

Datarate and Range

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Agenda

- Estimation of maximum data rate for a 868 MHz frequency shift keying (FSK) modulated transmitter
- Relationship of modulation type, data rate and range
- Examples of common technologies



Maximum datarate

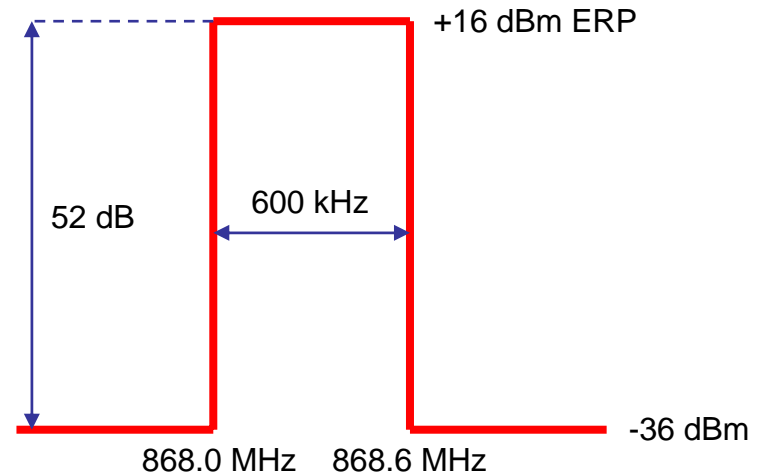
868 MHz FSK modulated transmitter



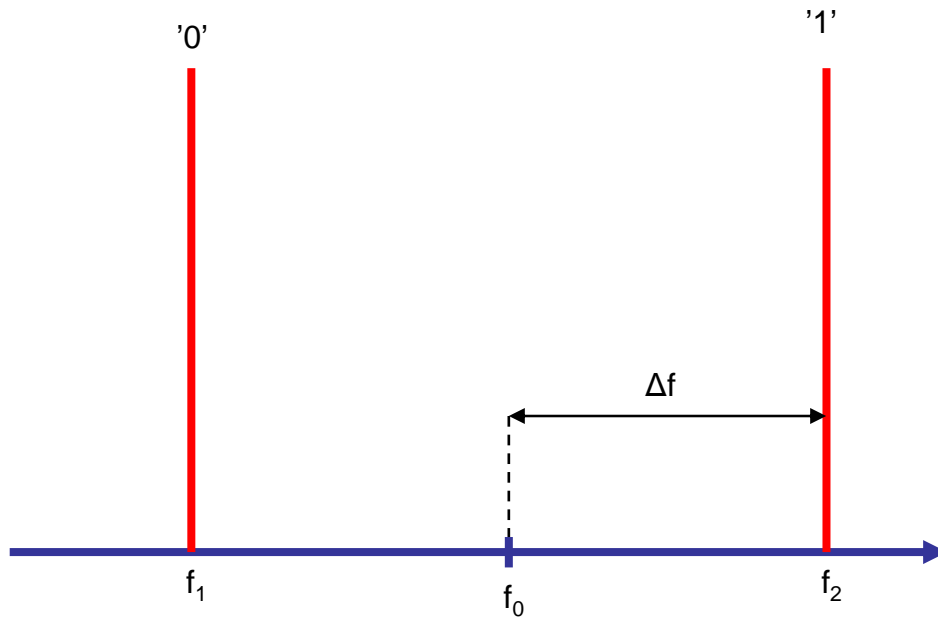
Regulatory requirements

ERC/REC 70-03 A1, g1:

- 868.0-868.6 MHz
- 25 mW effective radiated power (ERP)
- 1 % duty cycle or listen before talk (LBT)
- Spurious emission limit at band edge: -36 dBm



