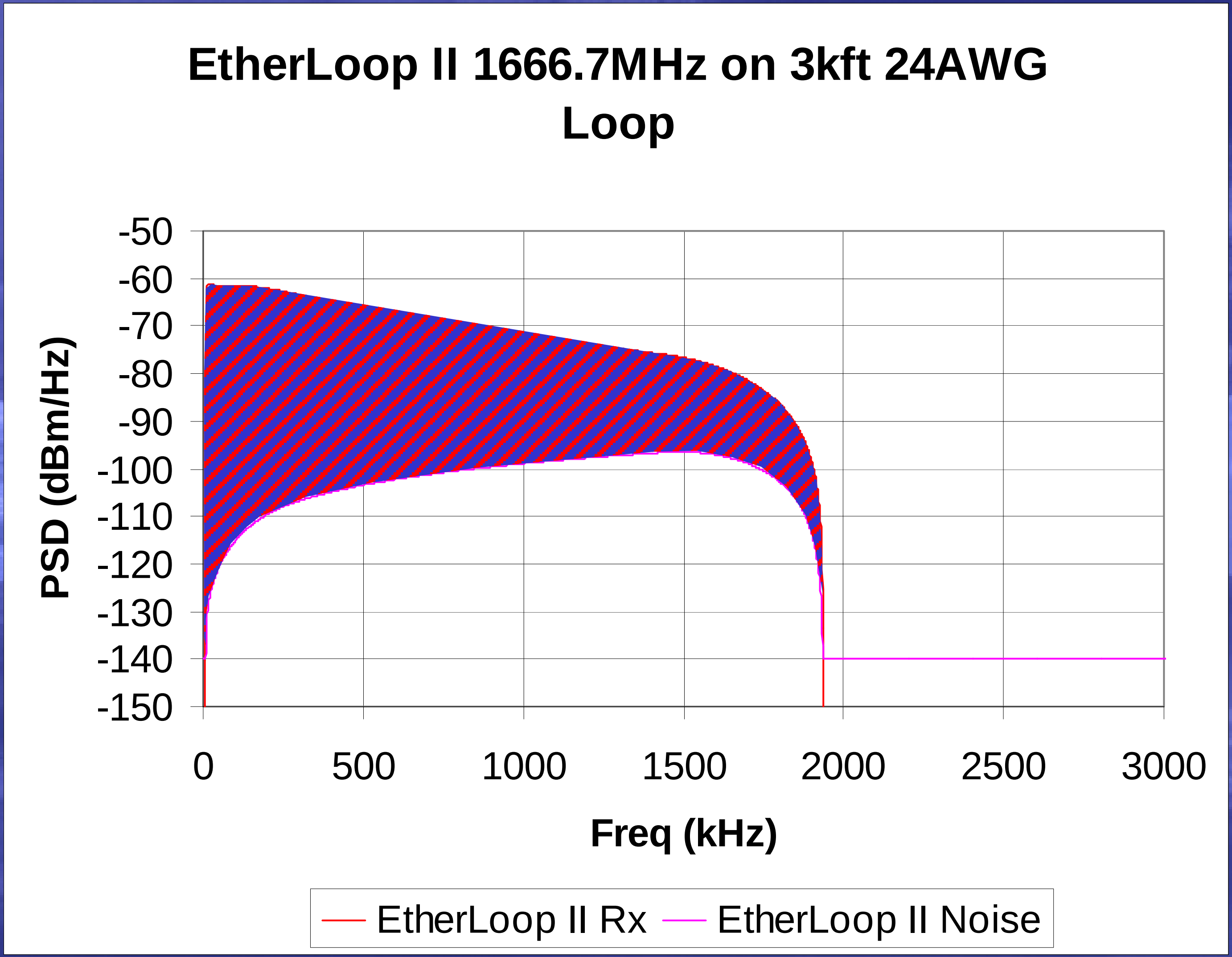
Loop Loss and Crosstalk both increase with Frequency

EtherLoop 1666.7 kHz @ 3kft 24AWG



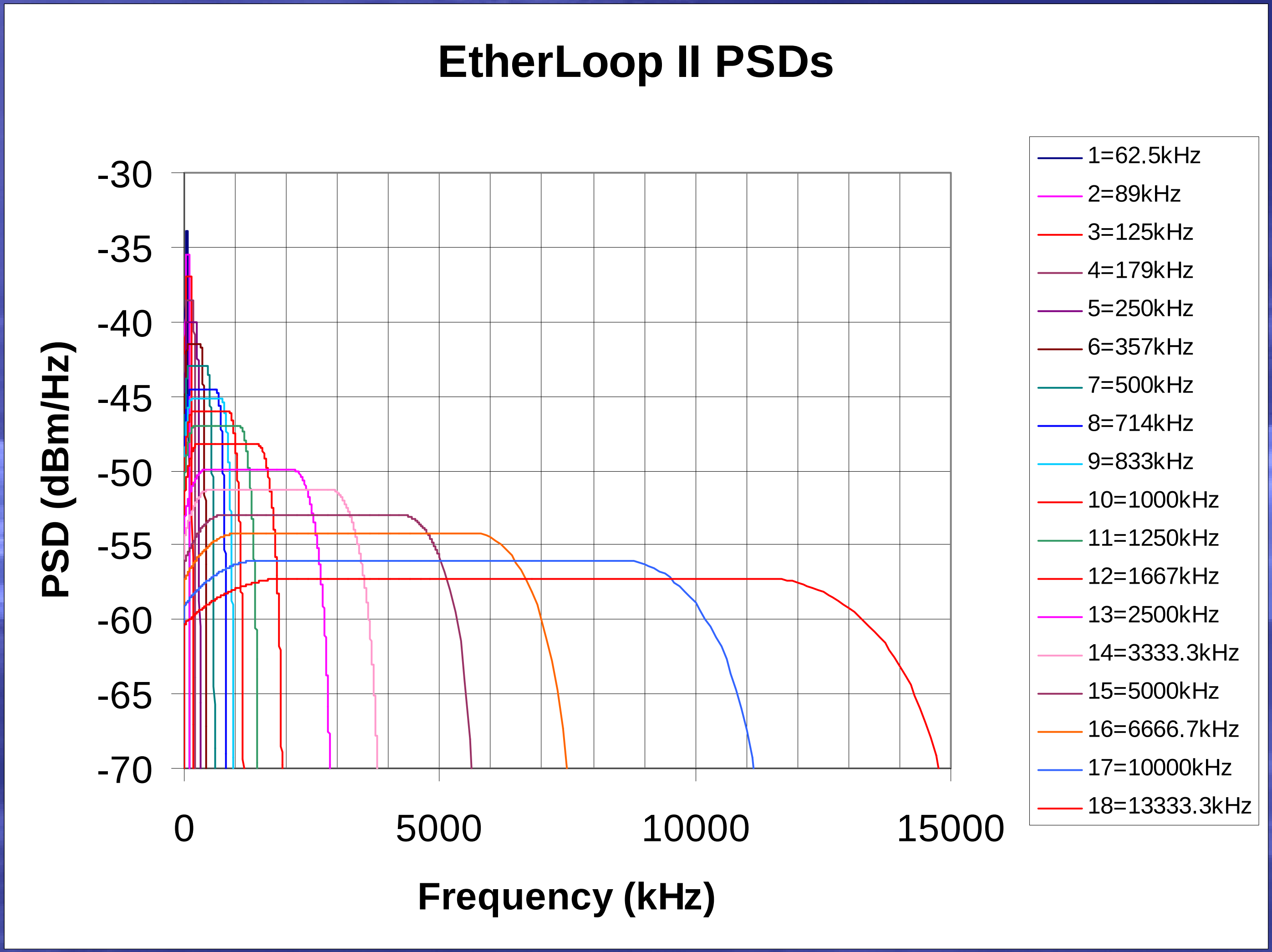
Average SNR is 26dB

EtherLoop II 1666.7 kHz @ 3kft 24AWG



Average SNR = 44dB

EtherLoop II PSD's



Lower Corner Frequency Fixed @ 20kHz

Analog High-pass Filter Corner @10kHz

EtherLoop II Speeds

EtherLoop II has 72 possible speeds

- Speed is a combination of center frequency and modulation
- Total of 18 center frequencies from 62.5kHz to 13.333MHz
- Total of 4 modulation levels: QPSK,Q16,Q64,Q256

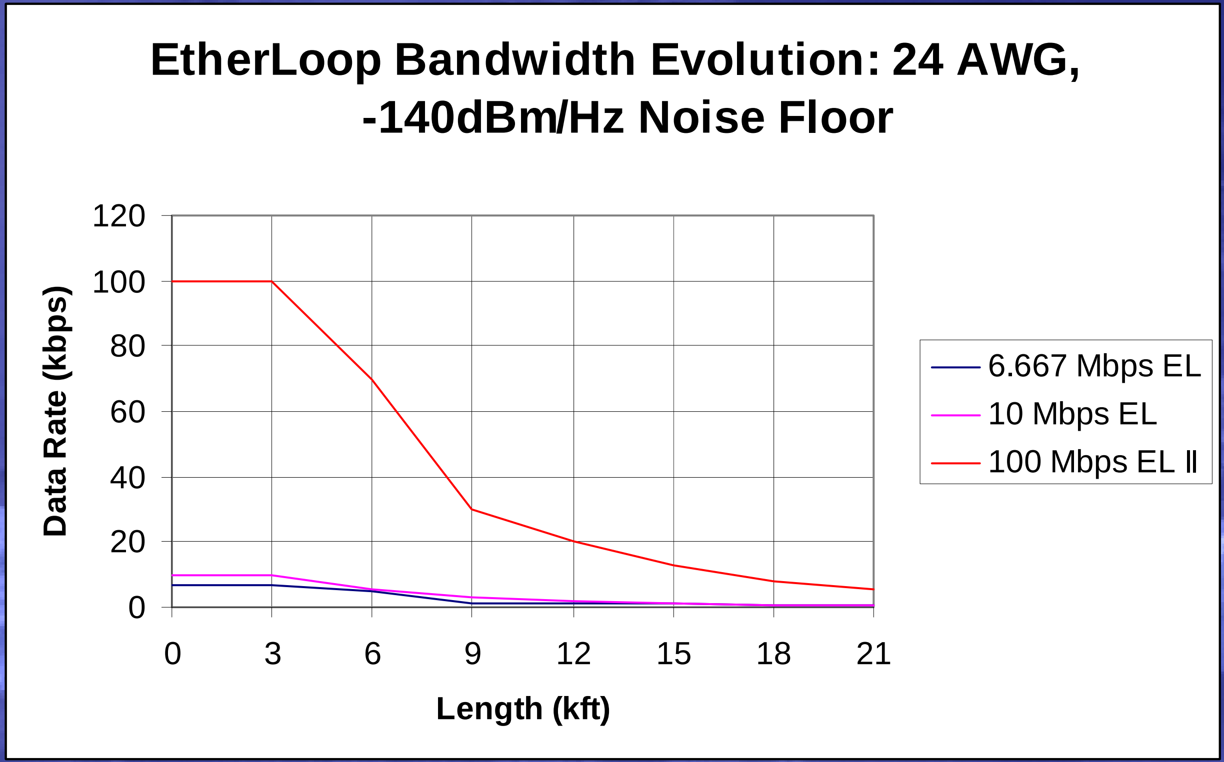
Data Rate = Symbol Rate * Bits/Symbol of Modulation

