

D.S.L. (“Digital Subscriber Line: ligne numérique chez l’abonné”)

•Jusqu’à 8 Mbps
par ligne
téléphonique ...!



clubinternet.



free

TELE2

Alice



- **Depuis 1876 ...**

- **Années 50 : Multiplexage en fréquence entre centraux**

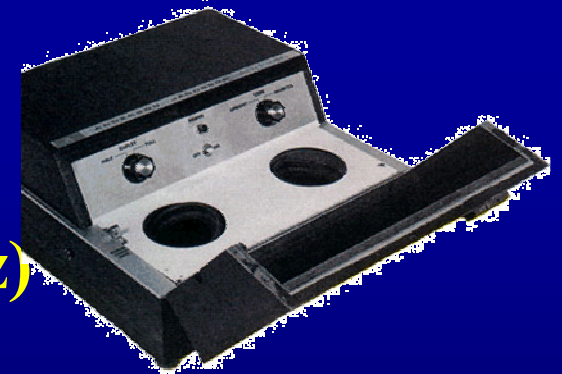
- **Années 60 : numérisation de la voix (8 bits 8 kHz)**

- **Norme PCM à 2.048 Mbps 30+2 canaux (Europe: E1), 24 + 2 canaux (US: T1) sur les artères**

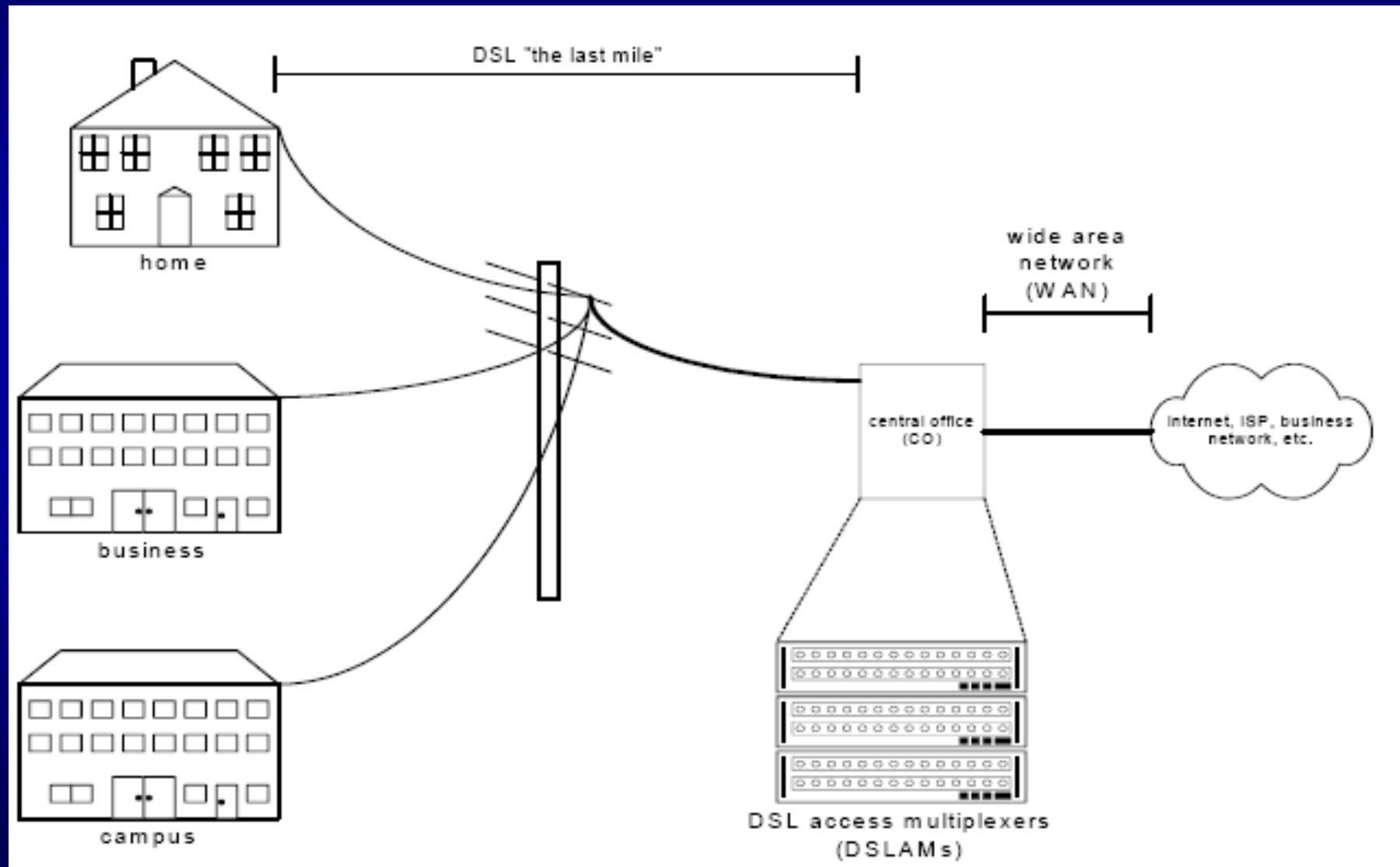
- **Et entre le central et l'abonné ...**

Transmissions numériques sur la boucle locale : Modems ...

- **Années 50** : Sur RTC 2 fils, FSK à 300 bauds puis 1200
- **QPSK** => 2400 bauds sur 1200 Hz
- **Avec égalisation ajustables**: 4800 bps sur 1600 Hz (8-PSK)
- **En // sur combiné, connexions directes**
- **QAM** => 1971 : 9600, 1984: 14400 -> 56000 bps
- **Liaison ISDN (RNIS) ...** (128kbps sur 160kHz)
- **HDSL ...** 2 Mbps (~PCM-MIC 30)
- **VDSL ...** 13+2, 13+13 ... 52+2 Mbps (~SDH-SONET)
- **Et l'ADSL ...**

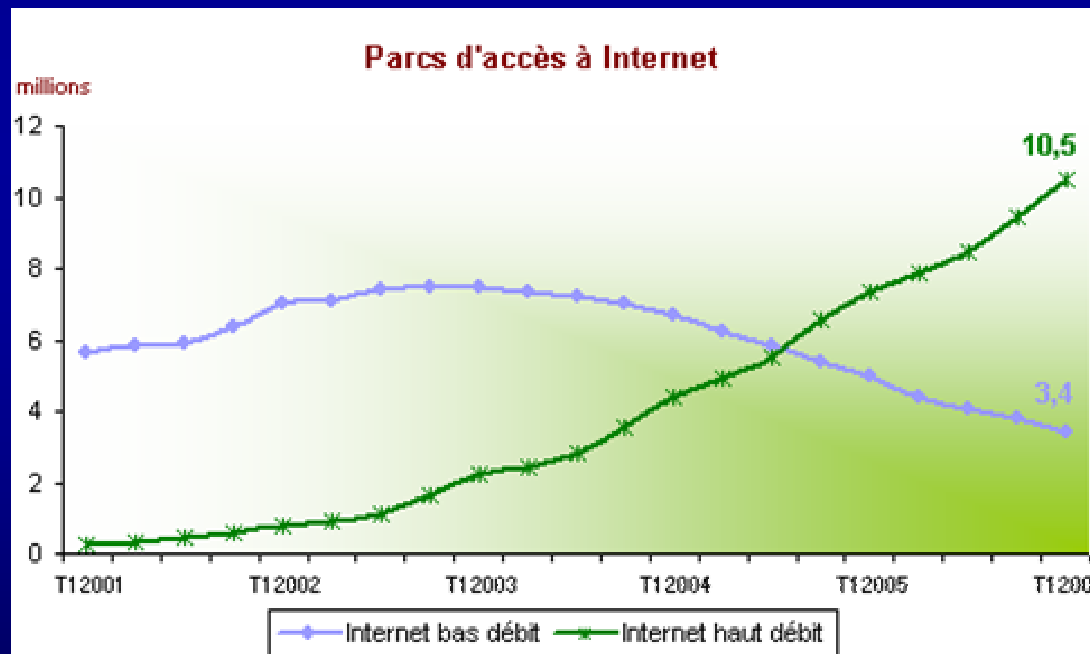


Systeme ADSL : DSLAM et utilisateurs



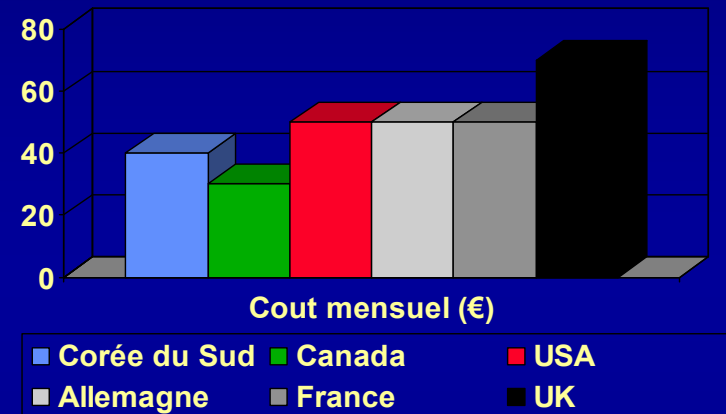
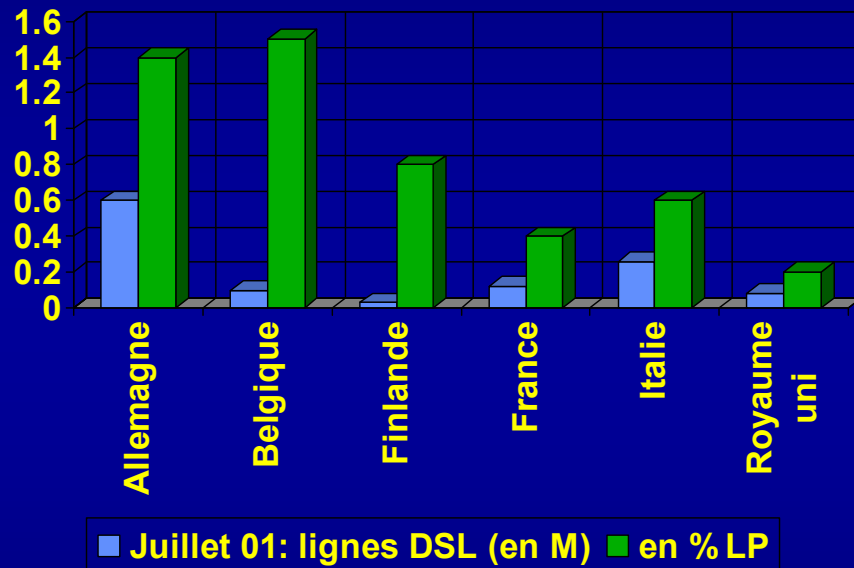
Déploiement haut débit en France:

- 500 000 lignes ADSL en 2002
- 10,6 millions 1er trimestre 2006 (94% ADSL)
- 80% des 14 millions de foyers raccordés à Internet



- Opérateurs : orange(40%),Free(20%), club internet, alice ...