FSK modulation



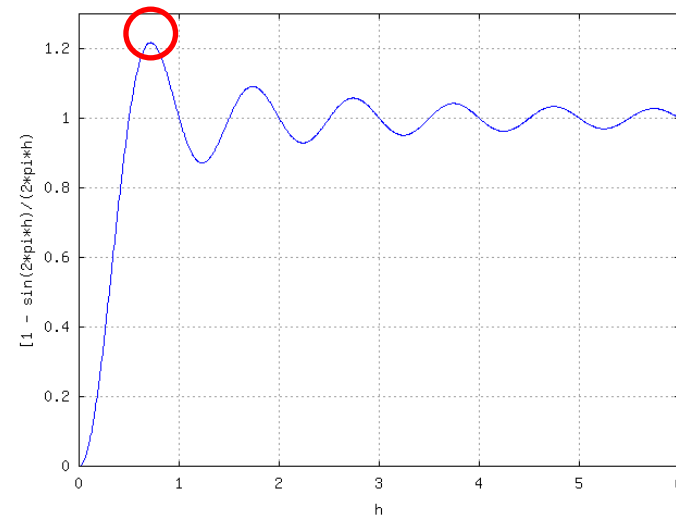
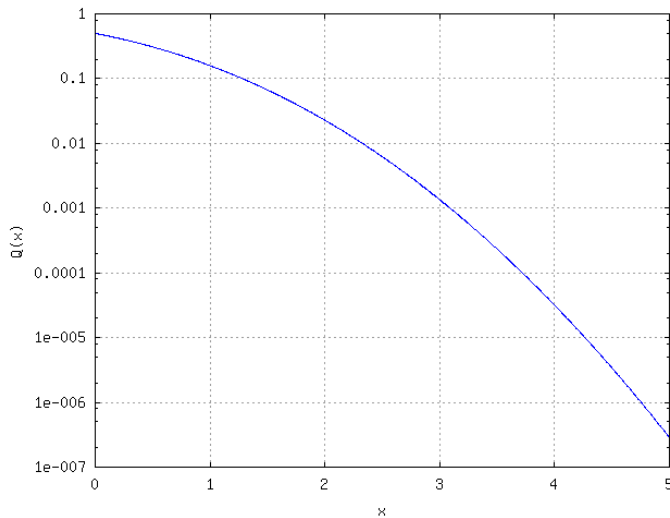
$$BER = Q \left(\sqrt{\frac{E_b}{k \cdot T_{eff}} \cdot \left[1 - \frac{\sin(2 \cdot \pi \cdot h)}{2 \cdot \pi \cdot h} \right]} \right)$$

$$h = \frac{2 \cdot \Delta f}{R_b}$$

$$BW \cong 2(\Delta f + R)$$

Determining modulation index, h

$$BER = Q\left(\sqrt{\frac{E_b}{k \cdot T_{eff}} \cdot \left[1 - \frac{\sin(2 \cdot \pi \cdot h)}{2 \cdot \pi \cdot h}\right]}\right)$$



- BER = Q(x) minimized → x shall be as high as possible
- x is max. for $\left[\frac{1 - \sin(2\pi h)}{2\pi h}\right] = 1.22$
for h = 0.715
- I.e. a modulation index of h = 0.715 results in minimum BER

