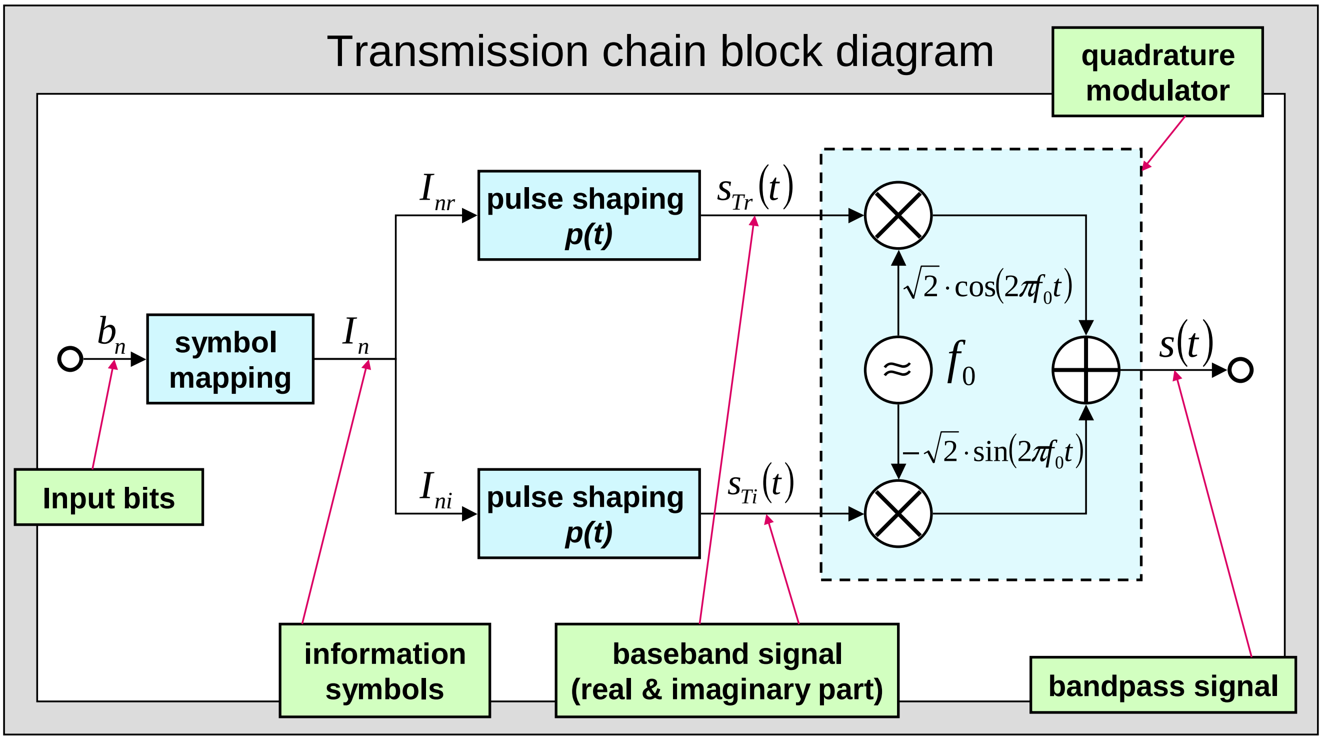
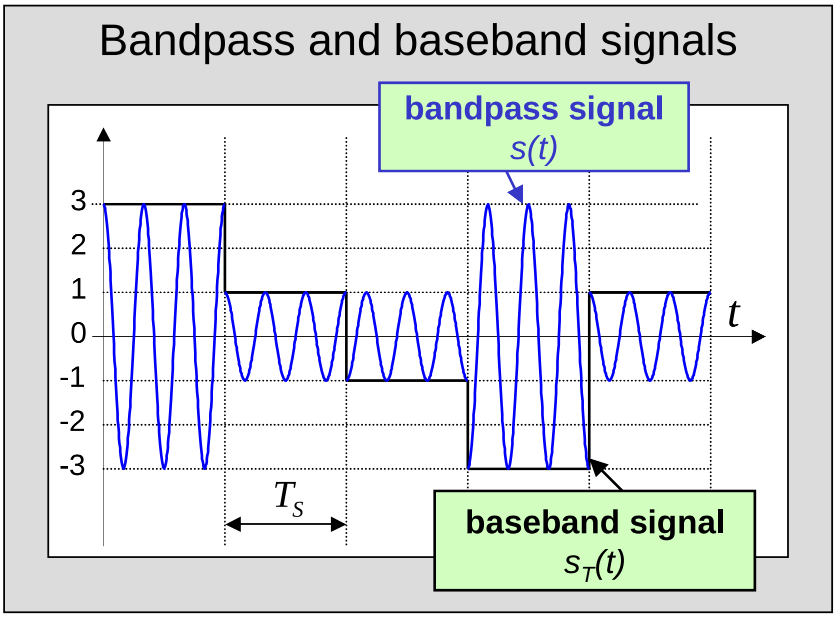
Digital Modulation Schemes

- Digital transmission chain
- Signal representation
  - Time domain
  - Frequency domain
  - Signal space
- Linear modulation schemes
  - Amplitude Shift Keying (ASK)
  - Phase Shift Keying (PSK)
  - Combinations (APSK, QAM)
- Pulse shaping
- Continuous Phase Modulation (CPM)
  - Frequency Shift Keying (FSK)
  - Special Cases (MSK, GMSK)
  - Generation of CPM signals

