Amplitude modulation

Pulse shaping and bandpass signaling: Binary modulation schemes

EE 160: Principles of Communication Systems

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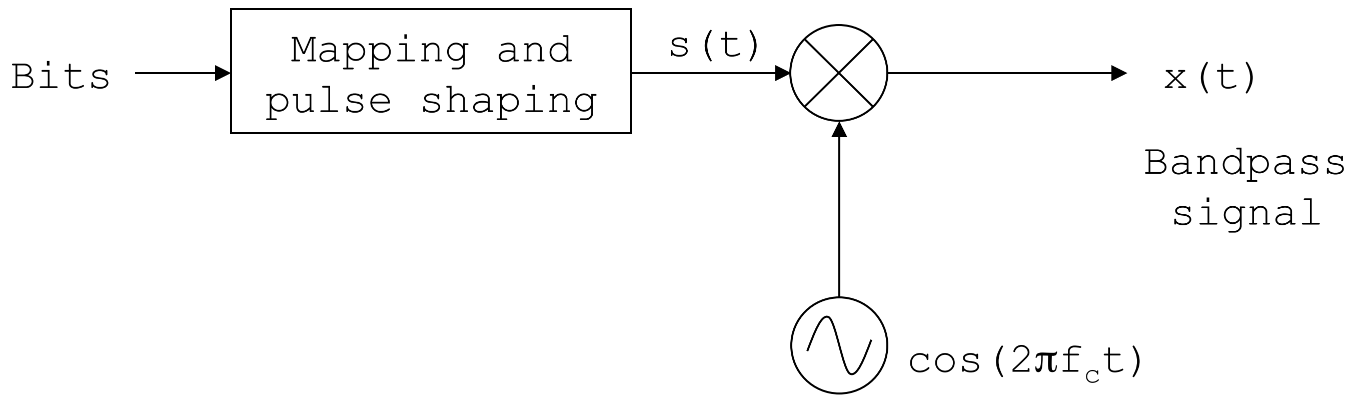
Block diagram



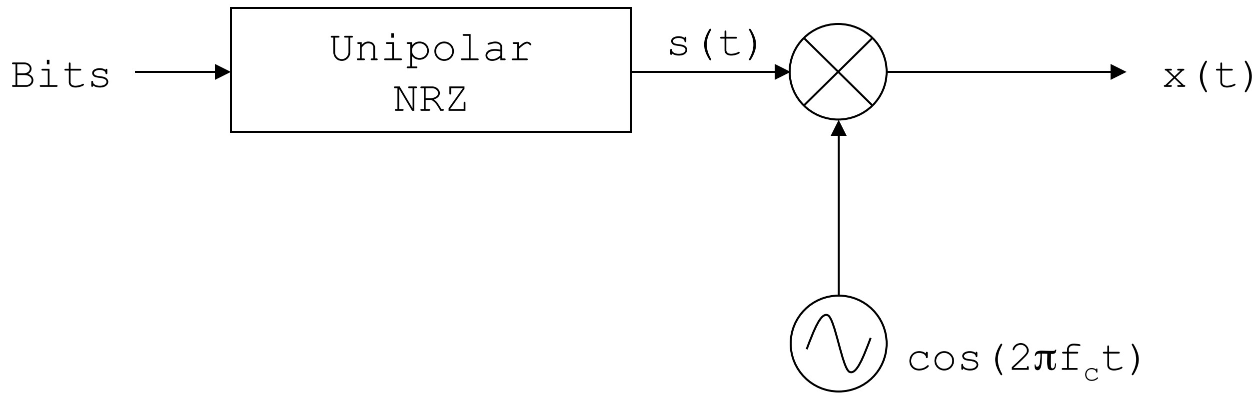
<u>Power spectral density</u>:

