Chapter 3

ADSL / VDSL Technologies

Both ADSL and VDSL are designed to operate on a subscriber's existing twisted copper access pair terminating at a Local Exchange Building (LEX) in conjunction with the existing Plain Old Telephone Service (POTS). Various types of both ADSL and VDSL exist or are under development, although only DMT ADSL has been standardised[1]. Dual operation alongside the POTS is achieved through frequency division multiplexing which supports the legacy unmodulated baseband voice service upto 4 kHz and modulated data transmission in a higher passband. Filters known as POTS splitters separate the two signals at both the customer's premises and LEX. ADSL offers asymmetrical data rates of upto 6 Mbps downstream and 768 kbps upstream, whilst VDSL will offer either symmetrical or asymmetrical transmission to a combined limit of 55 Mbps. The maximum achievable data rate for both systems is limited by reach and SNR. This chapter attempts to describe both DSL systems, but only to a level that the salient points related to a line simulator are brought out, not exhaustively. Where further detail is sought, reference texts are identified.

3.1 ADSL

ADSL is aimed at providing data rates from 1.5 to 6 Mbps downstream and upto 768 kbps upstream[2]. For a given data rate the maximum separation between the customer and LEX is limited by attenuation and SNR due to crosstalk and other noise. Simply, higher data rate lines have a shorter reach compared with lower rate lines as have lines with thinner conductors compared with thicker ones. As will be discussed shortly, two different ADSL modulation schemes exist which have slightly different performance objectives, but Table 3.1 gives an indication of approximate maximum and minimum ADSL performance for uniform, untapped access lines[3].

AWG	Maximum Reach	Maximum Rate
24	18 kft @ 1.5 Mbps	6.1 Mbps @ 12 kft
26	15 kft @ 1.5 Mbps	6.1 Mbps @ 9 kft

Table 3.1 Downstream ADSL performance figures

3.1.1 ADSL General Architecture

Practical deployment of ADSL to a new subscriber has been kept as simple as possible. No access line modifications are necessary, although a DSL service provider generally surveys the line to determine its length and condition and to determine the maximum possible data rate that it will support. A recent variation of ADSL is DSL Lite[4] which is designed to make the installation of a POTS splitter at the customer's premises obsolete allowing an ADSL Lite modem to be plugged into the existing phone socket as simply as a common 56 k PC analogue modem. DSL Lite, although not yet standardised, will use the same modulation scheme as DMT ADSL, but offer a reduced data rate.

Figure 3.1 shows the end to end model for full ADSL systems, for ADSL Lite, the customer's POTS splitter would be removed.

