Course 8-9
DSL (Digital Subscriber Line) access techniques.

Zsolt Polgar

Communications Department
Faculty of Electronics and Telecommunications,
Technical University of Cluj-Napoca

Content of the course

- Principles of DSL access;
- SDSL techniques;
  - Classification;
  - The HDSL technique;
  - The CAP/QAM modulation.
- ADSL techniques;
  - Classification/Characteristics;
  - ADSL frequency band allocation;
  - Access architecture/Connection to line;
  - Distortions which affects the ADSL transmissions;
  - The principles of DMT modulation/DMT performances.
- VDSL techniques;
  - VDSL frequency band allocation;
  - Categories of VDSL techniques;
  - Performances of the VDSL techniques.

Conţinutul cursului

- ADSL2 techniques;
  - Characteristics/Features;
  - Power management and rate adaptation;
  - The CVoDSL techniques;
  - Additional benefits.
- ADSL2+ techniques;
  - Allocation of the ADSL2+ frequency bands;
  - ADSL2+ / ADSL2 performances.
- VDSL2 techniques;
  - Characteristics/Features;
  - Allocation of the VDSL2 frequency bands;
  - VDSL2 performances.

The principles of DSL

- The term refers to the technologies and equipments used in a telephone network to ensure the access to a high speed digital network on a twisted wire line;
- There are two basic categories, namely:
  - SDSL – Symmetric DSL;
  - ADSL – Asymmetric DSL;
- SDSL ensures the same transfer rate in both directions:
  - upstream $\rightarrow$ subscriber – exchange;
  - downstream $\rightarrow$ exchange – subscriber;
    - due to the attenuation and crosstalk these systems can work only at medium frequencies;
    - the symmetric DSL variants include: SDSL, SHDSL, MSDSL, HDSL, HDSL-2, IDSL;
    - SDSL is ideal for LAN, bidirectional-video, web servers.

The principles of DSL

- ADSL ensures:
  - In downstream a large bandwidth channel;
    - situated at high frequencies;
  - In upstream a more narrow bandwidth channel;
    - situated at low frequencies;
- This division of the frequency bands has two reasons:
  - The information quantity transmitted in „downstream” is larger;
  - It is reduced the near end crosstalk at the user;
    - which is higher at high frequencies.
- ADSL variants include:
    - ADSL;
    - ADSL G.lite;
      - ensures smaller transfer rates but the connection to the line is simpler;
    - RADSL (Rate adaptive ADSL);
    - VDSL;
      - can work both in symmetric and asymmetric mode.

The principles of DSL

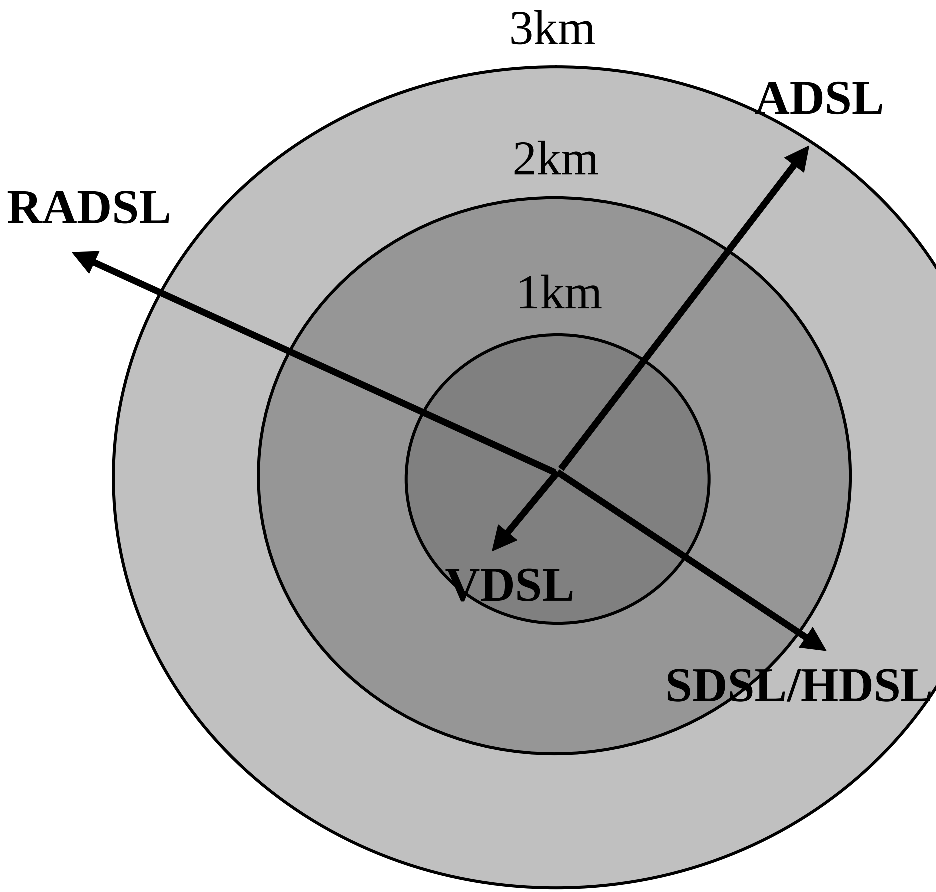
- Characteristics of various xDSL techniques;

DSL variant	Symmetric / Asymmetric	Bit rate		Telephone service	Number of pairs
		Downstream	Upstream		
ADSL	Asymmetric	1.5 Mbps up to 6.1 Mbps	64 kbps up to 640kbps	Yes	1
G.lite ADSL	Asimmetric	Up to 1.5Mbps	Up to 500kbps	Yes	1
HDSL	Symmetric	1.5Mbps	1.5Mbps	No	2/3
HDSL2	Symmetric	1.5 Mbps	1.5 Mbps	No	1
IDSL	Symmetric	144 kbps	144 kbps	No	1
MSDSL	Symmetric	1.5 Mbps	1.5 Mbps	No	1
RADSL	Both	1 Mbps up to 7 Mbps	128 kbps up to 1 Mbps	Yes	1
SDSL	Symmetric	2.3 Mbps	2.3 Mbps	No	1
SHDSL	Symmetric	2.3 Mbps	2.3 Mbps	No	1/2
VDSL	Asymmetric	Up to 52 Mbps	Over 1.5 Mbps	Yes	1

  - characteristic downstream and upstream bit rates;
  - number of pairs used;
  - compatibility with the standard telephone service.

The principles of DSL

- Average transmission distance ensured by different xDSL techniques;



SDSL techniques

- HDSL (High data rate Digital Subscriber Line);
  - Older version of symmetric DSL created as an alternative to the T1 and E1 services;
  - Transmits a rate of 1,544Mbps on two pairs of twisted wire;
    - on each pair a 784kbps rate is transmitted in full-duplex mode
    - it uses the echo compensation technique.
  - Allows the use of normal lines (0,5 mm – no preconditioning) with a 12000ft (3700m) maximum length without the use of repeaters;
    - does not allows the standard telephone service on these lines.
- HDSL2 (Second generation HDSL);
  - Ensures a rate of 1,5Mbps in both directions on a single pair of twisted wire;
    - does not allows the standard telephone service on these lines.

SDSL techniques

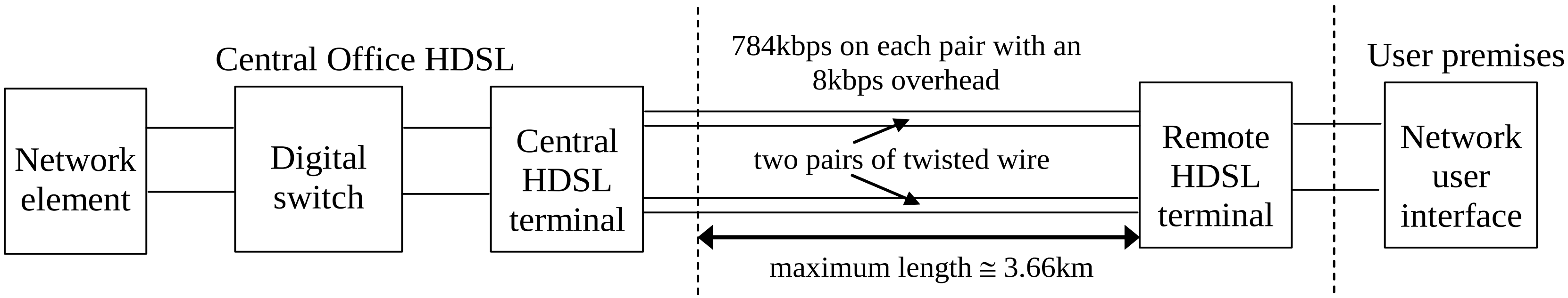
- IDSL (Integrated Services Digital Network DSL);
  - Ensures symmetrical rates up to 144kbps using existing telephone lines and ISDN terminal (ISDN modem);
  - Differs from the ISDN by the fact that it is continuously available;
    - it is used for WAN (Wide Area Network) type applications;
    - does not allow the standard telephone service;
- SDSL (Symmetric Digital Subscriber Line);
  - Ensures high transfer rates on a single twisted pair for T1 and E1 applications;
    - the maximum transfer rate is 2,32Mbps;
    - allows Ethernet interface between the SDSL modem and the user equipment.

SDSL techniques

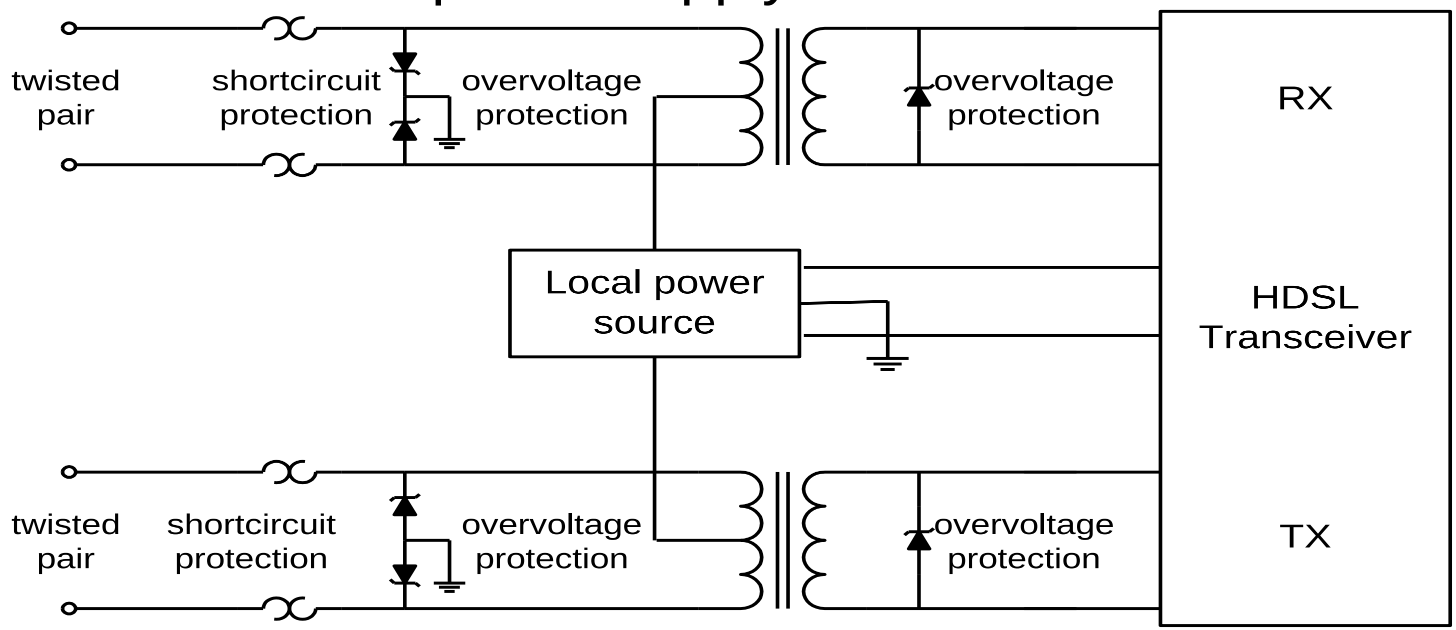
- SHDSL (Symmetric High bit rate Digital Subscriber Line);
  - Allows a 20% higher coverage than SDSL;
  - Allows the use of one or two pairs of twisted wire;
    - for ex. 1,2Mbps transfer rate can be transmitted at 20000ft (6100m) on two normal (0.4 mm) pairs.
- MSDSL (“Multi-rate Symmetric Digital Subscriber Line”);
  - Allows the adaptive change of the rate according to the type of the line;
    - for ex. using the CAP modulation (Carrierless Amplitude & Phase Modulation) are available 8 discrete rates between 64kbps/128kbps (29000ft – 8900m – 0,5mm) and 2Mbps (15000ft – 4600m).

The HDSL technique

- The basic schematic of a HDSL connection;

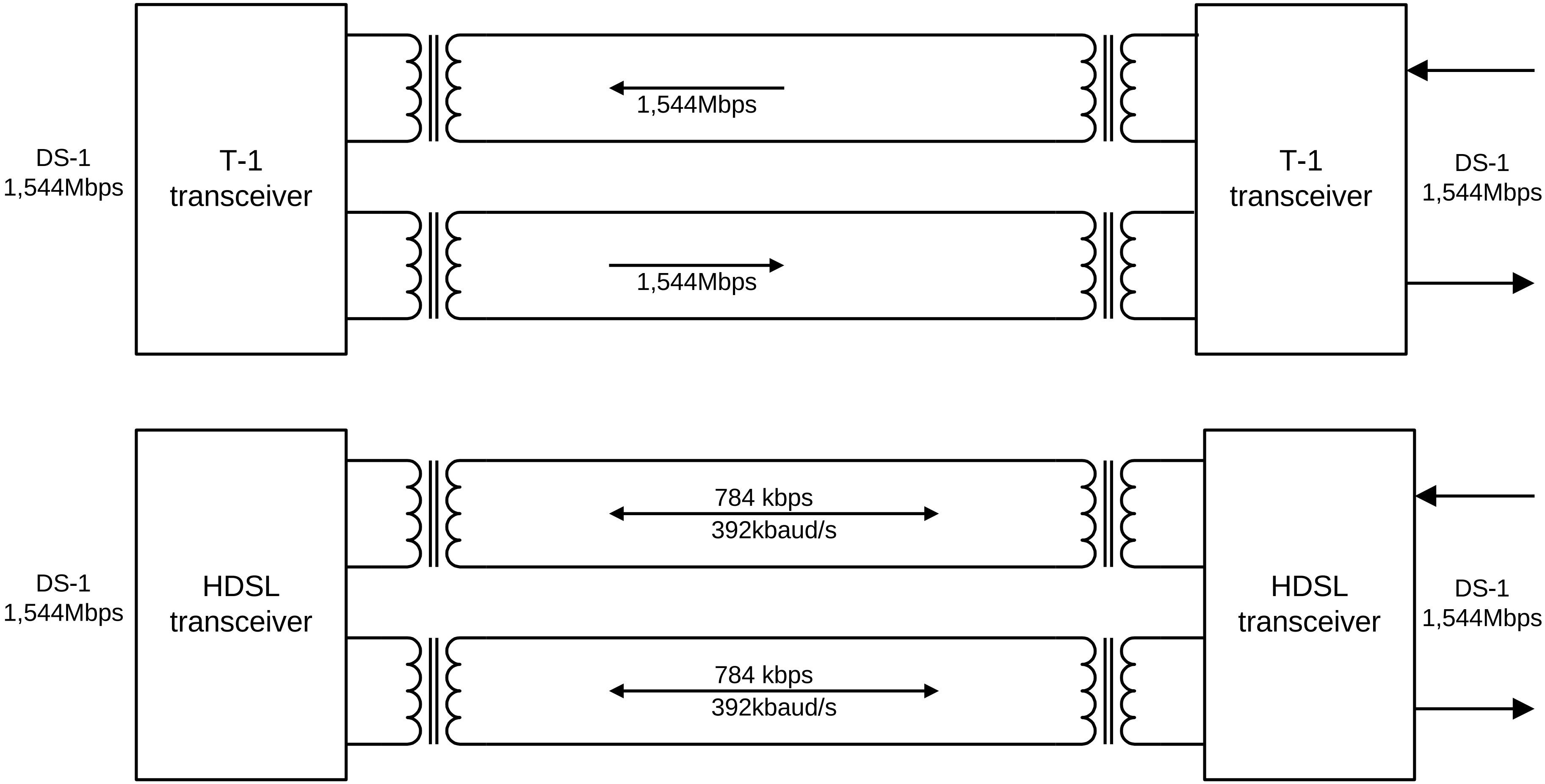


- Connection to the line and power supply of the remote HDSL terminal;



The HDSL technique

- Comparison between the HDSL and T1 transmission modes;



The HDSL technique

- Comparison between the HDSL and T1 transmission modes;
  - T1 technique:
    - lines must be preconditioned;
    - line repeater are required;
    - simplex transmission on each pair of wire;
    - line code: AMI or B8ZS;
    - sensitive to line swapping and polarity reversal.
  - HDSL technique:
    - no preconditioned lines are required;
      - allows bridge taps and wire gauge changes;
    - no repeaters are necessary for distances < 12000ft;
    - duplex transmission on each pair of wire;
    - line code: 2B1Q;
    - transparent to line swapping and polarity reversal.