- QPSK = 2bits/symbol
- Q16 = 4 bits/symbol
- Q64 = 6 bits/symbol
- Q256 = 8 bits/symbol

Uses a better equalizer, includes Forward Error Correction

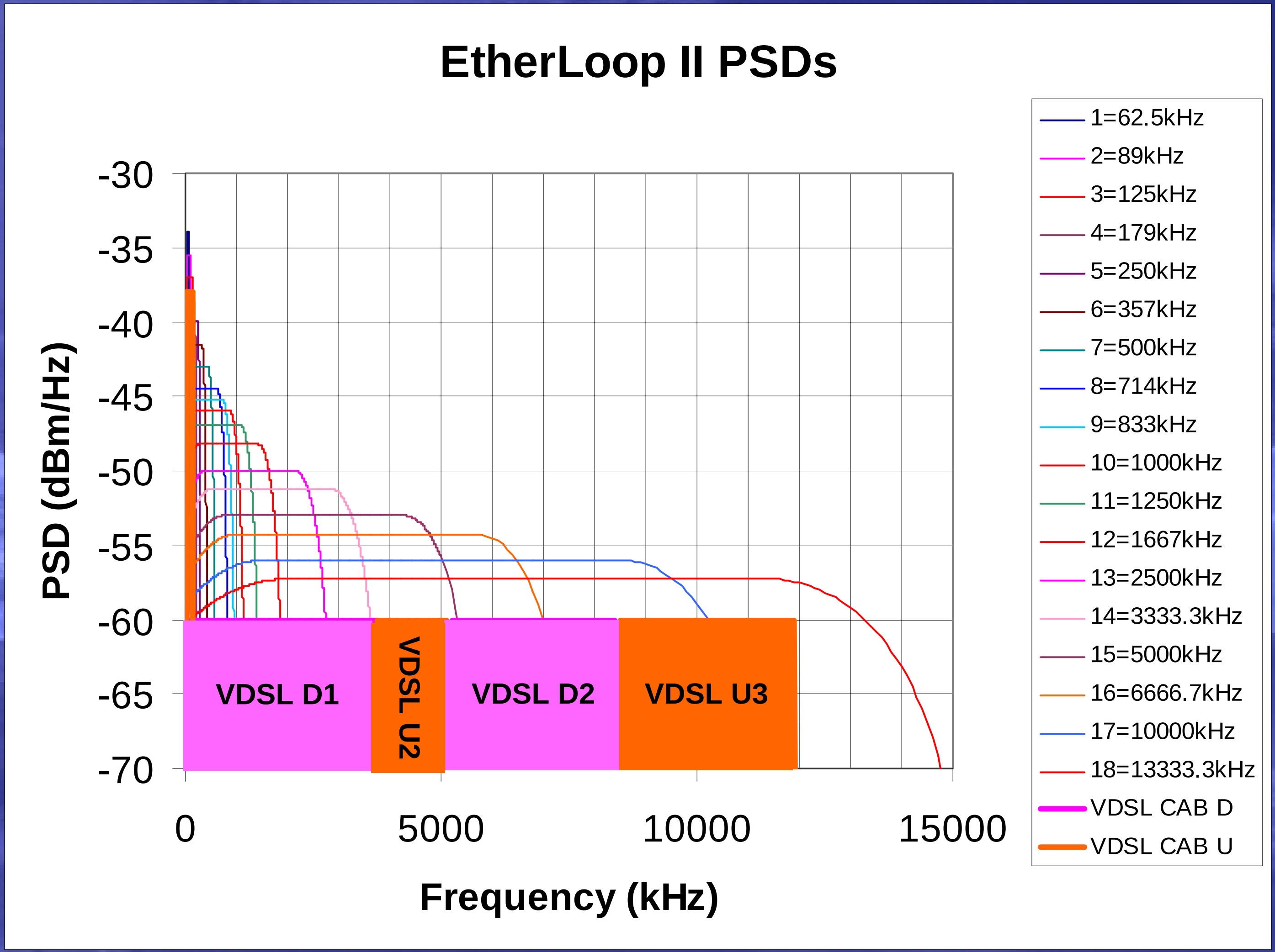
- Decision Feedback Equalizer (DFE) gives SNR improvement vs. Linear Equalizer (LE) of EtherLoop
- Forward Error Correction (FEC) adds coding gain

Data Rate Evolution



Distance (24 AWG)	6.67Mbps	10Mbps	100Mbps
0 kft	6.667 Mbps	10Mbps	100Mbps
3 kft	6.667 Mbps	10Mbps	100Mbps
6 kft	5 Mbps	5-6Mbps	70Mbps
9 kft	1.5 Mbps	3.33Mbps	30Mbps
12 kft	1.4 Mbps	2Mbps	20Mbps
15 kft	1.1 Mbps	1.4Mbps	13Mbps
18 kft	714 kbps	714 kbps	8Mbps
21 kft	500 kbps	714 kbps	5.5Mbps

Comparison to VDSL PSD



VDSL, FDD, depends on bandplan for performance

Upper bands cannot be used on longer loops

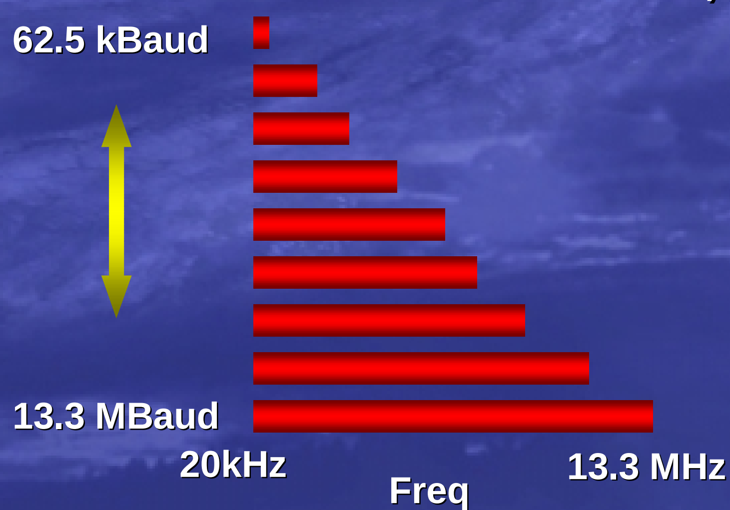
Band Plan Comparisons

VDSL, Draft T1E1 Trial Use Standard (T1E1), Upstream/Downstream

- 5 Bands, Depends on Frequency Division Duplexing (FDD) for Performance
- Superset of Echo Cancelled (EC) ADSL

EtherLoop 2 (EL2) (patent pending)

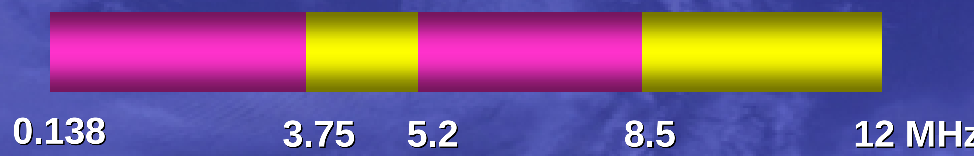
- Half-Duplex, Symmetry Agile, Frequency Agile, Same Freq Up/Down
- Fixed Lower Corner Freq, 20kHz, Symbol rates from 62.5kHz to 13.333MHz
- Option to use 200kHz lower corner, over ISDN and digital PBX



Band Plan Comparisons (Part 2)

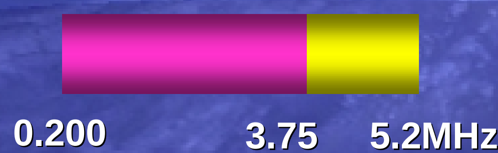
VDSL, FSAN Plan 998, (FSAN998) Upstream/Downstream

- 4 Bands, Depends on Frequency Division Duplexing (FDD) for Performance
- No Frequencies below 138kHz



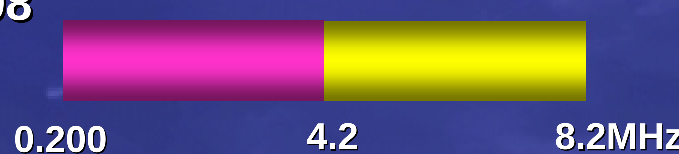
VDSL, Modified 998 (MOD998) , Upstream/Downstream

- 2 Bands, Depends on Frequency Division Duplexing (FDD) for Performance
- No Frequencies below 200kHz, over ISDN and Digital PBX



VDSL, Alternate 2 Band, (ALT2BAND) Upstream/Downstream

- 2 Bands, Depends on Frequency Division Duplexing (FDD) for Performance
- No Frequencies below 200kHz, over ISDN and Digital PBX
- INCOMPATIBLE WITH 998