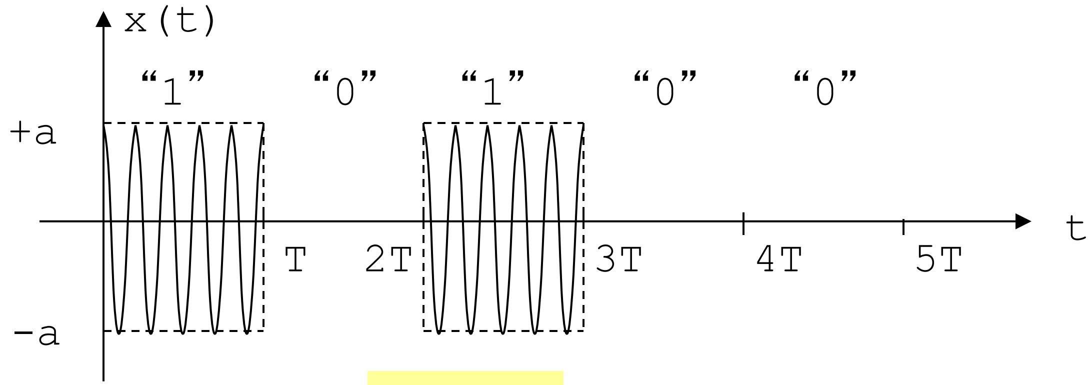
$$\boxed{S_x(f) = \frac{1}{4}\left[S_s(f+f_c) + S_s(f-f_c)\right]} \qquad (1)$$

Assumptions

- In this lecture, power spectral densities are presented of three binary modulation schemes: OOK, ASK and FSK
- The spectral properties of these modulations are measured in lab experiments 5 and 6
- The spectral densities in the next slides assume that bits are ***random***
- The power spectral density depends on a ***mapping*** and a pulse shape. Here we use ***rectangular pulses*** (this is the same as holding the amplitude constant over the duration of a bit)

Digital modulation 1: On-off keying (OOK)



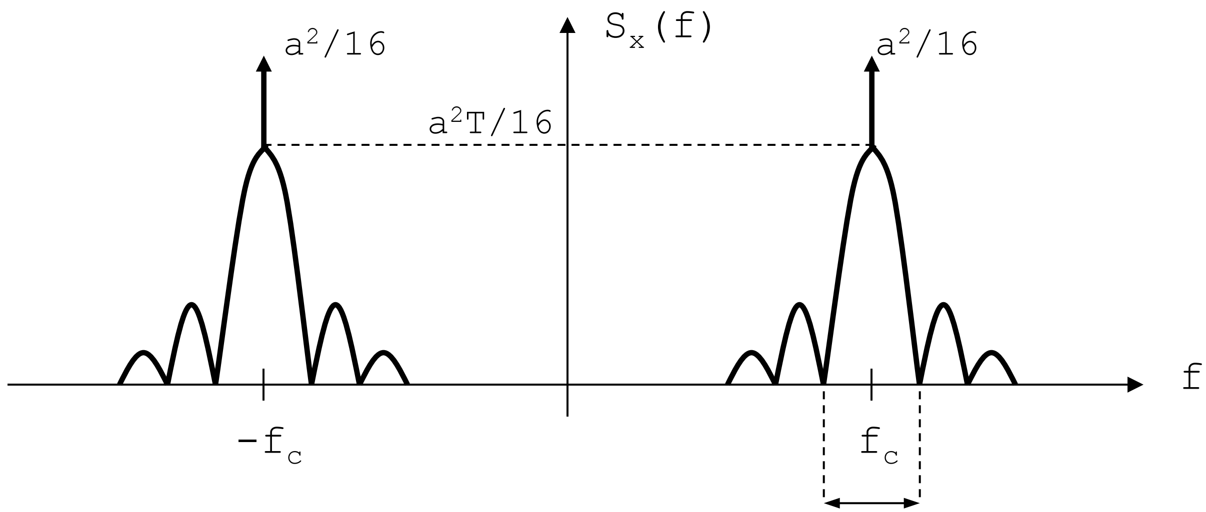


Same as DSB-LC (conventional AM)

Power spectral density of OOK

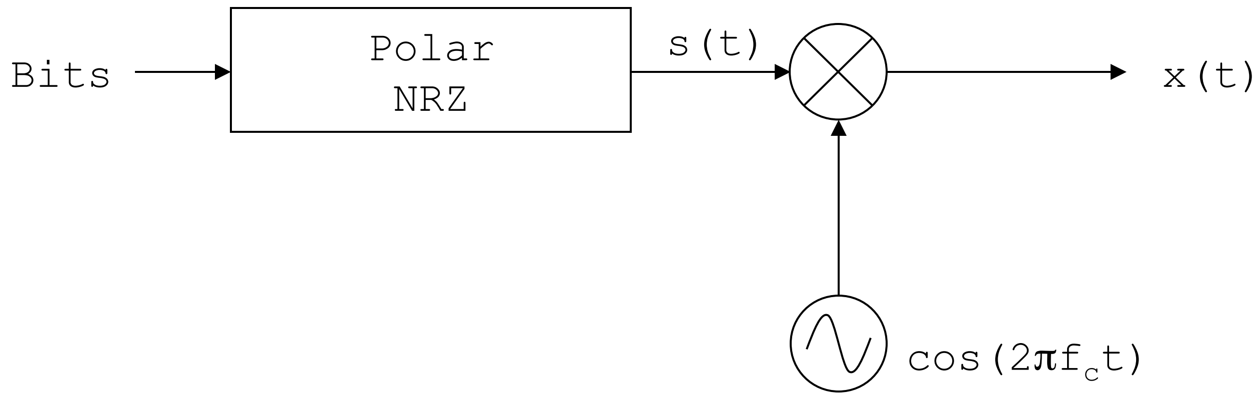
Using eq. (1):