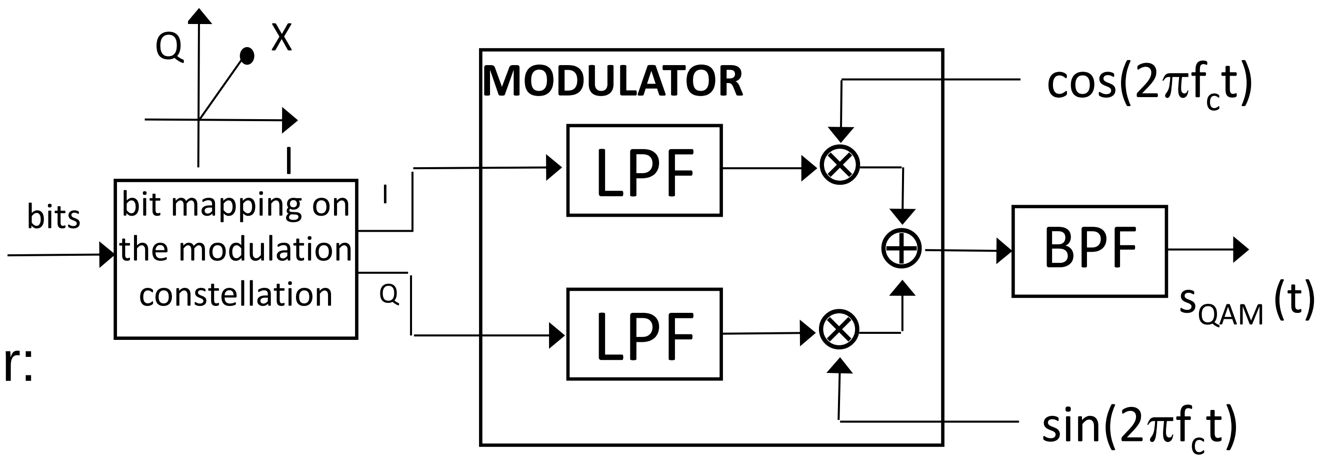
The CAP modulation

- The QAM modulation is one of the best options for data transmissions;
  - It allows the use in the same frequency band of two orthogonal sine carriers:
    - a sine carrier and a cosine carrier;
    - on each carrier are transmitted different signals in the same bandwidth.

$$s_{QAM}(t) = (I(t) * h_{LPF}(t)) \cdot \cos(\omega_c t) + (Q(t) * h_{LPF}(t)) \cdot \sin(\omega_c t) = I'(t) \cdot \cos(\omega_c t) + Q'(t) \cdot \sin(\omega_c t)$$

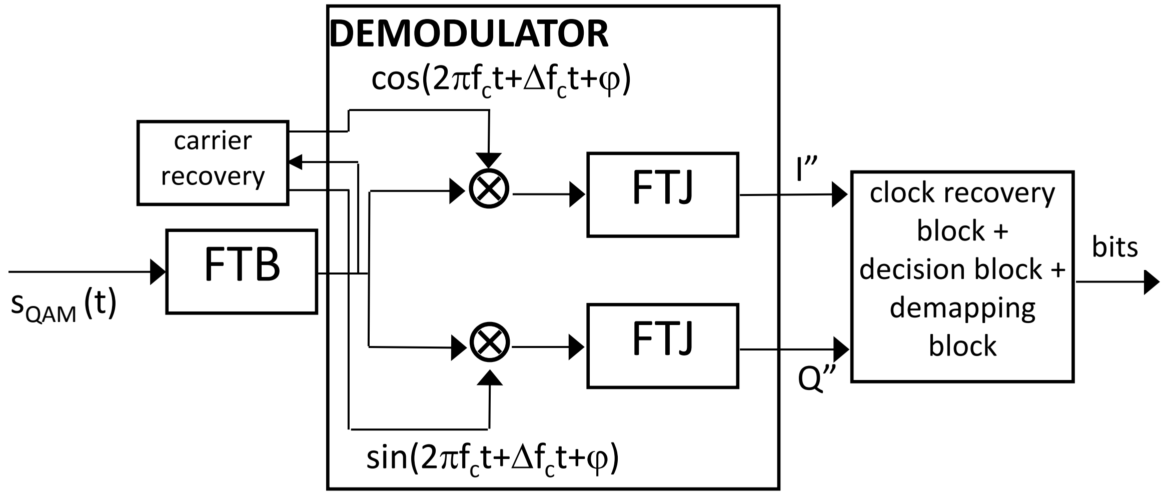
  - $h_{LPF}(t)$ is the impulse response of low pass shaping filters.

- Block schematic of a QAM modulator:



The CAP modulation

- Block schematic of a QAM demodulator:



  - The I”(t) and Q”(t) signals obtained after the QAM demodulation using a local carrier with $f_c+\Delta f_c$ frequency and phase φ:

$$I''(t)=\left(s_{QAM}(t)\cdot\cos\left(\omega_c t+\Delta\omega_c t+\phi\right)\right)*h_{LPF}(t)=\left(\left(I'(t)\cdot\cos\left(\omega_c t\right)+Q'(t)\cdot\sin\left(\omega_c t\right)\right)\cdot\cos\left(\omega_c t+\Delta\omega_c t+\phi\right)\right)*h_{LPF}(t)=$$

$$=\left[\frac{I'(t)}{2}\cdot\left[\cos\left(2\omega_c t+\Delta\omega_c t+\phi\right)+\cos\left(\Delta\omega_c t+\phi\right)\right]+\frac{Q'(t)}{2}\cdot\left[\sin\left(2\omega_c t+\Delta\omega_c t+\phi\right)-\sin\left(\Delta\omega_c t+\phi\right)\right]\right]*h_{LPF}(t)=$$

$$=\left[\frac{I'(t)}{2}\cdot\cos\left(\Delta\omega_c t+\phi\right)-\frac{Q'(t)}{2}\cdot\sin\left(\Delta\omega_c t+\phi\right)\right]*h_{LPF}(t)$$

The CAP modulation

$$Q''(t)=\left(s_{QAM}(t)\cdot\sin\left(\omega_c t+\Delta\omega_c t+\phi\right)\right)*h_{LPF}(t)=\left(\left(I'(t)\cdot\cos\left(\omega_c t\right)+Q'(t)\cdot\sin\left(\omega_c t\right)\right)\cdot\sin\left(\omega_c t+\Delta\omega_c t+\phi\right)\right)*h_{LPF}(t)=$$

$$=\left[\frac{I'(t)}{2}\cdot\left[\sin\left(2\omega_c t+\Delta\omega_c t+\phi\right)+\sin\left(\Delta\omega_c t+\phi\right)\right]+\frac{Q'(t)}{2}\cdot\left[\cos\left(\Delta\omega_c t+\phi\right)-\cos\left(2\omega_c t+\Delta\omega_c t+\phi\right)\right]\right]*h_{LPF}(t)=$$

$$=\left[\frac{I'(t)}{2}\cdot\sin\left(\Delta\omega_c t+\phi\right)+\frac{Q'(t)}{2}\cdot\cos\left(\Delta\omega_c t+\phi\right)\right]*h_{LPF}(t)$$

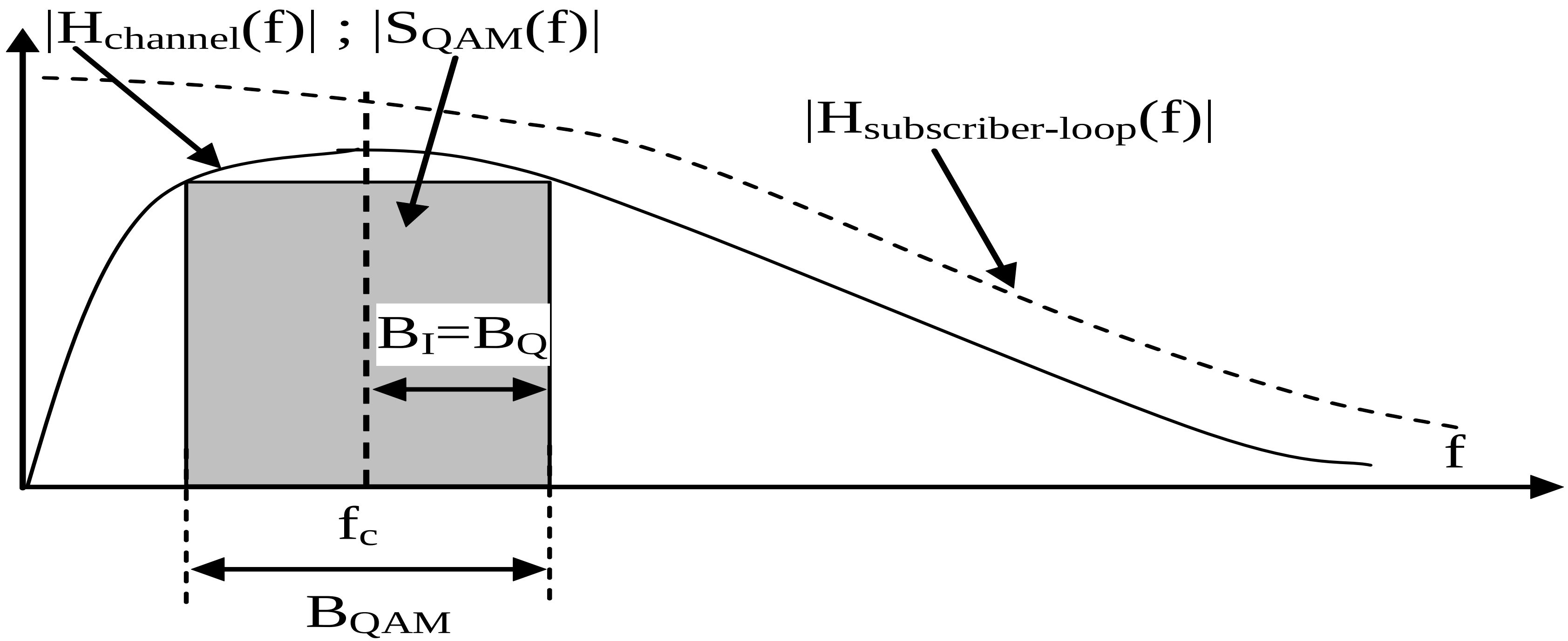
- If the carrier recovery is perfect, meaning $\Delta\omega_c=0$ and $\varphi=0$, then I"(t) and Q"(t) demodulated signals are:

$$I''(t)=I'(t)*h_{LPF}(t) \quad ; \quad Q''(t)=Q'(t)*h_{LPF}(t)$$

- The use of QAM type modulations in the subscriber loop implies the following issues:
  - the bandwidth of the QAM signal is twice of the I(t) and Q(t) modulator signals bandwidth;
  - the spectrum of the QAM signal is centered on the carrier frequency;
  - carrier recovery is necessary.
- The use of a base-band transmission with high spectral efficiency is the best idea.

The CAP modulation

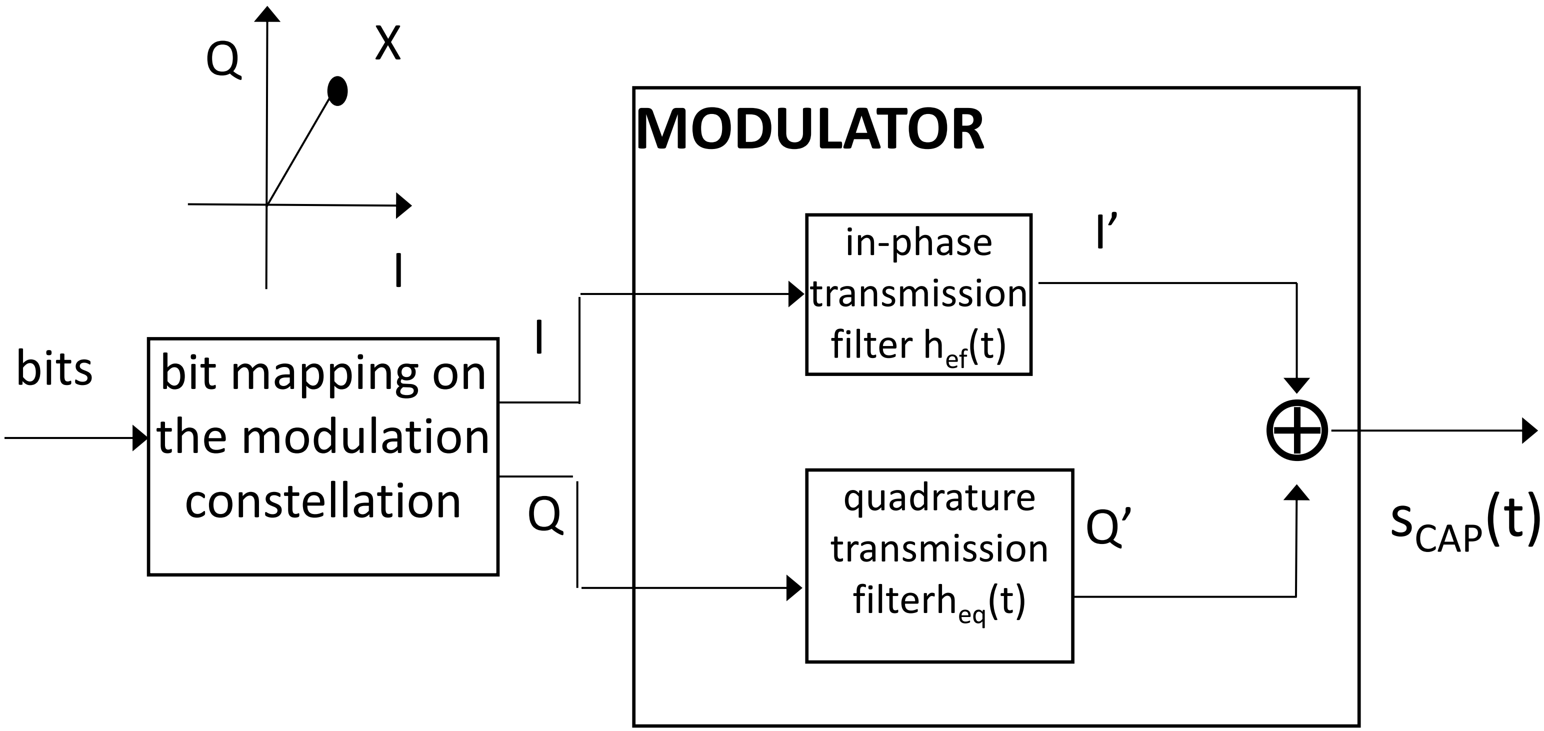
- Spectrum of QAM modulated signal; BPF and LPF channel transfer characteristics;



- The channel characteristic is given by the transfer function of the twisted wires and of the separation transformers;
- It is difficult to “position” the QAM spectrum in an efficient way the pectrul QAM in the channel characteristic of the subscriber loop.

