xDSL Modulation Techniques

Methods of achieving spectrum-efficient modulation for high quality transmissions.

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NEXTEP BROADBAND
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Introduction

All signals sent over conventional pair-cable telephone lines are subject to line attenuation, dispersion and electrical noise. Line attenuation and some forms of in-band noise both increase with frequency. Consequently, modern high-rate digital systems require special spectrally efficient modulation techniques, which can be implemented with appropriate equalisation and noise mitigation methods, to achieve high-quality transmission performance.

CAP Modulation

Carrierless amplitude and phase (CAP) modulation is closely related to the more familiar quadrature amplitude modulation (QAM) method.

- QAM typically generates a double sideband suppressed carrier signal constructed from two multi-level pulse amplitude modulated (PAM) signals applied in phase quadrature to one another.
- CAP modulation produces the same form of signal as QAM without requiring in-phase and quadrature components of the carrier to first be generated.

The essentials of the CAP technique are illustrated in the following diagrams.

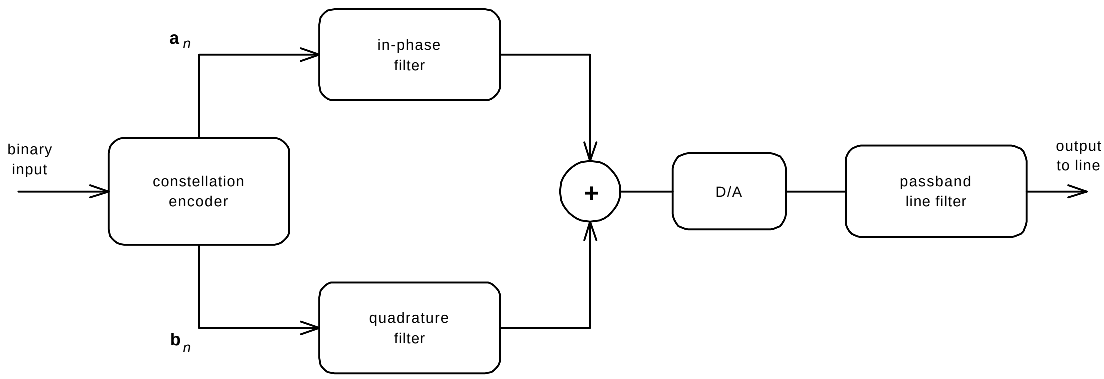

Figure 1 - Conceptual CAP Transmitter

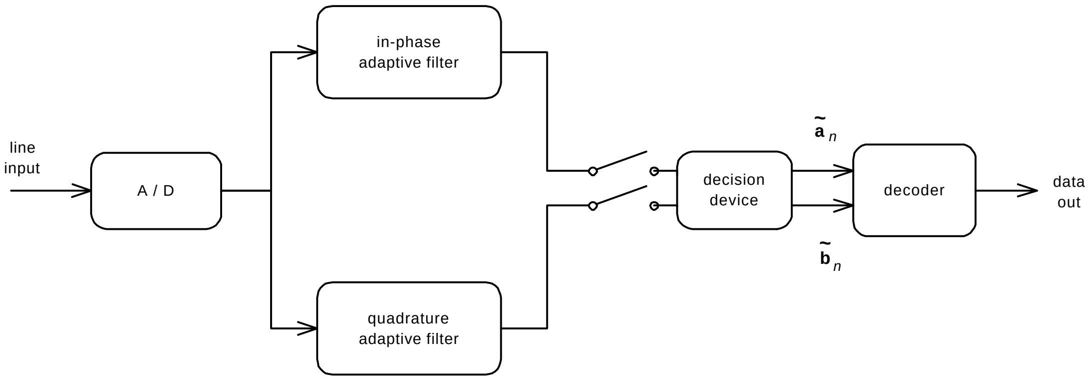

Figure 2 - Conceptual CAP Receiver

In its simplest form, the transmitter's constellation encoder maps groups of the incoming data bits into two multi-level symbol streams a_1, a_2 … a_n and b_1, b_2 … b_n. The usual requirements of multi-level PAM apply here, so that if K bits are mapped into every a_n and every b_n, then each of these symbols necessarily requires 2^k levels.

