The Merits of Synchronized DMT

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Outline

- Purpose of this presentation
- Overview of EFM copper PHY goals
- Dimensions of PHY solutions
  - Line code
  - Duplexing
- Synchronized DMT (SDMT)
  - Technology overview
  - Features
  - Performance
- Summary

Objectives

- This presentation does **NOT** propose SDMT as a solution for EFM in public copper networks.
- However, SDMT is well-suited for deployment in private networks.
- The presentation is offered primarily to facilitate discussions of requirements for EFM.
  - SDMT offers a number of nice features.
  - The EFM group should identify which of these features are important/necessary for the copper EFM PHY.

Ideal EFM Copper Solution

- Robust to common telephone line impairments:
  - Bridged taps, crosstalk, impulse noise, radio-frequency (RF) ingress
- Supports high data rates
  - At least 10Mbps cumulative over 2.5kft
  - Should it be symmetric or asymmetric?
  - The higher the rates, the better
- Ensures spectral compatibility with existing DSLs and over-the-air services
- Consumes low power to enable ONU deployment
  - 1 W/modem should be the target
- Is available
- Is not expensive

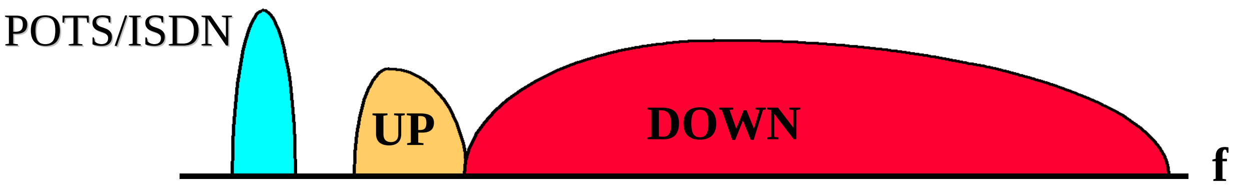
Dimensions of PHYs

- Line code
  - How are the bits encoded and transmitted?
  - Examples:
    - Single-carrier modulation (QAM, CAP)
    - Multi-carrier modulation (DMT)
- Duplexing
  - How are the downstream and upstream channels separated?
  - Examples:
    - Frequency-division duplexing (FDD)
    - Time-division duplexing (TDD)
- Line code and duplexing decisions are independent
  - But there may be advantages to certain pairings...

Duplexing Alternatives

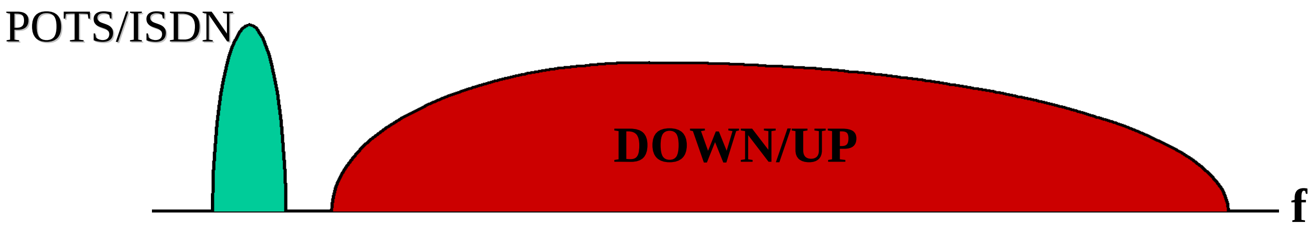
FDD (frequency-division duplexing)

- Upstream and downstream channels are disjoint in frequency
- Tricky to accommodate a specific downstream:upstream data rate ratio on many loops
- “What you get is what you get”



TDD (time-division duplexing)

- A single frequency band supports both upstream and downstream transmission
- Modems can either transmit or receive at any time, but not both simultaneously
- Synchronization to a common clock may or may not be required
  - That TDD = synchronization is a common misconception



