Analog Electronics 2

ICS905

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November 2016

Schedule

- Radio channel characteristics ;
- Analysis and conception of the couple Tx-Rx ;
- M-QAM Modulation - theoretical analysis ;
- Distortions in M-QAM ;

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Radio-channel characteristics

Microscopic effects

Transmitted signal :

$$s(t) = Re\{u(t).e^{j2\pi f_c t}\} = I(t)\ \cos(2\pi f_c t) - Q(t)\ \sin(2\pi f_c t)$$

f_c carrier frequency - $u(t)$ BB with $B_s\ Hz$.

Received Signal :

$$r(t) = Re\left\{\sum_{n=0}^{N(t)} \alpha_n u(t - \tau_n(t)).e^{j\{2\pi f_c (t-\tau_n(t)) + \phi_n^D\}}\right\}$$

$$\phi_n(t) = 2\pi f_c \tau_n(t) - \phi_n^D,$$

$$r(t) = Re\left\{e^{j2\pi f_c t}.\sum_{n=0}^{N(t)} \alpha_n u(t - \tau_n(t)).e^{-j\phi_n(t)}\right\}$$

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Components of *fading*

n corresponds to a path of length

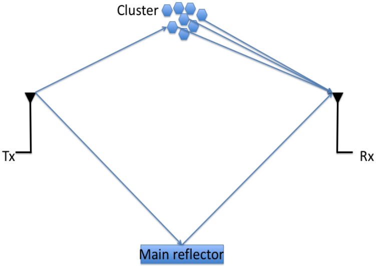
$$L_n \to \tau_n = L_n/c$$

$\alpha_n(t) =$ attenuation.

$\phi_n^D = \int 2\pi f_n^D(t)\ dt =$ Doppler f_c,

$f_n^D(t) = \frac{v \cos\theta_n(t)}{\lambda}$,

$\theta_n(t)$ angle relative to the mouvement direction.



Paths are *solvable* if $|\tau_j - \tau_i| \gg B_s^{-1}$

Impact of *fading*

If the delay dispersion is small compared to $B_s^{-1} \sim T_s$
$\Rightarrow$ *narrowband* fading ;

If the delay dispersion is big compared to $B_s^{-1} \sim T_s$
$\Rightarrow$ *wideband* fading ;

Delay spread

The delay dispersion is called *Delay spread* of the channel $\rightarrow T_m$.

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Model *narrowband*

If $T_m \ll T_s$.

If τ_i represents the ith delay, so $\tau_i \leq T_m$:

$$u(t-\tau_i) \simeq u(t).$$

$$r(t) = Re\left\{u(t)\, e^{j2\pi f_c t} \underbrace{\left(\sum_n \alpha_n(t)\, e^{-j\phi_n(t)}\right)}_{A(t)}\right\}.$$

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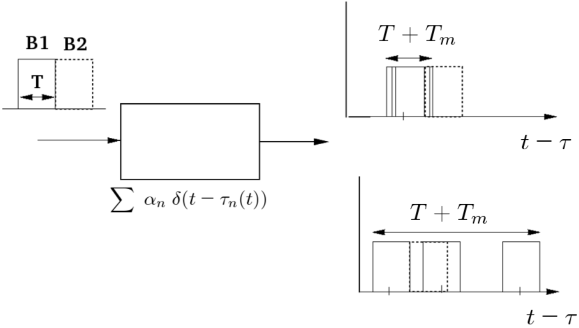
Model *wideband*

In this case $T_m \gg T_s$.



Conclusion : if $T_m \gg T_s \rightarrow$ ISI

Doppler effect

This phenomenon represents the variability of the channel in time :

The mean dispersion of the frequency beside the carrier is called *Doppler spread* B_D of the channel.

We call Coherence time of the channel, the duration of a complete cycle of dynamics induced by the Doppler efect.

$$T_c \approx 1/B_D$$

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A "Resumé"

Delay Spread - T_m

Delay spread give us a good idea of the dispersive characteristics of the channel in time.

Doppler Spread - B_D

Doppler dispersion give us a good idea of the variability of the channel.