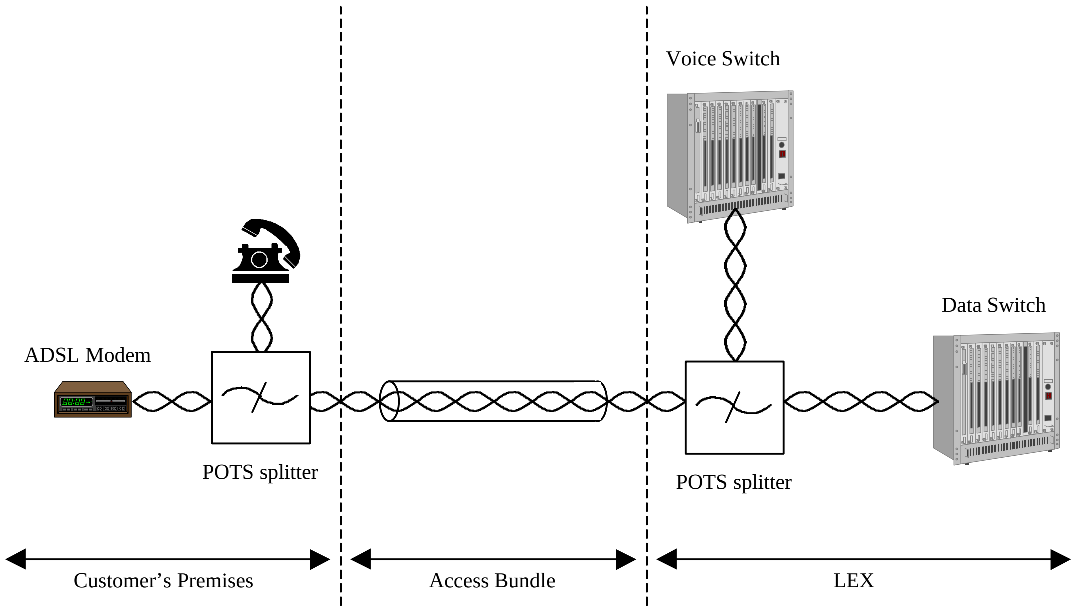

Figure 3.1 ADSL end to end model

3.1.2 DMT Modulation

The DMT ADSL modulation scheme is currently the only open standardised version of the access technology. ANSI have standardised all aspects of the service through the T1.413 series of documents. Full duplex operation is achieved either by Frequency Division Multiplex (FDM) or Echo Cancellation (EC), but both methods utilise the same basic multiple carrier QAM scheme.

QAM basically modulates data onto two orthogonal sine and cosine carriers of the same frequency. In its simplest form, 4 QAM, there are four possible combinations of the two carriers' amplitudes in the modulation scheme. 4 QAM modulates two binary bits per transmitted symbol (the symbol is transmitted through the combination of the two carriers for a duration called the symbol period). A succession of symbols in time is modulated by changing the amplitude of the two carriers according to the data bits' mapping onto the QAM constellation. The nature of the transition from one point to another in the constellation defines the bandwidth required by the modulation scheme. An instantaneous change from one point in the constellation to another produced by driving the modulator with a square wave would require an infinite transmission bandwidth. A modulating signal in the form of the Nyquist signalling waveform (a sinc function) gives the minimum required transmission bandwidth of half the symbol rate (one quarter the binary bit rate with 4 QAM).

Figure 3.2 shows the modulation of sine and cosine sinusoidal carriers for a constant input symbol.

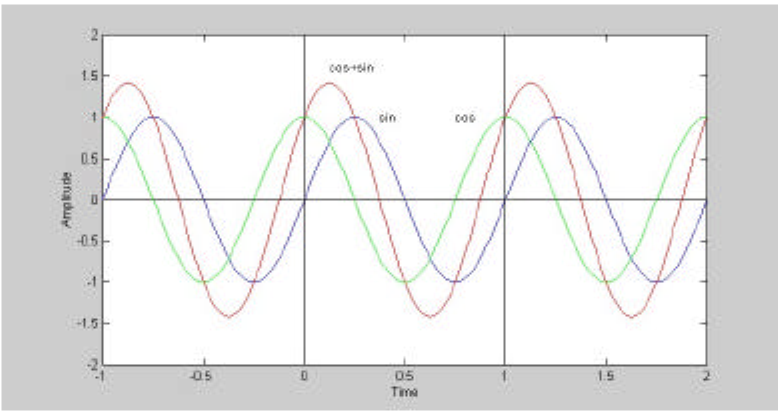

Figure 3.2 QAM modulation of a sine and cosine carrier

The information in figure 3.2 can also be represented by a constellation diagram which shows the magnitude of the carriers for each symbol and which binary bits are mapped to those symbols. If two binary zeros were mapped to the waveform in figure 3.2 the constellation diagram shown in figure 3.3 would result.

