

**SCM (QAM) VDSL  
for  
EFM Copper 10PASS- TS**

Ottawa June 2003

# Supporters

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QAM VDSL



# Introduction

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QAM VDSL

- **Enable an Ethernet-like model for Access**
  - Low cost transceivers through interoperability and standardized products
  - High volume
  - Low complexity
  - QAM has a great record on all these points
- **QAM VDSL has > 2.5 million lines installed worldwide**
  - Over 5% are deployed to Single Family Units, some estimates up to ~10%
  - Used for Data and Video and Data applications
- **QAM VDSL is deployed in over 20 countries**

# What is QAM (SCM) VDSL?

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- **QAM: Quadrature Amplitude Modulation**
- **Part of the SCM (Single Carrier Modulation) family, which includes PAM (SHDSL)**
- **QAM is a generalization of PAM, modulated to higher frequencies**
- **QAM/PAM is broadly used in many communication channels:**
  - **Cable modems**
  - **Ethernet 1000BaseT**
  - **Other DSL: HDSL, SDSL, SHDSL, RADSL**
  - **HPNA**

# PHY Sources and QAM Facts

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- **The following chipset vendors have QAM silicon developed**
  - Infineon
  - Metalink
  - ElectriPHY
  - Many others have QAM technology
- **Single carrier is well known in the industry**
  - All standard voice band modems
  - Cable Modems
  - Home PNA 3.0
  - Ethernet – 1000 Base-T
- **QAM VDSL highly successful with Ethernet**
- **If QAM is chosen for EFM many companies could rely on existing SCM/QAM knowledge to step into the market**

# QAM VDSL has a large partner base

## The following companies publicly endorsed QAM at FS-VDSL

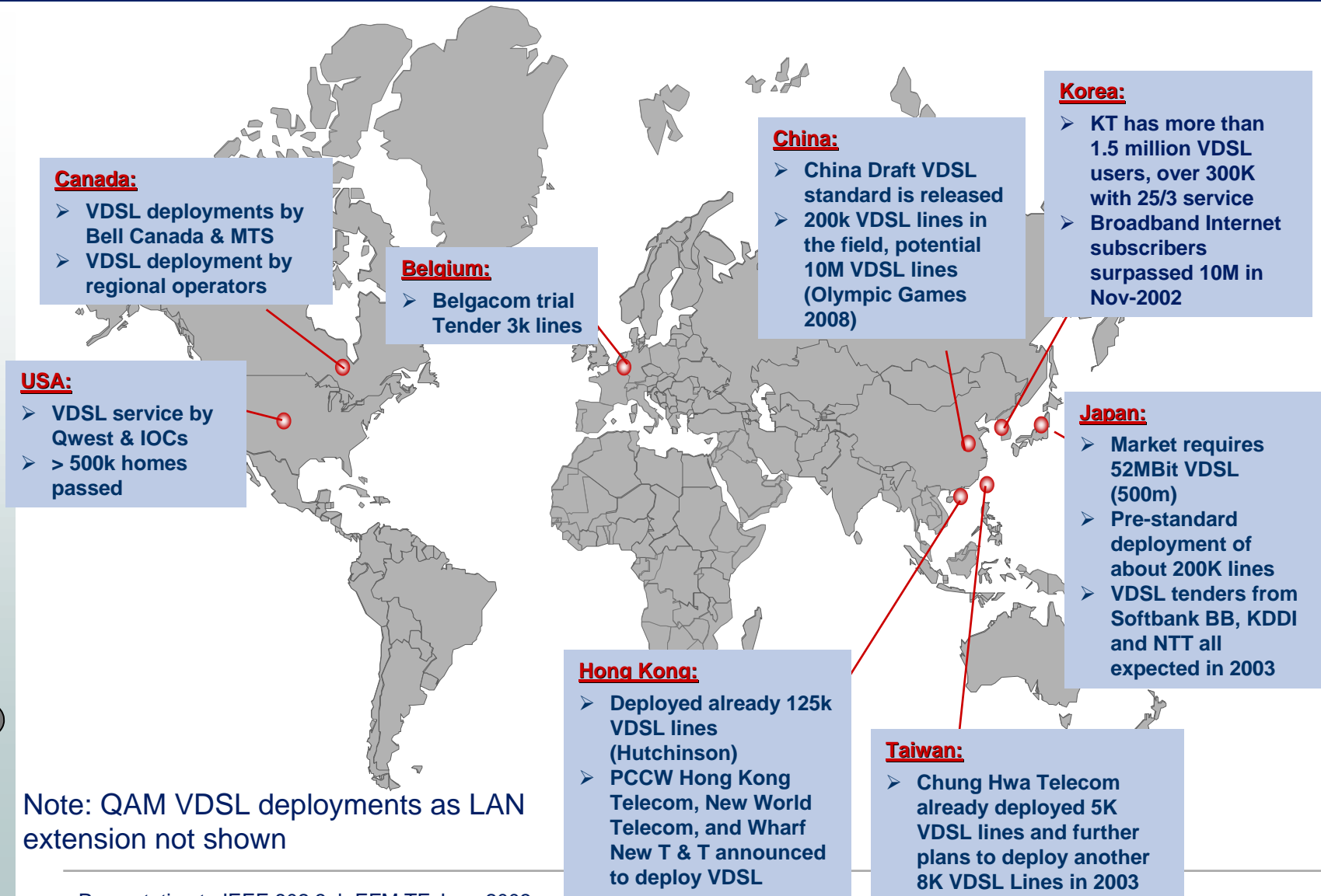
- Actelis
- ADC Communications
- BATM/Telco Systems
- Cisco
- Corecess
- ECI/Inovia
- Extreme Networks
- GoDigital Networks
- Iskratel
- MRV Communication
- Motorola / Next Level
- Paradyne
- Salira
- Siemens
- Stellar One
- Tellabs
- Telson
- Tut/VideoTele.com
- UTStarcom
- Wistron Nexus

## In addition, the following companies have publicly announced the availability of QAM VDSL systems

- Hitachi Communications
- Eastel System Corp.
- Gigalink CO LTD
- Hana System Inc.
- Hyundai Network Inc
- Huawei Technologies
- Lucent
- Locus Corp.
- NeoWave Inc.
- Samsung
- Tellion Inc.
- ZyXEL

# QAM VDSL has a large deployed base in the Access space – QAM is the only veteran First Mile VDSL under consideration

## QAM VDSL



# System Provider's perspective: Full Service Access QAM VDSL in NAFTA

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QAM VDSL

## ■ Field Deployment

- **>140,000 subscribers with pre- & standard Plan 998**
  - **>70,000 as Single Family Units (SFUs)**
- **2, 3, and 4-band solutions**
- **Asymmetric data rates mostly**
- **High percentage have video services**
- **Broad MDU/MTU deployments**

## ■ QAM report card

- **Low power consumption** means smaller cabinets, low heat dissipation requirements, low OPEX
- **Higher density** equates to low CAPEX
- **Impulse noise immunity** of QAM avoids a serious problem in homes. DMT is an unknown for VDSL & video versus impulse noise, no matter what a lab test may show



# System Provider's Perspective: Ethernet over QAM VDSL

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QAM VDSL

- QAM VDSL 2, 3, 4-band as 10/100BaseT extension
- MxU environment
- Requirements
  - Performance & Cost
  - Stability & Robustness
  - Symmetric rates delivery
  - Low Power & High Density
- Experience with QAM
  - No DSL experience necessary
  - PSD shaping
  - Impulse noise
  - Advanced blind equalization
  - Low power, low cost
- QAM delivered as promised

# QAM has lower complexity/cost

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- **Lower complexity and relative cost of chipset**
  - Cost is a function of die size, volume, and process
  - QAM VDSL wins in all three areas
- **Lower power consumption (<1w per port for singles and multi-port chipsets in 2003)**
- **Lower complexity of the analog part (even with implemented digital duplexing)**
- **EFM has two objectives, based on SHDSL(PAM) and on VDSL**
  - Lower complexity is also important for a combined SHDSL + VDSL EFM chipset

# How does the Transceiver cost affect equipment cost?

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*Transceiver cost includes everything between tip/ring and Utopia/MII*

## ■ ADSL CPE

- Today, transceiver w/ integrated network processor is > 50% of total Bill of Material cost

## ■ ADSL DSLAM

- Transceiver price is approximately 30-40% of total BOM

## ■ QAM VDSL Ethernet Switch

- Ethernet components are commoditized, VDSL transceiver costs make up >60% of BOM

## ■ QAM VDSL Ethernet CPE

- Transceiver w/integrated bridge is about 50% of total BOM cost

## ■ Trend is the same in IP and ATM

*Transceiver cost still has a big impact on equipment cost*

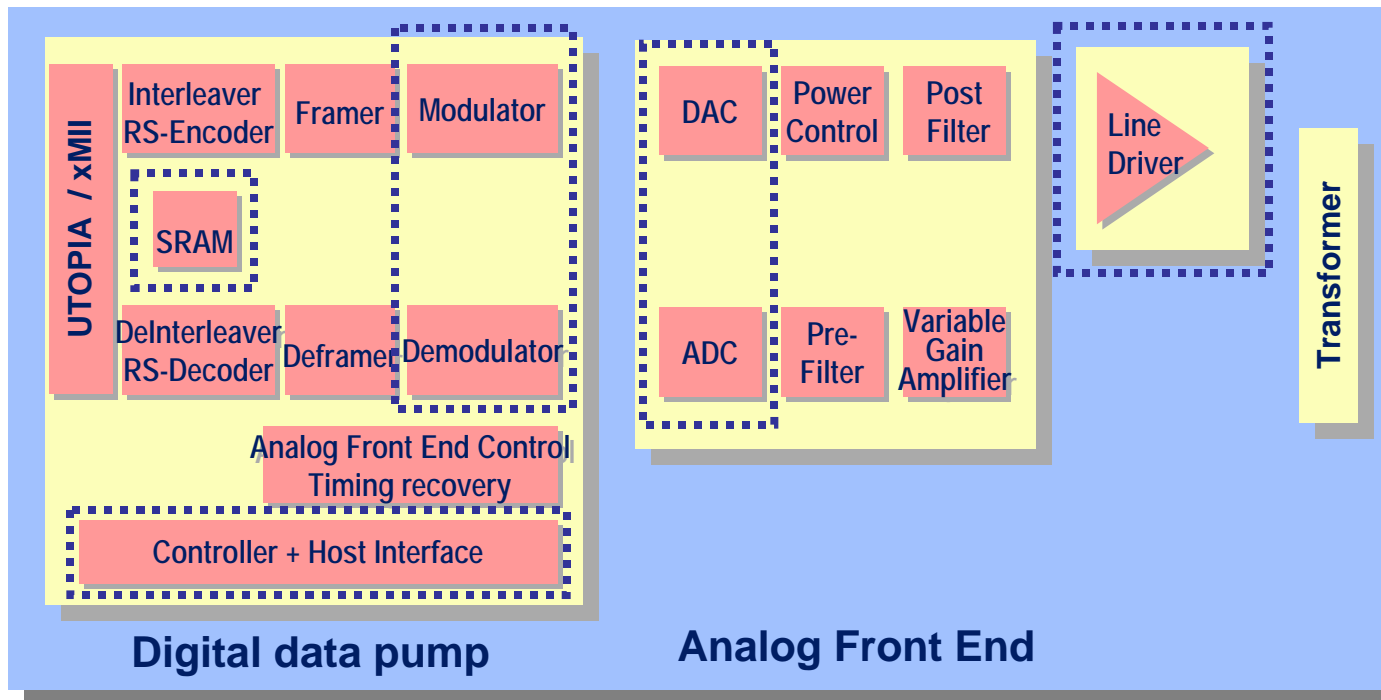
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# QAM VDSL Port density chip-sets