Parameters

Mean delay spread $\leftrightarrow$ Coherence bandwidth

$$T_m \leftrightarrow B_c$$

Coherence time $\leftrightarrow$ Doppler dispersion

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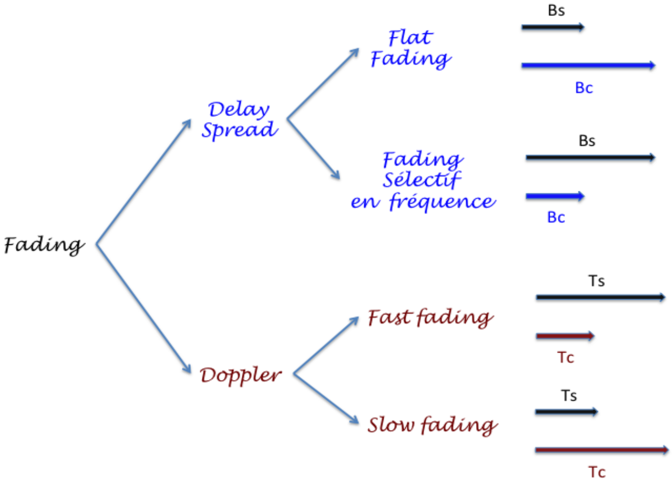
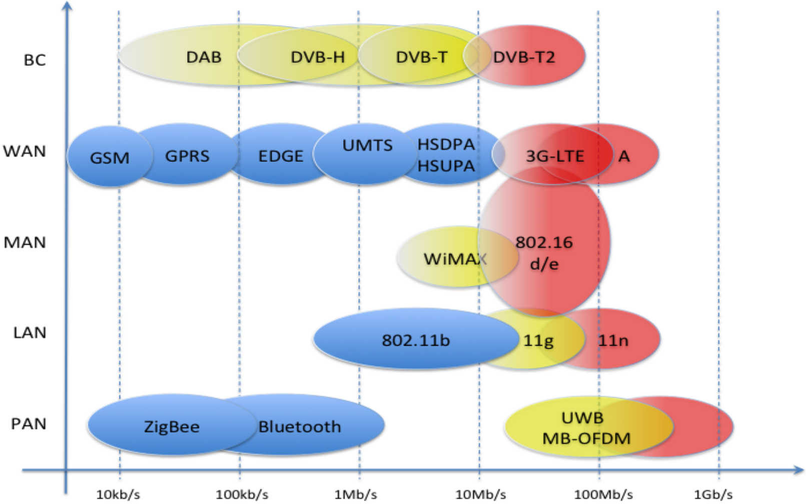
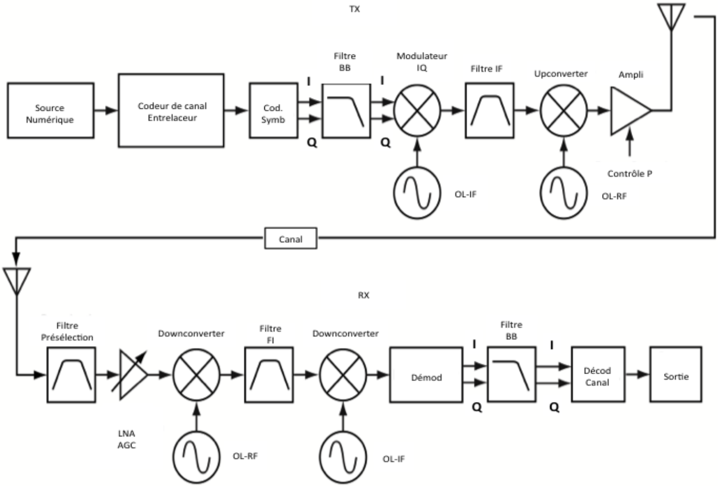
Channel models



"Etat de l'art"


BC
WAN
MAN
LAN
PAN
DAB
DVB-H
DVB-T
DVB-T2
GSM
GPRS
EDGE
UMTS
HSDPA
HSUPA
3G-LTE
A
802.16
d/e
WiMAX
802.11b
11g
11n
ZigBee
Bluetooth
UWB
MB-OFDM
10kb/s
100kb/s
1Mb/s
10Mb/s
100Mb/s
1Gb/s

Scheme of Tx-Rx



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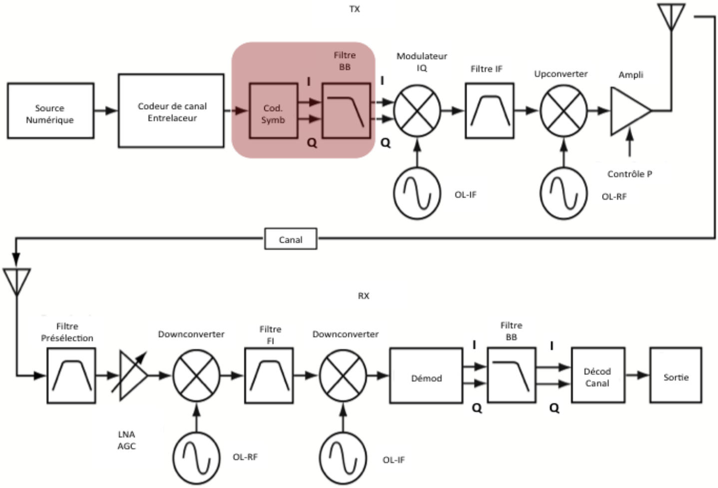