As shown in Figure 1, the a_n symbols are fed into a special in-phase passband filter and the b_n to a corresponding quadrature filter. These two filters are designed so that their impulse responses *h(t)* and h'*(t)* form a Hilbert pair. This means that the Fourier transforms of *h(t)* and h'*(t)* have the same amplitude characteristic, and phase characteristics that differ by + ð / 2 when the frequency *f* is positive and – ð /2 when *f* is negative. It can be shown that this property causes the responses *h(t)* and h'*(t)* to be orthogonal functions, in the sense that:

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$$h(t) * h'(t)\, dt = 0$$

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It is this orthogonality which enables each of the two separate waveforms to be combined into one two-dimensional signal to be transmitted over the line (as shown in Figure 1) and to be recovered and separated again at the receiver.

Note that since the above-mentioned properties of Hilbert pairs causes the two signal components to be in phase quadrature, the set of resultant two-dimensional signals produced by all possible two-dimensional symbols generates an appropriate signal constellation. It is usual to include the constellation size when describing a specific form of CAP modulation. For example, Figure 3 illustrates a constellation for 64 CAP.

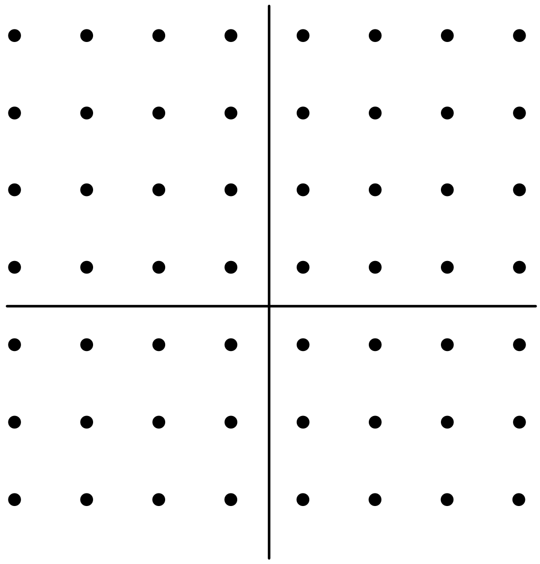

Figure 3 – Typical CAP Signal Constellation (64 CAP)

Note that although *h(t)* and h'*(t)* are altered when they are transmitted over the cable pair, the respective modified responses appearing at the receiver input are still orthogonal[1]. This property is of fundamental importance to two-dimensional modulation techniques like CAP because it enables the separate in-phase and quadrature symbols to be recovered independently at the receiver. The in-phase and quadrature adaptive filters within the CAP receiver perform this function.

Actual xDSL CAP transceivers are considerably more complex than the basic model described here. Tomlinson pre-coding is employed to remove inter-symbol interference (ISI) without introducing decision feedback error propagation. Noise predictive filtering is applied to optimise demodulation in the presence of coloured noise. Furthermore, both Trellis and Reed-Solomon coding are included to improve performance in the presence of continuous and impulsive noises.

In the ANSI xDSL CAP Standard[2] the respective up and downstream channels are separated in frequency. This does away with the need for echo cancellation, and provides good spectral compatibility with a number of other DSL services. In addition, the constellation sizes allow for up to 256 CAP. This enables downstream rates of over 7 Mbps to be carried when the maximum downstream symbol rate of 1088 kbaud is employed.

CAP transceivers produced on the basis of the ANSI xDSL CAP Standard achieve high spectral efficiency and performance, and

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[1] This is a property of the linearity of the channel, which guarantees that the modified responses g(t) and g'(t) still form a Hilbert pair.

[2] T1.413 "Network and Customer Installation Interfaces – Asymmetric Digital Subscriber line (ADSL) Metallic Interface" ANSI Standard

have a demonstrated ability to deliver high rates at good transmission quality over access network telephone lines.

DISCREET MULTI-TONE (DMT) MODULATION

The Discreet Multi-Tone (DMT) modulation technique has evolved from the concept of operating an array of N relatively low-rate transceivers in parallel to achieve an overall high rate on one line. The N low-rate information streams are kept separated from one another by sending them over N separate frequency sub-bands or sub-channels. DMT modulation effectively achieves this sub-channel arraying within the one transceiver set by utilising the Inverse Fast Fourier Transform (IFFT) and its counterpart, the Fast Fourier Transform (FFT).