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- QAM VDSL chip-set are 4<sup>th</sup> and 5<sup>th</sup> generation
- QAM VDSL chip vendors today offer various types of chip sets
  - Single port chip set
  - Quad port chip set
  - Octal port chip set
  - Single port in a single package
    - Digital pump, AFE, Filterless, Line driver

# Where DMT and QAM implementations differ in size/cost?



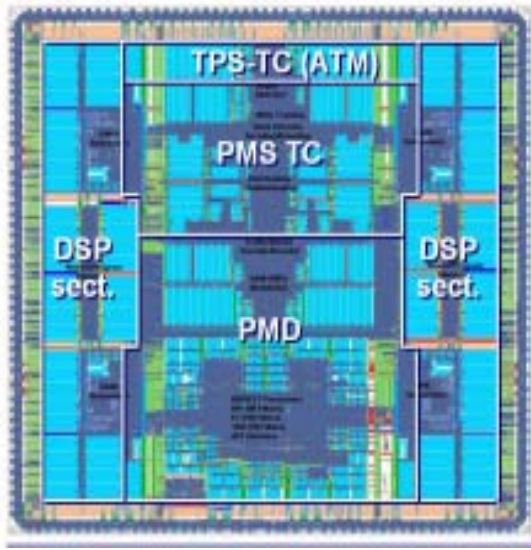
- A basic VDSL transceiver has a digital chip, and analog chip (AFE), a line driver and a transformer
- The dotted segments highlight the functions that differ the most in size/complexity between QAM and DMT
- The transformer, framer and data interface similar in size

# Analog part (AFE and Line Driver)

- **Both QAM & DMT use digital duplexing to meet flexible bandplan requirements**
- **Basic ADC & DAC requirements are equivalent, except...**
  - **DMT has Higher Peak-to-Average ratio**
    - 1 more bit is needed to compensate for higher PAR (each ADC bit equals 6dB)
    - The impact in area and power consumption on ADC is a factor of x2
  - **Impact on AFE**
    - Extra power -> 30%
    - Extra size -> 30%
    - Advanced AFE design can lower the extra DMT power and size to about 10 to 15%.
  - **Impact on Line Driver**
    - Extra power in the line driver ->40% (= higher power rails)
    - PAR reduction techniques can be used but will have capacity penalty

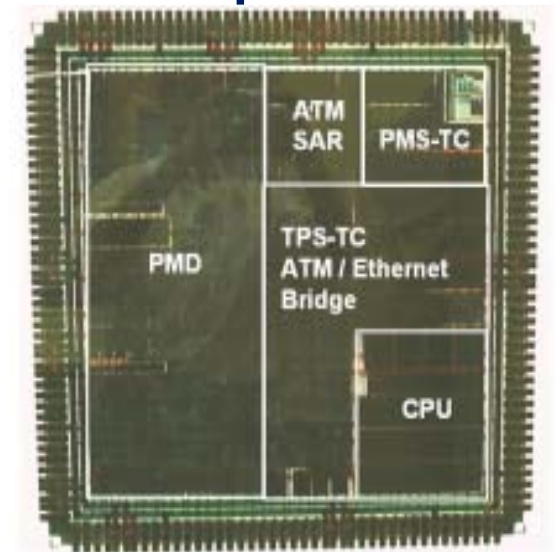
# Digital part (Data pump)

## ■ ADSL2+ (512 tones) chip vs. a QAM VDSL chip



ADSL2+

Same size,  
Yet,  
QAM modem  
smaller than  
DMT



4-band QAM VDSL

(note: a complete chip includes a QAM or DMT specific PMD and a TPS-TC part which is line code independent. The ADSL2+ chip shown has an ATM-only TPS-TC, the QAM VDSL chip shown has an ATM/Ethernet Bridge TPS-TC. If we compare the QAM & DMT specific PMD, the 4-band VDSL QAM is 30 % smaller than the ADSL2+ PMD)

**What about 2048/4096 tones vs. 4-band QAM VDSL?**

# QAM VDSL Interoperability

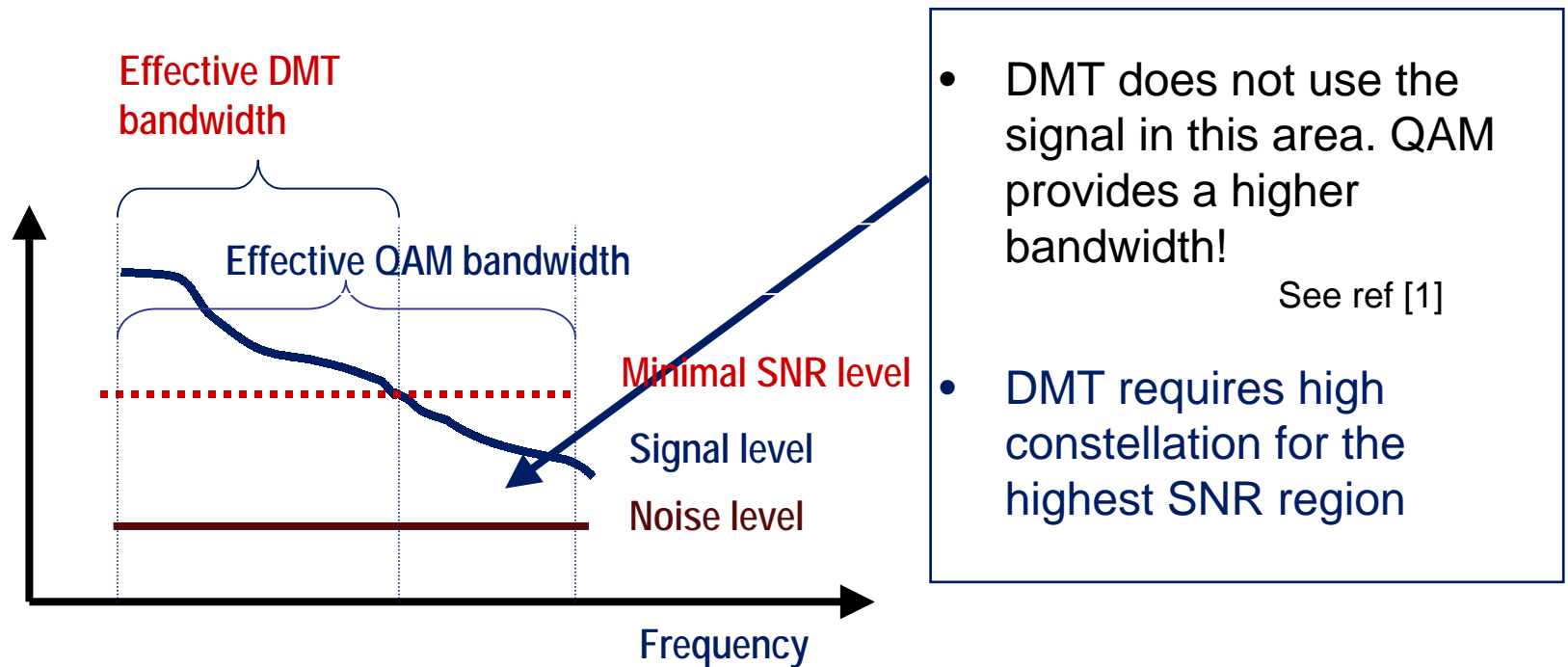
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- **QAM VDSL vendors are continuously working together in order to guarantee full interoperability between their chip sets**
- **Ethernet interoperability of QAM VDSL chip sets already demonstrated July 2002 in Vancouver**
- **QAM VDSL chip vendors committed to a simple definition of QAM VDSL**
  - **See the QAM Spec – compare it to Part 3 of T1.424 for DMT and see the difference**
  - **Guarantee ease of use**
  - **Plug&Play concept**



# SNR Averaging

- QAM VDSL uses its SNR Averaging capability to get optimal usage of the VDSL bands, with almost no loss of SNR
- QAM requires smaller constellations (= lower power)



