Short Reach PHY Proposal

Ethernet over DMT-VDSL

- Decision Time

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Supporters

- Behrooz Rezvani, Ikanos
- Sabina Fanfoni, STMicro
- Michael Beck , Alcatel
- Aidan O'Rourke, Broadcom
- Chris Hansen, Intel
- Krista Jacobsen, TI
- Craig Herro, Nokia
- John Hong, LSI Logic
- P. Ericksson, Ericsson
- Daun Langston, Metanoia Tech.
- Bernard Debbasch, GlobeSpanVirata
- Jim Carlo, Independent
- John Cioffi, Stanford University
- Jacky Chow, Astri
- Vladimir Friedman, ADI

Operators

- North American Operators Present at T1E1.4 meeting
  - **SBC**
  - **QWEST**
  - **MCI**
  - **Sprint**
  - **Bell Canada**

Which SR PHY?

- Two candidates: DMT and QAM
- Which PHY to select?
- Examine the 5 criteria that IEEE requires
  - Broad Market Potential
  - Compatibility
  - Distinct Identity
  - Technical Feasibility
  - Economic Feasibility

Criteria 1: Broad Market Potential

- Broad sets of applicability
- Multiple vendors and numerous users
- Balanced costs (LAN vs attached stations)

Does VDSL-DMT satisfy Crit. 1?	
1a)	Yes
1b)	Yes
1c)	Yes

Broad Market Potential

- Customers for SR EFM are primarily Telcos
  - SBC, Verizon, BellSouth, MCI, MCI, …
- Significant number of telcos already have selected DMT for VDSL and prefer VDSL-DMT for EFM as well
- FTTP: Fiber To The Premise, was just launched by Major RBOCs
- DMT technology has dominated deployment of any broadband technology in the market place with over 40 million subscribers worldwide for ADSL

Criteria2 : Compatibility

- Conformance with 802.d, 802.1q, 802.1f
- Conformance with 802 overview and architecture
- Compatible managed object definitions
  - DMT vendors are committed to ensuring and supporting the compatibility of managed object definitions

Does VDSL-DMT satisfy Crit. 2?	
1a)	Yes
1b)	Yes
1c)	Yes

Criteria 3 : Distinct Identity

- Different from other IEEE 802
- One unique solution per problem
- Easy for the document reader to select relevant spec

Does VDSL-DMT satisfy Crit. 3?	
3a)	Yes
3b)	Yes
3c)	Yes

Criteria4 : Technical Feasibility

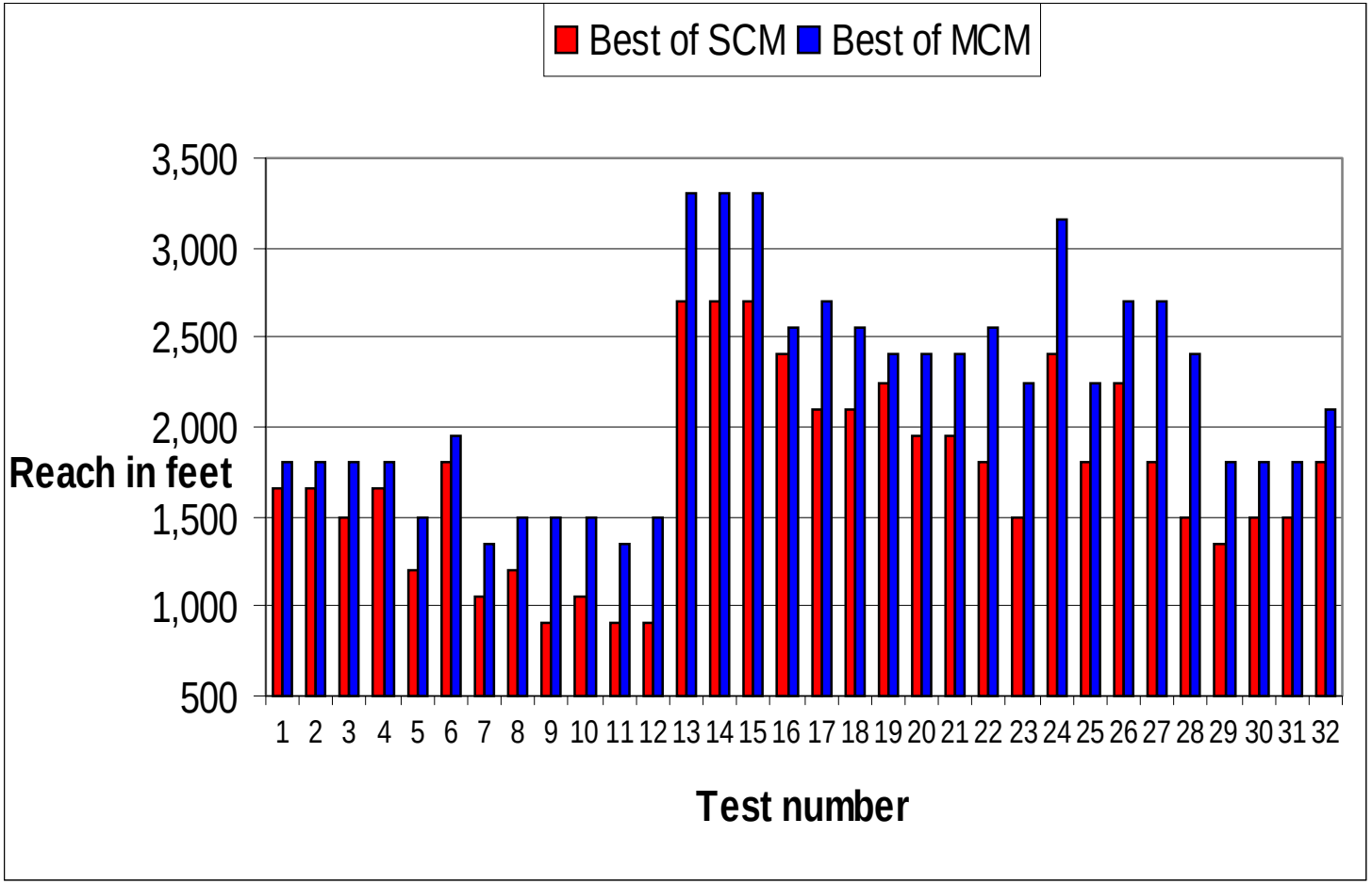
- Demonstrated system feasibility
- Proven technology, reasonable testing
- Confidence in reliability

Does VDSL-DMT satisfy Crit. 4?	
4a)	Yes
4b)	Yes
4c)	Yes

VDSL Olympics Mandatory Tests at BT and Telcordia

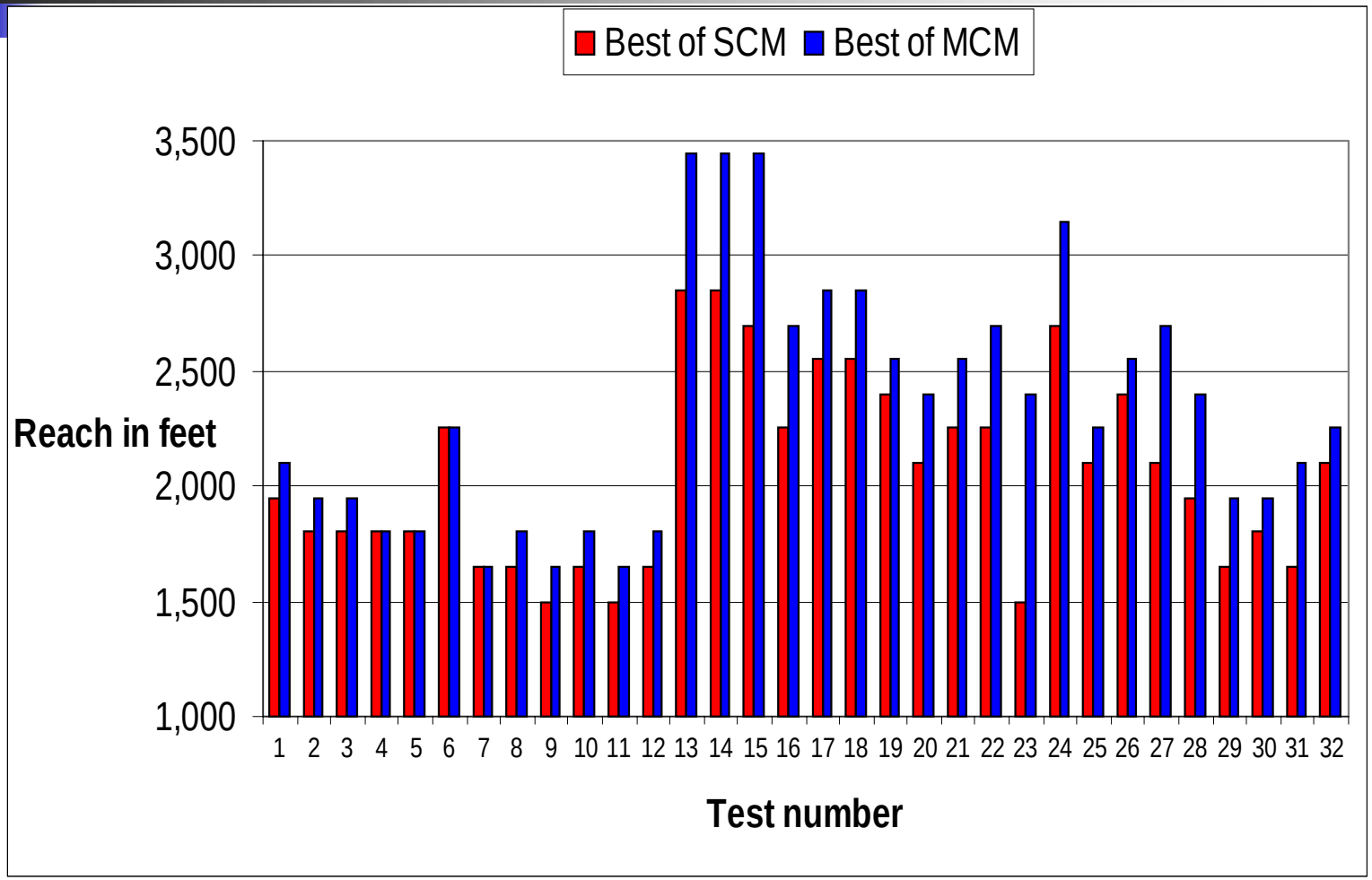
- **32 Reach test for various noise and loop conditions for the following service rates**
  - **10/10 Mbps, 13/13 Mbps, 6/6 Mbps 22/3 Mbps, and 16/1 Mbps**
  - **4 tests were defined by EFM group and total of 16 symmetrical tests**
  - **14 tests were defined by Service Providers**
  - **7 tests were defined by QAM and 7 tests were defined by DMT**
- **UPBO performance**
- **Impulse Noise immunity**
- **Latency between γ_O and γ_R interface**
- **Total number of tests 60 per lab**
- **Test plan and methodology was determined by T1E1.4 in discussions over 6 months preceding the tests by all interested parties**

