Technology and Applications

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Abstract

VDSL is the most powerful member of the xDSL family, capable of providing up to 50 Mbps on a single telephone wire. It provides unmatched flexibility in rate, reach and symmetry to satisfy the increasing demand for high-speed services such as corporate communications, fast Internet access and high quality digital audio and video delivery.

This presentation will provide an introduction to the VDSL technology and its applications. It will give an overview of a VDSL system, describing channel conditions, system architecture, and VDSL performance in terms of rate-reach-symmetry objectives. It will cover the basic principles of VDSL, explaining why VDSL is not just an upgrade of ADSL in terms of higher transmission speed, and summarizing the features in the current VDSL standard that allow customization and on-the-fly configuration of the modems. In the talk a general block diagram of a DMT-based VDSL modem will be presented, describing some of the signal processing techniques that enable this high performance operation and flexibility. Finally, some of the applications for VDSL such as ATM over DSL and Ethernet over DSL will also be described.

Disclaimer

- Information provided in this talk is of public nature and can be found in the references and the WWW
- For specific information about Ikanos VDSL products please contact the marketing department

Overview

- A definition for VDSL (What?)
- The need for VDSL (Why?)
- Anatomy of a VDSL system (How?)
- The VDSL standard
- Selection of line code
- Some VDSL-based applications (Where?)

What is VDSL?

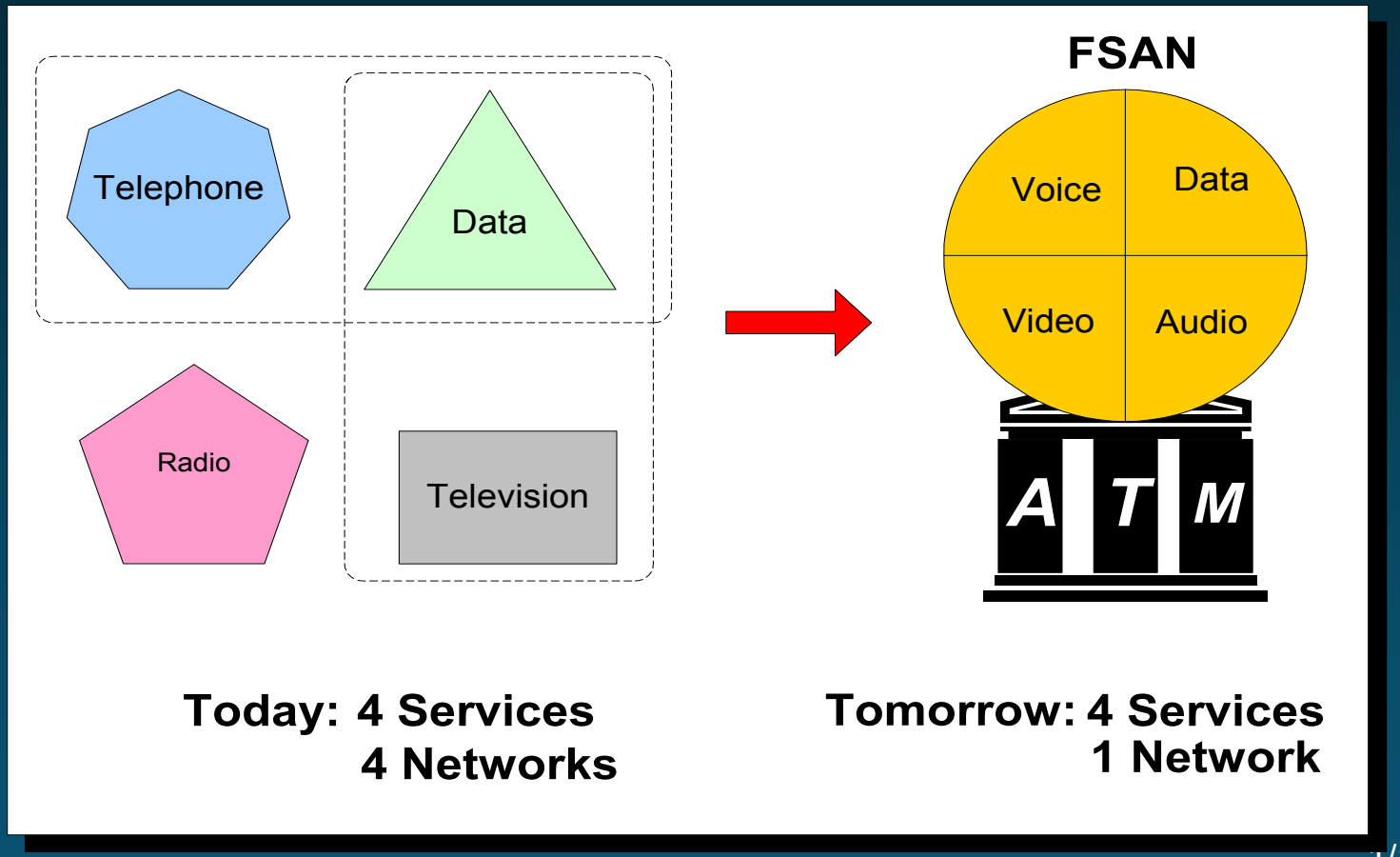
A dictionary definition (www.webopedia.com)

- VDSL: Very High Speed DSL, transmits data in the 13 Mbps - 55 Mbps range over short distances, usually between 1000 and 4500 feet (300 - 1500 meters), of twisted pair copper wire. The shorter the distance, the faster the connection rate.
- DSL: Digital Subscriber Line, technology using sophisticated modulation schemes to pack data onto copper wires. They are sometimes referred to as last-mile technologies because they are used only for connections from a telephone switching station to a home or office, not between switching stations.
- xDSL: Refers collectively to all types of DSL (VDSL, ADSL, SDSL, SHDSL, HDSL, ISDN)

The Need for VDSL

VDSL and FSAN

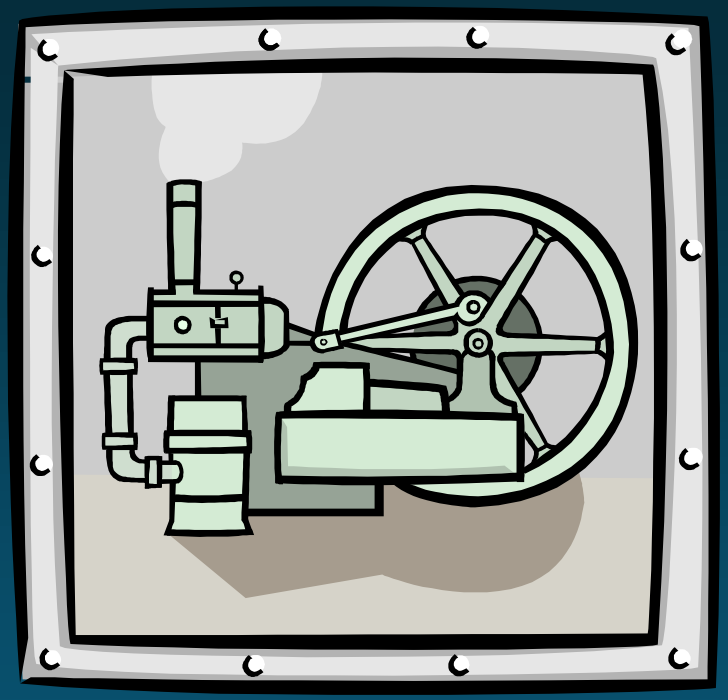
- Full Service Access Network:



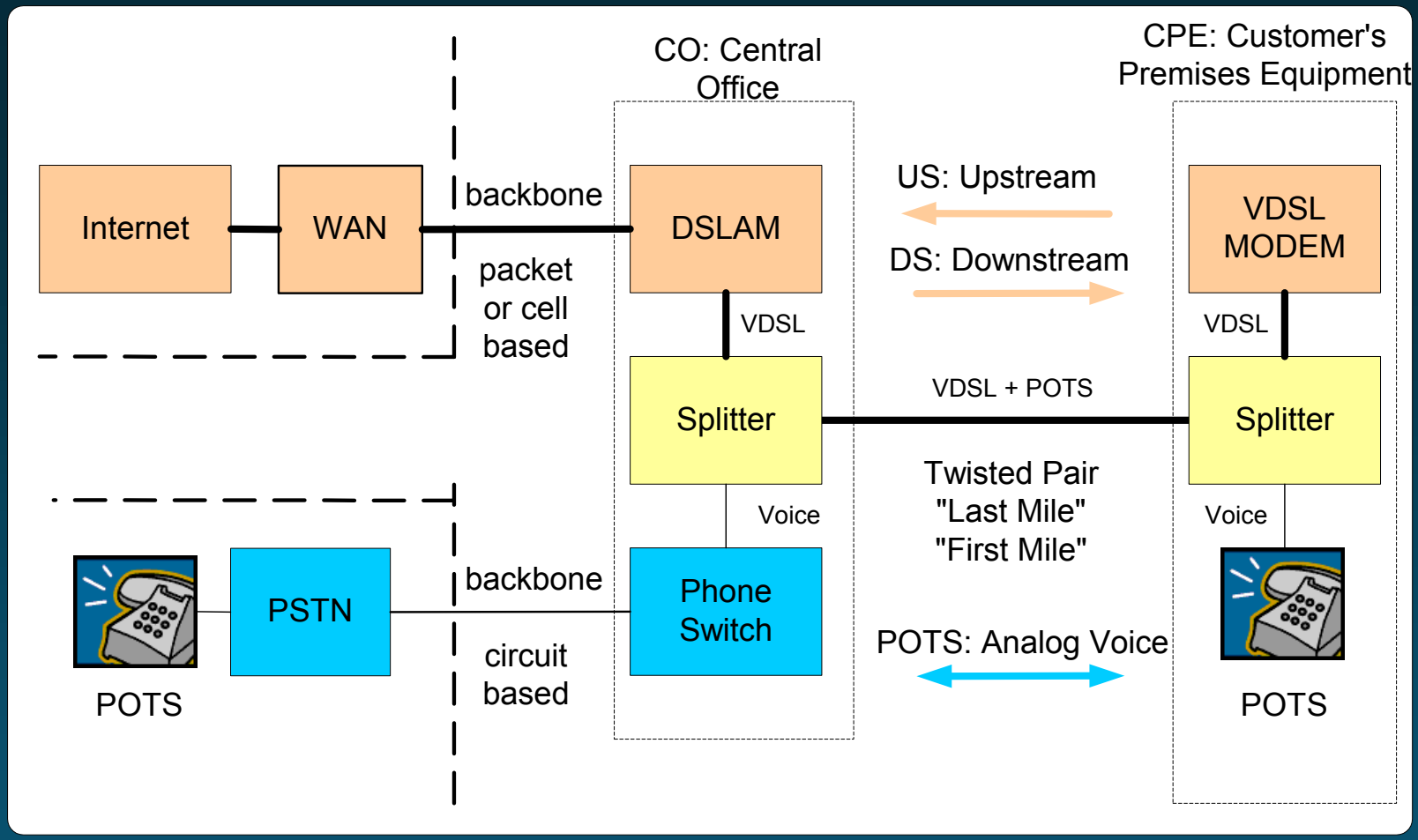
VDSL and other xDSL

Technology	DS/US Data Rate	Reach (26 AWG)	Applications
VDSL	52/30 Mbps 54/13 Mbps 26/26 Mbps 22/13 Mbps 13/13 Mbps 10/10 Mbps 6/6 Mbps 16/1 Mbps	1000 ft 3000 ft 4500 ft 6000 ft	Asymmetric: simultaneous multiple HDTV's and/or DTVs, internet, audio, games, POTS Symmetric: EFM, LRE Other: Video- Conference, Tele-Commuting, Tele-Medicine, Distance-Learning, Home-shopping.
ADSL+	20/0.8 Mbps 10/0.8 Mbps	7200 ft 14400 ft	Asymmetric: Two DTV, internet, audio, games, POTS
ADSL2	10/0.8 Mbps 3.5/3.5 Mbps	14400 ft	Asymmetric: One DTV, internet, audio, games POTS
SHDSL	2.3/2.3 Mbps	16000 ft	Symmetric: One or morel T1/E1, Data, and POTS, Remote LAN
HDSL-2	1.544/1.544 Mbps 2.044/2.044 Mbps	9600 ft	Symmetric: T1/E1 over 1 pair with no repeaters
ISDN	144/144 Kbps	14400 ft	Symmetric: Digital voice plus data
T1/E1 (not a DSL)	1.544/1.544 Mbps 2.044/2.044 Mbps	14400 ft or 12800 ft	Symmetric: Data, no POTS (leased line), uses two pairs with repeaters every 4800 ft

