ADSL

This lecture describes Asymmetric Digital Subscriber Line (ADSL), an access technology that allows data transmission over twisted pair cables of up to several km at data rates of up to several Megabits per seconds.
After this lecture you should be able to: identify the location and frequency response of the high- and low-pass filters used in ADSL systems, state the spectrum of the signal at a POTS phone and ADSL modem; convert from channel number to subcarrier frequency; solve problems involving DMT parameters (sampling rate, cyclic extension samples, symbol duration, and subcarrier spacing), and explain why shorter loops support higher data rates.

Introduction

Although the number of ADSL subscribers is declining, in 2013 about 2/3 of the approximately 700 million broadband subscribers in the world used ADSL for broadband network access. This is several times the number of cable modem users.

The ADSL standards are defined in ITU-T G.992. The first version (sometimes called ADSL 1) supported downstream/upstream data rates if 8/0.8 Mb/s. ADSL2 increased this to 15/3.5 and ADSL2+ to 24/3.5.

ADSL "modems" are called ATU-C (ADSL Termination Unit - Central (Office)) and ATU-R (ADSL Termination Unit - Remote) and are installed on either side of a conventional PSTN twisted-pair loops as shown in the following diagram from the ADSL2 spec (ITU-T G.992.3):

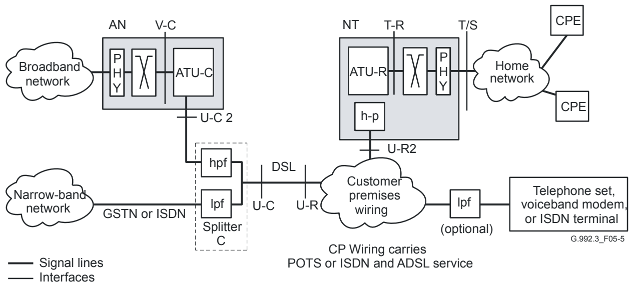


Figure 5-5 – Generic application reference model for splitterless remote deployment

Low-pass and high-pass filters are used to isolate the different uses.

Exercise 1: Based on the diagram above, are the ADSL signals higher or lower in frequency than the conventional telephone signals?

The signals on the twisted-pair cable appear at three different frequency ranges: POTS audio is below 4 kHz, the upstream signal is from about 25 to 138 kHz and the downstream signal from 138 kHz to 1.1 MHz

ADSL 1

Downstream - ATU-C Transmitter

The ATU-R can transmit upstream at frequencies from about 25 kHz to about 138 kHz as shown in the following power spectral density mask from the ADSL 1 spec (G.992.1):

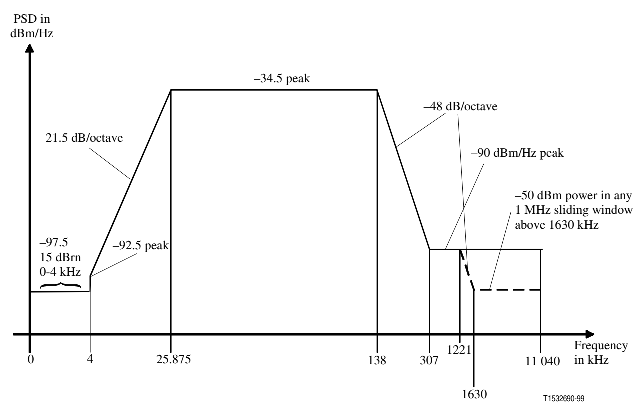


Figure A.3/G.992.1 – ATU-R transmitter PSD mask

The downstream signal can extend up to about 1.1 MHz:

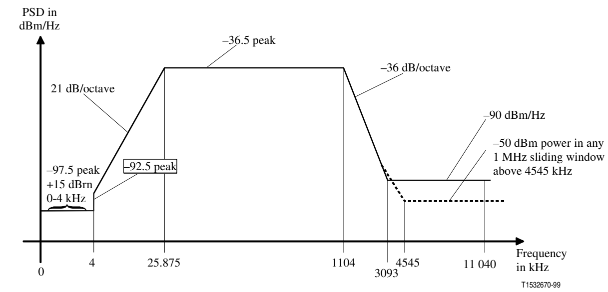


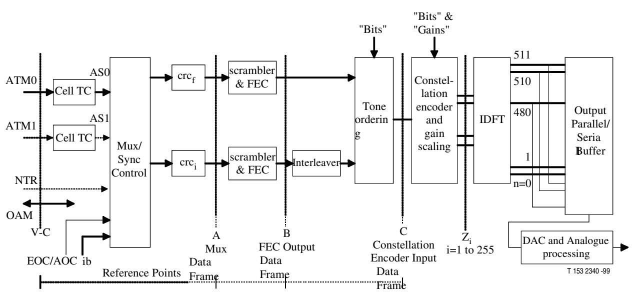
Figure A.1/G.992.1 – ATU-C transmitter PSD mask

Both ATUs use DMT (Discrete Multi-Tone), another name for OFDM (Orthogonal Frequency Division Multiplexing), to generate the transmitted signal.

The DMT signal consists of up to 255 subcarriers spaced 4.3125 kHz apart. Each subcarrier is numbered starting at 0 for DC.

Exercise 2: What ranges of subcarrier numbers are used for the upstream and downstream?

The signal processing for the downstream signal is shown in the following diagram:



NOTE – Solid versus dashed lines are used to indicate required versus optional capabilities respectively. This figure is not intended to be complete in this respect, see clauses 6 and 7 for specific details.