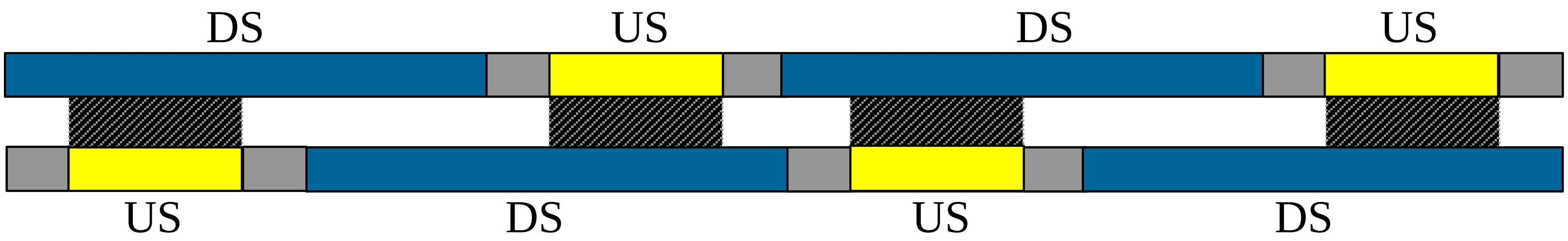
Synchronized DMT (SDMT)

- A DMT-based TDD system
- Optimal configuration:
  - Modems at the central site are synchronized so near-end crosstalk (NEXT) is eliminated
  - Entire channel bandwidth is used downstream during certain symbol periods and upstream during others
  - A quiescent period is provided after each transmit period to allow echo to die down before receive period begins
- Suboptimal configuration:
  - Appropriate when frequency usage is constrained by a spectral plan
  - Only subchannels in allowed downstream (upstream) bands are used during downstream (upstream) periods
  - Performance is degraded relative to optimal configuration

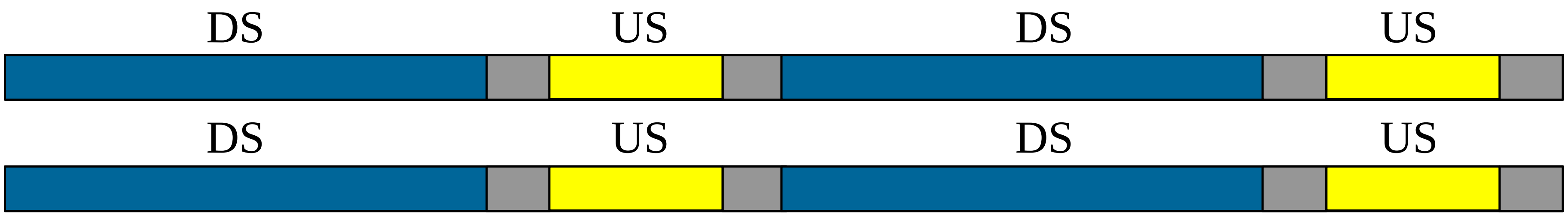
SDMT Superframes

- Used to coordinate downstream and upstream transmissions
- A superframe is a set of consecutive symbols, each of which is classified as downstream, upstream, or quiescent
- By varying the number of upstream and downstream symbols in the superframe, a wide range of data rate ratios can be supported
  - **Example**: 20-symbol superframe
    - 9-Q-9-Q superframe supports symmetric transmission
    - 16-Q-2-Q superframe supports 8:1 transmission
    - 12-Q-6-Q superframe supports 2:1 transmission