Determining frequency variation, Δf and maximum data rate, R

$$h = \frac{2 \Delta f}{R}$$

$$R = \frac{1}{2} BW - \Delta f$$



$$\Delta f = \frac{h \cdot BW}{4 + 2 \cdot h}$$

- $h = 0.715$
- $BW = 600 \text{ kHz}$



- $\Delta f = 79 \text{ kHz}$
- $R = 220 \text{ kbps}$

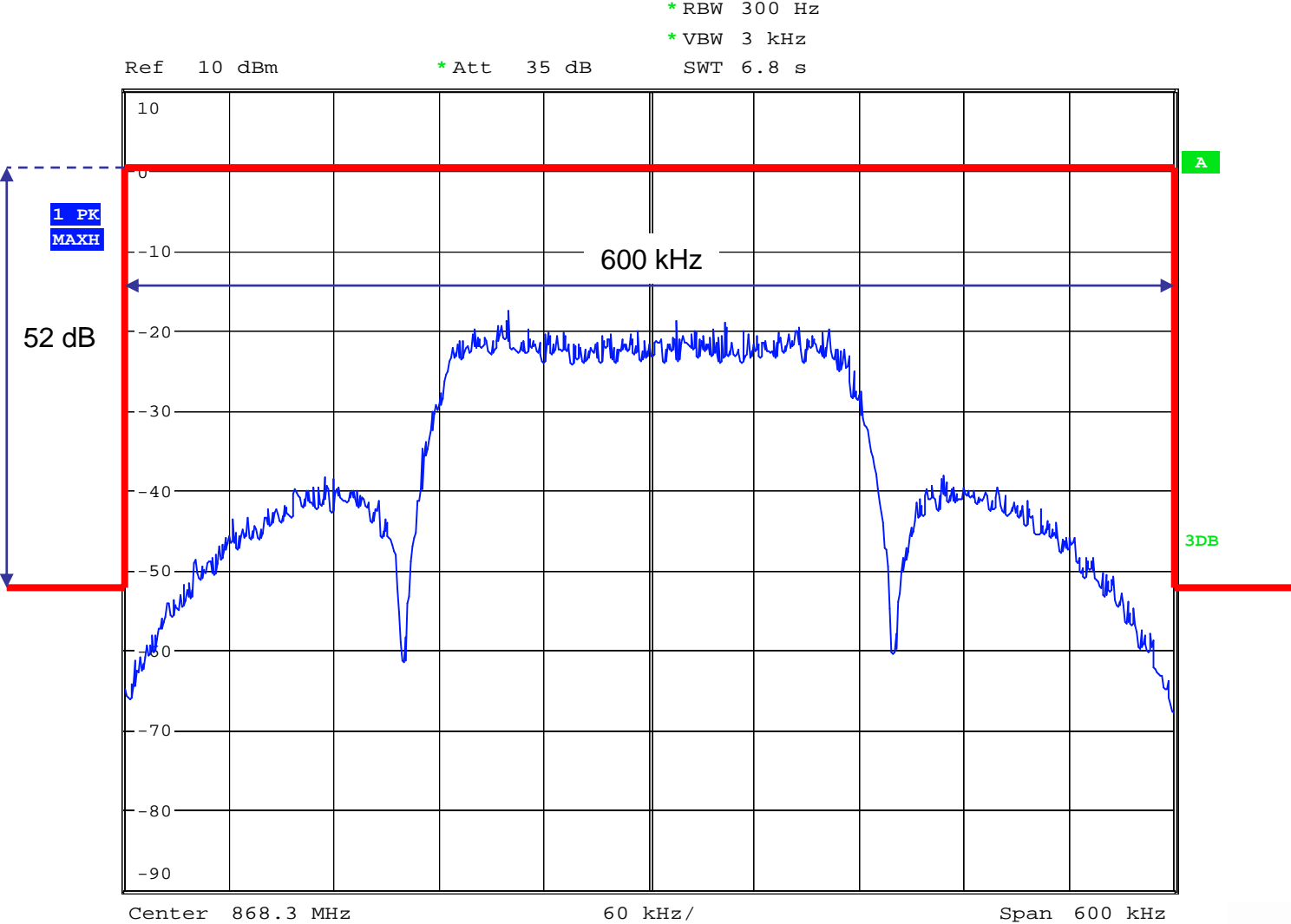
Verification

- FSK signal generated with vector signal generator
- Measured with spectrum analyzer

- Centerfrequency: 868.3 MHz
- Frequency deviation: 79 kHz
- Datarate: 220 kbps
- Datasource: pseudo random bit sekvens (PRBS9)
- Filter: Gauss, FSK
- Power level: 0 dBm