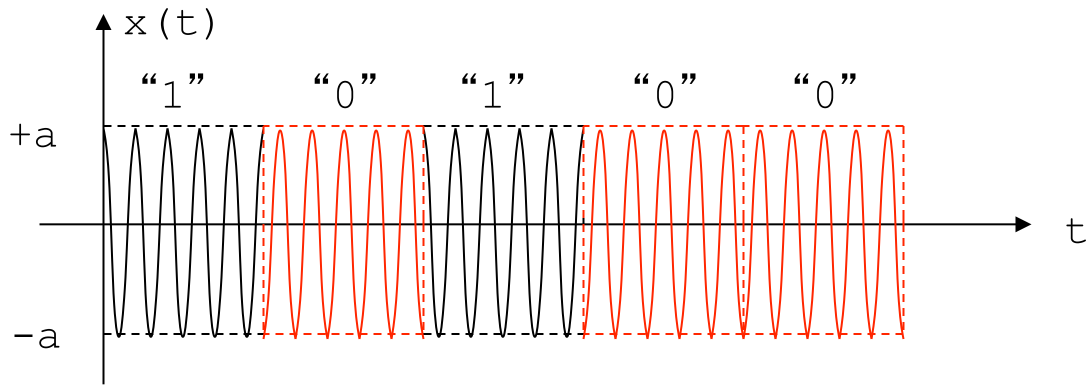
$$S_x(f) = \frac{a^2T}{16}\left[\mathrm{sinc}^2[T(f+f_c)] + \mathrm{sinc}^2[T(f-f_c)]\right] + \frac{a^2}{16}\left[\delta(f+f_c) + \delta(f-f_c)\right]$$



W=2/T: Null-to-null bandwidth

Digital modulation 2: Binary phase-shift keying (BPSK) or amplitude-shift keying (ASK)



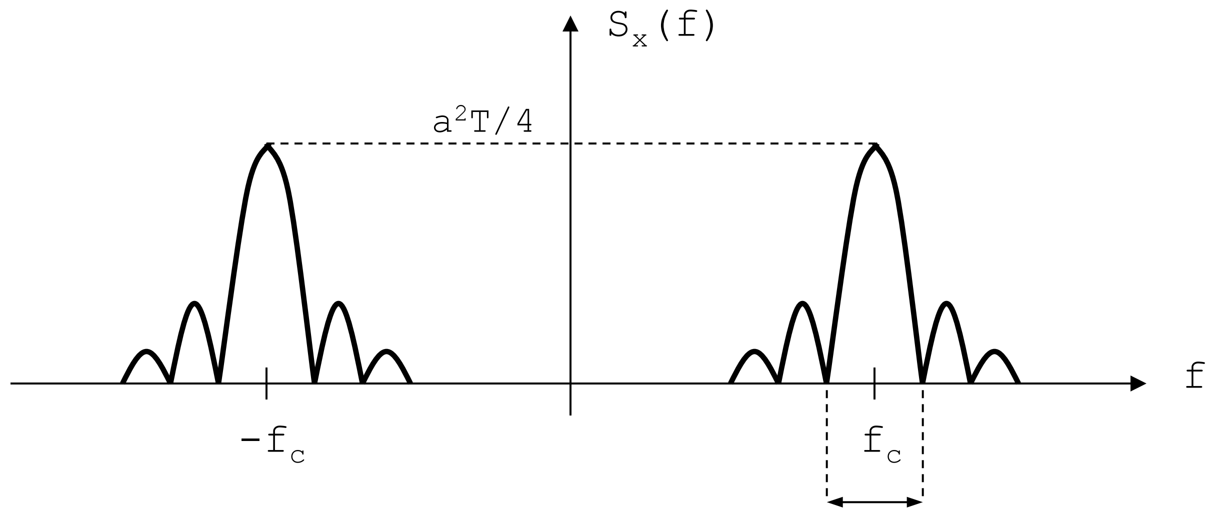


Same as DSB-SC

Power spectral density of BPSK/ASK

Using eq. (1):

