Transmitter Constellation Error

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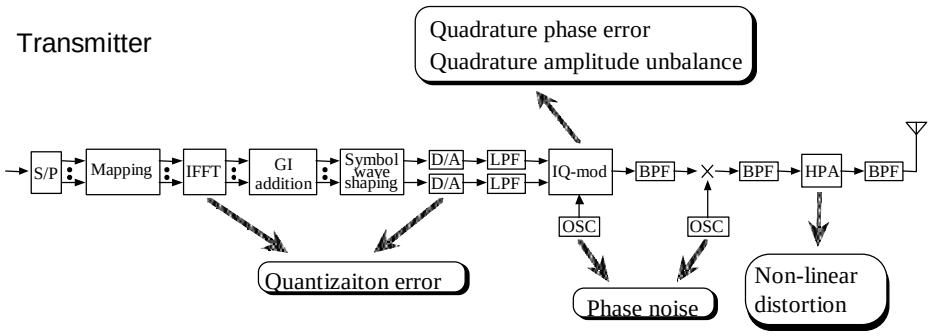
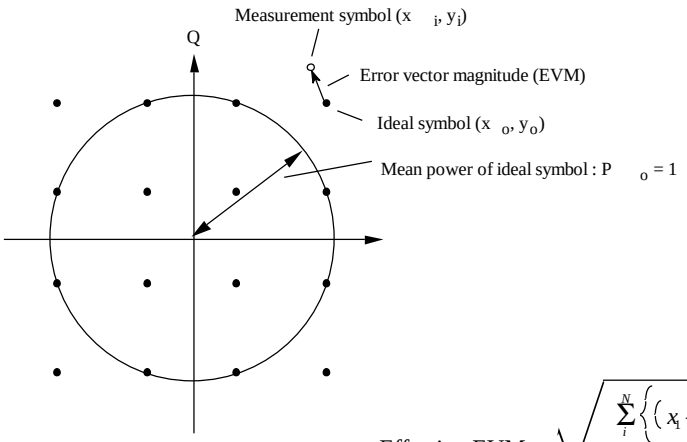
- Definition of transmitter constellation error (Vector error)
- Degradation factors in Vector error
  - Quadrature Phase Error
  - Quadrature Amplitude Unbalance
  - Non-linearity of High Power Amplifier
  - Quantization in IFFT
  - Phase Noise
  - Quantization at D/A converter
- Total degradation

Considered degradation factors at transmitter

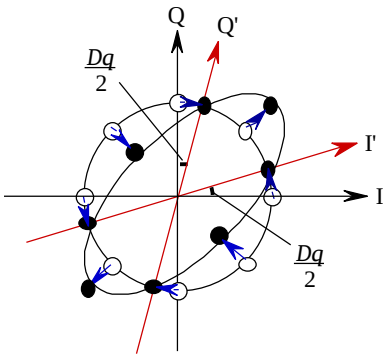


Definition of vector error



$$\text{Effective EVM} = \sqrt{\frac{\sum_{i}^{N}\left\{(x_1 - x_0)^2 + (y_1 - y_0)^2\right\}}{N \times P_0}}$$

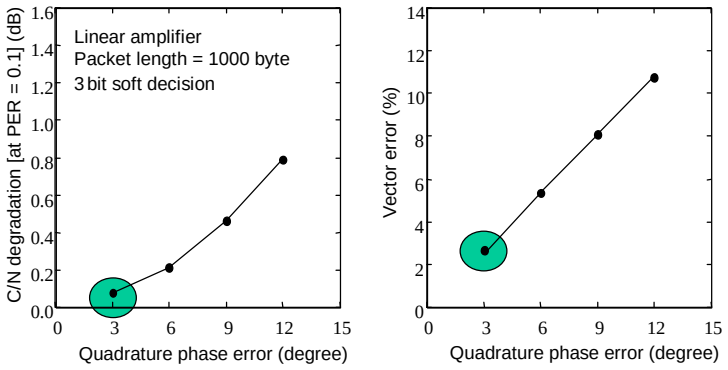
Degradation factor (1)



Quadrature phase error : *Dq*

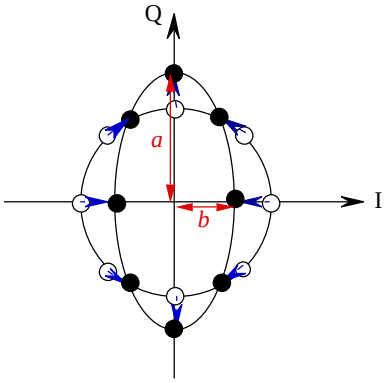
C/N degradation and vector error by quadrature phase error

