Voice Grade Copper

Characteristics, problems and spectral management

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EFM Copper Objective

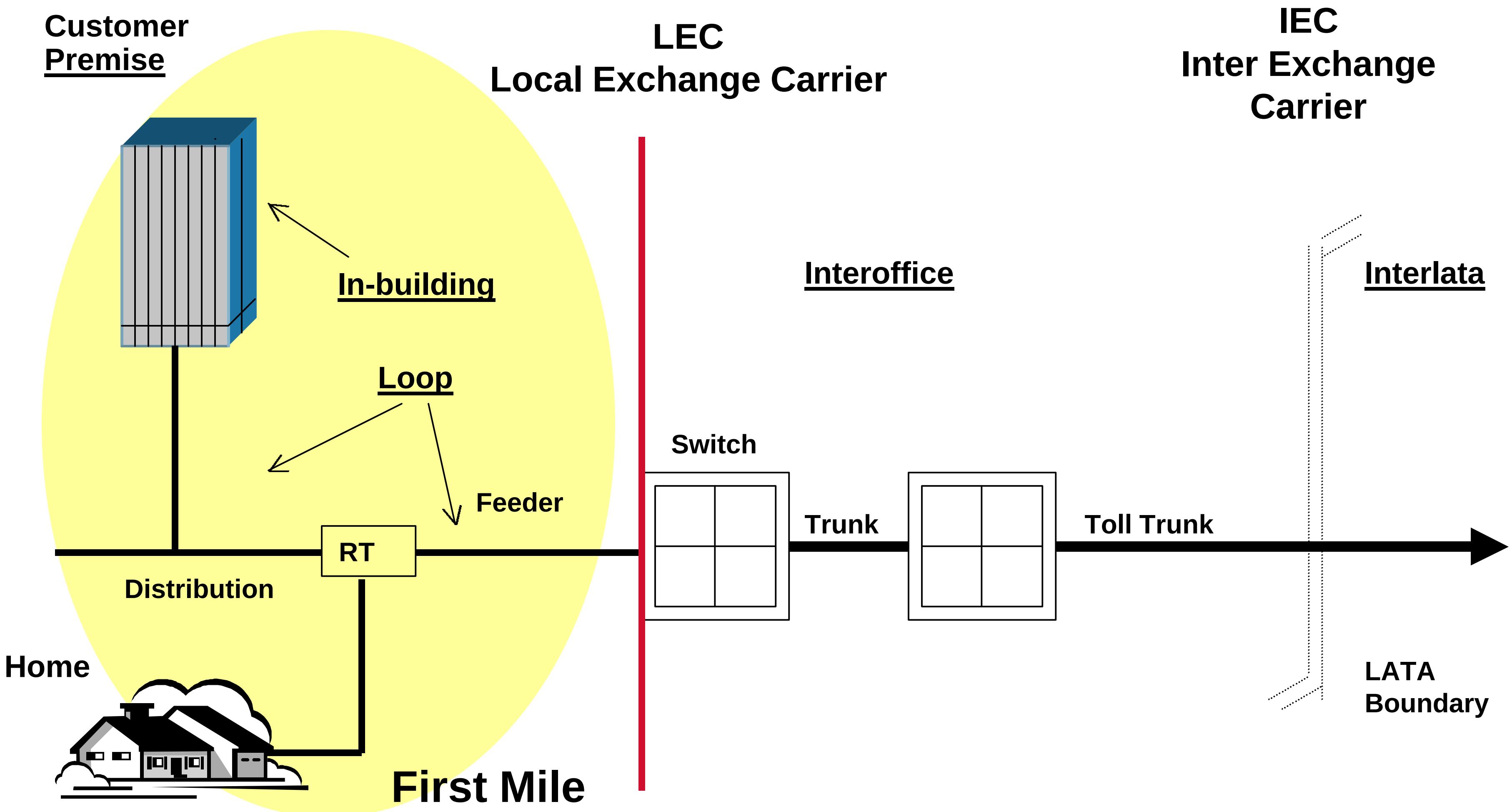
- **PHY for single pair non-loaded voice grade copper**