The CAP modulation

- The CAP modulation ensures the transmission of two different baseband signals in the same frequency band;
- Block schematic of the CAP modulator:



$$s_{CAP}(t) = I(t) * h_{ef}(t) + Q(t) * h_{eq}(t)$$

The CAP modulation

- Conditions imposed to the transmission and reception filters transfer functions: $|H_{ef}(\omega)| = |H_{eq}(\omega)| \quad \forall\omega$

$$\varphi_{ef}(\omega) = \varphi_{eq}(\omega) + \frac{\pi}{2} \quad \text{if } \omega > 0 \quad ; \quad \varphi_{ef}(\omega) = \varphi_{eq}(\omega) - \frac{\pi}{2} \quad \text{if } \omega < 0$$

$$h_{ef}(t) * h_{eq}(t) = 0$$

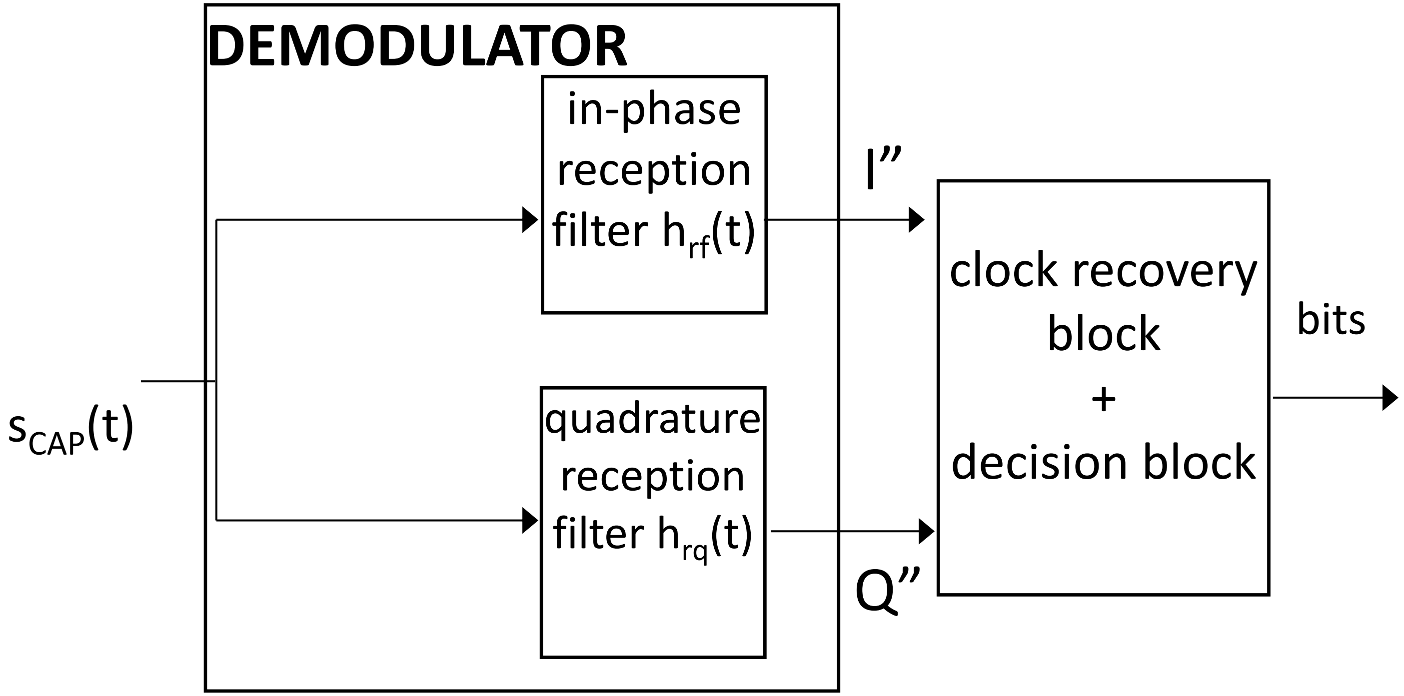
$$\varphi_{rf}(\omega) = \varphi_{eq}(\omega) + \frac{\pi}{2} \quad \text{if } \omega > 0 \quad ; \quad \varphi_{rf}(\omega) = \varphi_{eq}(\omega) - \frac{\pi}{2} \quad \text{if } \omega < 0$$

$$\varphi_{rq}(\omega) = \varphi_{ef}(\omega) + \frac{\pi}{2} \quad \text{if } \omega > 0 \quad ; \quad \varphi_{rq}(\omega) = \varphi_{ef}(\omega) - \frac{\pi}{2} \quad \text{if } \omega < 0$$

  - The in-phase and quadrature filters are related by the Hilbert transform:
    - the quadrature filter transfer characteristic can be obtained from the in-phase filter by applying the Hilbert transform to the in-phase filter transfer characteristic.
  - The bandwidth of the CAP modulated signals is half of the QAM modulated ones;
  - The spectrum is centered at low frequencies where the subscriber loop attenuation is low.

The CAP modulation

- Block schematic of the CAP demodulator;



$$I''(t) = s_{CAP}(t) * h_{rf}(t) = \big(I(t) * h_{ef}(t) + Q(t) * h_{eq}(t)\big) * h_{rf}(t) = I(t) * \big(h_{ef}(t) * h_{rf}(t)\big) + Q(t) * \big(h_{eq}(t) * h_{rf}(t)\big) =$$
$$= I(t) * \big(h_{ef}(t) * h_{rf}(t)\big)$$

$$Q''(t) = s_{CAP}(t) * h_{rq}(t) = \big(I(t) * h_{ef}(t) + Q(t) * h_{eq}(t)\big) * h_{rq}(t) = I(t) * \big(h_{ef}(t) * h_{rq}(t)\big) + Q(t) * \big(h_{eq}(t) * h_{rq}(t)\big) =$$
$$= Q(t) * \big(h_{eq}(t) * h_{rq}(t)\big)$$

ADSL techniques

- ADSL (Asymmetric Digital Subscriber Line);
  - Can provide rates between 6 and 9 Mbps in downstream and up to 1Mbps in upstream;
  - Was developed in the late 1980s, its original function being video delivery over copper (twisted pairs);
  - Currently is used for high bit rate data transfer – high speed Internet access;
  - Works on a single pair of twisted wire and allows the standard telephone service;
- ADSL G.lite – is a simplified variant of ADSL for domestic users;
  - It can deliver in downstream up to 1,5Mbps and up to 500kbps in upstream;
    - the connection to the telephone line is simpler.

ADSL techniques

- RADSL (Rate Adaptive Digital Subscriber Line);
  - Allows the adaptation of the transmission rate up to 7Mbps in downstream and up to 1Mbps in upstream;
  - The transceiver adapts automatically the bandwidth assigned to upstream and downstream transmission in order to obtain the highest possible effective rate;
  - Allows both symmetrical and asymmetrical applications.
- VDSL (Very high bit rate Digital Subscriber Line);
  - Can deliver transfer rates between 25Mbps and 50Mbps can be obtained over low distances (ten meters, maximum hundred meters);
    - meaning between the user and the optical fiber;
  - It can be configured also for symmetric transmissions;
  - The first standardization activities have started in 1995;
  - Standardized in 2003: G.993.1 (VDSL1):
    - the main transmission technique is DMT, QAM being an alternative possibility.

ADSL techniques

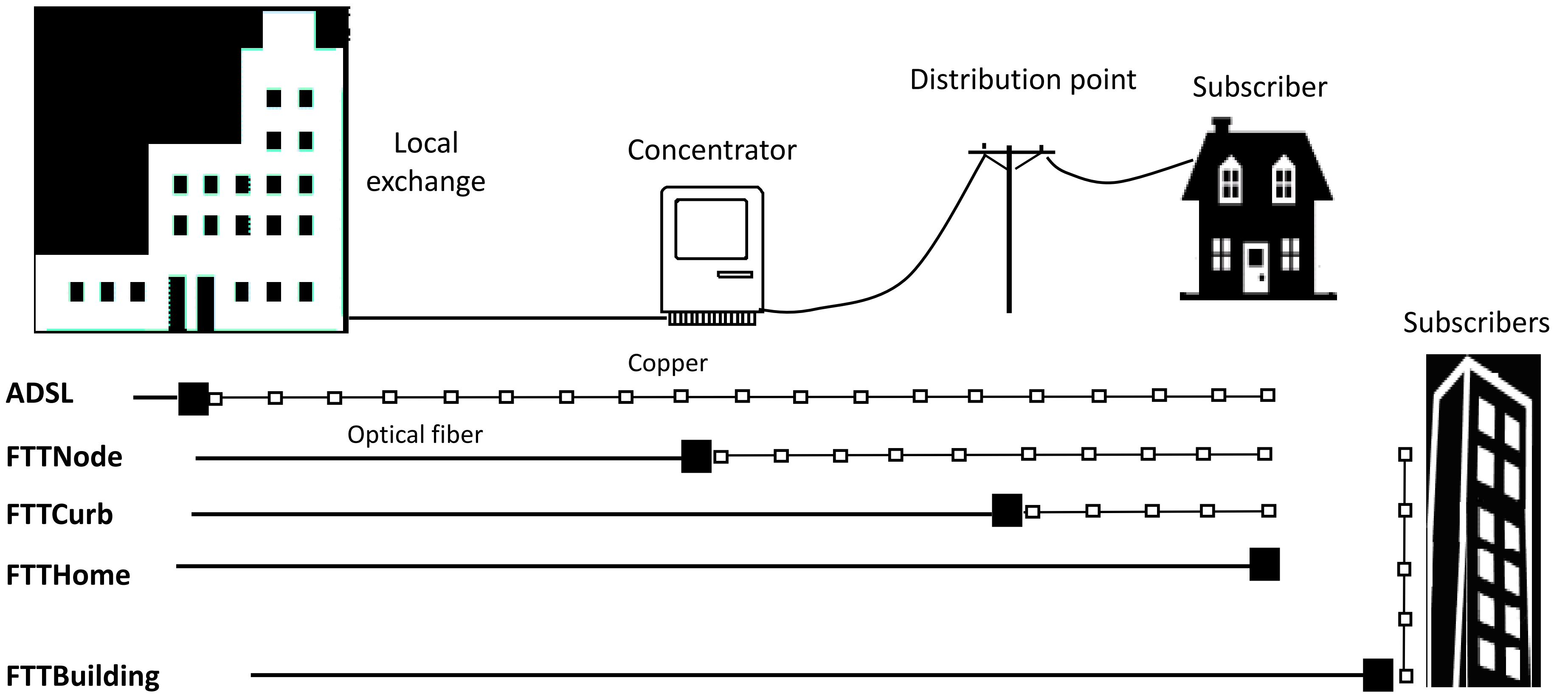
- Main parameters of the ADSL and VDSL techniques;

xDSL	Maximum downstream bit rate	Maximum upstream bit rate	Maximum transmission range	Number of pairs/ Connection to line
ADSL	8 Mbps	1,544 Mbps	5,5 km	1 pair; with splitter
ADSL G.Lite	1,5 Mbps	512 kbps	5,5 km	1 pair; no spliter
RADSL	8 Mbps	1,544 Mbps	5,5 km	1 pair; with splitter
VDSL	13 Mbps	1,6 Mbps	1,5 km	1 pair; with splitter
	26Mbps	3,2 Mbps	900 m	
	52 Mbps	6,4 Mbps	300 m	
	34 Mbps	34 Mbps	300 m	

Subscriber loop length (km)	Typical ADSL transfer rates	
	„upstream	downstream
5,5	64 kbps	1,544 Mbps
4,88	65 kbps	2,048 Mbps
3,66	256 kbps	6,312 Mbps
2,8	640 kbps	8,448 Mbps

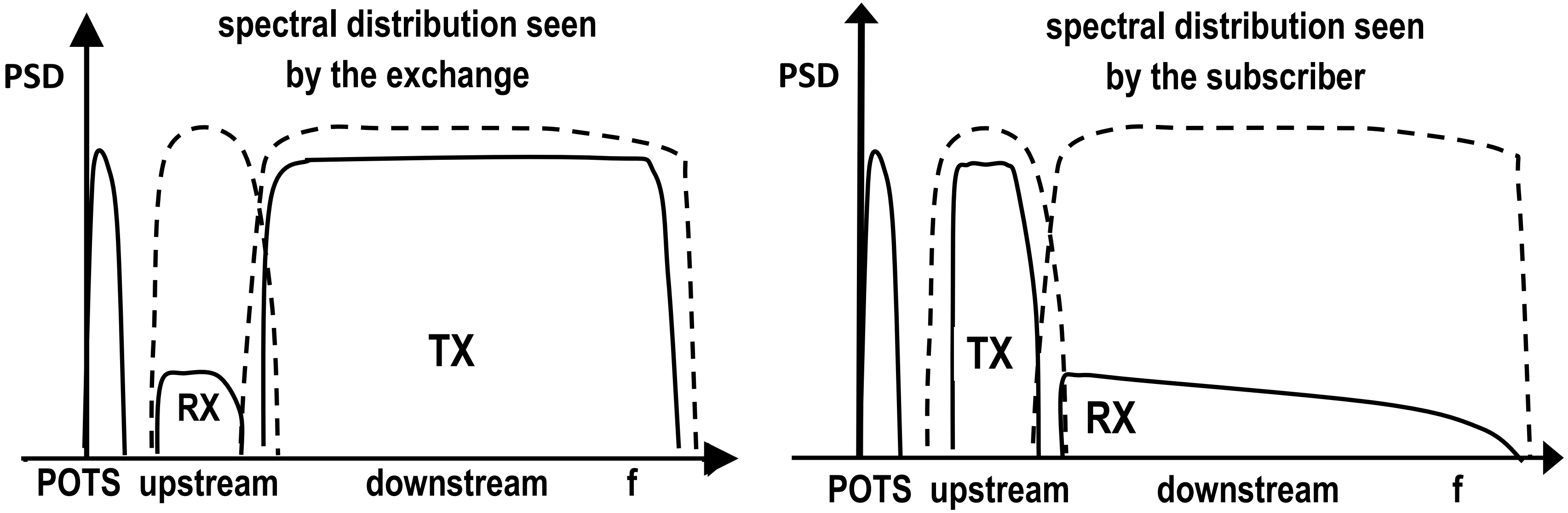
ADSL network access

- ADSL access scenarios;



Allocation of ADSL frequency bands

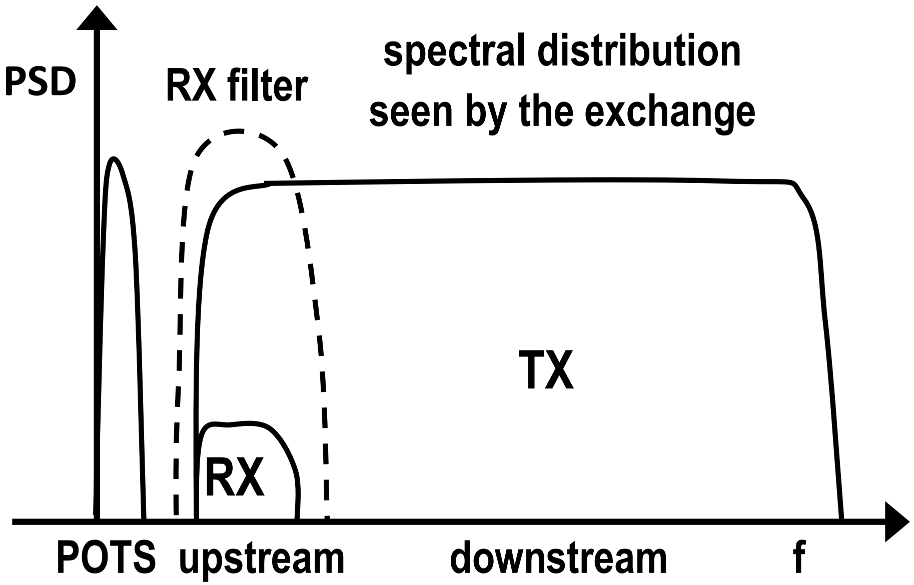
- ADSL frequency band allocation;
  - Depends on the duplexing technique employed:
    - separation of the upstream şi downstream transmissions by using frequency multiplexing;
      - is the most used duplexing method;
      - it provides a smaller downstream bit rate, but simplifies the duplexing and equalization.

