QAM-based VDSL
The EFM Copper Solution

(A multi-company presentation)

802.3ah Copper Track
May 2002, Edinburgh

Co-contributors:

Broadcom	Vladimir Oksman
MetaLink	Eyal Barnea
Infineon	Steven Haas
Tioga	Rami Verbin
VDSL Systems	Peter Kunas
Elastic/Paradyne	Patrick Stanley
NLC	Say Sabit
Tellabs	Janne Vaananen

Agenda

- Introduction
- Advantages of QAM technology
- QAM maturity
- Summary

Ethernet over QAM VDSL is out there

- 30+ vendors in Korea
- 20+ vendors in Taiwan
- 15+ vendors in China
- 4+ vendors in Japan
- 10+ vendors in USA and Europe
- More vendors are joining …

- A large number of system companies have already designed and deployed commercial systems with Ethernet over QAM VDSL

What does EFM-copper need ?

The Ethernet heritage calls for:

- Simple and reliable technology: Plug & Play
- Highly robust, Fat-pipe technology
- A commoditized low-cost technology
- Low-latency technology
- High port density
- Low power consumption

- **QAM VDSL continues the Ethernet heritage. How?**

Quadrature-Amplitude Modulation (QAM)

- QAM is a generalization of PAM which is widely used in:
  - DSL
  - Ethernet
- QAM is already used in many applications around us, also for Ethernet transport:
  - Voice Band modems
  - Cable modems
  - Satellite broadcasts
  - Ethernet
  - Home PNA (Ethernet over home wiring)
  - Ethernet over VDSL
  - Etherloop/ReachDSL

QAM is a standard for VDSL

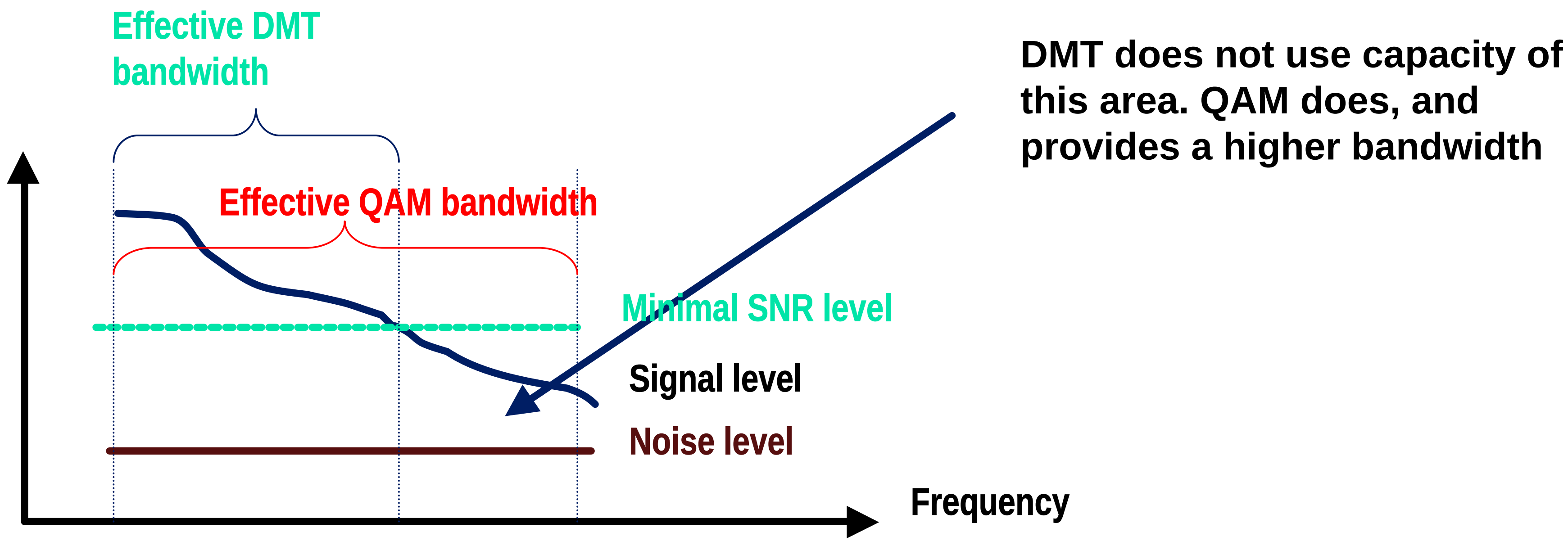
- QAM-based VDSL is defined in:
  - ETSI TS 101 270 Parts 1 & 2
  - T1.424 VDSL trial use standard published by T1
- QAM-based VDSL complies with 802.3ah requirements for full duplex 10 Mb/s operation over a single pair (ADSL, ADSL+, SHDSL, for example, don't)
- QAM-based VDSL is a mature solution. Standard-compliance ensures interoperability