Best of MCM vs. Best of SCM
At BT



All results were obtained from the appropriate test reports on T1 Website

Best of MCM vs Best of SCM
At Telcordia



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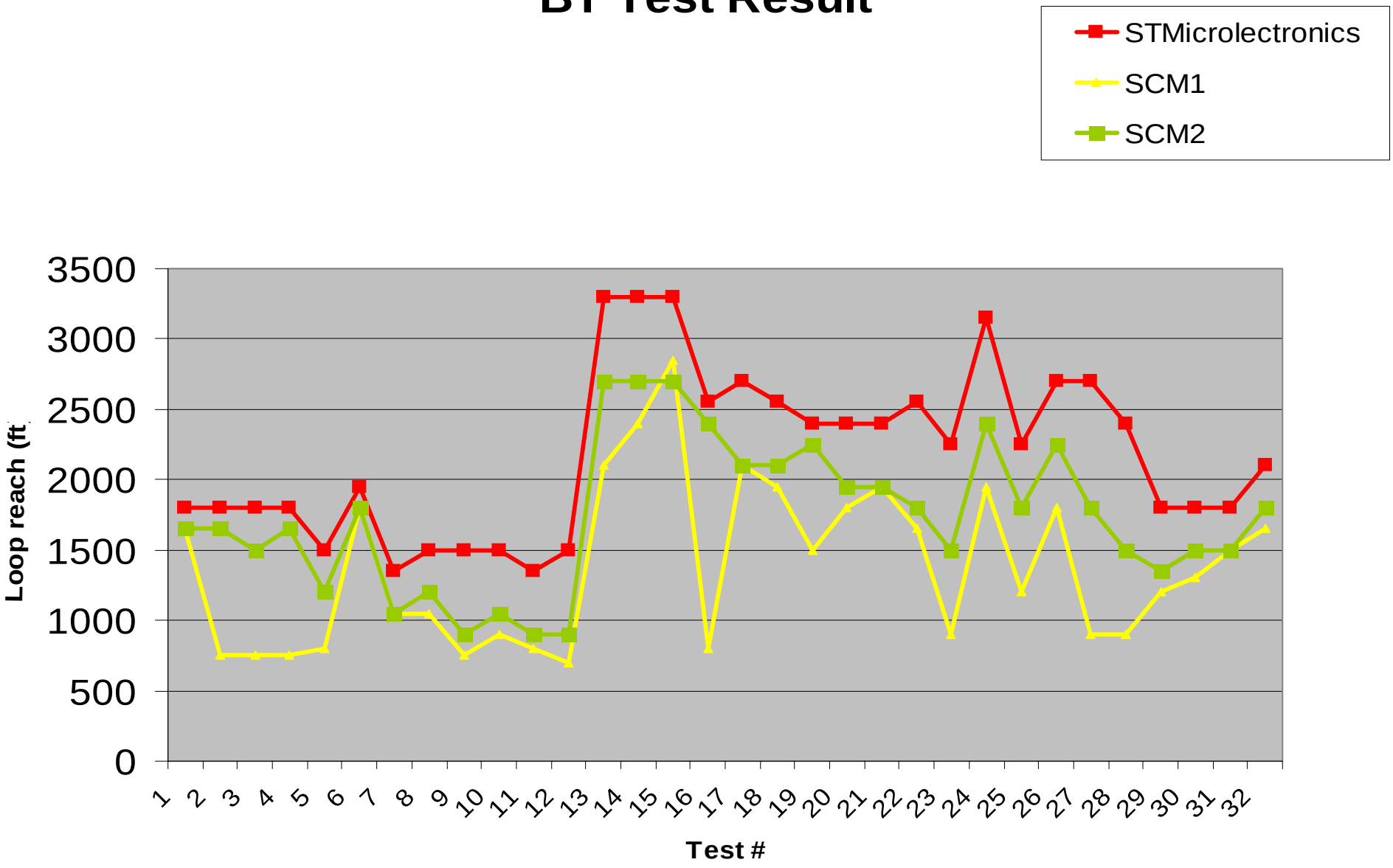
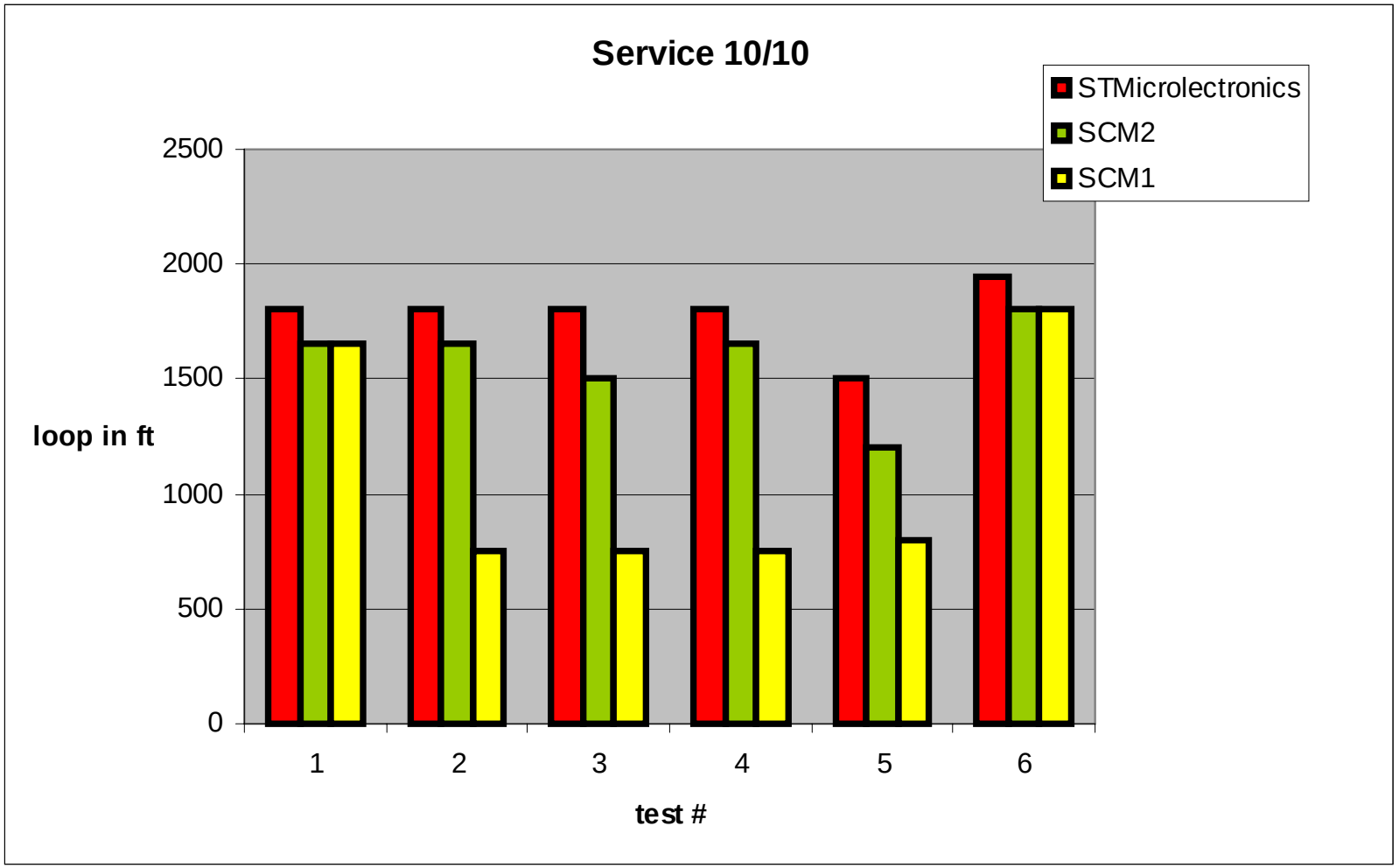
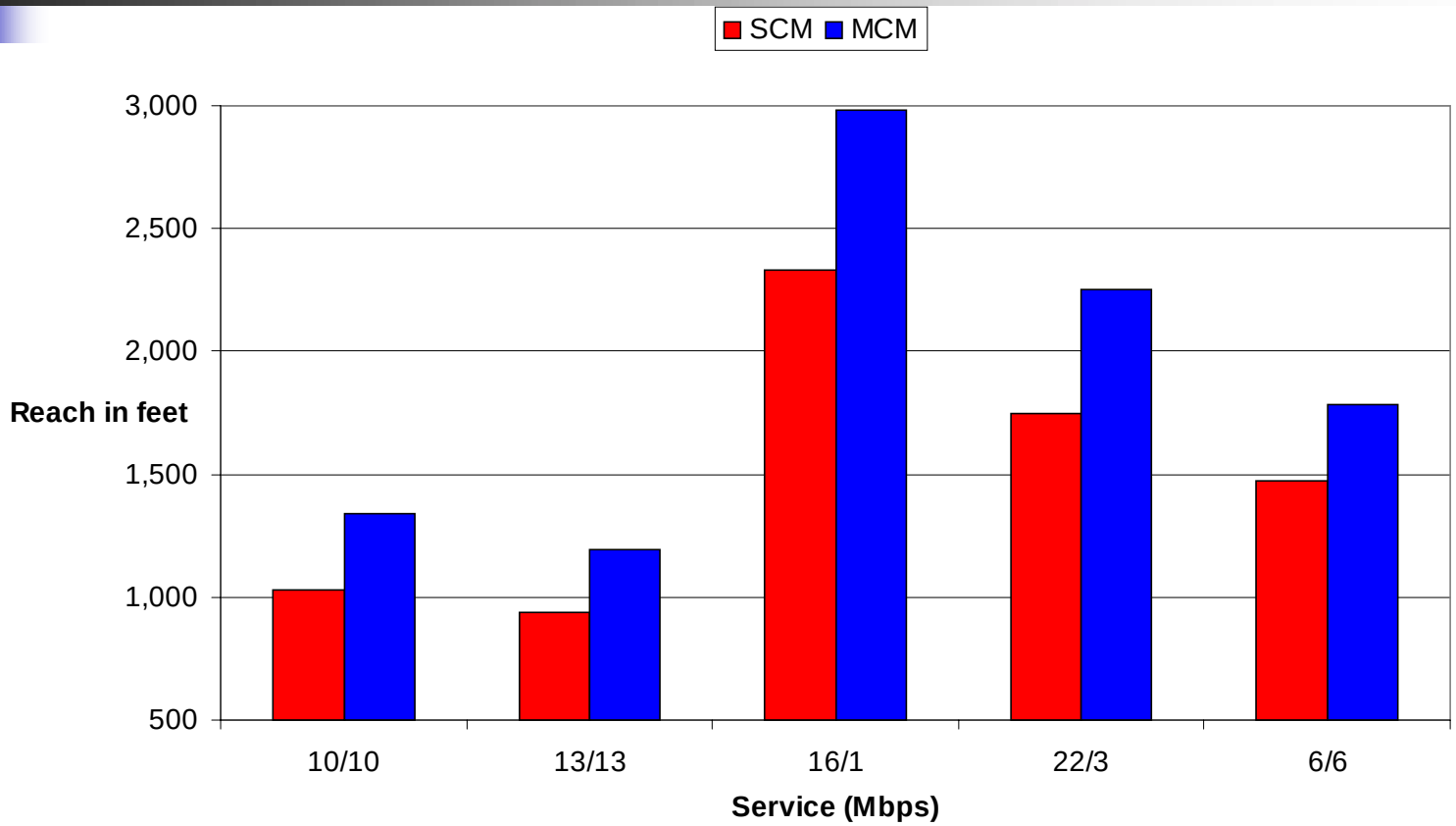
BT Test Result