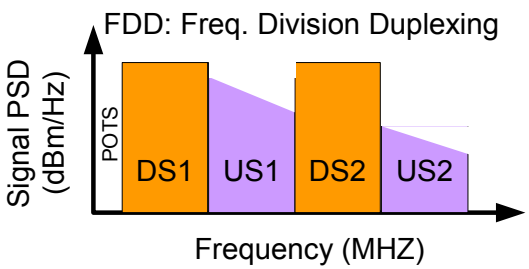
Anatomy of a VDSL SYSTEM

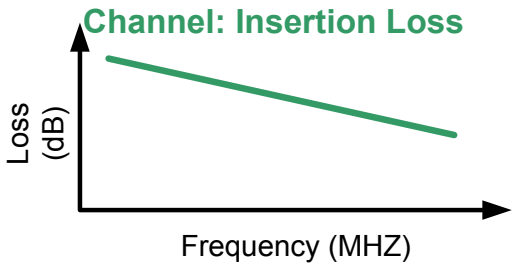


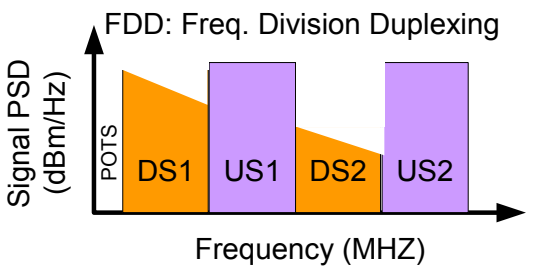
Network topology for VDSL over POTS

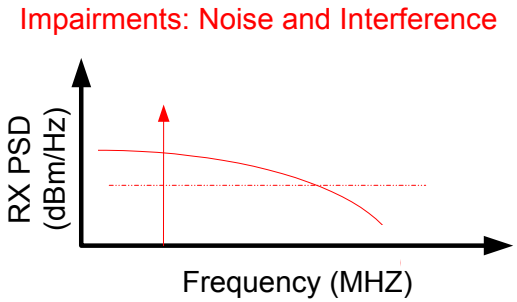


Transmission environment









Transmission environment

Channel Impairments

- Insertion Loss
- Bridge taps (BT)

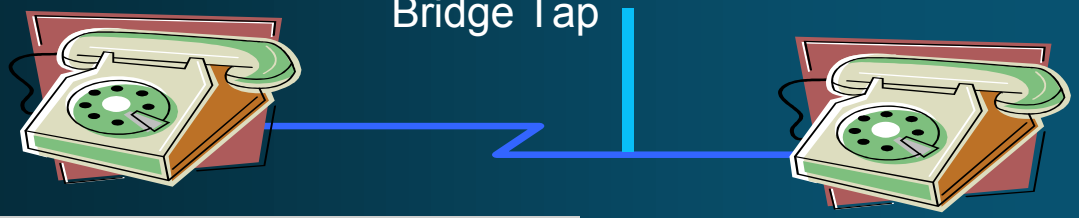
Noise Impairments

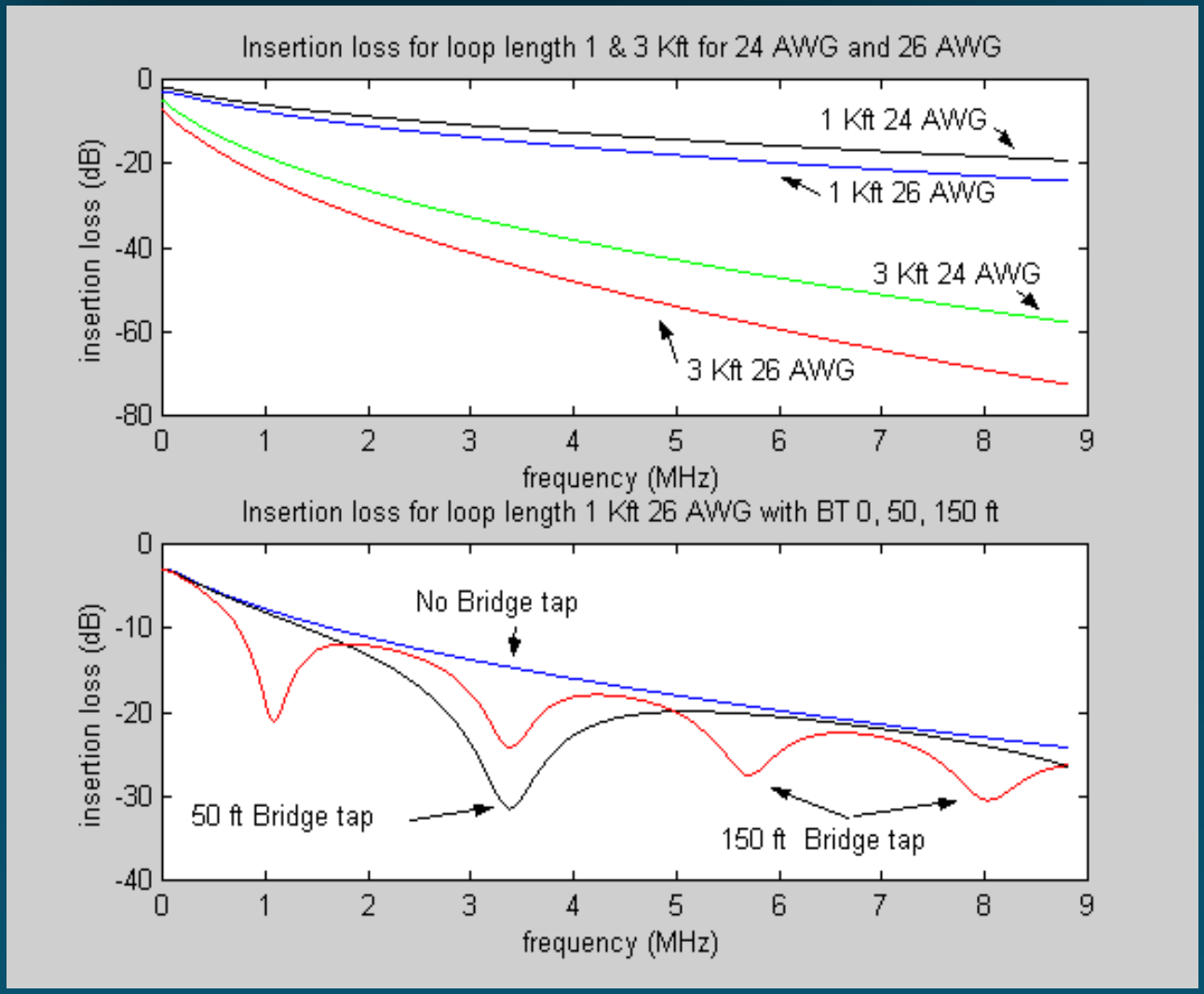
- Crosstalk:
  - Next ($f^{1.5}$)
  - Fext ($|H(f)|^2 \, d \, f^2$)
- RFI Ingress:
  - HAM Radio
  - AM Radio
- Impulse Noise.

Restrictions

- Spectrum compatibility.
  - **Legacy systems**
- RFI Egress.
  - HAM Radio

Channel impairments





- Attenuation a function of:
  - Length
  - Gauge
  - Frequency
  - Bridge taps

Transmission environment

Channel Impairments

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- Bridge taps (BT)

Noise Impairments

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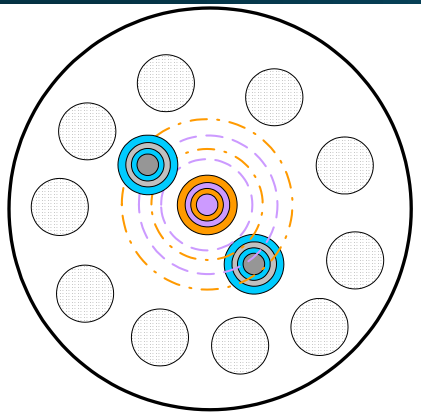
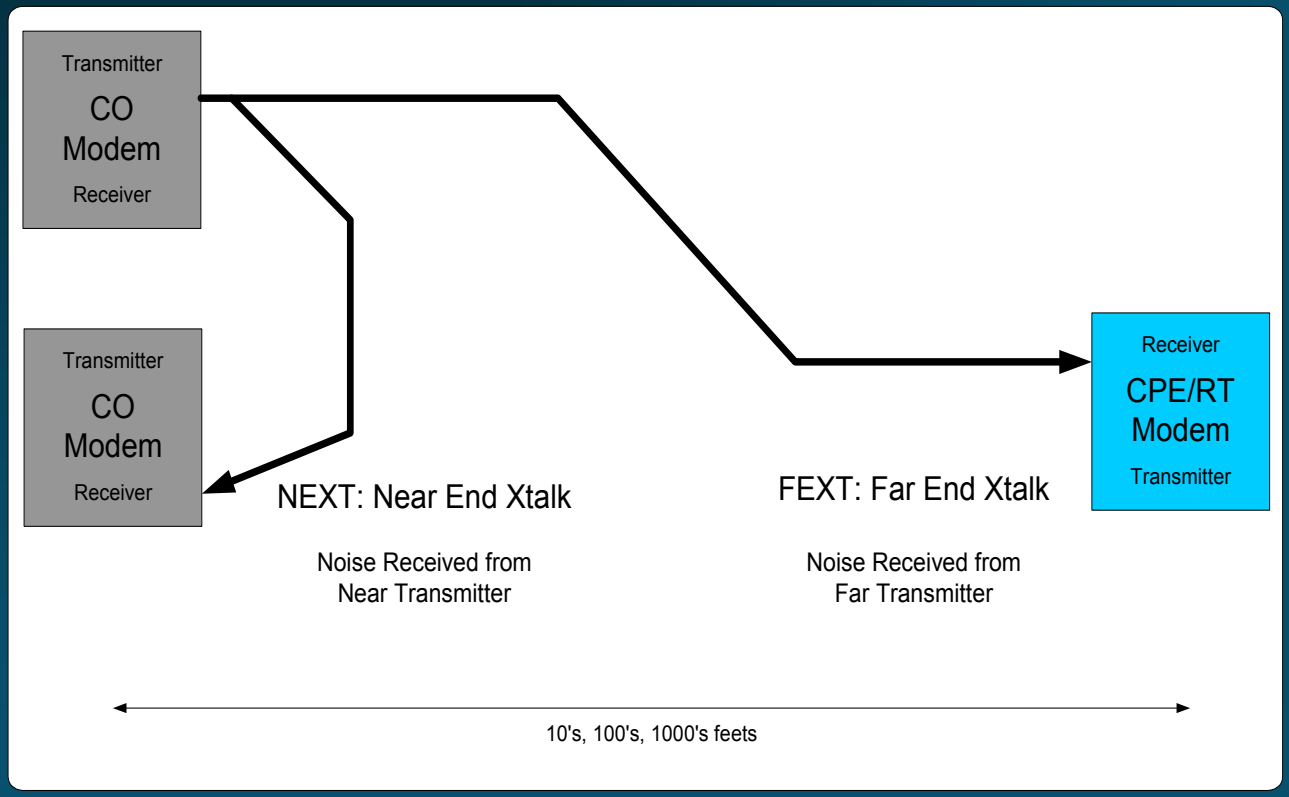
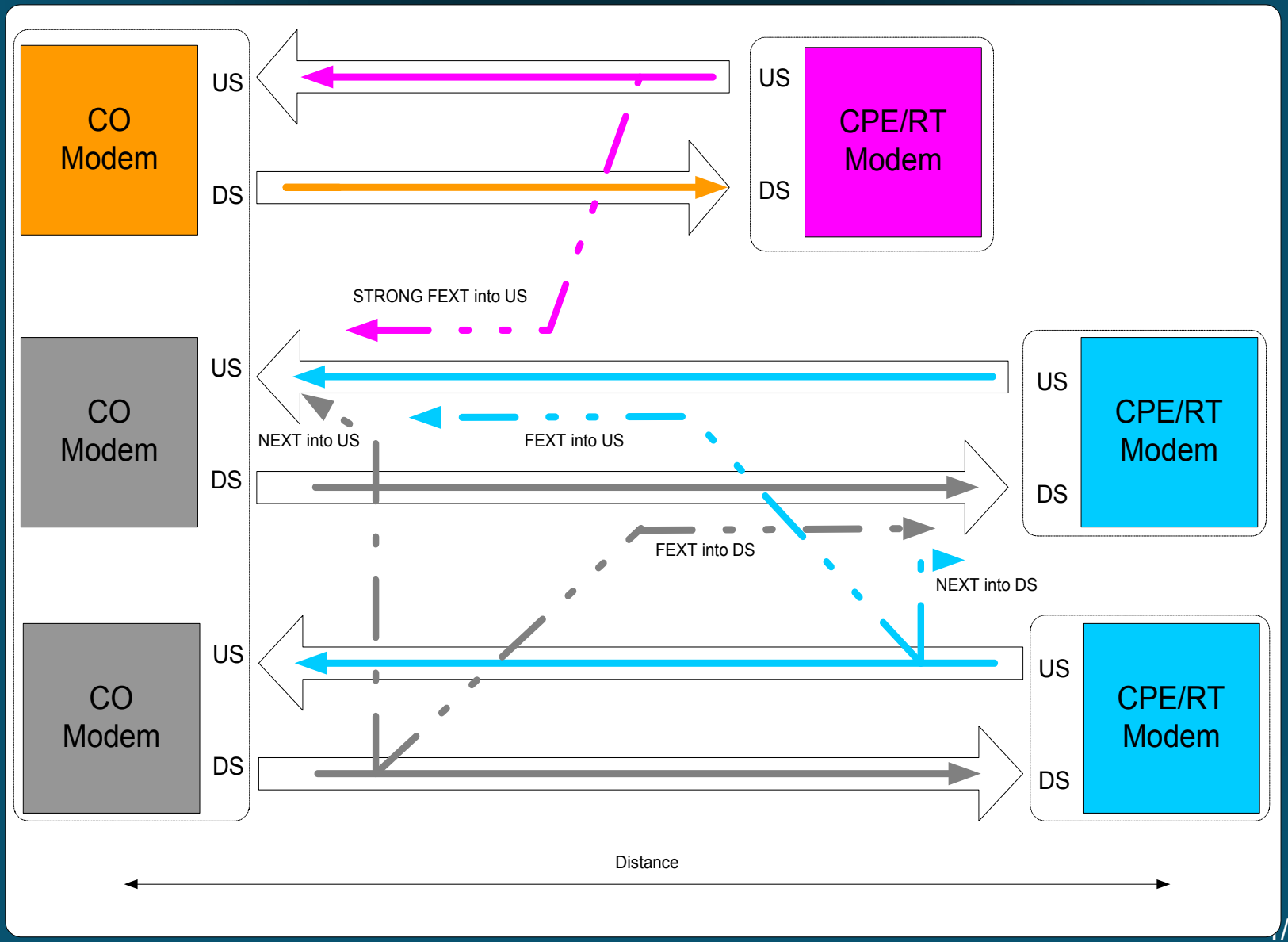
Crosstalk