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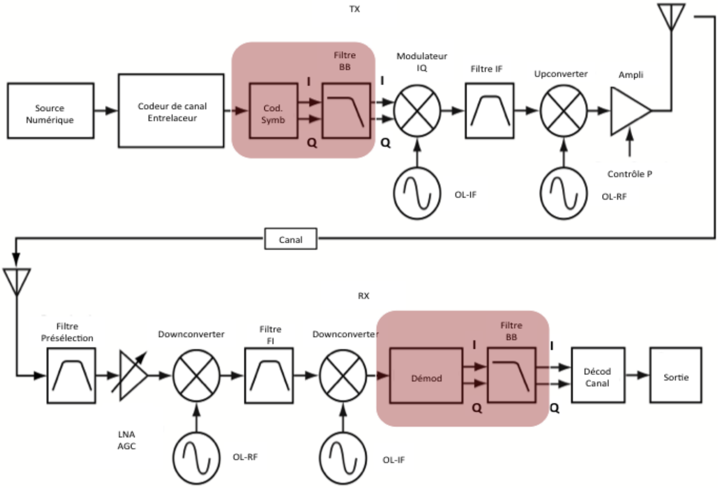

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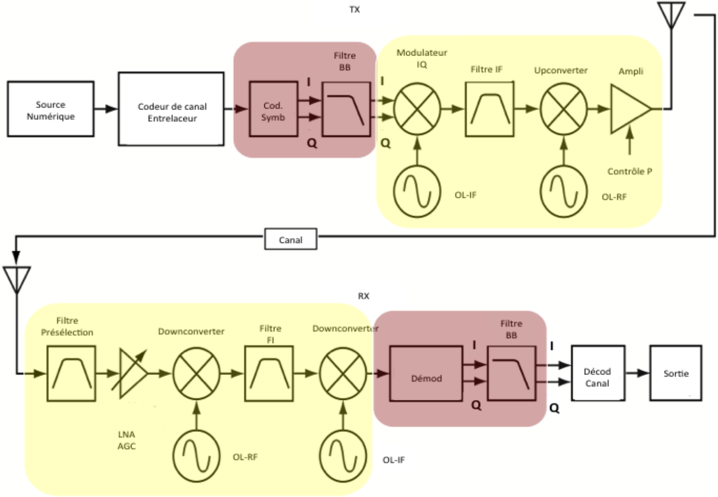

Baseband Modulation

Transmitted Signal :

$$s(t) = Re\{u(t).e^{j2\pi f_c t}\} = I(t)\ \cos(2\pi f_c t) + j.Q(t)\ \sin(2\pi f_c t)$$

f_c carrier frequency - $u(t)$ baseband signal.

$$u(t) = I(t) + j.Q(t)$$

Complex representation

$$I(t) - \text{In} - \text{phase component}$$

$$Q(t) - \text{Quadrature phase component}$$

Baseband modulation

Digital modulation : build $u(t)$ as a functions of source(discrete) states changes.

Heuristic approach :

$\{\alpha_n\}$ state sequence of source $\rightarrow$ $u(t)$ impulse superposition !

Example :

$\mathcal{S}$ maxentropic binary source, $\{\alpha_n\} = \ldots 0\ 1\ 1\ 0\ 0\ 1\ \ldots$

$$\{a_n\} = \cdots - A \quad + A \quad + A \quad - A \quad - A \quad + A \quad \ldots$$

$$u(t) = \sum_n a_n.h(t - nT)$$

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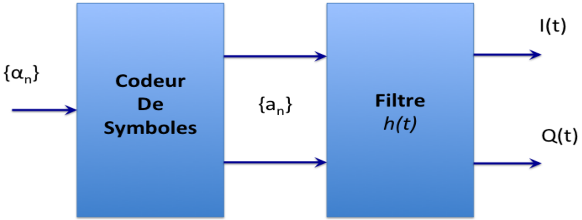
Baseband modulation

$u(t)$ is built in two operations :

- bits $\rightarrow$ amplitudes ;
- amplitudes $\rightarrow$ waveforms (thanks $h(t)$!).



In this example : $I(t) = \sum_n a_n.h(t - nT)$, $Q(t) = 0$.

Baseband modulation

How to choose $\{a_n\}$?

- Modulator architecture simplicity ;
- Spectral efficiency ($\eta = D/BW$) ;
- Demodulator architecture simplicity ;
- Synchronization simplicity ;
- Probability of error (P_b) ;
- Robustness to RF imperfections.

Baseband modulation

How to choose $\{h(t)\}$?

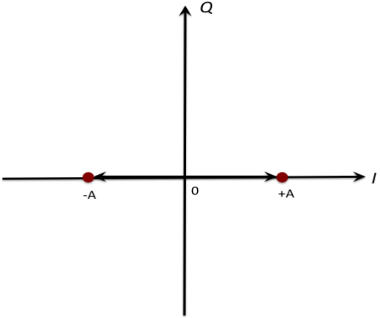
- simplicity of the BB filter ;
- Spectral efficiency ($\eta = D/BW$) ;
- ISI (Nyquist) ;
- Power amplifier performance ;
- PAPR.