Performance of 10/10



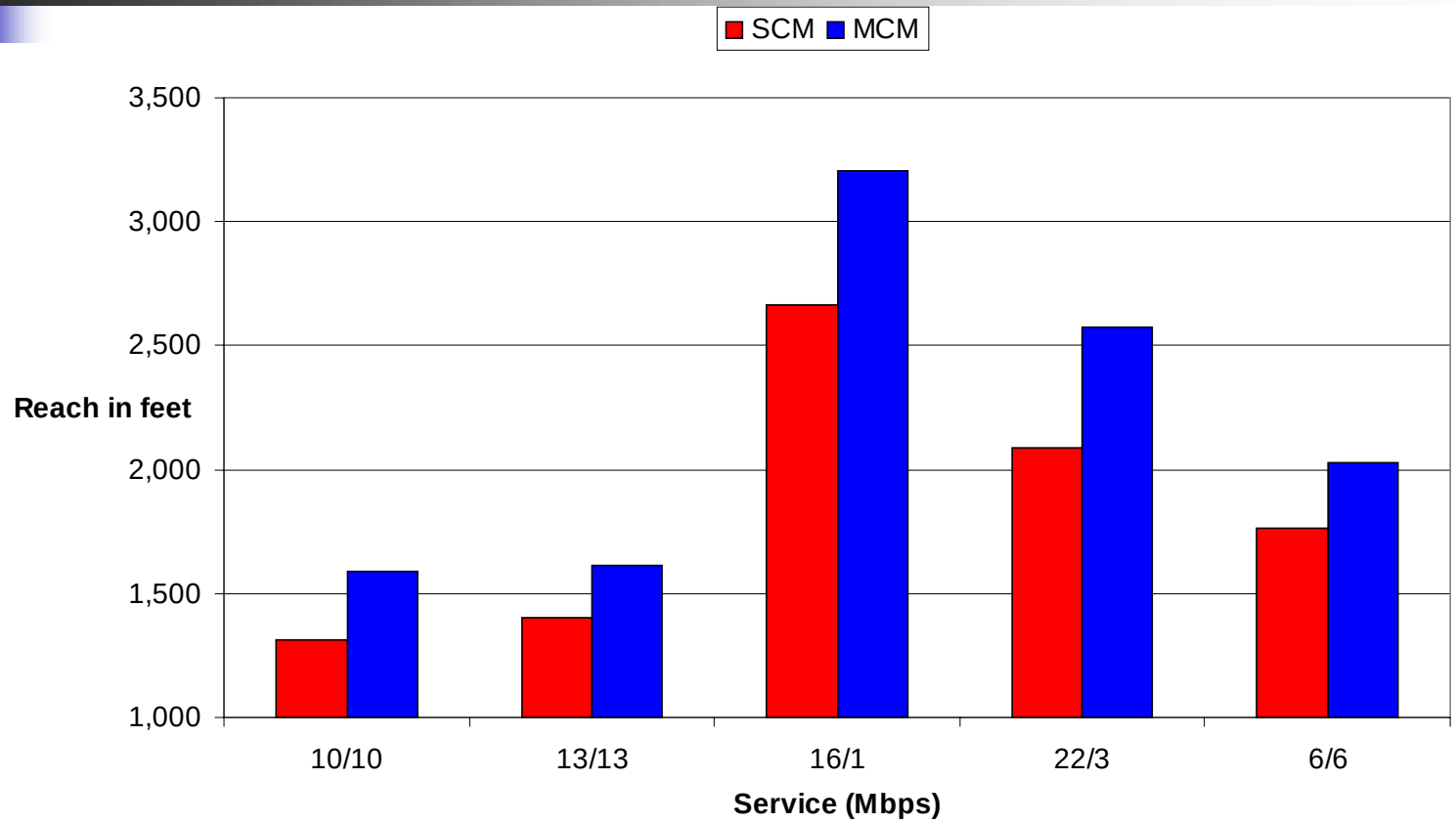
Average of MCM vs. Average of SCM
By Service at BTexact



Note:
PSD – SCM1: failed 11 out of 15 PSD configurations
Rate – SCM1: Rate and BER requirements was not satisfied for both directions simultaneously (29 cases out 32 tests)
Cell Error: SCM1 ?

All results were obtained from the appropriate test reports on T1 Website

Average of MCM vs. Average of SCM
By Service at Telcordia

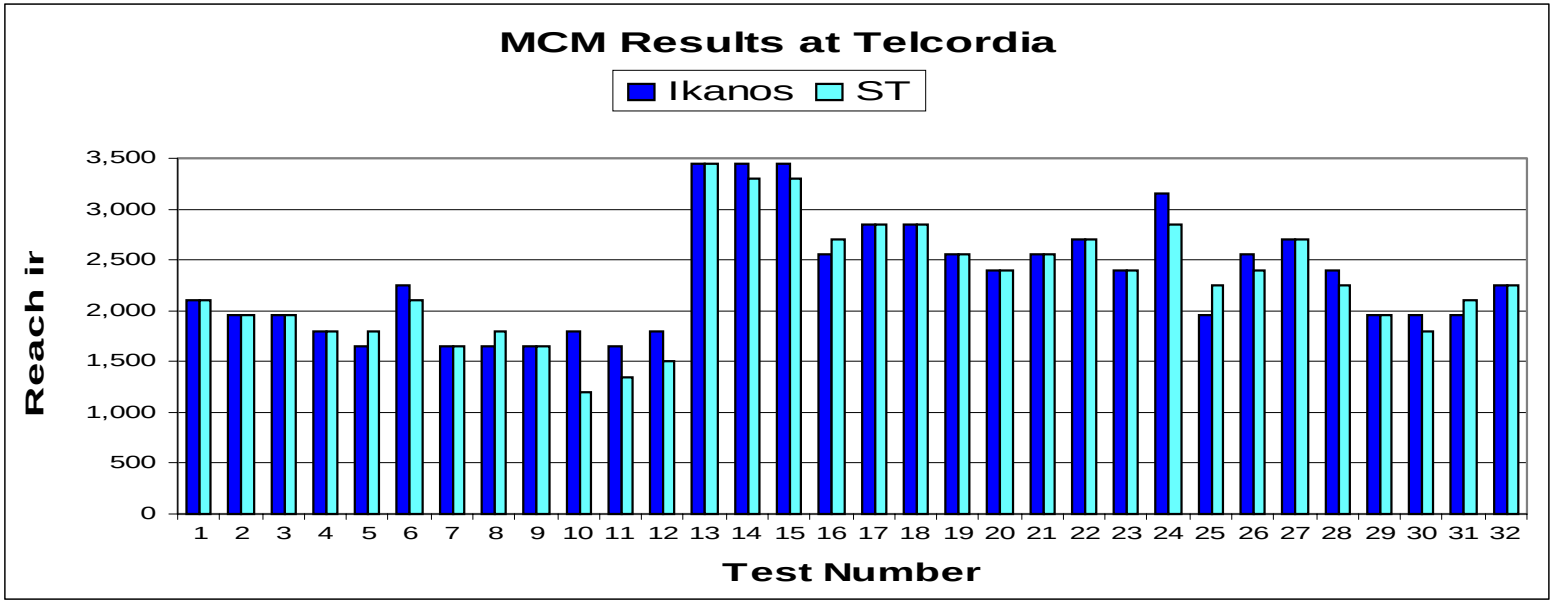


Note:
PSD – SCM1: PSD violation in majority configuration, SCM2: PSD issues in some configurations
Cell Error: SCM 1?