Déploiement dans le monde

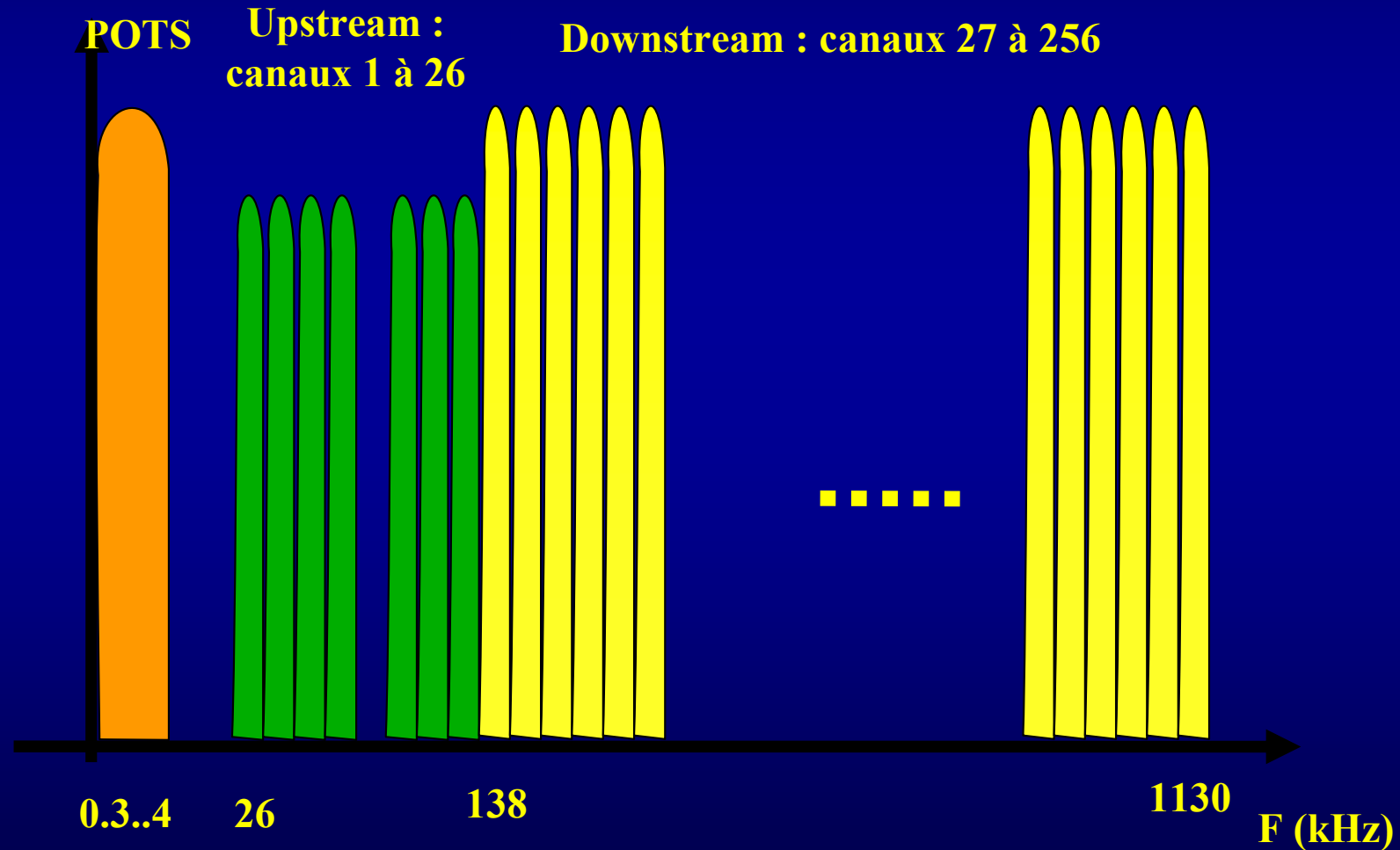


ADSL : caractéristiques

- **Assymétrique ...**
- **Toujours avec POTS**
- **Avec ou sans ISDN (RNIS)**
- **Performances fonction de la ligne**
- **Modulation “Discrete Multitone”**
- **QAM(quadrature amplitude modulation)**
- **CAP(Carrierless Amplitude Phase)**