Digital Transmission Chain



Representation in time domain



$$s(t) = \sqrt{2} \cdot \mathrm{Re}\left\{ s_T(t) \cdot e^{j 2\pi f_0 t} \right\}$$

with

$$s_T(t) = s_{Tr}(t) + j \cdot s_{Ti}(t)$$

$s_T(t)$ is the „**complex envelope**“ of the bandpass signal $s(t)$

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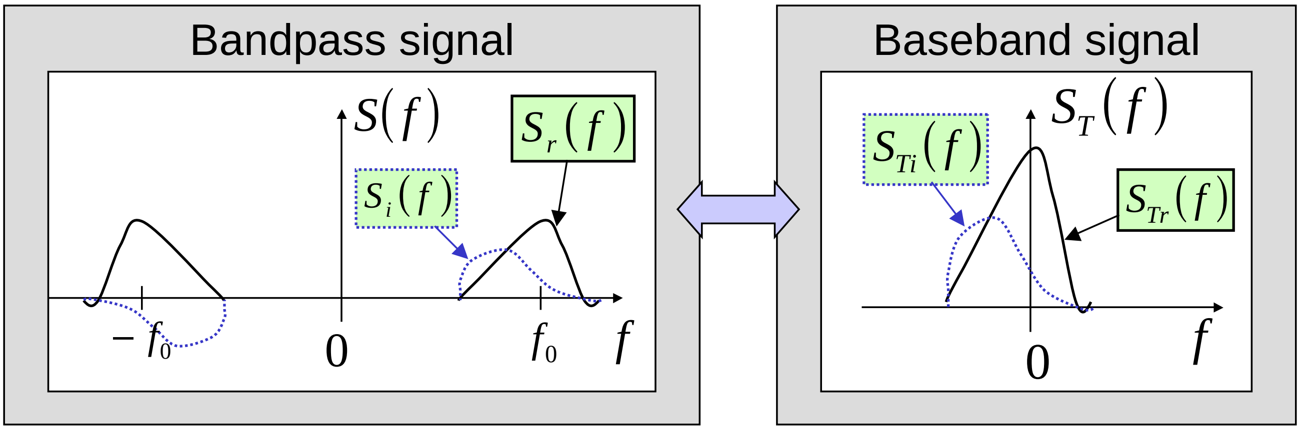
Representation in frequency domain



$$S_r(-f) = S_r(f) \qquad S_i(-f) = -S_i(f)$$

Real-valued bandpass signal can be characterized by baseband signal $S_T(f)$ and carrier frequency f_0

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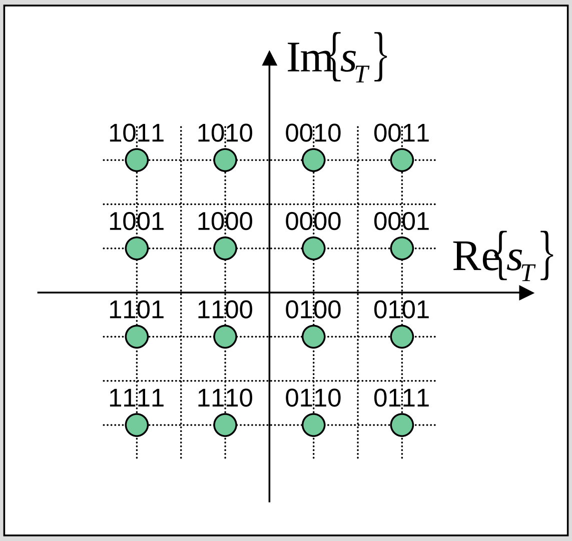
Representation in signal space

Constellation diagram



- Real part („inphase component") and imaginary part („quadrature component") of the baseband signal can be depicted in one two-dimensional diagram

$\Rightarrow$ **Constellation diagram**

- Modulation symbols usually plotted as fixed points in diagram
- Constellation diagram is very convenient for representation of **linear modulation schemes**

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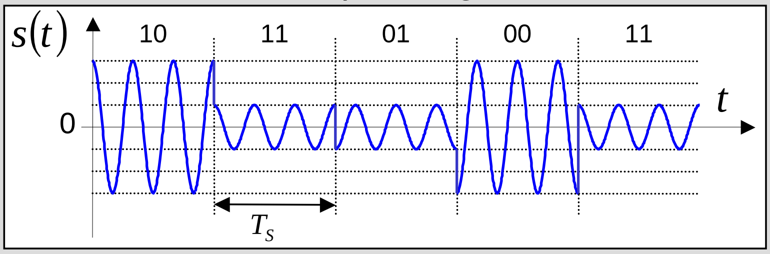
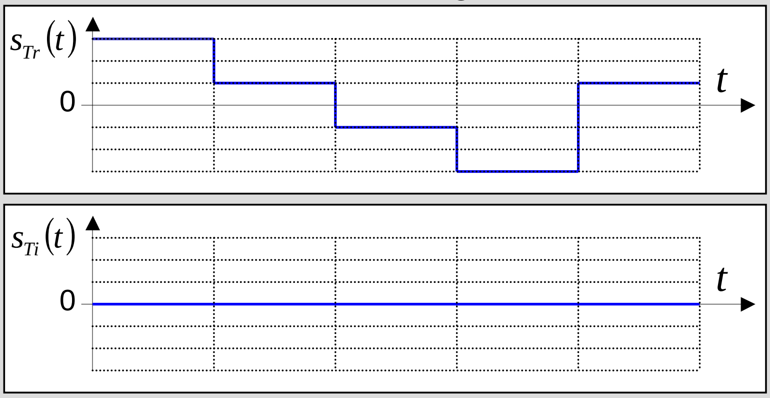
Amplitude Shift Keying (ASK)