All results were obtained from the appropriate test reports on T1 Website

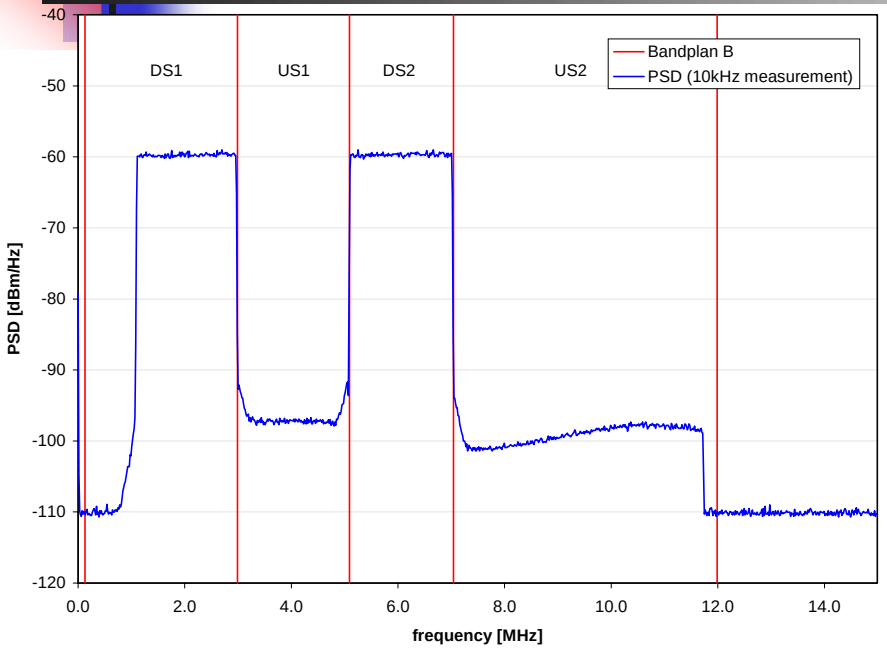
Mandatory Test Results at Telcordia

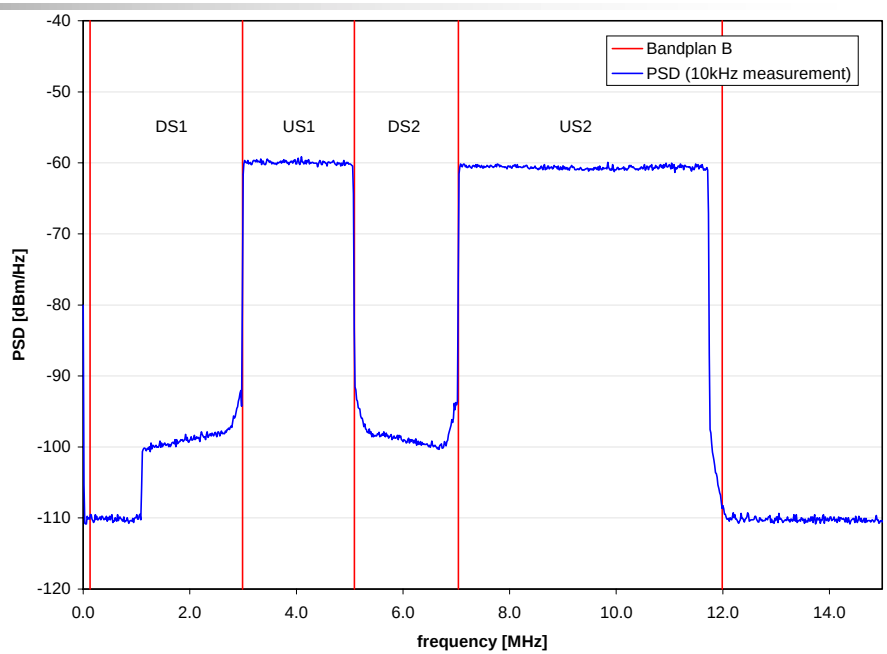
DMT shows consistent performance among vendors - like Ethernet



Telcordia results	QAM	DMT
Average Reach (ft)	1914.8	2287.5
Average reach difference (ft)	245.8	41.7
Consistency in performance	87%	98%

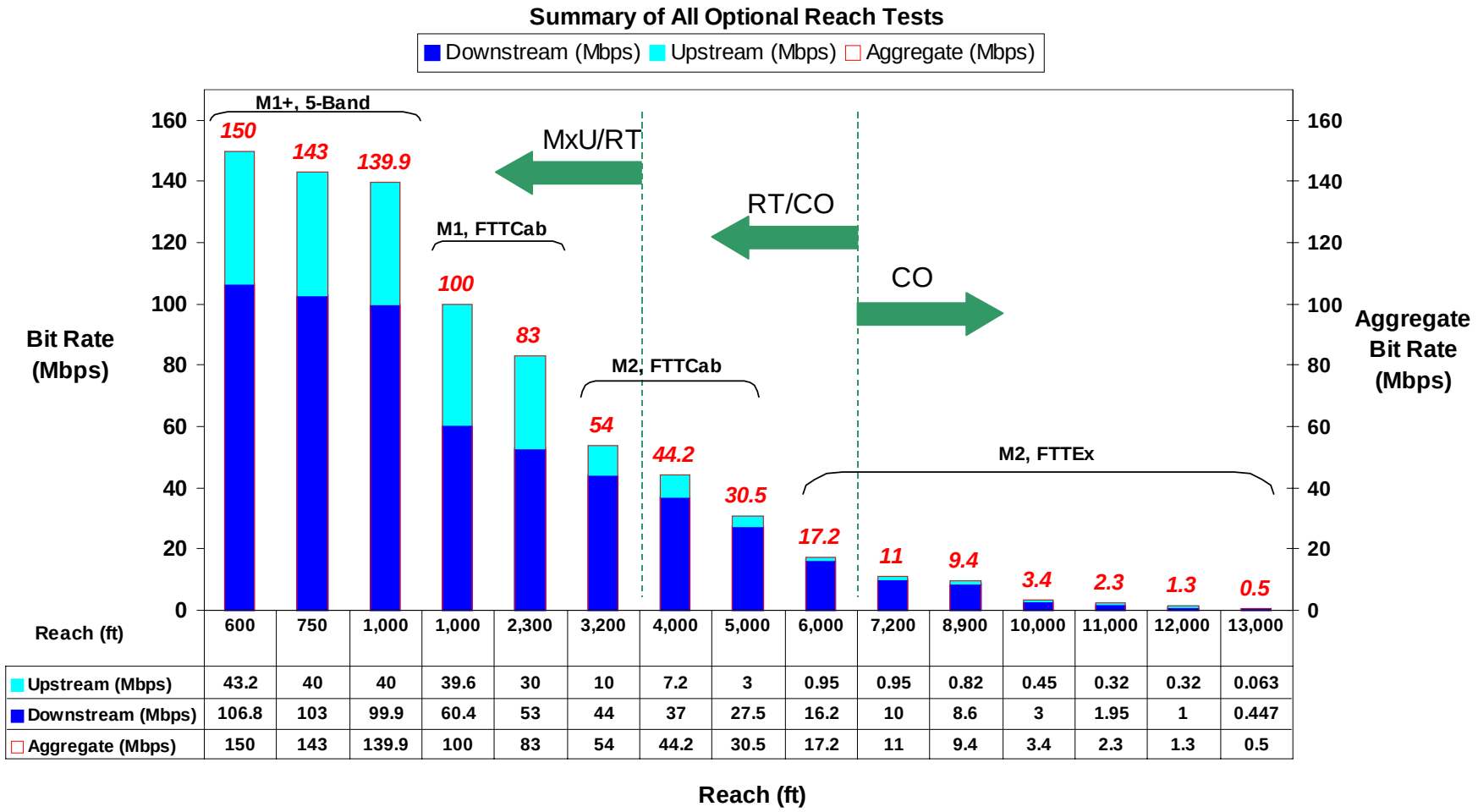
Plan 997





- Mandatory European band plan
- Reach 10/10: 3750 ft (3050 ft for plan 998)

Summary of 998 Optional Reach Tests



	600	750	1,000	1,000	2,300	3,200	4,000	5,000	6,000	7,200	8,900	10,000	11,000	12,000	13,000
Upstream (Mbps)	43.2	40	40	39.6	30	10	7.2	3	0.95	0.95	0.82	0.45	0.32	0.32	0.063
Downstream (Mbps)	106.8	103	99.9	60.4	53	44	37	27.5	16.2	10	8.6	3	1.95	1	0.447
Aggregate (Mbps)	150	143	139.9	100	83	54	44.2	30.5	17.2	11	9.4	3.4	2.3	1.3	0.5

Reach (ft)

Summary of Olympics results
DMT performs faster, better, longer

- Technical results from independent labs showed a compelling advantage of DMT over QAM in reach results
- DMT performance in presence of Bridge Taps and Notches were much better as had been predicted
- Only DMT showed plan 997, and China bandplan - achieving true single port type
- Only DMT showed all payload rate profiles as specified by Annex 62A.
- VDSL-DMT achieved 100 Mbps over a single twisted pair - true high speed Ethernet

criteria5 : Economic Feasibility

- Known cost factors, reliable data
- Reasonable cost for performance
- Consideration of installation costs

Does VDSL-DMT satisfy Crit. 5?	
5a)	Yes
5b)	Yes
5c)	Yes

DMT VDSL Economic Feasibility

- Economic Feasibility is One of the Five Criteria
  - “For a project to be authorized, it shall be able to show economic feasibility (so far as can reasonably be estimated), for its intended applications.
  - At a minimum, the proposed project shall show:
    - a) Known cost factors, reliable data.
    - b) Reasonable cost for performance.
    - c) Consideration of installation costs.