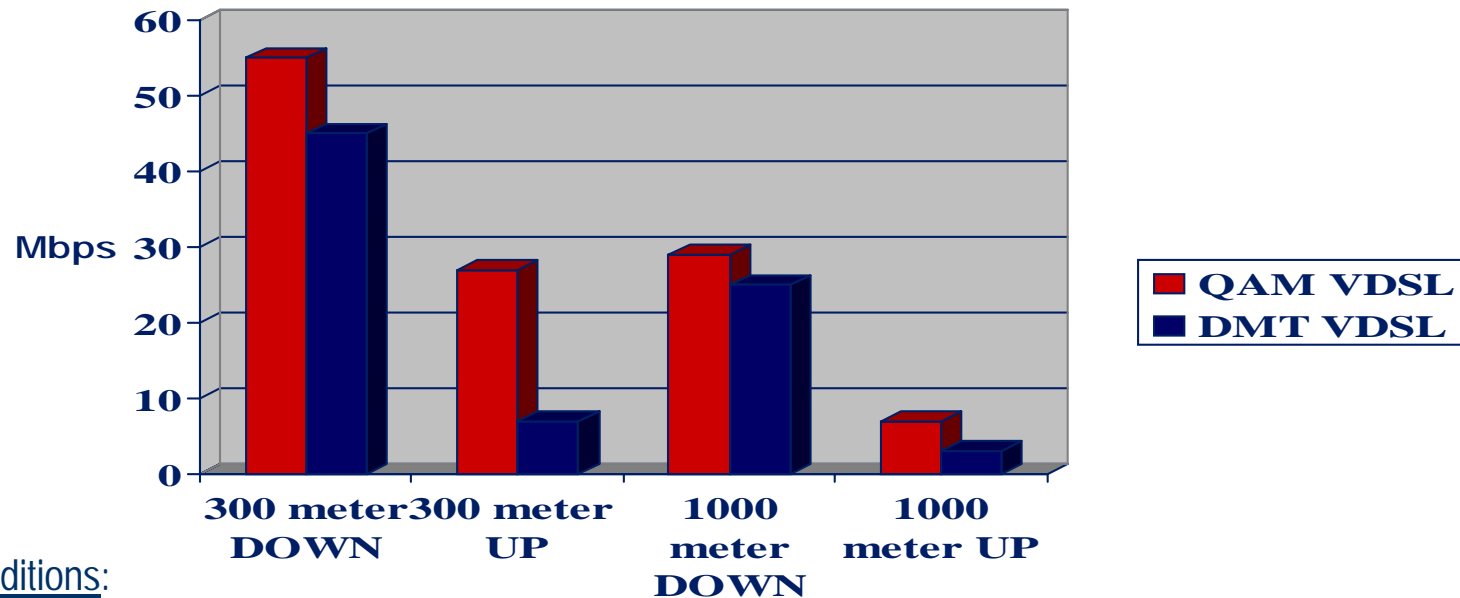
# Power Consumption

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- **Fact: QAM VDSL chipsets have small die sizes and low resolution ADC and DAC equating to low power consumption**
- **Fact: QAM vendors now supplying singles at less than 1 W/port and multi-port at even lower watts/port for all components needed in a design**

# Field Proven Performance: QAM has same or better performance

Field results from Korea - May 2003



Conditions:

Real cable 300m, CEPV 0.5 mm, bundle 50 lines, 24 modems in parallel, plan 998, start at 138 KHz

Real cable 1000m, CEPV 0.5 mm, bundle 25 lines, 24 modems in parallel, plan 998, start at 138 KHz

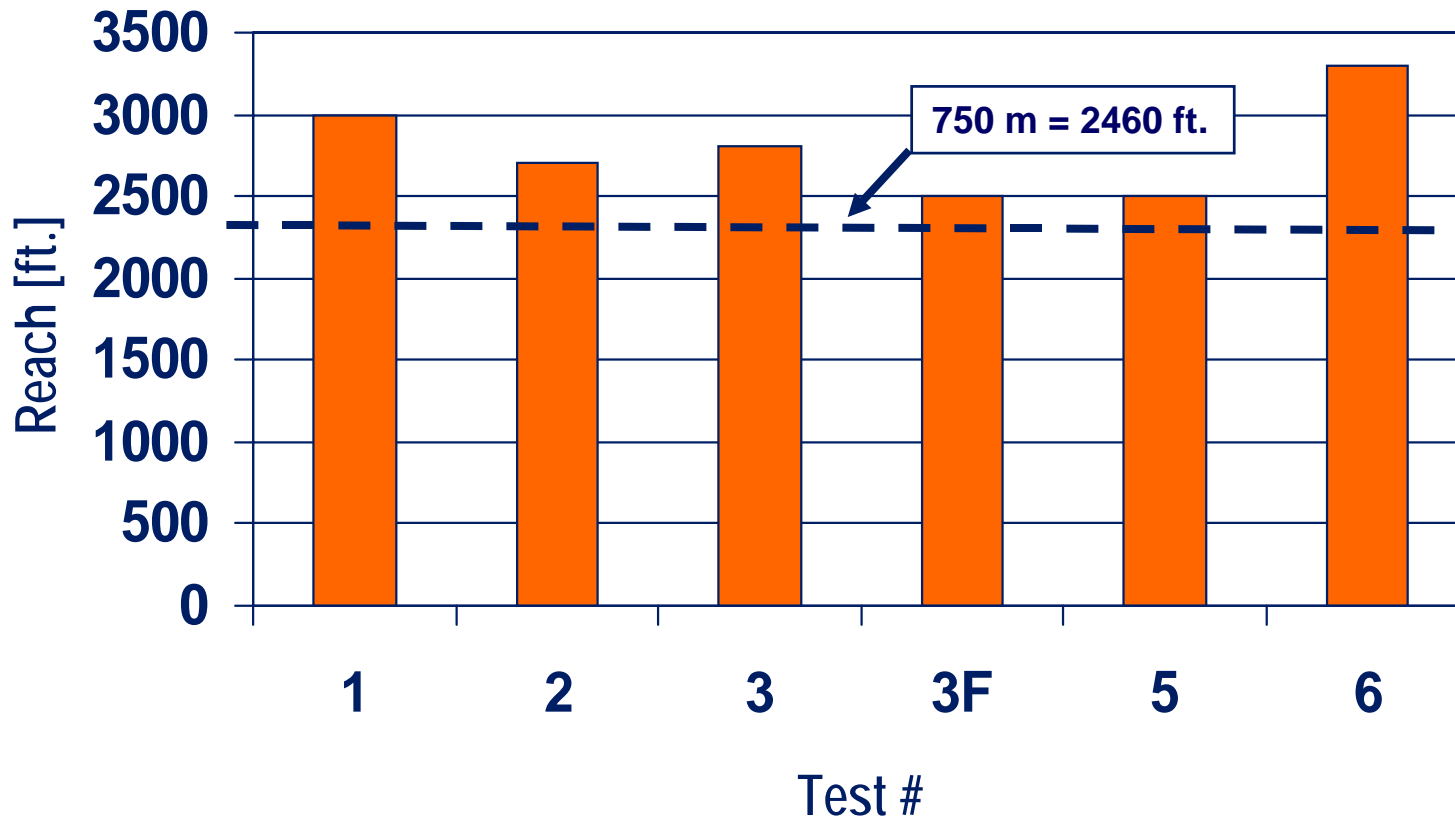
Note: DMT system did not provide more than 7Mbps upstream during those trials

Silicon with pricing constraints is very different from a demo silicon

That is why system vendors, having tested both, stand behind QAM

# QAM Met the Short Reach Performance Objective in lab tests... did anyone else?

## Optional Testing - 10 M Symmetric @ 24 AWG



## Performance at High Bit-Rates

- At high and symmetric data rates as required by EFM, extra RS coding and low bit constellations (the Alcatel/STM Gamba) are not applicable as extra BW not available
- These rates are important for MxU deployments worldwide and are of special interest in the Asia-Pacific region

The following results were tested at Telcordia optional testing:

- **QAM**: 40/25 Mbps      20 self FEXT      **1300 ft** 26 AWG
- **DMT**: 39.6/20.1 Mbps      20 self FEXT      **1000 ft** 24 AWG

# Real World, Real Results

# VDSL QAM future:

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- **QAM VDSL is a vital technology. Advances are achieved continuously:**
  - **True broadcast P2MP**
    - Blind equalization and blind acquisition makes it simple
    - High symbol rate improves U/S bursting
  - **Vectoring and alien noise cancellation (MIMO)**
  - **Matrix equalization, straightforward on SCM**
  - **Well known and widely used (1G/10G Ethernet and others)**
  - **DSM**
    - Compatible for layers 0-3
    - Coordination technologies, similar to IWF and alternative are available
  - **Combined 10PASS-TS and 2BASS-TL in a single QAM/PAM SCM EFM PHY**

# QAM is committed to the EFM vision & schedule

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QAM VDSL

- QAM VDSL is as simple as Ethernet
- The market has chosen QAM as the de-facto solution
- Korea and Japan moved to Ethernet over VDSL for their next generation access networks. Others are following.
- The vision of Ethernet in the access is prevailing. The simplicity and performance of QAM meet that vision
- **EFM can move ahead**

## Additional slides

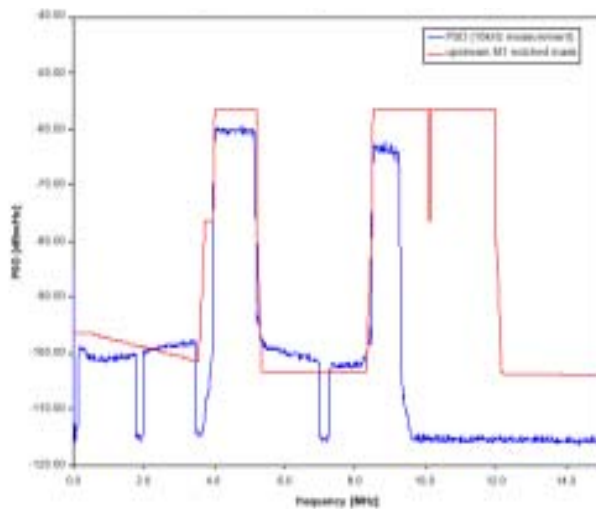
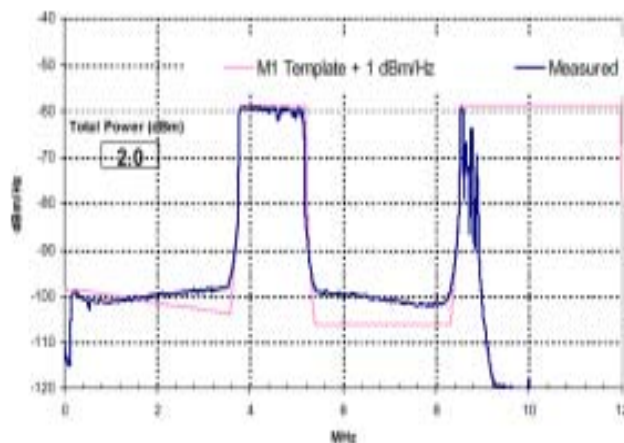