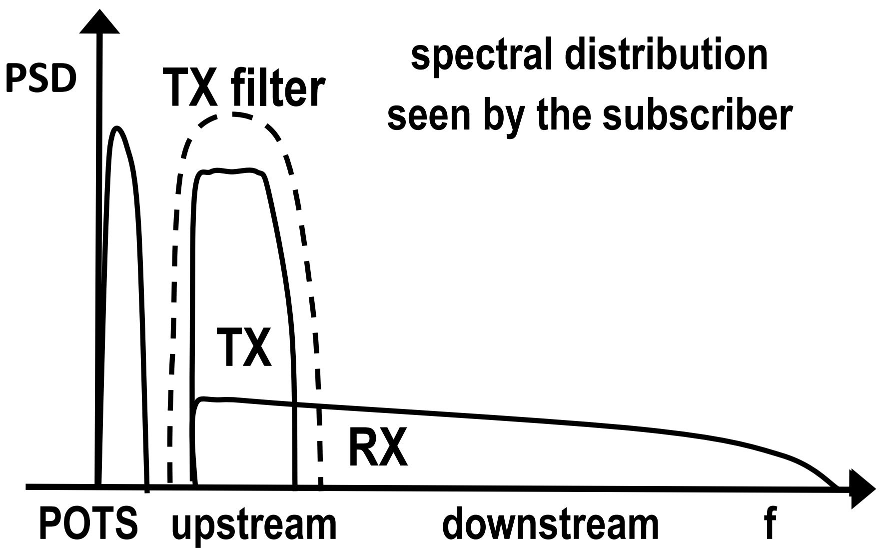


- the figure indicates also the filtering characteristics and the transmission and reception signal levels.

Allocation of ADSL frequency bands

- separation of the upstream and downstream transmissions by using the echo compensation technique;
  - allows larger downstream bit rates, but the duplexing and equalization become more complex;
  - this duplexing method is less used.

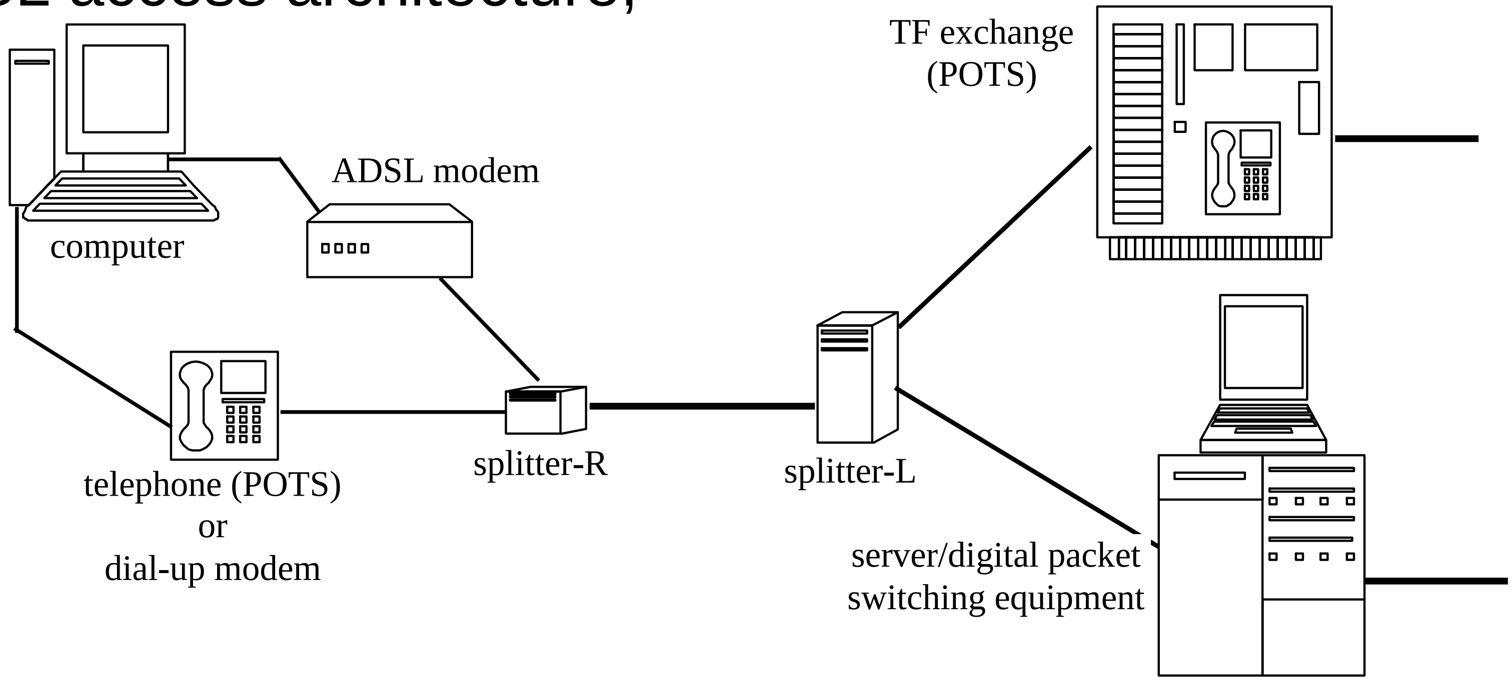




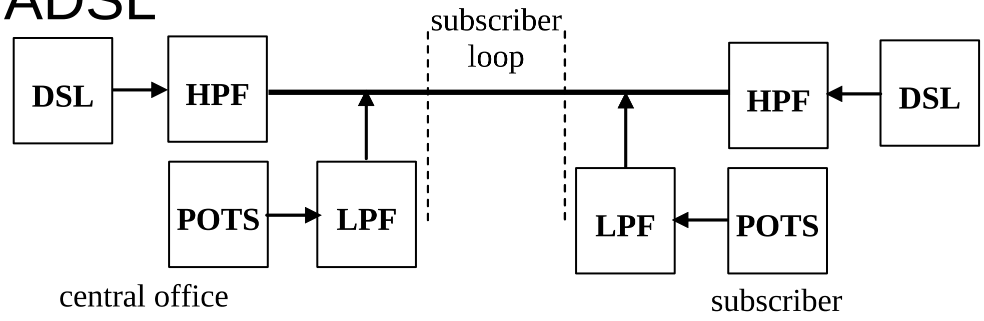
- the figure indicates also the filtering characteristics and the transmission and reception signal levels.

ADSL line connection

- ADSL access architecture;

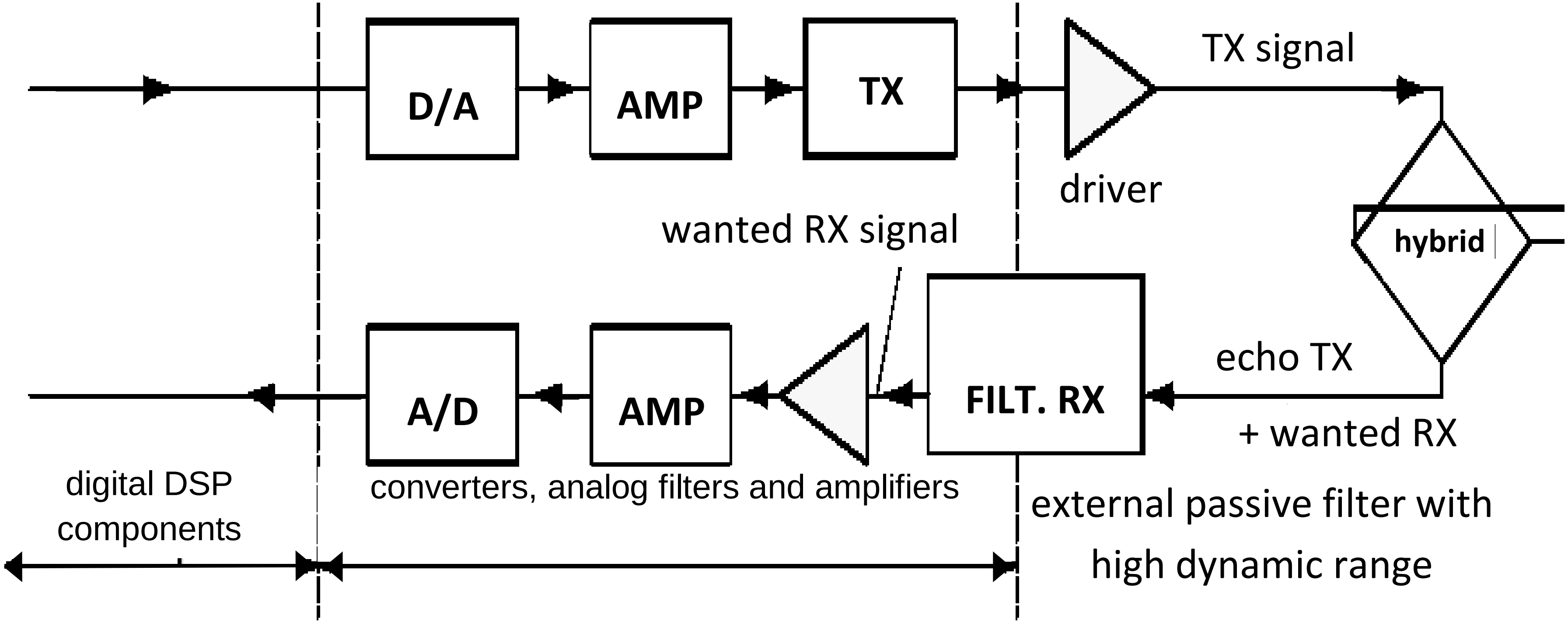


- Connection to the line of the ADSL modem and of the phone device when the splitter is used.



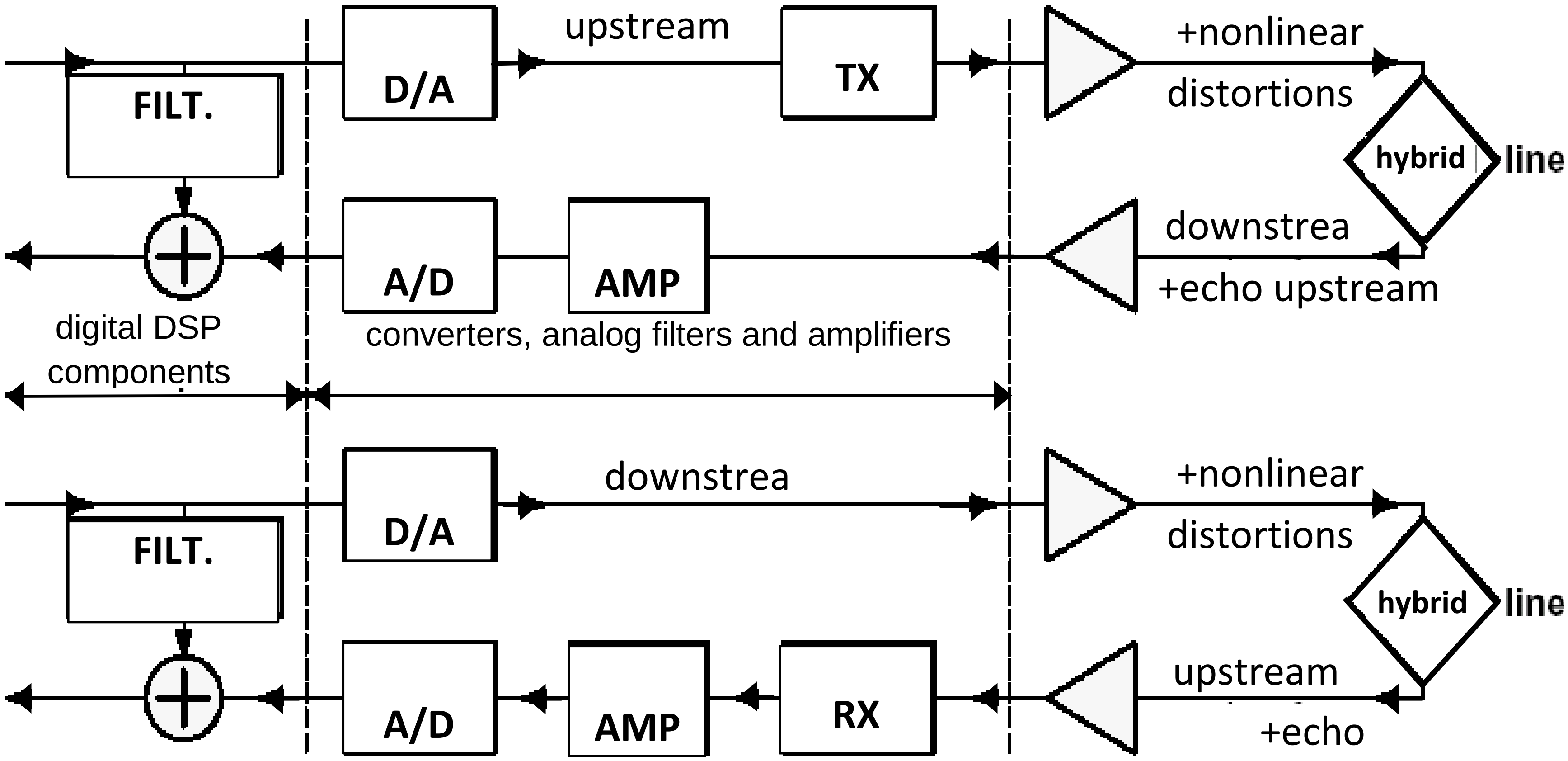
ADSL line connection

- ADSL modem line interface when transmission direction separation is performed by using frequency multiplexing;