Known Cost Factors

- **Three principle cost components**
  - **Analog Front End**
  - **Signal Processing**
  - **Memories**
- **Analog Front End**
  - **The circuitry required to interface the digital signal processing blocks to the copper pair**
  - **Consists of Analog to Digital/Digital to Analog Converters, Line Driver, Gain Control, Programmable Gain blocks, analog hybrid (2 wire/ 4 wire conversion) circuitry**
  - **Some or all of the above blocks may be present depending on implementation**
- **Signal Processing**
  - **Typically a high-performance Digital Signal Processor (DSP) with varying amounts of acceleration logic (implementation dependent)**
- **Memories**
  - **Interleaver Memory for Impulse Noise Protection**
  - **Program Memory for execution of signal processing code**
  - **Data Memory for storage of Data/Control path**

Analog Front End

- AFE PAR (Peak to Average Ratio), or Cost Factor
  - Dynamic Range
  - Noise
  - Sampling Bandwidth
  - Line Driver Power/Linearity Requirements
- Noise and Sampling Bandwidths
  - Line code independent
- Dynamic Range
  - Primarily dictated by trans hybrid loss and hybrid linearity
    - Independent of line code
  - Peak to Average Ratio (PAR), is similar in both line codes
    - 4-band QAM, notch filters and similar constellation resolution gives similar PAR values
    - No meaningful impact on converter cost points
- Line Driver
  - Costs primarily driven by transmit power, and bandwidth requirements
  - PAR for 4-band QAM and DMT is very close, this effect is second-order
- No measurable differences in QAM vs. DMT AFE cost or complexity

Signal Processing

- DMT Cost Factors
  - Heavily implementation dependent
  - Programmable Cores vs. Hardware Acceleration Blocks
  - DSP Architecture (VLIW, SIMD etc)
- QAM/DMT Cost about the same
  - About the same computational efficiency and use of memory to handle the proper functions. Difference of opinion exist between DMT and QAM vendors on how to account for various implementation
    - Computational block, DMT is more efficient
    - Usage of memory, QAM is more efficient

Memories

- **Interleaver Memory**
  - **Requirements dictated impulse noise robustness requirements , VDSL line rate and strength of FEC coding employed**
  - **32 kbytes typically, (approx 0.1mm^2 in 0.13u silicon): very small/low cost**
  - **Independent of line code**
- **DMT Program Memory**
  - **Multi-port DSP chipset share program memories between the ports**
  - **DSL CPE chipsets rapidly migrating to single-chip bridge/router products requiring multi-Mbytes of system memory.**
- **DMT Data Memory**
  - **Small number of symbol buffers**
  - **Very small and low cost (48 kbytes typical; 0.1mm^2 0.13u silicon)**
- **Memory is a commodity**
  - **No significant difference between QAM and DMT memory costs**
  - **100-200 kbytes ~ . 2-.4 mm^2 very small**

Reasonable Cost for Performance?

- DMT typically achieves several hundred additional feet in reach (100-500) on tested loops vs. QAM technology
  - For average 3kft FTTN loop assume 10% additional reach
  - Assume ,everything else being equal, 10% additional subscibers per node
  - Typical FTTN node subs 400, so 40 additional subs/node
  - More subs mean more revenues
- Cost of generating this incremental revenue?
  - One or two hundred kbytes of memory per port (CO plus CPE), offset by DMT advantage in computational blocks
- DMT VDSL has clear advantage in the category of reasonable cost for performance

Installation Costs

- VDSL deployments require fiber build-out
  - FTTP, FTTN, FTTB
- More chipset vendors support DMT VDSL. A greater number of vendors result in greater competition, which helps to ensure competitive pricing
- DMT has lower deployment cost
  - Multi-DSL chipsets (A/A2/A2+/V) enable multi-DSL linecards. With fewer line card. Variants for remote nodes training costs and inventory are reduced.
  - With multi-DSL line cards, customers can be migrated from ADSL to higher value VDSL without the need to deploy a truck.
  - Reduces the need to send craft person to deal with problems in the field due bridged taps, RFI interference, as a result of better performance and flexibility

Summary

- AFE, DMT and QAM dmt are about the same
- Signal processing cost about the same, varies according to implementation
- Usage of memory QAM has advantage of 100-200 Kbytes/Port, but small fraction of the chips cost
- DMT has significant advantage by providing a much larger coverage
  - Resulting in many times the overall cost of chips and equipment
- Installation and Operational cost
  - Much smaller for DMT
- Conclusion: DMT- VDSL cost less than QAM VDSL

Summary

- **T1E1.4 has done what we asked: DMT chosen for elevation to ANSI Std.**
- **VDSL-DMT is what the customers want**
- **VDSL-DMT meets the 5 Criteria**
- **VDSL-DMT outperforms VDSL-QAM**
- **VDSL-DMT is the right choice for SR EFM Cu**

Conclusions

- The supporters of this presentation request that DMT-VDSL be selected as the single line code for 10PASS-TS.

Summary
Olympic Results and Presentations from T1E1.4 meeting

ST Microelectronics/Alcatel

Ikanos Communications

T1E1.4/2003-187

Discussion of STMicroelectronics results in VDSL Olympics

Sigurd Schelstraete

Sabina Fanfoni

Disclaimer

All comparisons, views, presentation, information, and interpretations herein are entirely from STMicroelectronics and Alcatel. Some of the results used herein are based on VDSL test data from Telcordia Technologies and BTexact. The comparisons, views, presentation, information, and interpretations herein are not verified by, nor endorsed by, Telcordia Technologies or BTexact. This information is presented for discussion purposes only, and is not meant to be taken apart from the complete test results, which are available at the Committee T1 website, www.t1.org, and are listed below:

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Telcordia, "Optional VDSL Transceiver Test Results for Ikanos," T1E1.4/2003-614.

The tested system

- **STMicroelectronics ZipperWire VDSL**
  - VDSL chipset
    - STLC90114 digital transceiver
    - STLC90115 analog front-end
  - Originally co-developed by Alcatel and ST
  - Chipset now under final responsability of ST