Synchronization



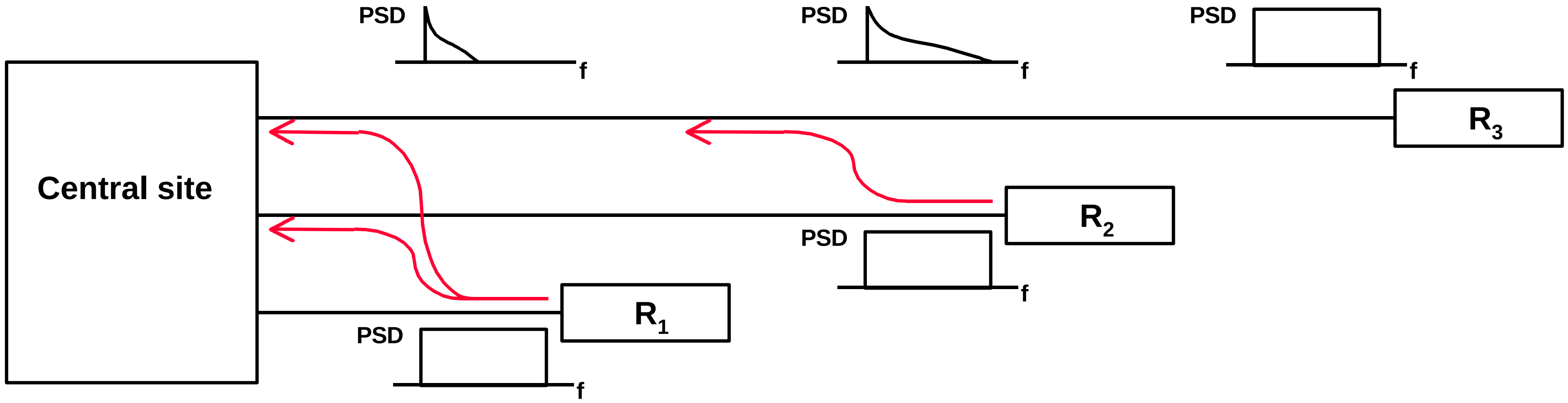
- To avoid near-end crosstalk (NEXT) between lines and provide best performance, superframes of different modems in the same binder must be synchronized and of the same format (i.e., 9-Q-9-Q)
- Synchronization can be achieved by:
  - **Providing a common clock at the ONU/CO (i.e., 8 kHz network clock)**
  - **Allowing one modem to source the master clock for all lines**
  - **Using GPS technology to derive a common clock**



SDMT Advantages

- Flexible
  - Both symmetric and asymmetric data rate ratios can be supported by the same hardware with ***no additional complexity***
    - Ratio is software-programmable, specified via the management interface
- Simple and inexpensive
  - Signal processing requirements are reduced relative to FDD approaches
    - DMT transmit and receive functions are essentially equivalent
    - A modem is either transmitting or receiving, so hardware is shared for transmit and receive functions - only one FFT is required!
    - Unused path is turned off to reduce power consumption
  - Analog requirements are reduced because the same band is used to transmit and receive

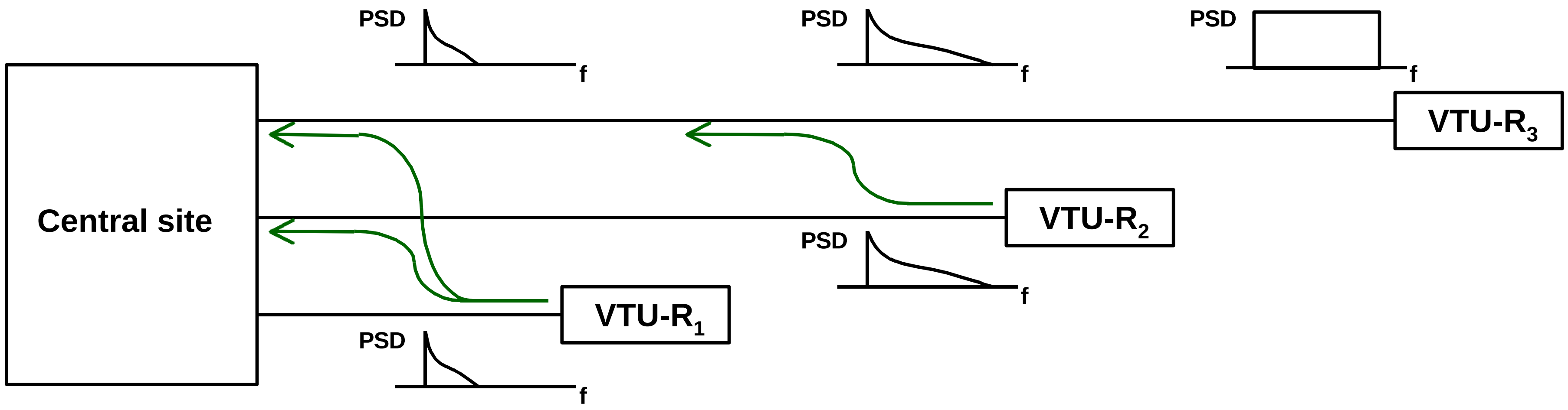
What about UPBO?