ADSL line connection

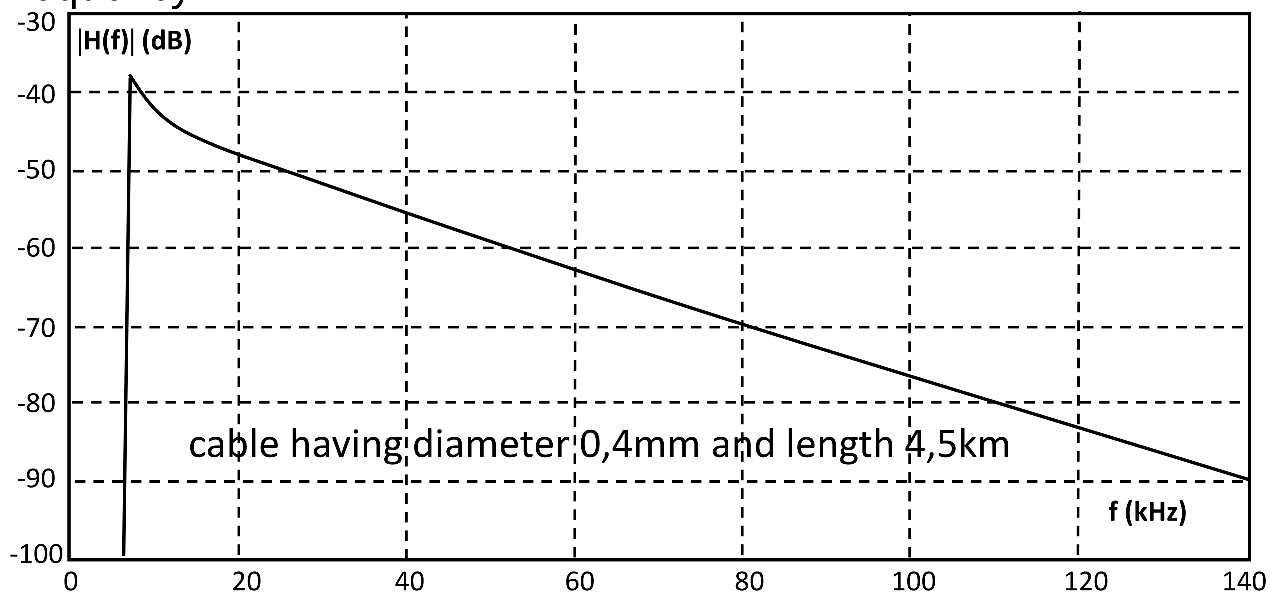
- ADSL modem line interface when transmission direction separation is performed by using the echo compensation technique;



ADSL distortions

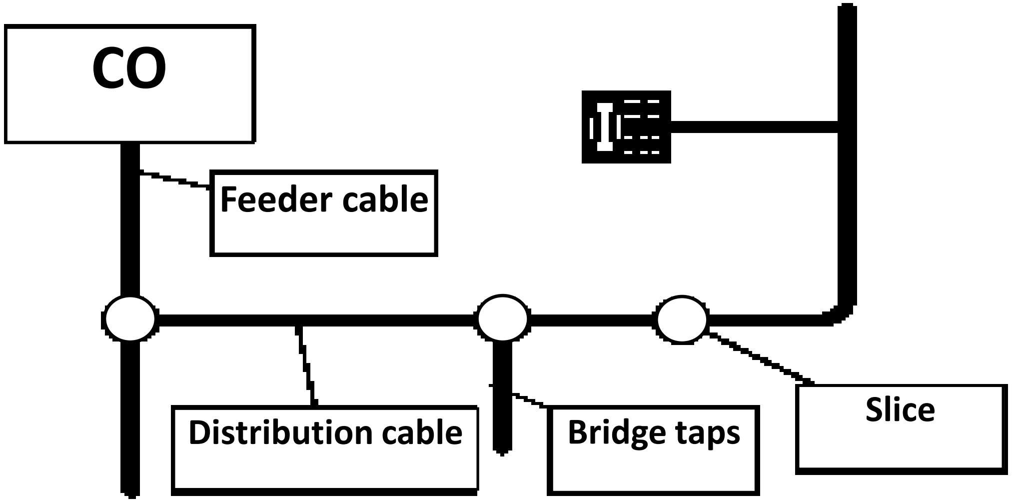
- The main distortions affecting the ADSL transmissions:
  - The frequency transfer characteristic of the twisted wires from the subscriber loop:
    - attenuation (loss);
      - increases with the length of the cable and the frequency;
    - attenuation distortion;
      - changes with the frequency.

- Ex.: frequency transfer characteristic of a cable:



ADSL distortions

- Reflected signals generated by impedance mismatches;
  - affect the frequency transfer characteristic;
    - generate spectral zeros at some frequencies;
  - unterminated bridge taps: represent a major cause for impedance mismatches.
  - ex.: typical architecture of a subscriber loop;



- Noise:
    - background noise: thermal noise, shot noise;
    - crosstalk: near-end and far-end crosstalk;
    - radio interferences;
    - impulse noise.
- Nonlinear distortions.

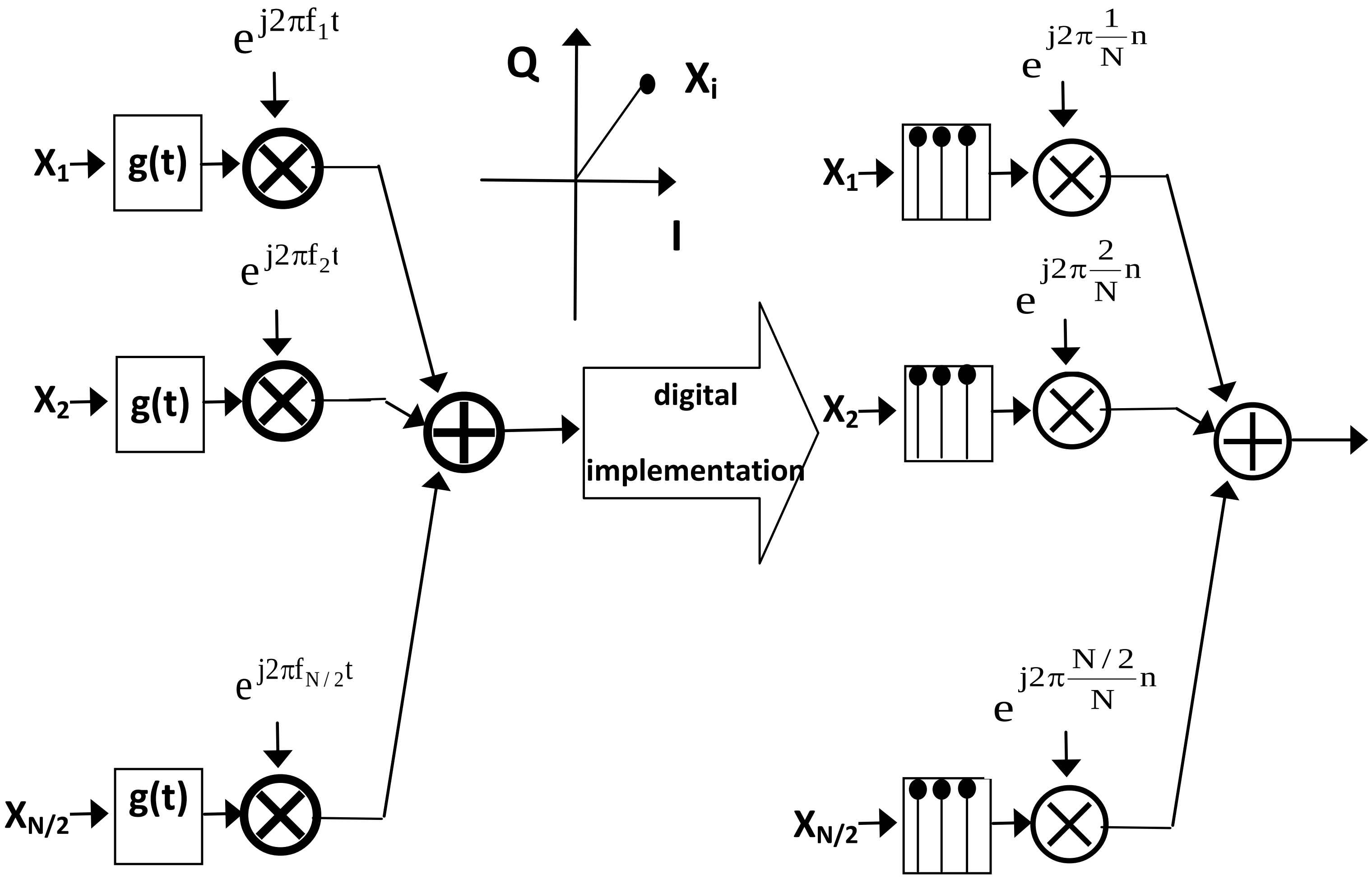
The DMT modulation

- The principle of DMT modulation:
  - The DMT modulation is a multicarrier modulation;
    - it splits the allocated frequency band into a number N (usually large) of sub-channels;
    - each sub-channel has a complex harmonic sub-carrier ($e^{j\omega t}=\cos(\omega t)+j\cdot\sin(\omega t)$);
      - the sub-carriers allocated to different sub-channels are orthogonal;
      - the orthogonality of the sub-carrier allows the separation of the sub-channel at the reception without filtering;
        - it is possible a spectral overlapping of the neighbor sub-channels and the provisioning of high spectral efficiency.
    - the DMT modulation is equivalent with a group of parallel QAM modulations;
      - can be used a separate modulation constellation on each individual sub-channel;
      - the filters having the impulse response g(t), used to filter the complex data impulses $X_i(t)$, could be avoided in most of the situations;
        - the modulator impulses are not filtered before modulation.
  - The orthogonality condition imposed to the complex sub-carriers: $e^{jk\omega_s t}$
    - f_s : bandwidth of a sub-channel;
    - k : sub-channel number;

$$\frac{1}{T_s}\int_0^{T_s} e^{jm\omega_s t}\cdot e^{-jn\omega_s t}\,dt = \begin{cases} 0 \text{ if } m \neq n \\ 1 \text{ if } m = n \end{cases}$$

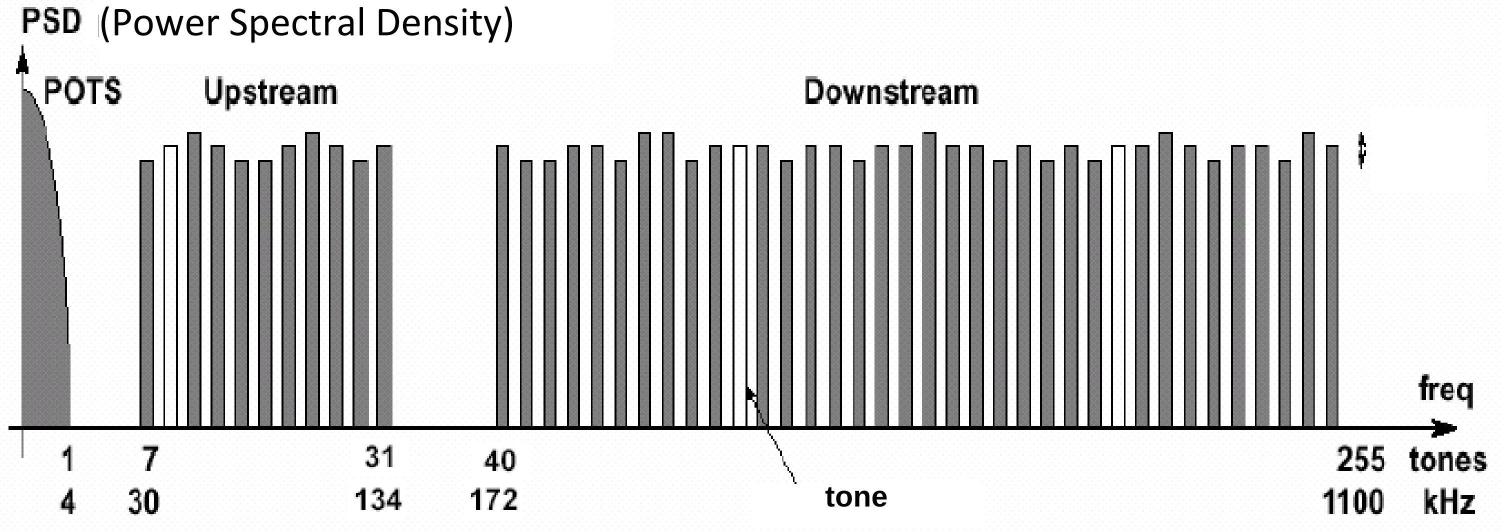
The DMT modulation

- The principle of the DMT modulation:



The DMT modulation

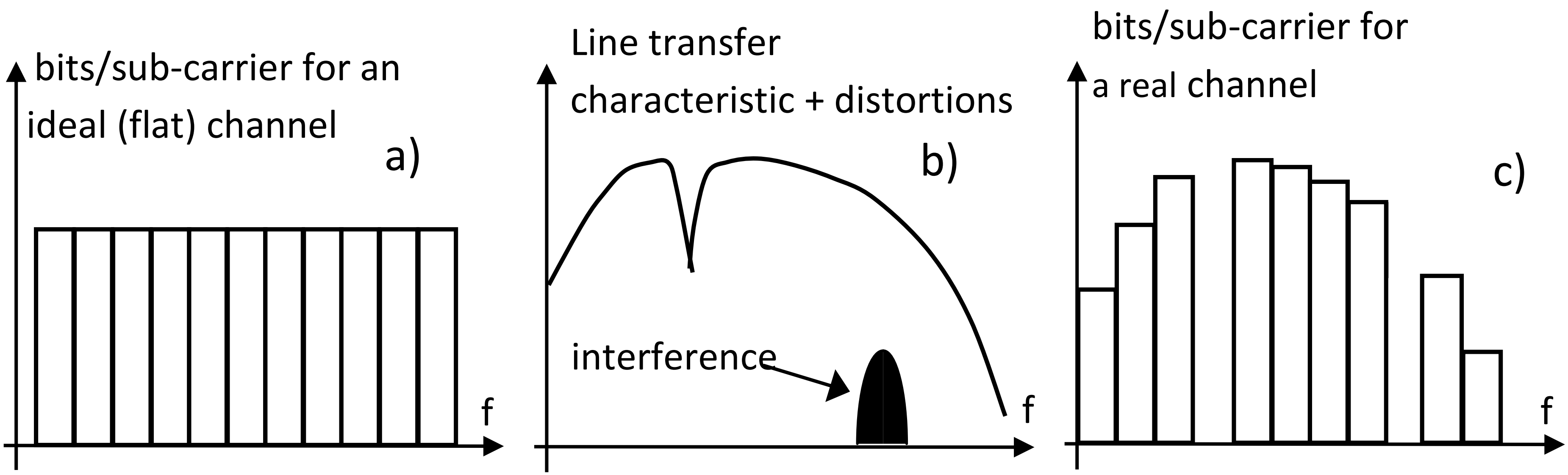
- Allocation of the ADSL sub-carriers:
  - Sub-carrier (tone) separation = 4,3125kHz= DMT symbol frequency;
  - There are used 255 sub-carriers; maximum no. bits/tone = 15.
- Frequency and tone allocation for ADSL transmissions using the DMT modulation frequency division duplexing;



  - 25 tones are allocated for upstream;
  - 215 tones are allocated for downstream;
  - there are guard tones between the ADSL bands and separately for the telephone band.