Figure 5-2/G.992.1 – ATU-C transmitter reference model for ATM transport

The ATM (Asynchronous Transfer Mode) inputs represent the data inputs to the ATU along with an 8 kHz network timing reference (NTR) and OAM (Operations, Administration and Maintenance) data. These are multiplexed into frames, a CRC added and scrambling, Reed-Solomon FEC encoding and interleaving are done. The resulting bits are the distributed to the different subcarriers, each of which can carry a different number of bits. The bits select a point from the appropriate constellation. The 256 complex values now represent the phase and amplitude of the subcarriers. An Inverse Discrete Fourier Transform (IDFT) converts the frequency-domain value to time samples which are then converted to a continuous analog waveform by an A/D and reconstruction filters.

The sampling rate is $f_s = 2.208$ MHz. Each OFDM symbol is $N = 512$ samples which results in symbol duration of $T_s = N/f_s = 512/2.208$ microseconds. The subcarrier spacing is the inverse of the symbol duration, $\Delta f = 1/T_s = 4.3125$ kHz. A 32-sample cyclic prefix is added to each symbol resulting in a symbol-plus-guard time duration of $(N + N_g)/f_s$ = (512+32)/2208μs.

As shown below, a synchronization symbol is inserted every 68 data symbols. The data symbol rate, not including sync symbols, is thus 1/(544/2208 kHz) * 68/69 = 4 kHz.

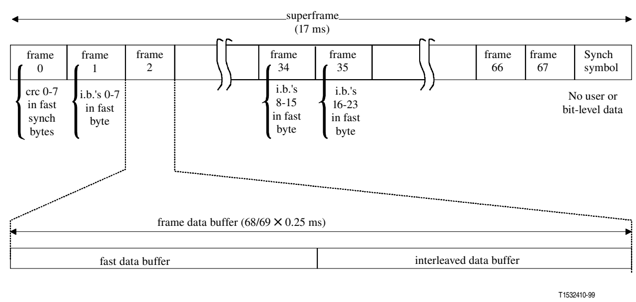


Figure 7-5/G.992.1 – ADSL superframe structure – ATU-C transmitter

A diagram of the scrambler is shown below:

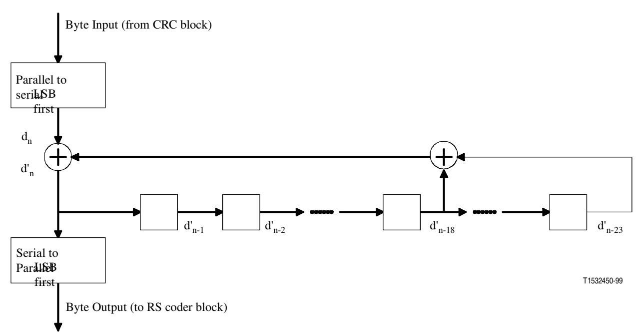


Figure 7-10/G.992.1 – Scrambler

Exercise 3: Is this an additive or convolutional (multiplicative) interleaver? Does it need framing synchronization?

A GF(256) Reed-Solomon FEC code is used with the number of parity bytes configurable between 0 to 16 bytes (in increments of 2).

Exercise 4: How many errors per codeword can be corrected?

A convolutional interleaver is used that distributes each RS codeword among between 1 and 16 DMT symbols (in powers of 2).

Since ADSL links are point-to-point there is no need for a MAC to handle contention for the medium. However, protocols are still required to handle ADSL-specific signalling and for framing and error detection.

Upstream - ATU-R Transmitter

The upstream signal uses the same type of modulation and coding with some changes to accommodate the smaller upstream bandwidth.

The sampling rate is reduced by a factor of 8 to 276 kHz. The number of samples is reduced by the same factor, to 64 samples, which results in the same symbol duration and subcarrier spacing as on the downstream.

The cyclic prefix is also scaled by a factor of 8 to 4 samples and so the net upstream symbol rate is also 4 kHz.

The maximum interleaving depth is reduced to avoid long interleaving delays.

ADSL2 and ADSL2+

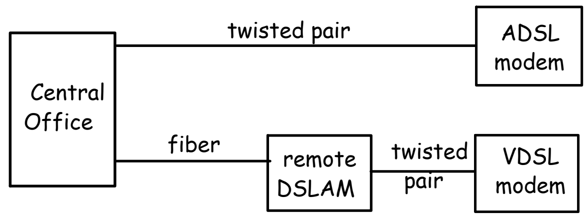
A higher-speed version of ADSL was specified in ITU-T Recommendation G.993.2. ADSL2 also uses DMT and shares many of the characteristics of ADSL1 but offers higher data rates by using more advanced modulation and coding techniques.

VDSL

The VDSL (very high-rate DSL) standards were designed to support "triple-play" service: phone, TV and internet services and support up to hundreds of Mb/s, but over short distances.

The attenuation of twisted pair loops increases with frequency. VDSL relies on the fact that shorter loops have less attenuation and thus higher effective bandwidth. VDSL also uses frequencies up to 12 MHz (30 MHz for VDSL2).

To allow for shorter loops the DSLAM has to be moved to a location outside the CO and nearer the customer. To achieve these distances and rates requires installing remote DSLAMs and fiber to the neighborhood (FTTN).A fiber link then connects the CO to this remote DSLAM. A similar approach can be used in apartment buildings and other MTU (multi-tenant units).



There are also variants such as SDSL (symmetric DSL) which support higher upstream data rates; typically for customers that run servers. These are much less common that ADSL.