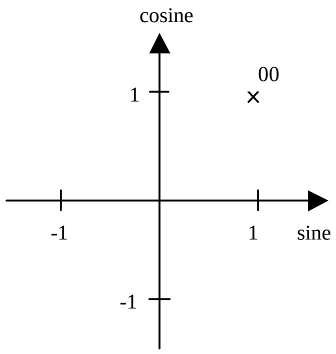

Figure 3.3 QAM constellation for a sine + cosine symbol

A complete 4 QAM constellation with the binary bit to sine and cosine amplitude mappings listed in table 3.2 is drawn in figure 3.4

Bits	Sine Amplitude	Cosine Amplitude
00	+1	+1
01	+1	-1
10	-1	-1
11	-1	+1

Table 3.2 4 QAM bit to carrier amplitude mapping

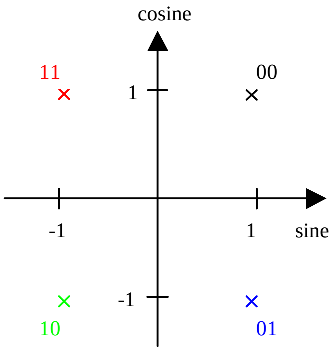

Figure 3.4 Complete 4 QAM constellation

DMT ADSL effectively modulates data onto 256 different sine and cosine carrier pairs. Since each carrier has a different centre frequency the technique is called Discrete MultiTone modulation. ANSI term each subcarrier pair as a 'bin' into which data is 'loaded' according to its constellation mapping. Each bin, i, is loaded with n_i data bits, with n depending on the measured SNR at the subcarrier frequency of the bin. A bin with a high SNR will be heavily loaded with data (i.e. use a large QAM constellation), whereas a bin with a low SNR will be lightly loaded or completely unloaded (i.e. use a small or null constellation). Figure 3.5 shows a conceptual 3 tone DMT modulation scheme with bins 1 and 3 loaded with 4 and 2 data bits per symbol respectively and bin 2 with none possibly due to intense coloured noise in its bandwidth.