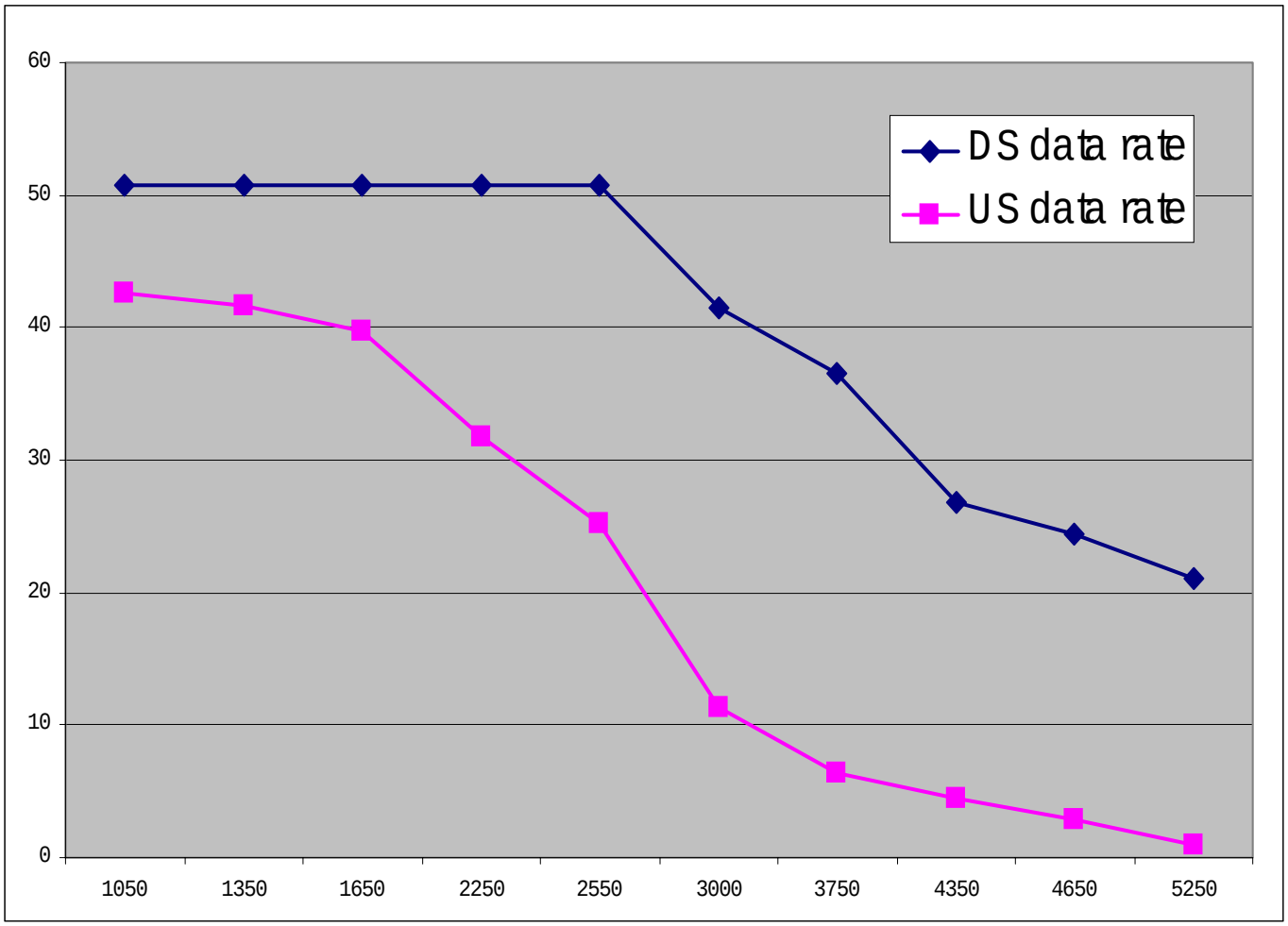
Mandatory tests

- Test plan for Olympics was compiled over a period of several meetings after intense discussion among the various parties (operators, SCM, DMT)
- Represents industry consensus on what is important for VDSL performance and what would be the basis for the line code selection
- Each camp has the freedom to complement this with additional tests
- Independently tested at BTexact and Telcordia

Optional tests

1. Rate adaptation
   - Rate/reach curves
   - Achievable rates for mandatory tests
2. PSD and frequency plan flexibility
3. HAM radio immunity
4. Additional impulse noise tests
5. Stability test
6. DSM

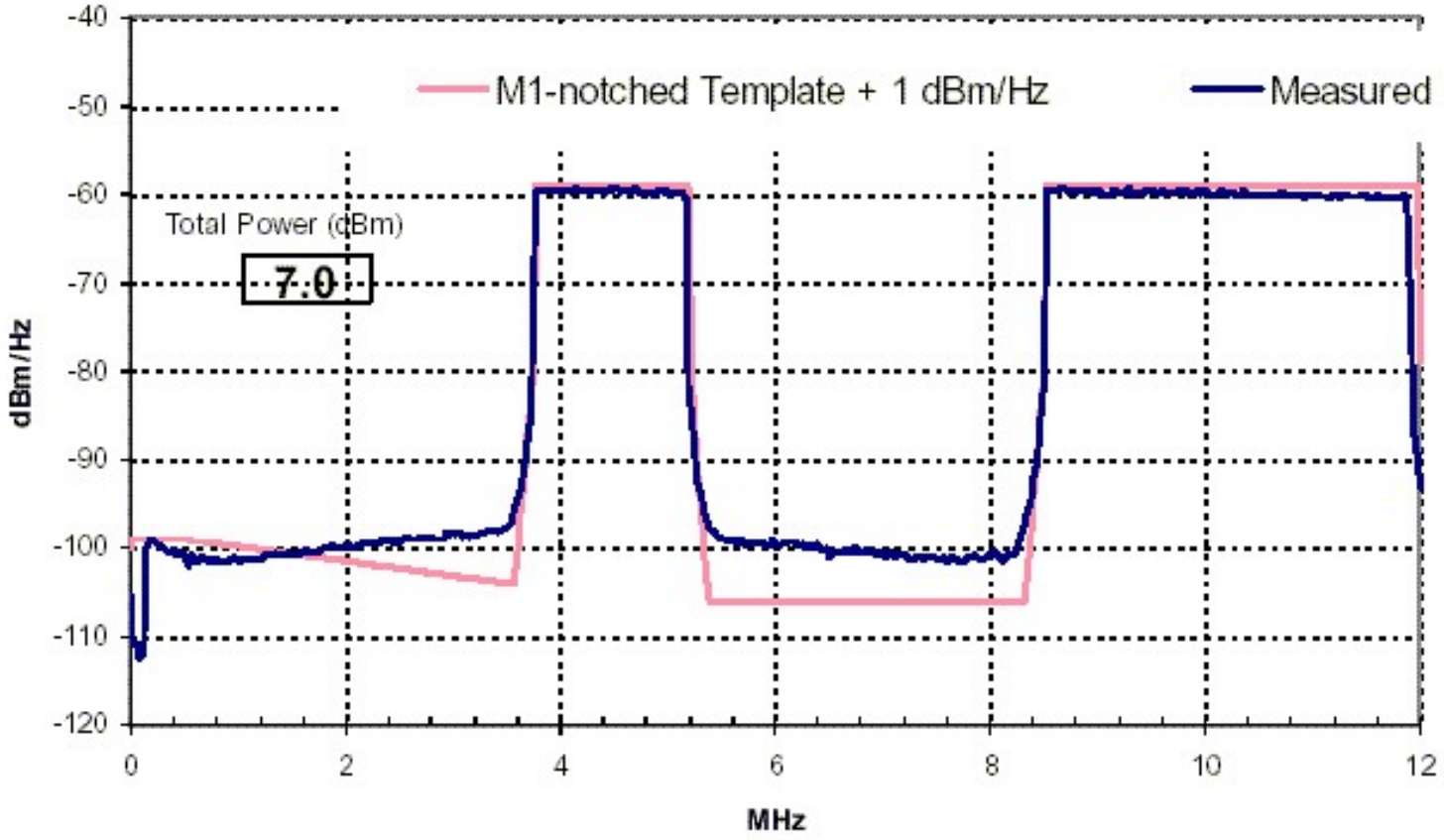
Rate Adaptation – AWGN only



- **Optimal rate** for any given distance
- Guaranteed ability to support any requested service