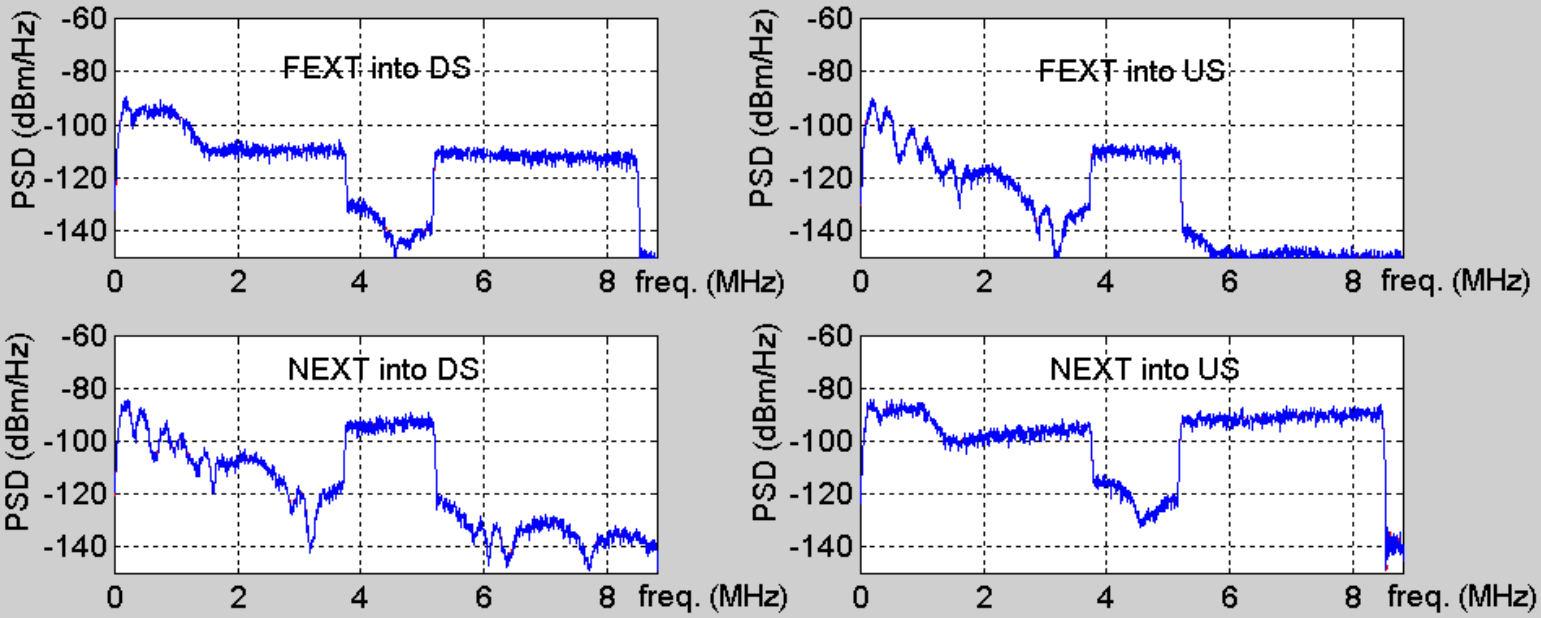
Cable with several
Twisted pairs



Crosstalk


CO Modem
US
DS
CPE/RT Modem
US
DS
STRONG FEXT into US
CO Modem
US
DS
CPE/RT Modem
US
DS
NEXT into US
FEXT into US
FEXT into DS
NEXT into DS
CO Modem
US
DS
CPE/RT Modem
US
DS
Distance

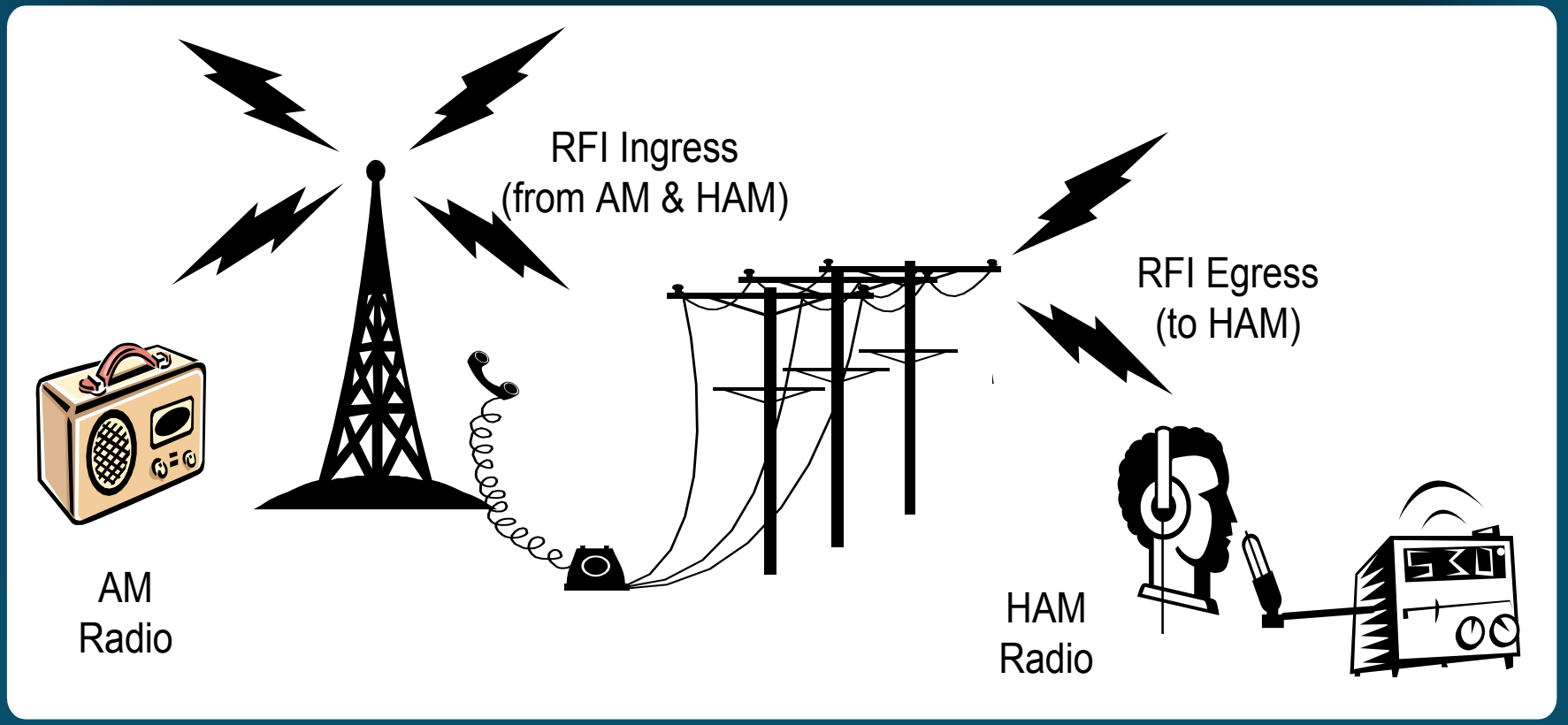
Crosstalk



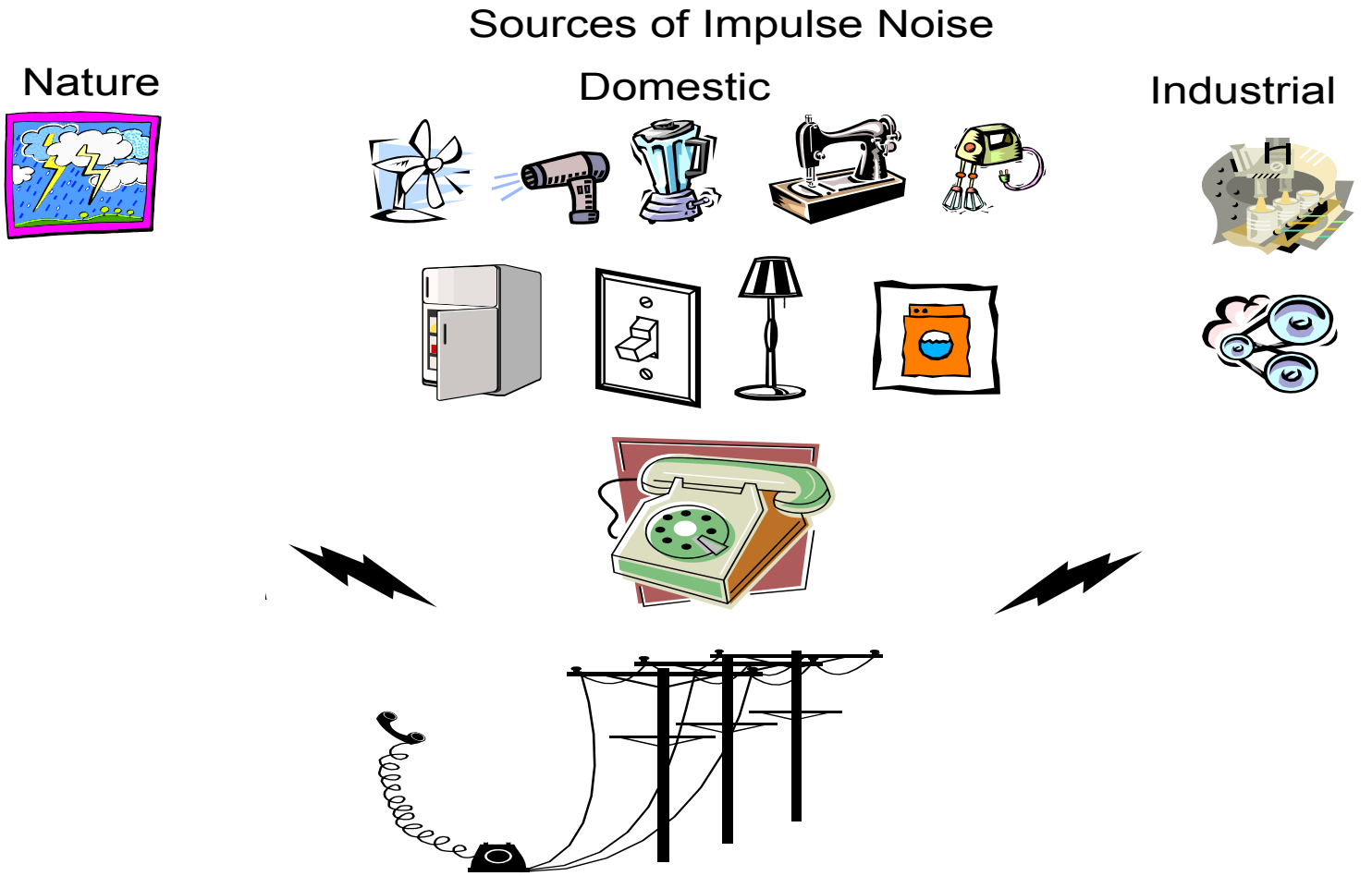
Crosstalk a function of:

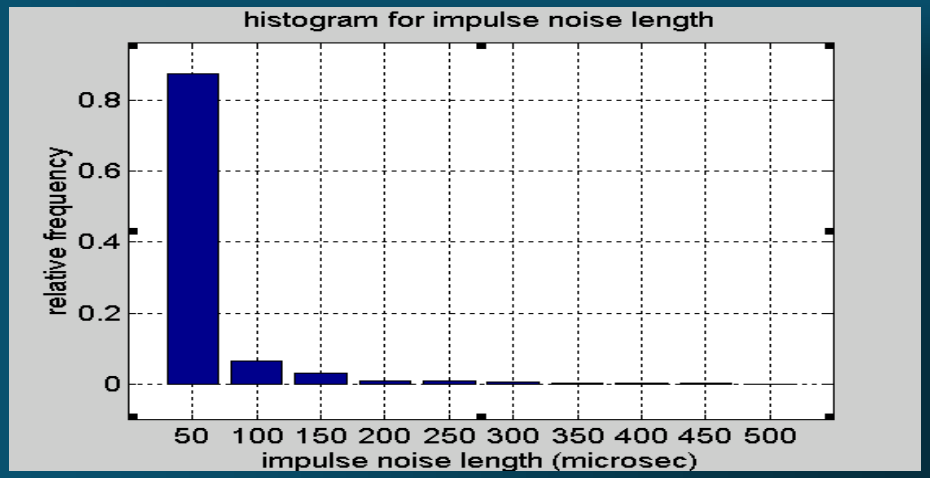
- Disturber's PSD (Self: VDSL, Alien: ADSL, SHDSL, etc)
- Frequency location and cable length
- Cable type (wrapping and insulation inside the bundle)