- Full-power upstream transmissions on short (near) loops result in high-level far-end crosstalk (FEXT) noise on long (far) loops
  - "Near-far FEXT"
- Upstream bit rates on long loops can be severely impacted

Combating the Near-Far Problem

- Upstream transmitters must reduce their PSDs so the levels of FEXT they inject to shorter loops are lower
- The process of reducing the upstream PSDs is known generically as *upstream power back-off (UPBO)*



UPBO and Duplexing

- Remote units must apply UPBO before transmitting any substantial signals
  - A small “help!” signal allows the remote unit to initiate a connection, but then it must do UPBO
- FDD systems require the remote unit to interpolate between received bands to estimate the “electrical length” of the loop
  - Procedure is dangerous, as evidenced by multiple recent standards contributions addressing estimation inaccuracies
- With SDMT, UPBO is simple
  - Remote transceiver can perform channel identification using the downstream received signal and then apply appropriate spectral shaping to transmit signal, which uses the same frequency band

UPBO and Line Code

- The best UPBO methods require the transmit PSD to be shaped in frequency
- Shaping is inconvenient for single-carrier modulation
  - Filters are required at transmitter
  - Filter order must be sufficient to support required dynamic range of PSD after UPBO
- Shaping is simple for DMT
  - Power per subchannel is easy to adjust
  - Subchannels are narrow, so fine granularity in frequency is possible

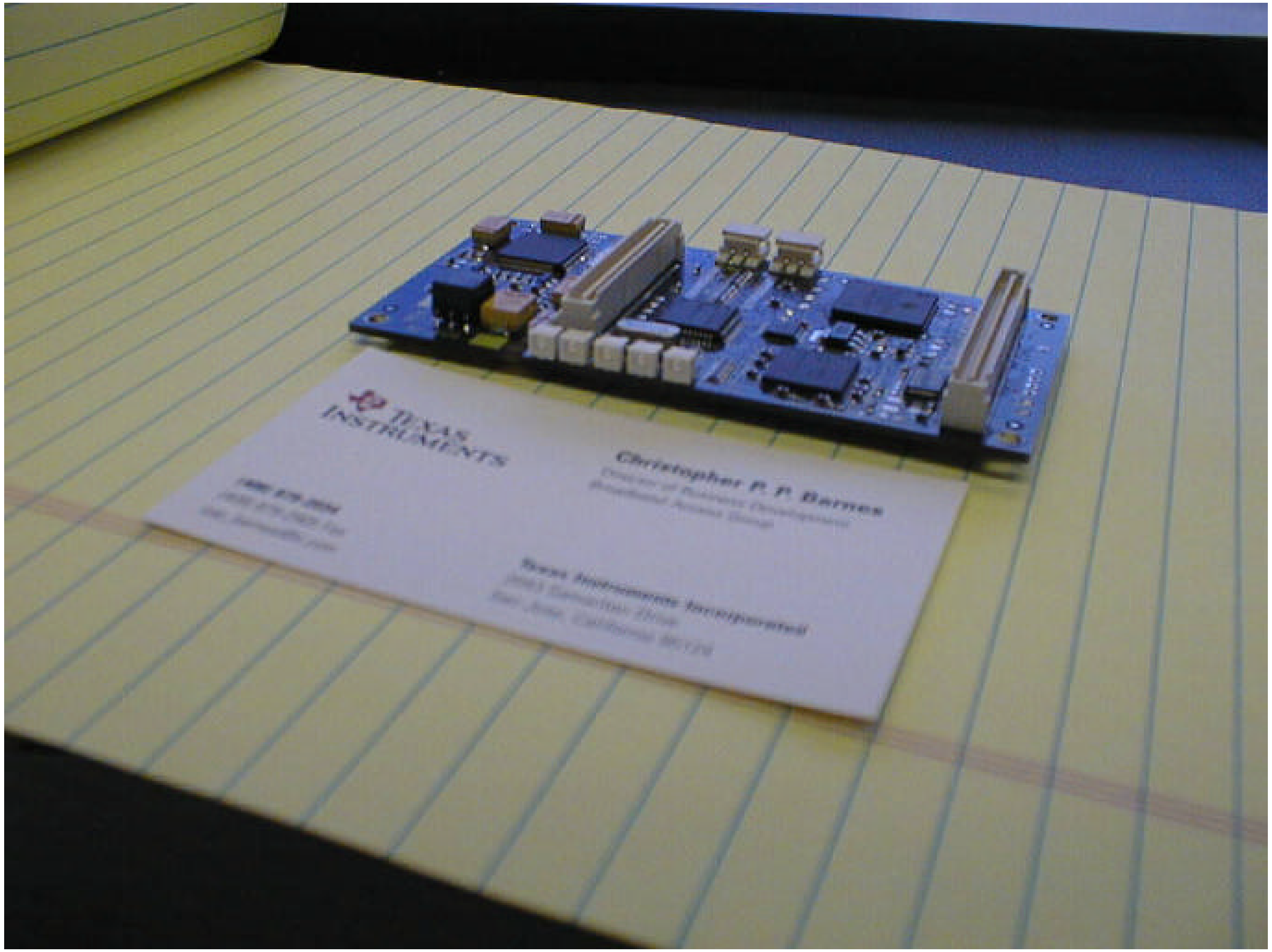
UPBO is easiest and most reliable with SDMT