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# QAM VDSL

# “S” DMT- 16/1 US PSD in Configurations 8 & 9

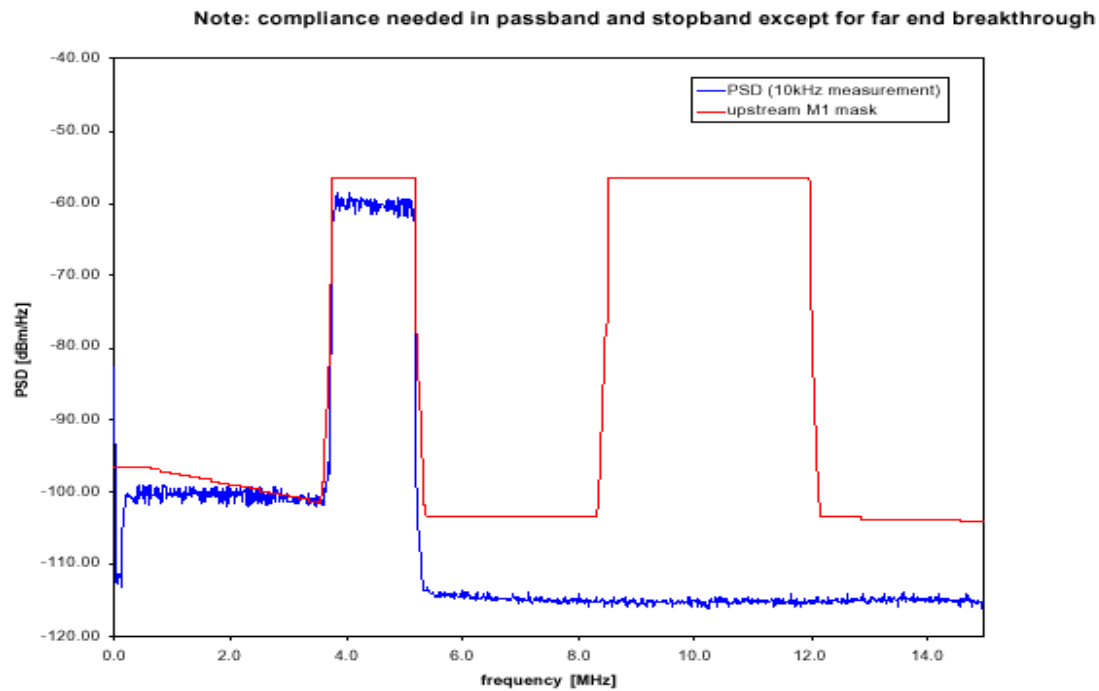
Figure A-16 Upstream PSD - Configuration #8



- 2.5 MHz used to transmit 1 Mbps
- Spectral efficiency of 0.4 bits/Hz
- Optional RS coding with high overhead need to be used
- *Use of optional mode should have been reported!*

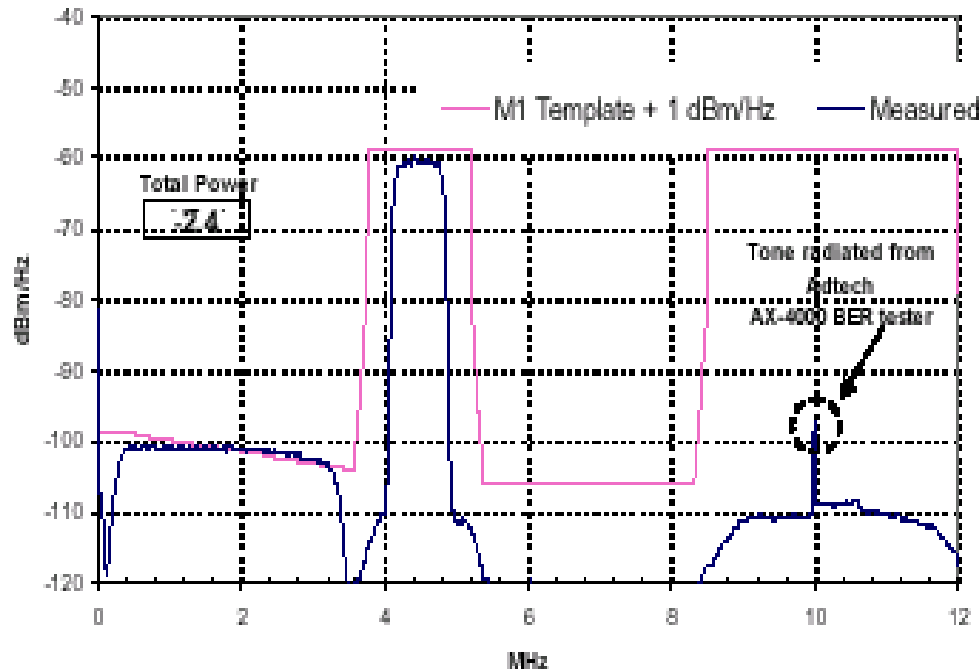
# “I” DMT - 16/1 US PSD configuration 8

- 1.5 MHz to transmit 1 Mbps
- Spectral efficiency of 0.66 bits/Hz



# QAM Configuration 8 US1 PSD mask

Figure A-16 Upstream PSD - Configuration #8



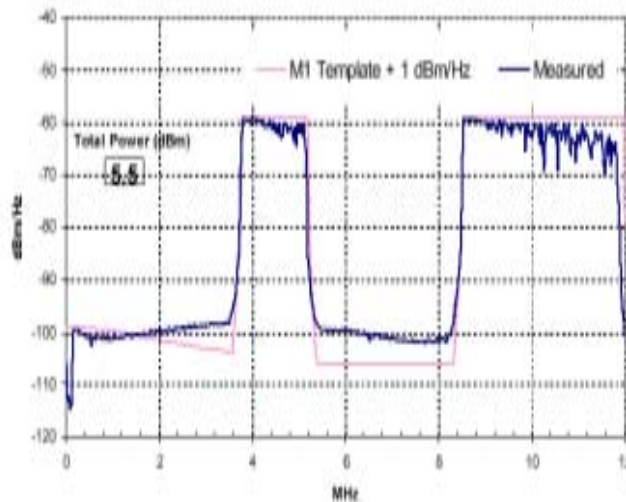
- 0.7 MHz BW used to transmit 1 Mbps
- Spectral efficiency of 1.4 bits/Hz
- **Mandatory RS coding used**

■ Field experience shows that in full binder high spectral efficiency is a better approach !

■ This is the foundation of DSM !

# “S” DMT- 22/3 Configuration 10 US PSD

Figure A-18 Upstream PSD - Configuration #10

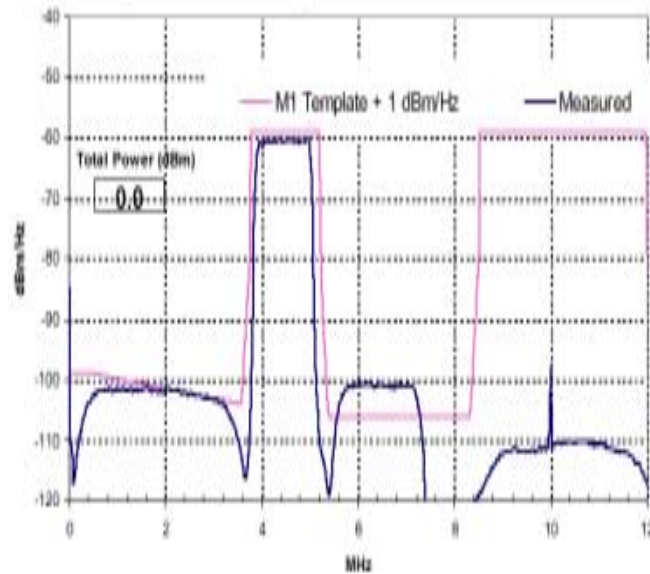


- 6 MHz BW is used to transmit 3 Mbps
- Spectral efficiency is 0.5 bit/Hz
- Extra BW is used for coding using short code words
- This is an optional mode.
- *Use of optional mode should have been reported!*
- Coding gain is **UNRELATED** to line code. QAM can use short code words as well.

# QAM PSD for the Same Configuration

- 1.2 MHz BW used to transmit 3 Mbps
- Efficiency is 2.5 bits/Hz !

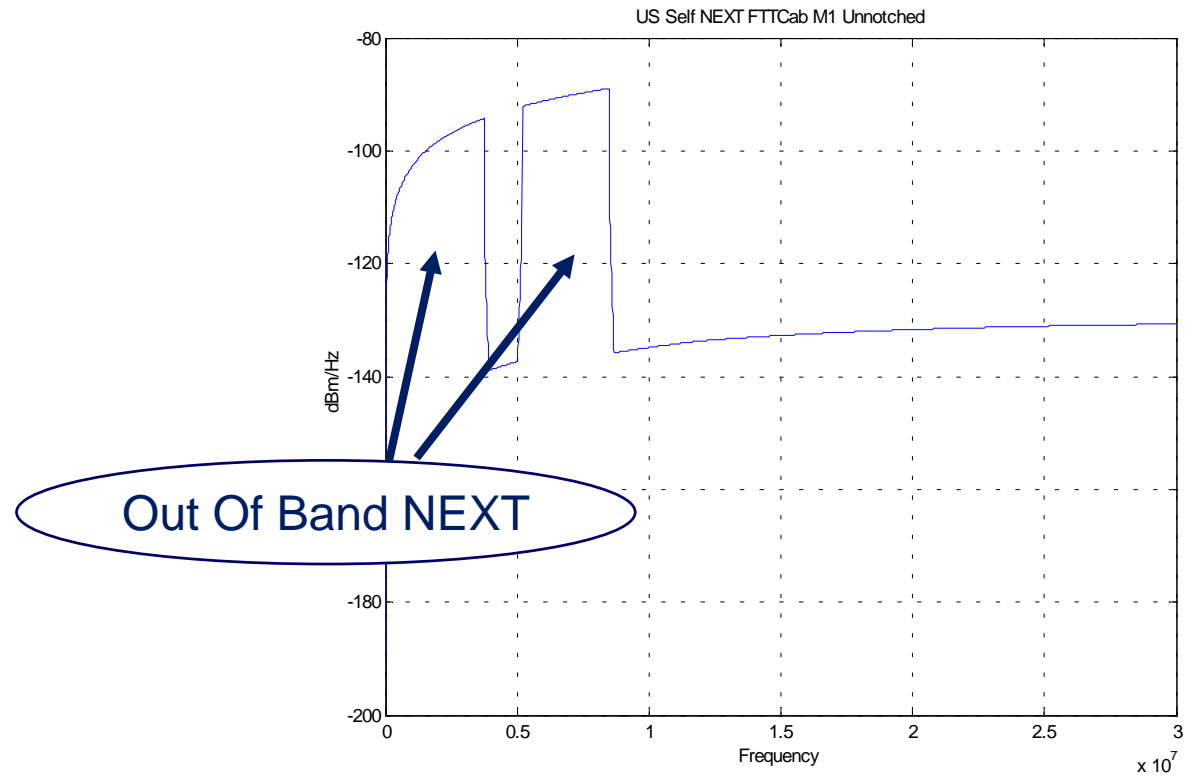
Figure A-21 Upstream PSD - Configuration #10