  Distance >=2500ft and speed >= 10Mbps aggregate

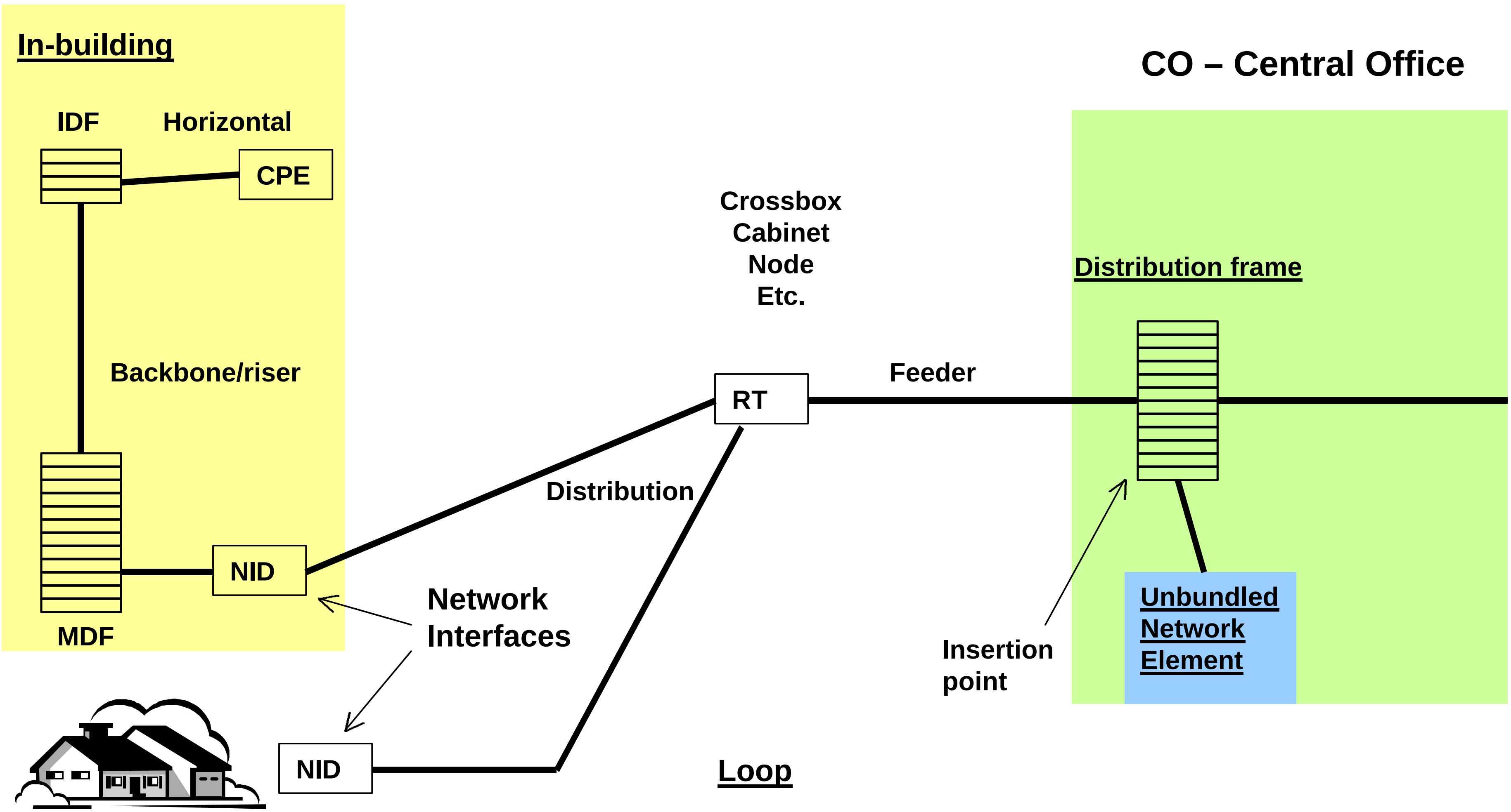
This means:

Single pair, bad wire, long wire

Where is EFM copper?



Some terminology



Definitions

- **Non-loaded**
  - **Load coil improves attenuation 0-3kHz (kills signals >3kHz!)**
- **Voice grade**
  - **Suitable for transmitting voice, “voiceband” = 300Hz – 3.3kHz**
- **Local loop**
  - **Path between Central Office (DF) and Network Interface**
- **In building**
  - **Un-structured cabling – does not meet TIA 568 etc.**
- **Distribution frame**
  - **Patch panel, punchdown, BixBlock, etc.**
    - **In CO, crossbox – also Master DF in-building, & Intermediate DF between MDF & end user**
- **Network Interface – also Demarcation Point**
  - **Physical or logical point at which the exchange carrier’s responsibility ends and the user’s starts**
    - **(Internal Network Interface – insertion point for unbundled elements)**
- **Terminal equipment**
  - **Equipment connecting to the customer end of the loop**
- **Network element (and unbundled network element)**
  - **Equipment (etc.) in the network provider loop**

Characteristics of EFM copper

- **Cable types**
  - Cat-7, Cat-6, Cat-5E, Cat-5 – almost never!
  - Cat-3, Cat-1 (aka "voicegrade")
  - Type-1, Type-2, 24AWG – in building (unstructured)
  - 26AWG – in local loop (sometimes 22, 24, 28AWG …)
  - Typically 1 twist per foot - 6 twist per foot
    - Flat pair (non-twisted) – for some drops & in-building
    - Also Non Staggered Twist (rare)
  - 25 pair – 3600 pair (25, 50 pair binder groups in cable)
- **Single pair, bad wire, long wire**
  - Mostly UTP, generally designed using resistance model
- **Installed sometime between 1876 and 2001**
- **Anything that conducts!**