Advantages of QAM technology

- High performance
- Flexibility and robustness
- Low complexity

SNR Averaging

- SNR averaging capability allows optimal usage of the frequency bands, with almost no loss of SNR even with rather low constellation size
- By SNR averaging, the effective bandwidth of QAM is greater compared to water-filling used by DMT



Impulse noise protection

- Impulse noise is one of the critical interferers in the EFM copper environment. Elevator shafts, home/office wiring, and general first-mile installations suffer from strong bursts of noise.

- Practice (and standards) require impulse noise protection of 500 us. VDSL overcomes impulse noise by a combination of FEC and interleaving.

- QAM uses short symbols and thus avoids impulse noise spreading, reducing the impact of impulse noise

- In DMT, erasure of a part of a symbol usually kills the whole symbol (due to FFT processing, and can not be fixed by FEC). A DMT symbol is 250uS of length.

Impulse noise effect: Example

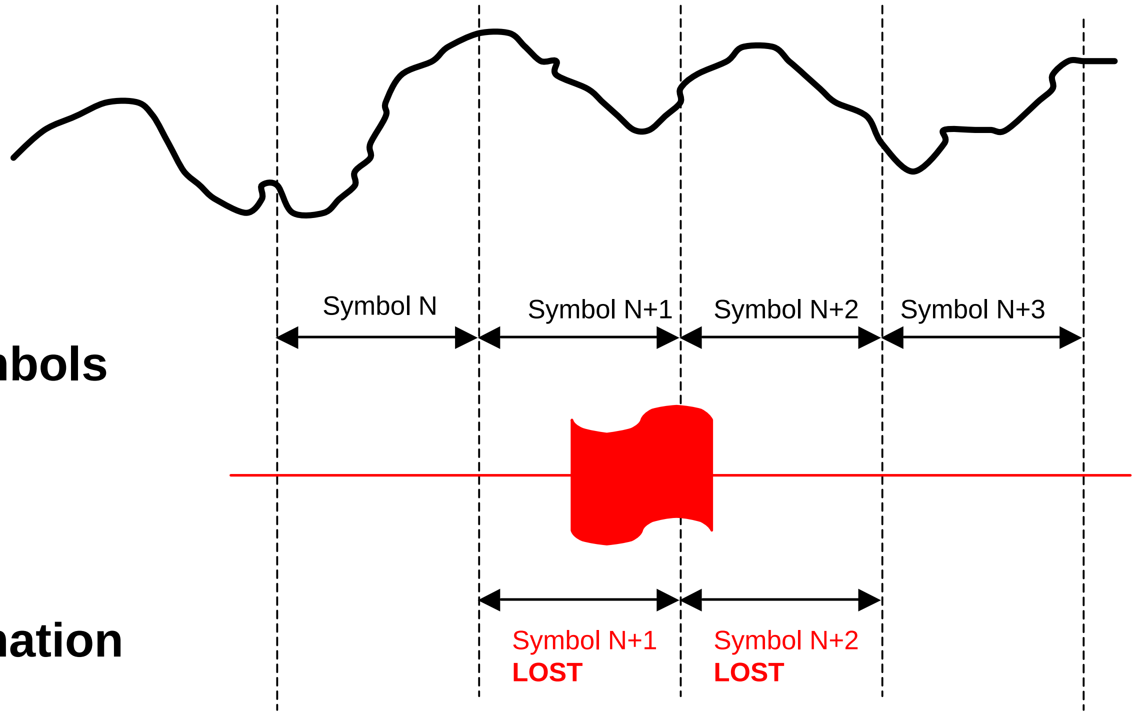
- In this example, a 250 uS impulse erases 2 DMT symbols (500 uS)
- In QAM, only 250 uS of data is erased.
- In this example, DMT needs twice more interleaving depth and introduces twice more latency than QAM.