# Out of Band NEXT – What is the Issue ?

- During the testing we have discovered that the high level of out of band next changes the statistical behavior of the noise.
- Out of band next is received out of the RECEIVER in-band.
- It does not affect capacity !
- To demonstrate this issue we have repeated testing with reduced power level of out of band NEXT
- 3 Test points have been tested:
  - Test case 13 (16/1) - 3400 ft. - 550 ft. improvement!
  - Test case 14 (16/1) – 3400 ft. – 550 ft. improvement!
  - Test case 17 (22/3) - 2850 ft. – 300 ft. Improvement!
- These results matches DMT performance on these cases

# VDSL NEXT PSD – VTU-C





# Noise Generated Eliminating OOB NEXT Effect

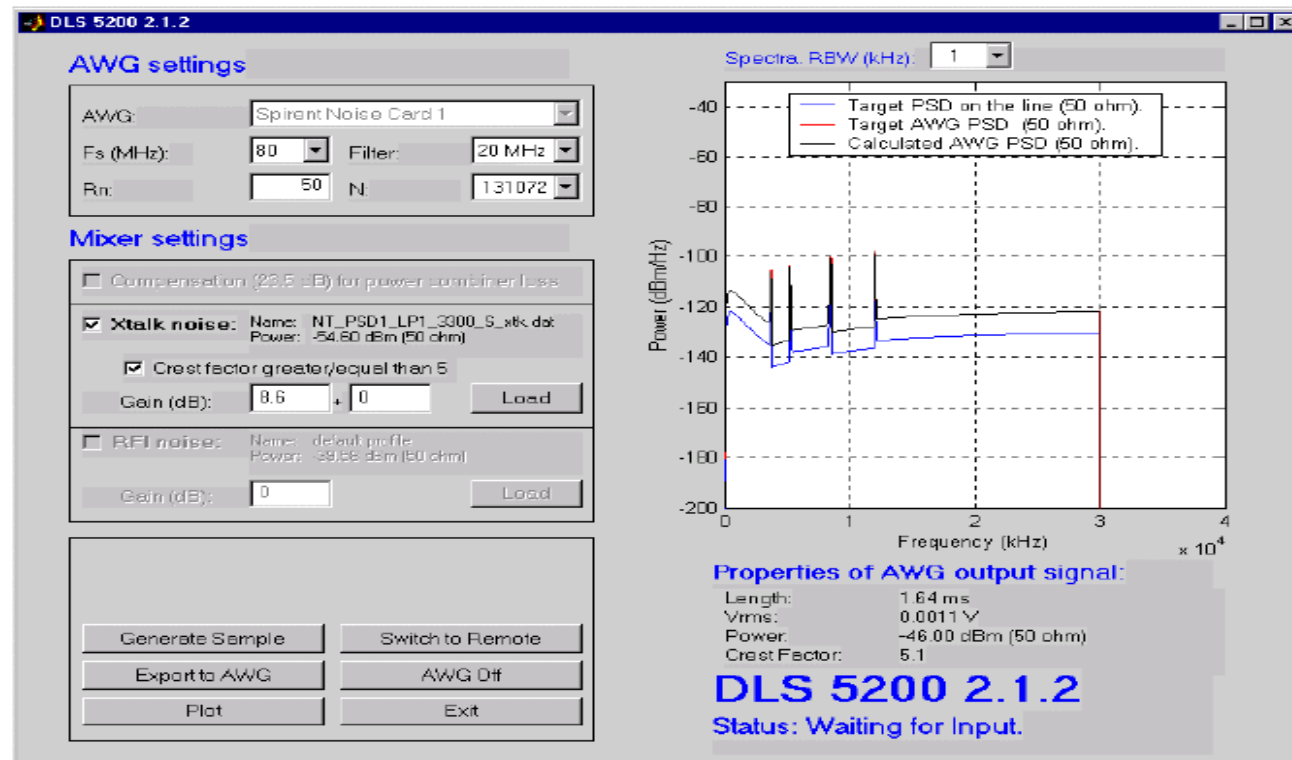


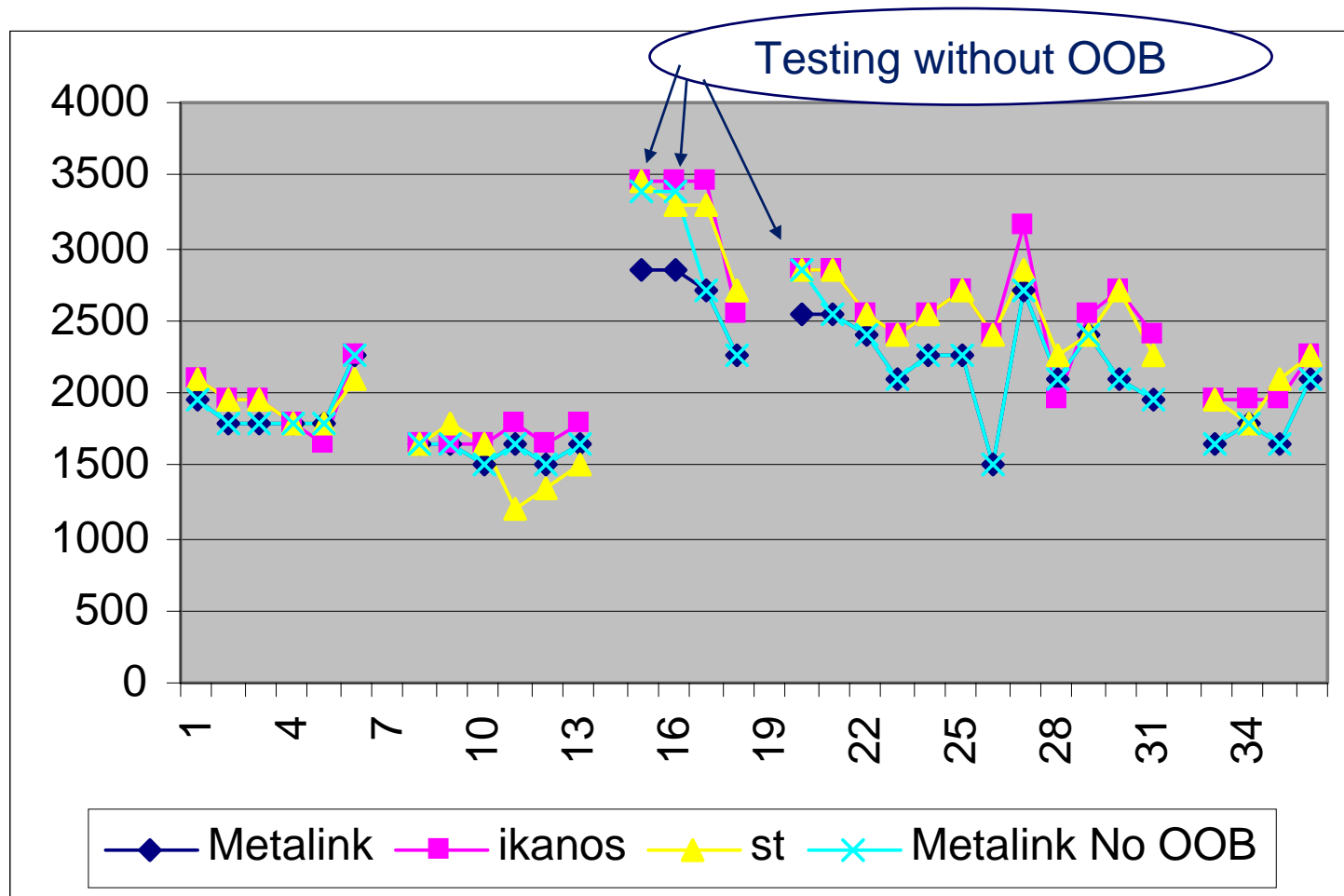
Figure 2-6: Example downstream noise spectrum

(Note, the noise spectra were generated using BTextact's noise generation software)

The Optional Band ("Band 0") extending from 25kHz to 138kHz was not used in this test.

# Comparative performance of QAM and DMT

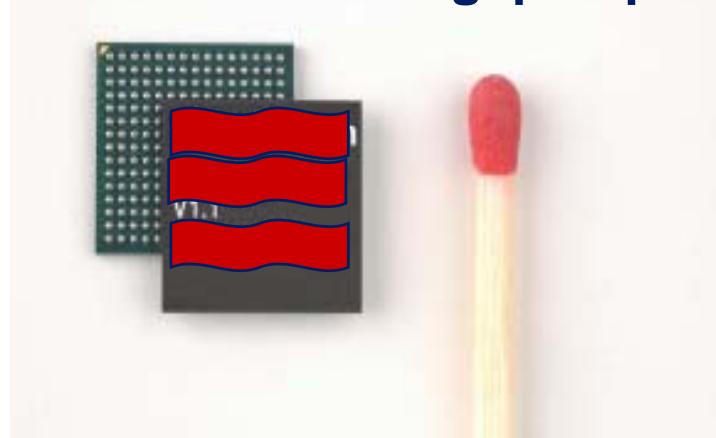
QAM VDSL



# Size comparison: The figure speaks for itself

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A QAM VDSL PHY: Dig. pump + AFE +