Bandpass signal



Baseband signal

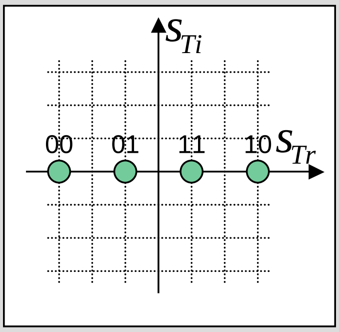


Example: 4-ASK

$$s_T(t) = \sum_n I_n \, p(t - nT_S)$$

$$p(t) = \mathrm{rect}\left(\frac{t}{T_S} - \frac{1}{2}\right)$$

Constellation diagram



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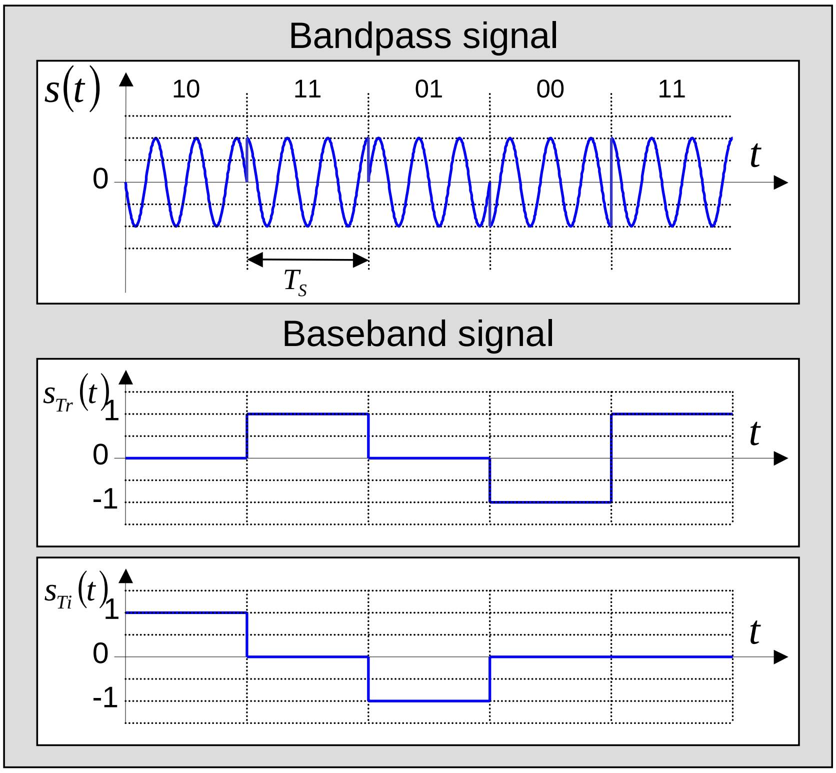
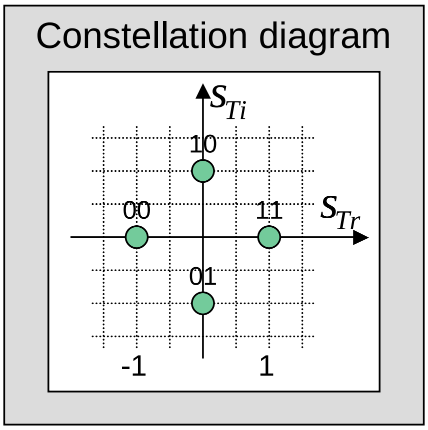
Phase Shift Keying (PSK)



Example: QPSK

$$s_T(t) = \sum_n I_n p(t - nT_S)$$

$$p(t) = \mathrm{rect}\left(\frac{t}{T_S} - \frac{1}{2}\right)$$



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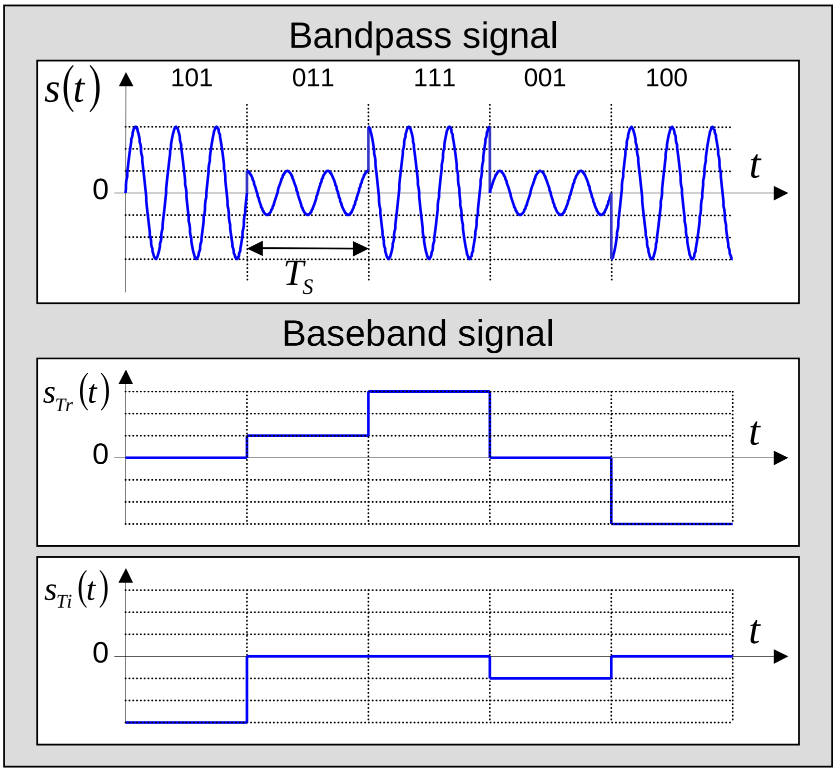
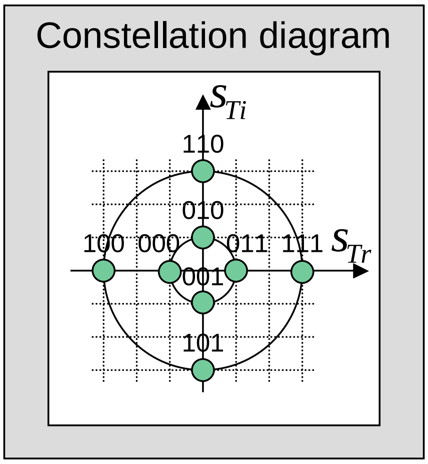
Amplitude Phase Shift Keying (APSK)