Radio Frequency Interference (RFI)

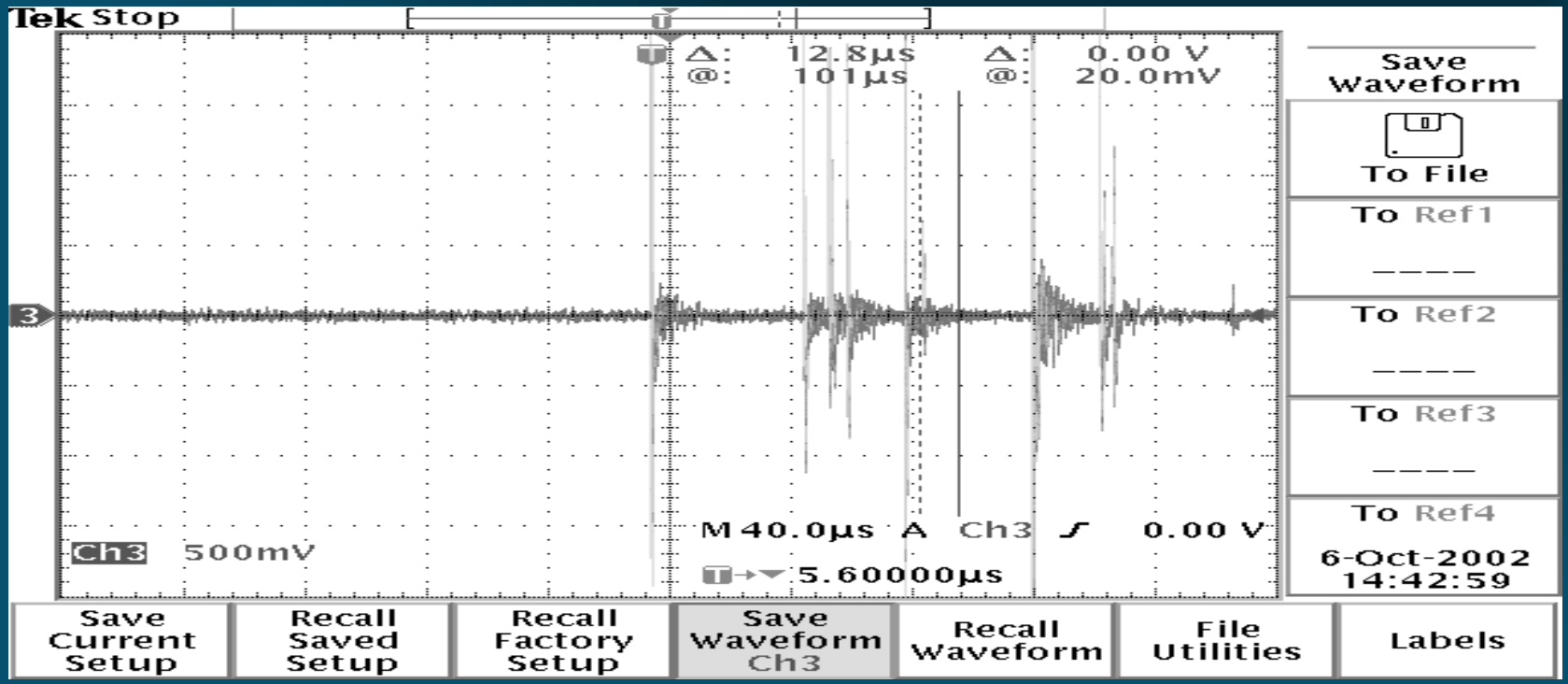


Impulse Noise





Impulse Noise



Transmission environment

Channel Impairments

- Insertion Loss
- Bridge taps (BT)

Noise Impairments

- Crosstalk:
  - Next ($f^{1.5}$)
  - Fext ($|H(f)|^2 \, d \, f^2$)
- RFI Ingress:
  - HAM Radio
  - AM Radio
- Impulse Noise.

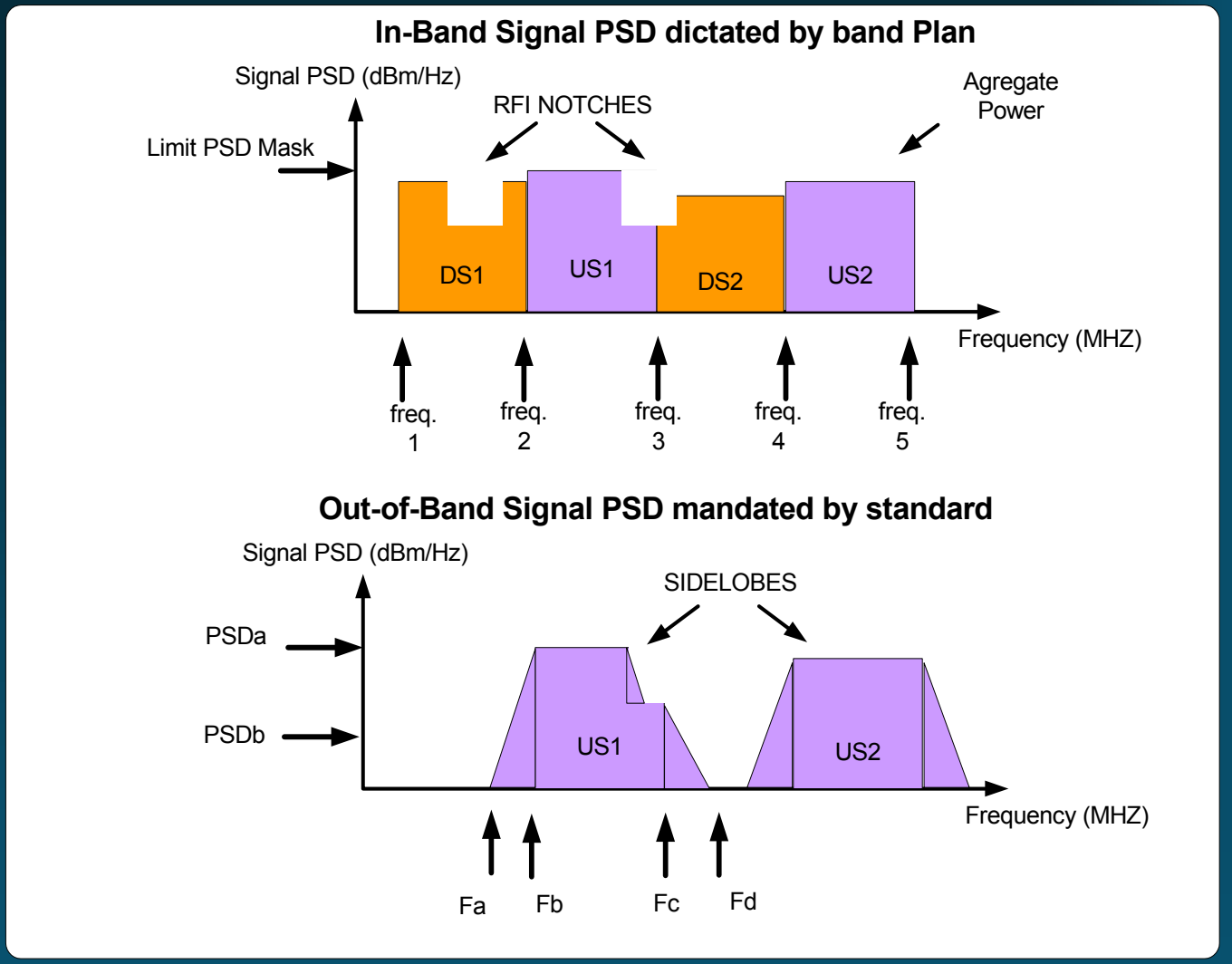
Restrictions

- Spectrum compatibility.
  - **Legacy systems**
- RFI Egress.
  - HAM Radio

Restrictions in transmission environment

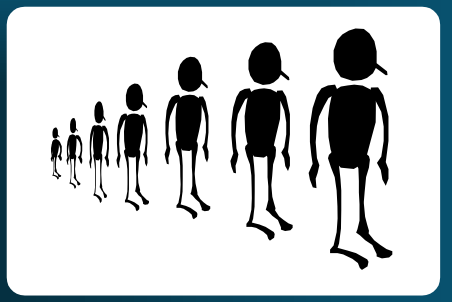
In-band Mask

Out-of-band Mask



The VDSL standard

Standards bodies



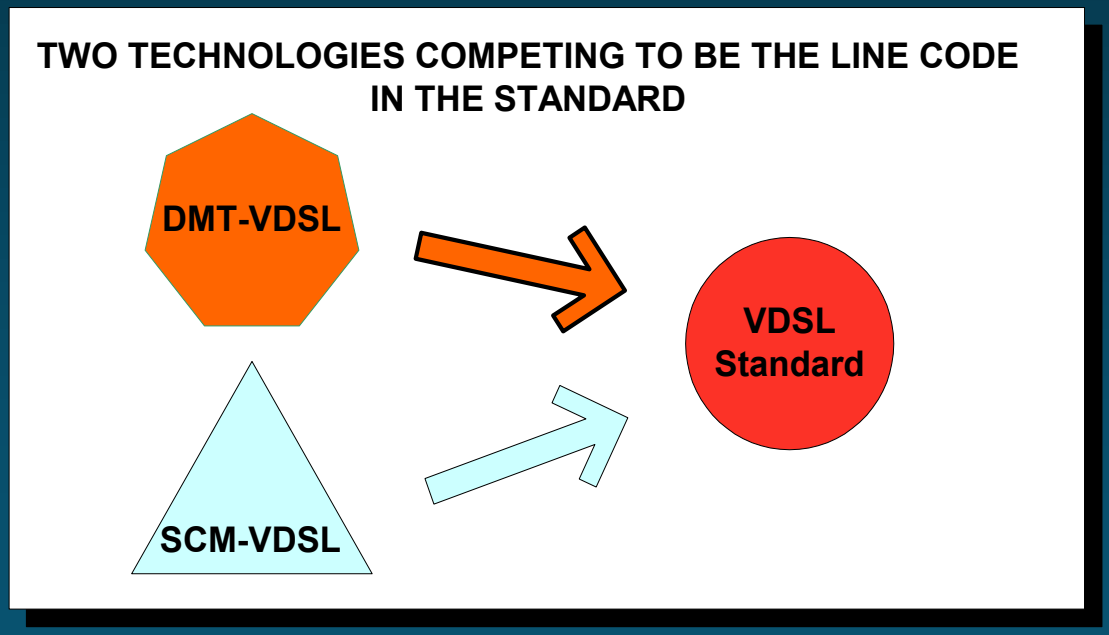
ANSI	ETSI	ITU	IEEE

Working groups and industry associations

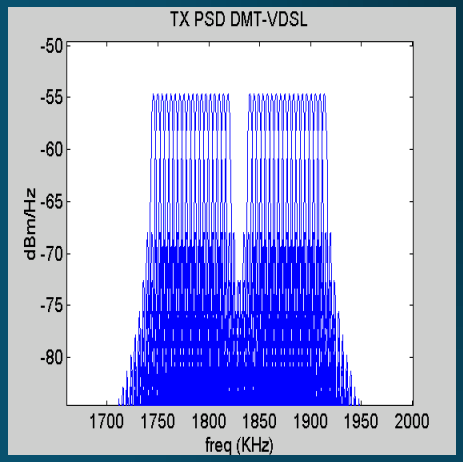
ANSI T1E1.4	ETSI TM6	ITU Study Group 15	IEEE EFM Task Force 802.3.ah
VDSL Alliance (DMT)	VDSL Coalition (SCM)	ADSL Forum	ATM Forum

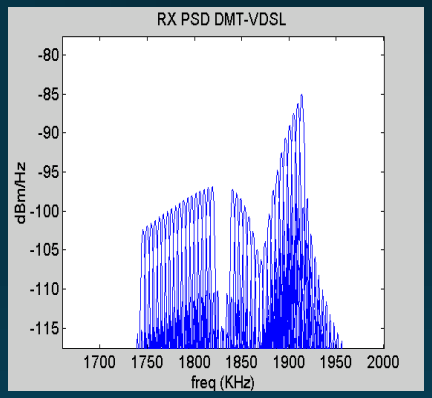
Current VDSL standards

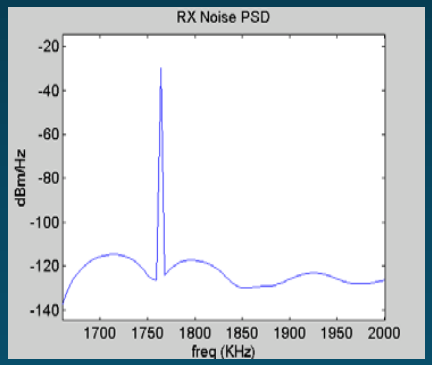
- **ANSI T1.424/Trial/Use**
- **ETSI TS 101 270-1&2**
- **ITU G993.1**
- **Two lines codes:**
  - **DMT-VDSL(Discrete Multi Tone VDSL)**
  - **SCM-VDSL: (Single Carrier Modulation VDSL)**