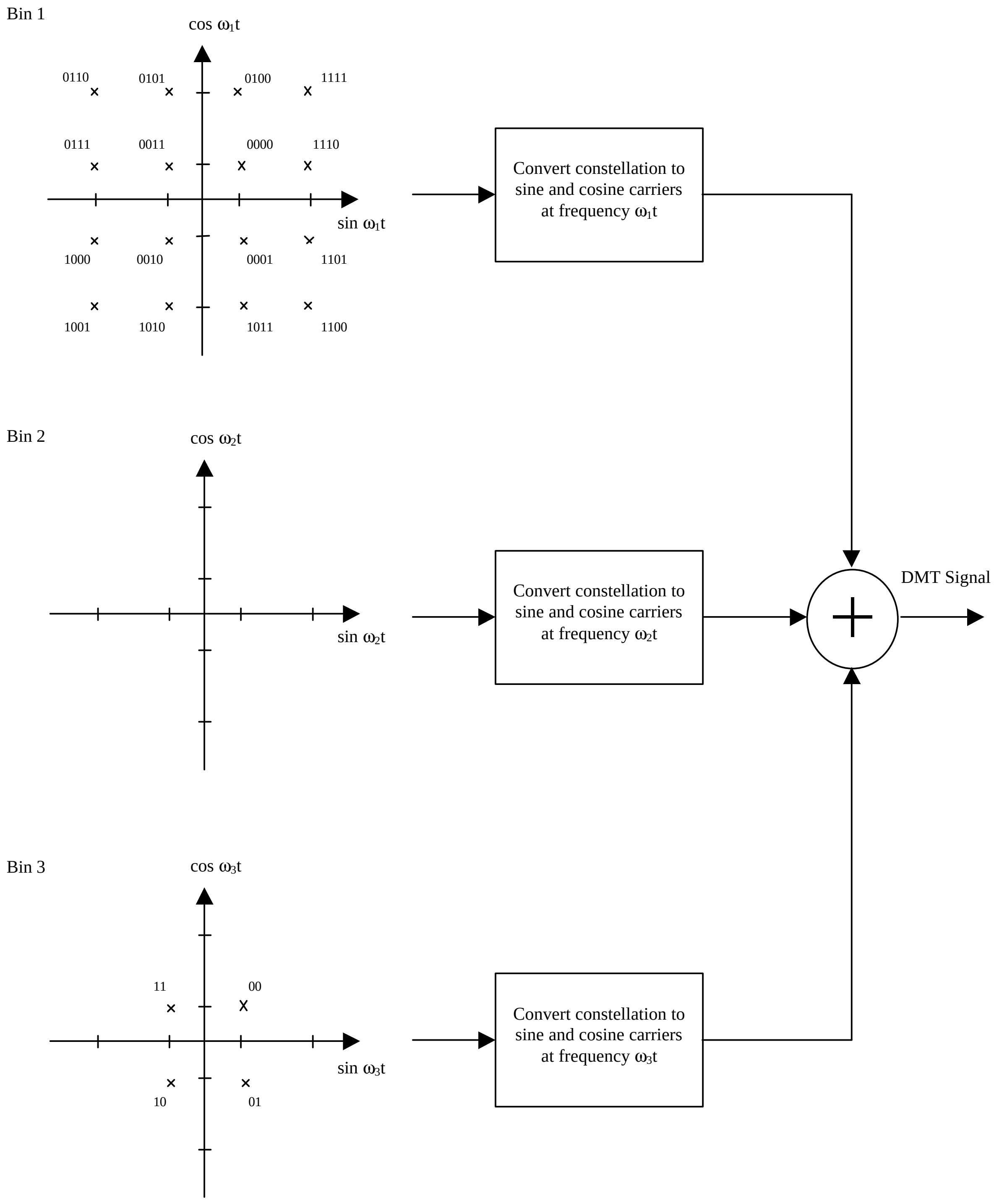

Figure 3.5 3 bin DMT modulation

In practical systems, this brute force method of summing up a set of separately generated QAM signals isn't adopted, rather each constellation output is placed along with its complex conjugate, in a vector on which an inverse Fourier transform is performed[5]. This produces a real-valued time domain sequence that, after D/A conversion and filtering, gives a signal equivalent to that produced by the summation of QAM signals.

The simplified model of a 3 bin DMT scheme illustrates the rate adaptive nature of DMT ADSL. The data rate on each carrier pair is software controllable, which enables

- Redistribution of data loading into different bins to overcome specific bandlimited interfering signals.
- Service provider controlled tiering of data rates using software reconfigurable modems.
- FDM of the up and downstreams, thus eliminating self NEXT.

All these features reduce modem costs and widens service provision to a multi rate access system.

3.1.2.1 ANSI T1.413 DMT Specification[1]

The T1.403 standardisation for downstream DMT ADSL is for 256 carriers separated by exactly 4.3125 kHz. The first subcarrier is at 4.1325 kHz, with the 256th at 1.104 Mhz (called the Nyquist tone). The standard limits the data loading on each subcarrier to 15-bits, equivalent to a QAM constellation of 2^{15} (32 768) points, with a symbol rate of 4 kBaud (250 µs symbol period). For the upstream, there are 32 subcarriers with the same spacing, the first at 4.3125 kHz and the last at 138 kHz. The maximum upstream subcarrier loading is the same as the downstream. Figure 3.6 shows the streams' subcarrier spacing and PSDs if all subcarrier channels were equally loaded equally (i.e. the equivalent of 256 QAM signals with the same sized constellation - a theoretical situation solely to show the nature of the PDSs).