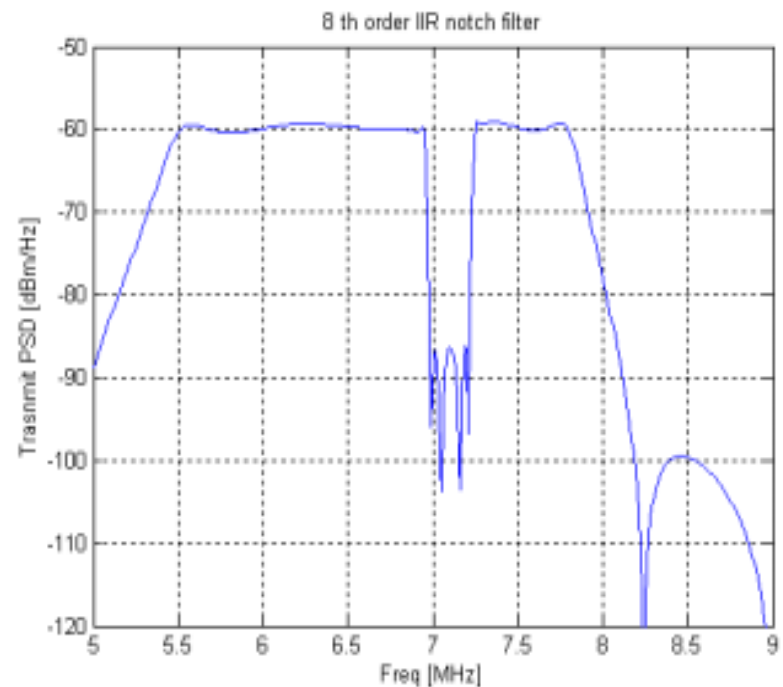
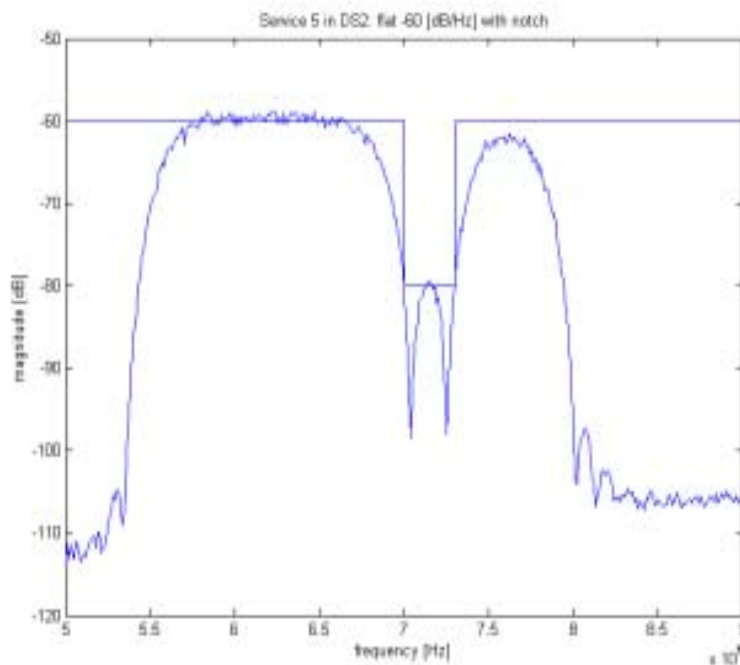


## Product Summary

Product Name	Package	Description
STLC90115	BGA416 27x27mm	Single-channel VDSL datapump (DMT transceiver) with ATM & Ethernet Interface along with embedded modem control software.
STLC90114	TQFP100 14x14mm	Single-channel VDSL AFE with embedded line receiver.

# QAM VDSL Notching and spectral shaping

- Notching in QAM is performed with an IIR filter. Different filter order and implementation will lead to different notch shapes



Example of an implemented notch

Example of an implementable notch

- QAM deployment so far have shown that QAM notching works
- Olympics results demonstrate that, even with notching, the capacity of QAM systems is close to theoretical capacity

# Blind Acquisition/Handshake

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To establish a link:

- QAM VDSL uses **Default link parameters**
- QAM VDSL includes an **embedded message channel** and a state machine.
- DMT, in the contrary, performs a training procedure of the system, and a Handshake process, which result in a very long cycle for link establishment.

# T1E1 Olympics: Line-Code or Implementation Evaluation

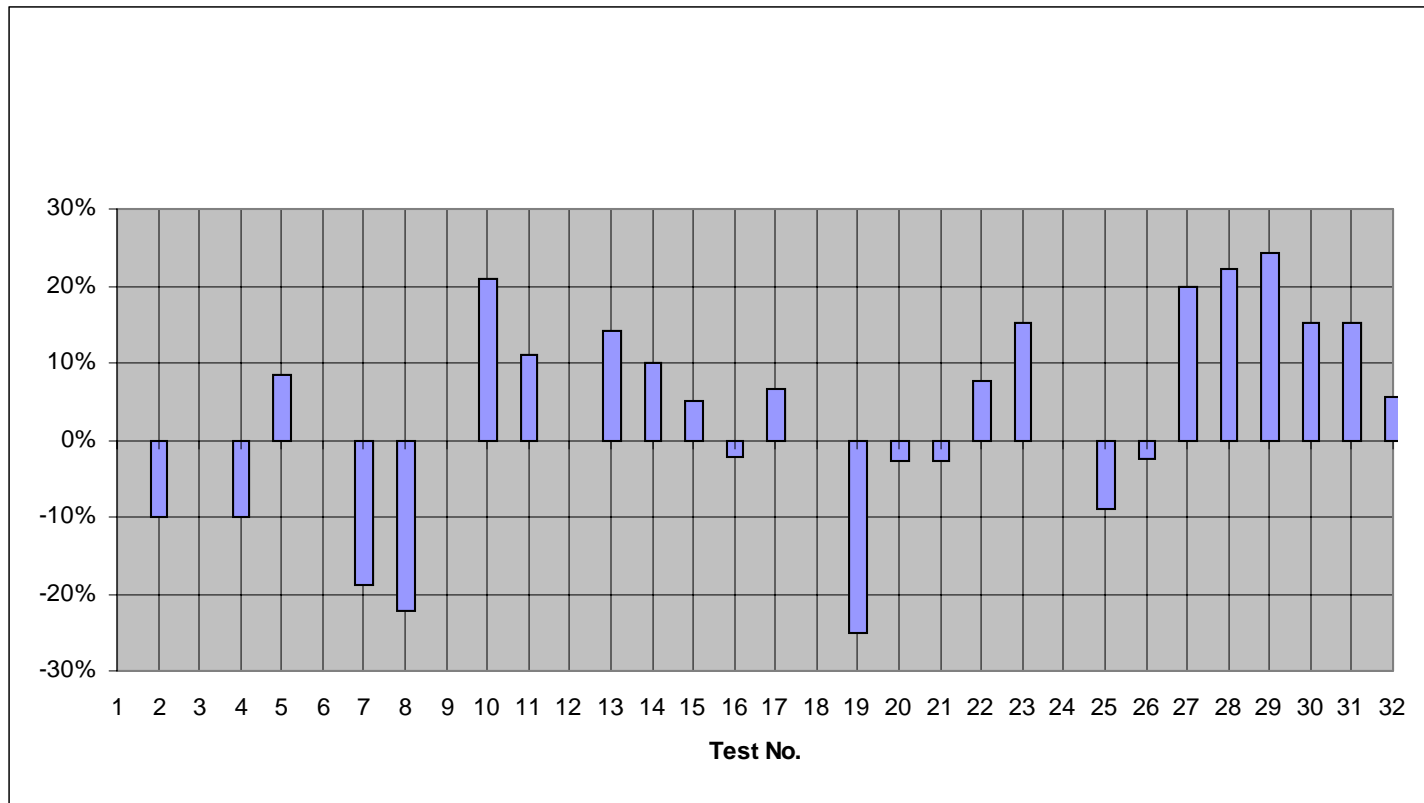
QAM VDSL

- EFM claimed: will give “Due Weight” to T1E1 Olympic results
- T1E1 Olympic compared rate/reach only. Other EFM criteria were not tested.
- The results demonstrate the effect of **implementation** on performance
- The results do not demonstrate the effect of **line code** on performance
- Specifically, BTextact test results demonstrate strongly that:
  - “M” QAM **implementation** significantly better than “I” QAM **implementation**
  - “S” DMT **implementation** significantly better than “I” DMT **implementation**
  - “M” QAM and “I” DMT performance is similar
- Different **implementations** affected strongest at low bit rate scenarios