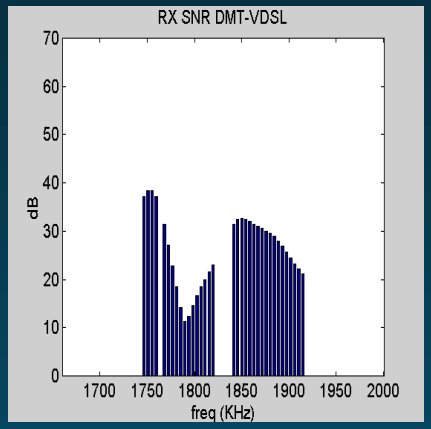


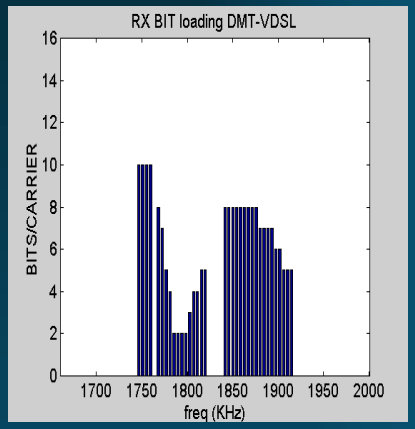
DMT Processing



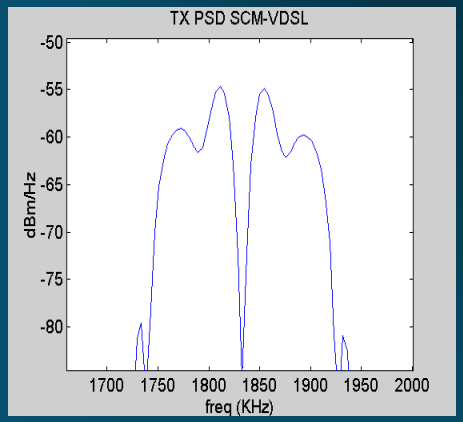


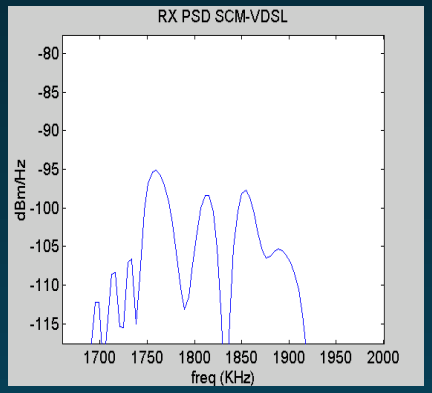


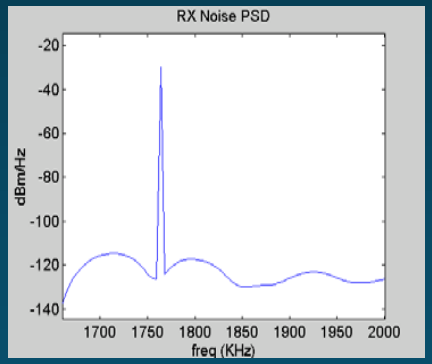


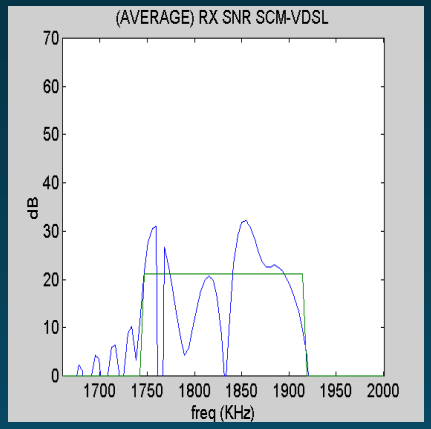


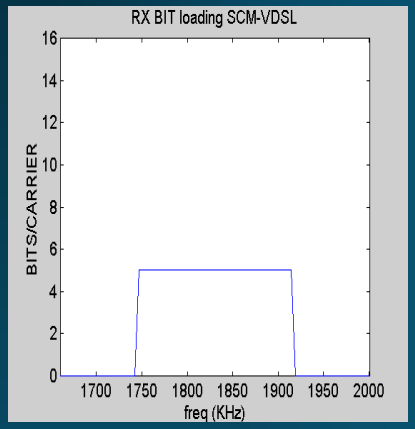
SCM Processing



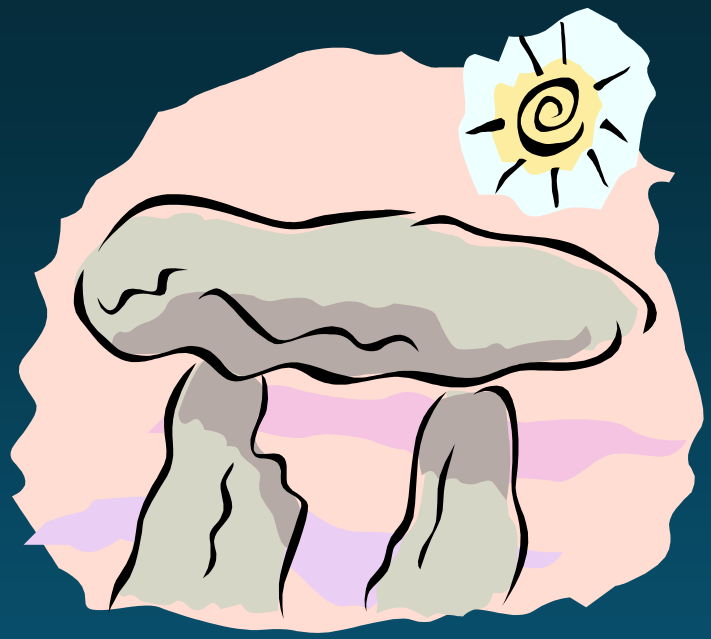






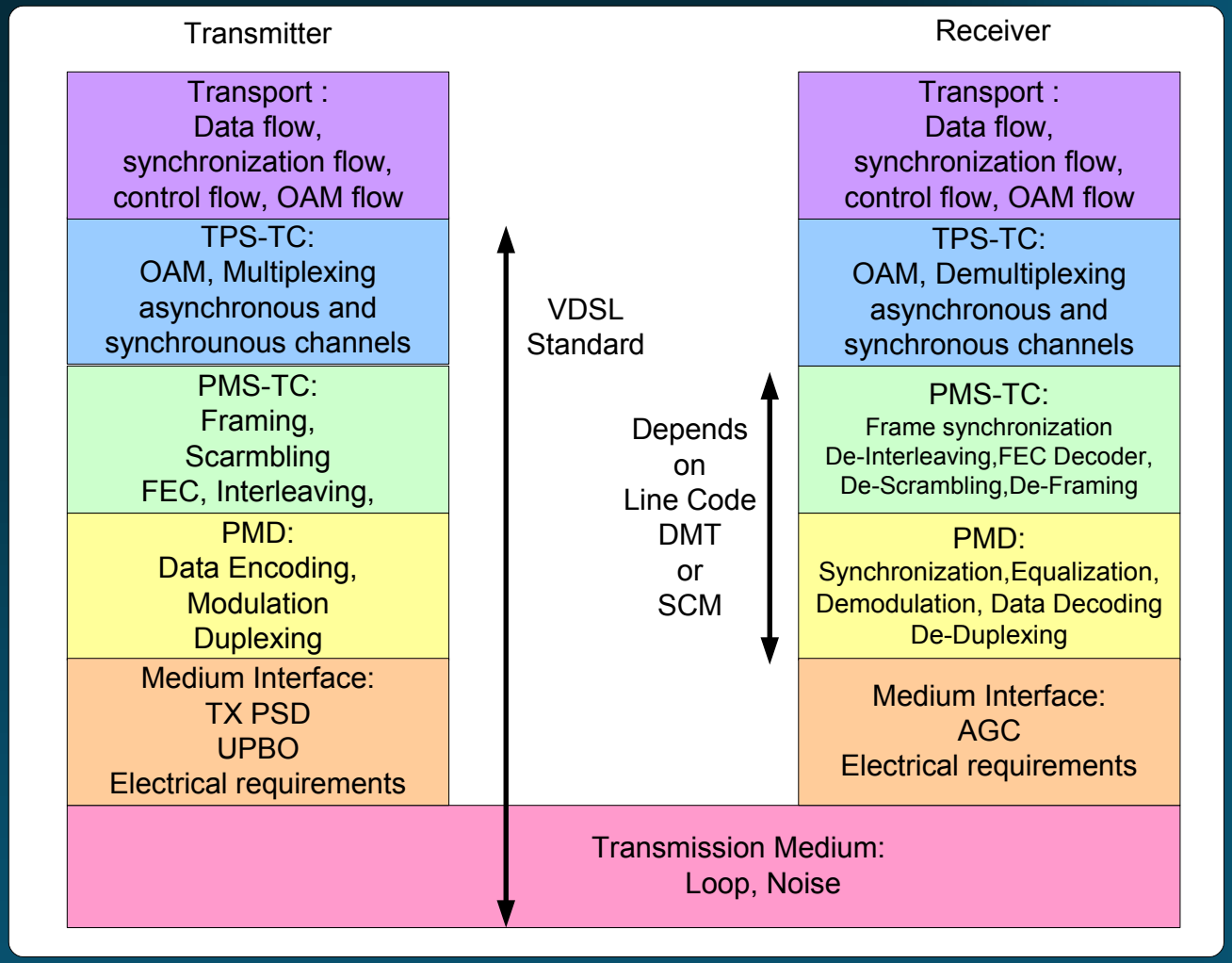


System Architecture in the VDSL Standard

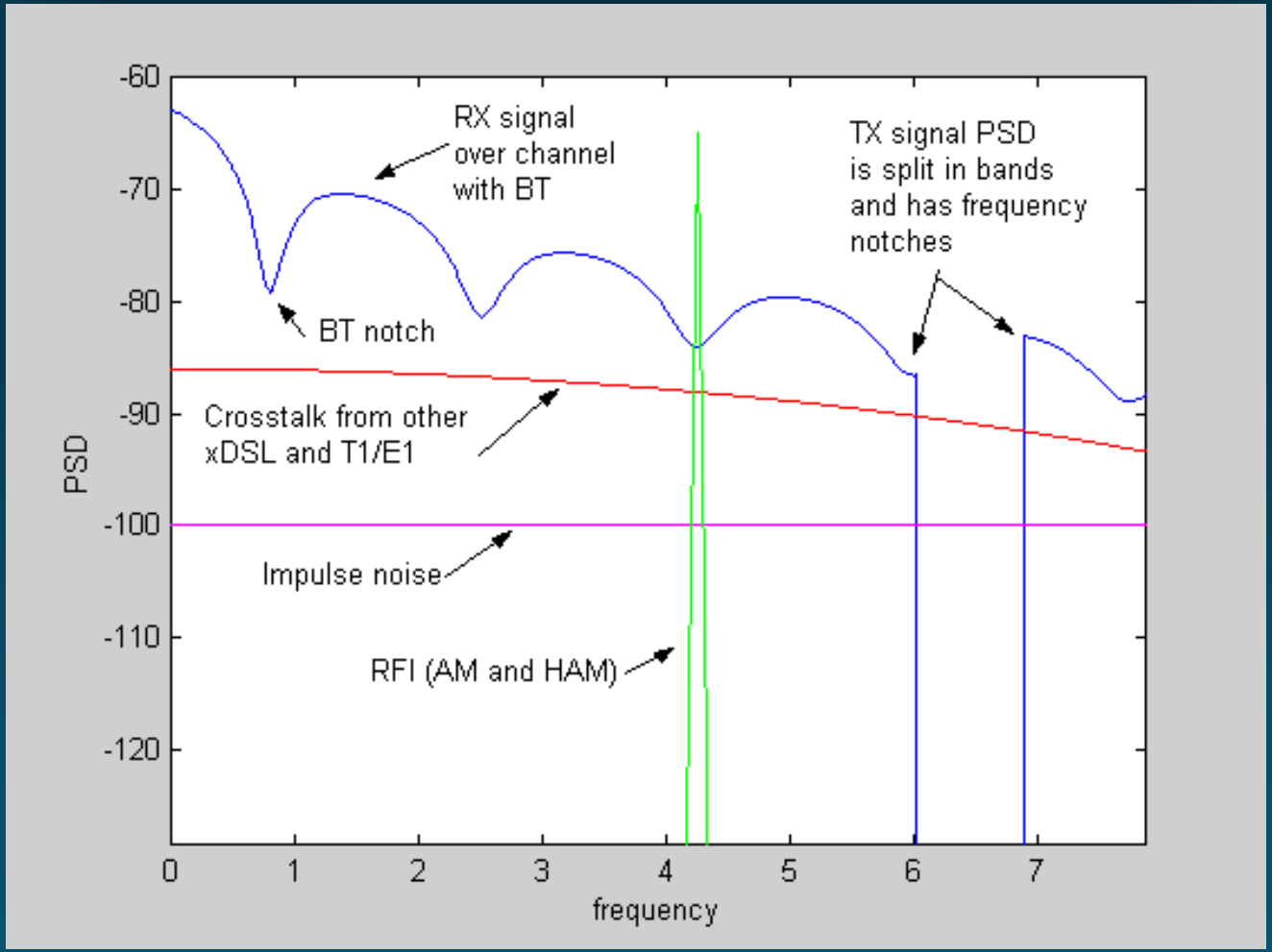


System Architecture

- TPS-TC: Transport Protocol-Specific Transmission Convergence
- OAM: Operation And Maintenance
- PMS-TC: Physical Medium-Specific Transmission Convergence
- FEC: Forward Error Correction
- PMD: Physical Medium Dependant
- UPBO: Upstream Power Back-off