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)



C/N degradation versus Quadrature phase error Vector error versus Quadrature phase error

Degradation factor (2)

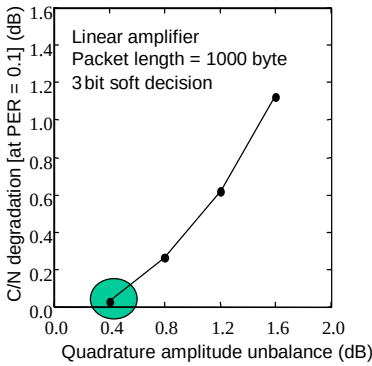


a : I axis amplitude gain
b : Q axis amplitude gain

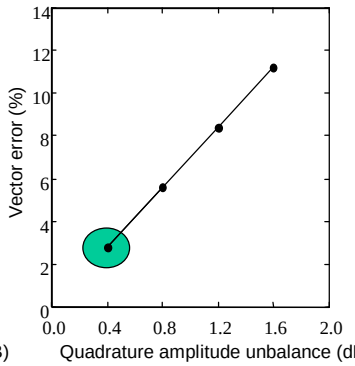
Quadrature amplitude unbalance : $\left| 20 \log \left(\frac{a}{b} \right) \right|$

C/N degradation and vector error by quadrature amplitude unbalance

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)



C/N degradation versus Quadrature amplitude unbalance



Vector error versus Quadrature amplitude unbalance

Degradation factor (3)

Rapp's power amplifier model

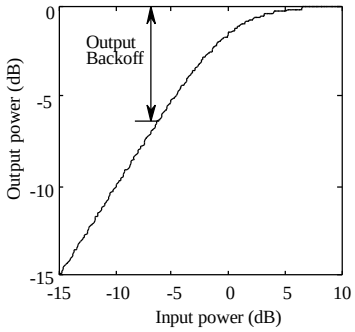
$$P_{SAT} = |V_{SAT}|^2$$

$$V_{OUT} = \frac{V_{IN}}{\left\{1 + \left(\frac{|V_{IN}|}{V_{SAT}}\right)^{2P}\right\}^{\frac{1}{2P}}}$$

$$Backoff = -10\log\frac{Avg\left(|V_{IN}|^2\right)}{P_{SAT}}$$

P_{SAT} : saturated power of amplifier

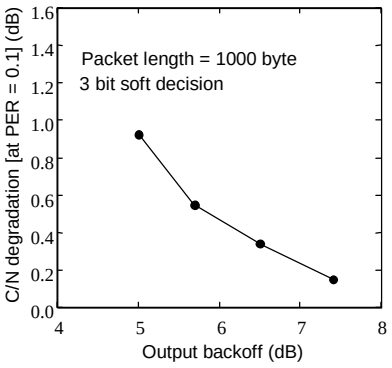
P : smoothness factor



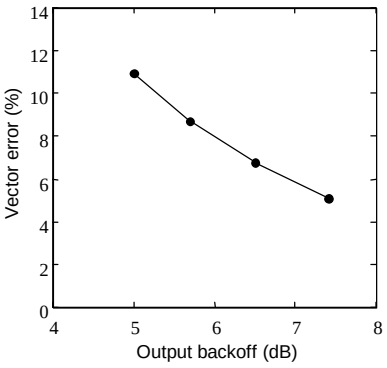
High power amplifier

C/N degradation and vector error by HPA non-linearity

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)