Vectorial description of $\{a_n\}$

Amplitudes $\{a_n\}$ are represented by real or complex numbers

In the previous case : $0 \rightarrow -A \quad 1 \rightarrow +A$

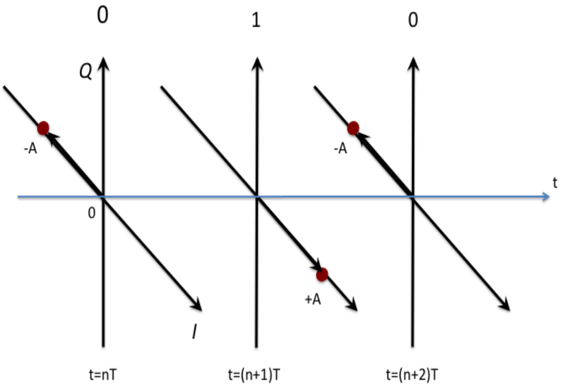
Viewed in the complex plane $I - Q$, this modulation can be represented by :



Vectorial description of $\{a_n\}$

Each « vector » carries 1 information bit

Only one complex dimension is required !



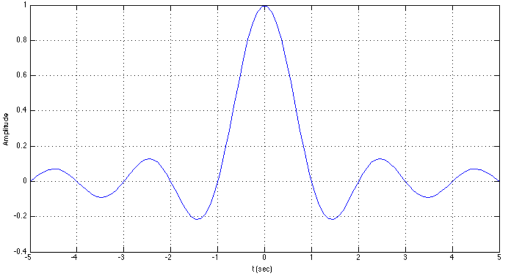
Vectorial description of $\{u(t)\}$

$h(t)$ do the "temporal link" between the discrete "vectors".

Two ways to realize $h(t)$:

- $h(t)$ limited in time $\rightarrow \quad h(t) \neq 0 \quad t \in [0, T)$;
- $h(t)$ Nyquist.

$$h(nT) = \begin{cases} 1 & \text{pour n} = 0 \ ; \\ 0 & \forall n \neq 0. \end{cases}$$



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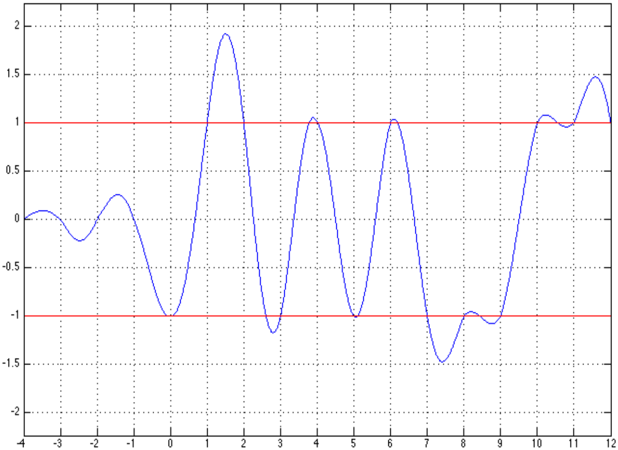

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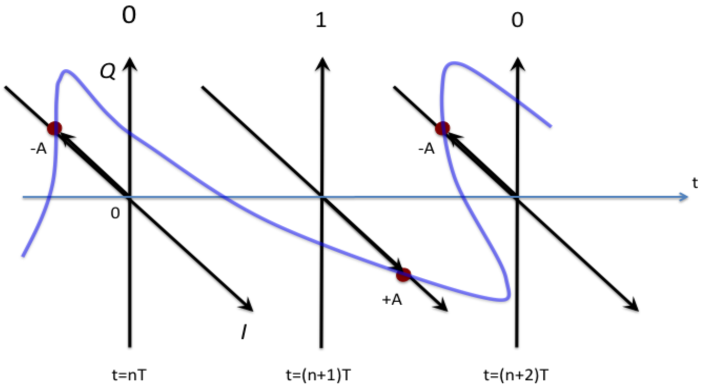
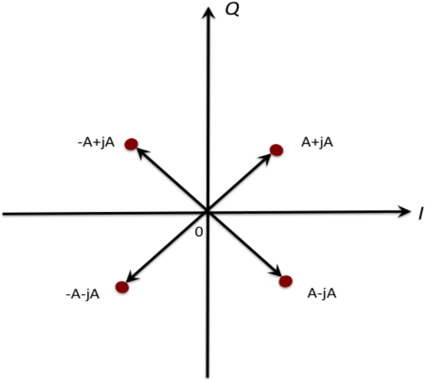