Transmission Medium:
(frequency, time and location dependant)



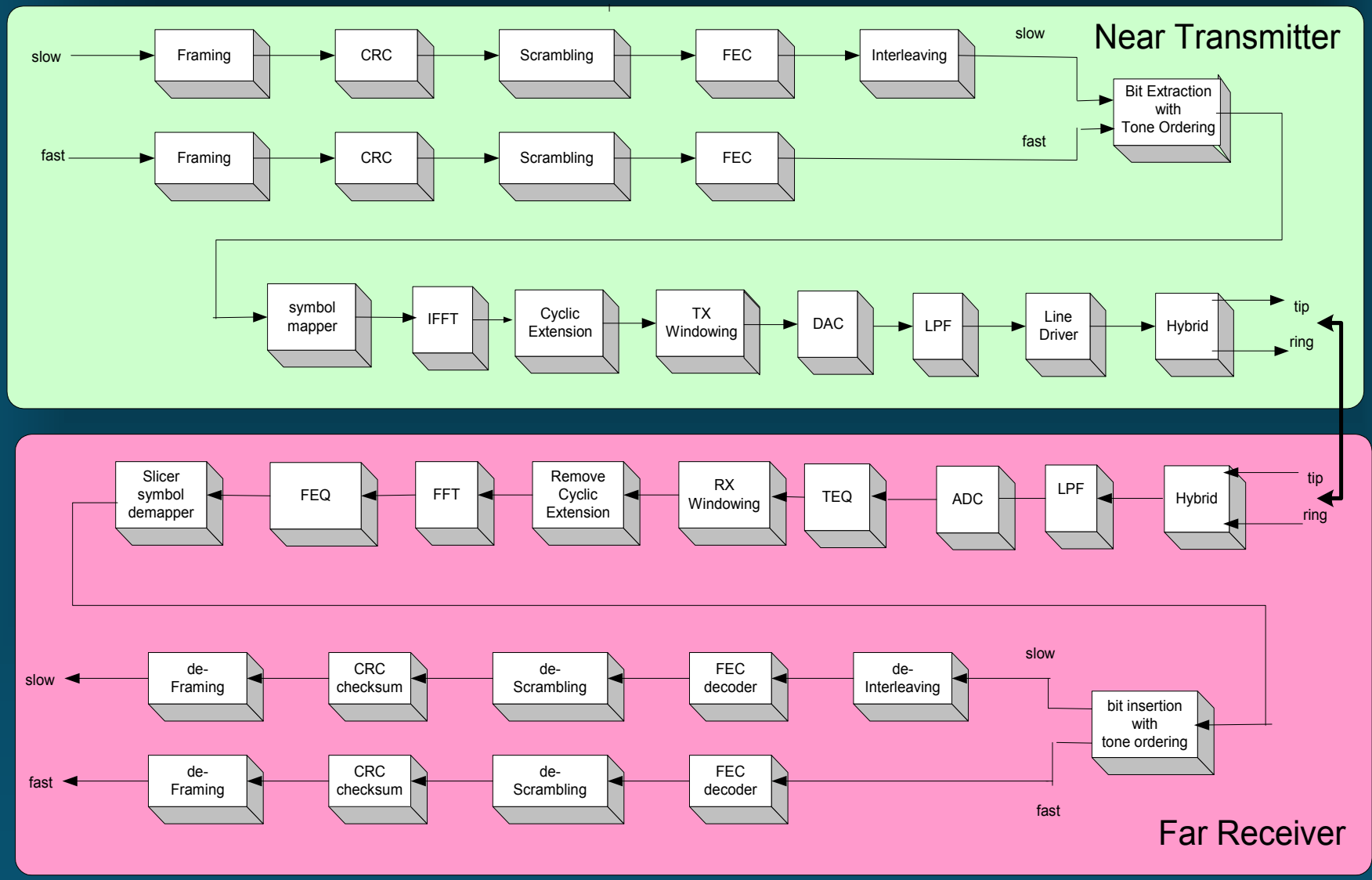
Medium interface:

- TX PSD: Conforms to a band plan:
  - FSAN 997,998, ITU FX
  - Proprietary
  - Symmetric or asymmetric
- Upstream power back-off at CPE/RT: alleviates near-far problem
  - Frequency dependant
  - Bandplan, crosstalk composition, wire gauge and cable type of bundling.

PMD layer for DMT

- TX PMD:
  - Data Encoding: Mapping bits to symbols
  - Modulation: Multicarrier QAM with bit loading
  - Duplexing: FDD
- RX PMD:
  - Synchronization: Sampling frequency and symbol time
  - Equalization: TDQ in time and FEQ in frequency
  - Demodulation: QAM slicer
  - Data decoding:De-mapping symbol to bits
  - De-Duplexing: Digital duplexing using FFT

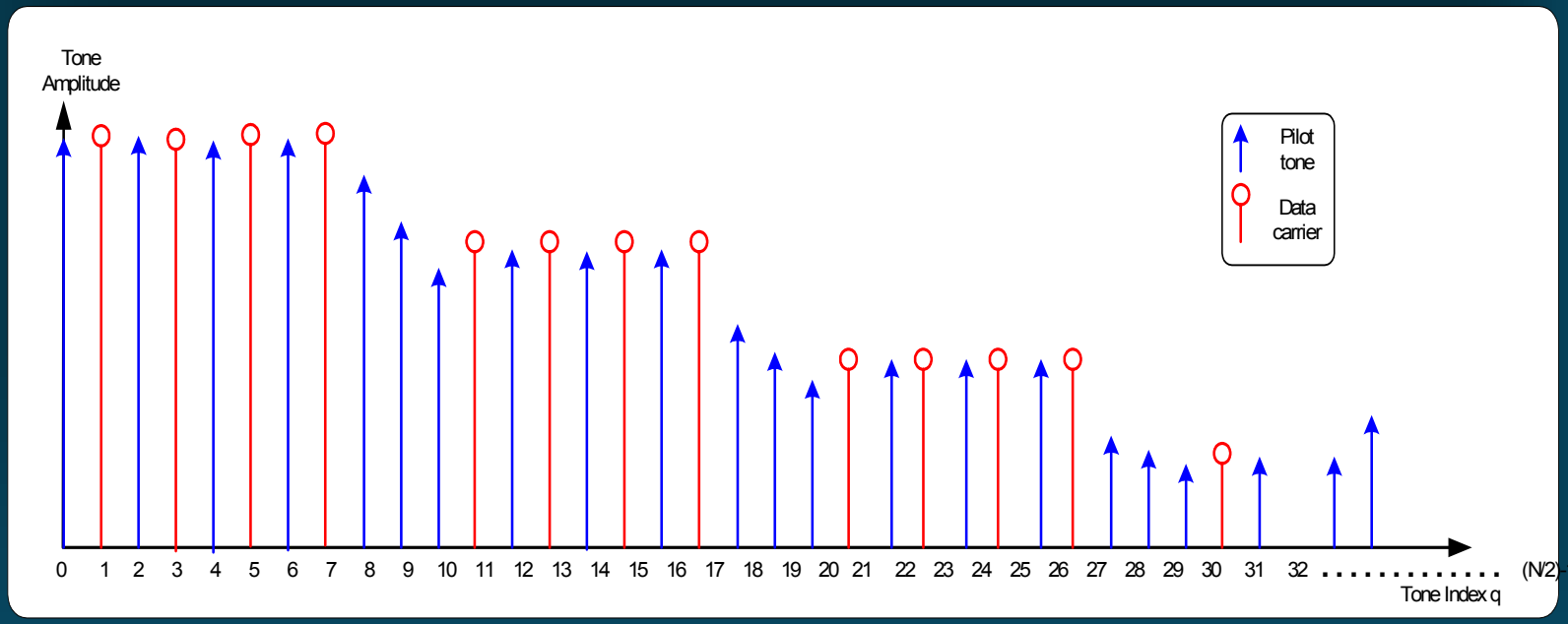
DSP in PMS-TC + PMD for DMT-VDSL



Training of the VDSL modem

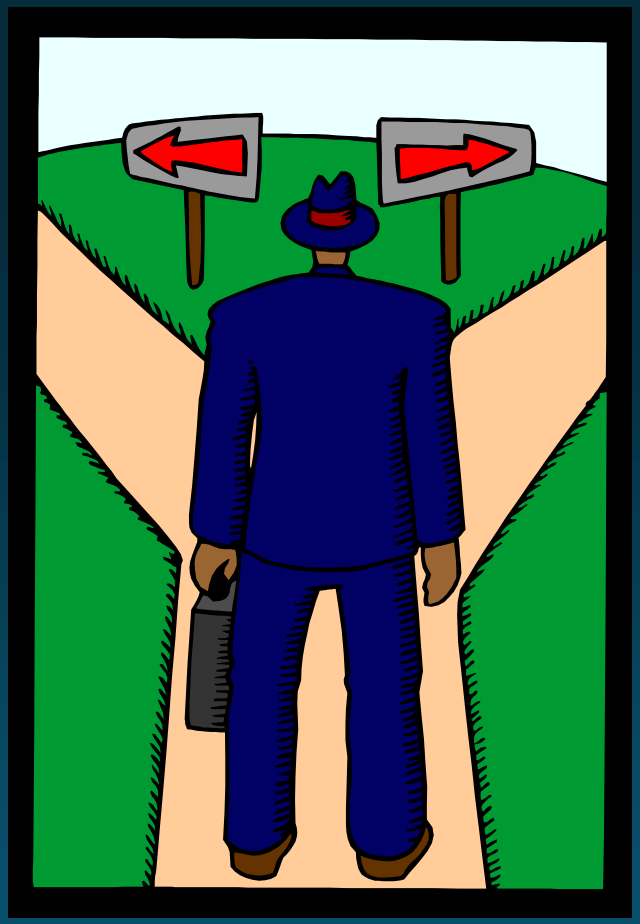
- Flexibility during training
- Training signals allows training the modem
  - Synchronization, Equalization, Bit Loading
- Training signals communicate parameters to allow configuration of modem during training
  - What frequency bands to use for US and DS
  - What PSD to use in each frequency band
  - Some Parameters for system optimization (performance optimization, overhead reduction)
  - Enable optional features

Training signals in DMT-VDSL

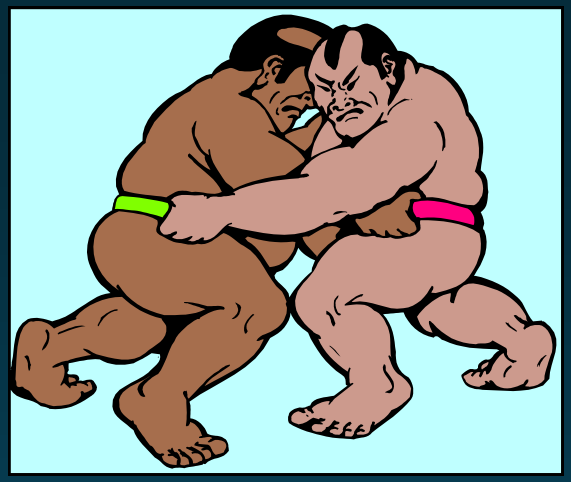


- VDSL training signals and FSM allow configuration of features during training

Selection of line code



DMT-VDSL vs. SCM-VDSL



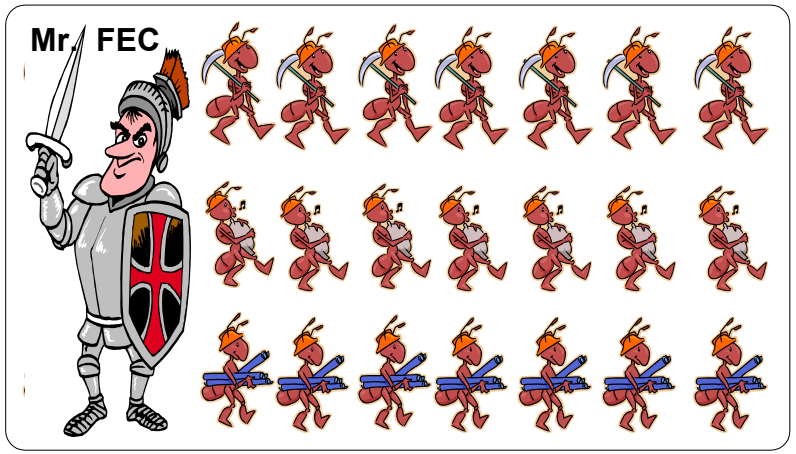
DMT corner

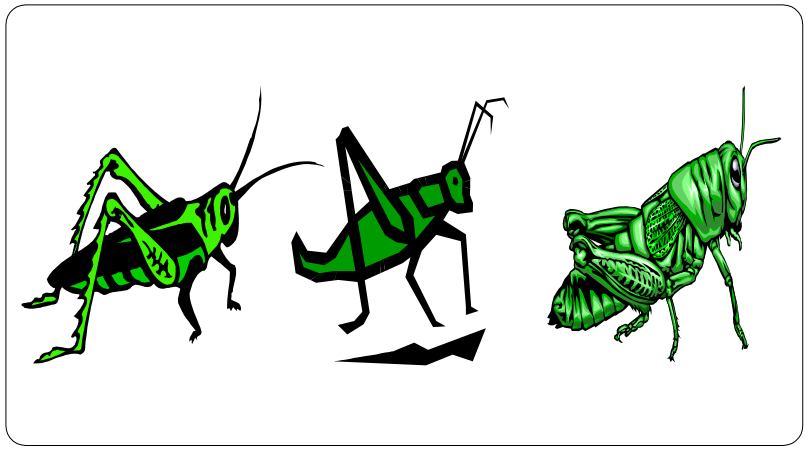
- "The Benefits of DMT for VDSL systems" (Ikanos)
- "Study of the Feasibility and Advisability of DSL operating at Rates Substantially in Excess of the Basic Access Rate", (Theoretical analysis by Author at Bellcore).
- The Winner in the "*ADSL Olympics*" .

