The Case for DMT VDSL

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VDSL in Japan – NTT deploying since 2002 Ethernet over VDSL-dmt 50 Mbps

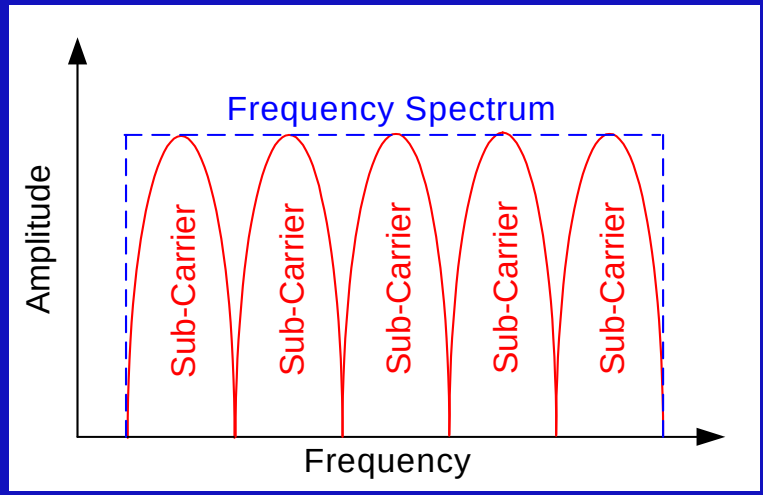
- NTT has already deployed a very large scale 50 Mbps EoVDSL-dmt

Korea Telecom (KT) and Hanaro Telecom are planning for 50 Mbps deployment in Korea

Summary VDSL_dmt

- **Superior Performance**
  - The first VDSL to demonstrate over 50 Mbps in Feb 27, 2002
  - The first 50 Mbps deployed technology in Japan and Korea
  - The first to demonstrate in excess of 110+ Mbps in Jan of 2003
  - Low Power consumption
  - Higher density
  - Much stronger Roadmap
- **Market momentum**
  - DMT technology over 40 million
- **Lower overall cost**

What is Multi-Carrier Modulation?



- **Frequency spectrum has many adjacent sub-carriers**
- **Each sub-carrier is orthogonal to others**
- **Each sub-carrier has different bit loading (bits per Hz) depending on SNR**
- **Each sub-carrier can be turned off**
- **Two common manifestations**
  - Discrete Multi-Tone (DMT) in wireline systems
  - Orthogonal Frequency Division Multiplexing (OFDM) in wireless systems

DMT technical attributes

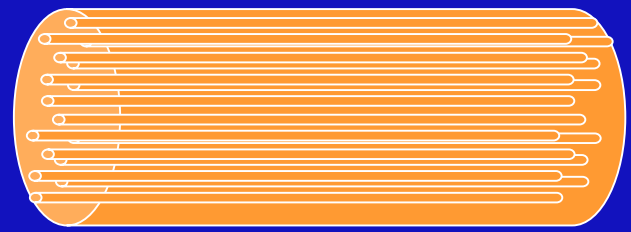
- Highest data rate and Optimal Shannon Channel Capacity
- Bridged taps environment
- Protection against RFI egress, as required by FCC and other regulatory bodies
- Digital Duplexing is superior to Digital Filtering
- Better Power and density results

Performance: Copper loop has many frequency dependent characteristics

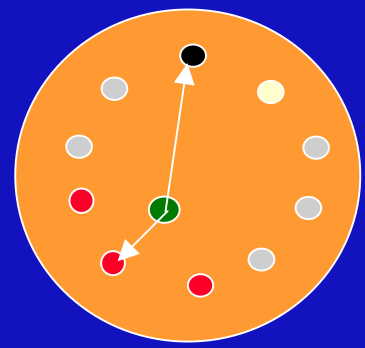
Unlike Cable modem interference between transmission lines is frequency dependent