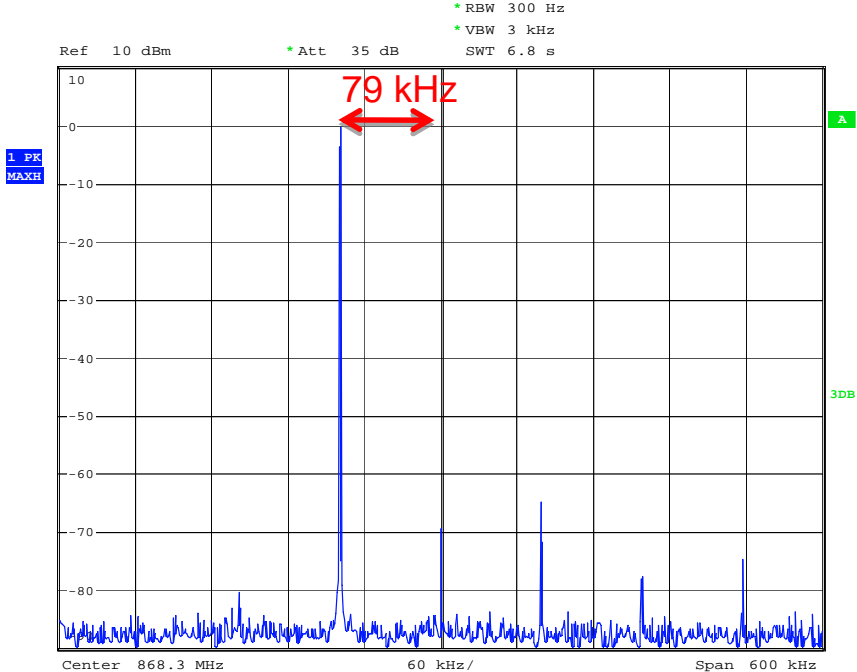


Verification measurement

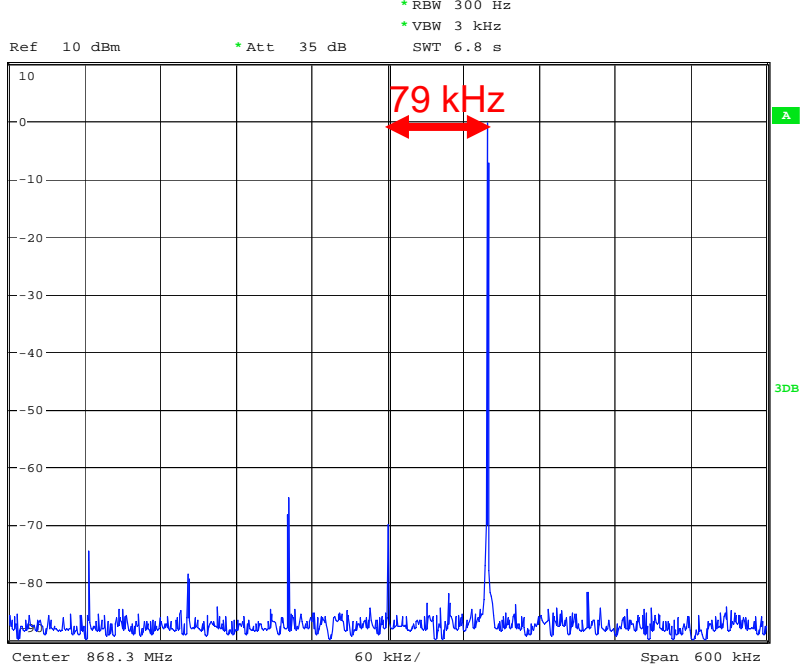


Verification measurement

'0' symbol



'1' symbol



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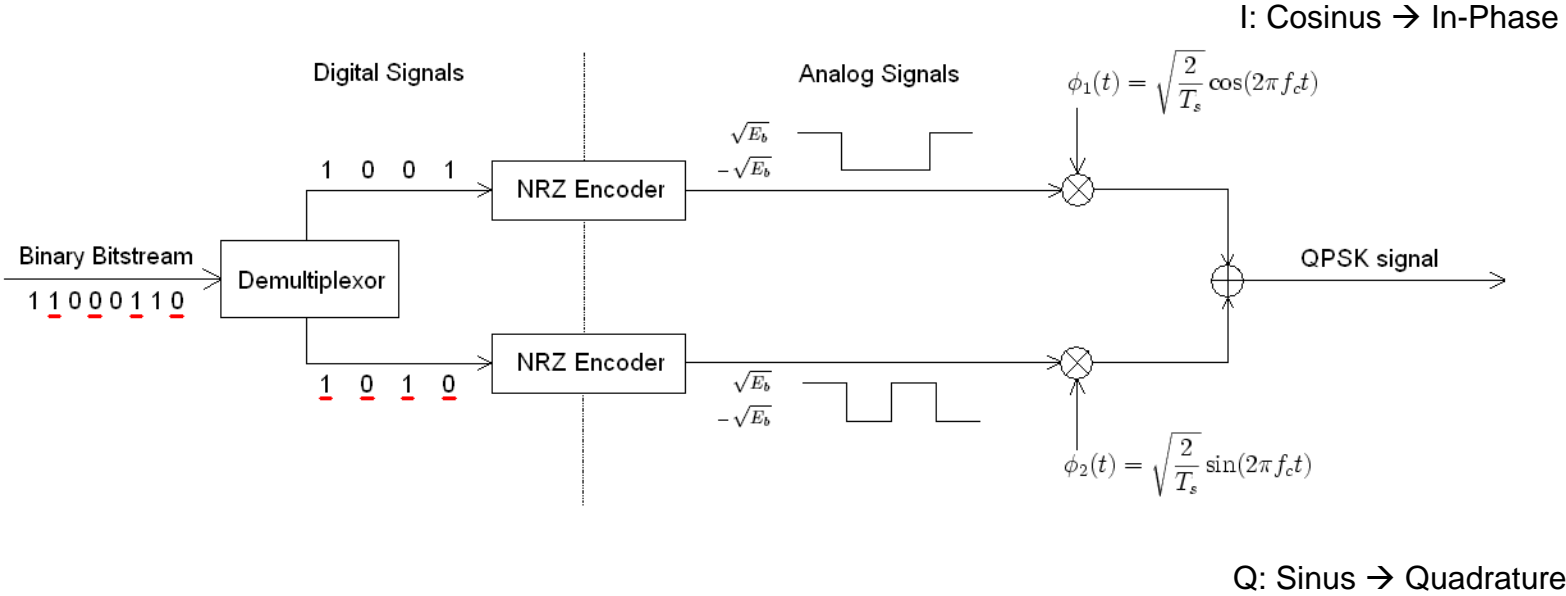


Modulation order, data rate and range

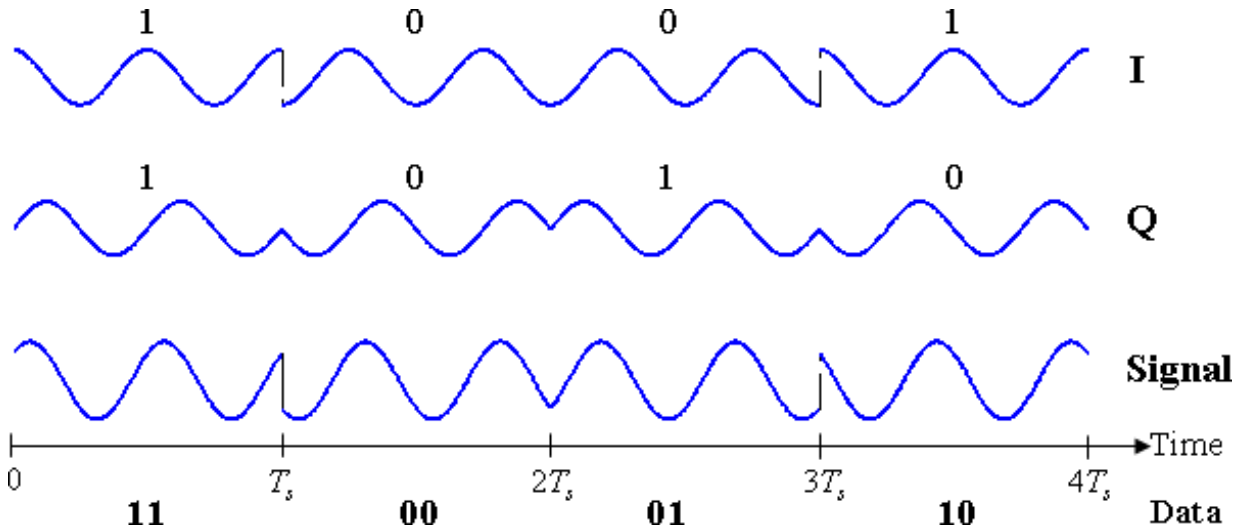
Example of higher order of modulation order
based on QPSK