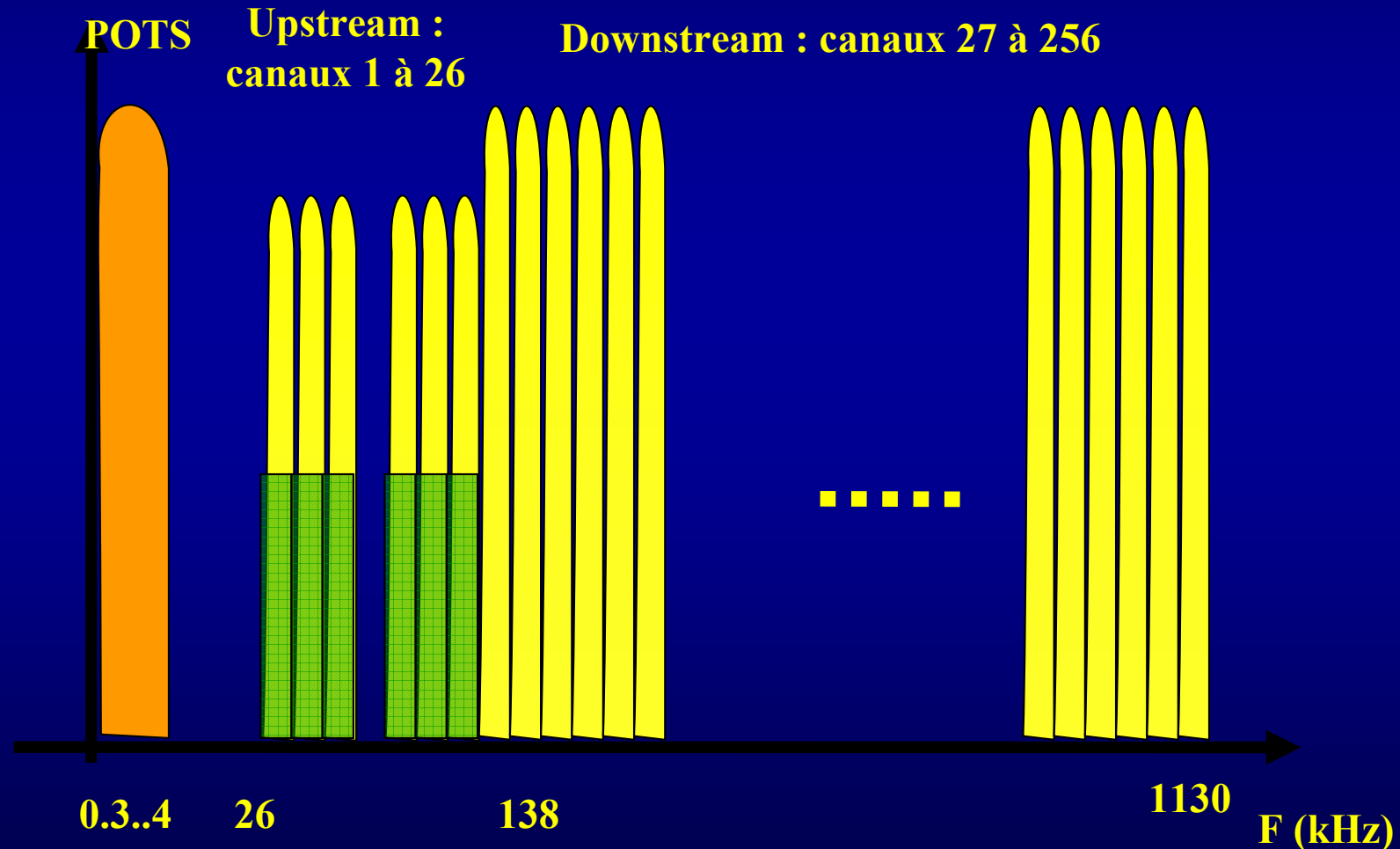
Spectre de l'ADSL

- 256 canaux de 4.3125 kHz



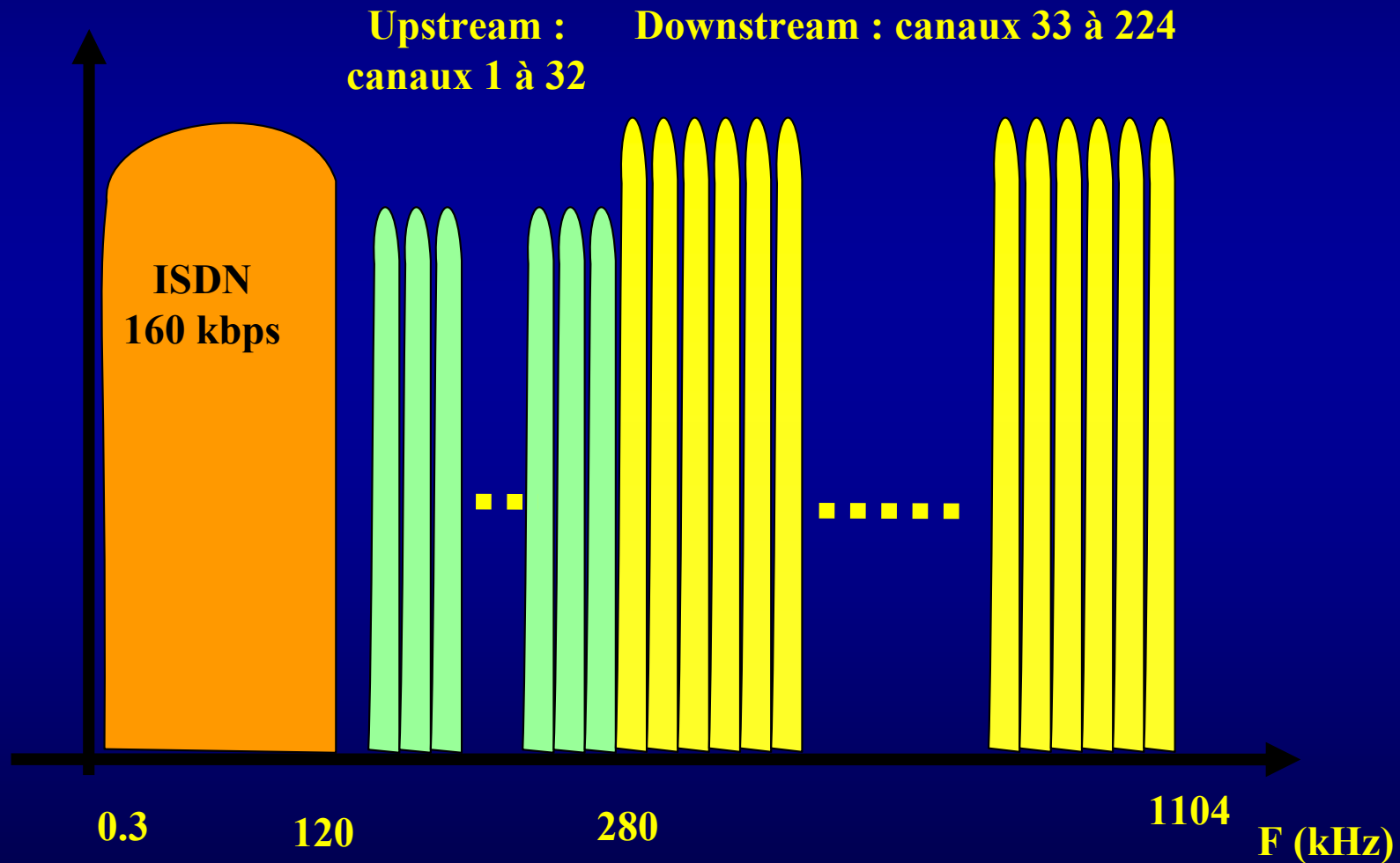
Spectre de l'ADSL avec suppression d'écho

- 256 canaux de 4.3125 kHz

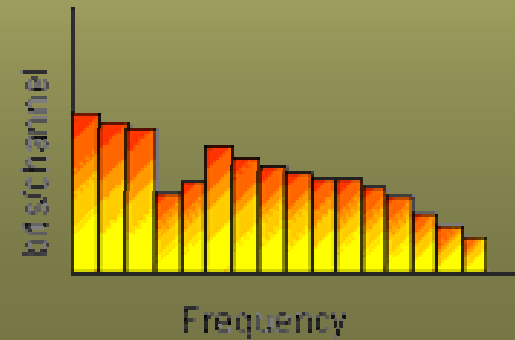
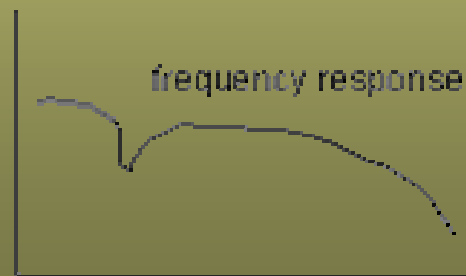
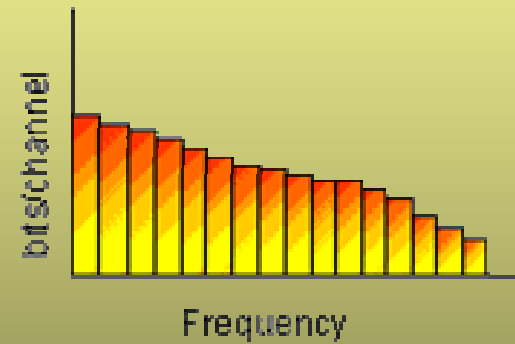
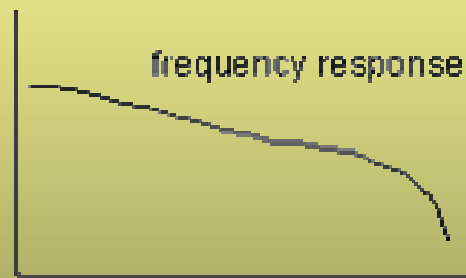
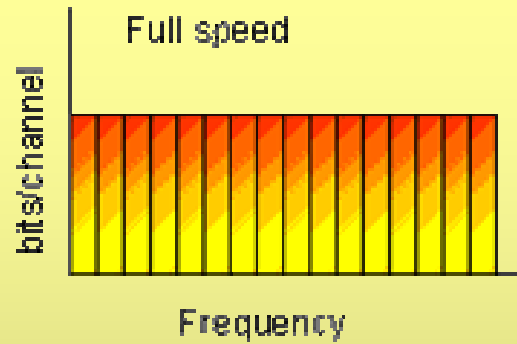


Spectre de l'ADSL avec ISDN

- 224 canaux de 4.3125 kHz



Débits variables



Chaque canal < - > sous porteuse (« tone »)

Lien descendant : 256 (max) sous porteuses

Sous porteuses 64 et 256 non utilisables pour les données

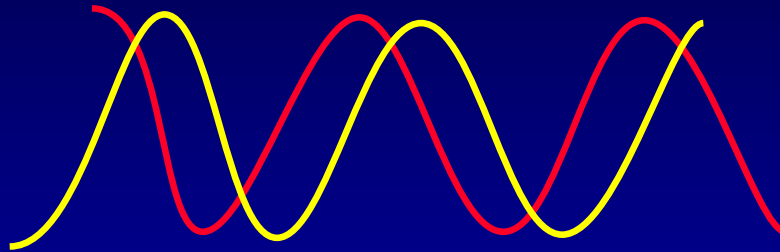
4000 trames/sec. * (0-15 bits) *254 => 15.24 Mb/s (théorique)

Mais taille du mot < 256 octets (pour code Reed Solomon de detection d'erreur) => debit max de 8.128 Mb/sec

Lien montant : 31 (max) sous porteuses (fréquences basses)

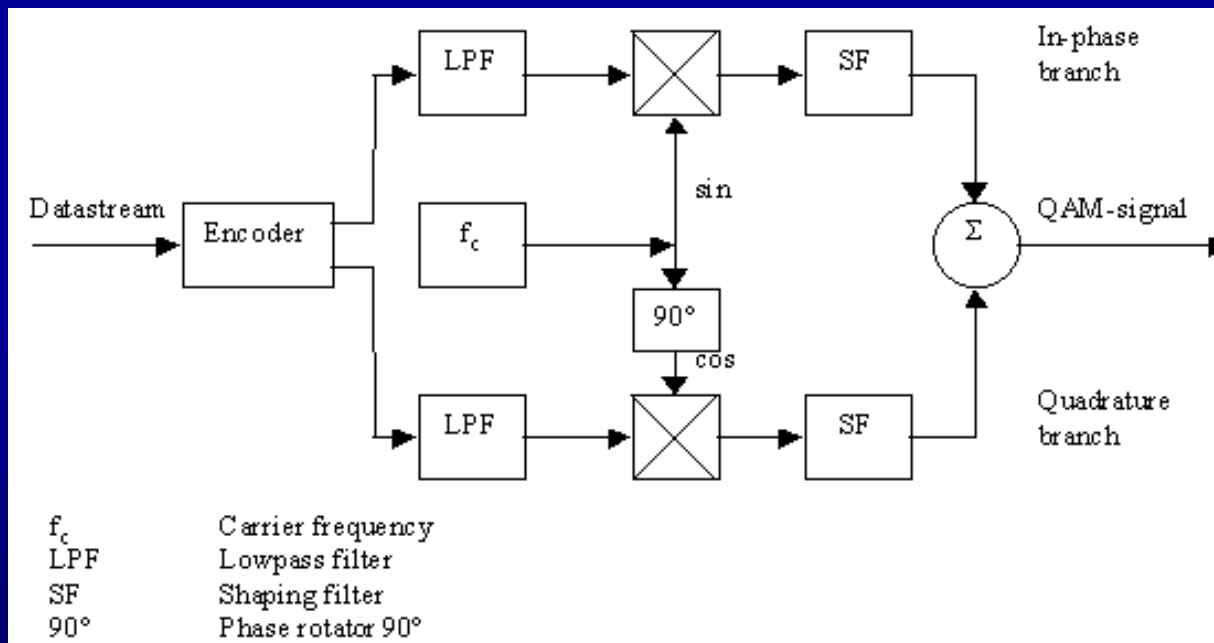
Sous porteuses 16 et 32 non utilisables pour les données