SCM corner

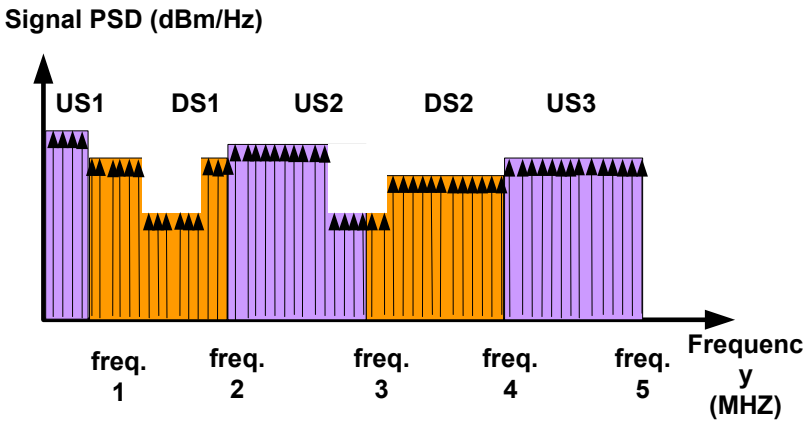
- "Why QAM is better for VDSL" (Infineon)
- "Comparisons of SCM and DMT for ADSL Applications" (Theoretical analysis by Author at Bell Labs).

DMT and SCM

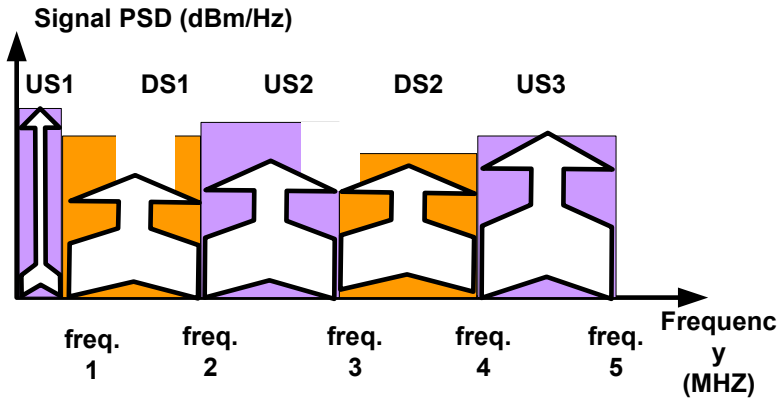




DISCRETE MULTI TONE (Divide and Conquer)



SINGLE CARRIER MODULATION



A basis for comparison

Who can overcome the challenges
in the transmission medium the best?

Challenge	Deleterious effects	Receiver signal processing
Channel Time Dispersion	Signal Smearing	Equalization
Frequency dependent Noise and Interference	Frequency dependent signal-to-noise ratio (SNR)	Bit loading
FDD operation in multi-band spectrum plans	Interference between Upstream and Downstream signals	Signal separation

Comparison along 4 dimensions

Spectrum utilization

- Frequency Division Duplexing
- Notches in in-band mask
- Sidelobes in out-of-band mask

Bandwidth efficiency

- Bit loading (bits/Hz)
- Reach and Rate

Resistance to impairments

- Narrowband interference vs. wideband Interference
- Impulse Noise vs. RFI

Practical implementation

- PAR, clipping and line driver
- Digital complexity vs. analog complexity
- Rate adaptation, Timing jitter
- Power consumption

Advantages of DMT over SCM

Issues	Deleterious effects	DMT solution	SCM solution	Advantages of DMT over SCM
Channel Time Dispersion	Signal Smearing	Two simple equalizers, one in time domain and one in frequency domain	One complicated equalizer in time domain	Simplicity in design and implementation
Frequency dependent Noise	Frequency dependent signal-to-noise ratio (SNR)	Transmit more bits in frequency bands where there is less noise and less bits in frequency bands where there is more noise	Transmit the same average number of bits in every frequency band regardless of amount of noise in each frequency band	Bandwidth efficiency and higher throughput
Full duplex operation in multi-band spectrum plans	Interference between upstream and downstream signals	Use no filtering, utilize Fourier Transform orthogonality properties	Use one complicated filter per transmission band	Higher spectrum utilization, higher throughput and flexible implementation of different band plans

- For numerical results and references, please see “The Benefits of Discrete Multi-Tone (DMT) Modulation for VDSL Systems”, White paper, Ikanos Communications

Some considerations:

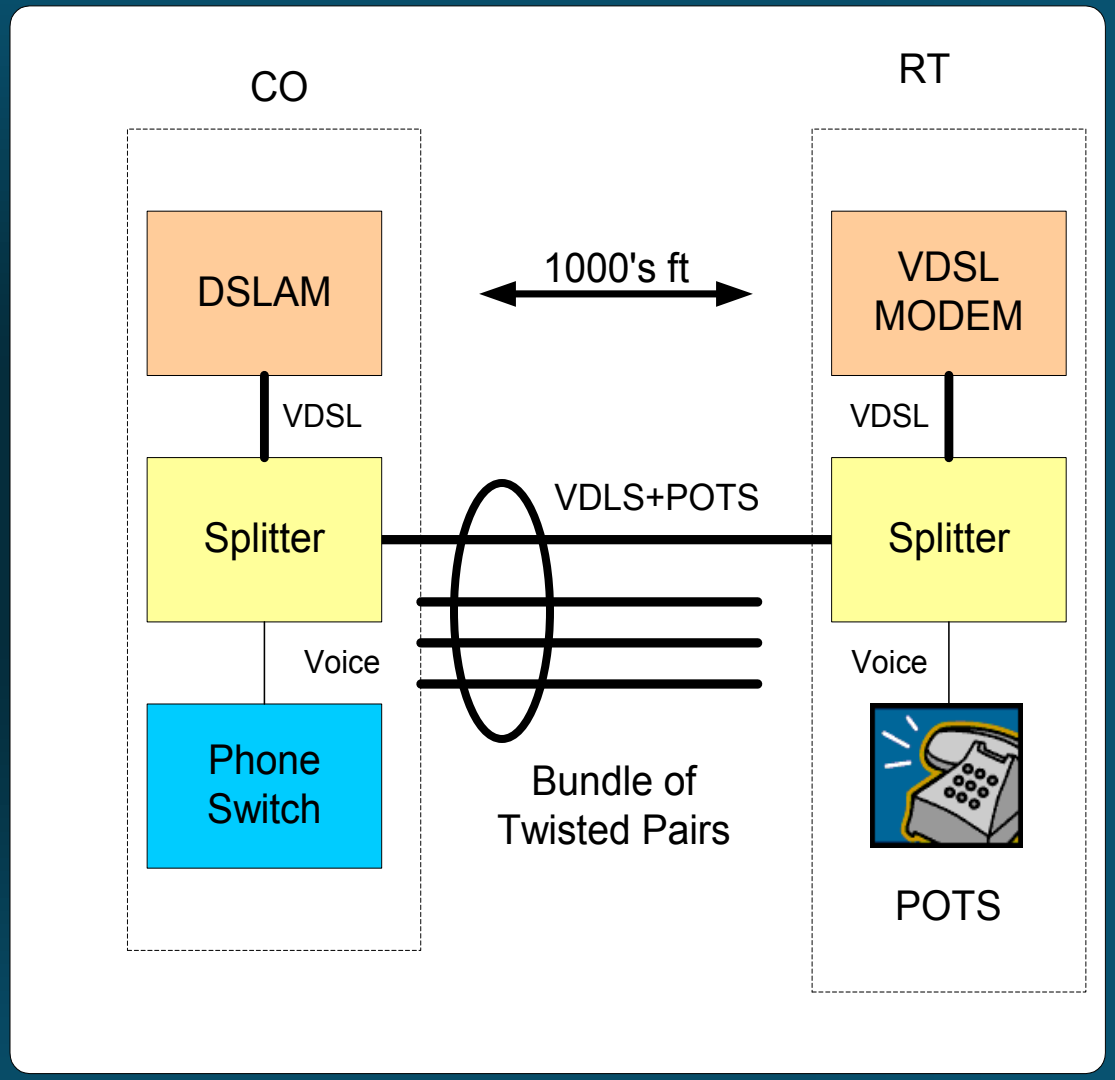
- Vendors of SCM-VDSL are promoting their DMT-ADSL solutions.
- Beware of size when looking at cost. DMT offers all VDSL “sizes”: “small” (2 bands), “medium” (3 bands), “large” (4 bands) and “super-size” (5 bands).
- Spectral flexibility minimizes incompatibility between standards and legacy systems.

Some VDSL Applications

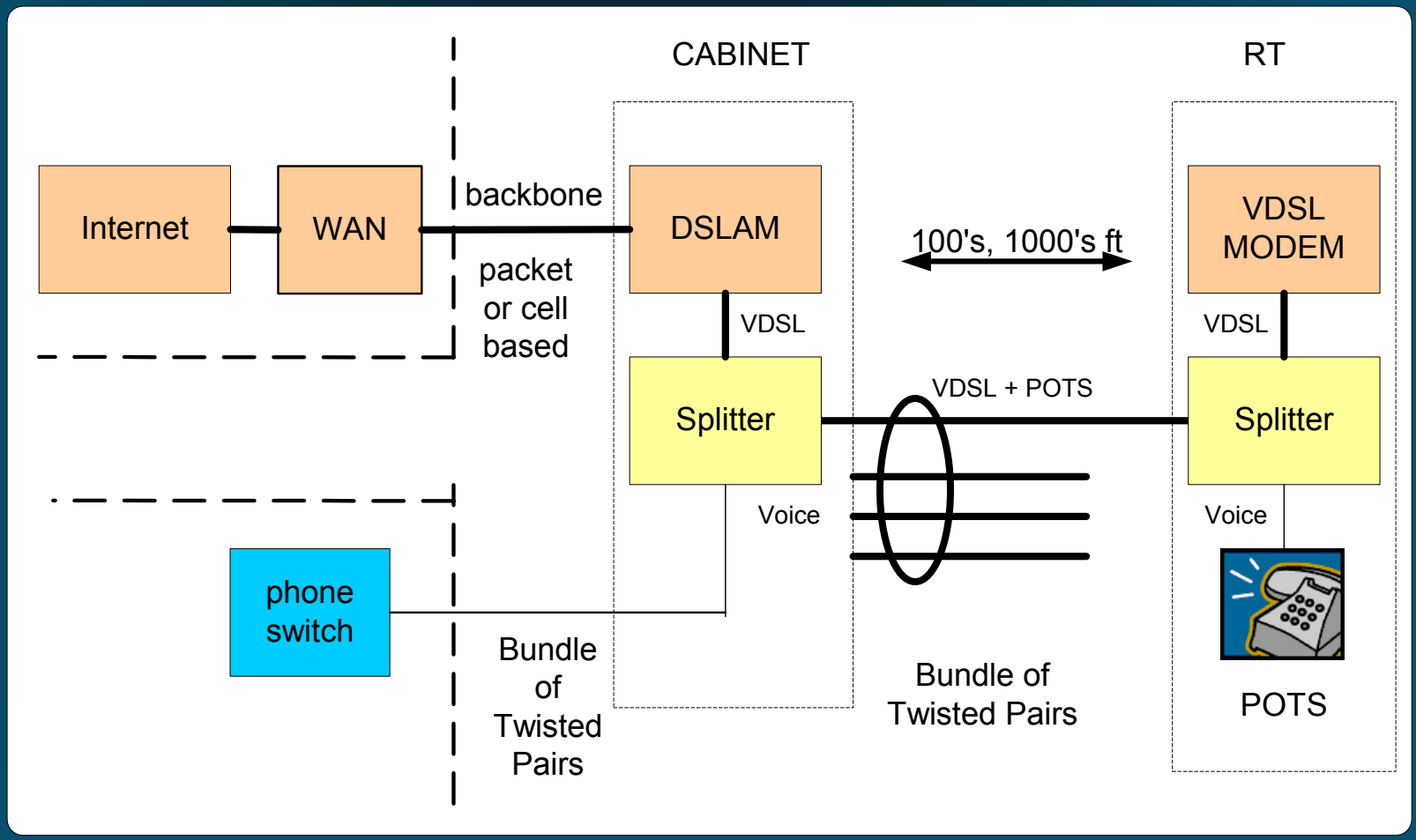
Deployment Scenarios

- 1)
  - CO/RT: Central Office/Remote Terminal.
  - FTTE: Fiber to the Exchange
- 2)
  - FTTC: Fiber To The Cabinet.
  - FTTN: Fiber to the Neighborhood
- 3)
  - FTTB: Fiber To The Building
  - MxUs: Multi-Tenant/Dwelling units