A basic DMT transmitter is illustrated in Figure 4, and a DMT receiver in Figure 5. In operation, the transmitter constructs and send DMT symbols at a rate of 1/T, where T is the DMT symbol period. During any given symbol period, the input data is buffered, and each bit is assigned or mapped into one of N complex (QAM) multi-level sub-symbols by the DMT symbol encoder[3]. Since these N sub-symbols are represented by N complex numbers, they can be regarded as the discrete frequency domain representation of some time domain signal. Hence, the time domain signal can be obtained by performing an appropriate inverse Fourier transform operation. As Figure 4 indicates, the DMT transmitter performs this inverse transform by computing the IFFT. The resulting time domain function is then sent serially through the D/A converter and line filter.

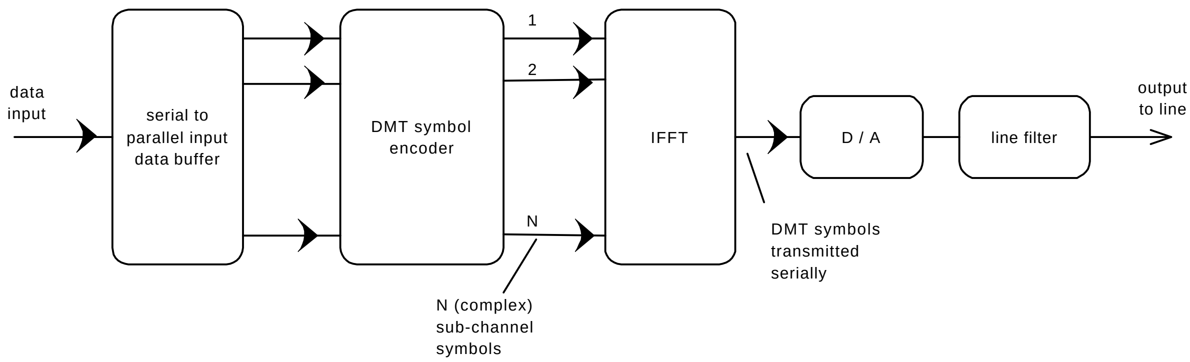

Figure 4 – Conceptual DMT Transmitter

[3] Thus, each sub-symbol is two-dimensional multi-level and can be represented by an appropriate constellation.

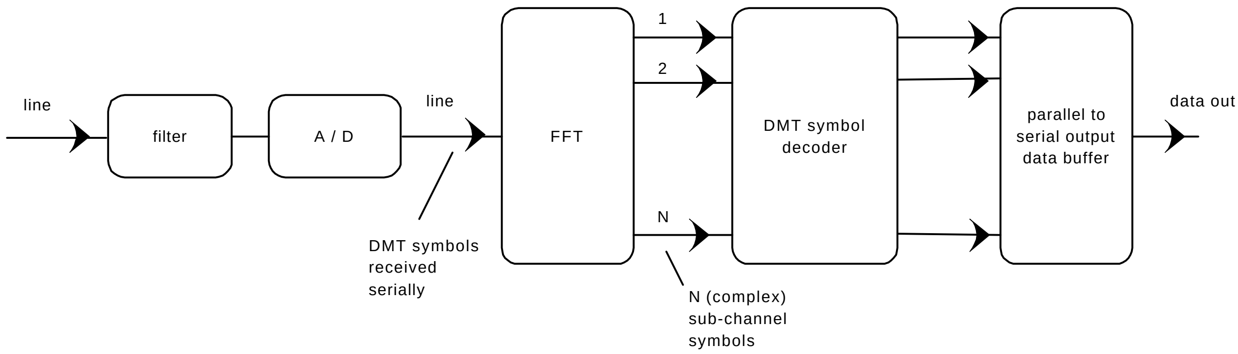

Figure 5 – Conceptual DMT Receiver

DMT is an inherently flexible form of modulation, especially in regard to the mapping of bits into the sub-channel symbols. For the best overall transmission performance, this mapping should be performed in accordance with the information capacities of the individual sub-channels. It is usual therefore to assign the greatest number of bits to the sub-channels with the highest sub-channel signal-to-noise ratio (SNR) and the least number to those with the lowest.