Quadrature amplitude modulation

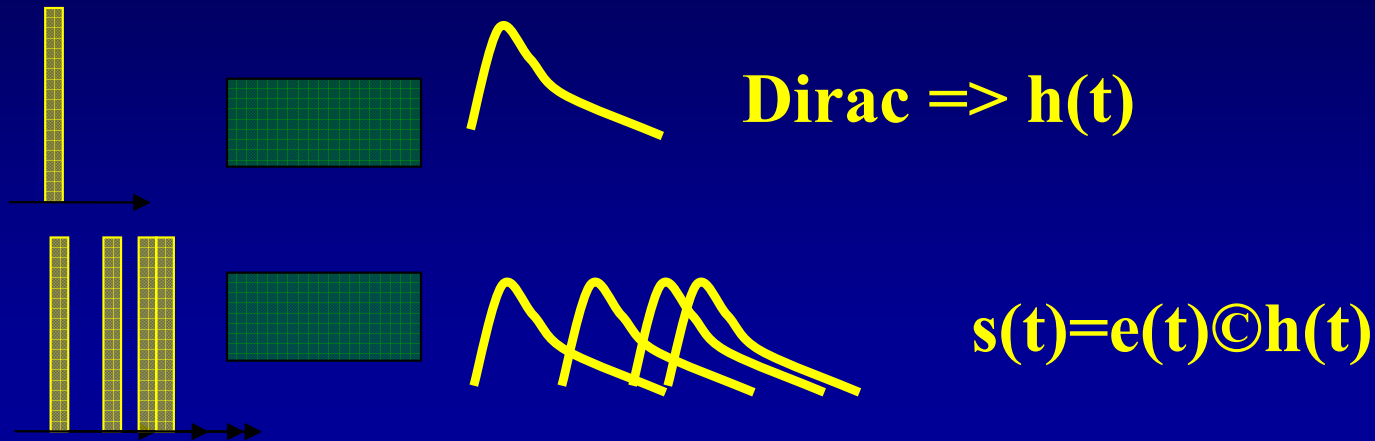


$$S(t) = X \cdot \cos(\omega \cdot t) + Y \cdot \sin(\omega \cdot t)$$

$$= (X^2 + Y^2)^{1/2} \cdot \cos(\omega \cdot t - \arctan(Y/X))$$



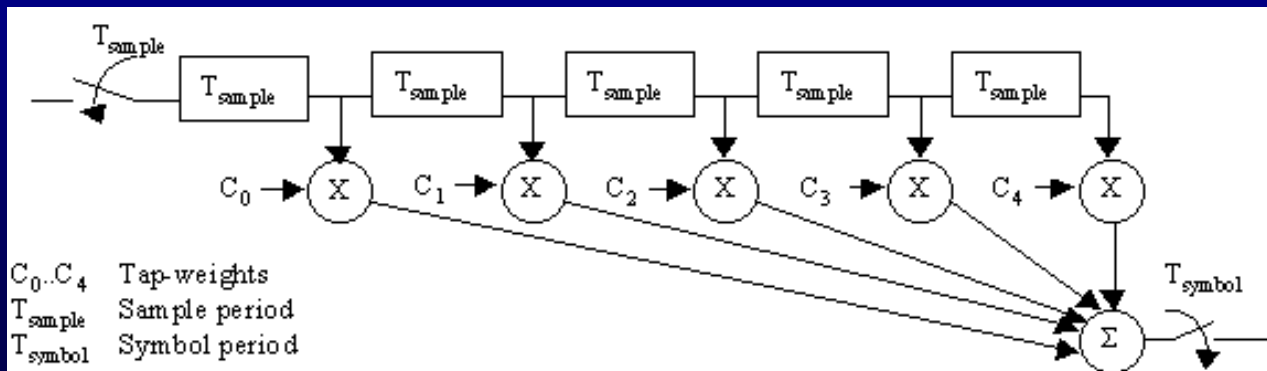
•Egalisation => réduire l'interférence intersymboles



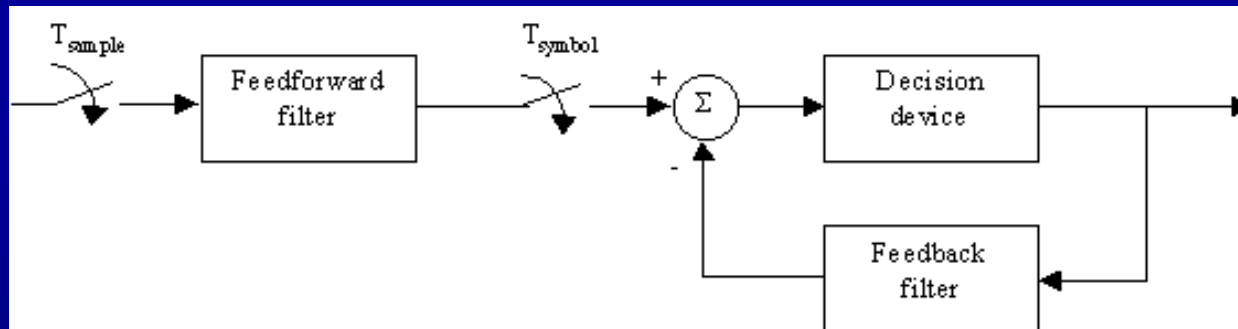
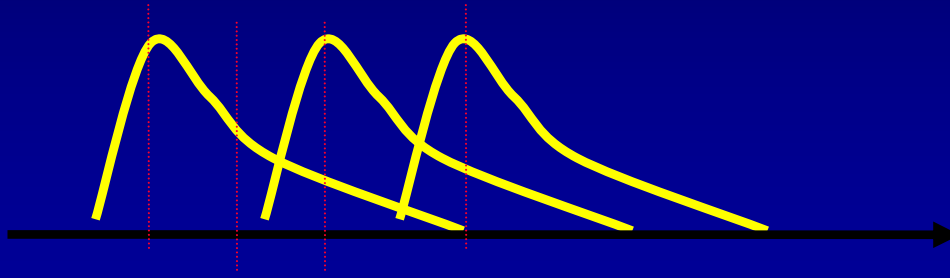
filtre rectangulaire

$h(t)$ en $\frac{\sin(\pi \cdot Fr \cdot t)}{\pi \cdot Fr}$

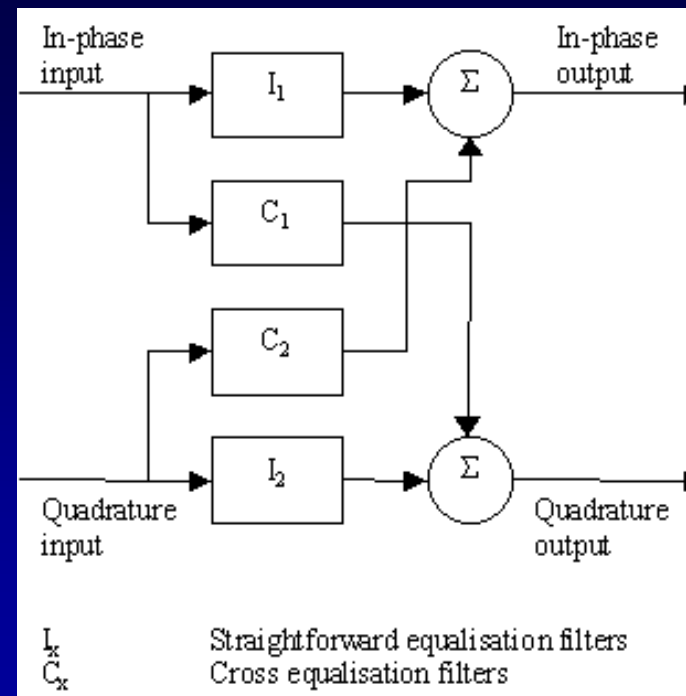
$h(t)$ s'annule à $t = k \cdot T = k / Fr$



Egalisation récursive (Decision Feedback Equalisation)