$$u(t) \in \mathcal{C}$$

$$u(t) = \sum_n a_n.h(t - nT)$$

$$a_n = \{A + jA; -A + jA; -A - jA; A - jA\}$$



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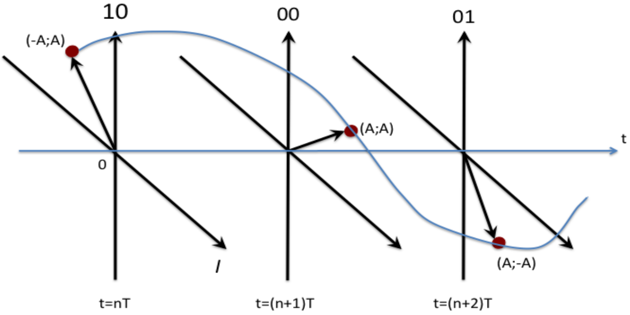
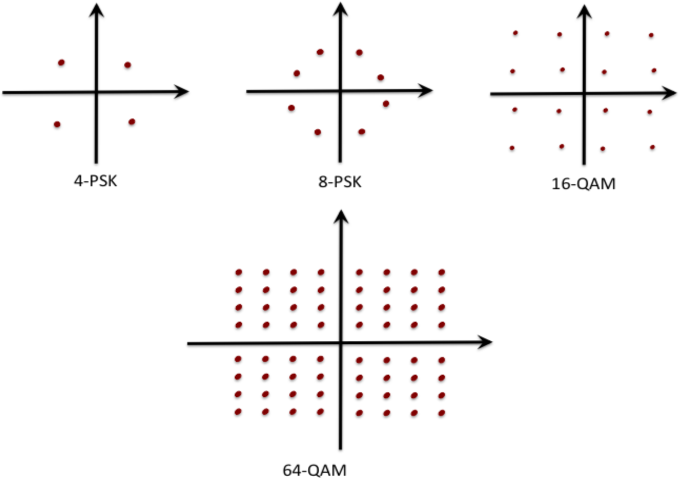


Generalization to the M^{th} order



Advantages of order M

Each complex symbol represents :

$$N = \log_2 M \quad \text{bits}$$

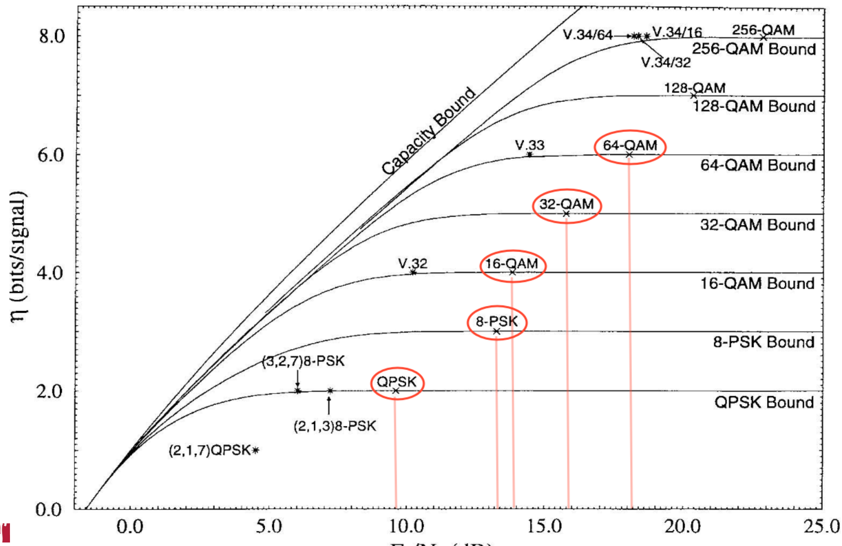
$$T_s = N.T_b$$

$$R = \frac{D}{N}$$

this means a great economy in bandwidth B_w !

Unfortunately, a significant increase in E_b/N_0 to have the same performances !

Spectral efficiency



M-QAM Modulation - theoretical analysis

Emitted signal

$$s(t) = \sum_n a_n h_t(t - nT)$$

Received signal

$$r(t) = \sum_n a_n h_{Rx}(t - nT) + b(t)$$

où

$$h_{Rx}(t) = h_t(t) * h_c(t) * h_r(t)$$

Sampled received signal

$$r(kT + \tau) = \sum_n a_n h_{Rx}(kT + \tau - nT) + b(kT + \tau)$$

M-QAM Modulation - theoretical analysis (2)

$$r(k) = \sum_n a_n h_{Rx}(k-n) + b(k)$$

$$r(k) = \underbrace{h_{Rx}(0).a_k}_{\text{symbole } k} + \underbrace{\sum_{n \neq k} a_n h_{Rx}(k-n)}_{\text{IES}} + \underbrace{b(k)}_{\text{bruit}}$$

$$\sum_k H_{Rx}(f + \frac{k}{T}) = T.h_{Rx}(0)$$

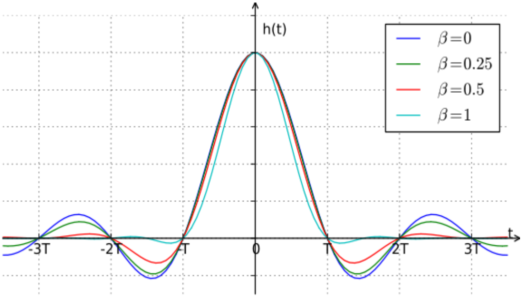
$$H_{Rx}(f) = \begin{cases} T & |f| \leq \frac{1}{2T} \\ 0 & |f| > \frac{1}{2T}. \end{cases}$$