Rate vs. Reach Simulations

Calculated in accordance to T1.417-2001

Parameters Common to All Bandplans

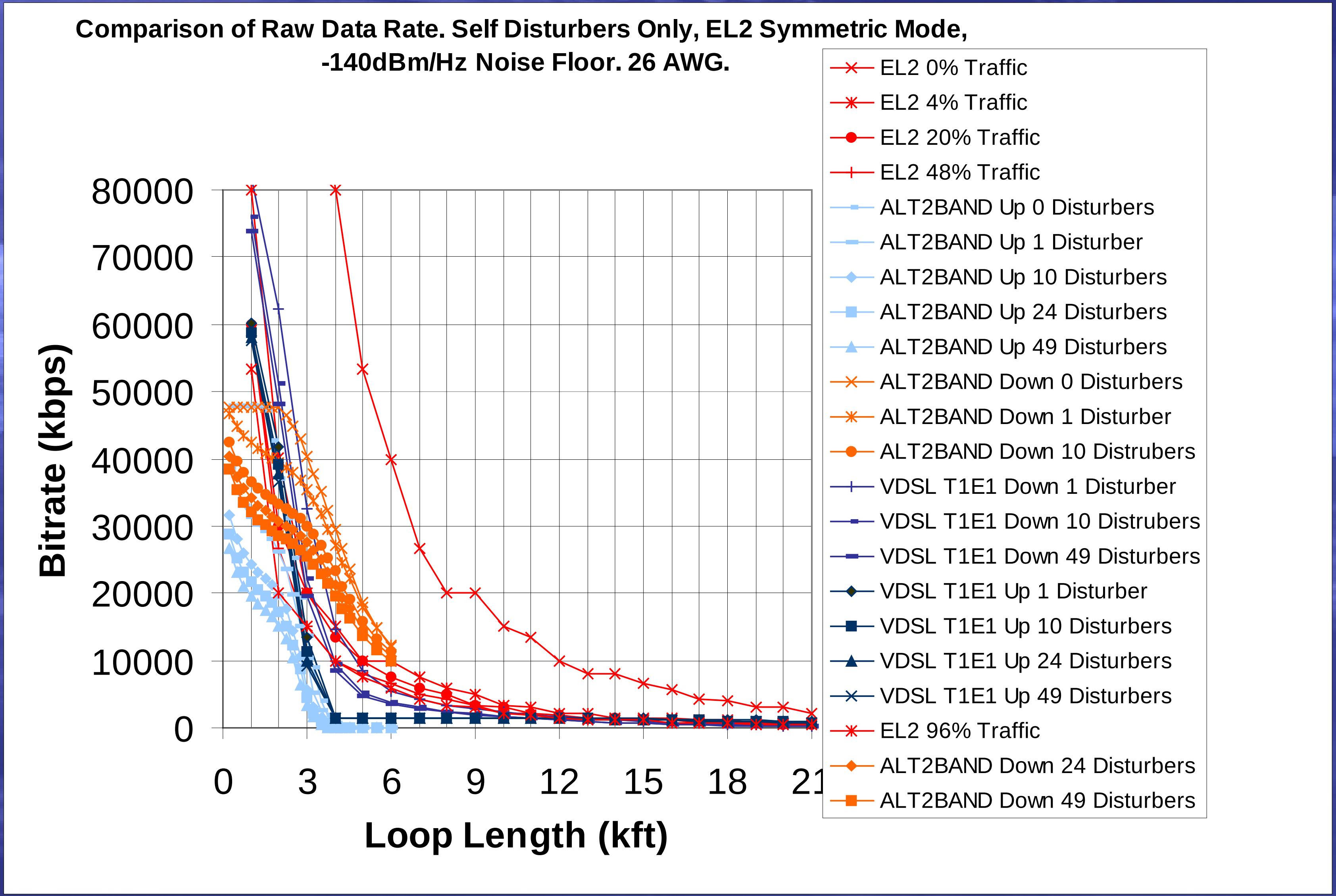
- Noise Margin = 6dB
- Coding Gain = 5.2dB
- Simplified T1E1 NEXT model
- 100ohm Termination
- -140dBm/Hz Noise Floor

VDSL Specific Parameters

- Based on Theroretical Capacity Calculation
- 11% Implementation Overhead
- Bits per tone range of 1 to 15

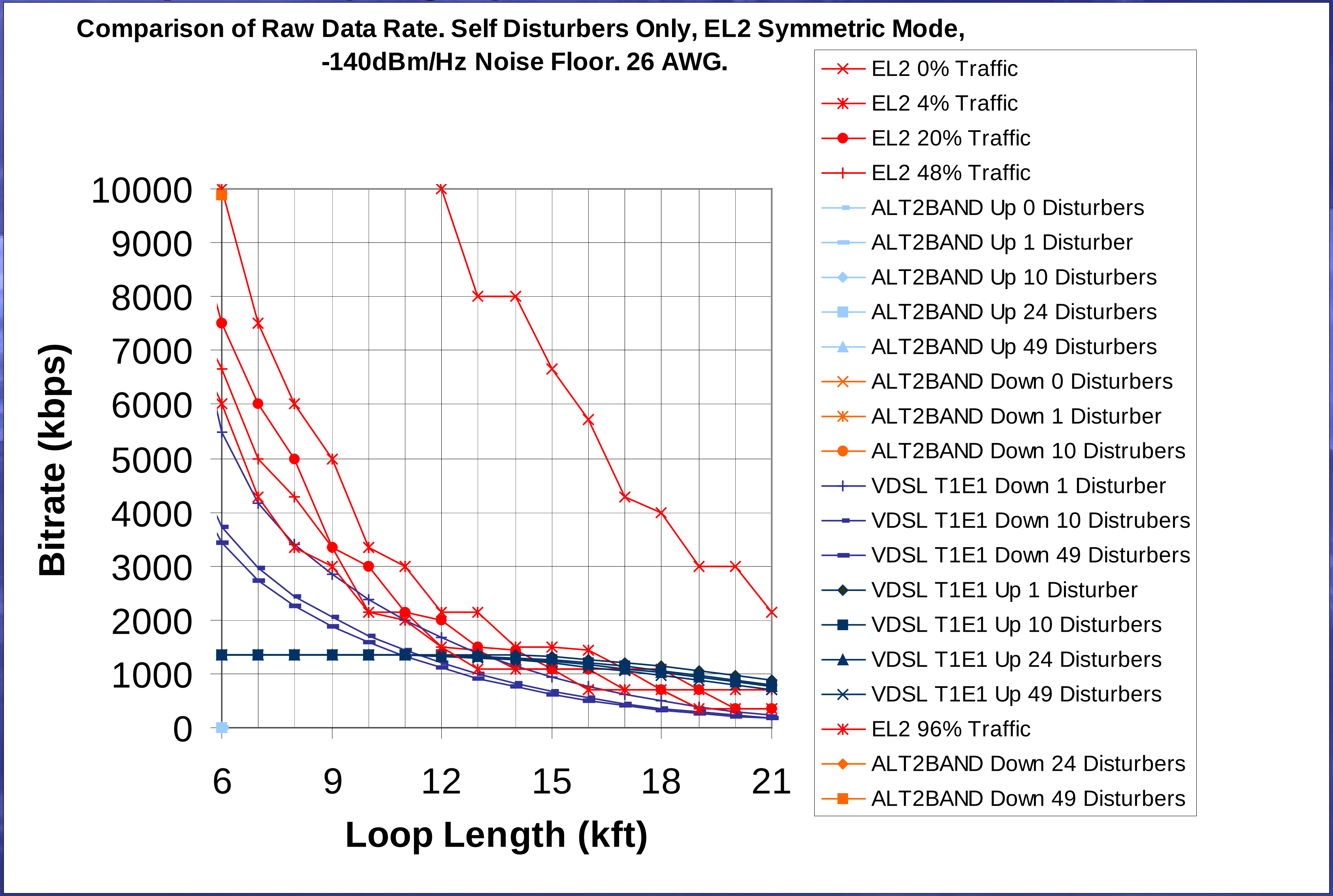
Performance with only Self Disturbers

EtherLoop II carrying symmetric traffic



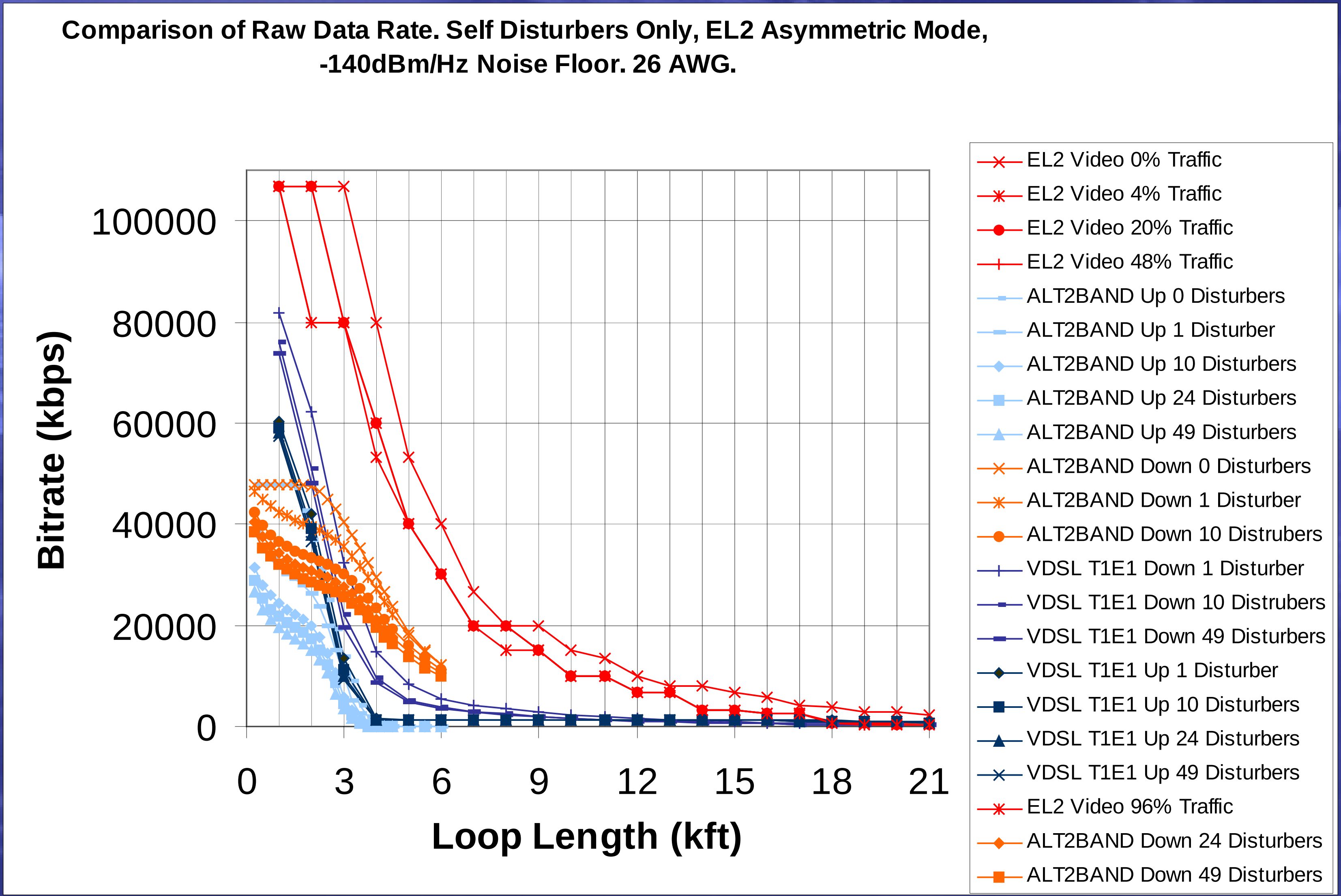
Performance with only Self Disturbers (Long Loops)