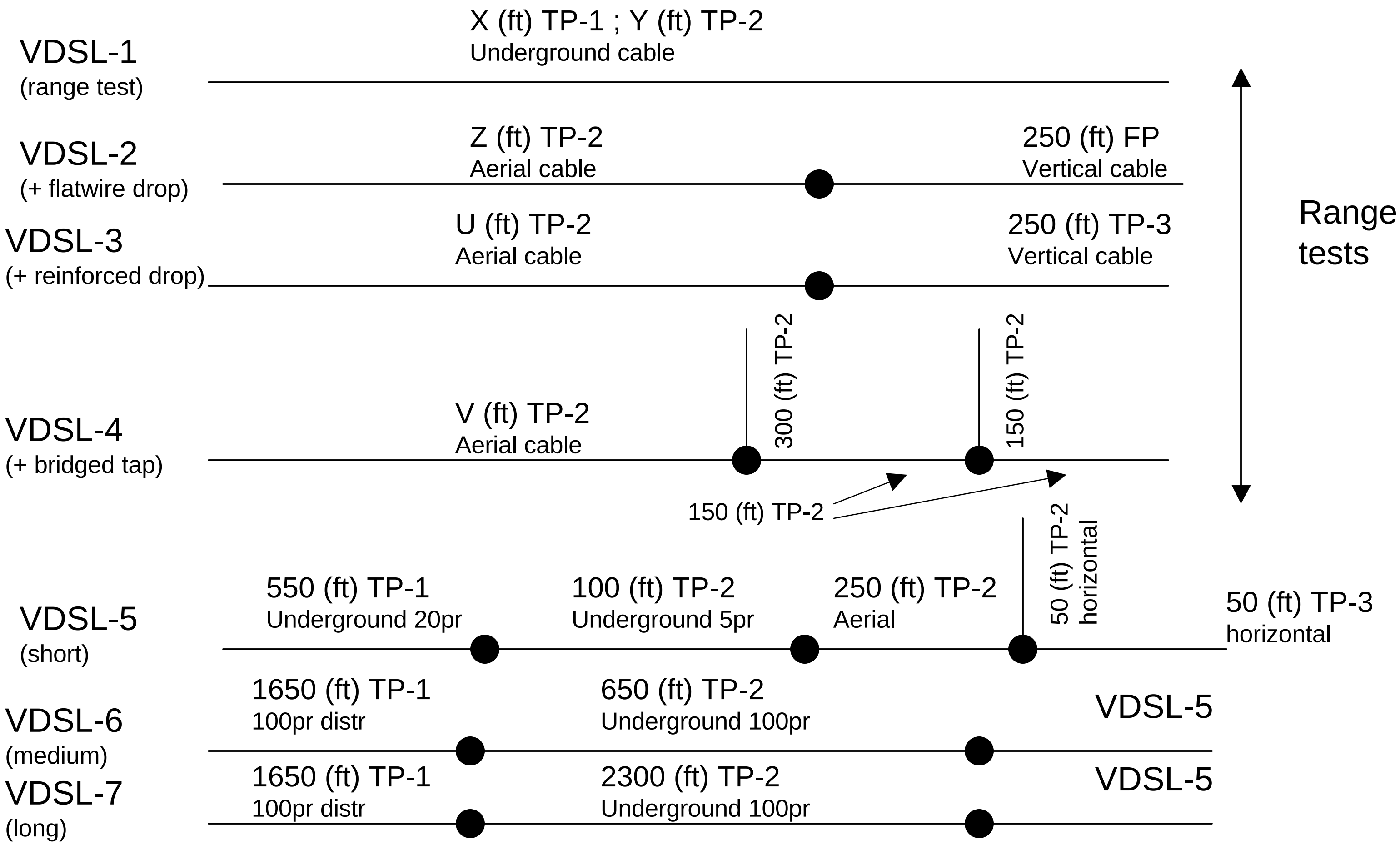
Wiring – a few rules of thumb

- **Older wire is less twisted**
  - **Higher crosstalk**
- **Loops from CO – shorter loops may be 26AWG (esp in Europe)**
  - **Longer loops and very old wiring could be 24 AWG - 18 AWG**
  - **Larger bundles – generally smaller gauge**
- **Statistics on local loop composition available from PTTs**
  - **T1E1.4 mostly for US, ETSI for Europe, FSAN more general**
  - **Standard test models allow for performance comparison**
    - **Simulation models for test loops available**
- **In building (unstructured) – all bets are off!**
  - **e.g. Cotton-clad, non-twisted, embedded in concrete**
    - **(very low attenuation & FEXT = good performance!)**
- **High percentage of unstructured voice wiring includes bridged taps**
  - **Short stubs (<75 ft) cause maximum disruption of high frequency signalling**
  - **US - assume multiple "bad" stubs**
  - **Some flat pairs (no twist)**
- **Distribution Frames – many configurations**
  - **CO – Main Distribution**
    - **(relatively uniform & well managed)**
  - **Crossbox/node/cabinet**
    - **many names even more configurations**
  - **In-building: MDF/IDF – sometimes none**

T1 Standard Test Loops

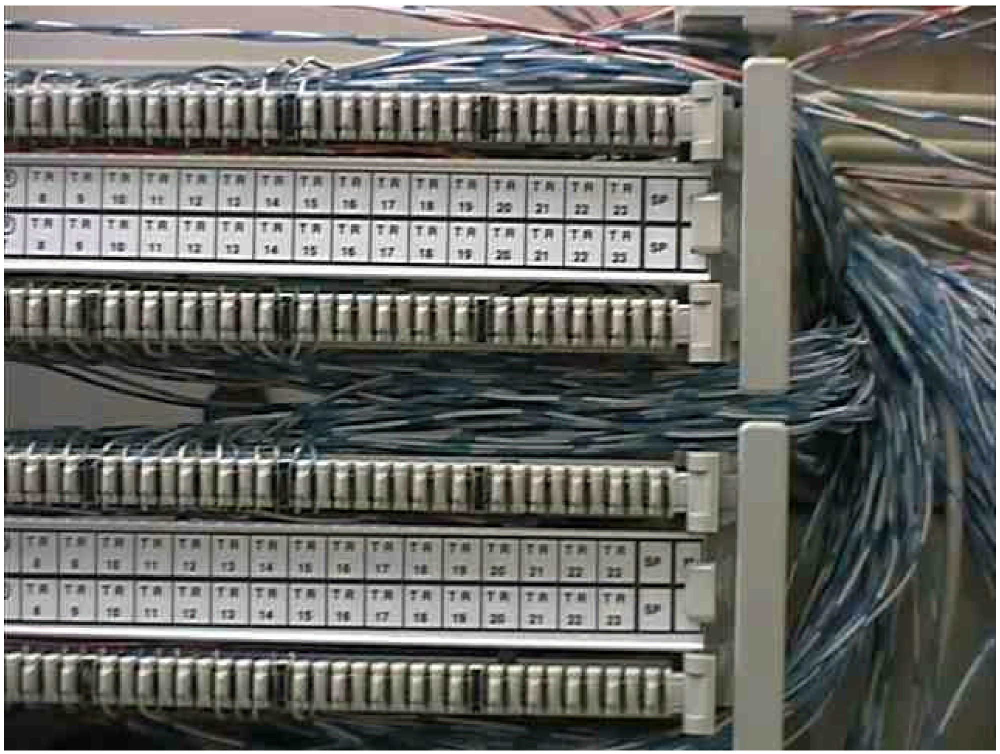
- **VDSL test loops – designed for data rates in EFM range**