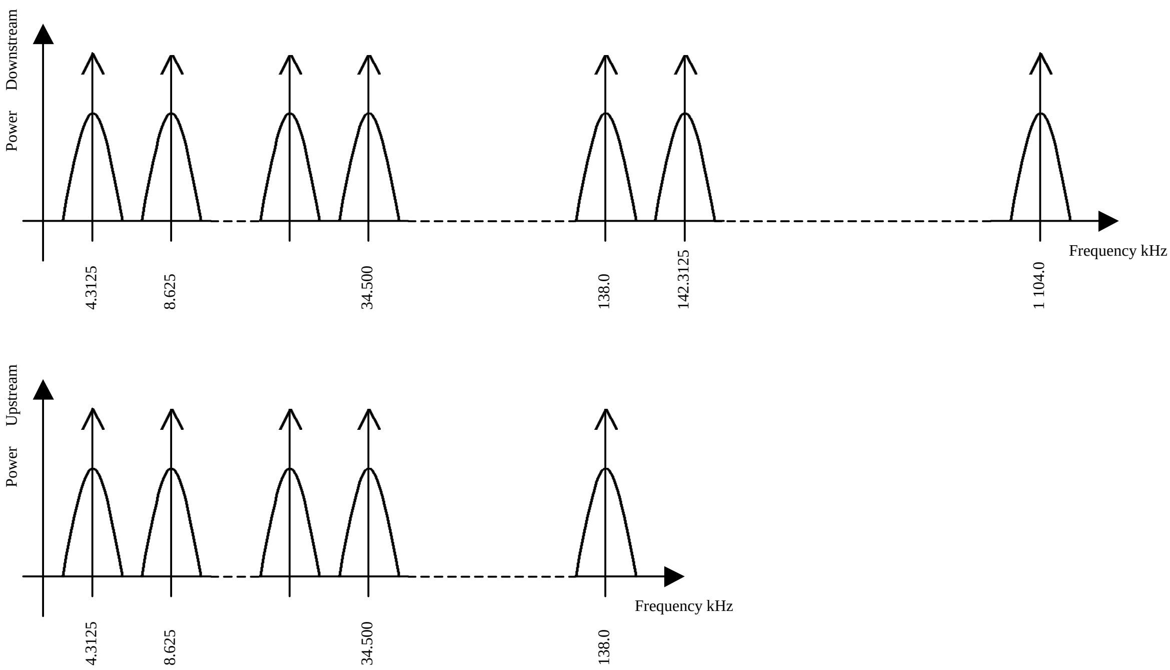

Figure 3.6 ANSI T1.413 carrier spacing and PSDs

Although the actual structure of the ADSL data framing and practical modulation scheme are very complex[6], the design of a line simulator is independent of such higher layer functionality as the ADSL signal is viewed at the physical layer.

3.1.2.2 Frequency Division Multiplexed DMT ADSL

FDM in ADSL systems is achieved by band limiting and spectrally separating upstream and downstream transmissions. The rate adaptable nature of DMT provides a simple way of implementing FDM by simply using null constellations for the downstream modulation bins where the upstream transmission spectrum is located. The same approach is used to give the FDM of the voice spectrum with the two ADSL signals. Upstream – downstream FDM is achieved by using null constellations for bins 8 to 32 in the downstream DMT transmission. Voice – ADSL FDM is through null constellations for bins 1 to 7 on both data streams. Overall, the PSD mask indicating the power spectra for all three signals is shown in figure 3.7.

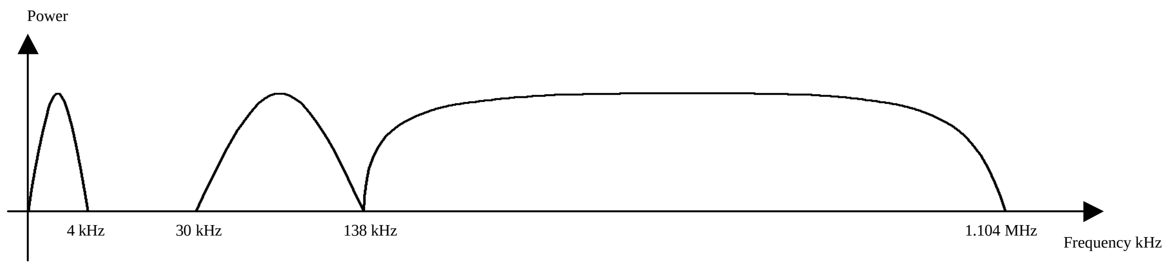

Figure 3.7 PSD mask for ANSI T1.413 FDM DMT ADSL

3.1.2.3 ADSL Lite

The PSD mask for ADSL Lite is spectrally limited by using null constellations for the higher frequency downstream subcarriers. The service is unstandardised, but uses the same subcarrier spacing as full ADSL.