EtherLoop II carrying symmetric traffic



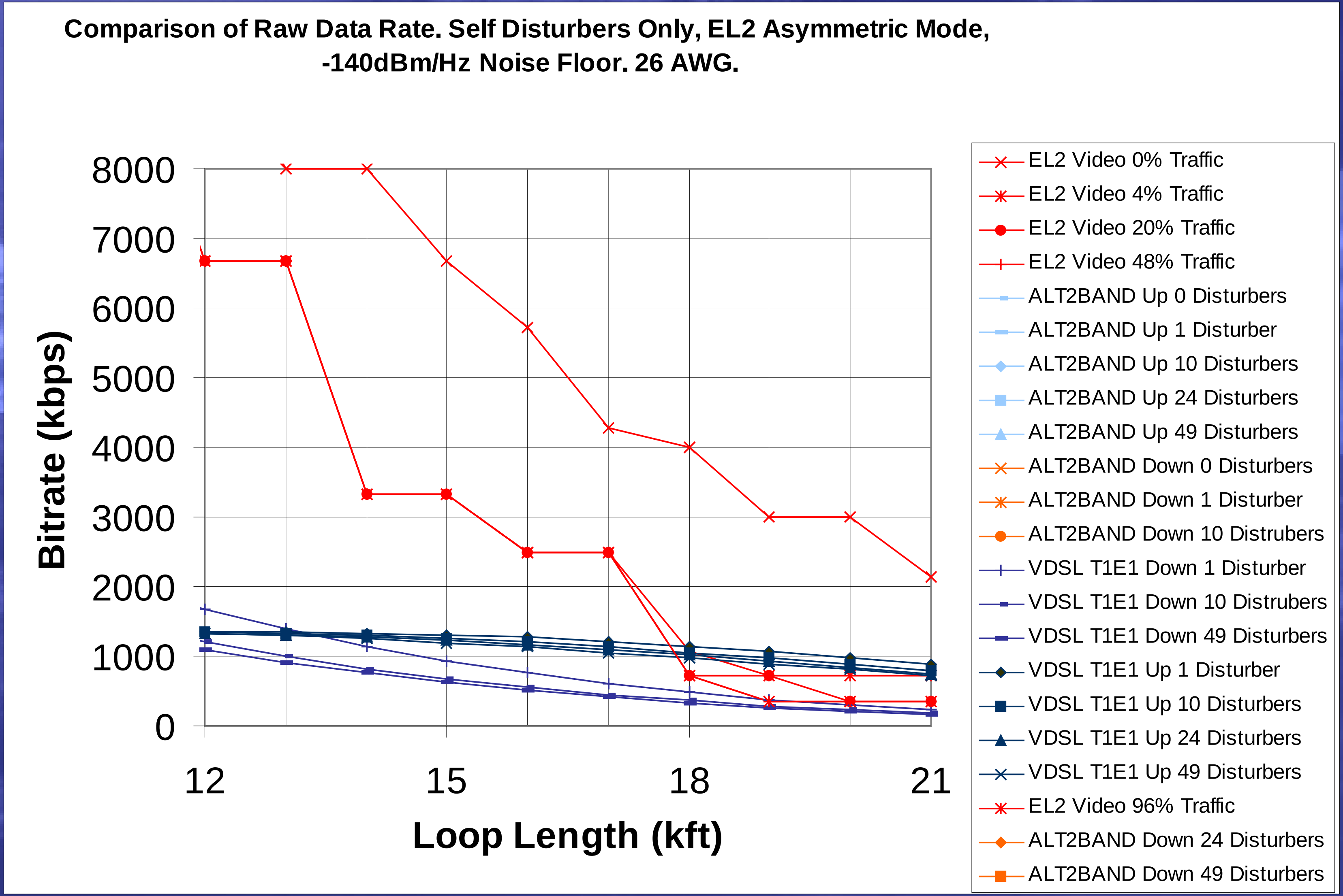
Performance with only Self Disturbers

EtherLoop II upstream limited to 1.8Mbps, tuned for video



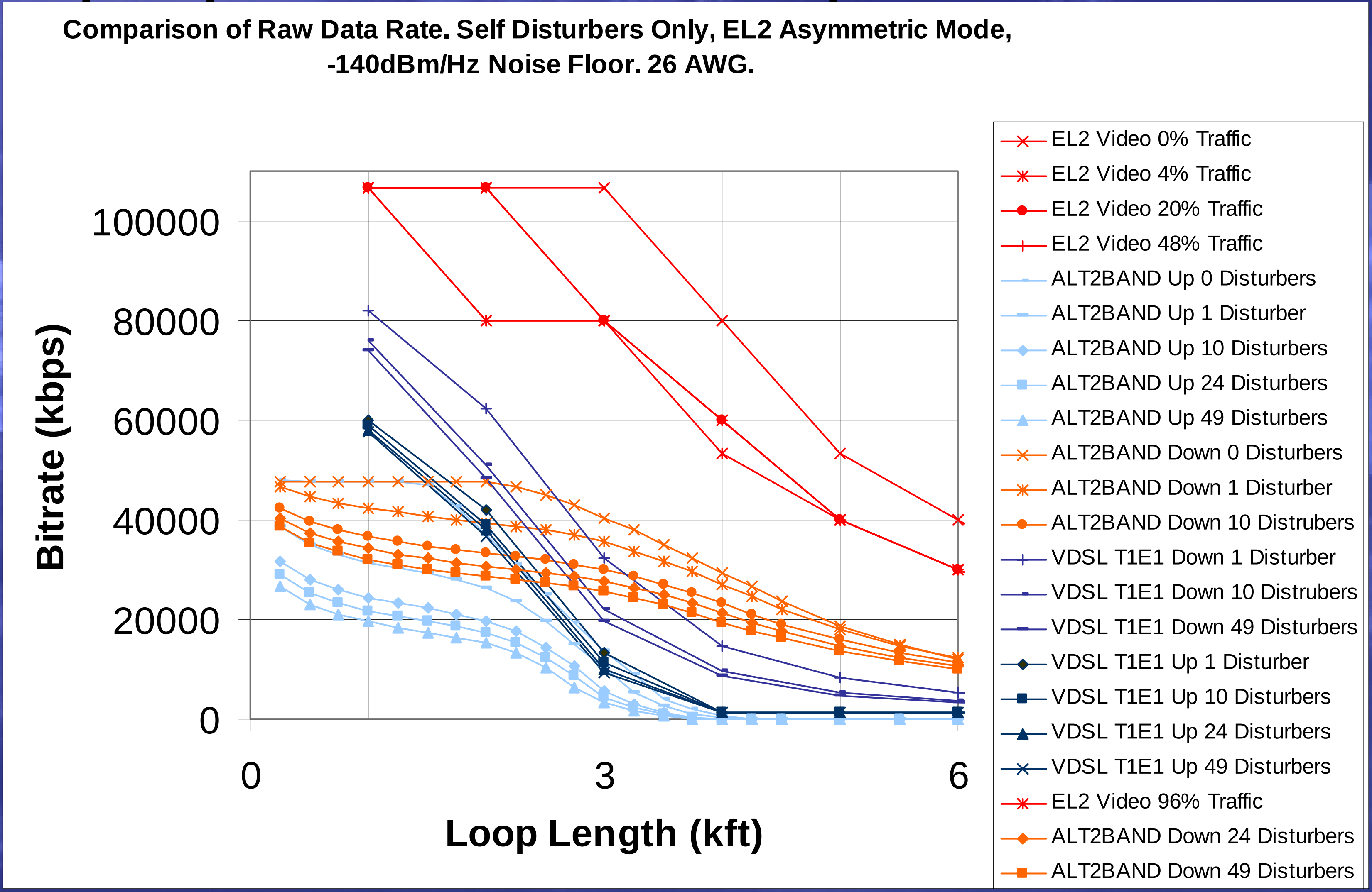
Performance with only Self Disturbers (Long Loops)

EtherLoop II upstream limited to 1.8Mbps, tuned for video



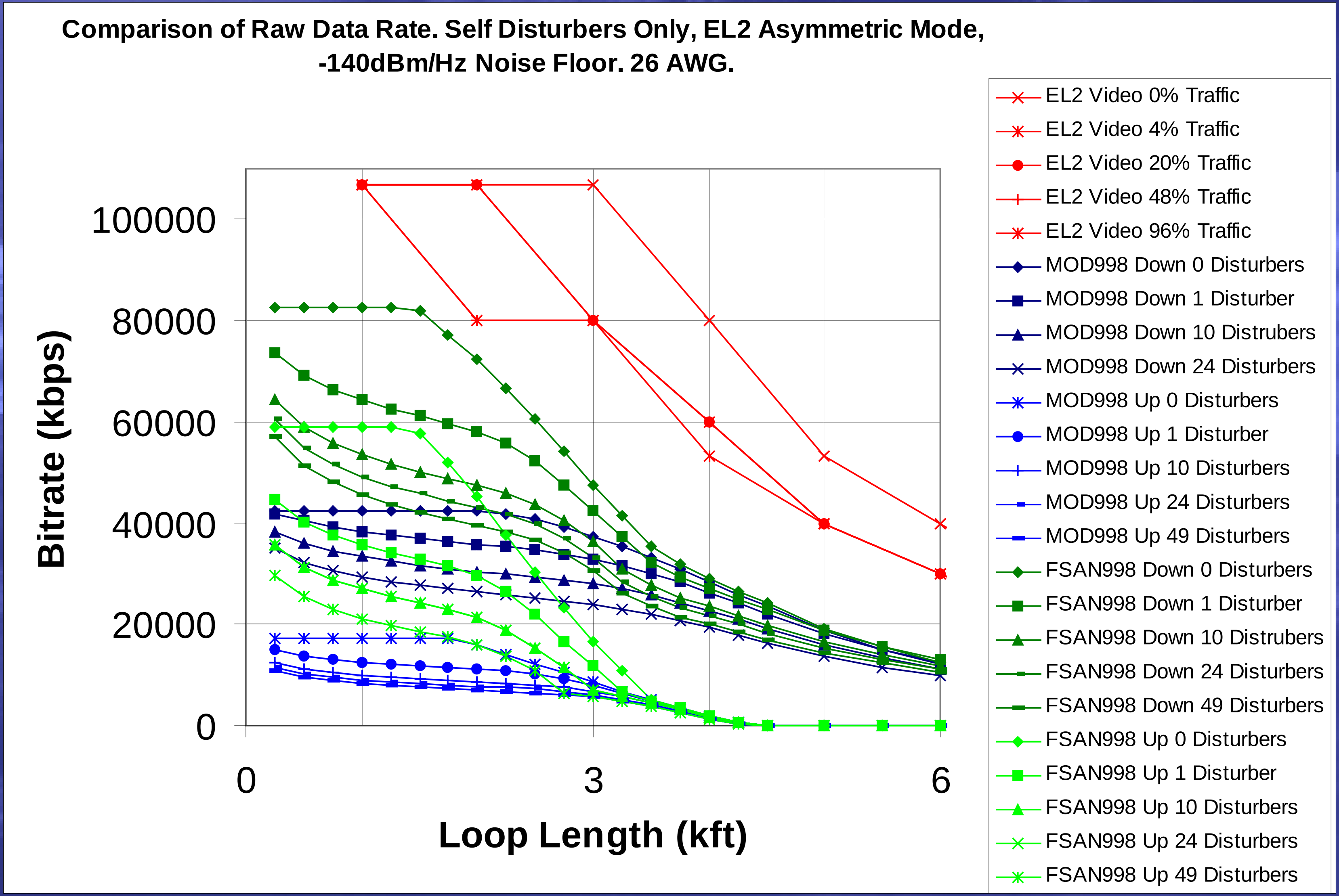
Performance with only Self Disturbers (Short Loops)