Example: 8-APSK

$$s_T(t) = \sum_n I_n p(t - nT_S)$$

$$p(t) = \mathrm{rect}\left(\frac{t}{T_S} - \frac{1}{2}\right)$$



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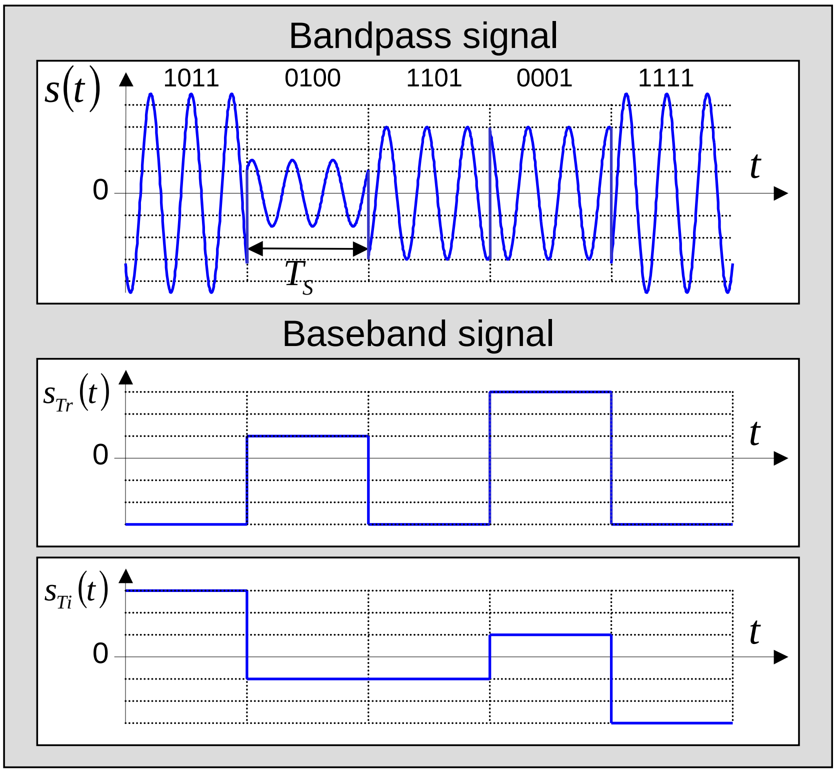
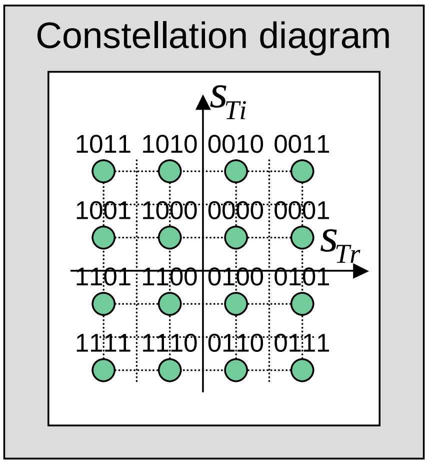
Quadrature Amplitude Modulation (QAM)



Example: 16-QAM

$$s_T(t) = \sum_n I_n p(t - nT_S)$$

$$p(t) = \mathrm{rect}\left(\frac{t}{T_S} - \frac{1}{2}\right)$$



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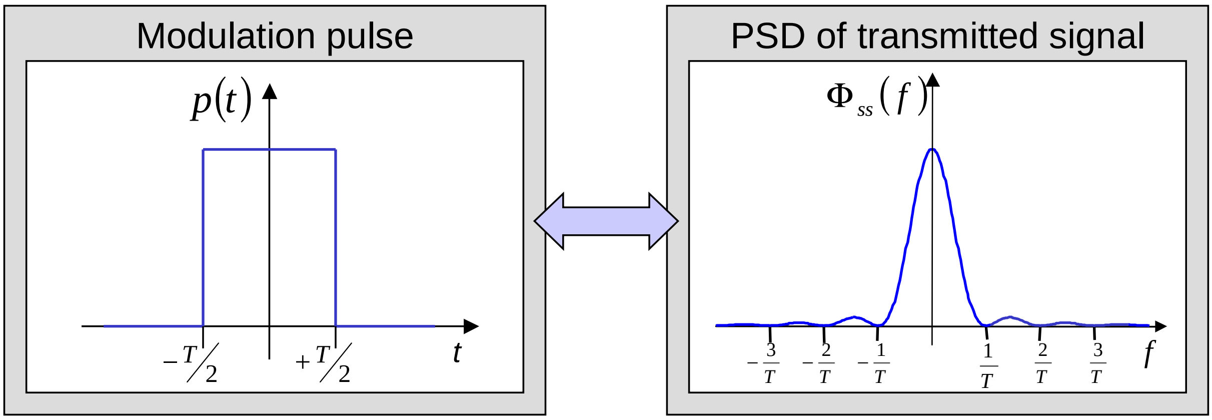
Pulse Shaping

- The power spectral density of the transmitted signal depends on the modulation pulse:

$$\Phi_{SS}(f) = C \cdot |P(f)|^2$$



Rectangular pulse shaping leads to a broadband spectrum

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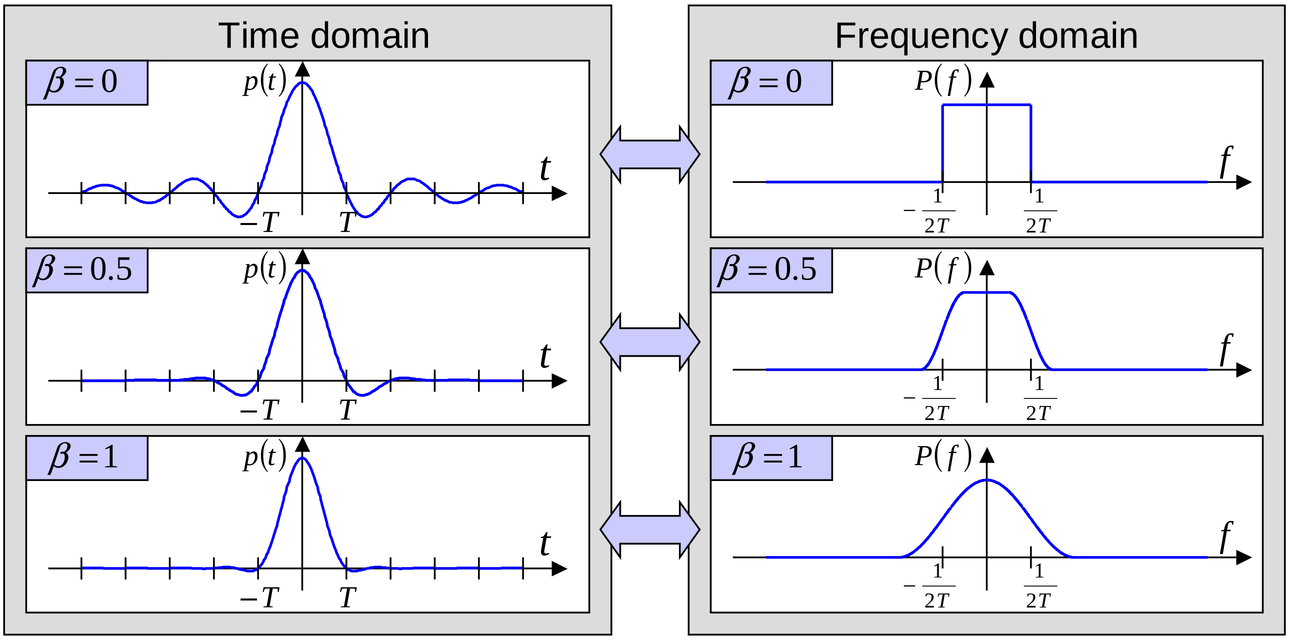
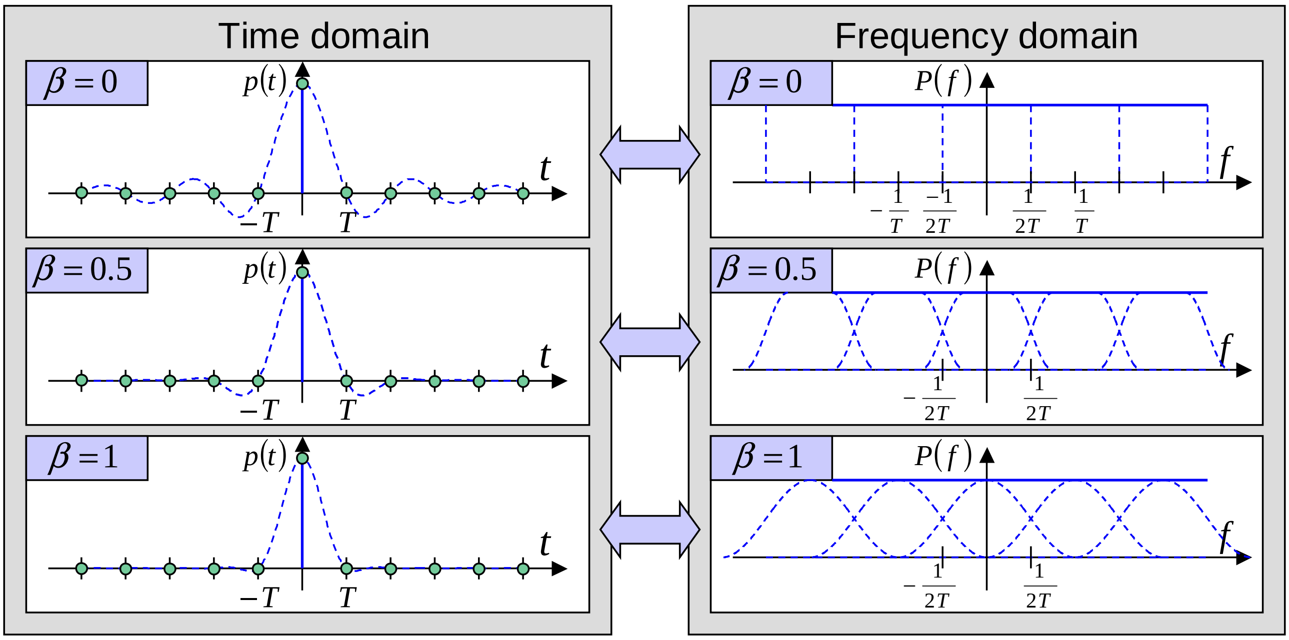
Raised Cosine Spectrum (1)

- Compromise between band limitation and time duration of the modulation pulse: **Raised Cosine (RC) pulse shaping**:



Raised Cosine Spectrum (2)

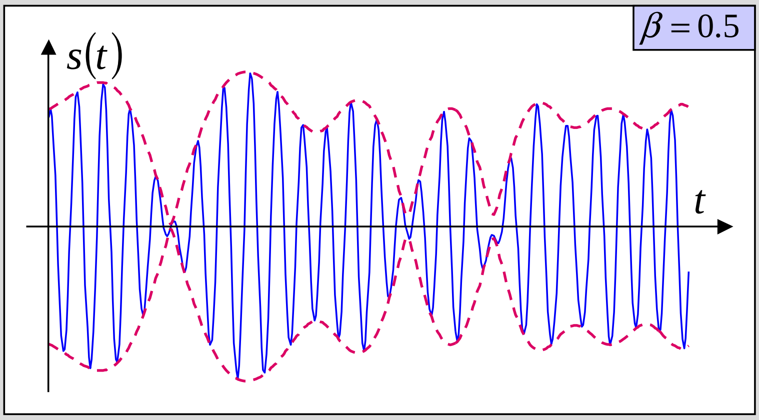
- After sampling with the sampling rate *f=1/T*, the spectrum of the signal is repeated periodically



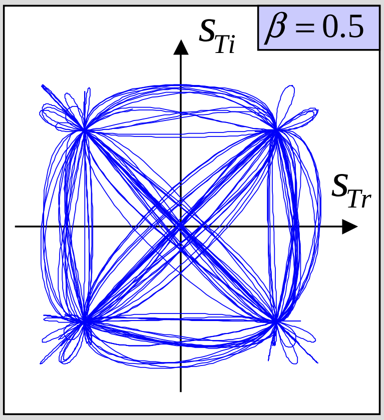
Envelope Fluctuation

- After pulse shaping the transmit signal *s(t)* of a linear modulation scheme has a non-constant envelope

QPSK signal after Raised Cosine shaping



Constellation diagram



⇒„Zero Crossings“ lead to strong power fluctuations

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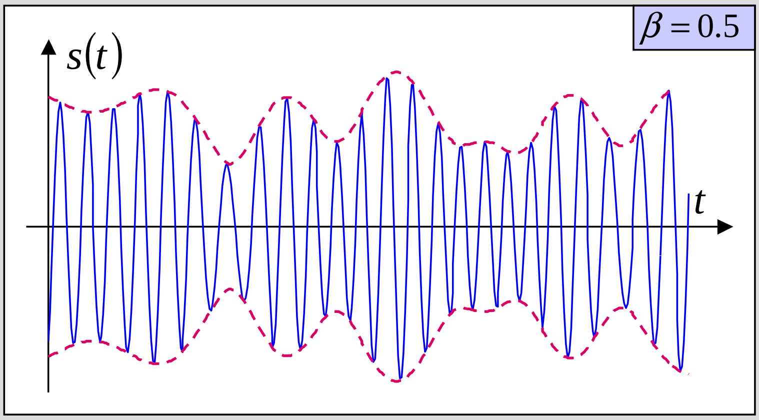
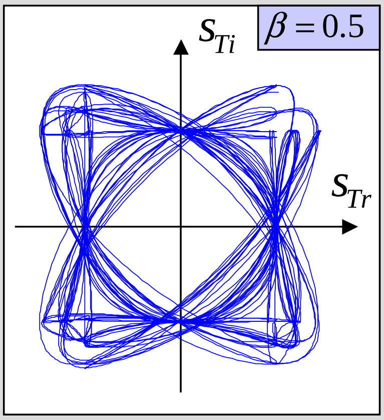
Offset-QPSK (1)