SDMT Chipset Features

- User-programmable superframe
  - Supports symmetric and asymmetric bit rate ratios via the management interface
- Transmit PSD notching in up to 4 user-programmable frequency bands
  - Ensures spectral compatibility with amateur radio
- Provides tested upstream power back-off mechanism
  - Based on the reference length method
- Provides user-selectable “ADSL-compatible” option
- Low power consumption of <1W
- Small footprint of 4 square inches
- Available today

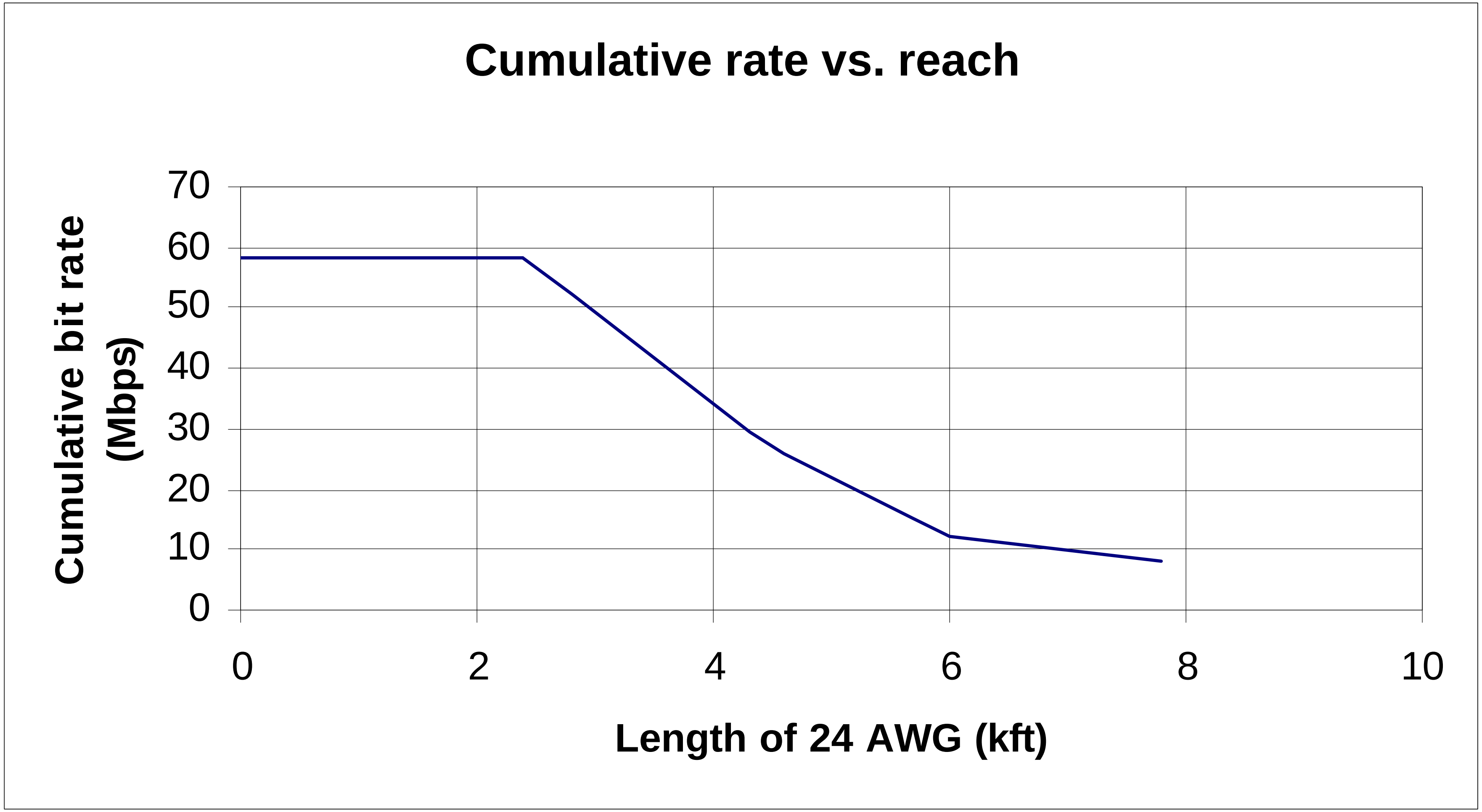
Example SDMT Chipset

Core modem
footprint:
2x2 inches



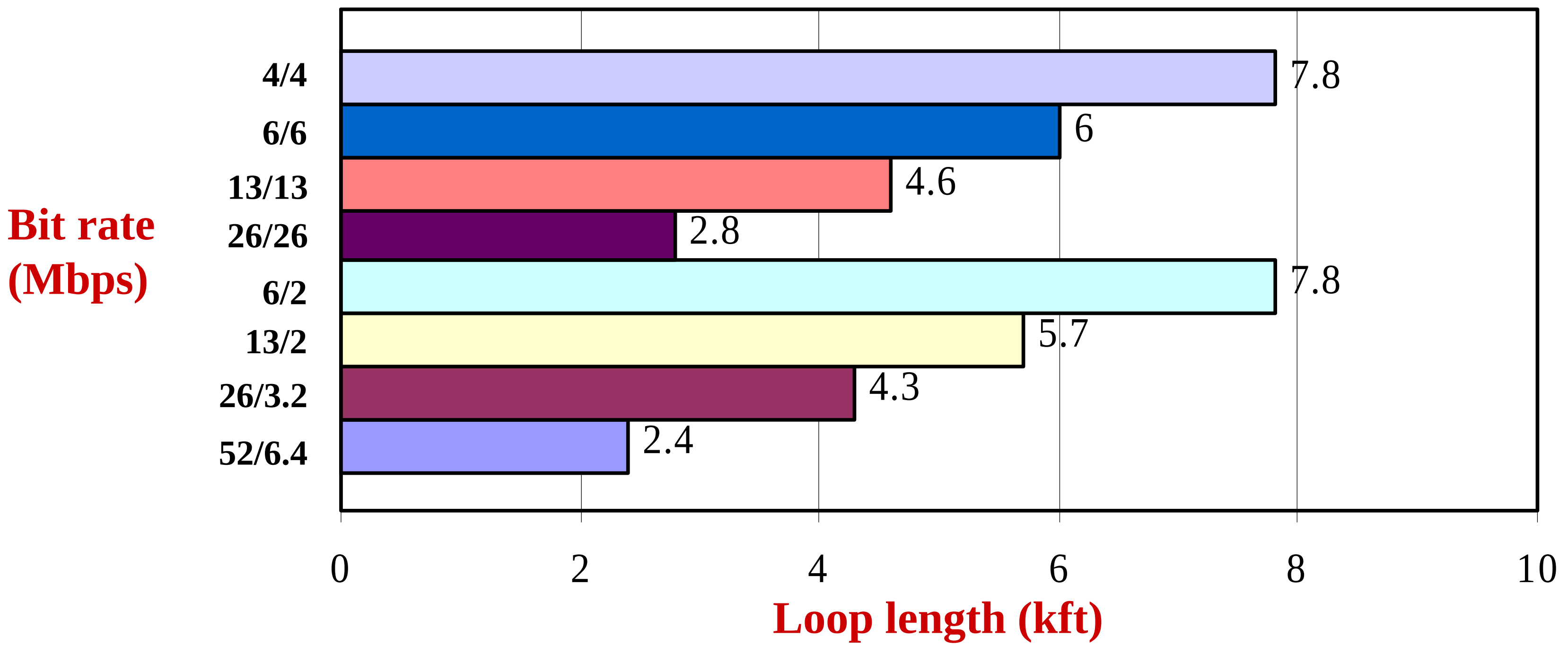
Measured SDMT Rate/Reach

24 AWG, ambient noise, 6dB noise margins, no UPBO