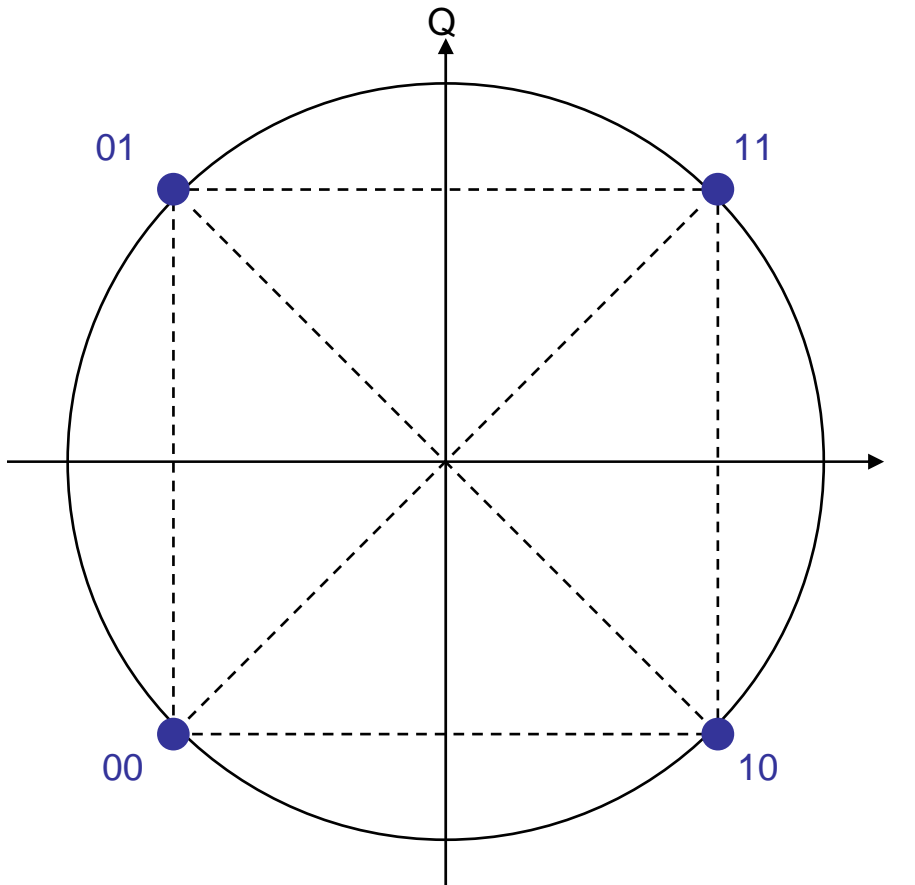
Quadratur Phase Shift Keying (QPSK)