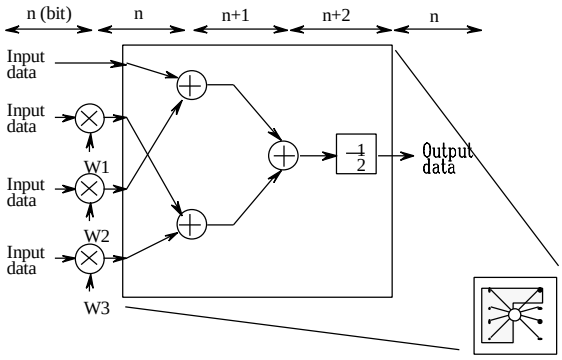


C/N degradation versus Output backoff



Vector error versus Output backoff

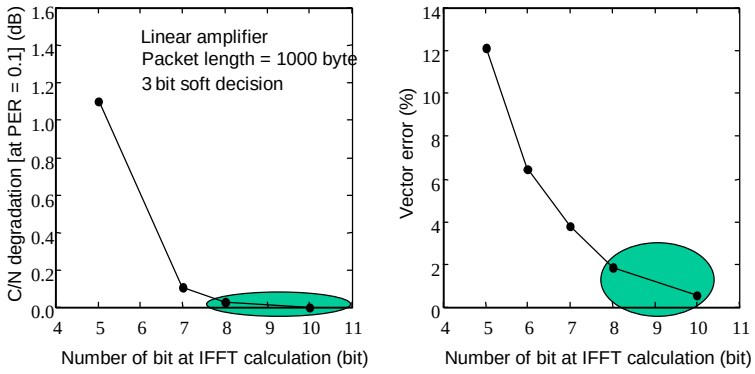
Degradation factor (4)



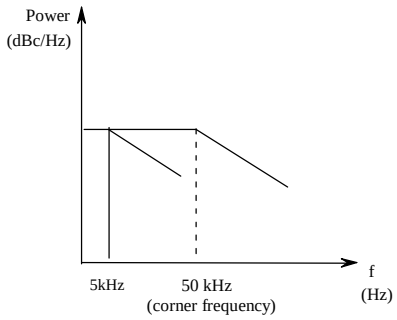
IFFT butterfly circuit model

C/N degradation and vector error by IFFT quantization error

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)



Degradation factor (5)



$$\exp(j\varphi_k) = \exp(j\varphi_{RMS} x_k)$$

$$x_{k+1} = x_k + \alpha(\beta N(0,1) - x_k)$$

$$x_o = N(0,1)$$

$$\alpha = 2\pi F_c T_s$$

$$\beta^2 = (2/\alpha) - 1$$

$\exp(j\varphi_k)$: Phase noise

N(0,1) Noise (mean value = 0variance =1)

Ts : Sampling period

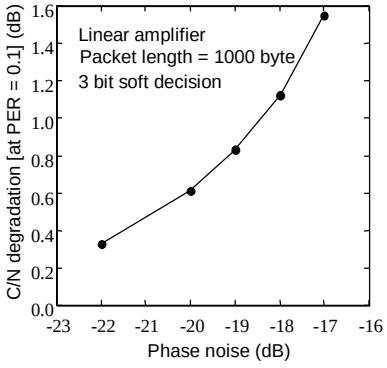
Fc : Corner frequency

φ_{RMS} : Phase variance

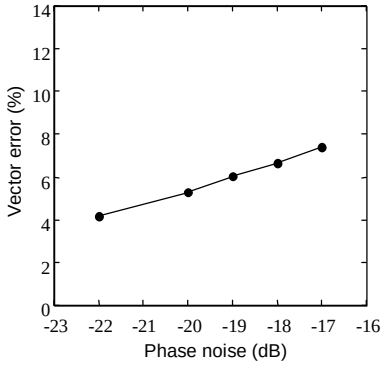
Phase noise model

C/N degradation and vector error by phase noise

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)
Corner Frequency=50kHz



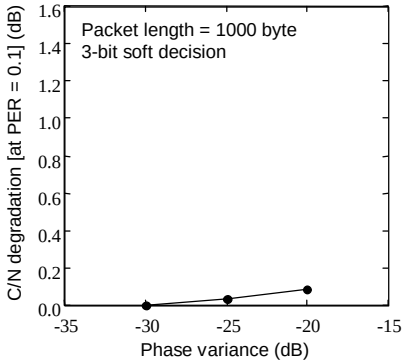
C/N degradation versus Phase noise



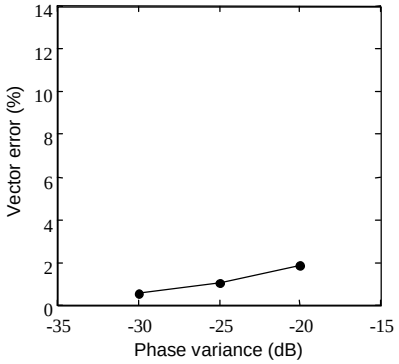
Vector error versus Phase noise

C/N degradation and vector error with phase noise

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)
Corner Frequency=5kHz



C/N degradation versus Phase variance



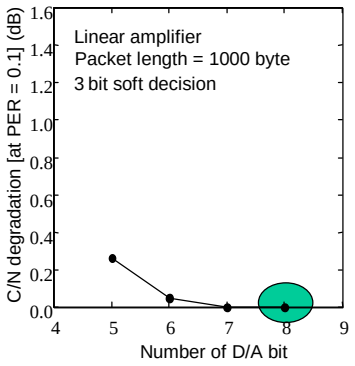
Vector error versus Phase variance

Degradation factor (6)