Performance Details

- Measured on 24 AWG (0.5-mm) cables
- Ambient noise
- 6dB noise margins
- No UPBO



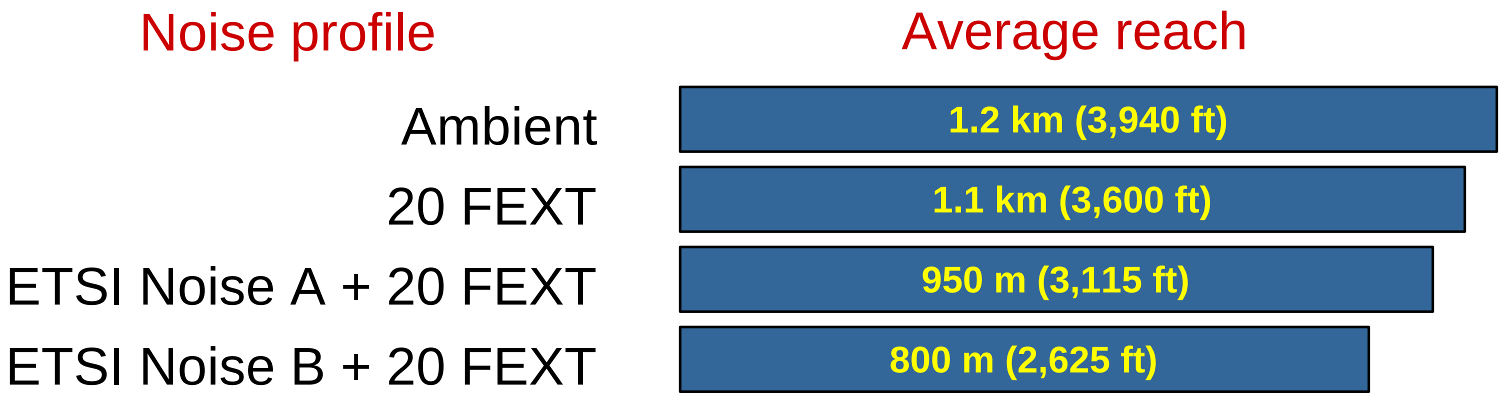
Performance: High-rate Symmetrical

- 26/26 Mbps
  - Ambient noise
  - Using subchannels from 300 kHz - 11.04 MHz (except amateur radio bands when notching is invoked)