EtherLoop II upstream limited to 1.8Mbps, tuned for video

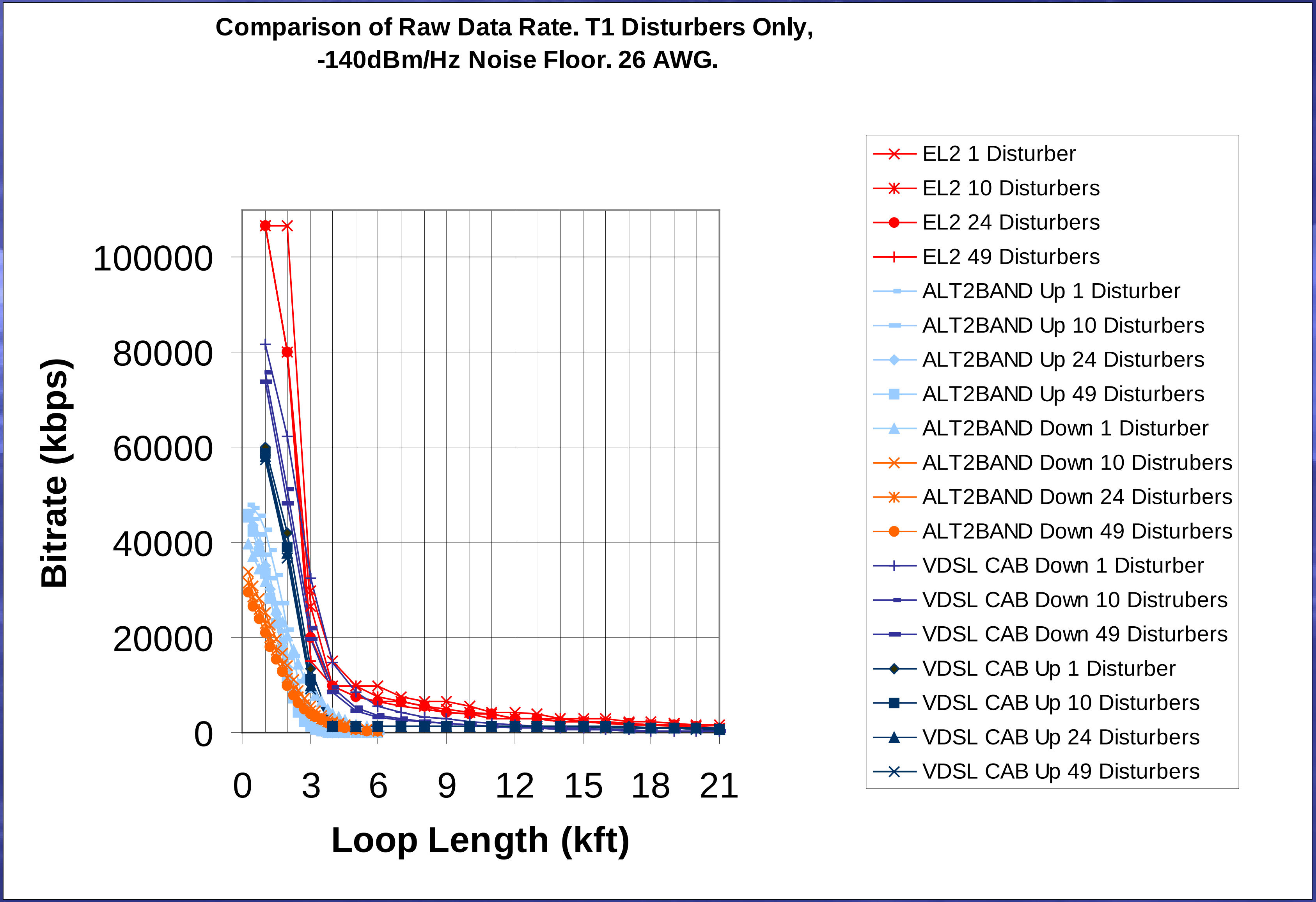


Performance with only Self Disturbers, (Short Loops) FSAN & MOD 998

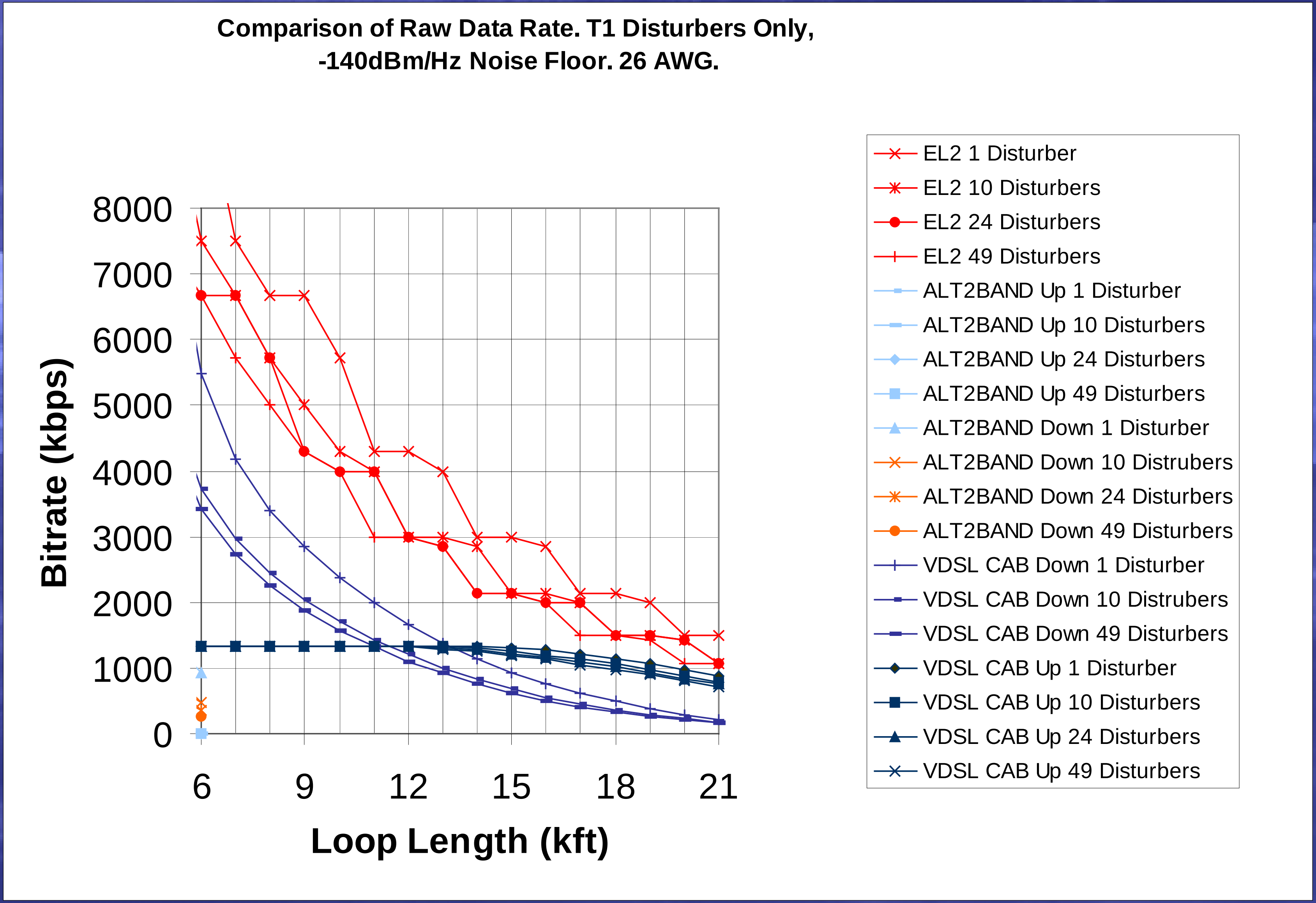
EtherLoop II upstream limited to 1.8Mbps, tuned for video