3.1.2.4 DMT Echo Cancelled ADSL

An alternative to using FDM for duplex operation is to allow the data stream spectra to overlap then remove any unwanted echo at the co-located receiver due to self NEXT using cancellation techniques[7]. This is possible as a transceiver has knowledge of what it is currently transmitting, therefore it is able to remove by subtraction any attenuated copy of its own transmission arriving at its receiver. Echo cancelled DMT ADSL systems offer higher data rates of upto 8 Mbps, but have not been standardised. It is interesting to note that by giving the downstream transmission an extra 26 usable subcarriers, the maximum data rate is increased to just over 8 Mbps. This represents an increase in data rate of 33% for only a 10% increase in occupied spectrum. This seemingly contradictory result is due to much higher SNRs at lower frequencies. In DMT ADSL systems, high frequency subcarriers tend to be lightly loaded whereas lower frequency carriers tend to be heavily loaded.

3.1.3 CAP Modulation

ADSL using CAP modulation has been developed by the company Globespan. No standarisation has been completed although several ad-hoc committees have made proposals[8,9]. Since CAP ADSL is a proprietary technology it is not precisely defined. Proponents of DMT ADSL have produced many papers championing their preferred solution at the expense of CAP[3,5]. Most of these papers have been written by companies after testing competitors' CAP modems and as such, one must view their findings with a pinch of salt.

CAP and QAM systems are very closely related. The term 'carrier-less' arises due to the primary difference between CAP modulation and true QAM. QAM modulators actually generate and mix two orthogonal sine and cosine carriers using analogue electronics. In contrast, CAP modulation is a digital process, where impulses are filtered by two filters with responses describing Hilbert transform pairs and then summed. Both techniques modulate data according to symbol to 'carrier' amplitude mapping constellations.

The ANSI proposal for CAP implementation[10] has a high symbol rate of 1088 kBaud with a maximum 256 point constellation. In comparison to DMT ADSL that transmits multiple, long 250 µs symbols, CAP ADSL transmits a single, short 0.91 µs symbol. Of greatest interest in relation to a line simulator is the PSD mask for CAP systems, shown in figure 3.8.

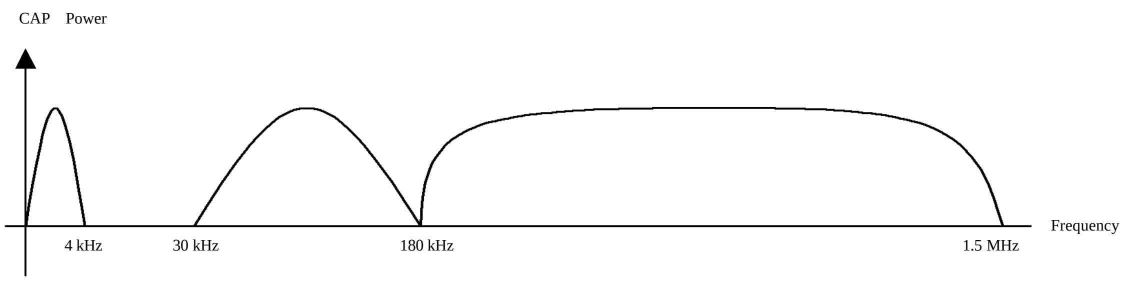

Figure 3.8 PSD mask for CAP ADSL

Whether both systems will survive is questionable. The overwhelming support for DMT is as equally accreditable to the reported merits of DMT over CAP as to the number of manufacturers producing DMT modems and chipsets compared with those producing CAP modems. Justifiably, manufacturers of DMT modems are concerned at the prospect of the possible wide deployment of DMT and CAP systems side by side in the same access bundle due to their overlapping spectra, shown in figure 3.9. T1.413 downstream DMT ADSL, which was designed specifically to eliminate self NEXT through FDM, would be adversely affected by CAP signals, especially since the lower DMT subcarriers are heavily loaded with data. Whatever the technical merits of DMT and CAP, market forces are likely to pick the winning technology.