The DMT modulation

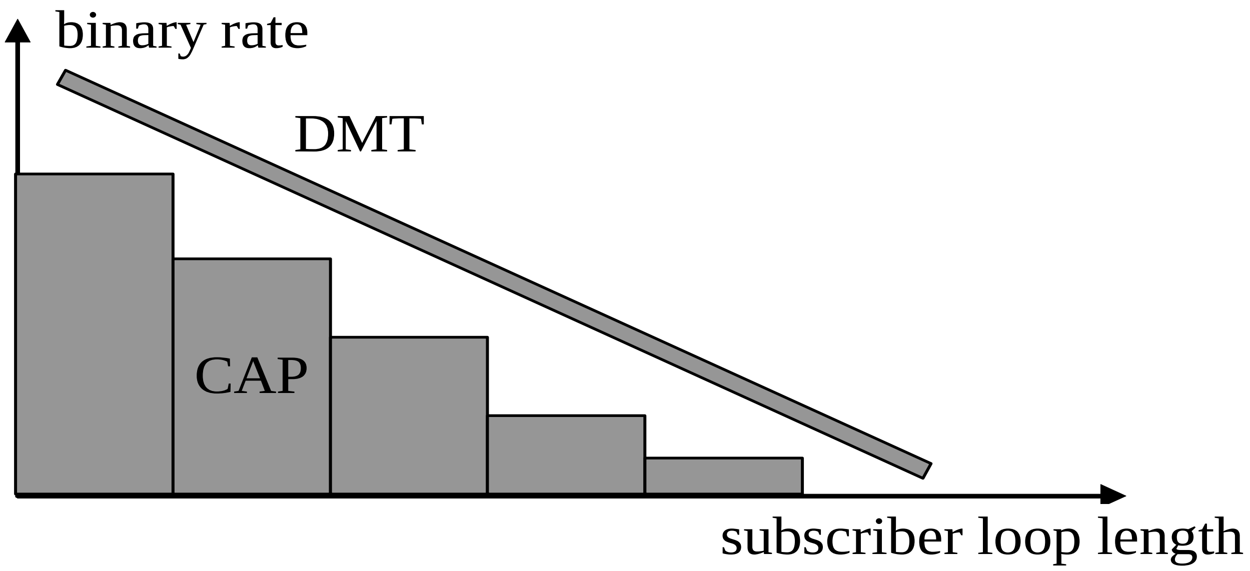
- Adaptation of DMT modulation to the channel frequency transfer characteristic and noises and interferences on the channel;
  - Possible due to the adaptation of modulation used in each sub-channel;

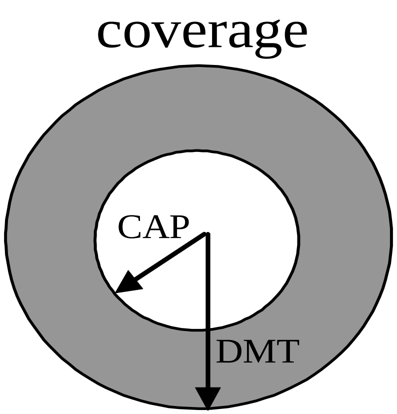


  - DMT has superior performance comparatively to CAP modulation;
    - the selective assignment of the number of bits/tone ensures an equalization of the channel;
    - it is possible to do a fine adaptation of the transmission rate to the channel distortions.

The DMT modulation

- Comparison between the DMT and CAP modulations:
  - Rate adaptation capability to the channel characteristics;
  - The transmission distance ensured.

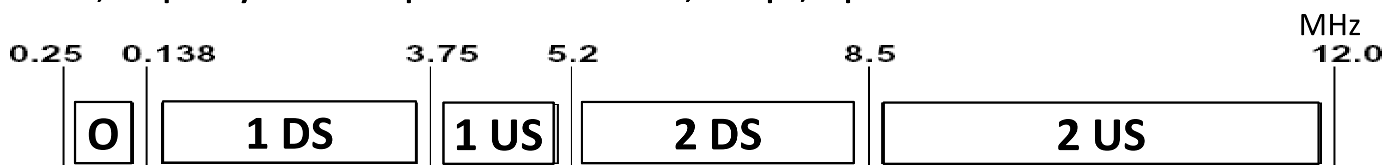




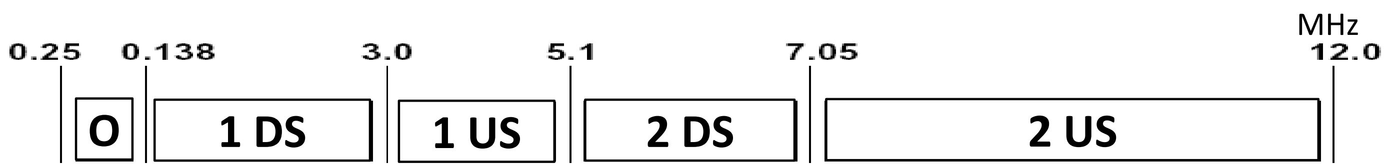
Allocation of the VDSL frequencies

- VDSL frequency allocation plans;

plan 998; frequency allocation plan: North America, Europe, Japan



plan 997; frequency allocation plan: Europe



band O is optional and can be used for either upstream or downstream transmission

- The frequency band allocation for the upstream and the downstream directions is more complex than for the ADSL;
  - there are two frequency allocation plans:
    - one valid globally and one valid in Europe;
  - it is allocated a wide band for upstream at high frequencies (the 2US band);
    - at high frequencies the channel inserts significant attenuation distortions;
    - it is not possible the use of modulation constellations with a large number of bits/symbol.

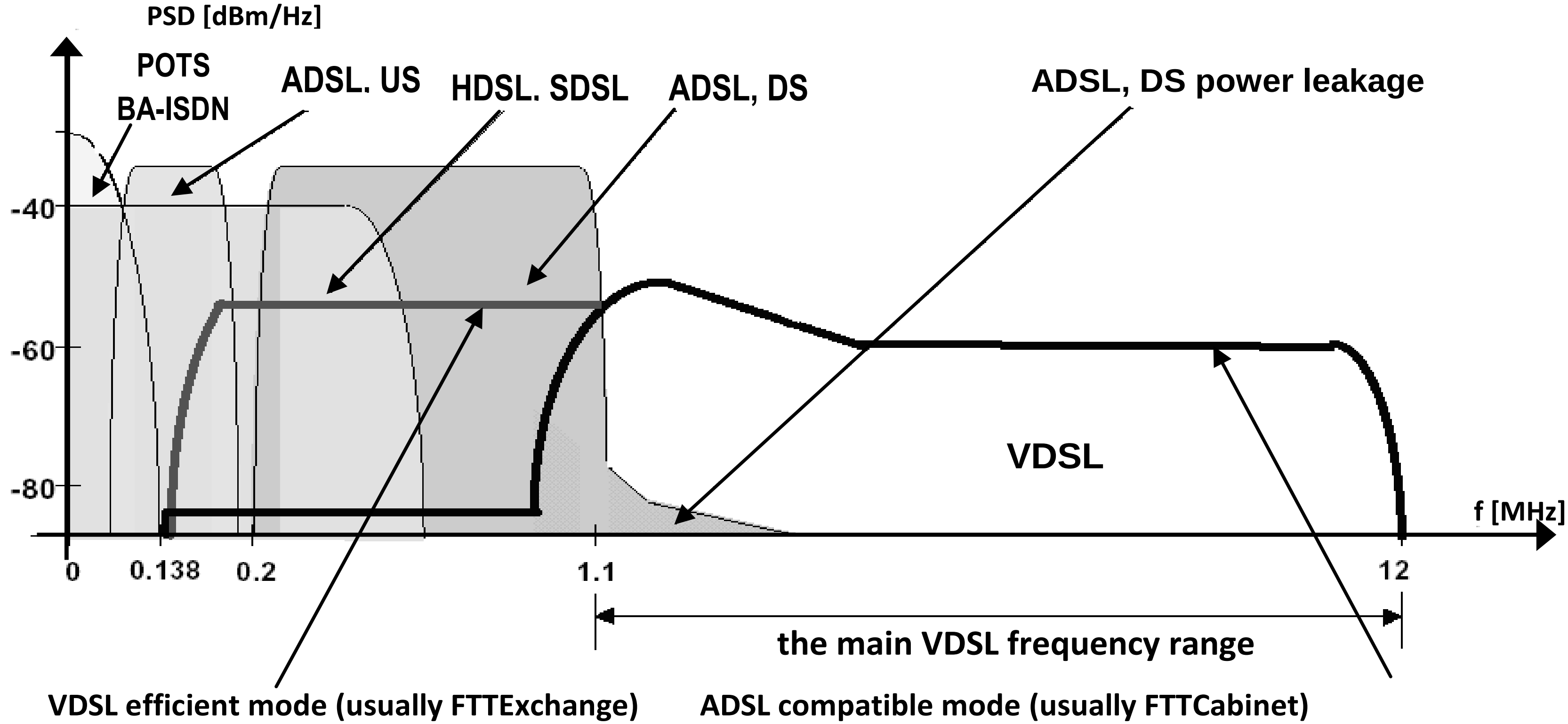
Allocation of the VDSL frequencies

- it is allocated a narrower upstream band (1US) at lower frequencies;
  - it used when the transmission can not be realized (or does not worth to be realized), due to the low quality of the channel, in the 2US band.
- in downstream are allocated two approximately equal frequency bands (1DS and 2DS), having bandwidths of 2 – 3MHz;
  - these bands are allocated at lower frequencies, where the distortions inserted by the channel are reduced.
- can be noticed the intelligent allocation of these frequency bands:
  - a DS band at lower frequencies where can be obtained a high downstream bit rate;
  - a US band where can be provided a high upstream bit rate;
  - another DS band where can be obtained a smaller bit rate than the one obtained in the first DS band (due to the larger attenuation inserted by the channel);
  - a second US band usable in the case of cables with low length.

- The frequency band allocation allows symmetrical transmission modes:
  - the same bit rate in upstream and in downstream.

The VDSL spectral mask

- The VDSL spectral mask and the spectral compatibility of the xDSL techniques;



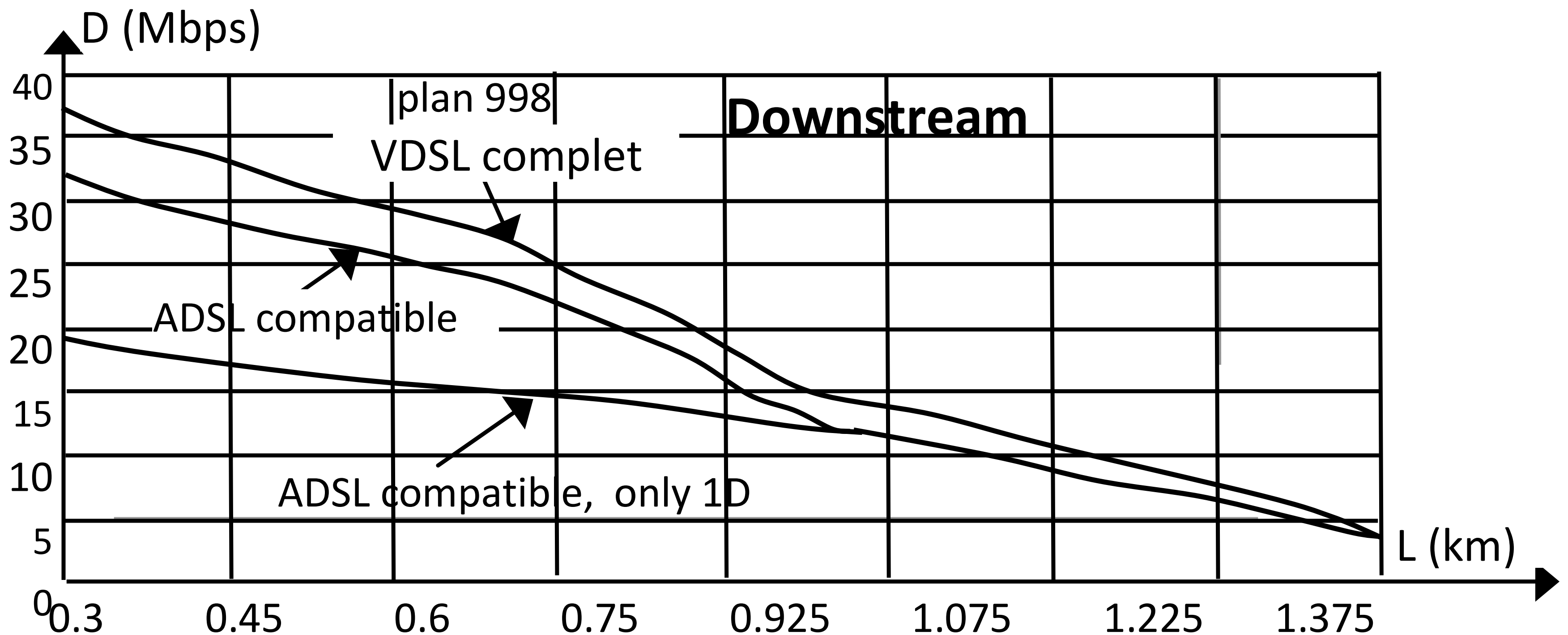
- The figure presents for comparison purposes the spectral density of the telephone and of the BA-ISDN signals;

VDSL techniques categories

- It is of interest the interaction between the ADSL and VDSL techniques:
  - if it is targeted the decrease of the crosstalk between the ADSL and VDSL transmissions:
    - the spectrum of the VDSL signals has to be inferiorly limited at 1.1Mhz;
    - has to be reduced the 1DS band;
    - could be also about the transmission on the same pair of the ADSL and VDSL signals;
    - ADSL compatible mode (called also “ADSL friendly” mode).
  - if the VDSL connection is established directly to the exchange (“Central Office based VDSL”), usually it is used the extended (entire) band;
    - VDSL efficient mode.
    - can be explained by the higher length of the subscriber – exchange connection cable relatively to the length of the subscriber – concentrator connection cable;
    - if the cable is longer the attenuation distortions induced by the line are larger and to provide appropriate bite rates has to be used also the ADSL frequency band.
  - if the VDSL connection is realized only to a concentrator (“Cabinet based VDSL”), usually it is used the reduced band;
  - usually we have the following situation:
    - “Cabinet based VDSL” works in ADSL compatible mode;
    - “Central Office based VDSL” works in VDSL efficient mode.

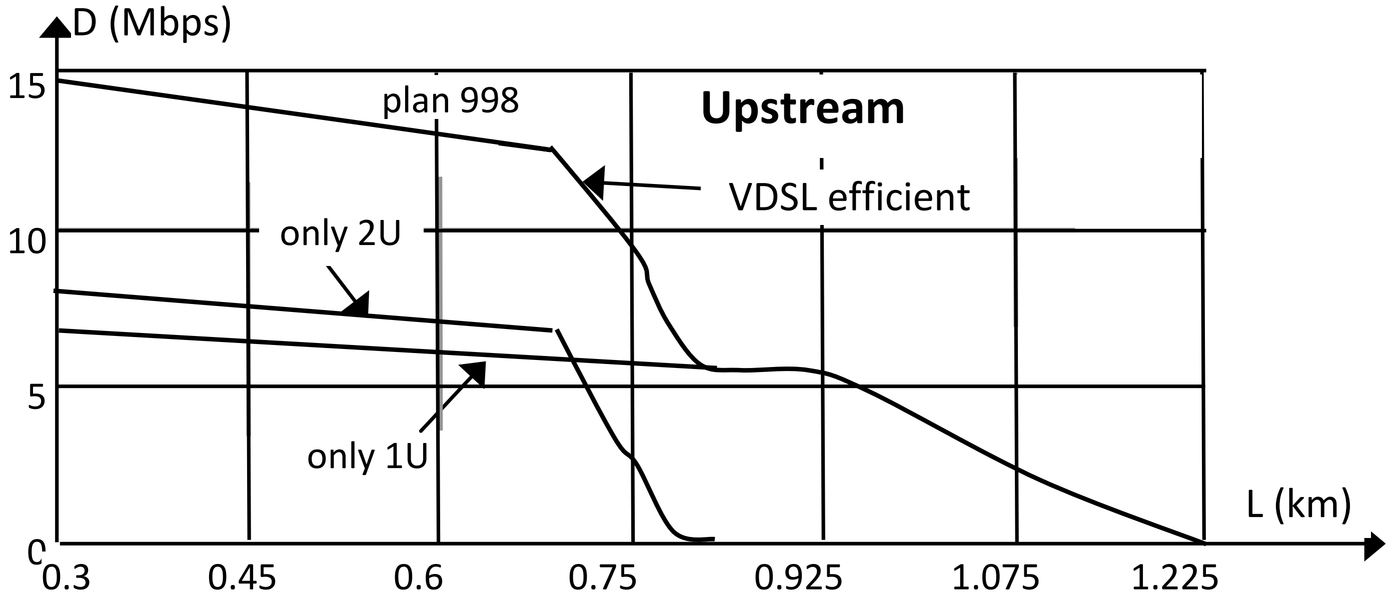
VDSL performances

- Case study:
  - The maximum bit rates attainable in downstream and upstream according to the usage of the available frequency bands and the length of the subscriber loop;
  - Downstream transmission;



VDSL performances

- The maximum downstream bit rate varies between 20Mbps - 40Mbps for loops shorter than 300m and decreases below 5Mbps for loops having a length of 1,5km;
  - can be noticed the bit rate difference between ADSL compatible and respectively the ADSL incompatible techniques;
  - can be noticed also the supplementary bit rate provided by the 2DS band, but only for short subscriber loops.
- Upstream transmission;



VDSL performances

- The maximum upstream bit rates are located between the following limits:
  - 5Mbps - 15Mbps for loops shorter than 300m;
  - the transmission in upstream is not possible for loops longer than 750m – 1200m;
  - can be noticed the impossibility of using the 2US band at loop lengths larger than 600m – 650m;
    - this is due to the significant distortions induced by the channel in this band.
  - the transmission in the 1US band is less affected by the increase of the subscriber loop length.