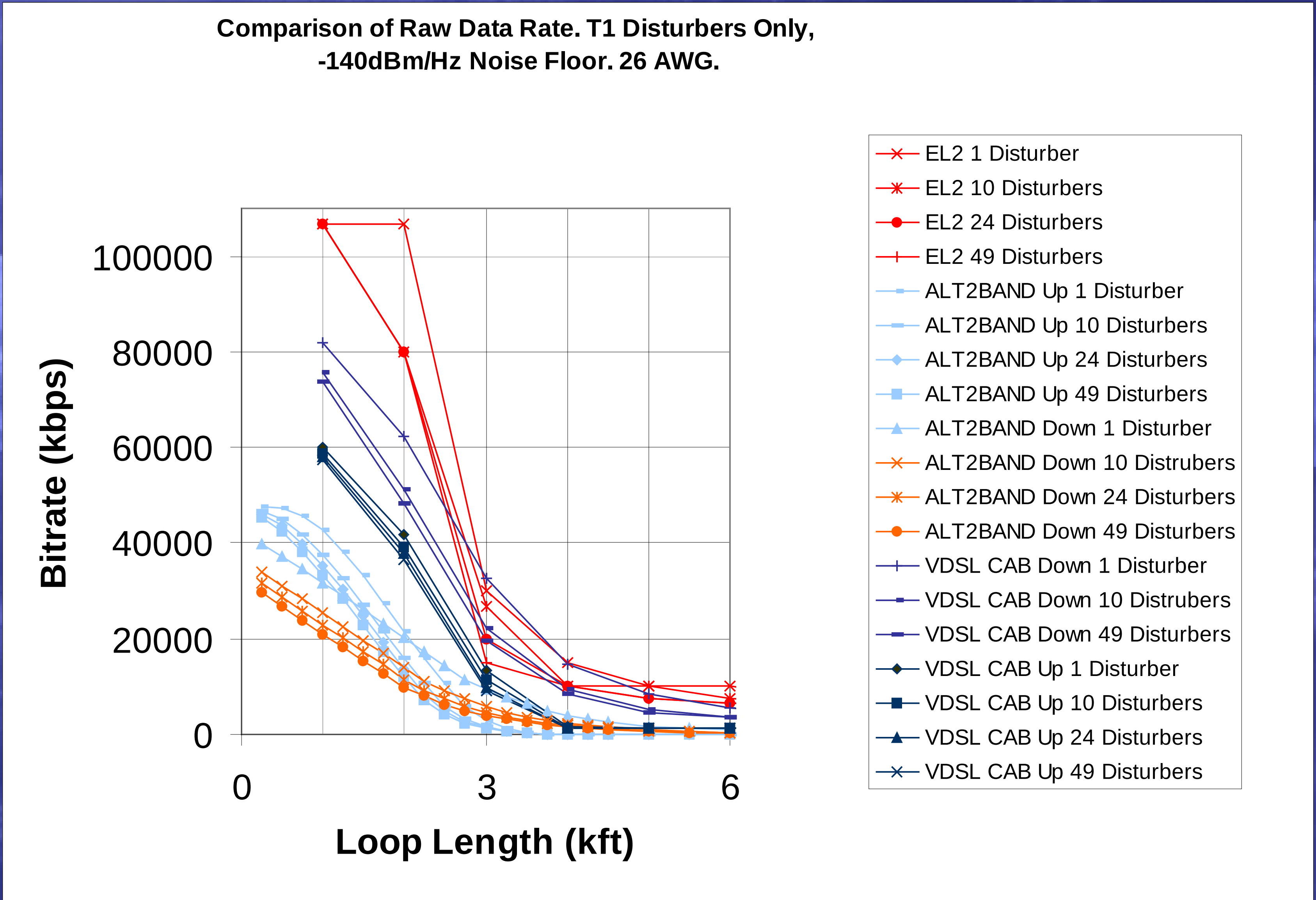
Performance with T1 Disturbers Only



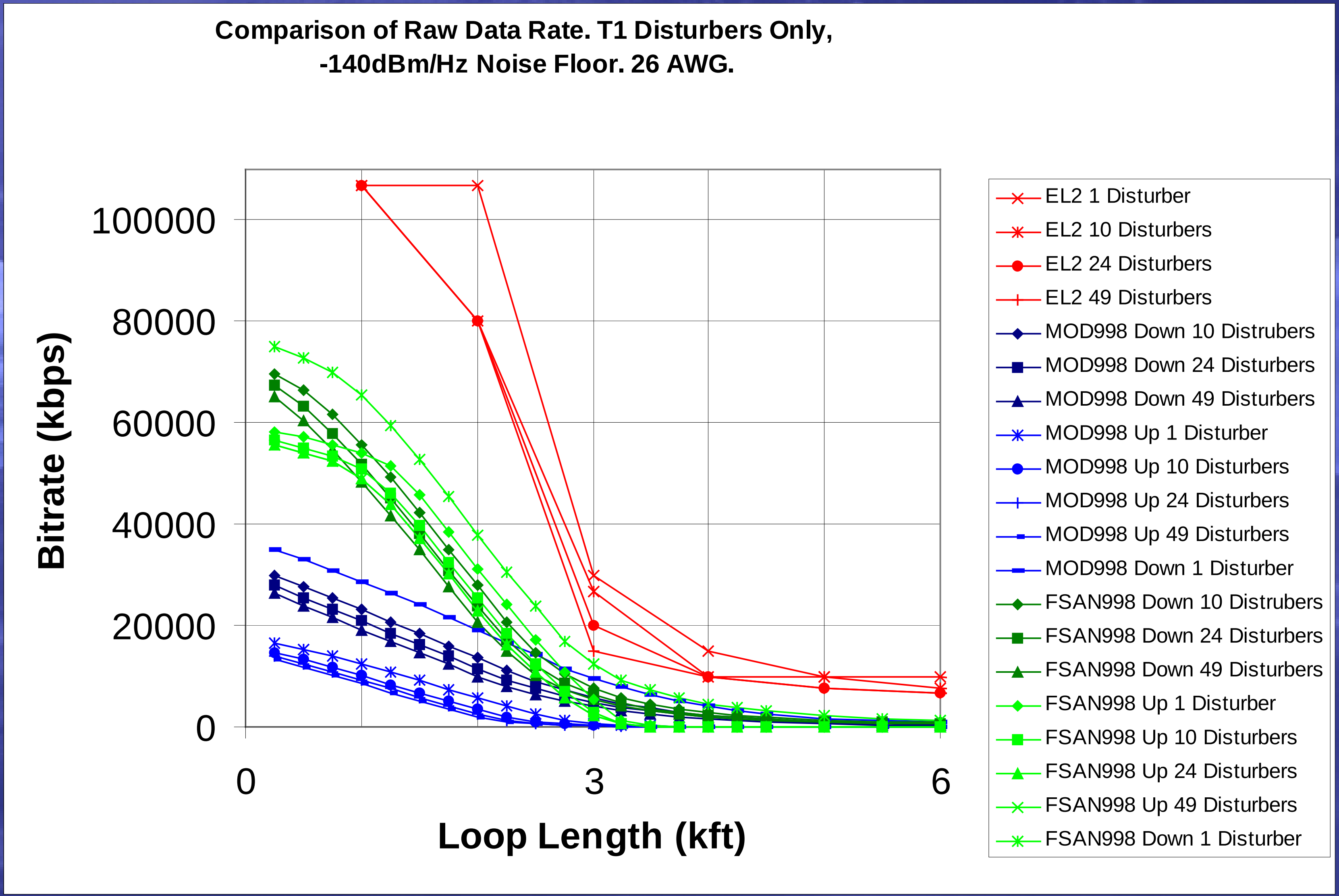
Performance with T1 Disturbers Only (Long Loops)



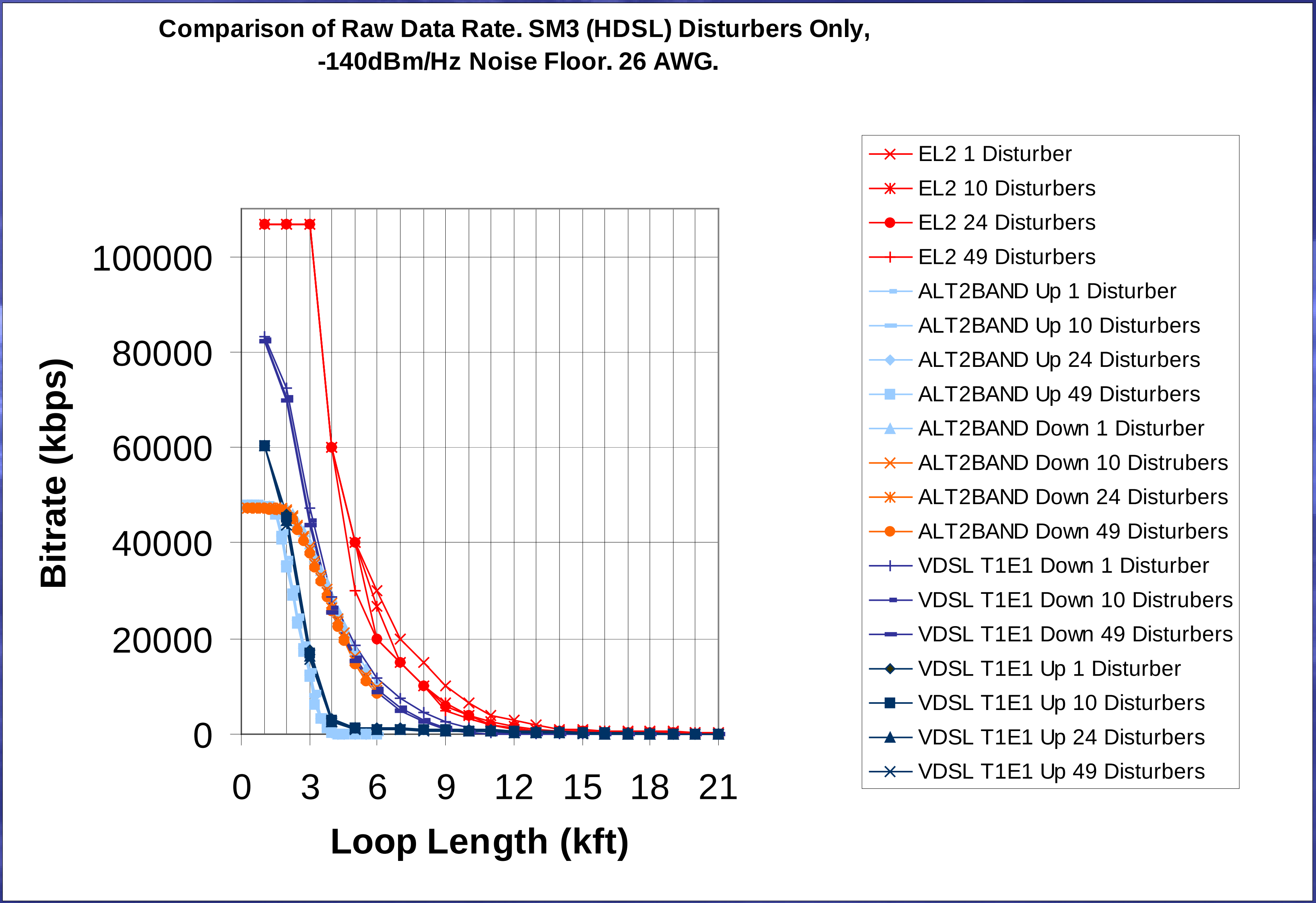
Performance with T1 Disturbers Only (Short Loops)



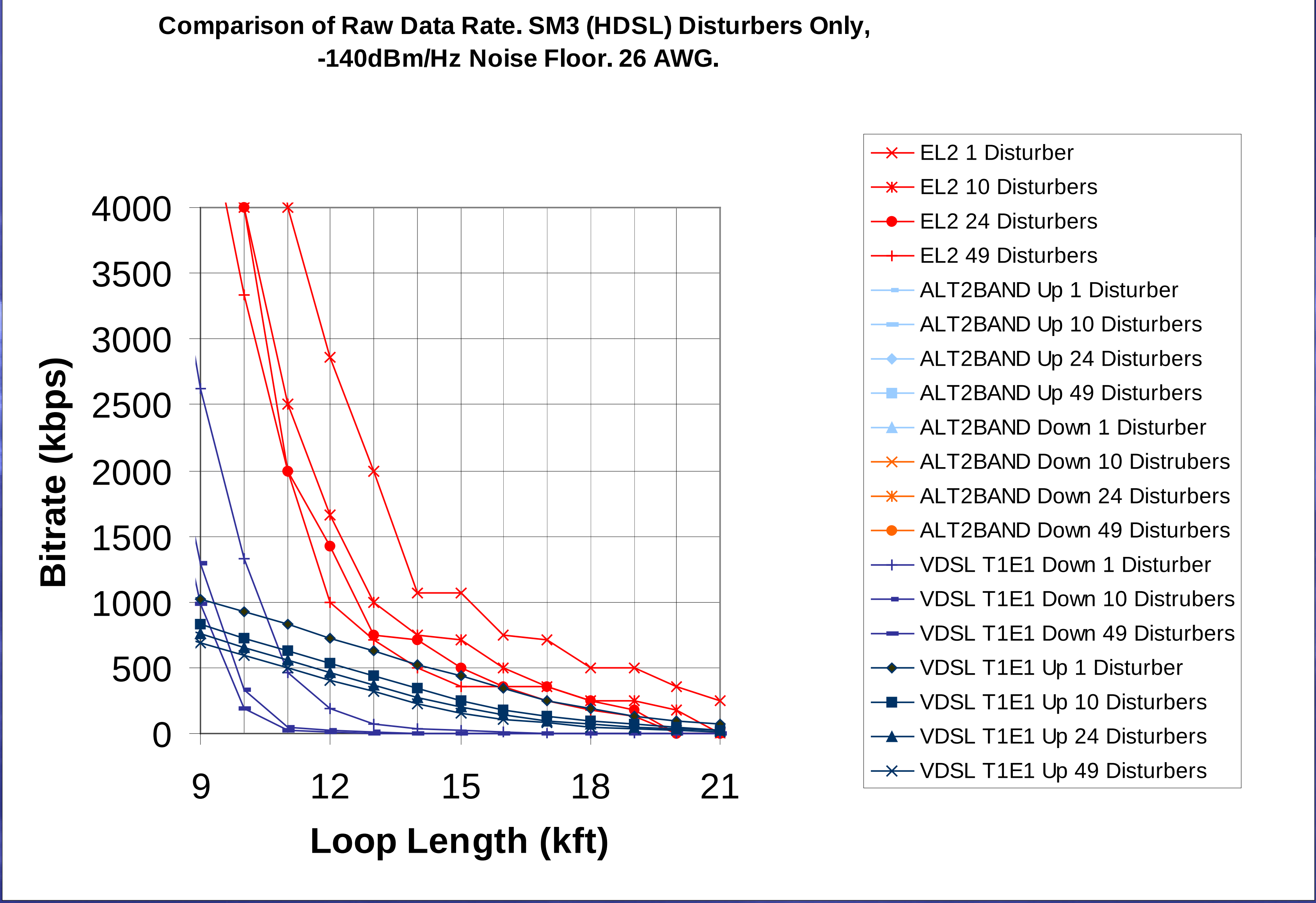
Performance with T1 Disturbers Only (Short Loops), FSAN & MOD 998



