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

ADSL is an access technology typically used for consumer internet access. The "Asymmetric" name is because, like DOCSIS cable modems, ADSL supports higher data rates in the downstream than upstream direction. This is to support typical customer use patterns (video streaming, file download, web browsing).

There are also symmetric versions of DSL for business uses that require symmetric data rates (telephony, mail and web servers, etc). However, symmetric DSL service is more expensive and less commonly used.

The customer equipment is an ADSL modem which connects to a DSL Access Multiplexer (DSLAM) at the CO or, increasingly frequently, at a cabinet on the curb. The DSLAM is connected by fiber to routers that provide internet access and to gateways to the PSTN.

VDSL and VDSL2 are higher-speed standards that are limited to short loops (a few blocks or inside a building). The higher data rates are primarily meant for video on demand. This enables telephone companies to provide "Triple Play" (TV, phone and Internet) services.

Standards

The ADSL standards are defined in ITU-T G.992. The first version defined in G.992.1 is sometimes called ADSL 1 and supported downstream/upstream data rates if 8/0.8 Mb/s. ADSL2 (G.992.3) increased this to 15/3.5 and ADSL2+ (G.992.5) to 24/3.5.

ADSL "modems" are called an ATU-C (ADSL Termination Unit - Central (Office)) and ATU-R (ADSL Termination Unit - Remote) in the standard. They 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):

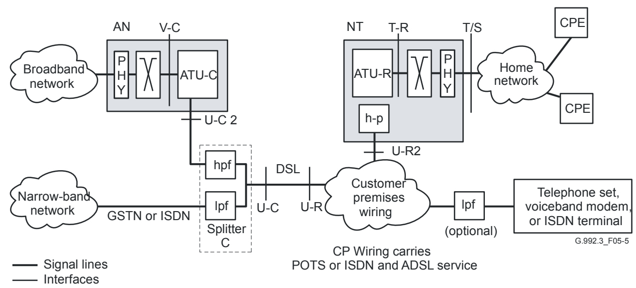


Figure 5-5 – Generic application reference model for splitterless remote deployment

A splitter is used to separate the different parts of the spectrum. Frequencies below 4 kHz are used for normal POTS service while frequencies above that are used for data. Often the high-pass filter is in the ADSL modem and a low-pass filter is customer-installed on each telephone as shown above.

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 actually appear at three different frequency ranges: POTS audio is below 4 kHz, and the upstream signal is from about 25 to 138 kHz and the downstream signal from 138 kHz to 1.1 MHz

The Local Loop

The average length of a POTS loop is 11kft (3km) of 24 or 26 gauge wire. Telephone loops were installed for POTS service using some practices that cause problems for ADSL.

The most significant is the use of "loading coils" on long loops. These are inductors inserted in series with the loop to equalize the frequency response in the voice frequency range. Unfortunately, they greatly increase attenuation at frequencies above 4 kHz and make ADSL service impossible. Fortunately, loading coils are typically found only on the long loops found in rural areas.

Another issue is that most loops will have unterminated "taps" connected in parallel. These could be from old drops or unused sections of cable that were not disconnected. Signals reflect from the open ends of these "bridge taps" and cause nulls in the spectrum. ADSL modems can typically deal with these.

A related issue is reflections from gauge discontinuities and splices that are necessary for installation and maintenance and the fact that most loops are longer than the length on a spool of cable.

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):

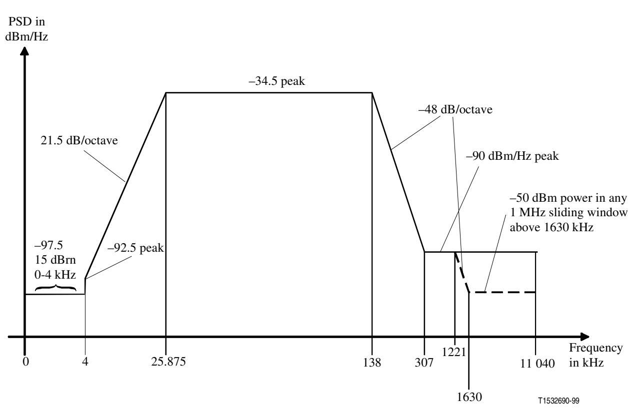


Figure A.3/G.992.1 – ATU-R transmitter PSD mask

The downstream signal can extend up to about 1.1 MHz:

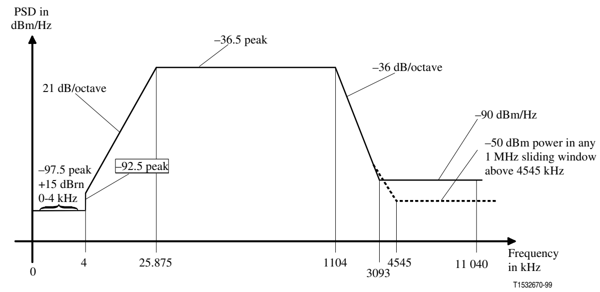


Figure A.1/G.992.1 – ATU-C transmitter PSD mask

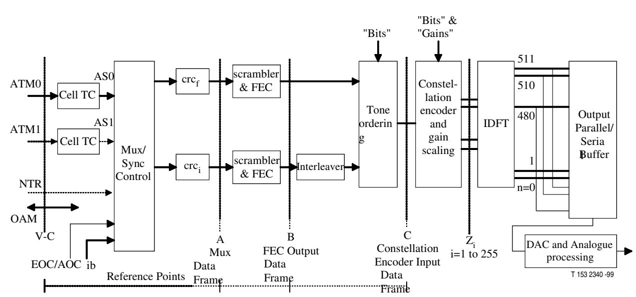
Exercise 2: Calculate the maximum upstream and downstream transmit powers (*consider only the frequencies where the power is highest*)?

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 3: What is the equation for subcarrier number as a function of frequency? 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.

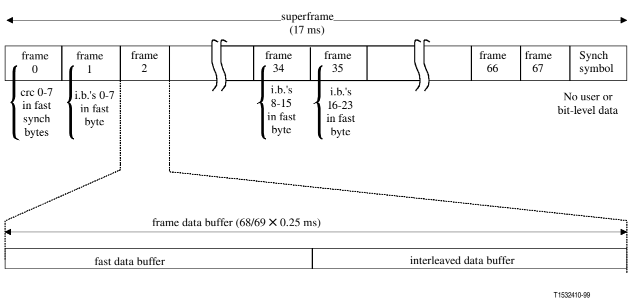


Figure 7-5/G.992.1 – ADSL superframe structure – ATU-C transmitter

A diagram of the scrambler is shown below:

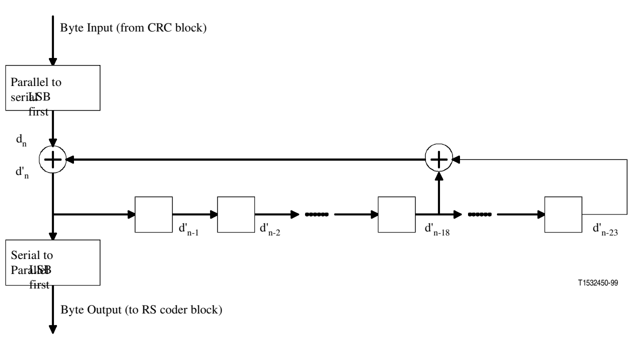


Figure 7-10/G.992.1 – Scrambler

Exercise 4: 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 5: 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.

VDSL is possible because on shorter loops frequencies significantly higher than 1.1 MHz are useful for transmission of data, and therefore it is possible to support higher bit rates than with ADSL on these shorter loops. Typically, a maximum loop length of 1500 m (4.5 kft) was assumed in the early VDSL work. VDSL can use frequencies up to 12 MHz (30 MHz for VDSL2).

To make the loops shorter the VDSL DSLAM has to be moved to a location and nearer the customer. This often requires installing remote DSLAMs and fiber to the neighborhood (or node) (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).