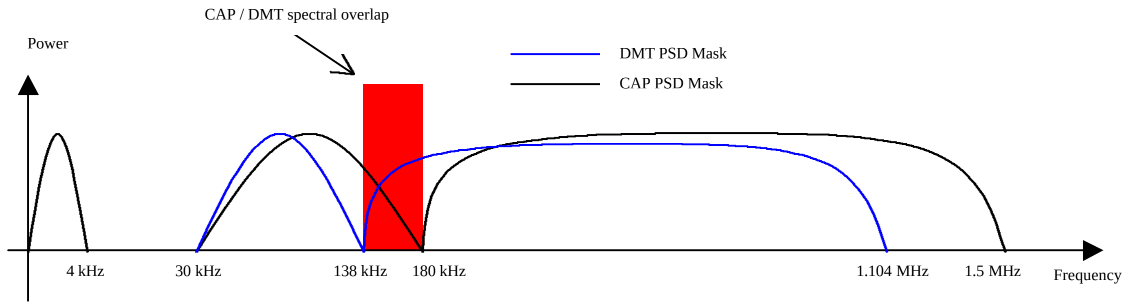

Figure 3.9 DMT / CAP power spectra comparison

3.2 VDSL

VDSL systems are designed to offer very high data rates upto 55 Mbps over distances of a few thousand feet. VDSL modems will be required to function with increased crosstalk and external interference due to the extended operational spectrum. Some typical performance targets proposed by ANSI[10] are illustrated in table 3.3.

Reach	Data Rate Downstream (max)	Data Rate Upstream (max)
1 000 ft	51.84 Mbps	2.3 Mbps
3 000 ft	27.6 Mbps	27.6 Mbps
4 500 ft	13.8 Mbps	13.8 Mbps

Table 3.3 VDSL performance targets

VDSL deployment is envisaged as a final drop to the customer in conjunction with fibre to the curb. Feasibility studies conducted by several companies have indicated CAP or QAM as the only commercially viable modulation techniques. Although DMT may well be preferable to CAP/QAM, DSP functionality has only recently reached a level advanced enough to implement ADSL DMT. As shown in figure 3.10, VDSL bandwidths are almost twenty times higher than for ADSL. DMT modulation using similar IDFT techniques to ADSL would require substantial parallel processing and is economically unattractive.

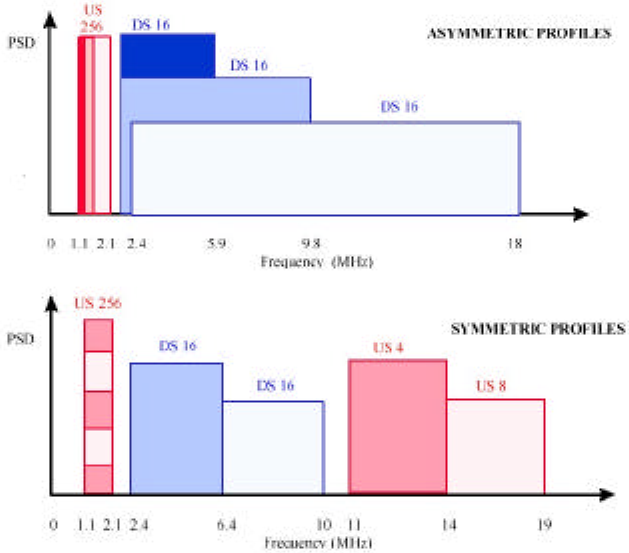

Figure 3.10 VDSL spectral spreads

3.3 ADSL and VDSL Data Rates and Reach

Although not directly relevant to the line simulator, an overall picture of the relationship between the probable deployment scenarios of ADSL and VDSL[11] is shown in figure 3.11.