Ref T1E1.4/2000-009R3

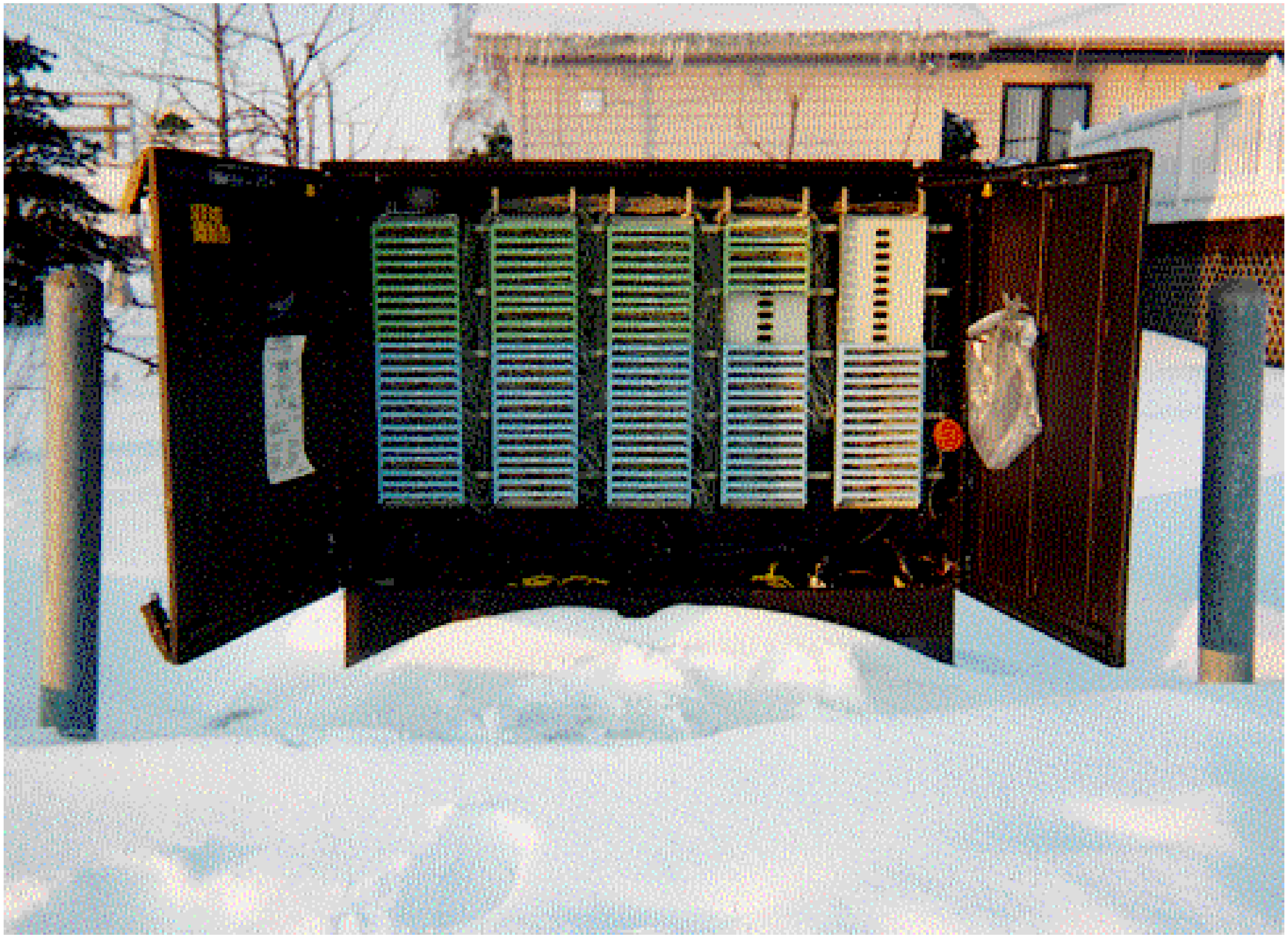


Distribution frames

- **Large building MDF**



Cabinet Distribution



Attenuation and balance

- **Attenuation**

  Generally controlled for voiceband, higher frequency behavior by default

  6-15dB/kft @1MHz

  15-25dB/kft @4MHz

  Statistical data from T1, ETSI, FSAN for local loop, less data for in-building unstructured (not worst case)

- **Balance – not guaranteed**

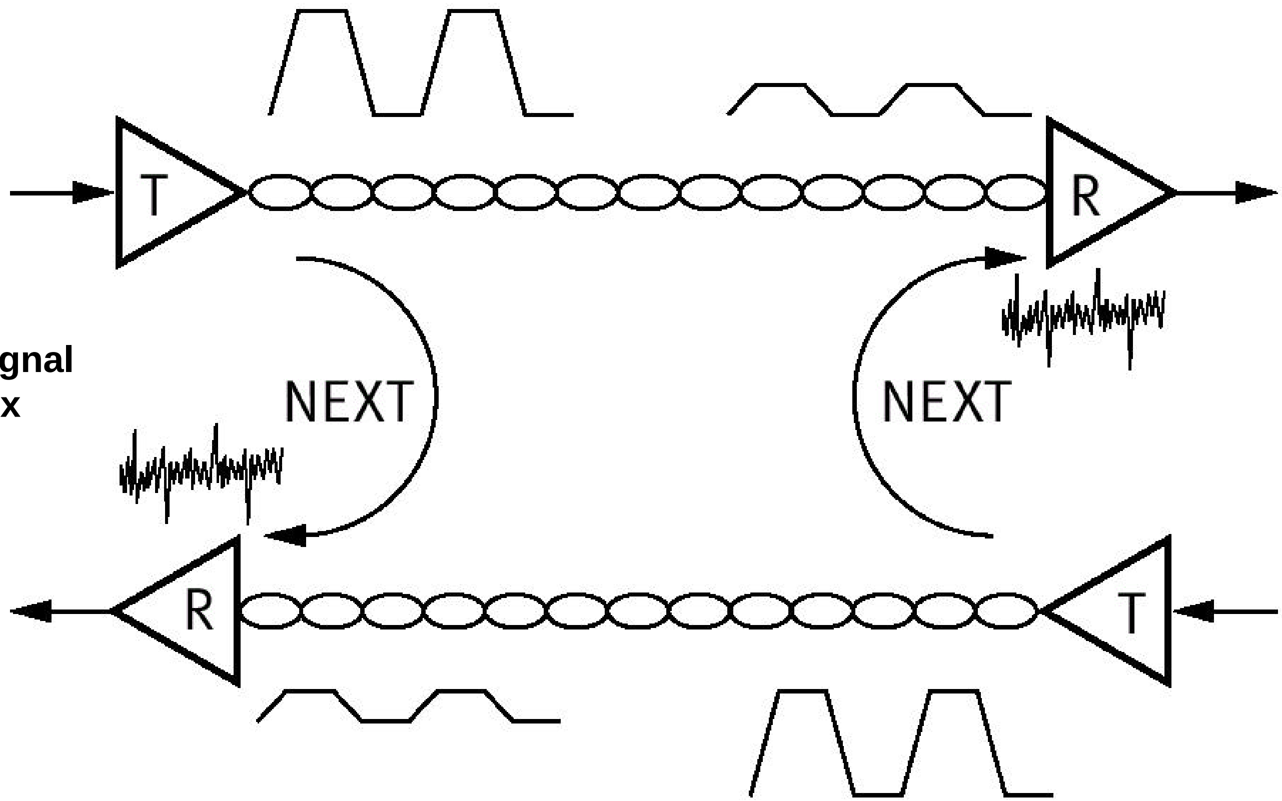
  Signalling above 12MHz problematic because of emissions