Signal

DMT 250 uS symbols

Impulse noise

DMT lost information



Blind equalization

- QAM VDSL uses blind equalization to establish the link:
  - No training sequences needed
  - No special handshake required

- DMT, on the contrary, needs both long handshake and training to start the system

Blind equalization: more

- Blind equalization:
  - Greatly speeds up the connection
  - Allows quick tracking of changing link conditions
  - Simplifies interoperability
  - Allows point-to-multipoint operation at CPE
  - Allows operation in the burst mode
- QAM’s integrated Equalizer operates over loops with Bridge-taps and RFI ingress.
- QAM VDSL can notch HAM Bands to comply with RFI egress requirements.

Blind equalization: even more

- QAM provides protection from time-varying noise:
  - QAM constantly and quickly adapts the equalizer to time varying noises
  - Quick adaptation allows tracking of hopping narrow-band ingress, automatically and almost immediately
- DMT adapts using a bit swapping routine and requires message exchange between the two sides: slower response.

PAR implications

- A DMT system has a high Peak to Average Ratio (PAR) which requires high resolution of ADC and DAC.
- In DMT:
  - A strong INPUT signal to the ADC causes clipping and generates a burst of errors.
  - A weak INPUT signal to the ADC is not fully digitized, and information is lost.
- DMT solution needs at least 14-bit ADC/DAC to avoid performance degradation due to quantization noise and clipping.
- Problem: Such requirements are hard to implement: an aggressive AFE technology with higher power consumption is required

PAR implications: more

- The PAR of QAM is 8-9 dB versus 14.5 dB for DMT. This allows reduced ADC and DAC resolution in QAM.
- The lower DAC/ADC resolution needed by QAM (11 bits) is already available. This leads to lower power consumption, complexity and cost.
- In QAM Reed Solomon FEC is used for coding gain, correcting errors generated by external sources.
- DMT “wastes” the coding gain on clipping noise.

QAM Flexibility

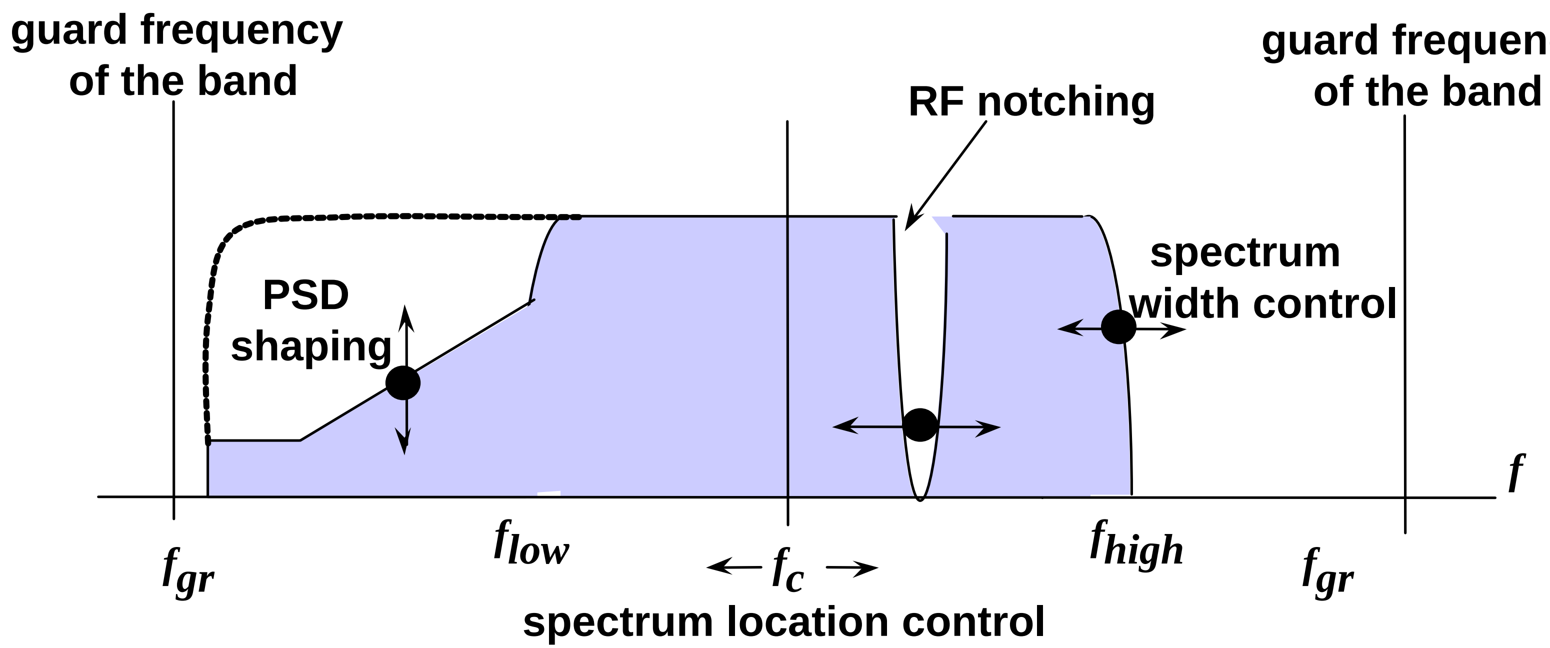
- DMT is flexible, but only in one dimension which is the transmit spectrum