QPSK timing

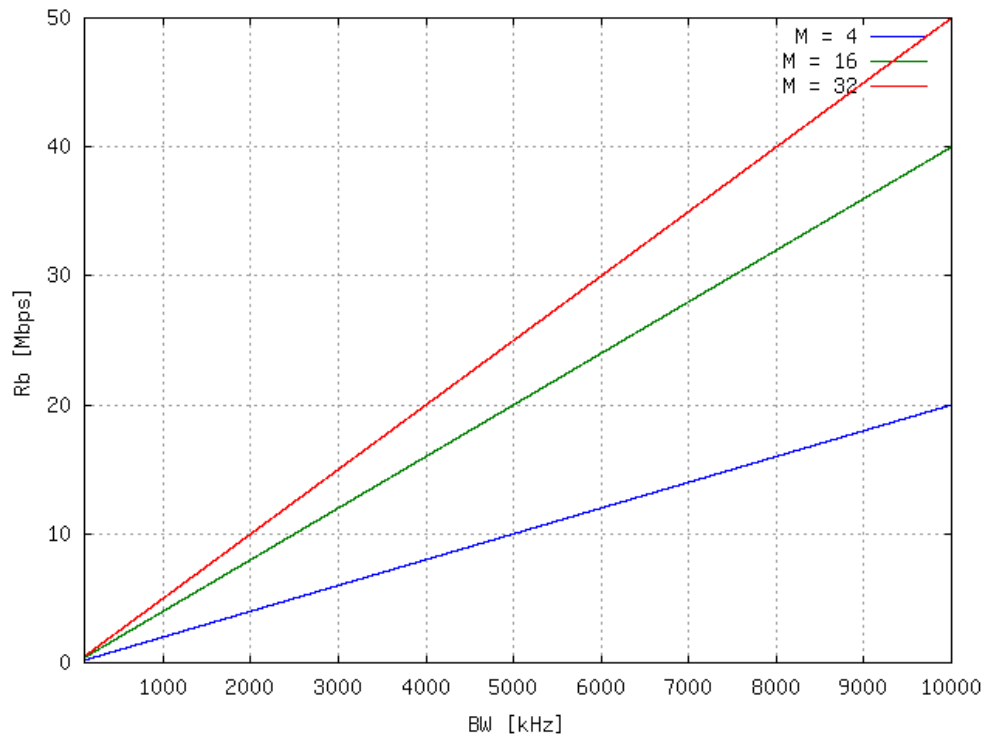


QPSK



- 4 symbols
- 2 bit per symbol
 - Double data rate compared to 2PSK
- $E_b = \frac{1}{2}E_s$
 - Half energy per bit compared to 2PSK

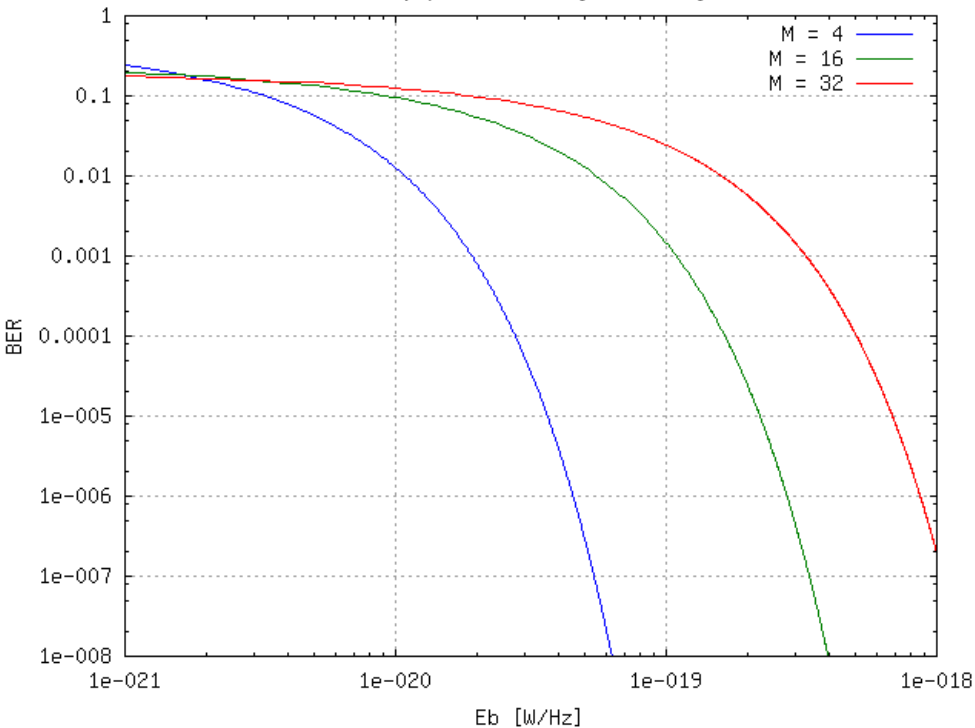
Spectrum efficiency of MPSK



- For a given bandwidth a higher modulation order will result in a higher data rate

Bit error rate, MPSK

$$P_{in} = E_b \cdot R_b$$



- Higher order of modulation requires higher energy per bit
- Low required energy per bit E_b can for a given BER be traded to:
 - Increased range
 - Increased datarate