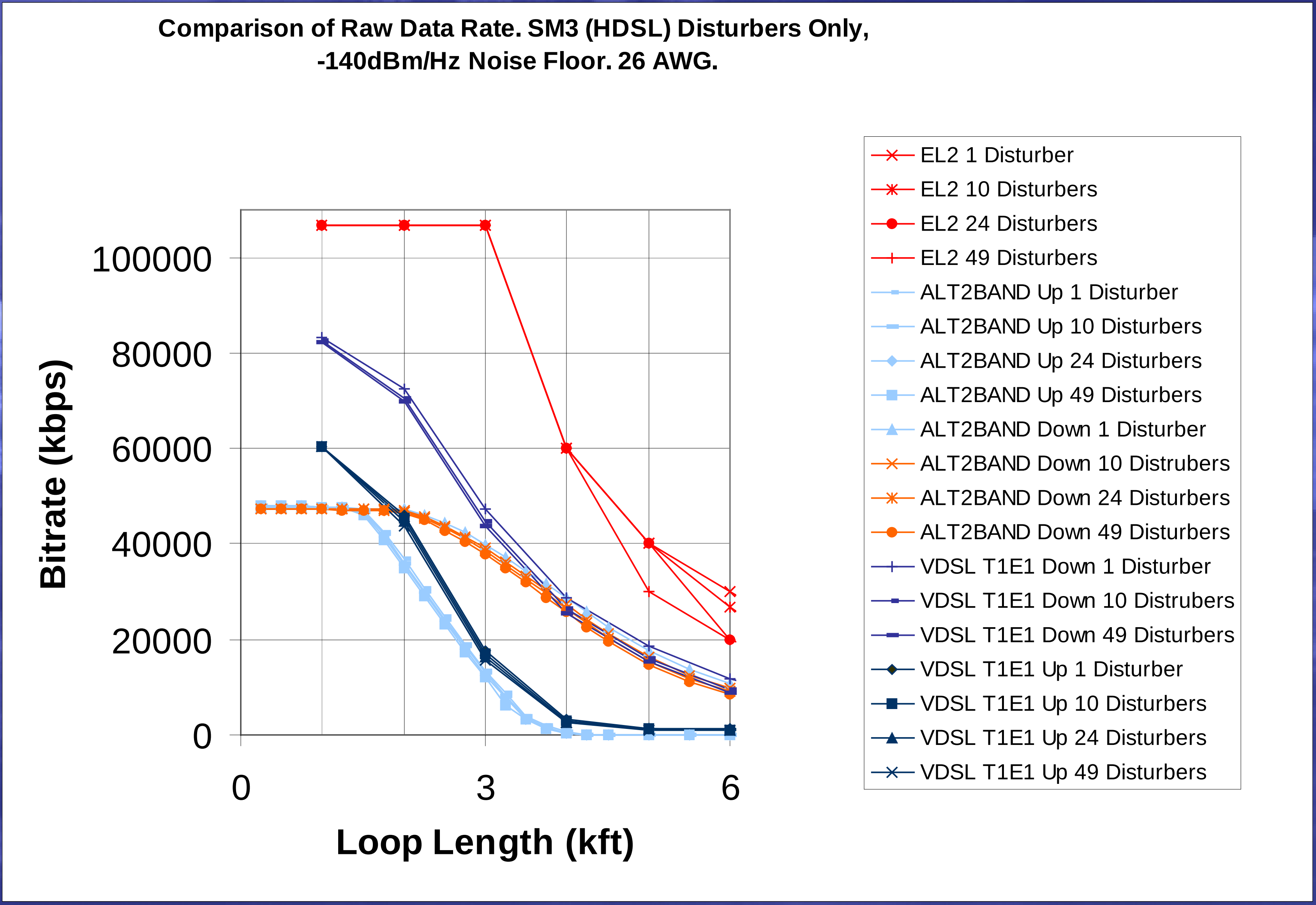
Performance with SM3 (HDSL) Disturbers Only



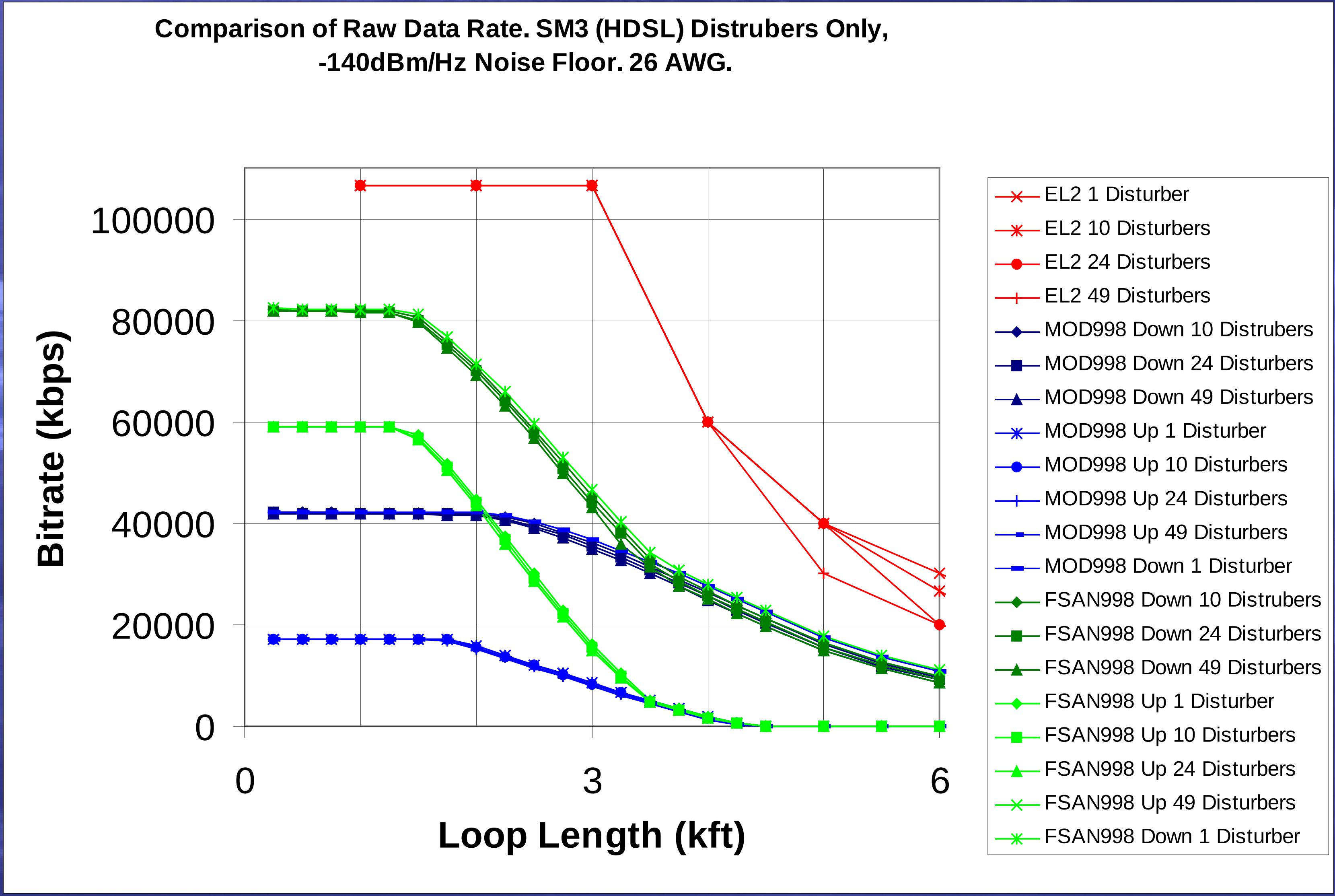
Performance with SM3 (HDSL) Disturbers Only, Long Loops