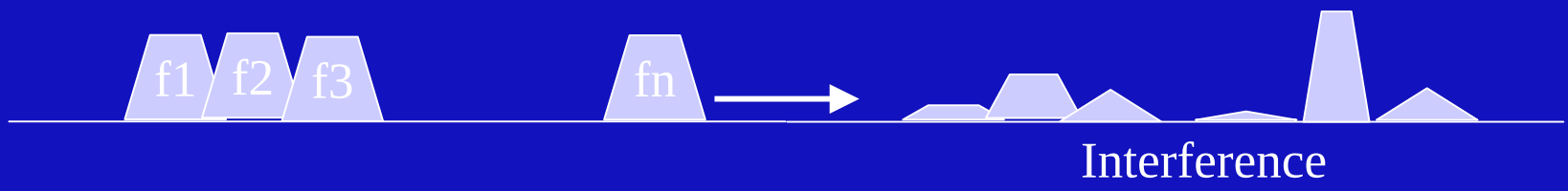
Optimal transmission is obtained when SNR is optimized

DMT technology can deliver maximum Shannon capacity when dealing with harsh multi-band/freq. dep. environment

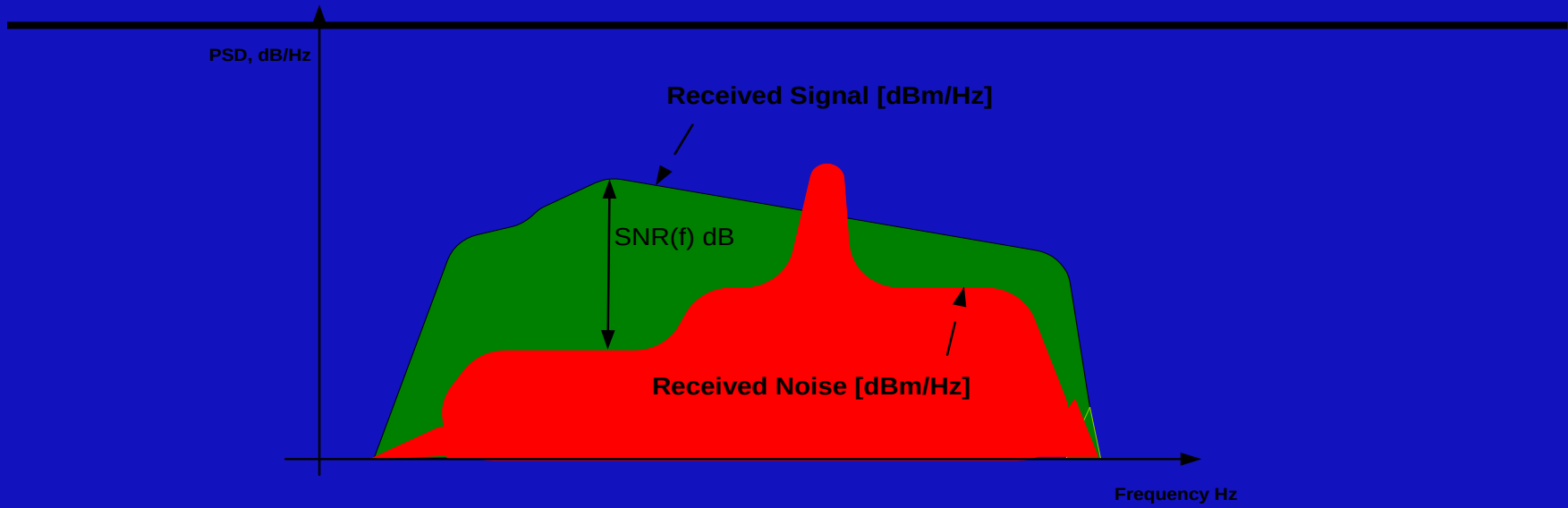


Copper Binder



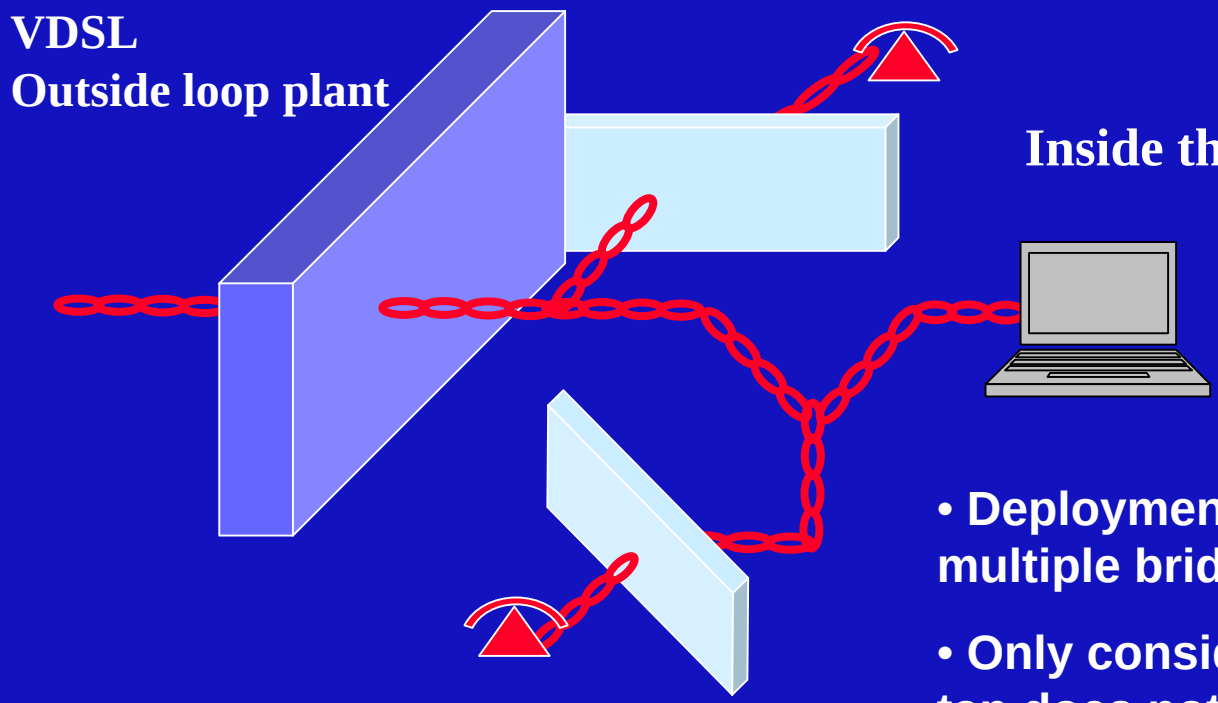


The Use of Bit-Loading to deal with Frequency Dependent Channel



- Channel Capacity (through put) is a function of the Signal-to-Noise Ratio (SNR) of the receiver.
- Frequency dependent noise
  - Self FEXT
  - RFI and burst noise
- Water filling algorithms are optimal solutions for frequency dependent channels
  - The spectrum is divided into narrow sub-carriers
  - System measures SNR in each sub-carrier
  - System assigns bit loading for each sub-carrier based on measured SNR
- Net result is optimal performance in presence of frequency-dependent degradation

Multiple Bridged Taps – Unavoidable in VDSL Applications



- Deployment Environment contains multiple bridged taps
- Only considering zero or one bridged tap does not depict real world

Effect of Bridged Taps on Transmission loss

Test results from "Effect of Bridged Taps" - Bellcore Study 1993

ADSL Loop 9 from tables 1 and 2:

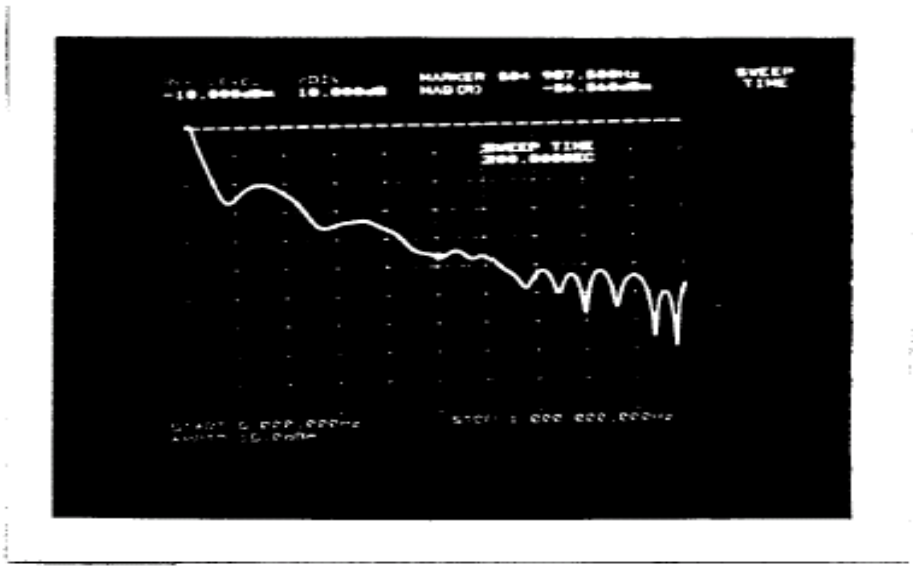
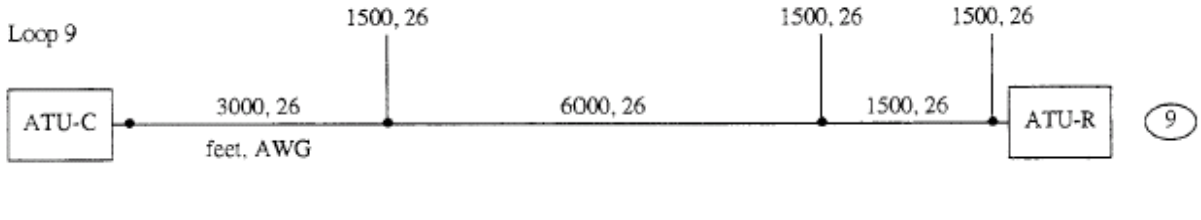
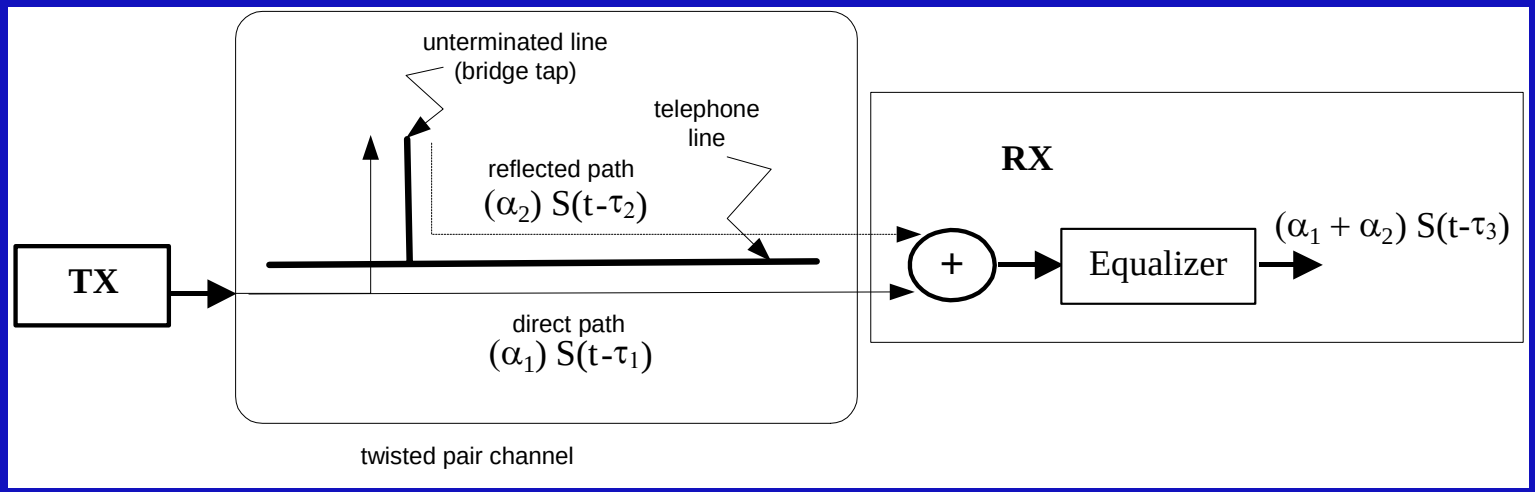