- To avoid „Zero-Crossings“, the imaginary part of the transmit signal can be shifted by *T/2*, compared to the real part

Offset-QPSK signal after RC shaping



Constellation diagram



⇒„Zero Crossings“ can be avoided using Offset-QPSK

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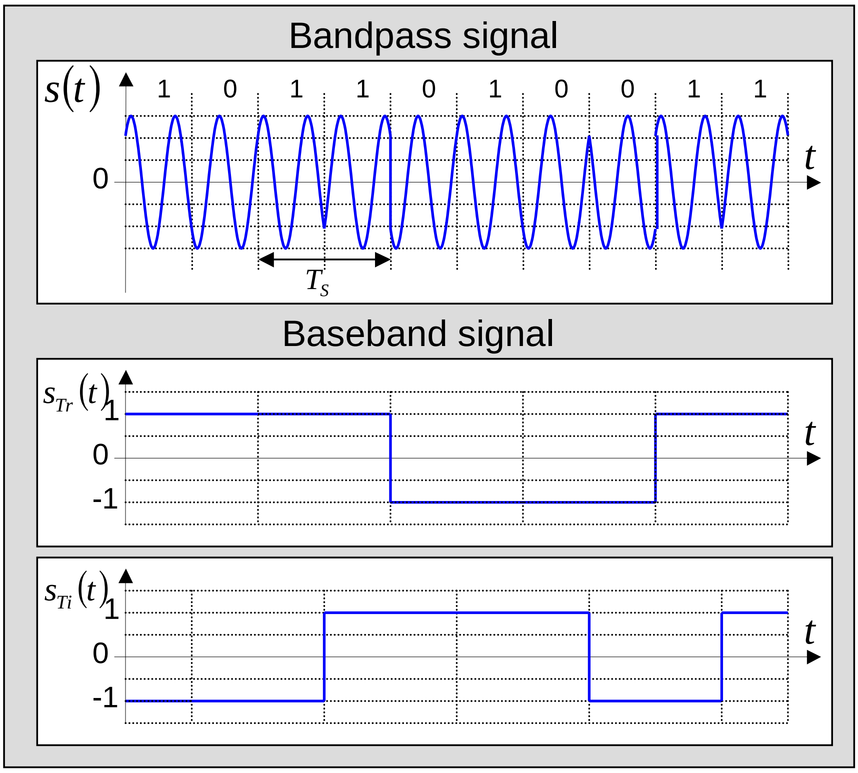
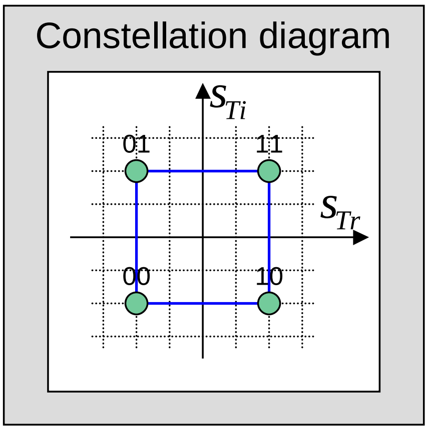
Offset-QPSK (2)

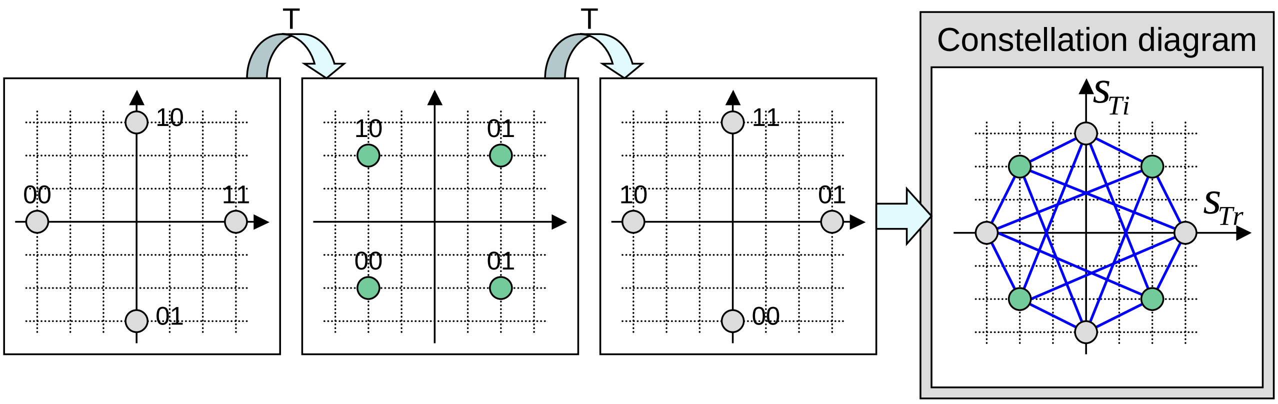


Offset-QPSK



π/4-QPSK

- For the π/4-QPSK modulation scheme, the phase of each symbol is additionally shifted by $\pi/4=45°$

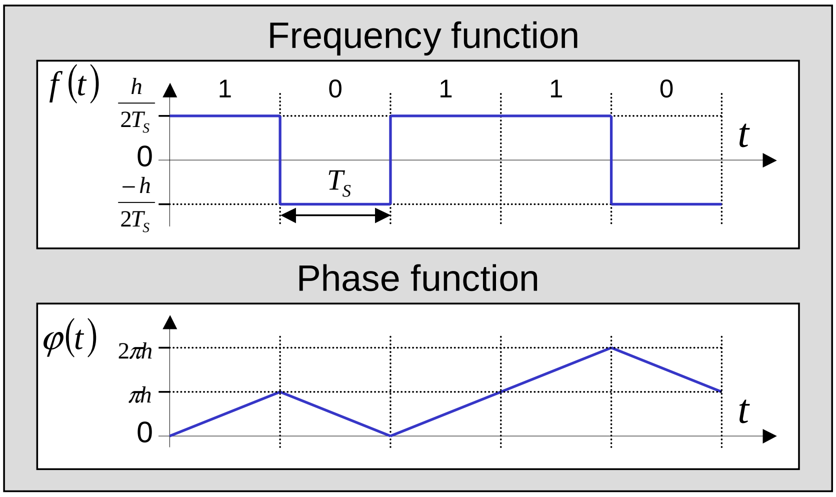


$\Rightarrow$„Zero crossings“ can be avoided
$\Rightarrow$Time synchronization is independent from transmitted symbols