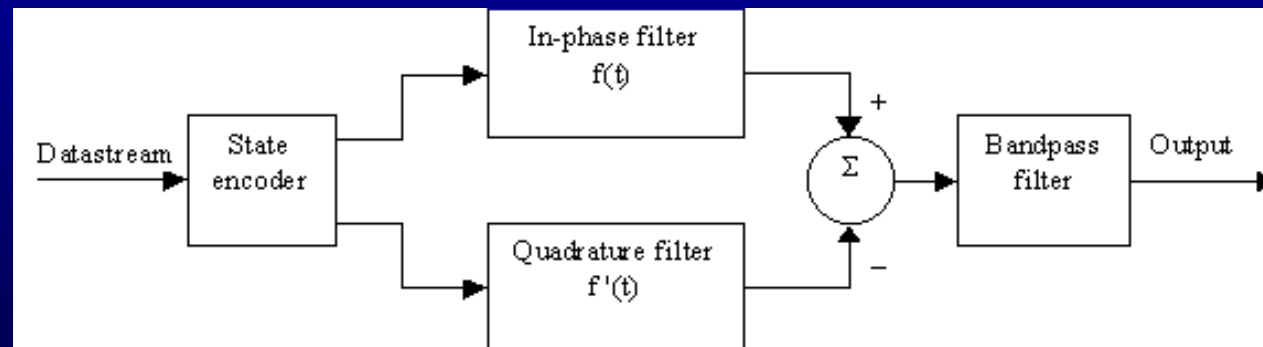


Egalisateur en croix pour QAM



Variante : Carrierless Amplitude Phase Modulation

Facile à implémenter

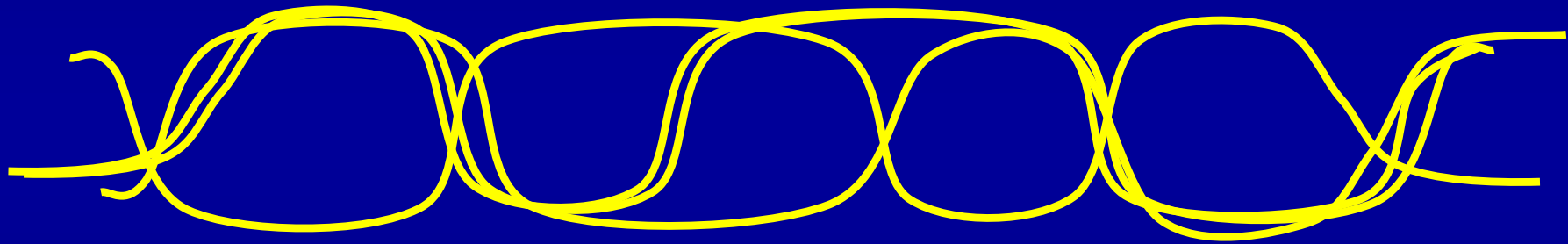


Modulations

PAM, PPM, PDM

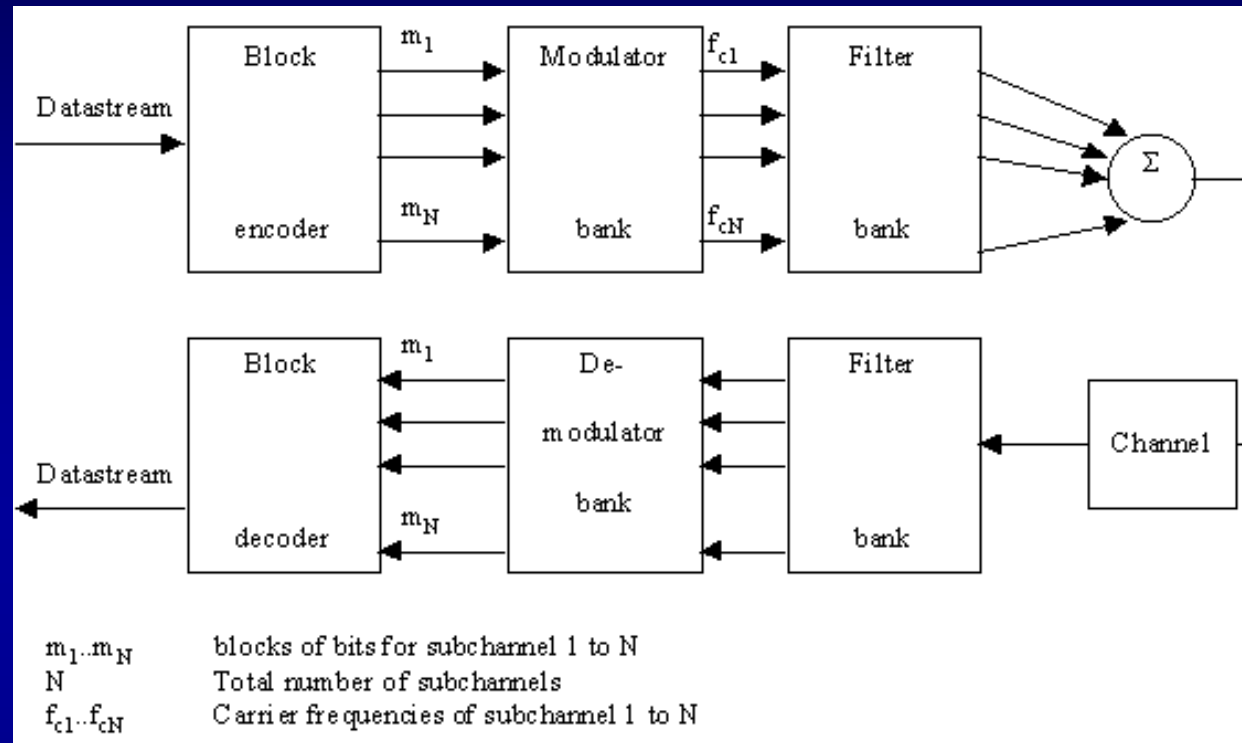
- **Pulse amplitude modulation :**
symboles à 2^n niveaux (n entier ou non):

- **Diagramme de l'oeil**



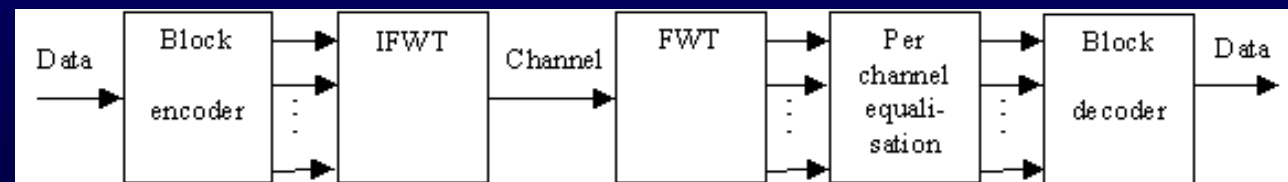
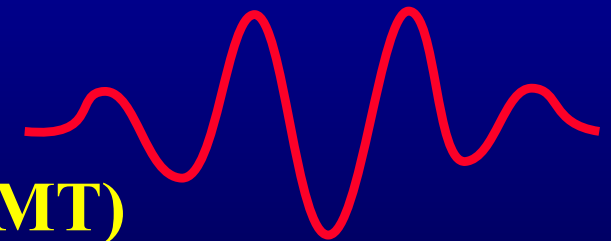
- **Détection par maximum de vraisemblance**
calcul par corrélation

Multicarrier Modulation System



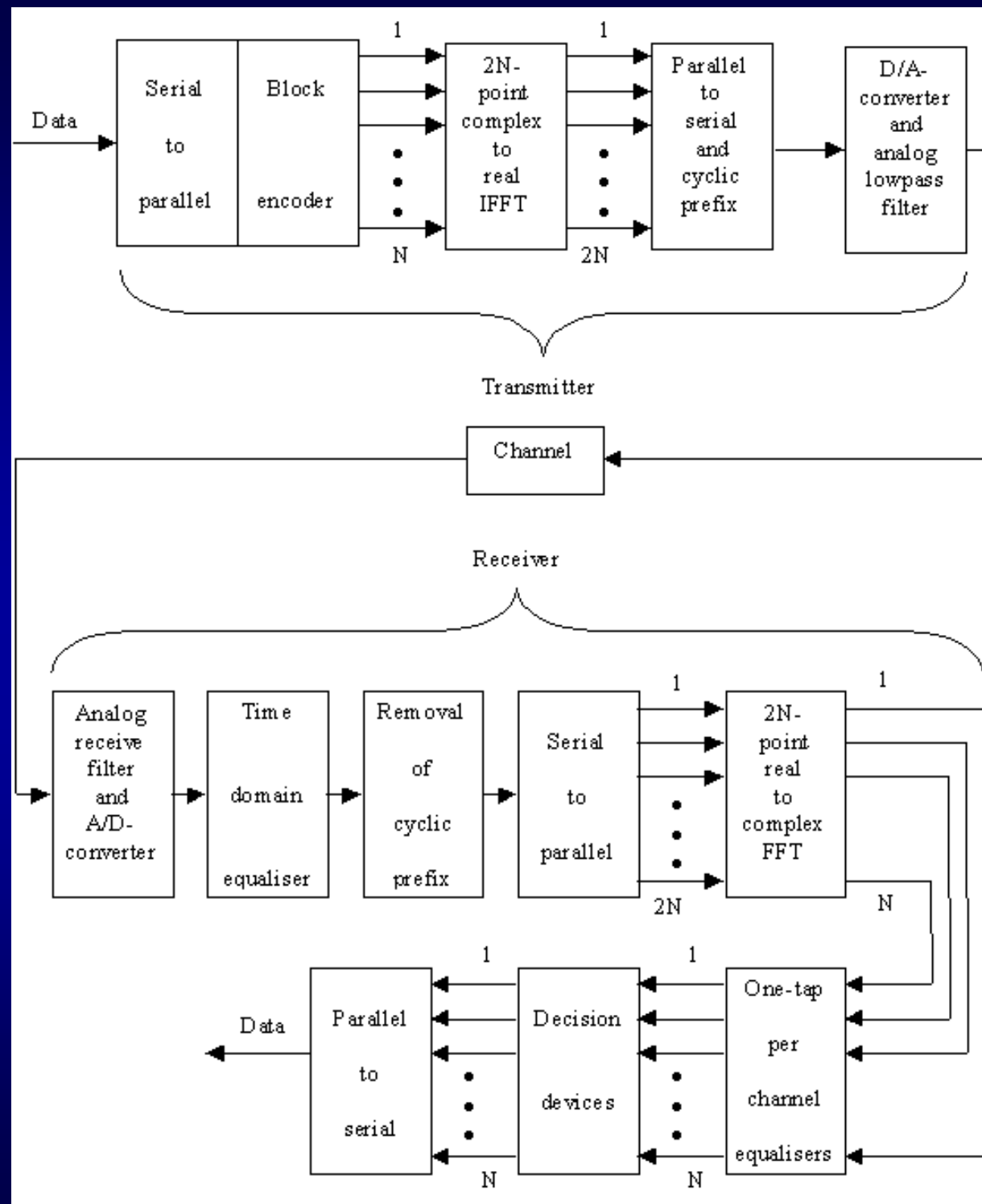
• **Discrete MultiTone (DMT) => ADSL**

• **Variante: Discrete Wavelet MultiTone (DWMT)**



Synthese de Fourier :

$$S(t) = \sum (X_k * \cos(w_k t) + Y_k \sin(w_k t))$$



Génération du signal par IFFT:

FFT : $1.5 * M * \log(M)$ au lieu de M^2 opérations

M en 2^N : 128, 256, 512

**=> conditionne la
fréquence des
symboles (largeur de
spectre)**

$$X_{2*N-k} = X_k \text{ conjugué}$$

$$f_{\text{symbol}} = \frac{1}{T} = \frac{f_{\text{sample}}}{2*N + CP}$$

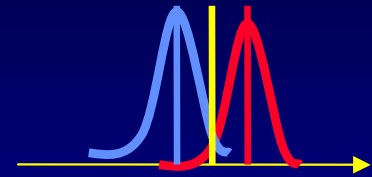
$$\Delta f = \frac{f_{\text{sample}}}{2*N}$$

Préfixe cyclique rajouté ~40 bits

Débit binaire (binary rate):

$$R_{\max} = \int_{f_{\text{low}}}^{f_{\text{up}}} \log_2 \left(1 + \frac{3}{\left(Q^{-1} \left(\frac{\text{BER}}{4} \right) \right)^2} * \text{SNR}(f) \right) df$$

$$Q(x) = \frac{1}{\sqrt{2} * \pi} * \int_x^{\infty} e^{-\frac{y^2}{2}} dy$$



$$R_{\max} = \int_{f_{\text{low}}}^{f_{\text{up}}} \log_2 \left(1 + 10^{\frac{\text{SNR}_{\text{vg}}(f) - 9.8 \text{ dB} - \text{CFloss} + \gamma}{10}} \right) df$$

Efficacité spectrale de l'ADSL: -> 15bits/sec/Hz

$$= 256 * 4 \text{ k symb/sec} * 16 \text{ bits/symb} / 1.1 \text{ MHz}$$

Max rate per channel : $68/69 * \text{symb.rate} * \log_2(1 + \text{SNR}/\Gamma)$

Symbol rate : 4.058 kBauds pour 4.135 KHz (canal)

SNRgap=9.8 dB pour BER max de 10^{-7} + SNRmargin=6 dB (G992.1) = $\Gamma = 15.8$ dB

Nb de bits par canal:

$$b_n = \log_2 \left(1 + \frac{3}{\left(Q^{-1} \left(\frac{BER}{4} \right) \right)^2} * SNR_n \right)$$

$$b_n = \log_2 \left(1 + \frac{PSD_{signal}(n) * |H(n)|^2}{PSD_{noise}(n) * \Gamma} \right)$$

$$\Gamma = 10^{9,8-r+10 \cdot \log \left(\frac{2 \cdot N}{2 \cdot N - CP} \right)}$$

			Without ISDN			With ISDN		
			2km	3km	4km	2km	3km	4km
			dBm	dBm	dBm	dBm	dBm	dBm
0,4mm	Twisted pair	Real world	18,95		17,71	18,95		17,90
		Worst case	19,07	16,25		19,14	15,83	
	No crosstalk		16,75		17,72	17,35		17,79
	Quad	Real world	18,93		17,91	18,99		17,86
Worst case		18,57	15,88		18,62	15,40		
0,5mm	Twisted pair	Real world	18,95		18,97	18,93		18,99
		Worst case	18,96		16,47	19,01		16,07
	No crosstalk		12,28		18,57	13,07		18,90
	Quad	Real world	18,96		18,98	19,03		18,99
Worst case		19,02		16,03	18,96		15,42	

			Without ISDN			With ISDN		
			2km	3km	4km	2km	3km	4km
			Mbits/s	Mbits/s	Mbits/s	Mbits/s	Mbits/s	Mbits/s
0,4mm	Twisted pair	Real world	8,28		3,38	7,40		2,97
		Worst case	5,01	2,15		4,11	1,43	
	No crosstalk		15,00		6,25	13,17		4,12
	Quad	Real world	9,87		3,97	8,80		3,34
Worst case		5,22	2,72		3,96	1,64		
0,5mm	Twisted pair	Real world	8,41		6,13	7,51		5,71
		Worst case	7,45		1,66	6,57		1,14
	No crosstalk		15,92		10,74	14,10		8,77
	Quad	Real world	10,02		7,34	8,94		6,70
Worst case		7,52		2,20	6,25		1,32	

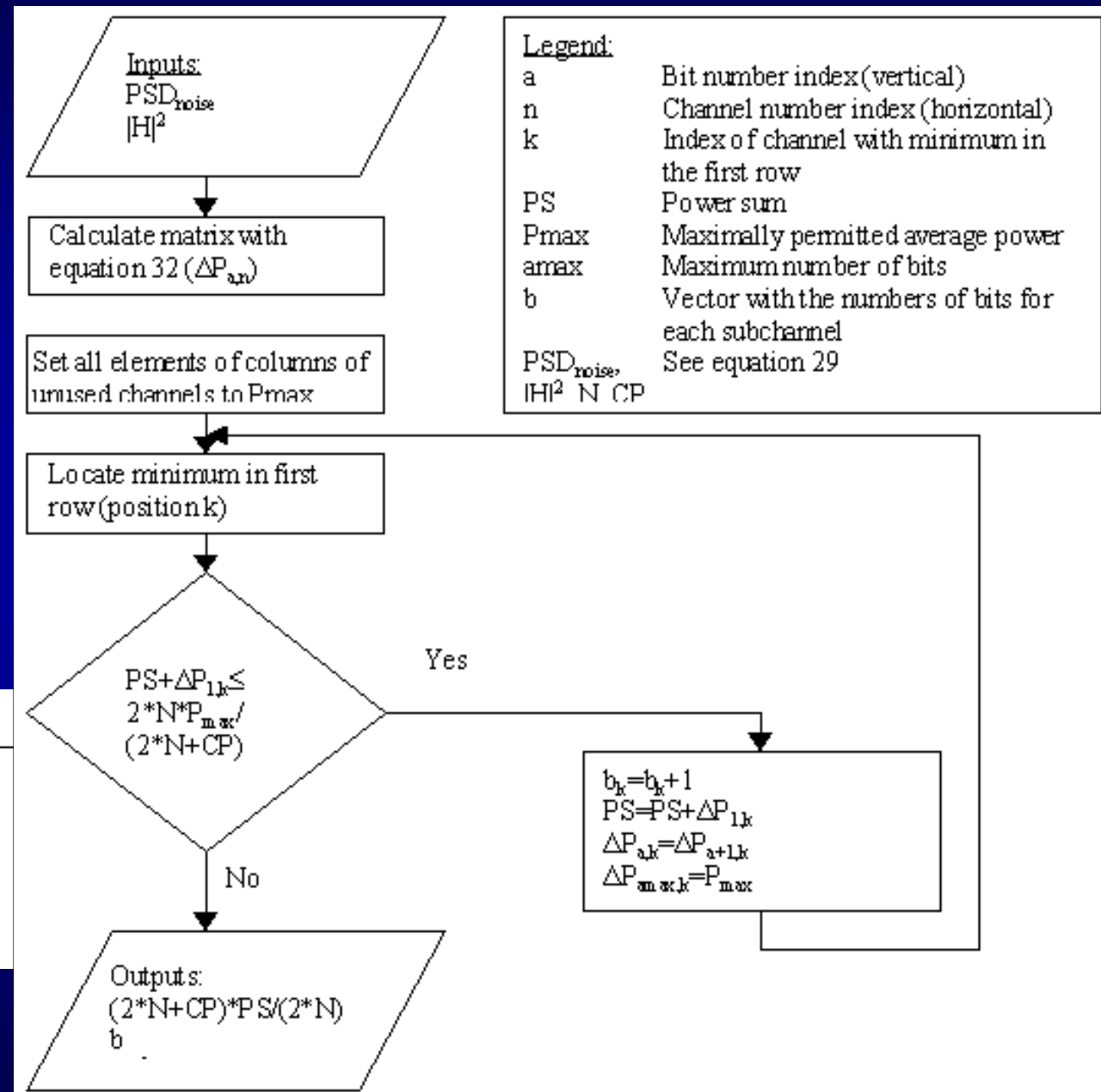
Allocation des bits par l'algorithm d'optimisation matricielle:

Puissance supplémentaire pour un bit de plus:

$$\Delta P_{a,k} = \frac{f_{\text{symd}} * PSD_{\text{noise}}(n) * \Gamma}{|H(n)|^2} * (2^{b_n-1})$$