Figure 9. Measured Insertion Loss (5 kHz - 1 MHz) for ADSL Test Loop #9



The Use of Equalization to Overcome Effects of Time Dispersion



- **Time dispersion exists in typical wireline channels (with or without bridged taps)**
- **Bridged taps further degrade wireline conditions**
- **Time dispersion effects can be eliminated by equalization at the receiver**
- **Equalizer complexity depends on**
  - Required Performance
  - Width of spectrum
  - **Symbol rates**
- **DMT Symbol Rate is significantly Lower**

Performance of Equalizers in presence of Bridged Taps
Decision Feed-Back Equalizers, TEQ and FEQ

- – DEF performance in BT environment
  - **“The effects of bridged taps on the DEF-based VDSL transmission system have been investigated. It has been shown that the short bridged taps introduce more linear distortion and propagation loss than the longer bridged taps. The overall propagation loss introduced by multiple bridged taps can become unmanageable at VDSL frequencies when the number of bridged taps is increased. “**

- **DMT uses FEQ that are linear and very predictable in nature for fine tuning for maximum performance**

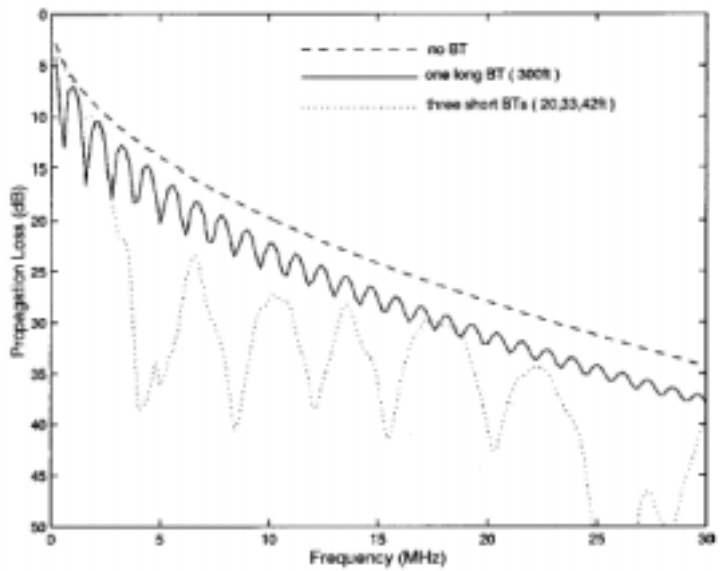


Fig. 6. Propagation loss characteristics for the loop with and without bridged taps.