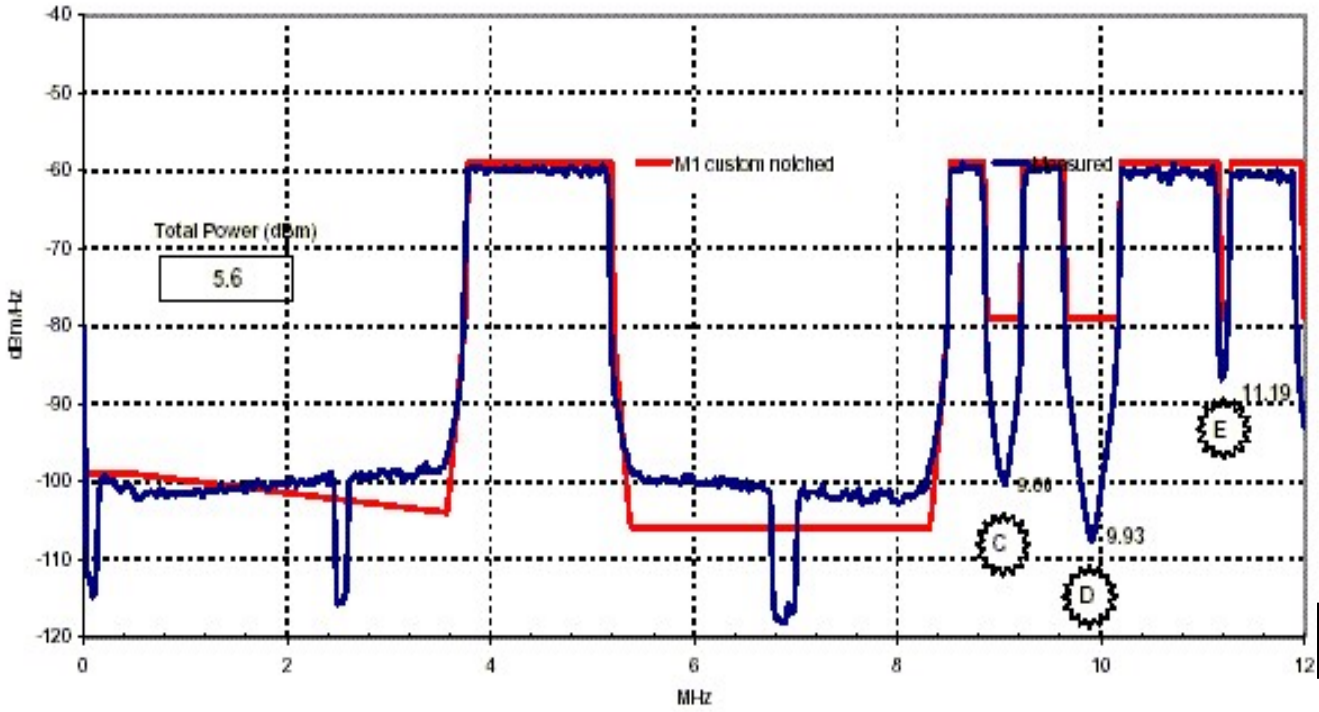
Spectral flexibility

- **Not a single PSD violation** reported in test reports



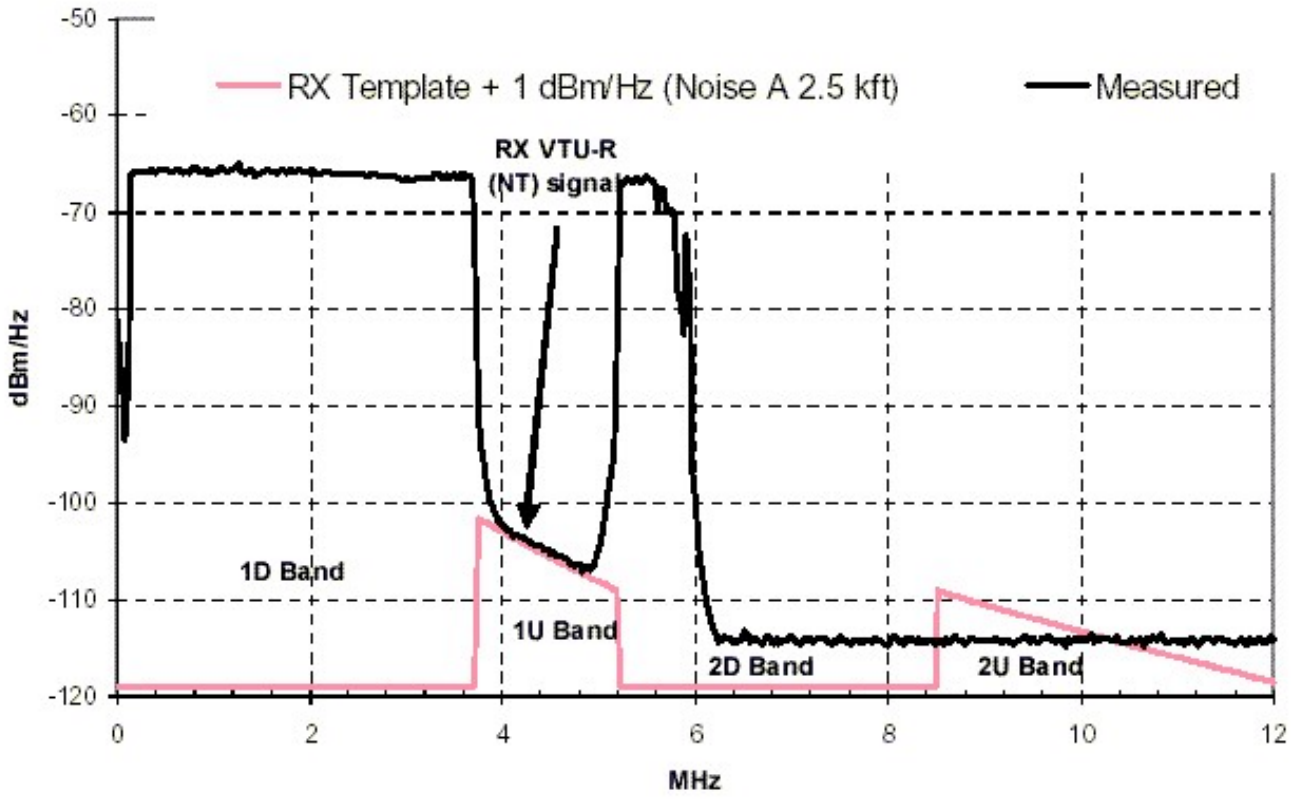
Spectral flexibility - **notches**

- **Multiple notches** per band , No complexity penalty



31.3/7.4 Mbps

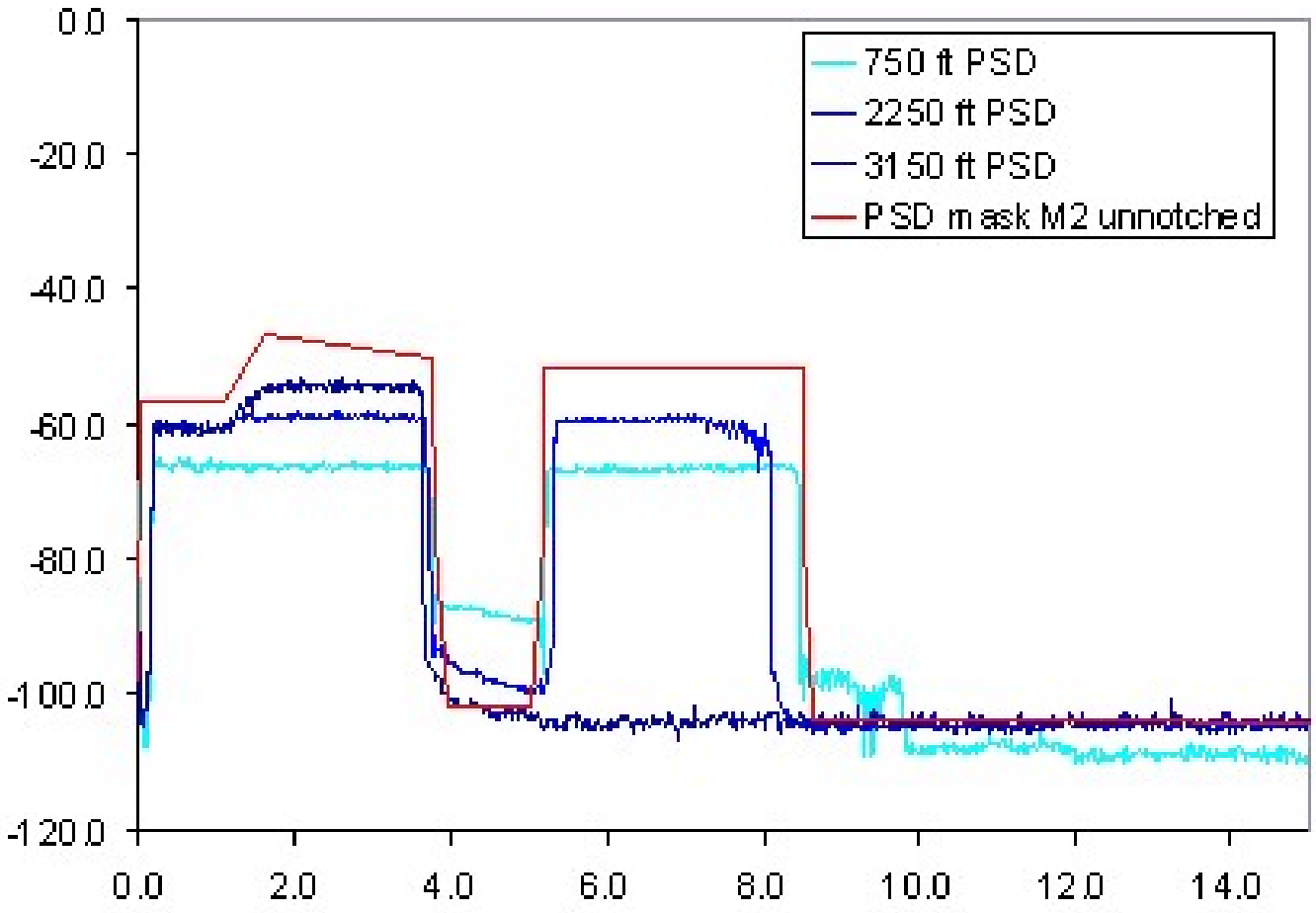
Spectral flexibility - UPBO



Spectral flexibility – **support of band plans**

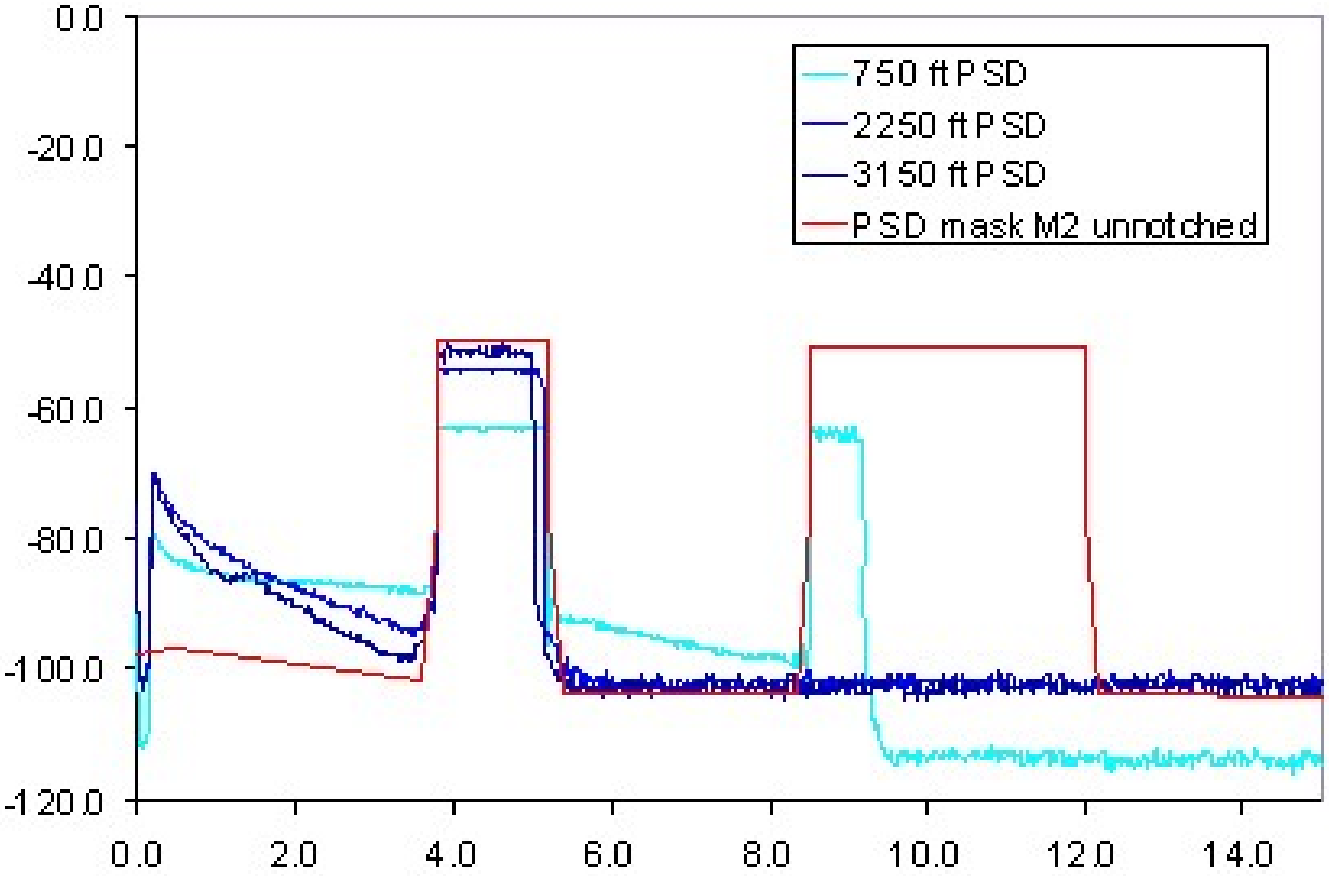
- Any band plan can be supported through simple OAM configuration
  - Plan 998
  - Plan 997
  - Fx-plan
  - CO or Cabinet
  - Chinese band plan
  - Any user-defined band plan …
- Configured through SW only (thanks to digital duplexing)