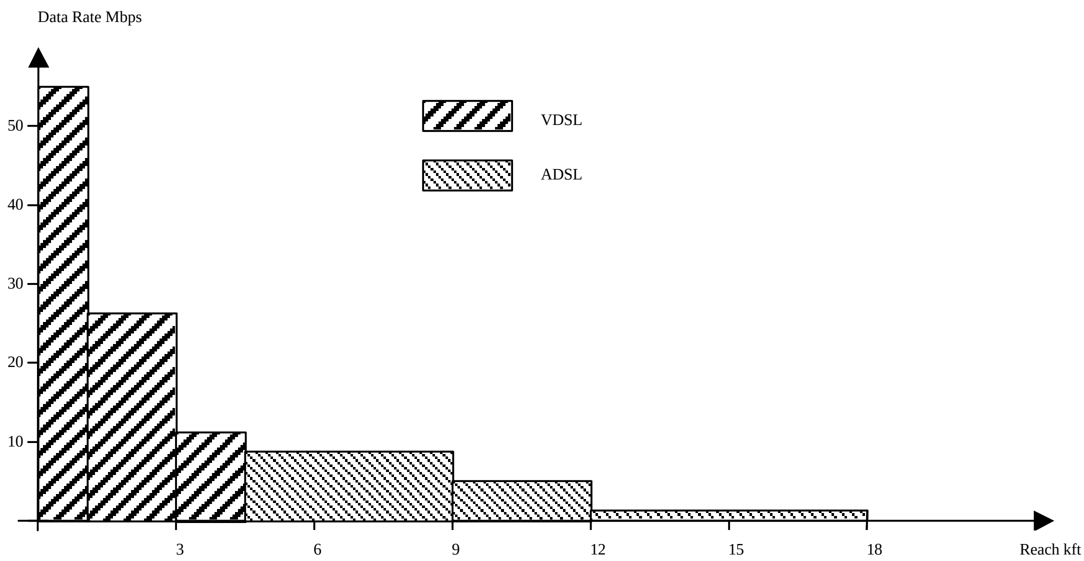

Figure 3.11 VDSL data rates and reach

References

[1] American National Standards Institute, ANSI T1.413-95, Asymmetric Digital Subscriber Line (ADSL) Metallic Interface, 1995.

[2] “The DSL Source Book”, Paradyne Corp, February 1999, p24.

[3] Rupert Baines, “Discrete Multitone (DMT) vs. Carrierless Amplitude / Phase (CAP) Line Codes”, Analog Devices, May 1997, p1-2 (Performance and Trials).

[4] “Consumer Installable ADSL: An In-Depth Look at G.Lite Technology”, Orckit Communications Ltd, December 1998.

[5] “CAP vs DMT”, Aware Ltd, White Paper, March 1999.

[6] “How does ADSL work?”, DSL Knowledge Center, Orckit Communications Ltd, 1998.

[7] M. Ho, J. Cioffi, and J. Bingham, “An Echo Cancellation Method for DMT with DSLs”, Amanti and Stanford University T1E1 Contribution, T1E1.4/92-201, December 1992.

[8] American National Standards Institute, contribution to standards review, T1E1.4/96-170R1, April 1999.

[9] M. Darveau et al, NorTel Inc, “QA / CAP RADSL Interference into DMT-ADSL”, American National Standards Institute, contribution to standards review, T1E1 Ad Hoc/97-166, 1997.

[10] V. Freidman et al, “VDSL Draft Specifications”, American National Standards Institute Document T1E1.4/98-054R1 (June 1998).

[12] P.Chow, J. Tu, and, J. Cioffi, “Performance Evaluation of a Multichannel Transceiver System for ADSL and VDSL”, IEEE JSAC, Vol. 9, no. 6, August 1991.