Ref: IEEE JSAC

See Rezvani_1_0503.pdf

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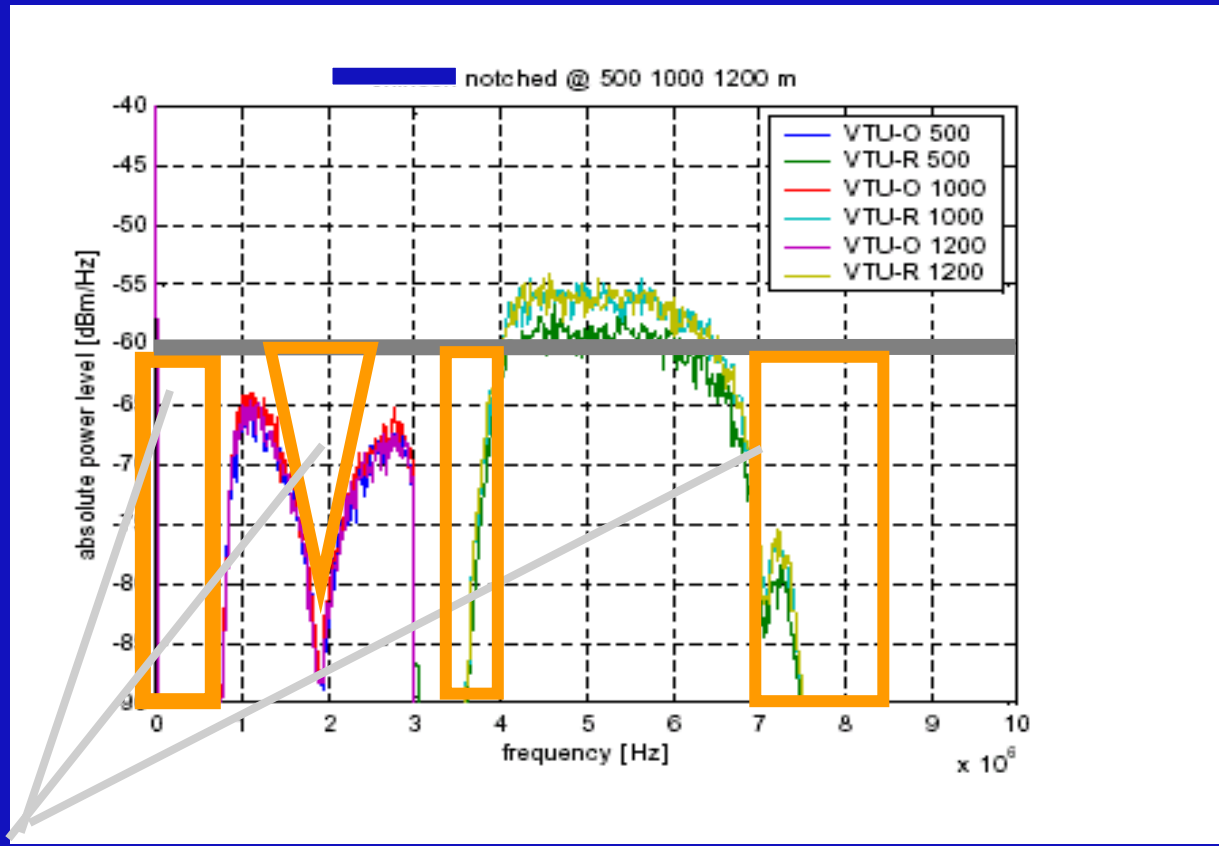
Effect of digital or analog filtering to produce Notches in a typical 2-band