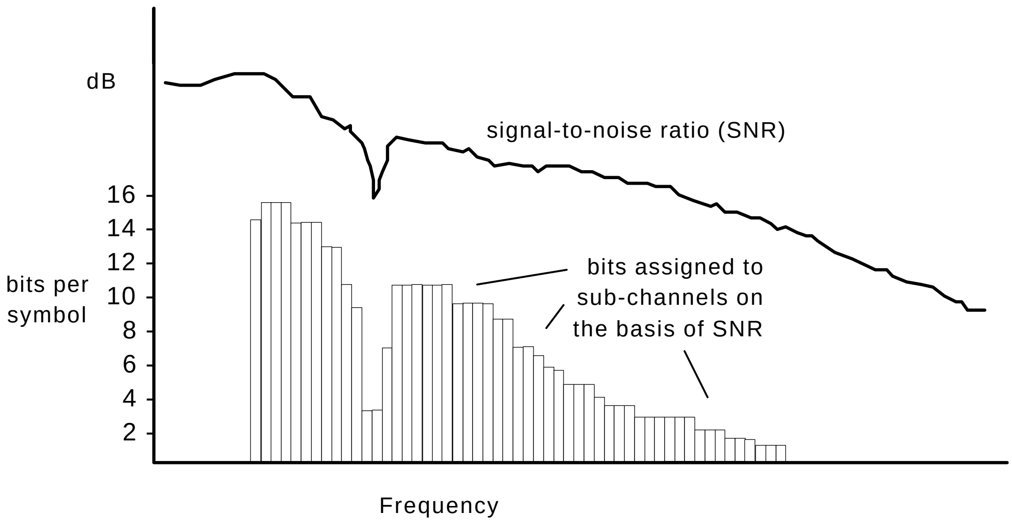

Figure 6 – Variable Bit-rate Mapping into DMT Sub-channels

By comparing Figure 5 with Figure 4, it is observed that the DMT receiver essentially performs the reverse set of operations to the transmitter to produce its estimates of the original transmitted data.

By employing a large number of sub-channels (N large) and a relatively large maximum sub-channel capacity (in bits per symbol) DMT modulation has the capability to handle high information rates at a low symbol rate. Consequently, channel dispersion effects can be corrected without the need for highly complex equalization.

Actual DMT transceivers utilise Reed-Solomon coding to correct the signal clipping that can occur (typically with very low probability) with this form of modulation. As with CAP Transceivers, this coding enhances the system performance under impulsive noise. Trellis coding may also be used on the sub-channels to gain additional overall performance capability.

The ANSI standard specifies DMT modulation allowing for a theoretical total of 255 sub-channels centred on frequencies of mÄ*f* , where m = 1 to 255, and Ä*f* = 4.3125 kHz. Not all of these sub-channels can be used in practice, as voice-band splitting filters are employed to separate the xDSL band from that of the Plain Old Telephone Service (POTS). The design of these filters determines the minimum useable value of m. The Standard also allows for either frequency separation of the respective downstream and upstream channels, or for separation by echo cancellation.

DMT xDSL transceivers based on the Standard have been proven to provide high-grade performance in the field.

CONTRIBUTING COMPANIES

For over a year, two of Australia's leaders in DSL technology have worked together to perfect a cost-effective high speed broadband service for small and medium enterprises (SMEs).

The result is a new business enterprise, Nextep Broadband, bringing together the expertise of NEC Australia and xDSL Limited.

NEC Australia

NEC Australia has more than 7 years experience with broadband deployments in Australia, New Zealand, Spain, Venezuela, Japan and Hong Kong, and is the DSL Global Design Centre for NEC Corporation.

NEC's DSL-based system is a standards-based, fully managed, multi-service access platform designed for carrier and enterprise applications. System interoperability has been tested and confirmed with more than 20 major customer premises equipment (CPE) vendors and a range of backend server, switch and transmission equipment.

xDSL Limited

xDSL Limited was established in 1999 to explore the commercialisation of DSL as a broadband technology in Australia. Its major shareholders include ASX-listed Sirocco Resources N.L., the RMB Ventures group and AIB investments.

xDSL has a 26.7% interest in VOD Pty Limited, a joint venture with the Sirocco group and Civic Video. VOD is currently deploying video-on-demand over the TransACT network in Canberra.

xDSL has considerable experience in deploying content and other broadband services in commercial environments. The success of xDSL is due in large measure to its highly focused and skilled team assembled from a broad mix of backgrounds and disciplines.

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