- QAM is flexible in three dimensions:
  - spectrum
  - transmission media
  - duplexing

- QAM VDSL provides all the flexibility needed for EFM.

QAM Transmit spectrum flexibility

- Spectrum management tools control:
  - spectrum location (Δfc=*33.75 kHz*)
  - spectrum width (ΔSR=*67.5 kHz)*
  - shaping of the transmit PSD
  - support of both pass-band and base-band implementations



Flexibility of duplexing options

- The main objective - 10Mb/s full duplex over a single pair of 750m - could be achieved by using FDD only.
- For long loops and very long loops agile TDD and EC are usually more effective compared to FDD.
- Agile TDD (burst mode) option could be easily accommodated in QAM transceiver due to its capability of quick blind equalization.
- EC accommodation is also convenient due to rather low peak-to-average ratio of QAM signal (8-9 dB).

QAM Service bit rate flexibility

- QAM VDSL provides high flexibility in determining the service bit rate:

Center Frequency:	Granularity of 33.75 KHz
Symbol rate:	Granularity of 67.5 Kbaud
Constellation Size:	QAM-4 and higher
Bit rate:	**Granularity of 135 Kb/s**

- The carrier frequency, and the carrier width are fully programmable to support any band plan or environment.

QAM Power Consumption

- VDSL system integrators call for maximum 1.0W per VDSL port
- QAM already reached:
  - singles at <1.5W/port
  - multi-port at <1W/port

  for <u>all components</u> needed in a design
- QAM's low power consumption translates to higher silicon integration, and denser line cards

This is what EFM needs!

QAM Maturity

- QAM vendors are already introducing third and fourth generation VDSL chips.
- QAM VDSL Shipments: over 1M chipsets in 2001
- QAM in Cable modems: More than 8.5M installed
- QAM for HPNA: Millions installed
- QAM-based Ethernet over VDSL already deployed:
  - over 0.5M deployed in the field as of start of 2002
  - over 1.5M will be installed by end of 2002
- QAM Etherloop: 0.5M lines installed
- **QAM VDSL interoperability: in June.**

QAM Chips/Systems availability

- QAM VDSL is 3-year **commercially available.**
- QAM VDS Chips now available: Single, Dual, Quad and Octal chips.
- Multiple system-vendors have products: This **pushes costs down.**

Does QAM offer what EFM needs? Yes !

- QAM VDSL: already available for 3 years
- QAM Ethernet over VDSL: already deployed
- QAM-based products: multiple system vendors
- QAM-based EoVDSL maintains Ethernet heritage:
  - Fast blind synchronization: Plug & Play
  - Simple technology
  - Low cost
  - Low power consumption
  - High port density
- QAM VDSL is an existing proven Ethernet Technology
- DMT is ATM-related rather than Ethernet Technology