# “M” QAM vs. “I” DMT performance in BTextact

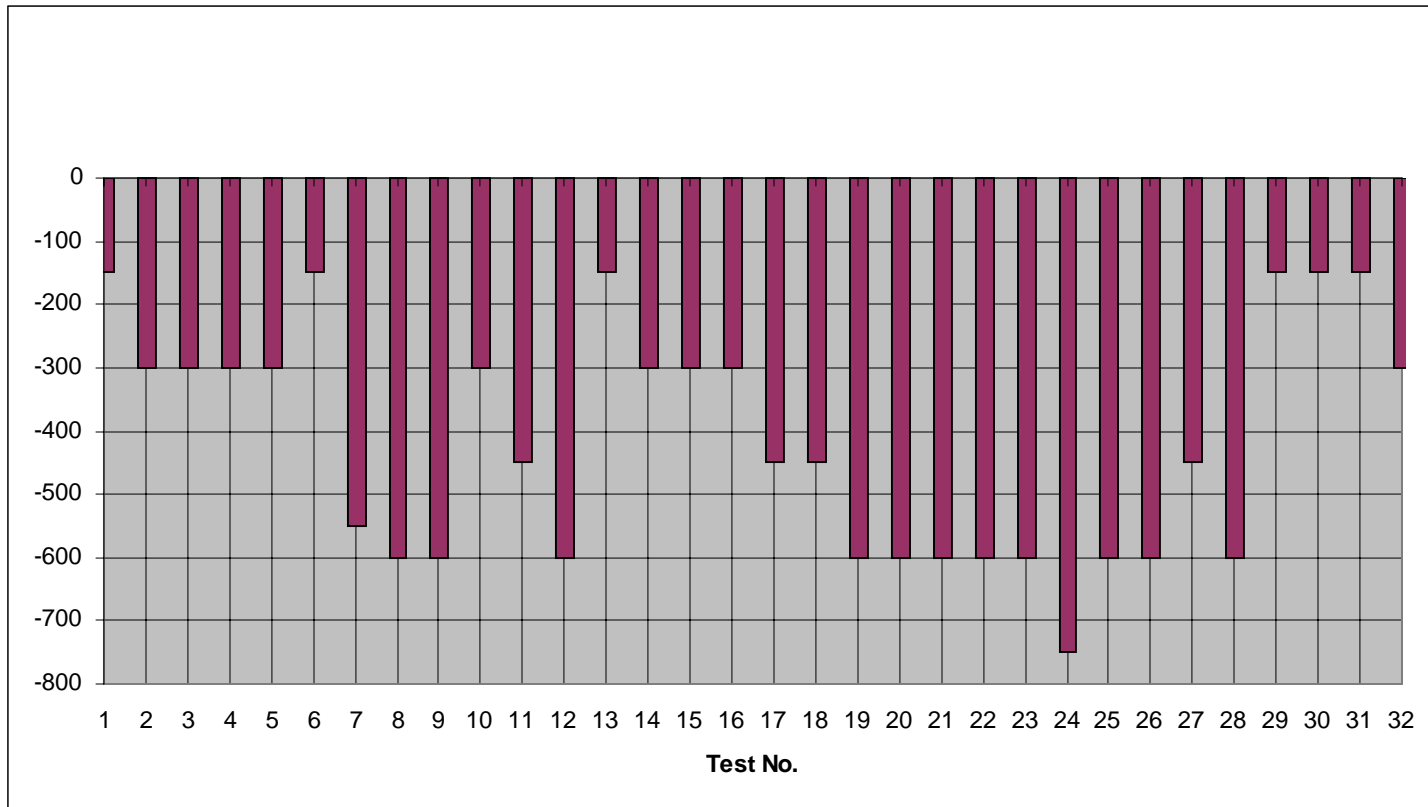
QAM VDSL

■ Difference is an average of 3%



# “I” DMT vs. “S” DMT performance in BTextact

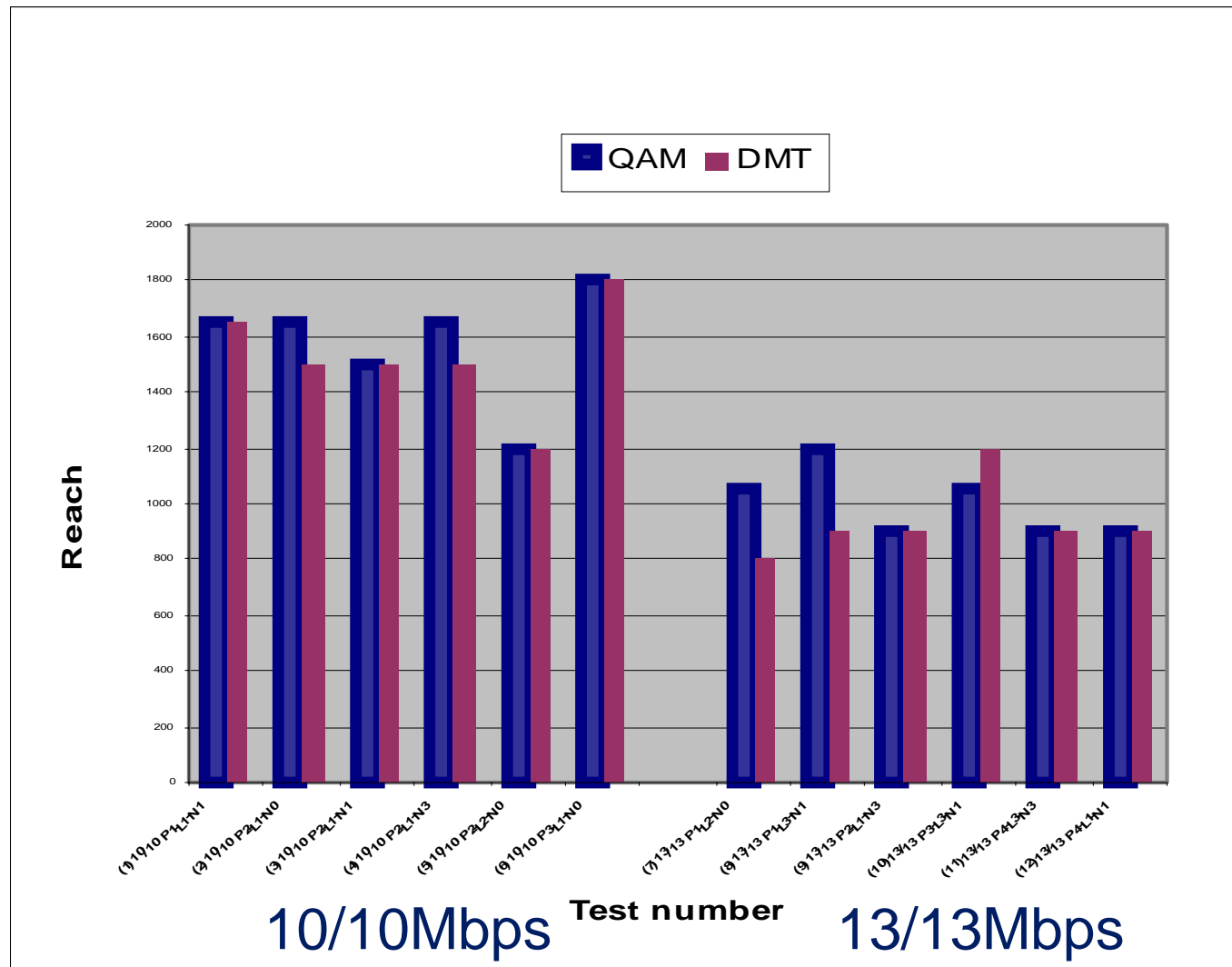
- Difference is an average -416 feet





# “M” QAM vs. “I” DMT: Symmetric service test results

QAM VDSL



# How does Implementation Affect Performance?

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- Performance is affected by:
  - Spectral utilization (transmit signal PSD)
  - Coding Gain
- Both are line-code independent
- In some cases QAM and DMT implementation for Olympics were very similar
  - Particularly, 10/10 and 13/13 cases utilized entire 4-band spectrum in all implementations resulting in similar performance results
- In low bit rate cases, particularly 16/1 and 22/3, different spectral utilization, probably due to coding implementations, created performance gaps
- These implementations are applicable to both SCM and MCM

# What was Different Between the Results?

- The results differ in cases where low speeds are in use:
  - Specifically 16/1 and 22/3 cases
- The difference in implementation in these low bit rates were:
  - Low spectral efficiency of less than 2 bit/Hz (and even 1 bit/Hz)
  - Coding gain achieved by high-redundancy RS coding
- Both QAM chip-sets showed:
  - Higher spectral efficiency of **2 bits/Hz** using QAM-4 constellation
  - *Mandatory* coding using the **RS(200,16) code**
- Both DMT chip-sets showed:
  - Spectral utilization as low as **0.5 bits/Hz**
  - This low spectral utilization, might be a result of using

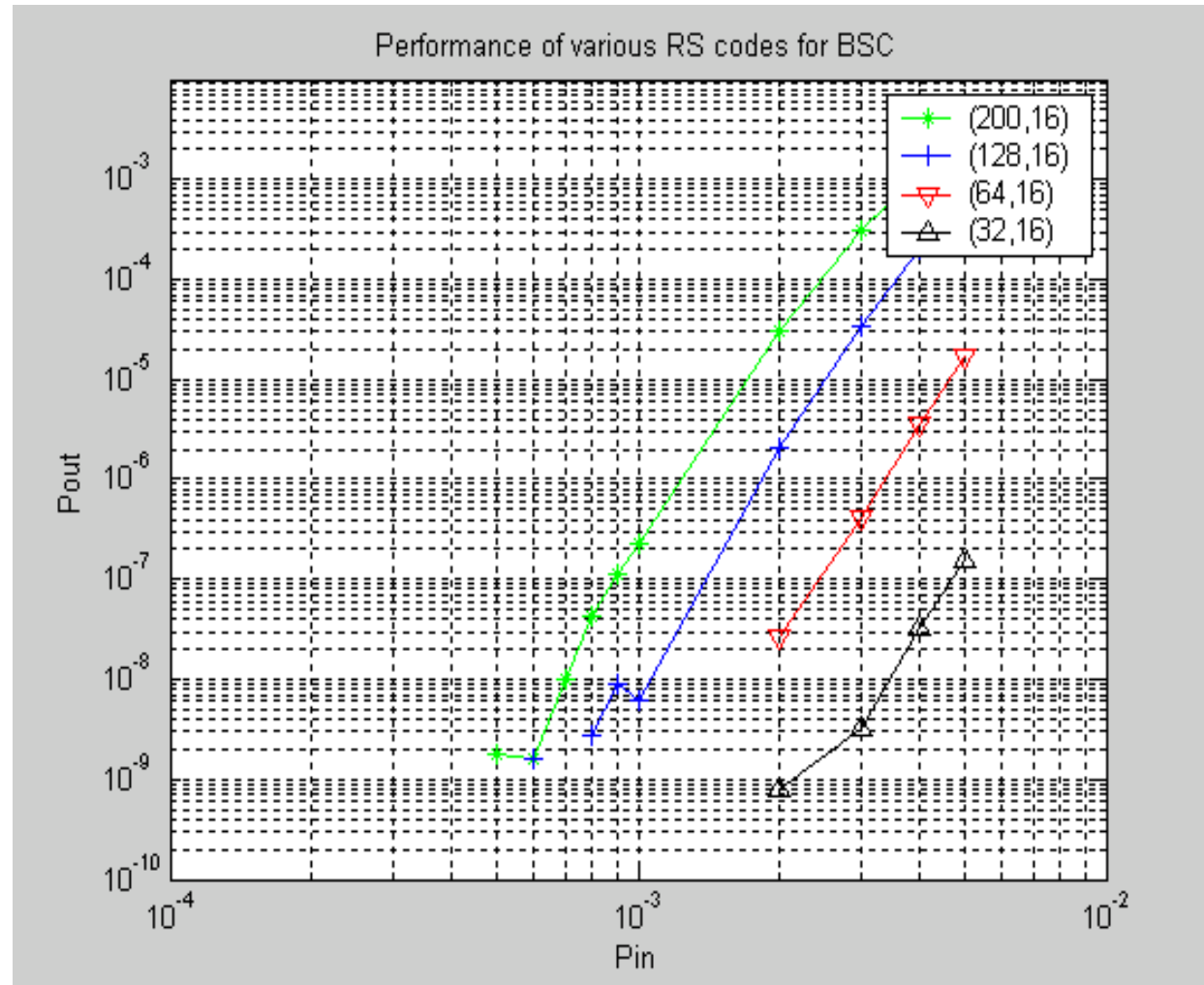
*optional RS coding* with higher redundancy, yields