Bridged taps and wet pairs

- **Bridged taps**
  - Very high proportion of unstructured wiring includes taps (extra phone sockets)
  - Most stubs in the 10ft – 100ft range – worst possible frequencies for EFM
  - Short stubs cause much higher propagation loss for high frequencies
    - Eg 80ft, -25dB, 2MHz : 32ft, -35dB, 5MHz : 16ft, -45dB, 10MHz
  - 3.5dB broad band loss with termination
- **Wet/dry pairs**
  - A pair (already) carrying a service is called “wet”
  - High percentage of homes with no spare line
    - One of the key market opportunities!
  - Requirement to share the line with existing service:
    - POTS & DC power : 0 – 8kHz - definitely
    - ISDN BRI : 128kHz - definitely
    - Others : ISDN PRI, T1, xDSL – to be decided

Near-End Crosstalk (NEXT)

Strong Tx signal
Kills weak Rx



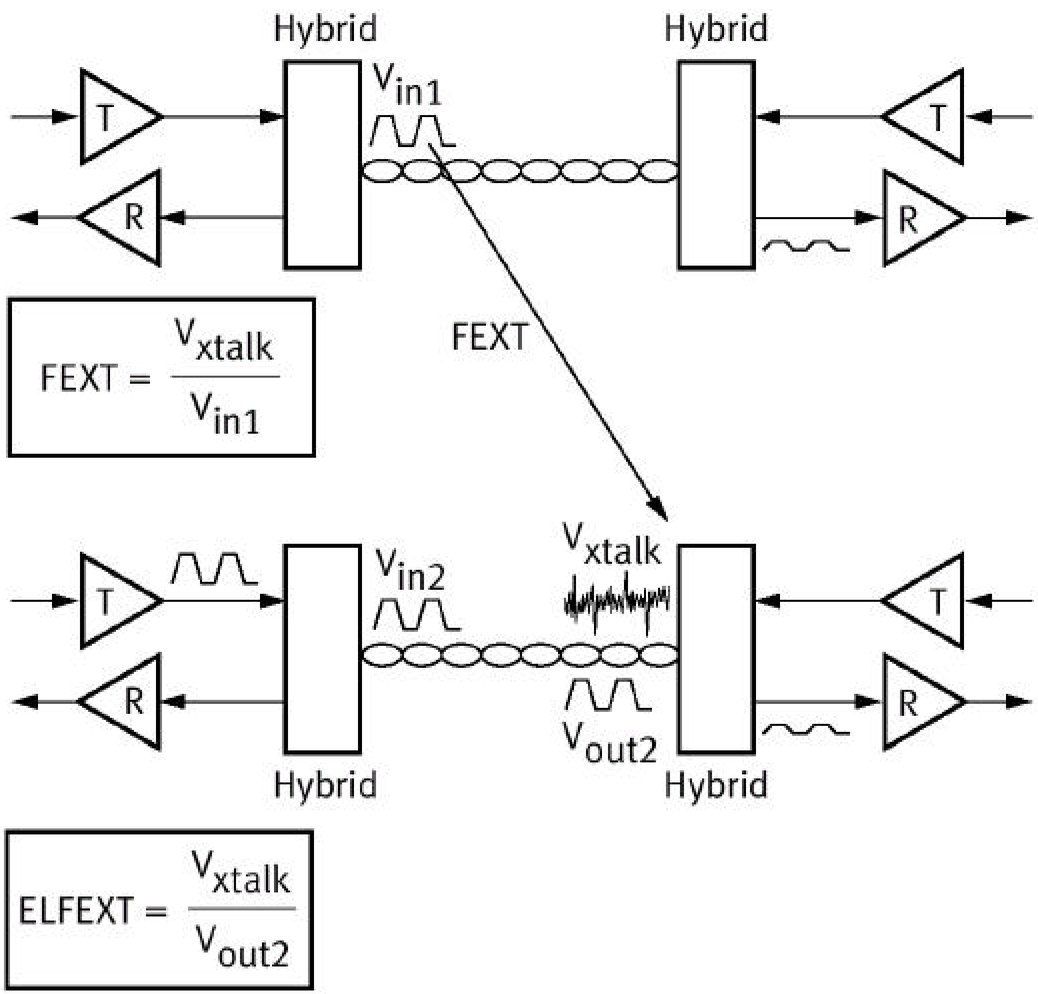
•**Coupling higher with frequency – CAT-5,** -62dB @1MHz, -52dB @4MHz