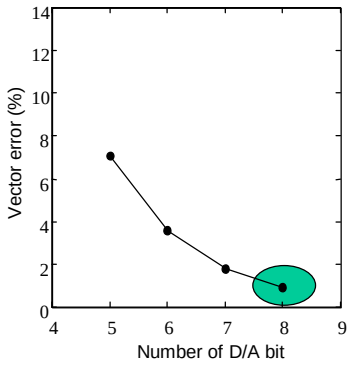
D/A quantization error
(Quantization error of digital part)

C/N degradation and vector error by D/A quantization error

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)



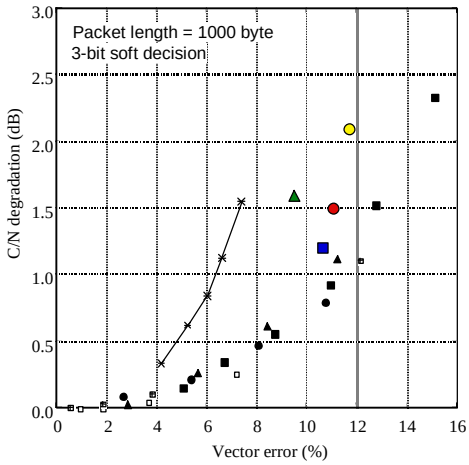
C/N degradation versus number of D/A bit



Vector error versus number of D/A bit

C/N degradation with transmitter degradation factor

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)



- Quadrature phase error
- Quadrature amplitude unbalance
- Non-linear amplifier (Rapp's model)
- Number of D/A bit
- IFFT internal bit number (Radix 4)
- **Phase noise (corner freq. = 50 kHz)**

Case study of total degradation

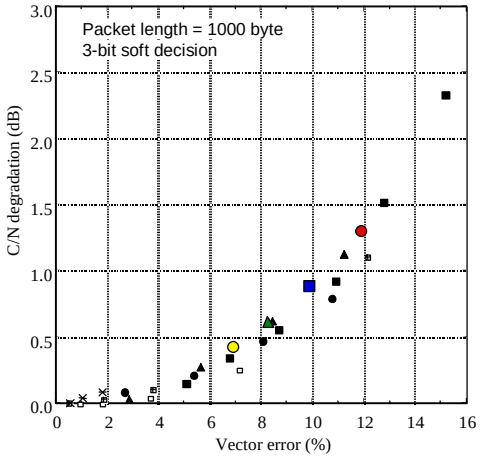
OBO = 5.7 dB ,	Phase noise = -20 dB	
5.7	-22	
7.4	-18	
5.7	-18	

with QPE = 3 (V.E. = 2.7 %)
QAU = 0.4 dB (2.8 %)
Number of D/A bit = 8 bit (1.9 %)
IFFT bit number = 8 bit (0.9 %)

C/N degradation versus Vector error

C/N degradation with transmitter degradation factor

(16QAM-OFDM Information data rate = 24 Mbit/s, Coding rate = 1/2)



C/N degradation versus Vector error

- Quadrature phase error
- Quadrature amplitude unbalance
- Non-linear amplifier (Rapp's model)
- Number of D/A bit
- IFFT internal bit number (Radix 4)
- **Phase noise (corner freq. = 5 kHz)**

Case study of total degradation

- OBO = 5.0 dB
- 5.7
- 6.5
- 7.4

with QPE = 3 (V.E. = 2.7 %)
QAU = 0.4 dB (2.8 %)
Number of D/A bit = 8 bit (1.9 %)
IFFT bit number = 8 bit (0.9 %)
Phase noise = -23 dB (1.3 %)

Conclusion

- Phase noise and non-linearity of HPA are the dominant factors for total vector error (transmitter constellation error).
- About 12% Vector error is required to implement a transmitter in the case of 16QAM and r=1/2.