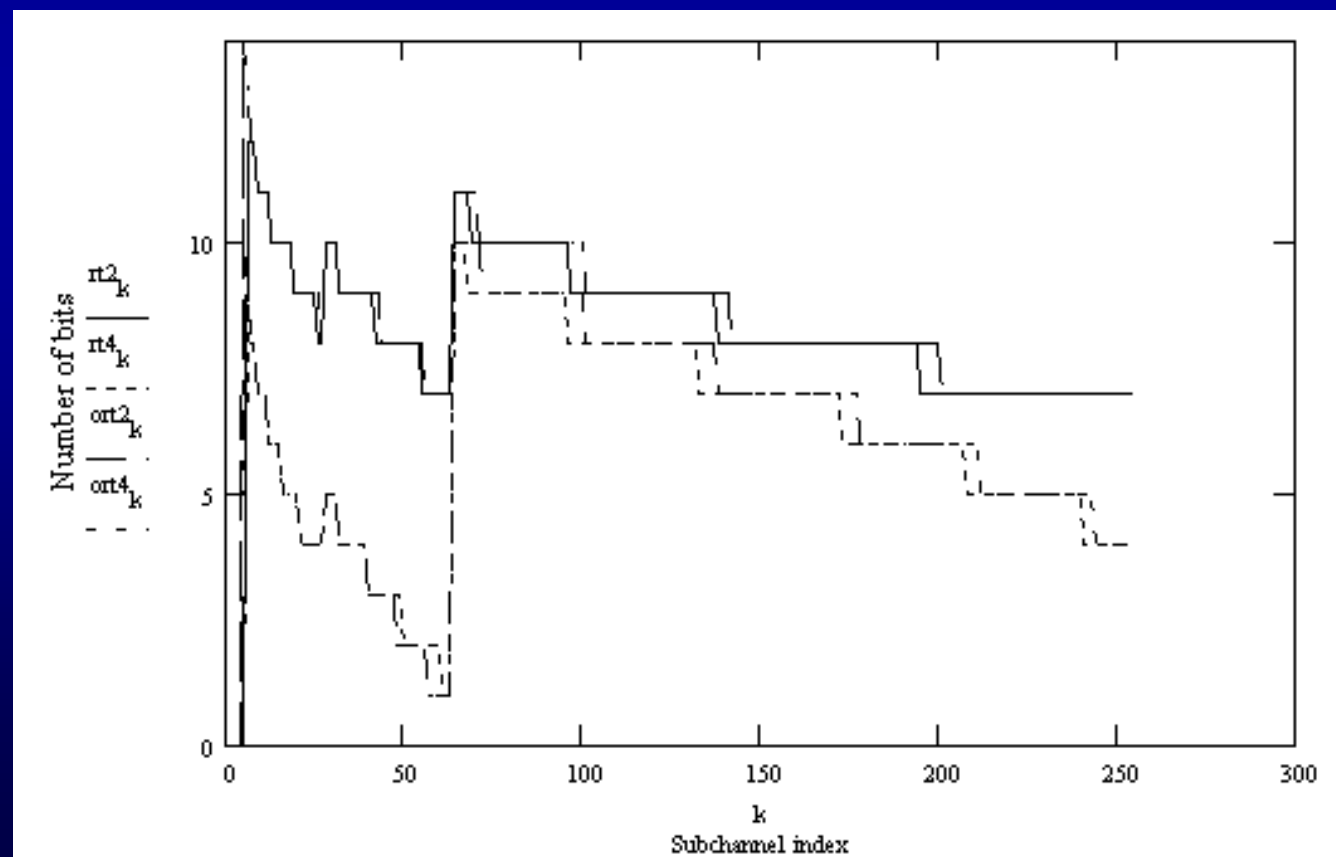
	Subchannel n						
	$\Delta P_{1,1}$	$\Delta P_{1,2}$	$\Delta P_{1,3}$	$\Delta P_{1,4}$	$\Delta P_{1,5}$	$\Delta P_{1,6}$	$\Delta P_{1,7}$
	$\Delta P_{2,1}$	$\Delta P_{2,2}$	$\Delta P_{2,3}$	$\Delta P_{2,4}$	$\Delta P_{2,5}$	$\Delta P_{2,6}$	$\Delta P_{2,7}$
	$\Delta P_{3,1}$	$\Delta P_{3,2}$	$\Delta P_{3,3}$	$\Delta P_{3,4}$	$\Delta P_{3,5}$	$\Delta P_{3,6}$	$\Delta P_{3,7}$
	$\Delta P_{4,1}$	$\Delta P_{4,2}$	$\Delta P_{4,3}$	$\Delta P_{4,4}$	$\Delta P_{4,5}$	$\Delta P_{4,6}$	$\Delta P_{4,7}$
	$\Delta P_{5,1}$	$\Delta P_{5,2}$	$\Delta P_{5,3}$	$\Delta P_{5,4}$	$\Delta P_{5,5}$	$\Delta P_{5,6}$	$\Delta P_{5,7}$

Number of bits



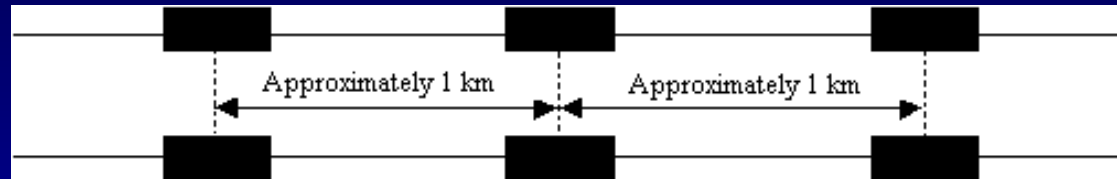
Débit binaire avec l'algorithme d'optimisation matricielle

			Without ISDN			With ISDN		
			2km	3km	4km	2km	3km	4km
			Mbits/s	Mbits/s	Mbits/s	Mbits/s	Mbits/s	Mbits/s
0,4mm	Twisted pair	Real world	8,42		3,77	7,52		3,28
		Worst case	5,22	2,67		4,28	1,89	
	No crosstalk		15,53		6,68	13,60		4,52
	Quad	Real world	10,02		4,35	8,91		3,67
		Worst case	5,54	3,28		4,23	2,12	
0,5mm	Twisted pair	Real world	8,55		6,25	7,63		5,80
		Worst case	7,59		2,13	6,66		1,55
	No crosstalk		16,06		11,00	14,40		8,92
	Quad	Real world	10,17		7,46	9,04		6,80
		Worst case	7,65		2,73	6,38		1,78



Boucle locale

- Loading coils
- Bridged taps



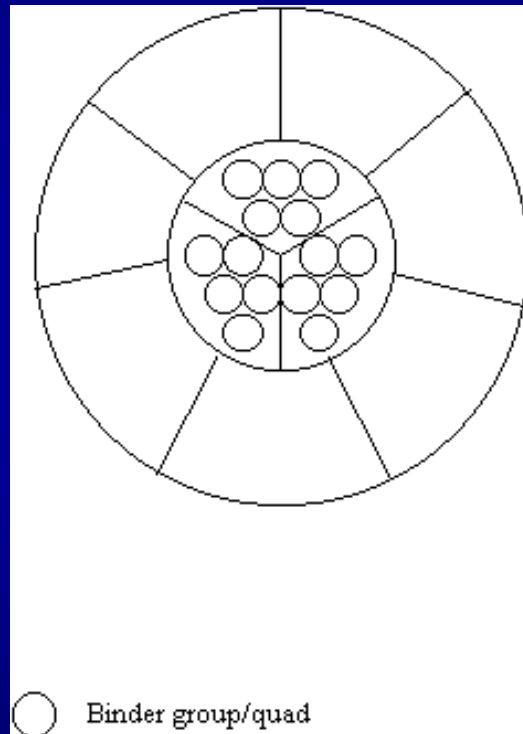
f (kHz)	R' (Ω/km)	L' (μH/km)	C' (nF/km)	G' (mS/km)
5	179	694,81	55,43	0,003
10	179	694,56	55,40	0,007
50	183	692,06	55,34	0,036
100	193	688,47	55,32	0,073
500	316	661,64	55,27	0,385
1000	438	640,00	55,15	0,789
5000	974	598,93	55,21	4,160
10000	1376	591,53	55,20	8,510
20000	1947	587,94	55,19	17,420
30000	2384	586,83	55,18	26,480

Câble enterré (0.5 mm)

f (kHz)	R' (Ω/km)	L' (μH/km)	C' (nF/km)	G' (mS/km)
5	191	724,63	74,72	0,13
10	191	721,82	72,89	0,92
50	195	707,05	69,15	0,99
100	207	694,78	67,75	1,7
500	342	648,79	64,88	6,73
1000	475	624,65	63,81	12,19
5000	1056	578,22	61,62	48,34
10000	1493	565,74	60,79	87,5
20000	2112	557,33	60,03	158,39
30000	2586	553,87	59,61	224,12

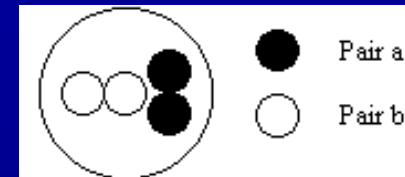
Câble aérien (0.5 mm)

Quelques câbles utilisés dans la boucle locale :



Bundle twisted cable

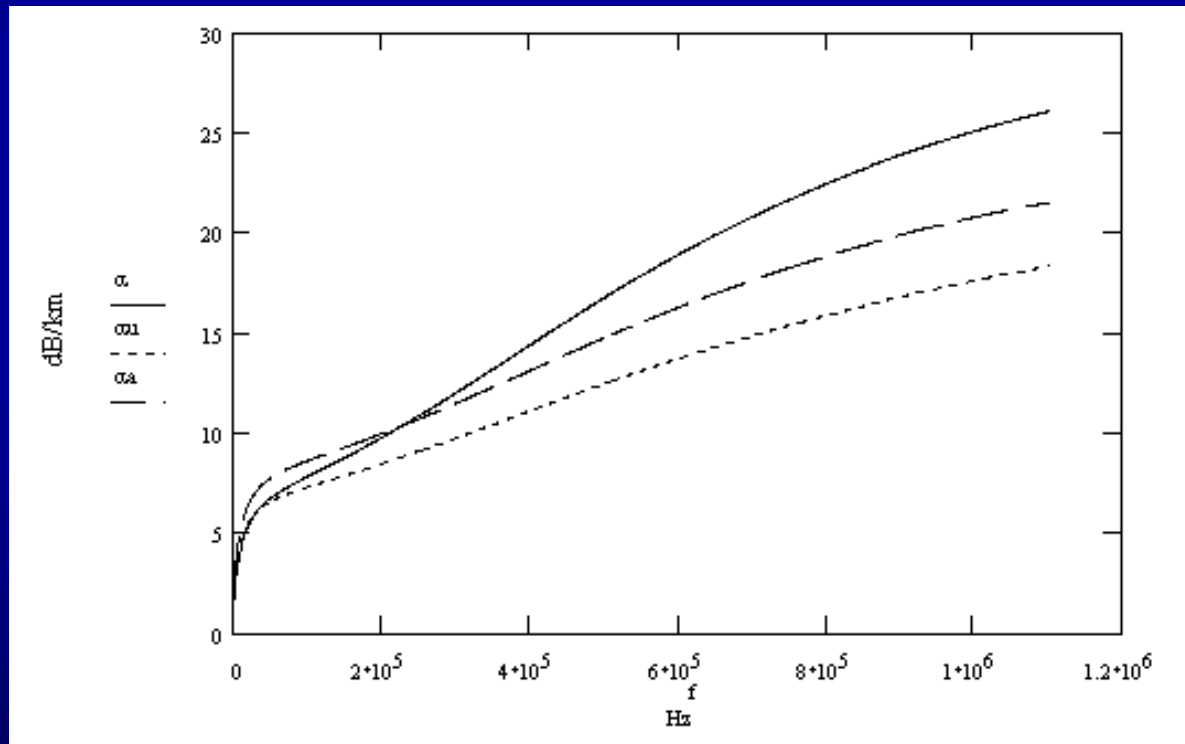
Quad cable



Atténuation dans la boucle locale:

$$H(f) = \frac{U_2(f)}{U_1(f)} = e^{-\gamma z}$$

$$\gamma = \alpha + i\beta = \sqrt{(R' + i2\pi fL') * (G' + i2\pi fC')}$$

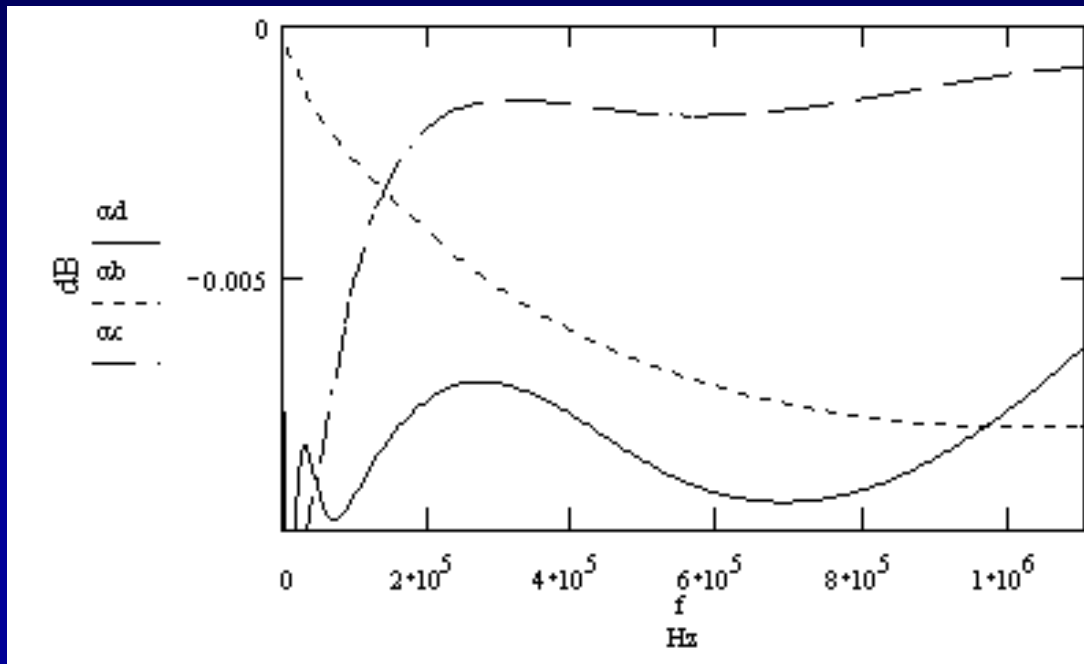


Cat.3 (0.4 mm)

Aérien (0.5 mm)

Enterré (0.5mm)

Discontinuités => pertes supplémentaires

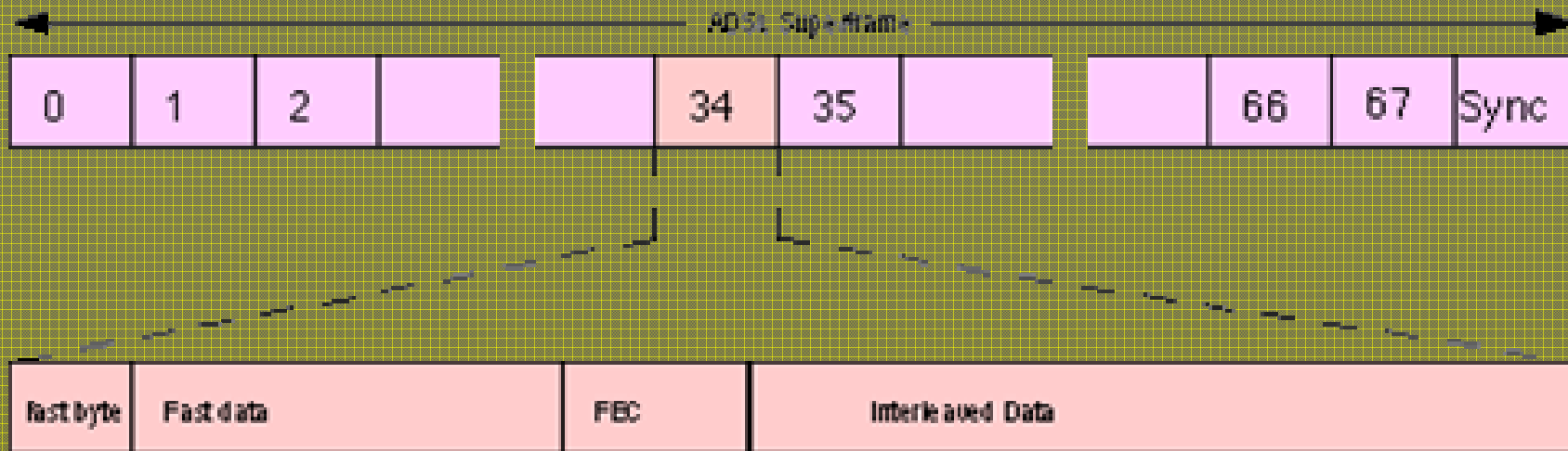


$\hat{\alpha}_d$ Change from underground to aerial cable (both 0,5 mm)

$\hat{\alpha}_b$ Change from underground (0,5 mm) to category 3 installation cable (0,4 mm)

$\hat{\alpha}_c$ Change from aerial (0,5 mm) to category 3 installation cable (0,4 mm)

Frames et superframe ADSL



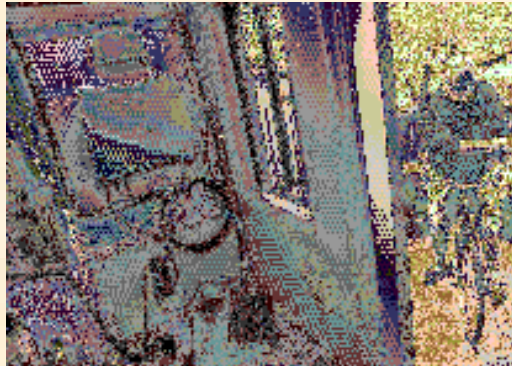
Conclusion et perspectives

- **VDSL** **2000 porteuses => 56 Mbps** **<1.5 km**
- **Fibre optique: Bande passante 25 TeraHz**
(FTTH après FTTC)

Surfing faster with fiber Palo Alto residents test high-speed Internet lines



A single strand of optical fiber can handle 5 million telephone
Photo by David Duprey



Bob Harrington got on his bike outside his Palo Alto home, for high-speed Net access.
Chronicle photo by Penni

Bob Harrington has long been an Internet speed demon. Three years ago, the Palo Alto angel investor signed up for cable modem service, letting him access the Net at speeds dozens of times faster than traditional dial-up modems. But Harrington says his new connection leaves his cable modem in the dust. For the past few months, Harrington and 66 neighbors have been testing a next generation fiber-optic network, which is three to four times faster than cable or DSL service. The speed advantage over wireless and satellite is even starker. "It feels real good to be one of the fastest Internet users on the planet," said Harrington, who pays \$85 per month for the service. "It is way too early to tell you how my Internet habits will change, but they certainly will."

Although more than 10 million U.S. households now* have DSL or cable modem service, making Internet access as common as SUVs in upscale communities, a few neighborhoods around the country are now experimenting with even faster links, using packets of light instead of electrons to move data at blazing speeds.

To be sure, access is limited to a handful of new developments and experimental trials. Indeed, the figure is so small that the Yankee Group, a Boston research firm, hasn't bothered to include fiber optics in its projections for residential high-speed Internet access through 2005. "Fiber to the curb is very limited," said Yankee analyst Imran Khan.

But proponents say the Palo Alto trial provides a glimpse into the future of Internet access -- a time when residents will be able to easily rent movies online, chat with friends on near-broadcast quality Webcams or play sophisticated Internet games.

PLUGGED IN

Close to 1 in 10 U.S. households now has high-speed Internet service

	U.S. users	Speed* (Megabits per sec)	Monthly price X
Cable modem	7 million	1.5	\$46 (1)
DSL	3.3 million	1 to 1.5	50
Wireless	300,000	0.5 to 1.5	50 (2)
Satellite	61,300	0.15 to 0.5	75 (3)
Fiber	N/A	4.5 to 9	\$85 (4)

* Typical download speed. Varies by company and location.

¹ AT&T Broadband, the dominant cable modem provider in the Bay Area.

² Speeds and price are for Sprint Broadband Direct, which operates in the Bay Area but has stopped signing up customers.

³ Speed and price are for Starband/Dish Network.

⁴ Speeds and prices are for Palo Alto's Fiber-to-the-Home trial.

Source: Yankee Group, Chronicle research

Free investit 1 milliard d'euros dans la fibre optique

Le Monde.fr 12 Septembre 2006

LE FOURNISSEUR d'accès à Internet (FAI) Free a décidé de se lancer dans le très haut débit. Lundi 11 septembre, il a annoncé qu'à compter du premier semestre 2007, il commercialiserait une offre à 50 mégabits par seconde, reposant sur la fibre optique, pour 29,99 euros par mois. Aujourd'hui, l'ADSL permet des débits s'élevant au maximum à 28 mégabits. L'Internet à très haut débit offre aux consommateurs la possibilité d'utiliser toutes les fonctionnalités du Web (téléphone, vidéo à la demande, télévision haut définition, jeux en ligne...) dans des conditions de rapidité et d'affichage inégalées et de façon simultanée.