ADSL2 techniques

- Extra functionalities provided by the ADSL2 standard:
  - Higher transmission bit rate;
  - Larger coverage area;
  - More flexible adaptation of the transfer rate to the channel characteristics;
  - Channel diagnostic functionalities;
    - can be measured:
      - the background noise;
      - the loop attenuation;
      - signal to noise ratio;
    - the diagnostic information are sent to the central office and are used for service quality monitoring.
  - Stand-by functioning mode;

ADSL2 techniques

- ADSL2 provides the following performances:
  - downstream bit rate up to 12Mbps;
  - upstream bit rate and up to 1Mbps;
  - these performances are obtained due to the following techniques:
    - the increase of the modulation efficiency;
    - the decrease of framing overhead;
    - larger coding gain:
    - more complex signal processing;
    - improved initialization.

ADSL2 techniques

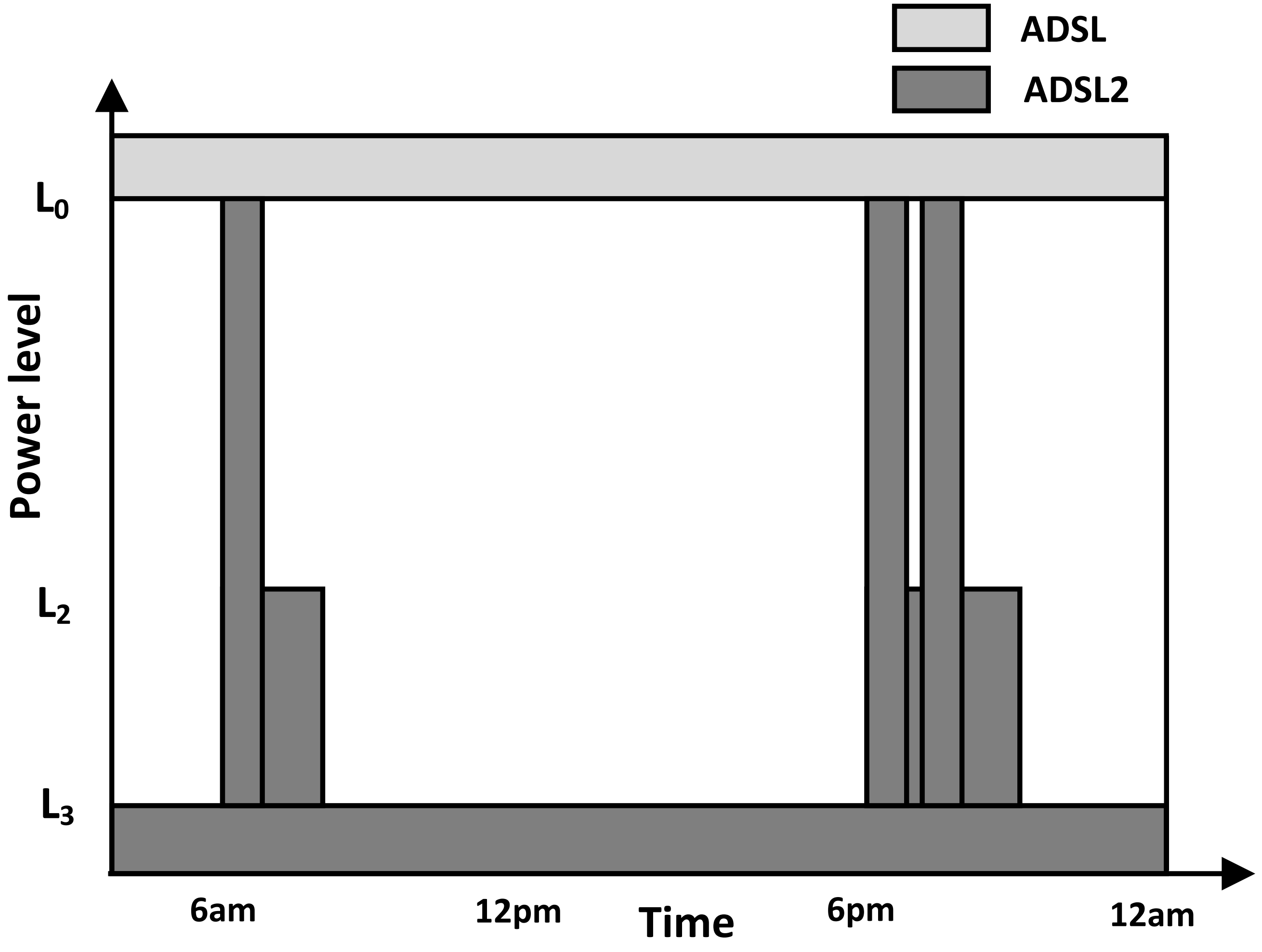
- Improved power management methods:
  - ADSL modems operate continuously in the “full-power” mode;
    - L0 mode (even when nothing is transmitted);
      - significant consumption of energy which is a problem especially in the case of “cabinet based ADSL”: problems related to power supply and heat dissipation;
  - The ADSL2 techniques brings two new power management techniques, namely:
    - L2 “low-power mode”: dedicated to the ATU-C modem located in the CO (or cabinet);
      - it is allowed the fast entering and exiting of the low-power mode based on the data traffic on the connection;
        - if the traffic is large the modem works continuously in the full power mode (L0) to maximize the transmission speed;
        - in the moment when the traffic decreases the modem enters the L2 operation mode and a reduced bit rate is used to transmit;
        - the switching between the two functioning modes is realized instantaneously and without affecting the error probability or the service quality;

ADSL2 techniques

- L3 “low-power mode”: dedicated both to ATU-C and ATU-R modems;
  - the modem enters a “sleep mode” in the moment when no traffic is detected on the connection for a longer time interval;
  - transition to normal operation requires approximately 3s.

ADSL2 techniques

- Power management techniques used by the ADSL2 modems;



ADSL2 techniques

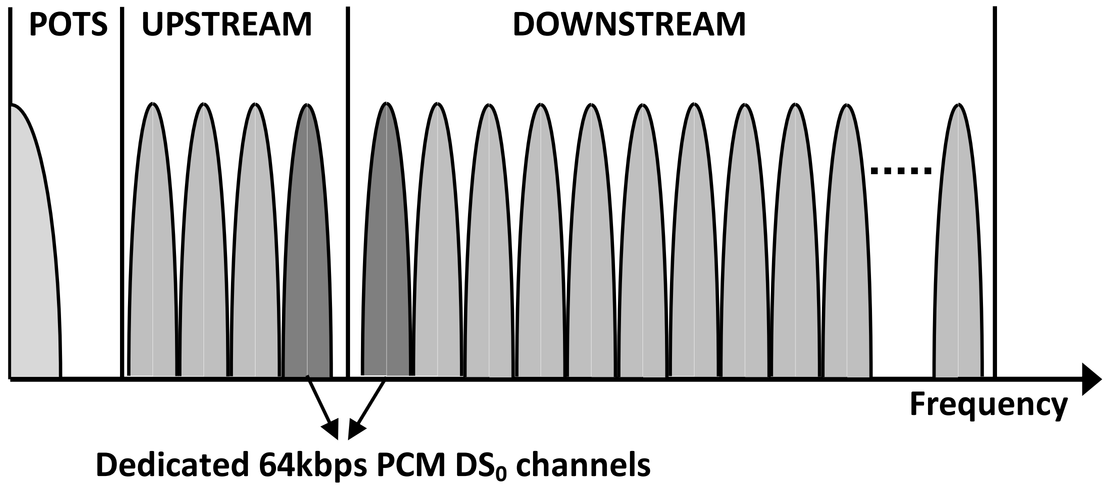
- Bonded ADSL (developed in 2005);
  - Is an important functionality of ADSL2;
  - Allows the increase of the bit rate by coupling several telephone lines in a single ADSL connection;
    - it is necessary the insertion of a multiplexing/demultiplexing layer which allows the distribution of a larger flow on different physical connections.

ADSL2 techniques

- ADSL2 offers the possibility to split the bandwidth in channels with different characteristics for different applications;
  - ADSL2 offers support for voice applications in parallel with data transmissions;
    - higher allowed bit error probability but smaller delay for voice transmissions;
    - smaller allowed bit error probability but larger delay for data transmissions.
    - this capacity for channelization provides support for CVoDSL – Channelized Voice over DSL;
      - transparent transmission method of TDM voice channels with DSL technique;
      - 64kbps bit rate channels are reserved for transmission of DS0 channels to CO or to a multiplexer;
      - have to be reserved channels both in downstream and in upstream.

ADSL2 techniques

- The principle of CVoDSL technique for transmission of TDM voice channels over DSL;



- Additional benefits offered by the ADSL2 technique:
  - Improved interoperability;
    - the improvements of initialization procedures offer a better interoperability of equipment with chips from different suppliers;
  - Fast initialization (startup);
    - the initialization time can be reduced from 10s (ADSL) to 3s (ADSL2);

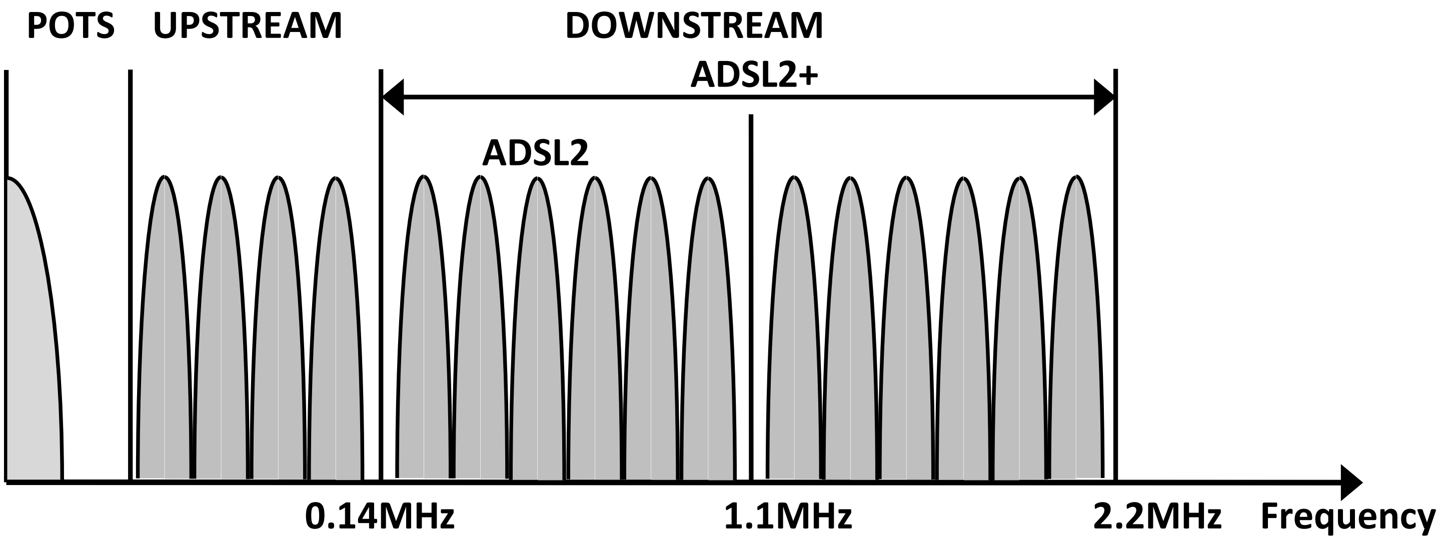
ADSL2+ techniques

- All-digital mode;
  - optional mode in which the standard telephone band is used for data transmissions – the bit rate can be increased with 256kbps;
- Support for packet based services;
  - it is provisioned a special convergence level which allows packet based services (for ex. Ethernet) to be transported over ADSL2;

- ADSL2+ it is an extension of the ADSL2 standard;
  - ADSL2 specifies a downstream band of 1.1MHz or 552kHz (ADSL G.lite.bis), and ADSL2+ specifies a band of 2.2MHz;
    - significant increase of the downstream bit rate for lines shorter than approximately 5000 feet;
    - the upstream bit rate is around 1Mbps, according to the transmission channel parameters (length of the line).