M-QAM Modulation - theoretical analysis (3)

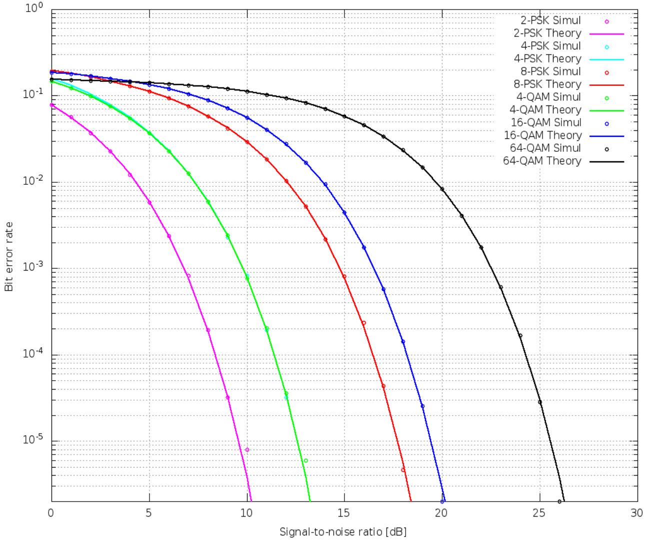
$$H_{Rx}(f) = \begin{cases} T & 0 \leq |f| \leq \frac{1-\alpha}{2T} \\ \frac{T}{2}\left(1 - \sin[\frac{\pi T}{\alpha}(f - \frac{1}{2T})]\right) & \frac{1-\alpha}{2T} < |f| < \frac{1+\alpha}{2T}. \end{cases}$$

Raised cosine filter

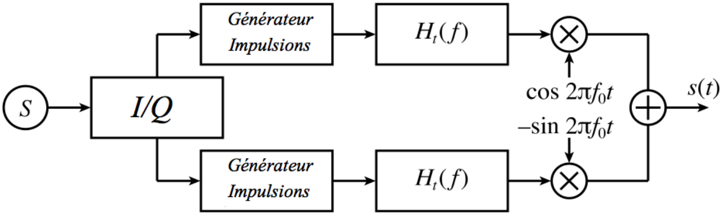
$$h_{Rx}(t) = \frac{\cos(\alpha\pi t/T)}{1 - 4\alpha^2 t^2/T^2}\ \mathrm{sinc}(t/T).$$

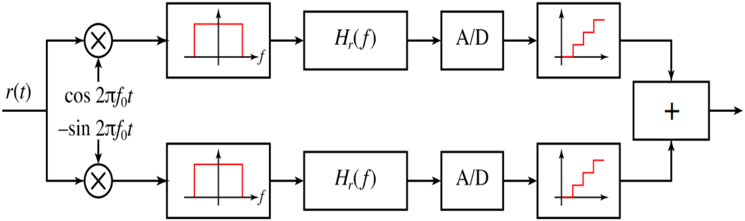


M-QAM Modulation - Performance in AWGN



M-QAM Modulation - Structure of Tx/Rx





Distortions

Distortion sources :

- channel linear distortion ;
- Tx distortions ;
- Rx distortions.

Channel distortions - M-QAM

Possible sources :

- bandwidth limitation ;
- frequency selectivity (*fading*) ;

If $B_c \lll \frac{1}{T}$ ISI !

ISI impact on Tx signal

At sampling times, signal is not at "RV" !