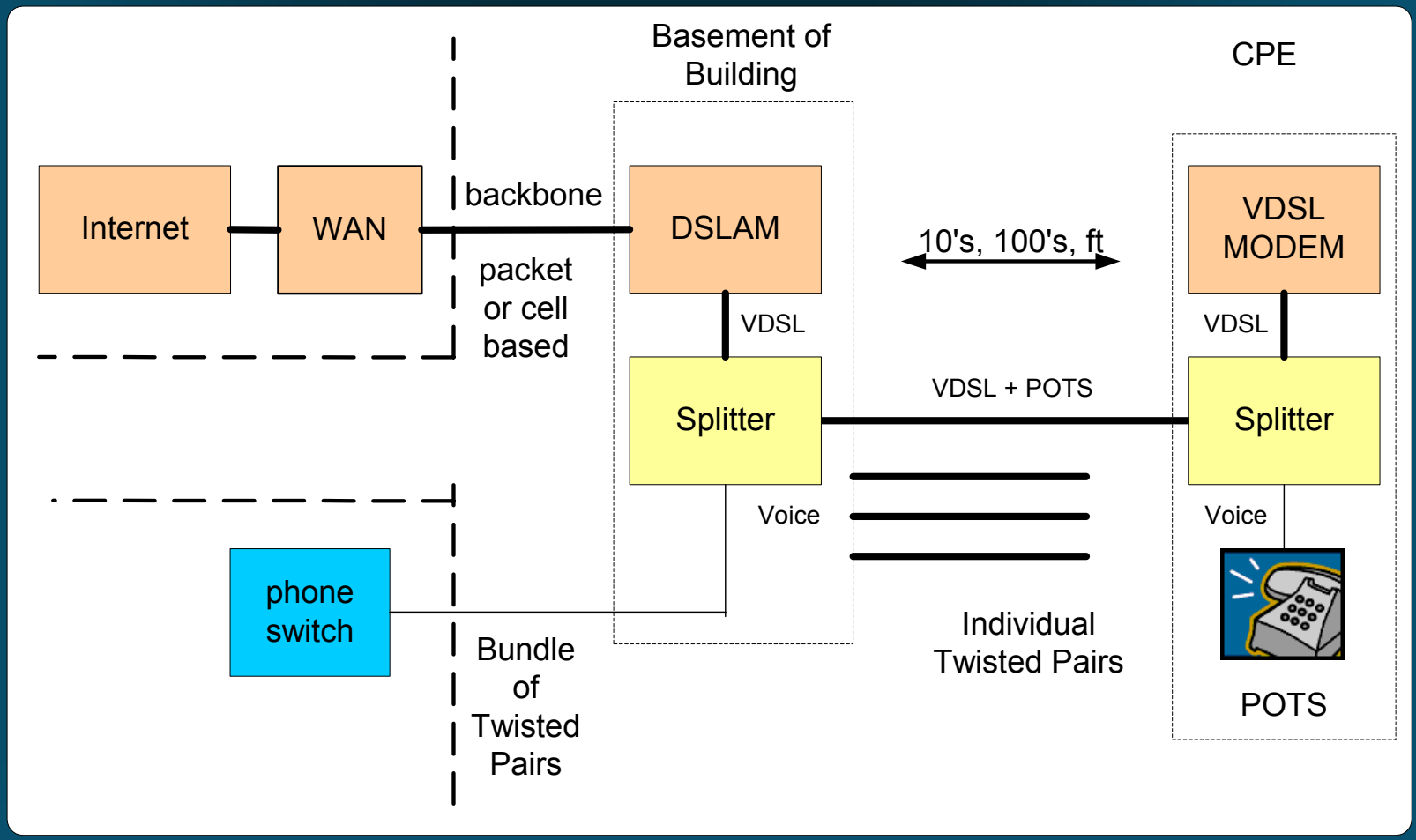
CO/RT


CO
RT
DSLAM
1000's ft
VDSL MODEM
VDSL
VDSL
Splitter
VDLS+POTS
Splitter
Voice
Voice
Phone Switch
Bundle of Twisted Pairs
POTS

FTTC


CABINET
RT
Internet
WAN
backbone
packet
or cell
based
DSLAM
100's, 1000's ft
VDSL
MODEM
VDSL
VDSL
Splitter
VDSL + POTS
Splitter
Voice
Voice
phone
switch
Bundle
of
Twisted
Pairs
Bundle of
Twisted Pairs
POTS

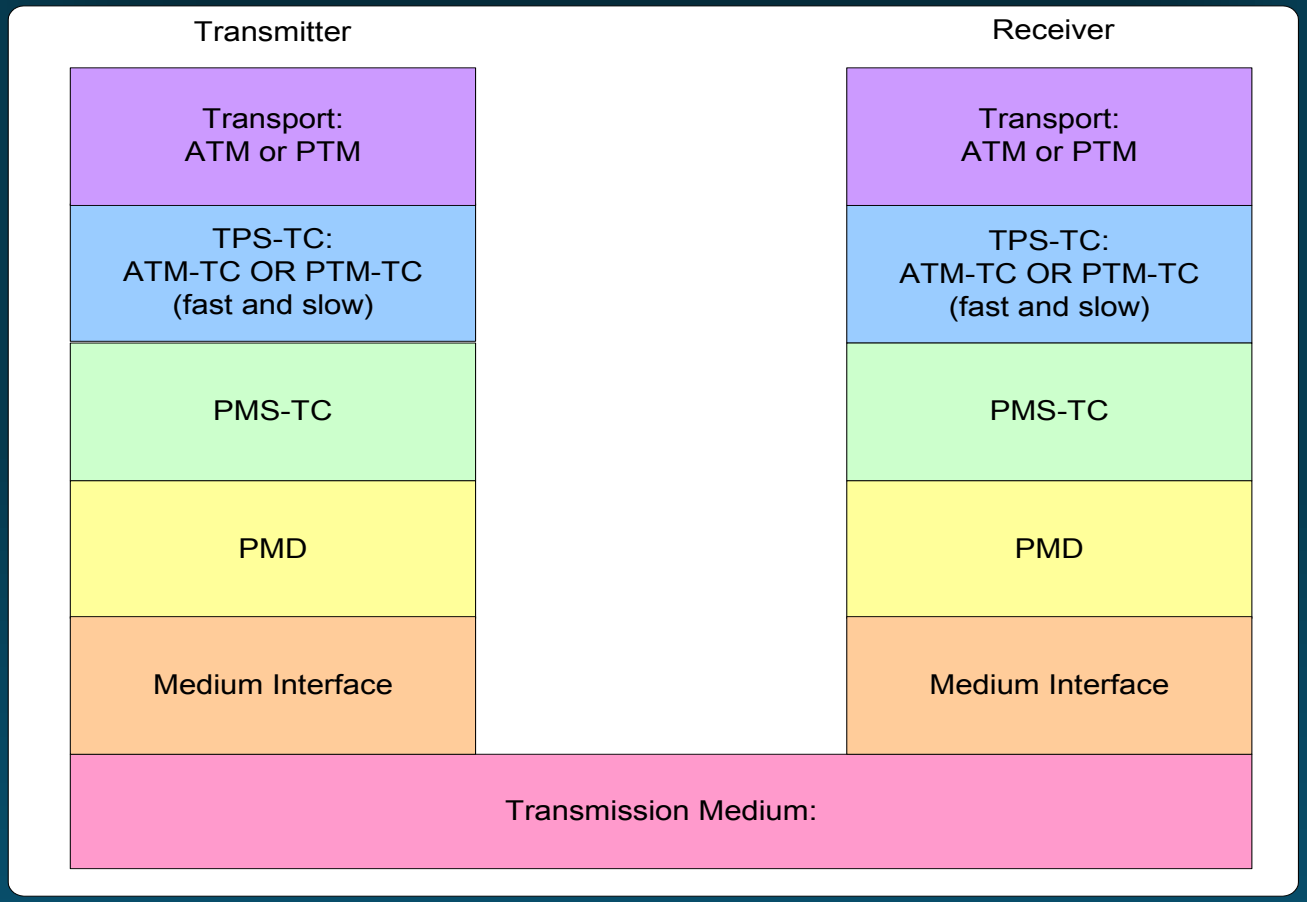
FTTB


Basement of Building
CPE
Internet
WAN
backbone
packet or cell based
DSLAM
10's, 100's, ft
VDSL MODEM
VDSL
VDSL
Splitter
VDSL + POTS
Splitter
Voice
Voice
phone switch
Bundle of Twisted Pairs
Individual Twisted Pairs
POTS

Applications

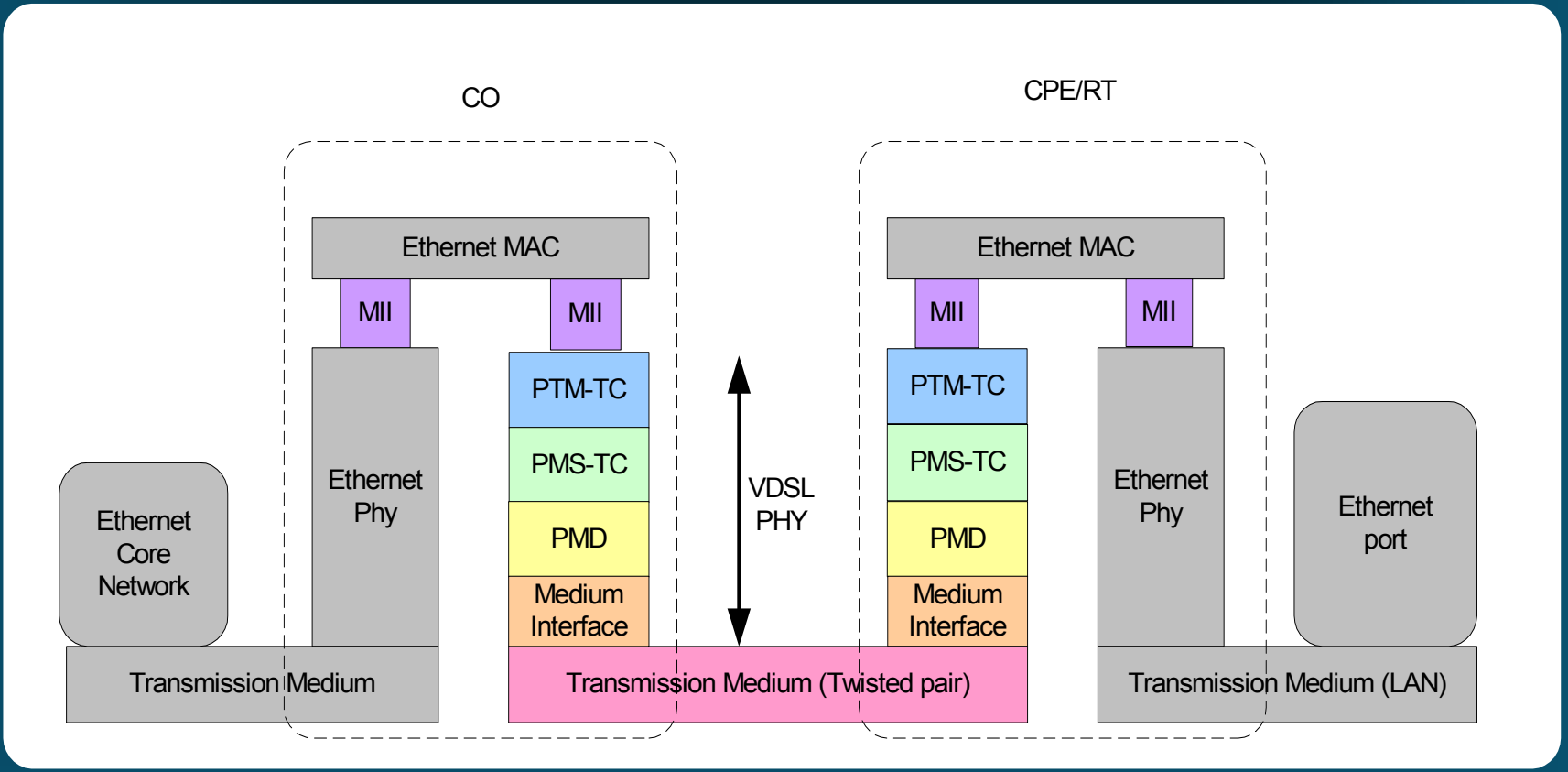
- **VDSL-DMT: ATM/PTM over DSL (Symmetric/Asymmetric)**
- **EFM: Ethernet in the first mile (10BT)**
- **LRFE: Long reach fast Ethernet (100BT)**

ATM/PTM over VDSL



- For more details, please see Annex G: “ATM-TC” and “Annex H: “PTM-TC” in the “Draft Recommendation G.9993.1, Very-high-speed Digital Subscriber Line Foundation”, ITU-T.

Ethernet over VDSL



- For more details, please see “Baseline Proposal EFM_PHY_rev 0.3”, available at http://grouper.ieee.org/groups/802/3/efm/public/mar02/rezvani_1_0302.pdf

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Thanks!!!