DSM - Downstream PSD



- Short lines use broad spectrum at minimal PSD
- Long lines use narrower spectrum at higher PSD
- Total crosstalk between lines is reduced

DSM- Upstream PSD



- Also applicable in upstream
- Can be combined with UPBO

Conclusion

- DMT outperforms QAM at practically every single test!
- Consistent results between different DMT vendors

Based on mandatory tests alone, DMT clearly “wins” the VDSL Olympics

VDSL-DMT Performance Highlights

Sam Heidari, Ph.D

Important Note for Presentation

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Overview of Discussion

- Test plan and methodology
- Mandatory test results
- MCM and SCM comparison
- Optional test results for Ikanos
- Conclusion and Summary

Mandatory Tests Overview

- Reach test for various noise and loop conditions for the following service rates
  - 22/3 Mbps, 16/1 Mbps, 13/13 Mbps, 10/10 Mbps and 6/6 Mbps
  - Total of 32 tests
  - 14 tests were defined by Service Providers
  - 4 tests were defined by EFM
  - 7 tests were defined by SCM and 7 tests were defined by MCM
- UPBO performance
  - Total of 4 tests
- Impulse Noise immunity
  - Total of 22 tests
- Latency between gamma and gamma interface
  - Total of 2 tests
- Total number of tests 60 per lab
- Test plan and methodology was determined by this committee in discussions over prior 6 months

Best of MCM vs. Best of SCM at BT

	10/10 Mbps	13/13 Mbps	16/1 Mbps	22/3 Mbps	6/6 Mbps
Plain loops (No BT, Notching, or RFI)	Tests 1 & 6 MCM: 2 SCM: 0	N/A	Tests 13 & 14 MCM: 2 SCM: 0	Tests 17, 18, & 24 MCM: 3 SCM: 0	N/A
Bridged Taps	Test 5 MCM: 1 SCM: 0	Tests 7, 8, 10, & 11 MCM: 4 SCM: 0	Test 16 MCM: 1 SCM: 0	Tests 20, 21, 23, 25, 26, & 28 MCM: 6 SCM: 0	Tests 29, 30, 31, & 32 MCM: 4 SCM: 0
RFI Interference	Test 4 MCM: 1 SCM: 0	Tests 9 & 11 MCM: 2 SCM: 0	N/A	Test 19 MCM: 1 SCM: 0	Test 30 MCM: 1 SCM: 0
RFI Notching	Tests 2, 3, 4, & 5 MCM: 4 SCM: 0	Tests 9, 11, & 12 MCM: 3 SCM: 0	Tests 15 & 16 MCM: 2 SCM: 0	Tests 22, 23, 27, & 28 MCM: 4 SCM: 0	Tests 29, 30, & 31 MCM: 3 SCM: 0

SCM is Superior

MCM is Superior

Best of MCM vs. Best of SCM at Telcordia

	10/10 Mbps	13/13 Mbps	16/1 Mbps	22/3 Mbps	6/6 Mbps
Plain loops (No BT, Notching, or RFI)	Tests 1 & 6 MCM: 1 SCM: 0 Tie: 1	N/A	Tests 13 & 14 MCM: 2 SCM: 0	Tests 17, 18, & 24 MCM: 3 SCM: 0	N/A
Bridged Taps	Test 5 MCM: 0 SCM: 0 Tie:1	Tests 7, 8, 10, & 11 MCM: 3 SCM: 0 Tie: 1	Test 16 MCM: 1 SCM: 0	Tests 20, 21, 23, 25, 26, & 28 MCM: 6 SCM: 0	Tests 29, 30, 31, & 32 MCM: 4 SCM: 0
RFI Interference	Test 4 MCM: 0 SCM: 0 Tie: 1	Tests 9 & 11 MCM: 2 SCM: 0	N/A	Test 19 MCM: 1 SCM: 0	Test 30 MCM: 1 SCM: 0
RFI Notching	Tests 2, 3, 4, & 5 MCM: 2 SCM: 0 Tie: 2	Tests 9, 11, & 12 MCM: 3 SCM: 0	Tests 15 & 16 MCM: 2 SCM: 0	Tests 22, 23, 27, & 28 MCM: 4 SCM: 0	Tests 29, 30, & 31 MCM: 3 SCM: 0

SCM is Superior **MCM is Superior**

Overview of Optional Tests

- Additional (optional) tests on the same hardware
  - Extended performance results for other applications and loop lengths
  - Extended Impulse Noise immunity
  - Extended UPBO
  - Flexibility to configure for different band plans (998, 997 and optional band)

997 Performance

- The performance was tested on the same hardware
- MCM system is easily reconfigurable for any band plan
- MCM system is universal

	Performance (Mbps)	
Loop (feet)	**Downstream**	**Upstream**
3,200	40	26
4,000	25	10

Conclusion on VDSL - Olympics

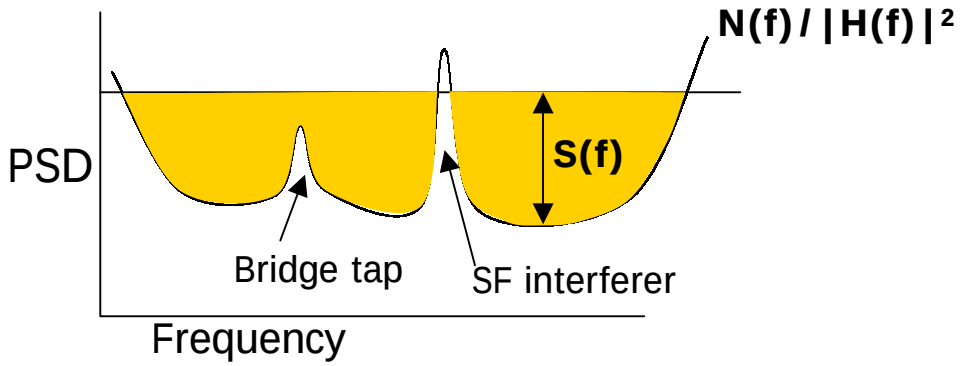
- MCM technology has clearly out-performed SCM technology irrespective of analysis methodology
  - Outperformed SCM on all symmetric services including 10/10
  - Outperformed SCM on all asymmetric services including 22/3 and 16/1
- VDSL MCM has the highest verified performance
  - Aggregate performance is 150 Mbps
- VDSL MCM has the longest verified reach
  - Reach of 13,000 ft in VDSL mode
- VDSL MCM is extremely flexible
  - Completely software configurable
  - 997 / 998 or any other band plan on the same hardware
  - With or without optional band
- VDSL MCM is a solid, stable, and reliable technology

Why DMT

- VDSL is a deployment of infrastructure
- DMT-VDSL serves all identified needs of today as well as prospective needs of the future
- How?
  - Outperforms SCM in T1.424/Trial-Use standard
  - Provides the longest reach (13 kft)
  - Provides the highest performance (150 Mbps aggregate)
  - Flexible in band plan configuration
    - Universal CPE
    - Universal Line Card
  - Rate adaptive – provides the best performance for the given condition
  - Compatible with ADSL, ADSL+, ADSL2

Why DMT VDSL Outperforms QAM VDSL

- "But I thought DMT and QAM were theoretically equivalent?"
  - *Not* as implemented in QAM VDSL spec.
- Gallager* shows that theoretical optimum transmit spectrum is achieved with "water pouring"
  - i.e., Given noise spectrum N(f) & channel H(f), optimum TX PSD S(f) is:



*R.G. Gallager, *Information Theory and Reliable Communication* (Wiley 1968)

Why DMT VDSL Outperforms QAM VDSL (2)

- QAM, as used in VDSL, does not /cannot do this
  - Rudimentary transmitter with non-optimized Tx spectrum
  - Receiver DFE cannot completely compensate for this deficiency
- Challenging voice-grade copper copper channel
  - Bridge taps, EMI notches, etc. cause large, significant variations in $|H(f)|^2$
  - RFI ingress, Xtalk from poor longitudental balance cause large, signification variations in N(f)
- DMT naturally adapts to channel conditions found in access network
  - “water-filling” bit loading is DMT optimization to channel
  - “built-in spectrum analyzer” in receiver measures channel at no additional implementation complexity (cost)
  - Transmitter architecture inherently adaptive, training sequence re-uses computational units used in data mode; implemented at no additional complexity (cost)