•Varies with cable type - riser cable -35dB @1MHz, -25dB @4MHz

Attenuation to Crosstalk ratio

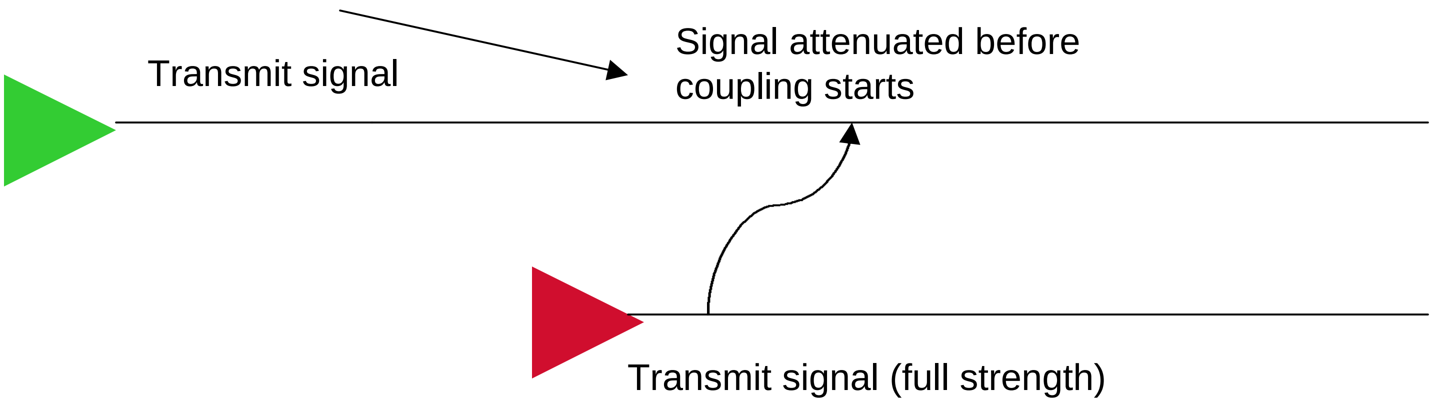
- **ACR - Effectively a measure of SNR for NEXT limited systems**
  - **CAT-5 ~ 32dB for 5kft @1MHz, 18dB for 3kft @4MHz**
  - **CAT-3 ~ 20dB for 3kft @1MHz, 0 for 2kft @4MHz**
  - **Distribution cable ~ 21dB for 3kft @1MHz, 0 for 2kft @4MHz**
  - **Riser cable ~ 20dB for 2kft @1MHz, 0 for 1kft @4MHz**
  - **"worst cable" 22dB for 1kft @ 1MHz, or 0 for 1kft @ 4MHz**
- **In general – useful range of NEXT limited systems drops rapidly as frequency increases, especially on lower grade cables.**
  - **Advantage for duplexed transmission (TDD or FDD)**

Far-End Crosstalk (FEXT) and Equal-Level Far-End Crosstalk (ELFEXT)



- **FEXT less limiting than NEXT at EFM frequencies**
- **ELFEXT determines rate available for most EFM**
- **Includes distance component**
- **(e.g.** –40.75 + 20.log(f) + 10.log(d) – 6.log(m/n) dB)
- **Difficult to measure**

Importance of power back off

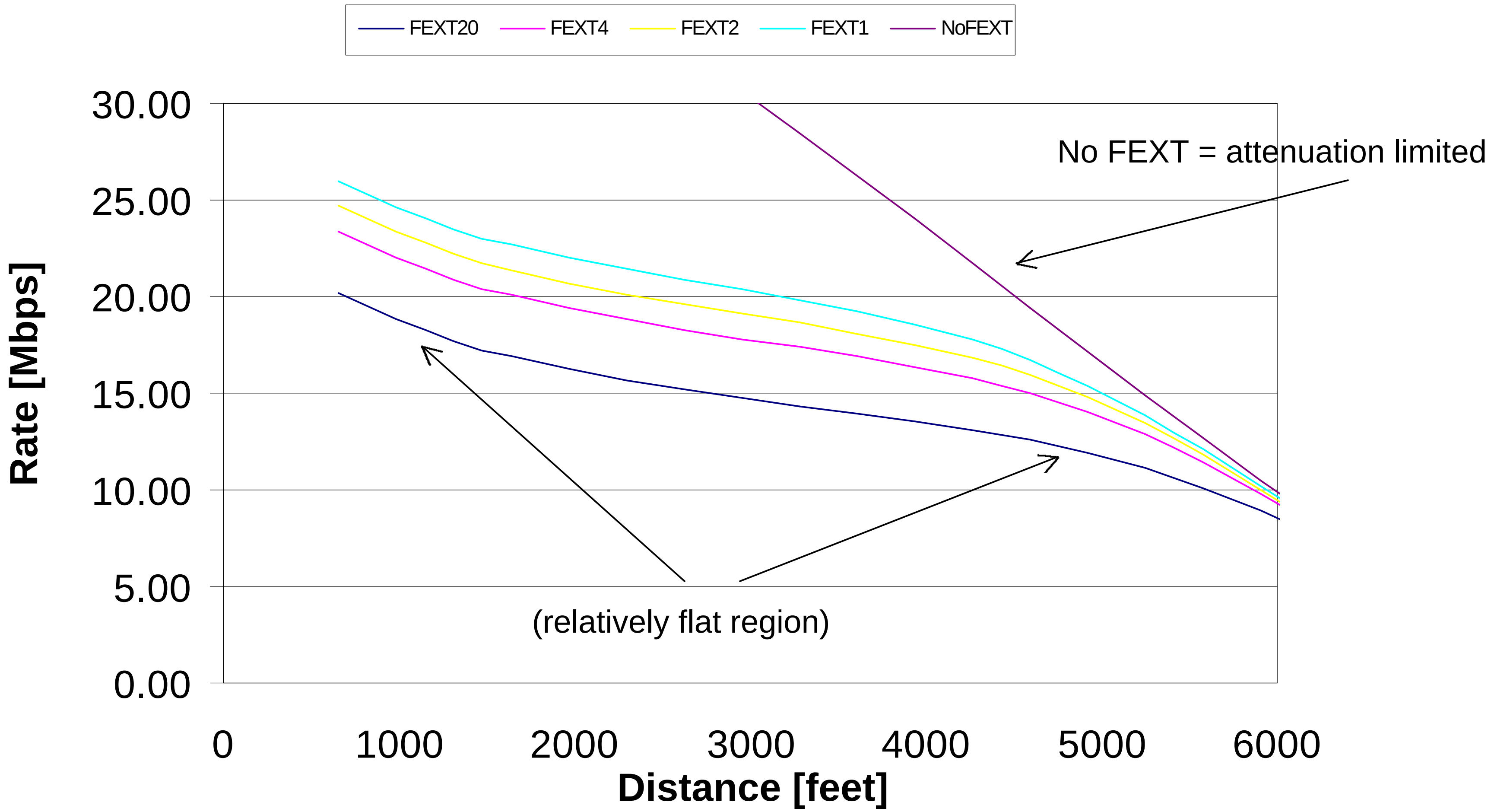


- **Systems with pairs of different lengths pose an extra problem**
  - **Effective SNR predicted by ELFEXT could be reduced by the attenuation before coupling**
  - **Only matters for shorter (high data rate) loops**
  - **For longer loops, attenuation and noise floor govern SNR**