Cable (mm)	Margin (dB)	Notching	Average reach
0.5	0	No	1 km (3,280 ft)
0.5	3	No	915 m (3,000 ft)
0.5	6	No	900 m (2,950 ft)
0.4	6	No	700 m (2,300 ft)
0.5	0	Yes	900 m (2,950 ft)
0.5	6	Yes	800 m (2,625 ft)

Performance: Asymmetrical with Noise

- 26/3.2 Mbps with added noise:
  - Real 0.5-mm cable
  - 6 dB noise margin
  - Using subchannels from 300 kHz - 11.04 MHz
  - No notching



Performance with Bridged Taps

- 26/3.2 Mbps with unterminated bridged taps:
  - Real 0.5-mm cable
  - 6 dB noise margins
  - Ambient noise
  - Using subchannels from 300 kHz - 11.04 MHz (no notching)

Bridged tap length	Average reach
0	1.2 km (3,940 ft)
18 m	1.2 km (3,940 ft)
33 m	1.1 km (3,600 ft)
96 m	950 m (3,115 ft)
157 m	850 m (2,790 ft)
310 m	915 m (3,000 ft)

Extended Reach Version

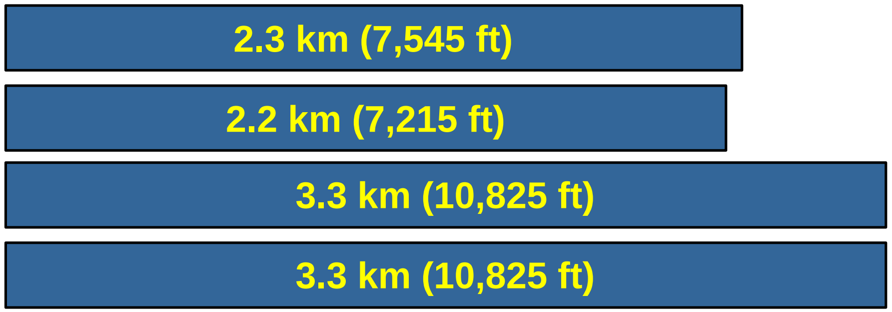
- ER = Extended Reach
- Operates at a lower sampling rate to provide lower bit rate services on longer-range loops
  - Symmetric rates such as 2, 4, 6, 8, 10 Mbps
  - Also supports asymmetric rates
- Total transmit power is the same as full-speed version
- Uses same management software interface
- Provides compatibility with HPNA
  - Upper band edge is 5.5MHz

Measured ER Performance

- Real (but high-quality) 0.5-mm cable
- Ambient noise
- Symmetrical configuration
- No UPBO

Data rate (Mbps)	Margin (dB)	Notching
8/8	6	No
8/8	6	Yes
4/4	0	No
4/4	0	Yes

Average reach



Summary of Test Results

- Performance on all loops is excellent
  - Both full-speed and extended-reach versions
  - With ambient noise
  - With crosstalk from other self-similar modems and other services in the same binder
  - With radio-frequency ingress (AM radio, amateur radio)
  - High tolerance to bridged taps
  - Close to theoretical performance

Summary of SDMT Benefits

- DMT enables maximum bit rate transmission through a noisy channel
- DMT performs well in the presence of all kinds of noise (crosstalk, impulse noise, RF ingress)
- DMT enables simple provision of notches in the amateur radio bands (low RF egress)
- TDD enables user-configurable data rate and symmetry
- TDD reduces modem complexity and power consumption when DMT is the modulation

SDMT Value Proposition

- Excellent measured performance on real loops
  - Provides good immunity to RF ingress
  - Suppresses RF egress in amateur radio bands
  - Provides a tested UPBO mechanism
- Lowest power consumption of any available solution
  - Just under 1W per modem
- Small size
  - 4 sq. in. footprint
- Low cost
- Spectrally compatible with ADSL
- Flexible
  - Programmable symmetric and asymmetric data rates
- All of these features are desirable for EFM!
  - Which are critical to have?

Summary

- Presented the individual benefits of TDD and DMT
- Discussed the advantages of SDMT (DMT-based TDD)
- Described example SDMT chipset
  - Features
  - Performance
  - Value proposition