ADSL2+ techniques

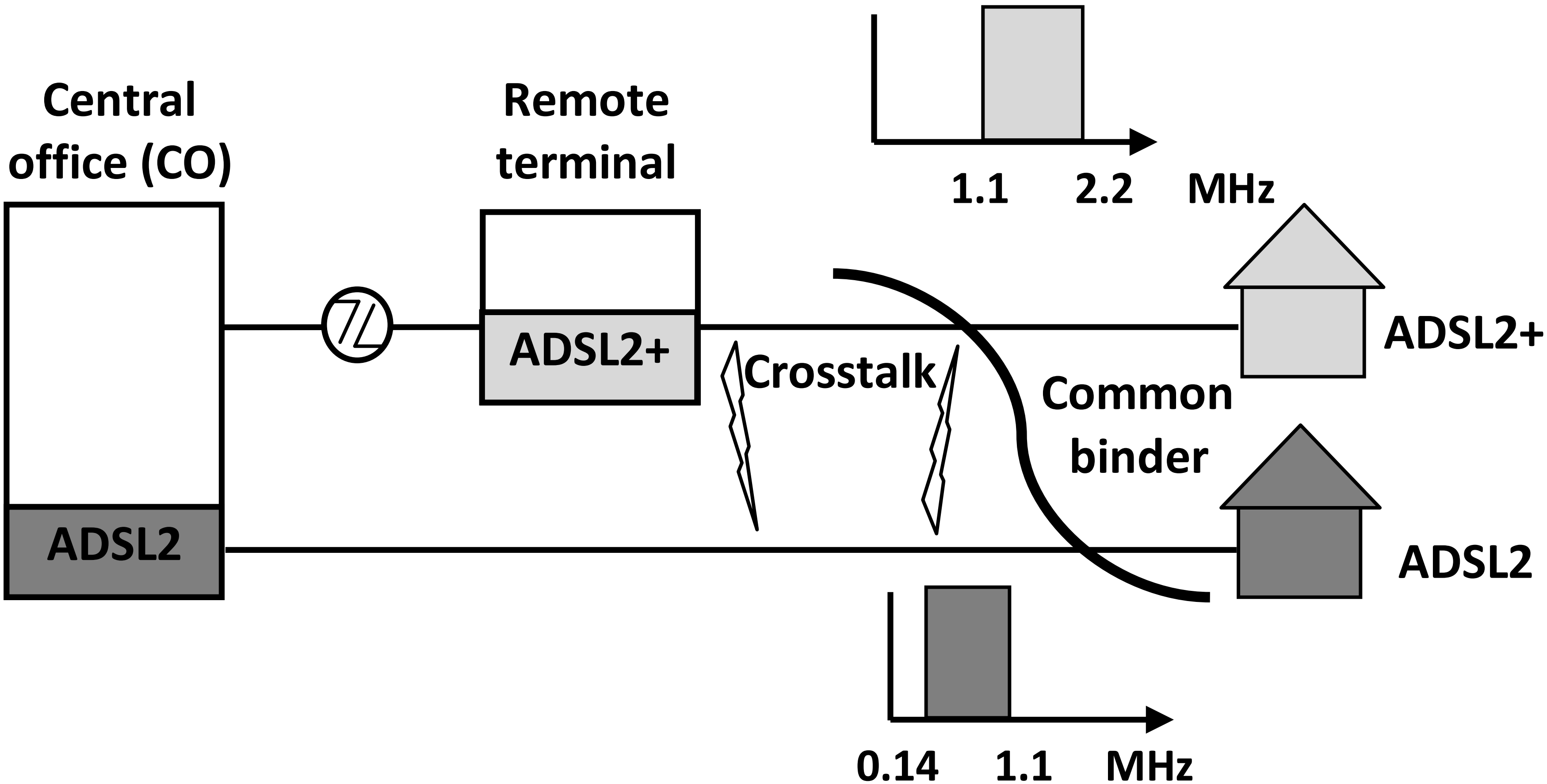
- Frequency band allocation for the ADSL2 and ADSL2+ techniques;



- ADSL2+ can be used to decrease the crosstalk by appropriate allocation of the downstream bands;
  - The frequency band located between 1.1MHz and 2.2MHz can be used for "cabinet based DSL";
    - the shorter line induces smaller distortions of the frequency characteristic;
  - The ADSL2 band can be used for "central office based DSL";

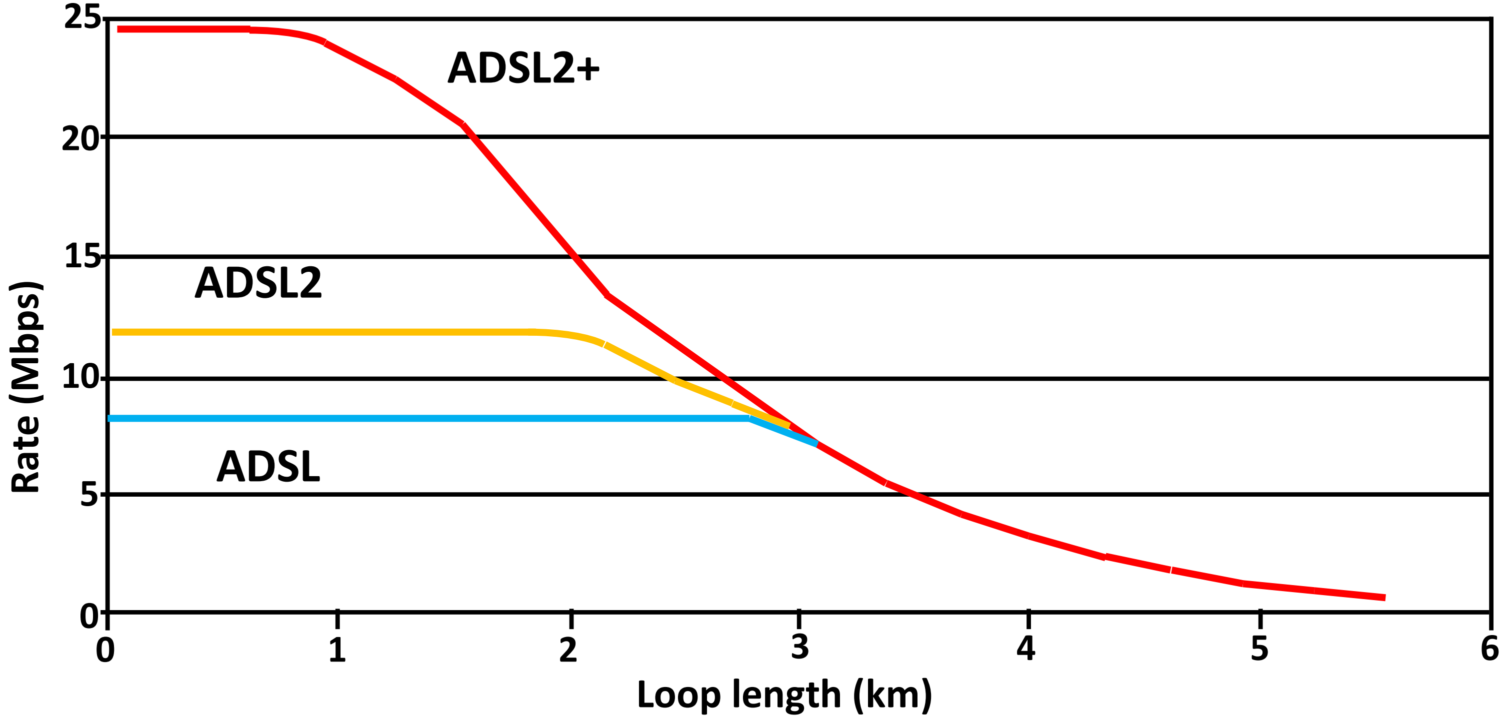
ADSL2+ techniques

- Decrease of the crosstalk by appropriate allocation of the ADSL2+ downstream frequency bands;



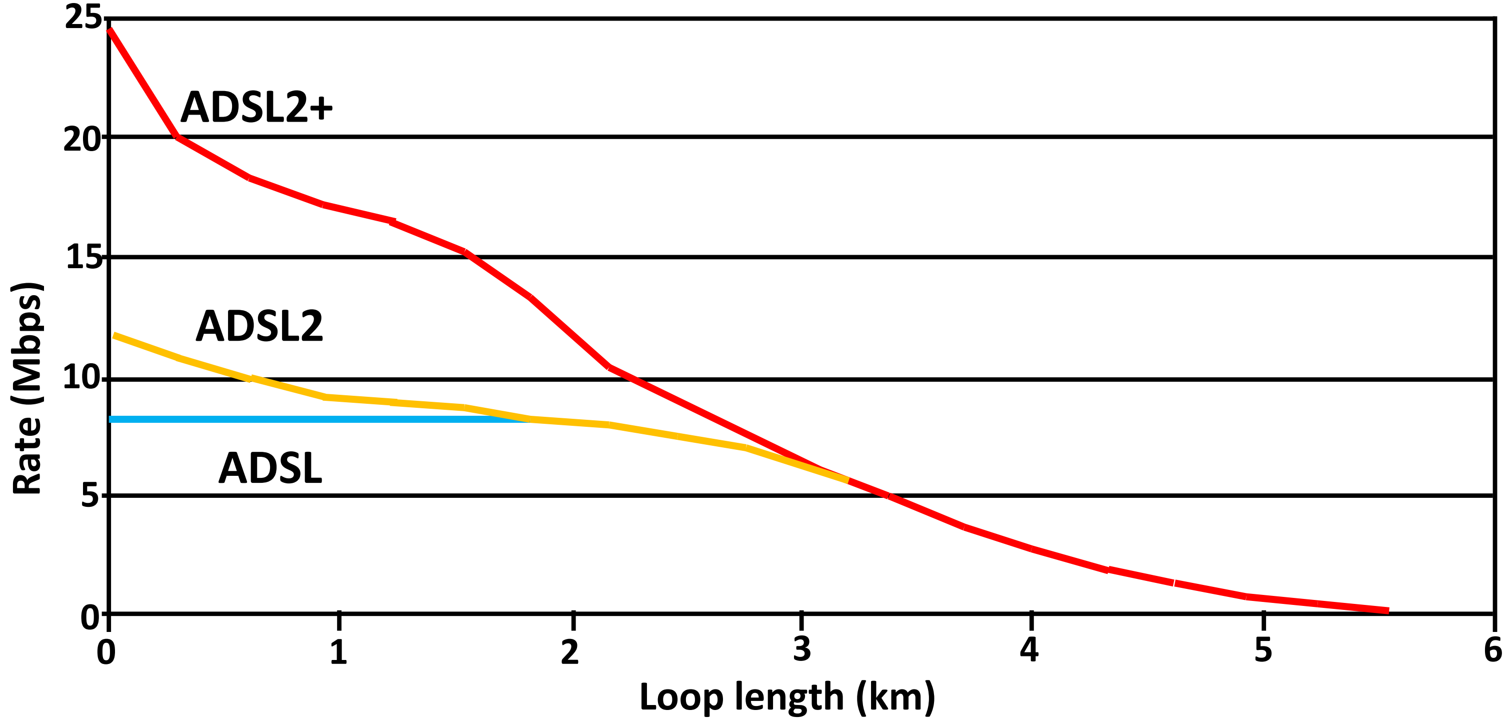
ADSL2+ techniques

- ADSL, ADSL2, and ADSL2+ downstream bit rates obtained in white noise condition for different length of the subscriber loop;
  - Cable 26awg (“American wire gauge”);
    - diameter 0.4mm;
  - White noise spectral density: -140dBm/Hz.



ADSL2+ techniques

- ADSL, ADSL2, and ADSL2+ downstream bit rates obtained in crosstalk condition for different length of the subscriber loop;
  - Cable 26awg (“American wire gauge”);
  - 12 identical interference sources;
    - 12 “Self cross-talk”;



VDSL2 techniques

- Is the newest and most advanced DSL technology;
  - Was designed to support a wide category of services;
    - voice, video, data, high definition TV (HDTV), interactive gamming.
  - It is specified by the ITU-T G.993.2 standard and it is an enhancement of the G.993.1 (VDSL1) standard;
    - it is a complex standard with numerous profiles and frequency bands adapted to various bit rate and reach (coverage) requirements.
  - It allows symmetrical and asymmetrical full duplex transmissions up to bit rates of 200Mbps on twisted pairs using a bandwidth of 30MHz;
- The VDSL2 standard includes many of the features and functionalities contained in the ADSL2+ standard;
  - Advanced functionalities:
    - advanced diagnostic, management, fault localization;
    - ability to maximize the bit rate and the efficiency of bandwidth use.

VDSL2 techniques

- VDSL2 uses completely different initialization procedures compared to the ones used by VDSL1;
  - Advanced channel measurement and modem training techniques;
    - the VDSL2 system allows the use of the US0 frequency band (used by ADSL systems) on long channels.
- VDSL2 ensures support for services based on packet transmissions (for ex. Ethernet or IP);
  - Evolved management facilities allow the transmission on the same physical layer of packets with different priorities and lengths;
  - VDSL2 provides also support for transmission on the same physical channel of services with completely different requirements:
    - bit error probability, delay, protection against impulse noise.
- VDSL2 ensures also:
  - Compatibility of equipment with different chip-set and compatibility with ADSL and ADSL2 techniques.

VDSL2 profiles

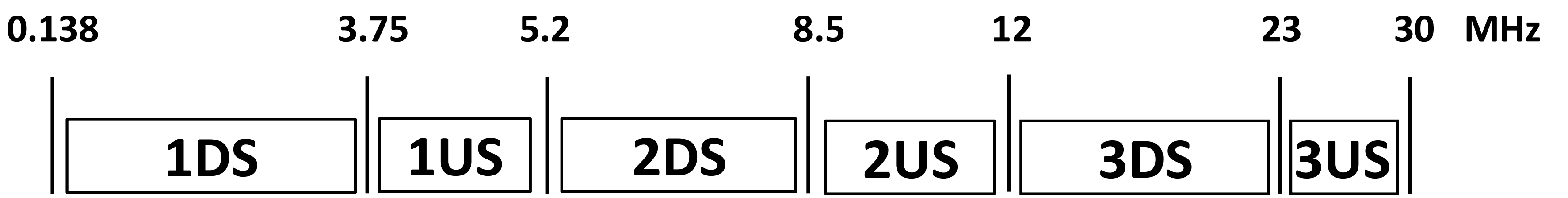
- Transmission profiles defined by VDSL2 techniques;
  - These profiles are characterized by:
    - allocated bandwidth;
    - number of tones (subcarriers) used (especially in downstream);
    - tone separation;
    - transmission power;
    - transfer rate (especially in downstream).

Profile / Parameter	8a	8b	8c	8d	12a	12b	17a	30a
Bandwidth MHz	8.5	8.5	8.5	8.5	12	12	17.7	30
Tones DS	1971	1971	1971	1971	2770	2770	4095	2098
Tone separation kHz	4.312	4.312	4.312	4.312	4.312	4.312	4.312	8.625
TX power DS dBm	17.5	20.5	11.5	14.5	14.5	14.5	14.5	14.5
Minimum net bit rate Mbps	50	50	50	50	68	68	100	200

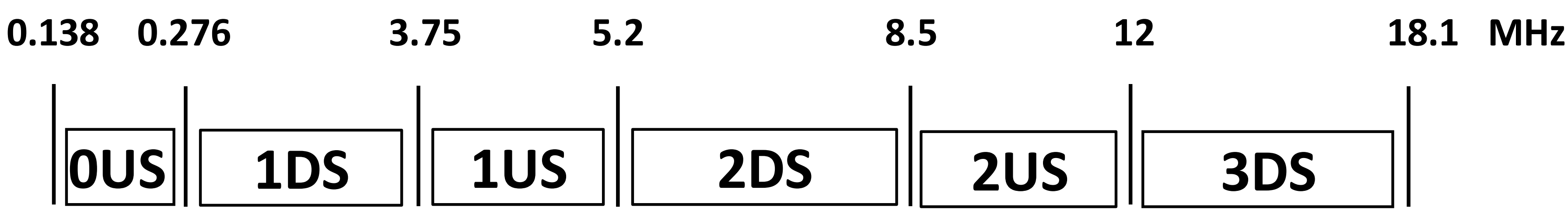
VDSL2 profiles

- Frequency band allocation plans for VDSL2 techniques;

plan 998 extension; North America



plan 998B (Annex B); Europe



VDSL2 performances

- The VDSL2 system provides an improved protection against impulse noise;
  - The impulse noise is one of the most important distortions which affect DSL transmissions;
  - The VDSL2 system allows the correction of error packets generated by impulses with period between 250μs and 3,75ms;
- VDSL2 allows a large transmission distance similar with ADSL, meaning 1 – 4 Mbps at distances of 4 - 5 km;
  - In this case the transmission is similar with that of ADSL2;
  - The VDSL2 systems, contrary to VDSL1 systems, are not limited to short subscriber loops;
    - the VDSL1 have a typical reach of 3kft;
    - some of the ADSL characteristics are integrated in the VDSL2 systems (typical reach of 9kft).

VDSL2 performances

- The maximum VDSL2 bit rate at source is 250 Mbps;
  - the bit rate deteriorates quickly to 100Mbps at 0.5km and to 50Mbps at 1km;
  - at a distance of 1.6km the maximum bit rate degrades slowly;
    - the performances are identical with those of ADSL2 systems.