Simple example



Morse system

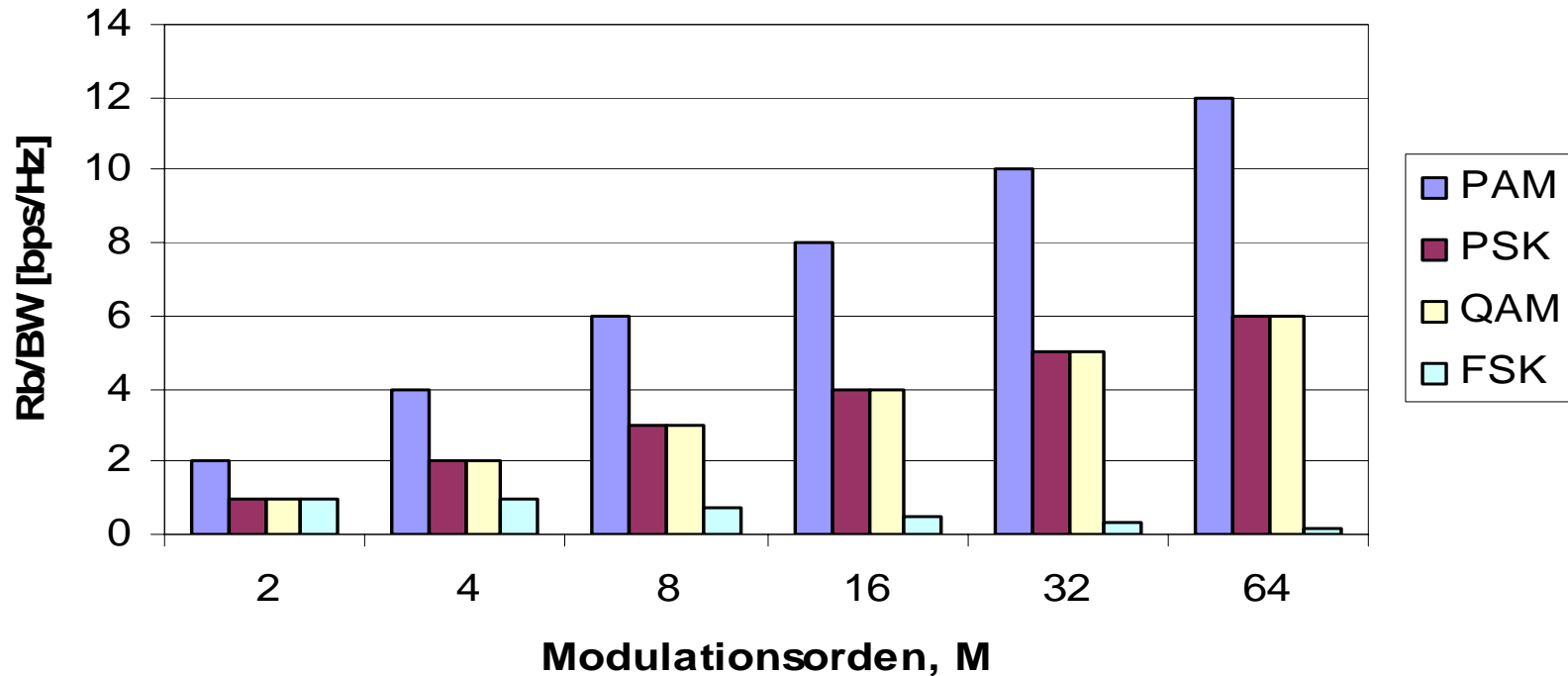
- Low datarate
- Low BW
- High energy/bit
- Long range



Speech

- High datarate
- High BW
- Low energy/bit
- Short range

Bandwidth efficiency for various modulation schemes



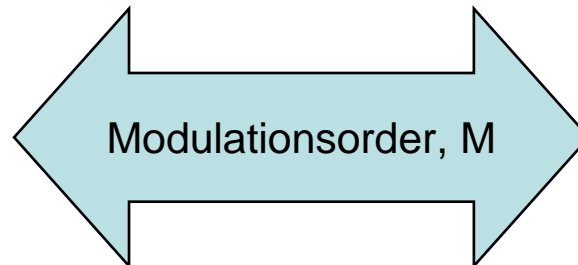
PAM: Pulse Amplitude Modulation
QAM: Quadrature Amplitude Modulation

PSK: Phase Shift Keying
FSK: Frequency Shift Keying



The big trade-off

- Low datarate
- High range
- Low BER



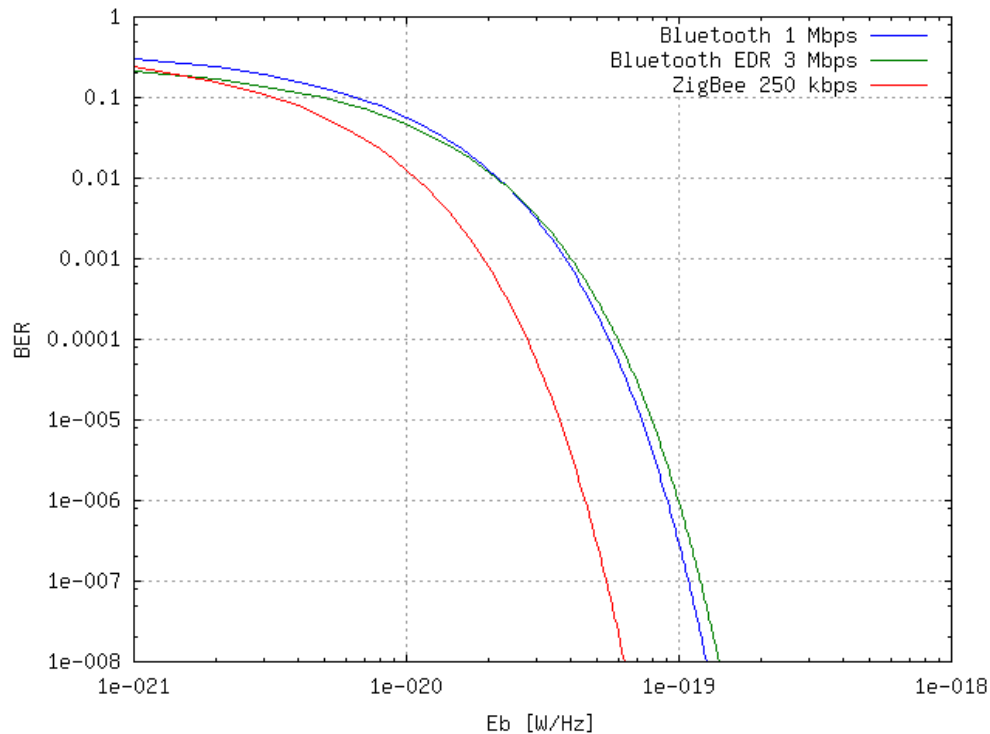
- High datarate
- Low range
- High BER

Examples of common technologies

Modulation, data rate and range



Bluetooth and ZigBee bit error rate (BER)