Data rate loss
Can be high very high
Depending on implementation



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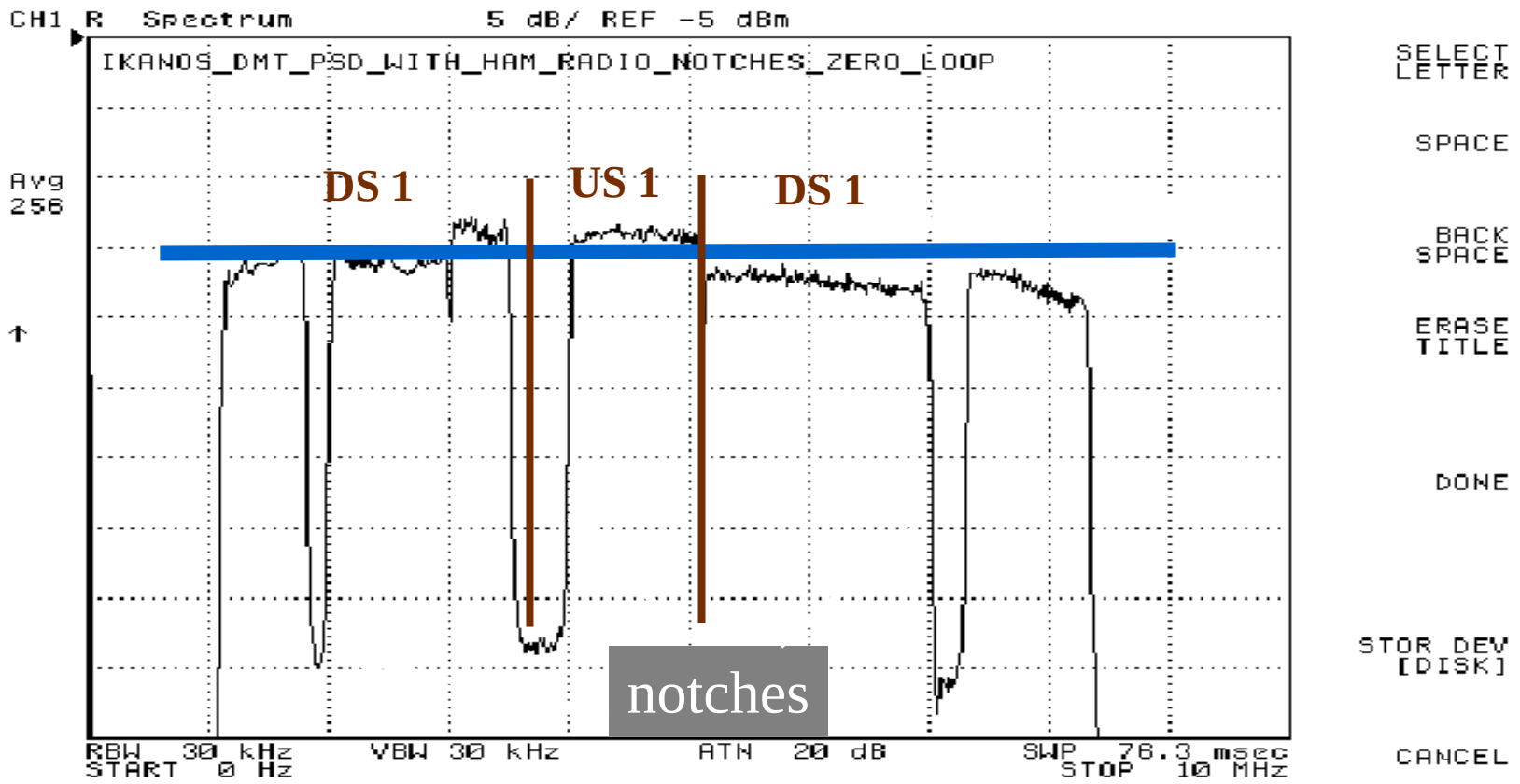
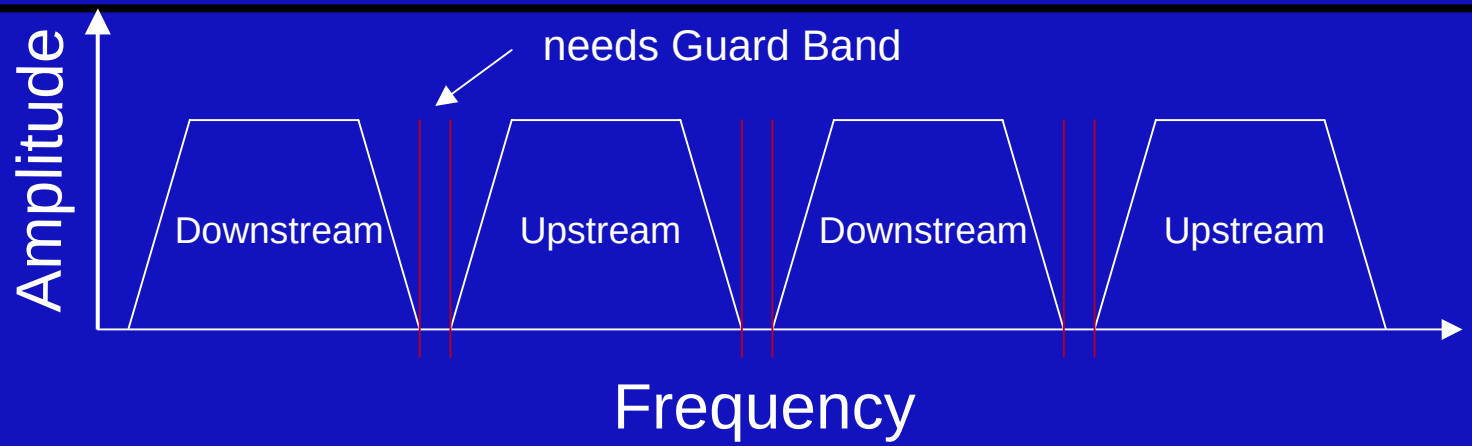
Notches in a typical DMT systems using FFT function