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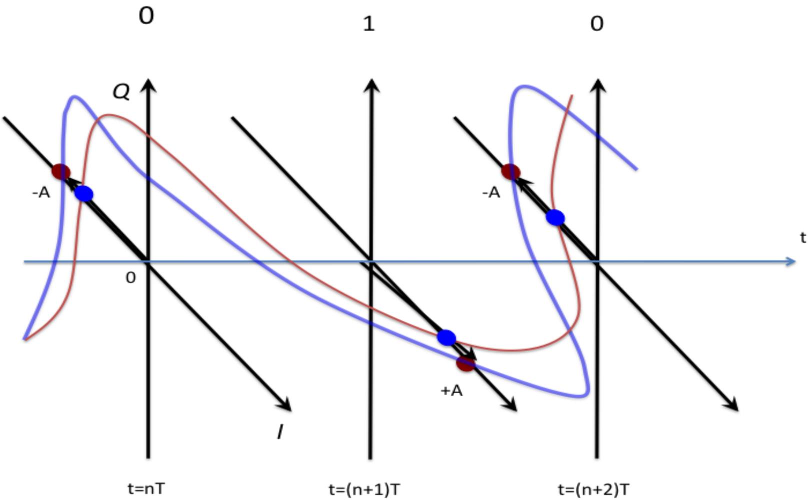
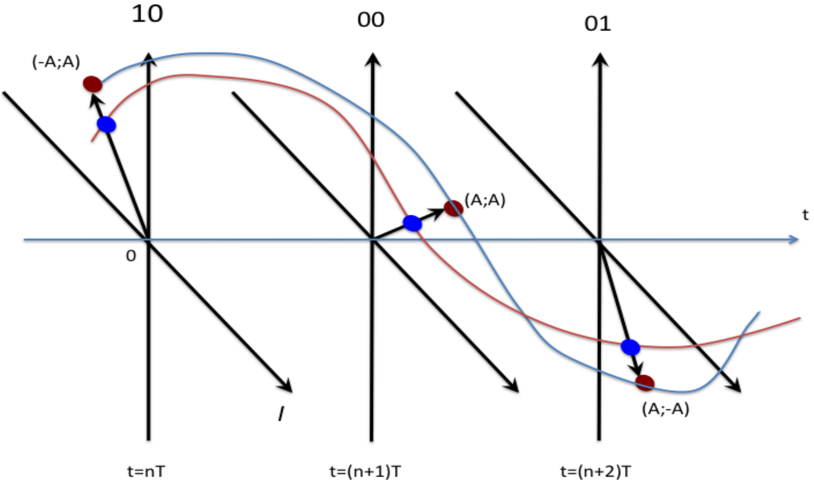
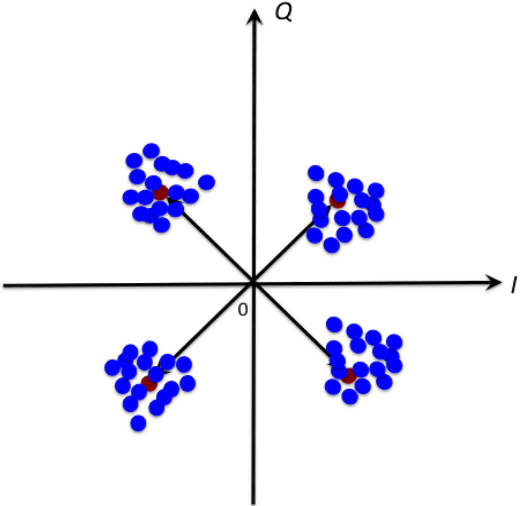
Example - BPSK



Example - QPSK



Impact of ISI - Dispersion diagrams



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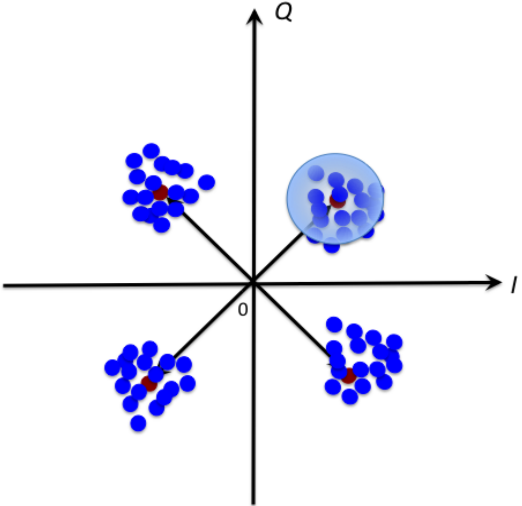
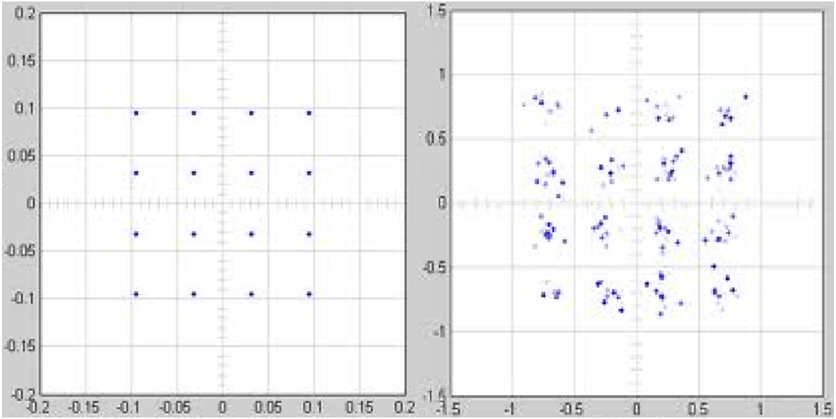
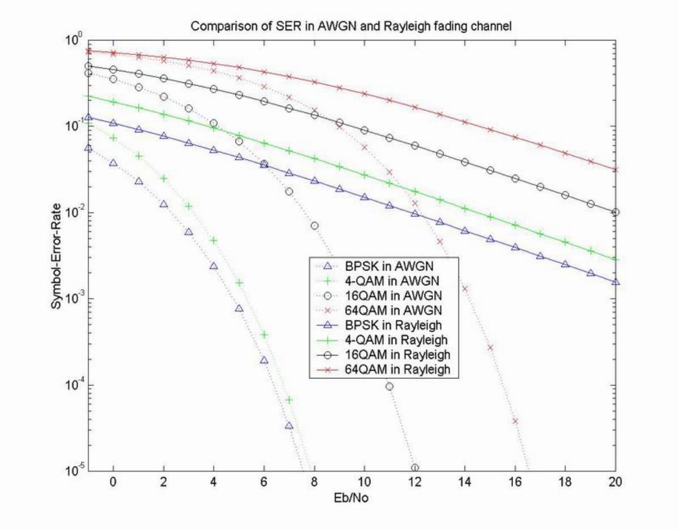