- Bluetooth 2.1
 - GFSK – Gaussian frequency shift keying
 - Modulation index, $h = 0.3$
 - 1 Mbps
- Bluetooth 2.1 + EDR
 - 8DPSK – differential phase shift keying
 - 3 Mbps
- ZigBee 2.4 GHz
 - OQPSK – Offset quadrature phase shift keying
 - 250 kbps

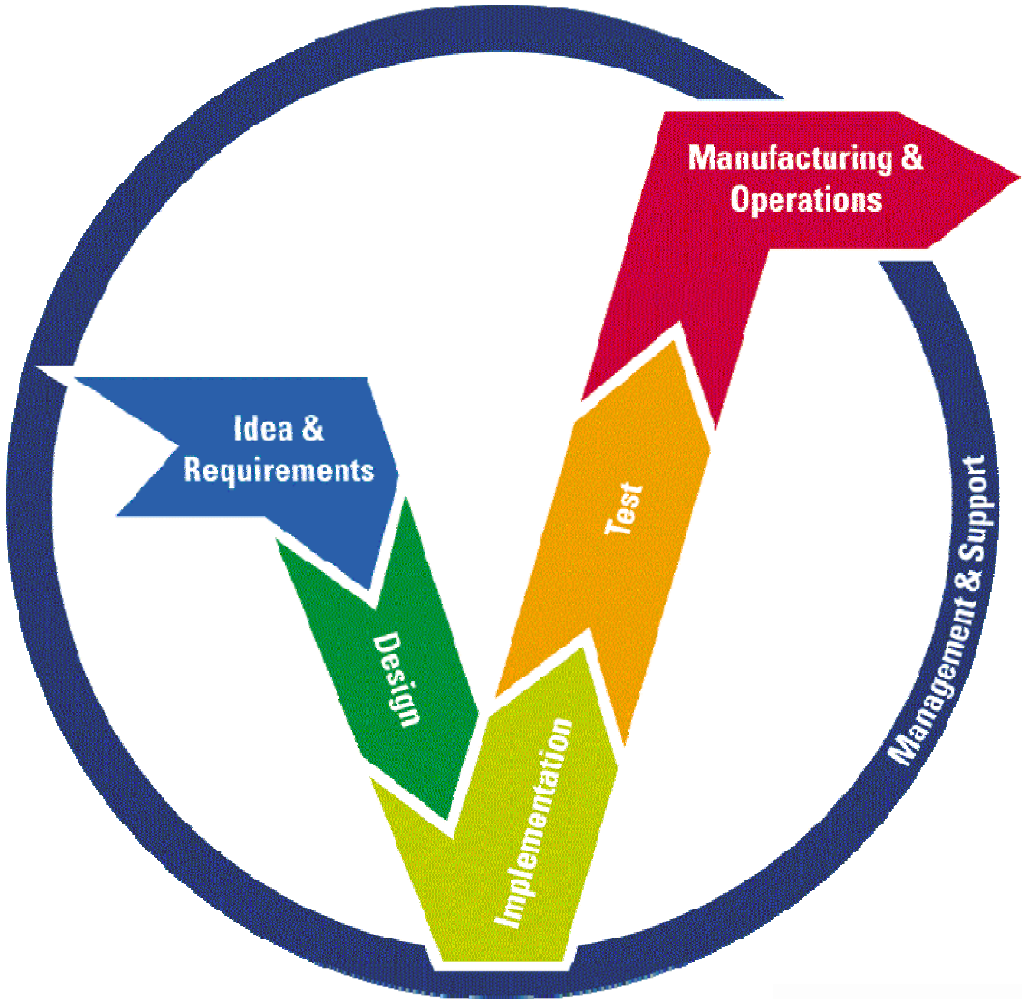


Common technologies

Name	Frequency	Datarate	Tx power	Range	Max. nodes
Bluetooth 2.1, Class 1	2.4 GHz	1-3 Mbps	100 mW	100 m	7 slaves per master
ZigBee, 2.4 GHz	2.4 GHz	250 kbps	1 mW	10-100 m	4090 nodes
ZigBee, 868 MHz (EU)	868 MHz	20 kbps	1 mW	10-100 m	4090 nodes
Z-Wave	868 MHz	9.6/40 kbps	1 mW	30-100 m	232 nodes



When should you list your requirements?



Why are we doing this?





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