# Applicability to QAM VDSL

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- **QAM-2 support (as defined in EFM spec)**
  - Both QAM vendors are ready for re-testing in the Olympics labs
  - Preliminary lab testing shows **300 ft. improvement** in all relevant cases
- **Higher redundancy RS coding**
  - Provides additional coding gain
  - Provide immunity against short and frequent impulses
  - Such impulses were observed particularly in the implementation of Out of Band NEXT in noise generators
  - Will be demonstrated off-line by Q3 of this year!
  - Implemented and ready for testing by Q4 of this year!
  - This will increase performance by **additional 300 ft.**

# The gain of high redundancy RS codes



# Olympic Conclusions

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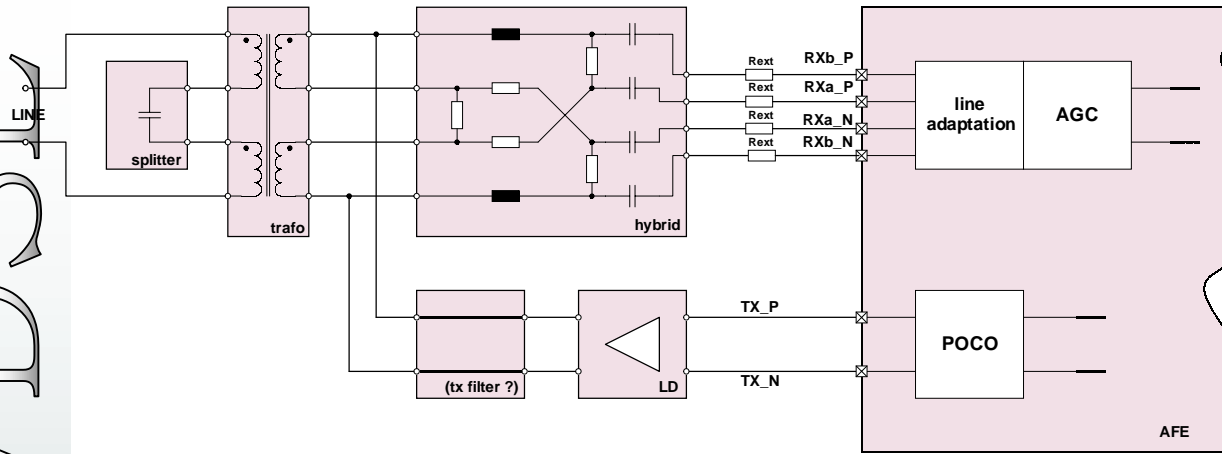
- **Olympics results highlight the difference of performance with different implementations**
  - None of these are line-code dependent
  - Low spectral efficiency and high redundancy RS coding improves performance in low bit rates scenarios
- **Both methods are applicable to both line-codes**
- **The Information provided by the results is not sufficient for a line-code decision**
  - Points differences in implementation which are line-code independent
- **EFM Line code decision based only on T1E1 results, is dangerous.**
  - power consumption ?
  - Footprint ?
  - Complexity ?

# QAM developments over the last 4 years

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- Filter-less – no duplexing filters, flexible band plans
- Multi-Band – From fixed 2 band to flexible 4 band
- Support for band 0
- 12 bit constellation, QAM-4096
- Lower excess bandwidth: 10% only
- Ham radio notching
- Advanced blind equalization
  - Simple, fast, automatic and autonomous – Ethernet like
- Rate adaptive solutions for the field
- Low power, low cost – Ethernet based on QAM VDSL links provide better price/performance than ADSL!!!
- Multi-port solutions
- Single chip solutions

# Digitally Duplexed QAM



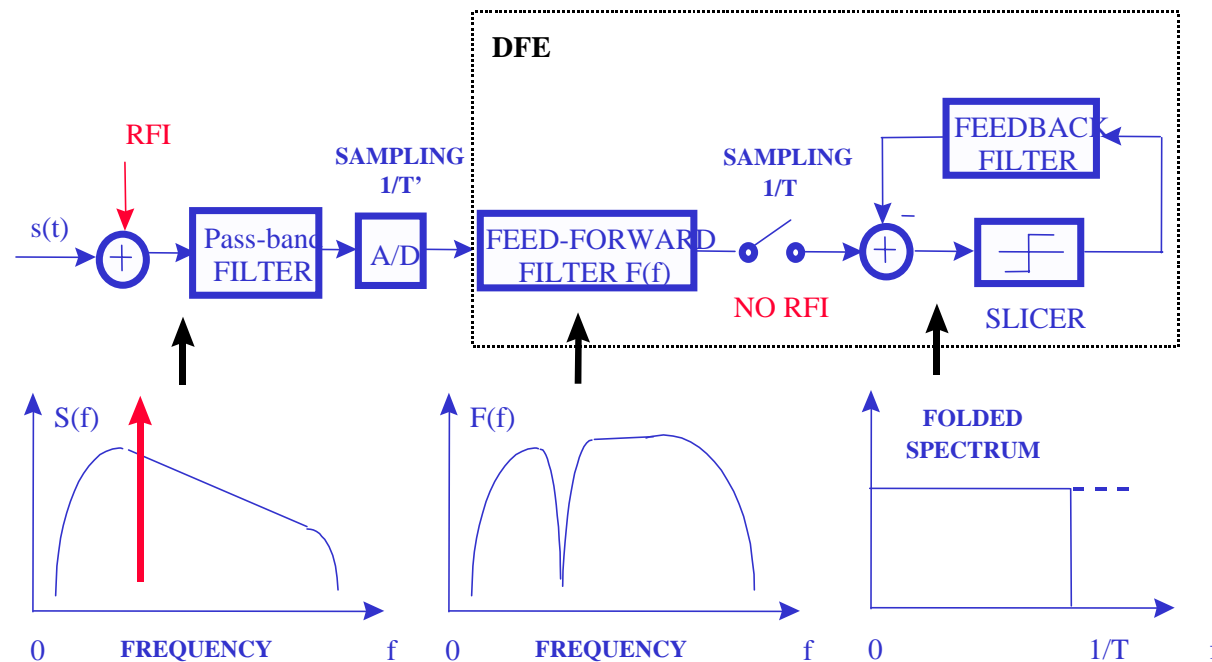
- 1<sup>st</sup> gen. QAM had discrete filters
  - Low cost and performed well
- Current gen. QAM from multiple vendors implement digital duplexing today.
- Band plans configurable by software
  - 998, 997, China, Private, FX ...
- Frequency agility is as feasible with QAM





# Myth: QAM is vulnerable by RFI ingress Reality: RFI ingress is tracked in real time

- When RFI ingress appears, the DFE tracks the RFI frequency and notches it out



# Myth: QAM VDSL operates over short loops only

## Reality: QAM VDSL can operate over long loops

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- The basic principle of operation is to use US0
  - upstream in the VDSL Band 0
  - downstream in the VDSL Band D1
- How can a QAM accomplish this?
  - Band allocation and symbol rates are programmable with granularity of 16.875 kHz and 33.75 kBaud, respectively
  - Filterless operation allows PSD scaling
  - High constellations (up to 12 and higher)

# Detailed analysis: QAM vs. DMT VDSL complexity

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## – QAM

- Using Digital Duplexing
- Digital portion consists of
  - Constellation Mapper
  - Transmit Filtering
  - Receive Filtering
  - DFE

## – Three factors define a silicon design. Let's assign them variables to compare QAM with DMT

Size of computational units:            **X**

Size of memory:                            **Y**

Total Die size:                            **Z**

# 4-band DMT VDSL Digital Complexity analysis

## DMT

- A DMT modem consists of N x Tone/Constellation Mappers and Trellis coding that feeds an IFFT. This constitutes of 20% of the modem.
- The signal passes through bit loading, clipping and PAR Reduction functions
- Transmit Filtering/Windowing reduces interference to the receive path
- Rx Filtering, Windowing and (possibly) Time domain equalization (TEQ) is performed on the received symbols
- FFT and tone equalization is performed according to the bit loading algorithm.
- A dedicated DSP and memory performs SNR margin calculations, bit loading and coefficient calculations for the equalizers

**Size of computational units:** 0.6X (DMT is lower complexity!)

**Size of memory:** 4Y

**Total Die size:** 27 (But DMT is 3 times the

# Complexity/Cost Summary: DMT vs QAM

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## ■ Analog

- AFE and line driver -> bigger for DMT vs QAM
- AFE and line driver -> more power for DMT vs QAM
- AFE and line driver not affected by Moore's law

## ■ Digital

- DMT has lower computational unit complexity (0.6X)
- DMT has higher memory requirements (4Y)
- DMT Die size is 3 times larger than QAM (3Z)

## ■ What about Moore's law – won't it fix things?

- Both QAM and DMT benefit from Moore's law
  - Memory doubles density every 18 months
  - Computations double density and speed every 18 months
    - Redesigns could get a 4x improvement every 18 months
- **DMT improves slower because its size is limited by memory, not computations**

# Examine the barrage of DMT myths

- The complexity of DMT VDSL is comparable to SCM VDSL
  - Not TRUE Die Size of MCM 3 times die size of SCM
- DMT VDSL is a straightforward extension of ADSL DMT
  - Not TRUE VDSL and ADSL have different AFE requirements
- The cost of a DMT VDSL modem is lower than a QAM modem
  - Not TRUE The die size is proportional to cost  
2-band QAM VDSL is the same cost as ADSL
- DMT VDSL will allow better development efficiencies
  - Not TRUE Multi-mode chips (PAM/DMT) exist today
- QAM VDSL is not flexible enough to deal with DSM, M2DSL, etc...
  - Not TRUE QAM can do digital duplexing and all required shaping
- Moore's law plays in DMT's favor

# References

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- [1] Gottfried Ungerboeck, Broadcom corp., “A spectral efficiency advantages of SCM over MCM”, document FI-083, ITU, Fiji Island, jan-Feb 2000.
- [2] Cioffi, Dudevoir, Eyuboglu, & Forney, “MMSE Decision-Feedback Equalizers and Coding - Part I: Equalization Results,” IEEE Transactions on Communications, vol. 43, no. 10, October 1995.
- [3] B. Saltzberg, “Comparison of Single-Carrier and Multitone Digital Modulation for ADSL Applications,” IEEE Comm Magazine, Nov. ‘98.
- [4] L. Vandendorpe, “Asymptotic Performance of MMSE MIMO Decision-Feedback Equalization for Uncoded Single Carrier and Multicarrier Modulations,” IEEE International Conference on Communications 1998, Atlanta, GA, June 1998.