Dispersion diagrams - 16-QAM



P_{symb} - M-QAM in Rayleigh chanel



Equalisation

The idea consists to suppress the distortion induced by channel.

two ways to solve this problem :

– frequency domain filtering ;
– deconvolution in time (with the good IR !).

Three techniques are possible :

- linear equalization ;
- decision feedback equalization ;
- sequence estimation equalization.

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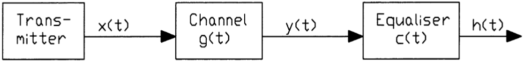
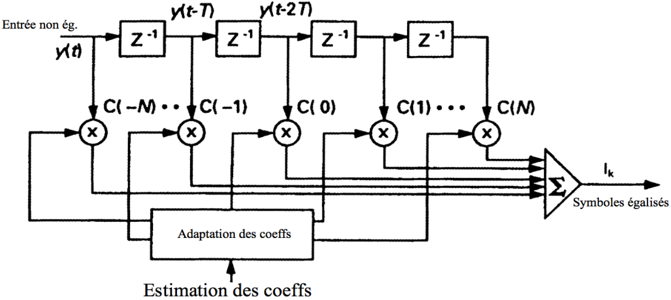
Linear equalization

Model

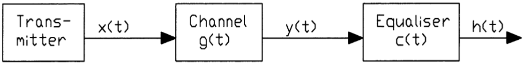


It's a linear filter with IR : $c(kT) = \sum_{k=-N}^{+N} c(k).z^{-kT}$



Zero forcing and **MSE** criteria

Model



The filtre coefficients can be calculateur as :

- suppress the ISI in and sample interval $(-N;+N)$ $\rightarrow$ *Zero Forcing* ;
- minimise the mean error distortion $\rightarrow$ EQM.

Zero forcing and MSE criteria

If $h(n) = y(n) * c(n)$, we call Mean square error ;

$$MSE = \frac{1}{h^2(0)} \sum_{k=-\infty;k\neq 0}^{+\infty} h^2(n)$$

To minimize the ISI, minimise the MSE

$$MSE = \epsilon = \left(\sum_{k=-\infty;k\neq 0}^{+\infty} h^2(n) \right) - h^2(0)$$

This is a quadratic fonction of the coefficients → classic problem in spectral estimation (Levinson-Durbin).

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$$MSE = \epsilon = \left(\sum_{k=-\infty;k\neq 0}^{+\infty} h^2(n) \right) - h^2(0)$$

This is a quadratic fonction of the coefficients $\rightarrow$ classic problem in spectral estimation (Levinson-Durbin).

Zero forcing and MSE criteria

If $h(n) = y(n) * c(n)$, we call Mean square error ;

$$MSE = \frac{1}{h^2(0)} \sum_{k=-\infty;k\neq 0}^{+\infty} h^2(n)$$

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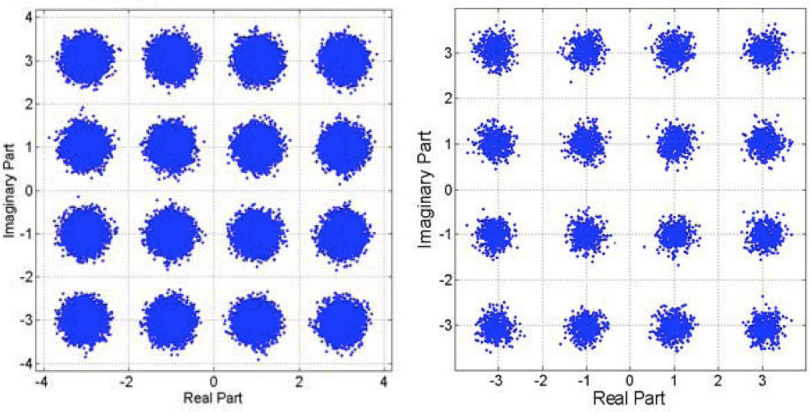
Example MSE-16-QAM, 3 coeffs channel



The End