Continuous Phase Modulation

$$f(t) = h \sum_n I_n \, p(t - nT_S) \qquad \varphi(t) = 2\pi \int_{-\infty}^{t} f(\tau) \cdot d\tau$$

Frequency function | **Modulation index** | **Modulation symbol** | **Frequency pulse** | **Phase function**



Example: 2-CPFSK

$$s_T(t) = e^{j\varphi(t)}$$

$$p(t) = \frac{1}{2T_S} \operatorname{rect}\left(\frac{t}{T_S} - \frac{1}{2}\right)$$

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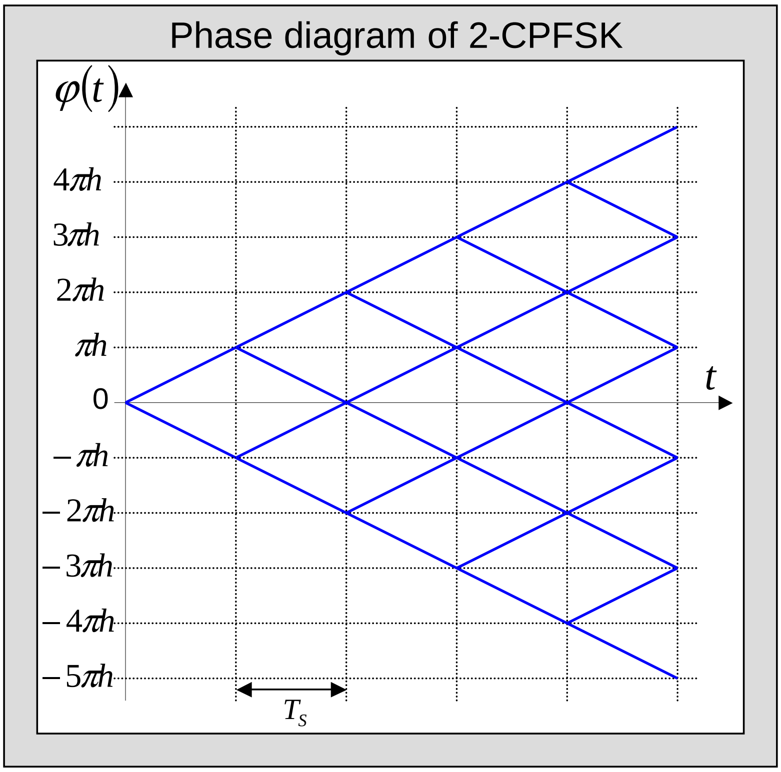
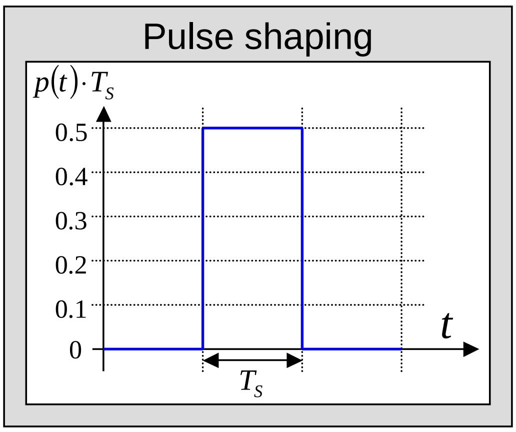
Frequency Shift Keying (FSK)



Example: 2-CPFSK

$$p(t) = \frac{1}{2T_S} \operatorname{rect}\left(\frac{t}{T_S} - \frac{1}{2}\right)$$



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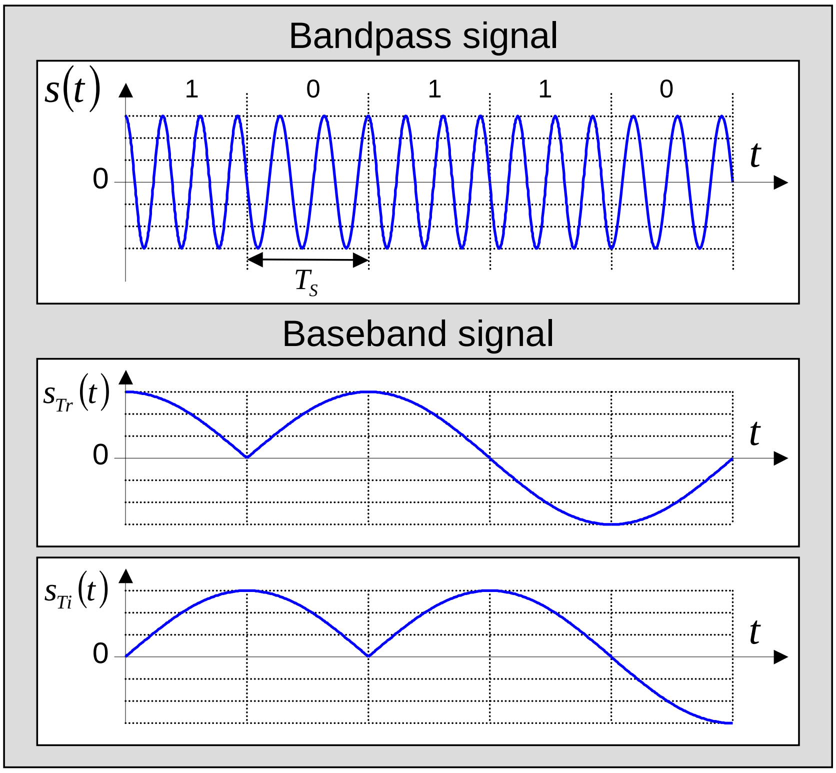
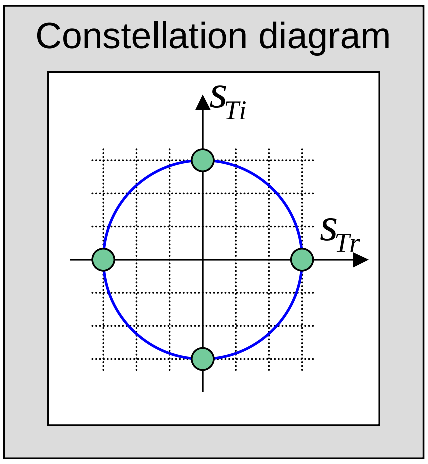
Minimum Shift Keying (MSK)