FEXT vs Attenuation

- **Effective SNR with distance is obtained by superimposing 2 graphs: ELFEXT and attenuated receive SNR**
  - **The lower of the 2 will be the SNR limit**
  - **(for a full binder) FEXT will dominate for the shorter lines**
    - **(e.g.) up to 4kft @ 2MHz, 2.5kft @ 5MHz (distribution cable)**
  - **Attenuation will dominate for longer loops because of noise floor**
- **Remaining problem:**
  - **Performance will be limited by FEXT for most systems >20Mbps**
  - **FEXT coupling can vary by >6dB within a binder, PS FEXT can vary by >3dB for binders within a cable**
  - **Measure of PSELFEXT vital for performance assessment**
  - **Measurement of PSELFEXT problematic because of cable plant layout**
    - **Invite input from test solution providers!**

Example rate vs reach



Results for arbitrary 24AWG distribution cable, 2MHz carrier – for illustration only

Noise - standard

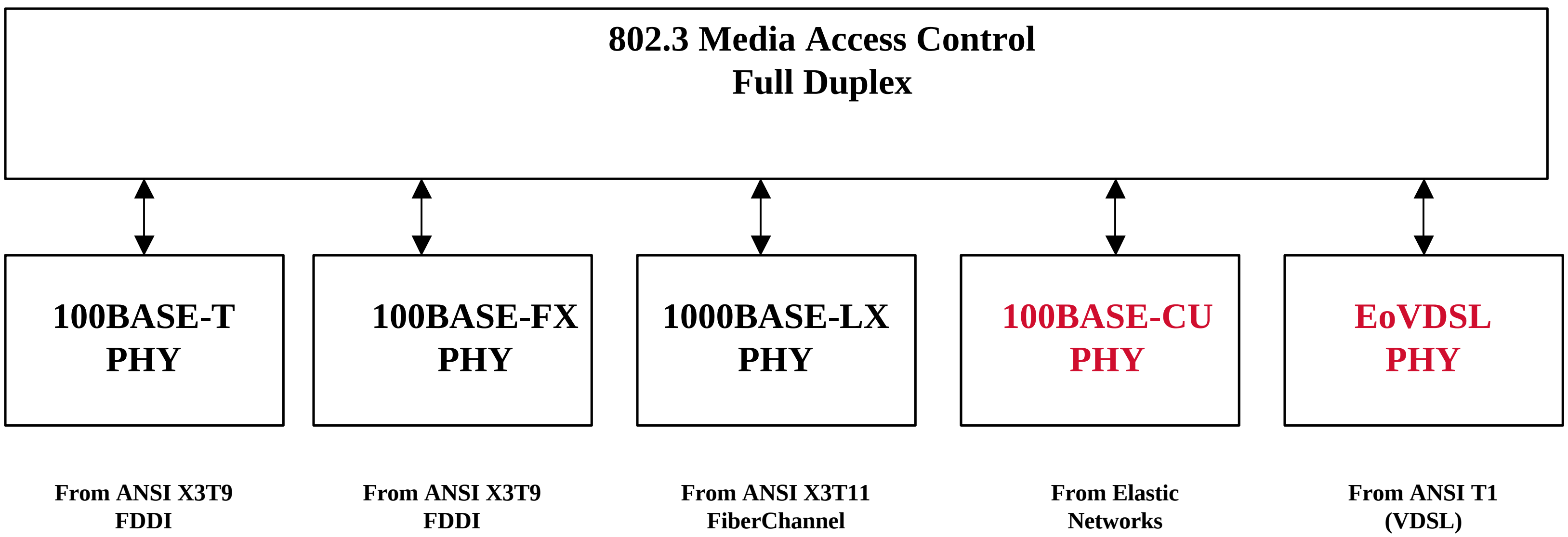
- **Background noise**
  - **ANSI T1E1.4 defines AWGN –140dBm/Hz**
  - **Includes 6dB margin because of non-Gaussian behavior in real world**
- **Radio Frequency Interference**
  - **Multiple narrow band standards internationally**
    - **Both ingress and egress must be considered**
  - **3.75MHz – most common**
  - **Rarely more than 2 or 3 in one installation site**
- **Noise sources in binder (from other services)**
  - **Regulated frequencies – spectral planning (NRIC-V)**
    - **Can be predicted and simulated**
  - **Other impairments – ringing, T1, badly balanced lines**
    - **Often unpredictable and time variant**

Noise – in-building

- **Binder noise much worse**
  - **Shorter lines for PBX noise**
    - **Less attenuation, more reflections**
  - **More impedance changes / kft**
    - **2 – 5 distribution frames per line**
    - **Cable changes between horizontal & vertical**
- **Extra in-building noise…**
  - **Cable ducts in lift (elevator) shafts – motor noise, surges, EMI**
  - **Observed dynamic range >60dB**
  - **Bursts typically 1-300uS**