Methods of Separating Signals for Full Duplex Operation in Multi-Band Spectrum



- **Analog (*or Digital*) filtering separates downstream and upstream bands**
  - Needs guard bands
  - Compromises performance
  - Quality is directly proportional to cost
  - Both DMT and QAM can do that
- **Digital Duplexing separates downstream and upstream bands**
  - Orthogonal properties of sub-carriers ensure clean separation
  - Minimizes performance loss
  - Cost effective
  - Only DMT can do that
- **Difference: Using the mathematical property of FFT.**

Future Performance Advancements

- **DSL employing DMT line code is well-suited for future advanced signal-processing techniques**
- **Trellis coding is very natural for DMT**
- **Dynamic Spectrum Management**
  - Will support on-the-fly upstream and downstream PSD optimizations based on required service mix
  - Will enable advanced bandwidth/spectrum management capabilities
  - Per line and Aggregate Binder Capacity Optimizations
- **Vectored Transmission**
  - Subset of DSM
  - Enables superior line bonding performance

Development Efficiencies

- **VDSL-Allocated Development Costs are Lower**
  - Reuse of technical knowledge.
  - Maps on to ADSL platform (DSP based design).
  - Reduces the number of VDSL specific chips required for development
  - Fosters early competition among ADSL vendors by lowering the entrance cost.
- **Lower development cost translates into lower CapEx**
- **Total combined ADSL/ADSL+/VDSL market drives faster development cycle times**
  - More competition
  - Drives new chipset generations every year
  - Lower R&D expenses amortized over much larger unit volumes
  - Does not work as well for single-point VDSL only developments
- **ADSL CPE advances are directly leveraged into VDSL**
  - Example is ADSL+ / ADSL++, receiver technology for these ADSL categories is same as for VDSL

Summary

- **The vast majority of DSL chip vendors support DMT for VDSL line code**
  - Larger supplier base drives competition hence reducing costs more quickly
- **Leading DSL equipment vendors support DMT VDSL**
- **DMT has superior performance/flexibility at costs comparable to QAM**
- **DMT has lower CapEx and OpEx for service providers**
- **DMT will foster Universal DSL CPE retail model**
- **DMT is the logical choice**
  - proven track record in mass volume deployments
  - relentlessly increasing performance capabilities
  - well-functioning interoperability process
  - solid quarter-on-quarter record of cost cutting