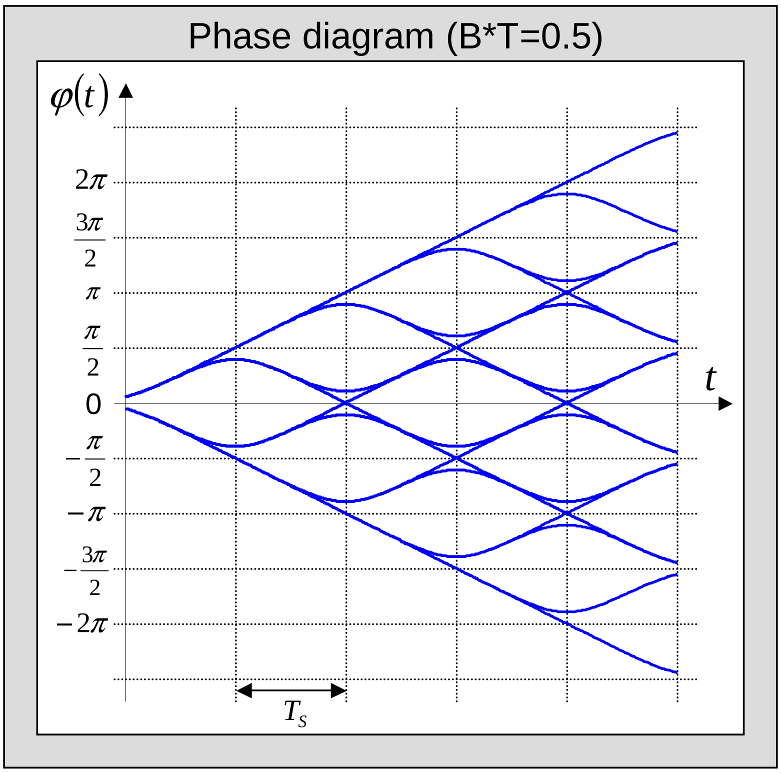


$$h = \frac{1}{2}$$

$$p(t) = \frac{1}{2T_S}\,\mathrm{rect}\left(\frac{t}{T_S} - \frac{1}{2}\right)$$



Gaussian Minimum Shift Keying (GMSK)

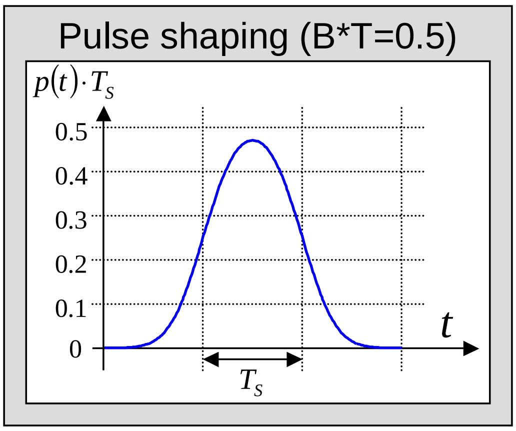


Example: B*T=0.5

$$h(t) = \frac{1}{\sqrt{2\pi}\,\sigma T_S}\exp\left[-\frac{1}{2\sigma^2}\left(\frac{t}{T_S}\right)^2\right]$$

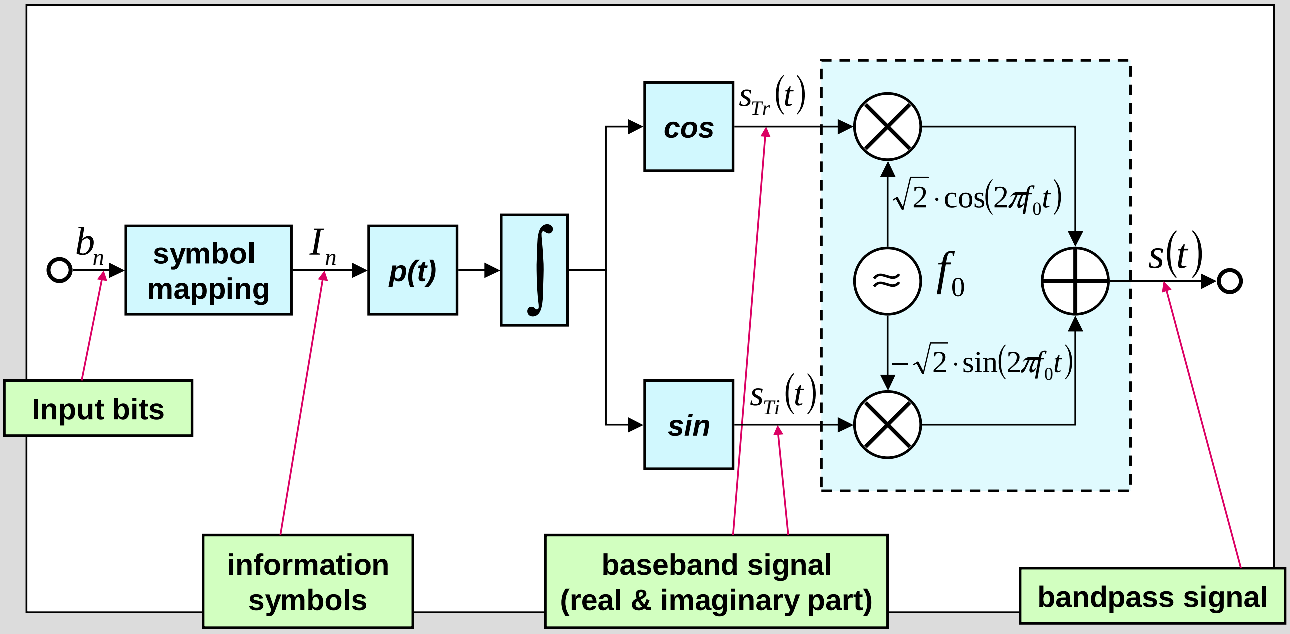
$$\sigma = \frac{\sqrt{\ln 2}}{2\pi \cdot BT}$$

$$p(t) = \frac{1}{2}h(t) * \mathrm{rect}\left(\frac{t}{T_S}\right)$$



Generation of CPM signals

Realization of a CPM modulator as quadrature modulator



Power Spectral Density

Power Spectral Densities of BPSK, QPSK and MSK