How to solve…

Historical precedent – use existing PHY

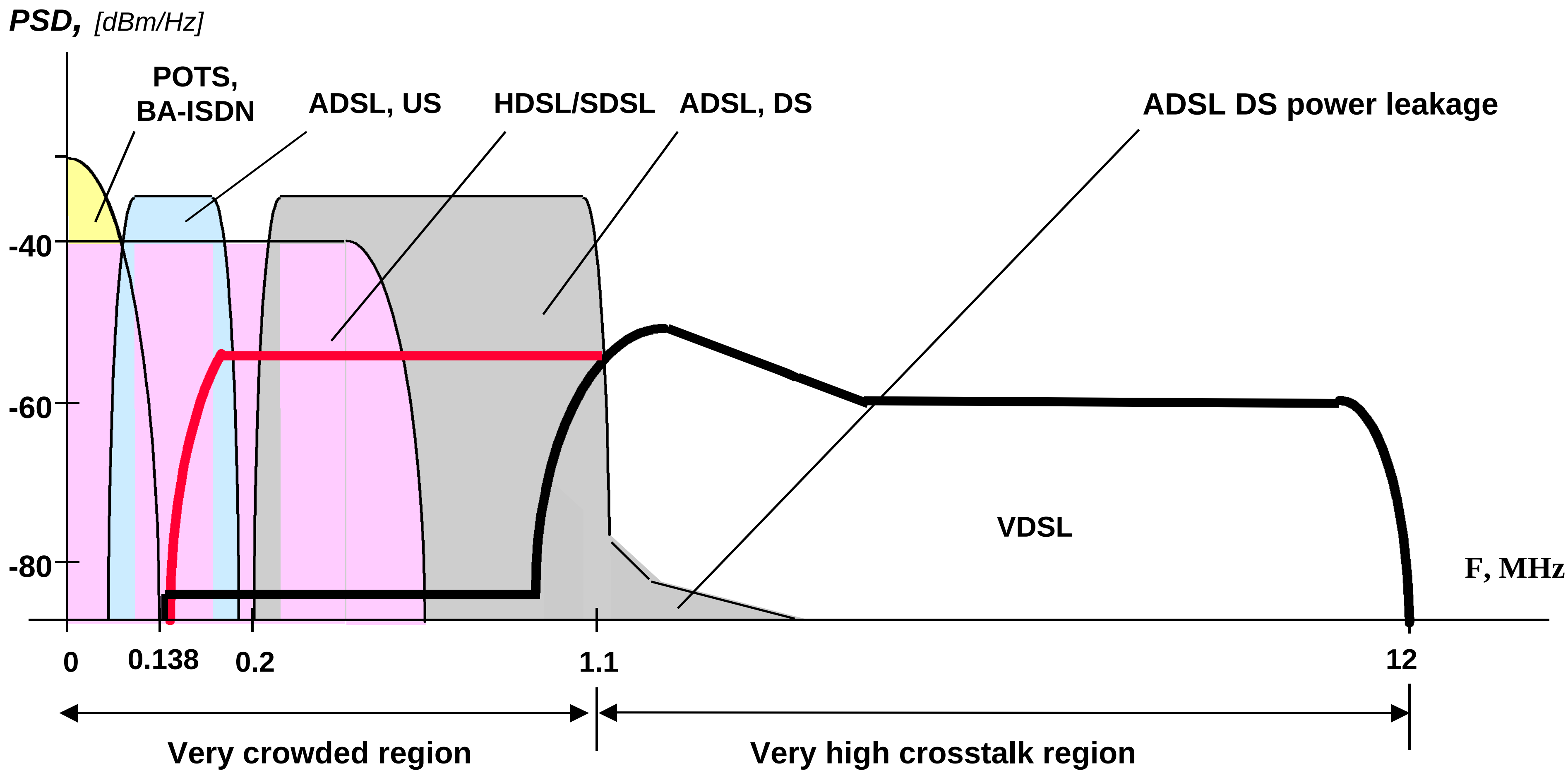


- **Builds on known working Physical Layer (historical precedent)**
- **Ethernet “value add” – simple & low cost**
- **Other presentations cover solutions shown**

Spectral compatibility for dummies

- **Key definition**
  - ANSI T1E1.4 defines spectral compatibility in T1.417
  - A “must read” for anyone deploying in the local loop or shared environment
- **National Reliability and Interoperability Council (V)**
  - Advisory body for FCC – spectral planning with teeth!
    - In process of adopting T1.417
- **Why does it matter?**
  - Crucial for unbundling
- **Is it new?**
  - No

“Borrowed” spectral illustration



What does spectral management achieve?

- **Cable bundle behaves like a shared medium for the crosstalk domain**
  - **At frequencies required for >10Mbps, significant coupling**
- **SM ensures controlled interference between different technologies**
  - **Several classes defined – most retrospectively**
  - **Crucial for new technologies to be compatible with existing**
- **SM aims for ELFEXT limited performance**
  - **(particularly for new technologies in 1.1MHz – 12MHz range)**
  - **Unequal power level FEXT – strong signal kills weak**
    - **If ELFEXT is only ~20dB, 15dB difference in signal strengths may prevent communication**
  - **ACR is 0 (thus NEXT limited systems inoperable) for much of the spectrum at reasonable distances**

T1.417 “in a nutshell”

- “In a multi-service installation, services shouldn’t kill each other”
  - Services listed include: voice, ISDN, HDSL, ADSL, RADSL, SDSL etc.
  - Ref. 4.3.1
- “Everybody use defined PSD mask”
  - Includes power, frequency and location/direction
  - Safest method
  - Ref. 4.3.3
- …or “Prove that you don’t interfere”
  - “Method B”
  - Risk of 2 “method B” services interfering with each other…
  - Ref. 4.3.5
- NRIC-V added an extra clause
  - “If you can, you may listen & adapt to be compliant when you need to be”
  - Clause 4 (a)

References / reading list

- **T1.417**

  Seminal work on spectral compatibility and loop characteristics (also applicable to unstructured wiring)

  T1E1.4/2000-002R6 - ftp://ftp.t1.org/T1E1/E1.4/DIR2000/0e140026.pdf

- **ANSI TR-60**

  Unbundled Voicegrade Analog Loops – T1A1.7 working group

- **Some others**

  ANSI IEEE 820-1992, loop design methodologies, signal levels, and bridged taps.

  Standards Committee T1 – www.t1.org

  AT&T/Bellcore Loop Surveys