Performance with SM3 (HDSL) Disturbers Only, Short Loops



Performance with SM3 (HDSL) Disturbers Only, Short Loops, FSAN & MOD 998



Non CAT5, In Premises Network

EFM Access Candidates are point-to-point

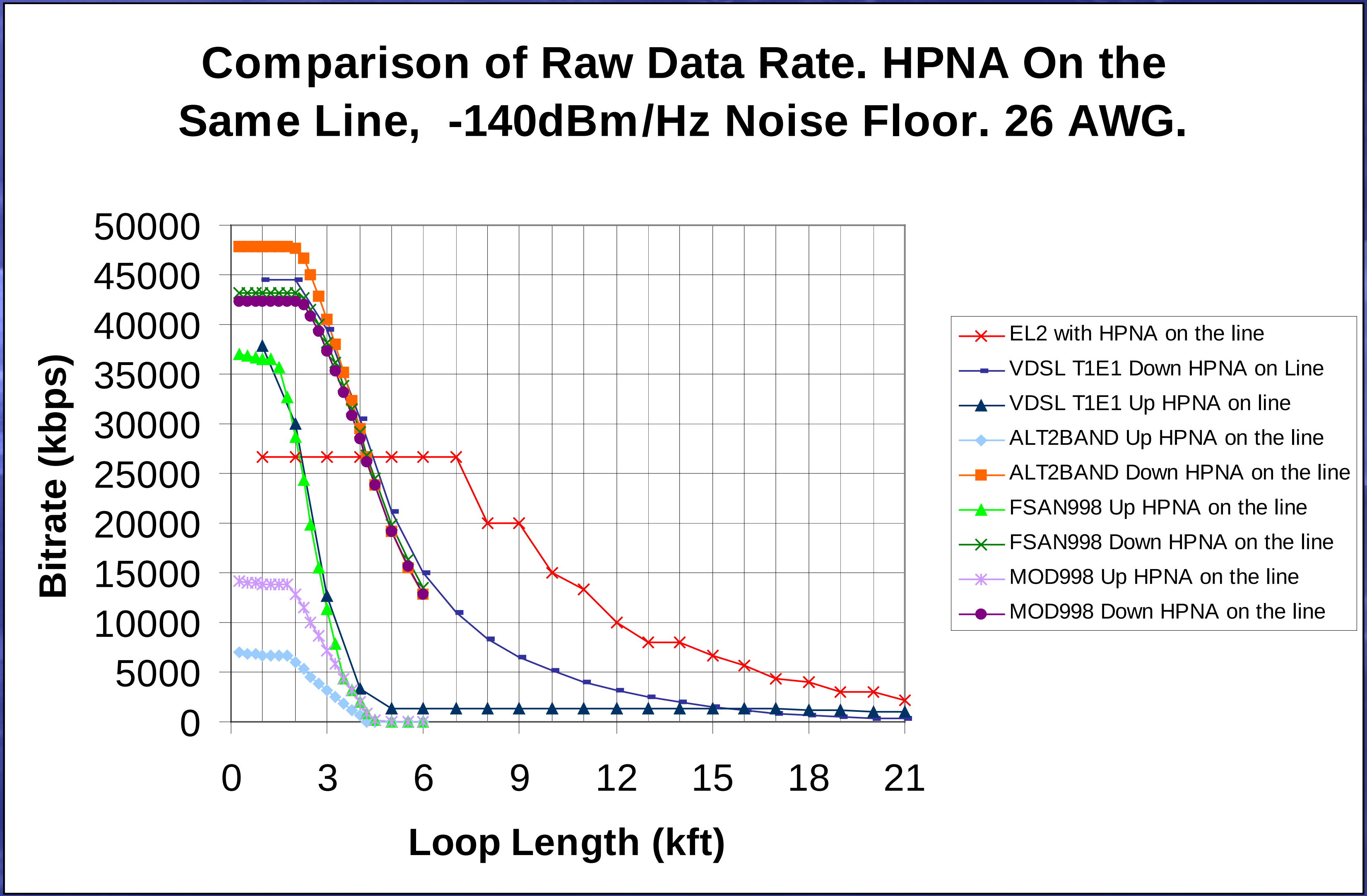
Customers may want multiple IP appliances

HPNA is a top candidate for In Premises Networks (non CAT5)

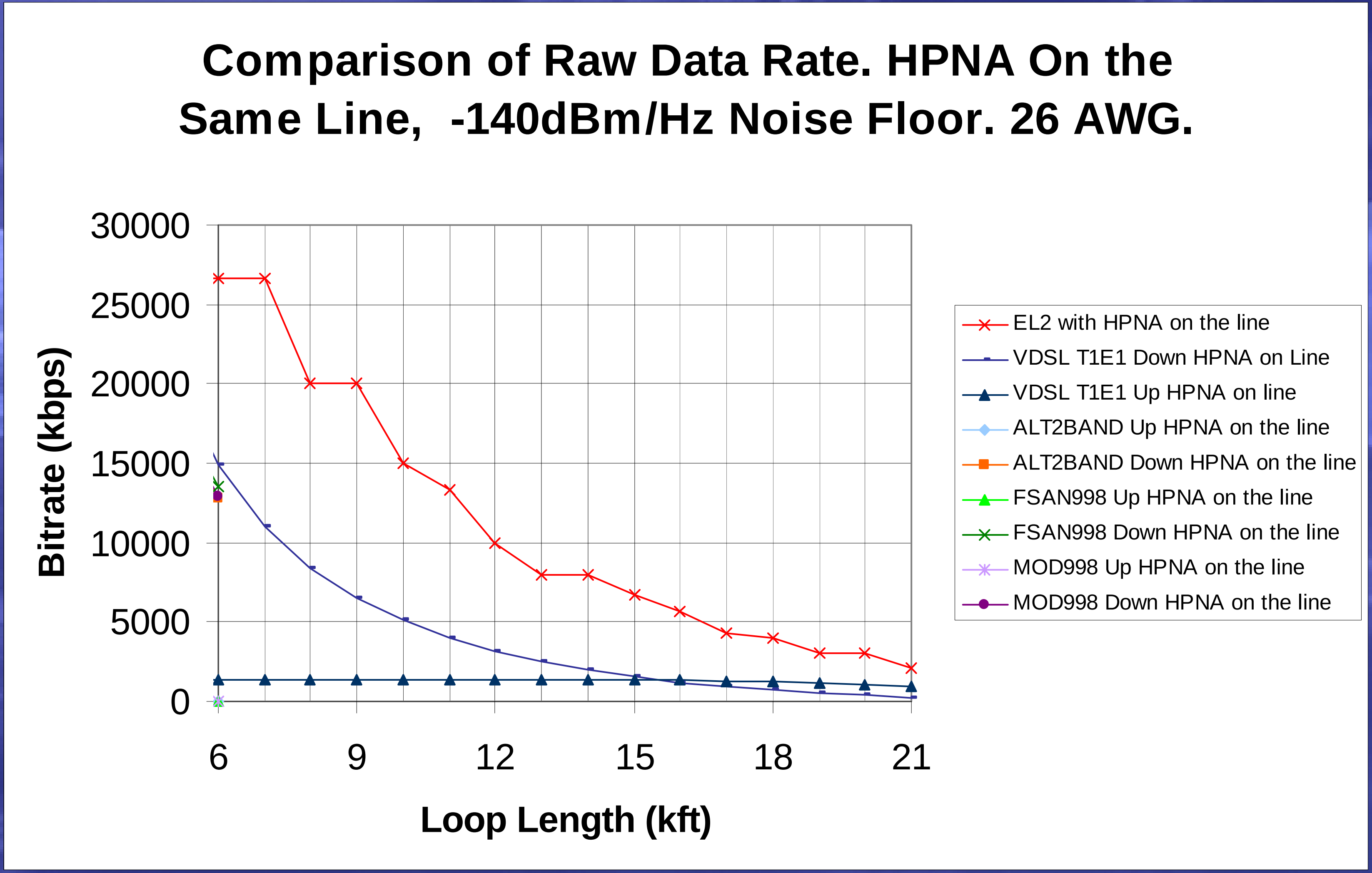
HPNA PSD occupies 5.5MHz to 9.5MHz

In splitterless installations, EFM must share the line with HPNA

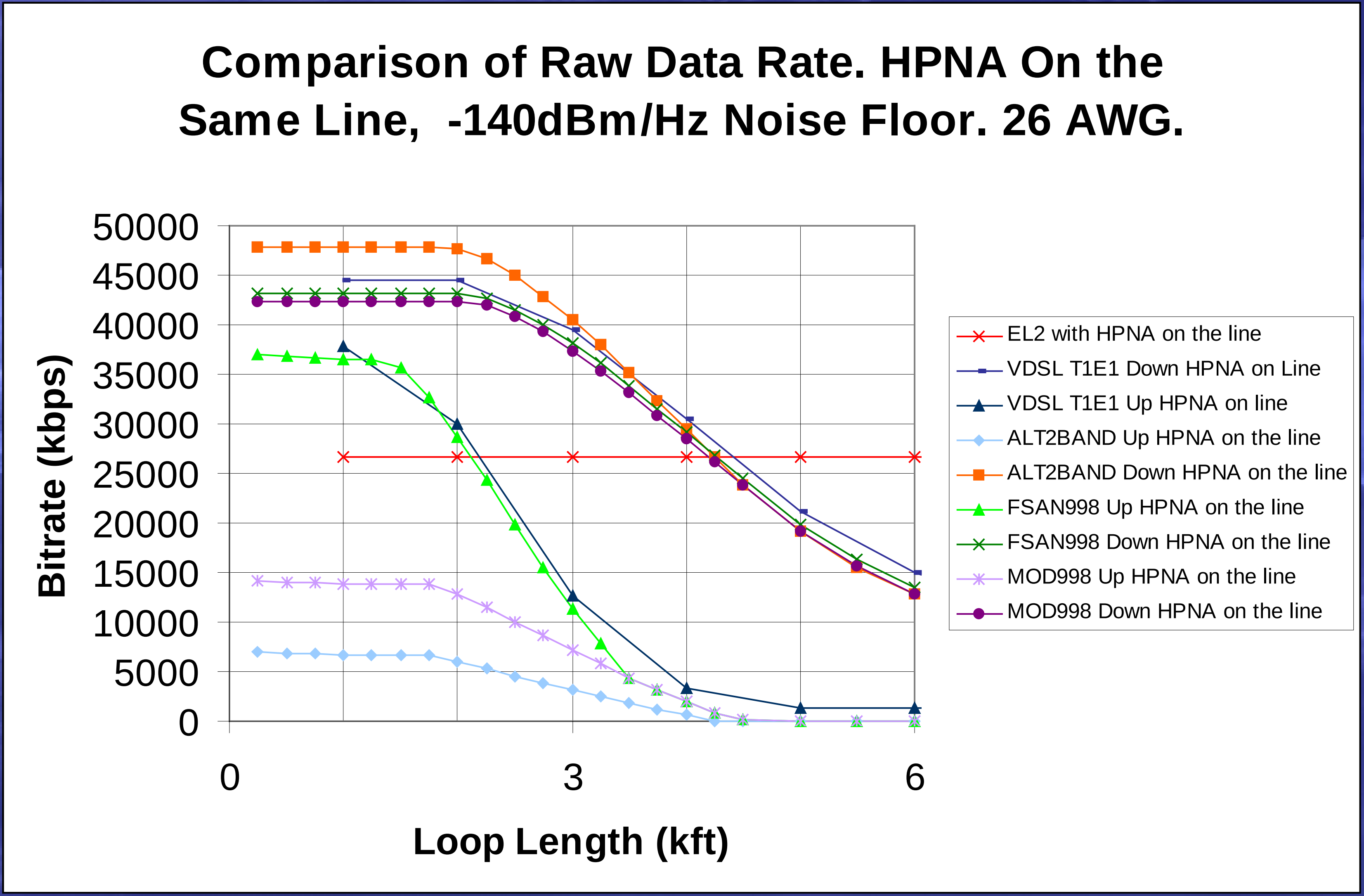
Performance with HPNA on the same Loop



Performance with HPNA on the same Loop (Long Loops)



Performance with HPNA on the same Loop (Short Loops)



Proposal for Goals & Objectives

In addition to the optical portion of the EFM standard, which is important, propose that the EFM standard include:

Copper based EFM to offer high speed service over all nonloaded copper loops, including Outside Plant, in the presence of mixed crosstalk.