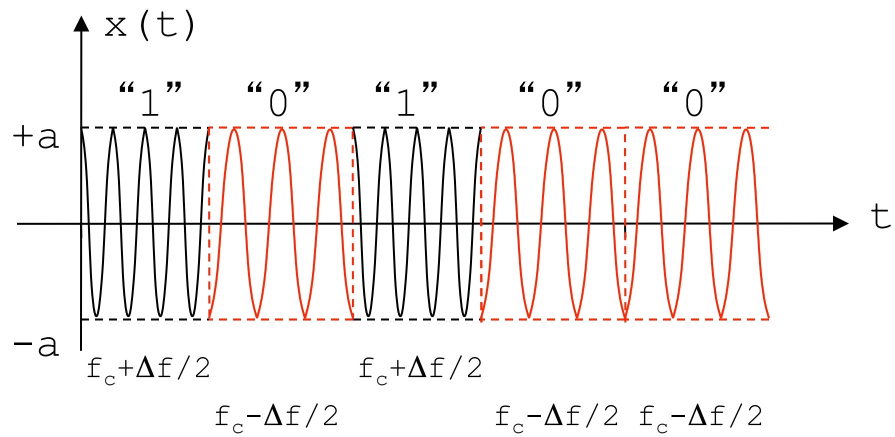
$$\boxed{S_x(f) = \frac{a^2T}{4}\left[\mathrm{sinc}^2[T(f+f_c)] + \mathrm{sinc}^2[T(f-f_c)]\right]}$$



W=2/T: Null-to-null bandwidth

Example 3: Binary frequency-shift keying (BFSK)

Bits → [a*cos(2π(f_c-Δf/2)t), if B=0 ; a*cos(2π(f_c+Δf/2)t), if B=1] → x(t)



Power spectral density of BFSK

In general: $f_1 - f_2 = \Delta f$

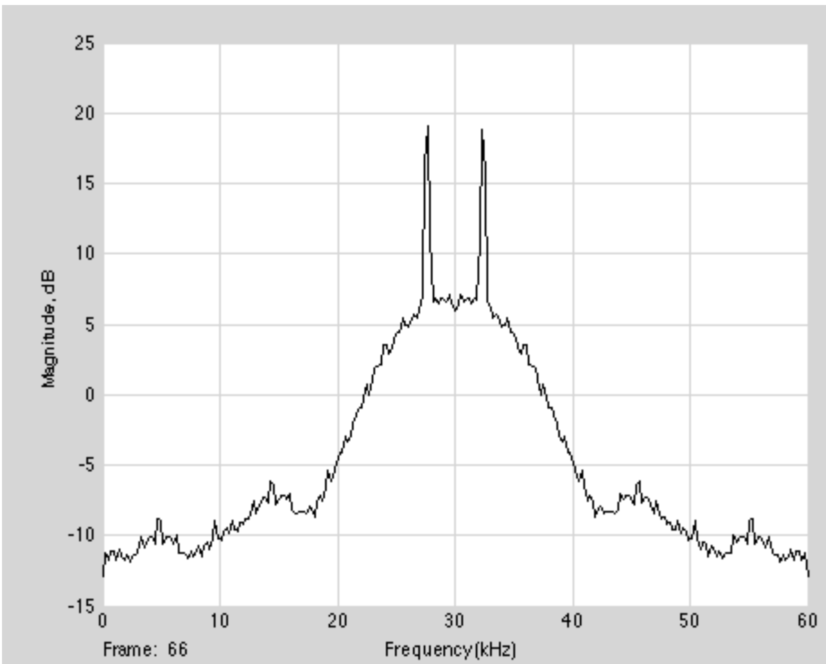
$$S_{\mathrm{FSK}}(f) = \frac{1}{4T_b^2} \sum_{n=-\infty}^{\infty} \left\{ \left[\left| S_0\left(\frac{n}{T_b}\right) \right|^2 + \left| S_1\left(\frac{n}{T_b}\right) \right|^2 \right] \delta\left(f - \frac{n}{T_b}\right) \right\} + \frac{1}{4T_b} \left[|S_0(f)|^2 + |S_1(f)|^2 \right],$$

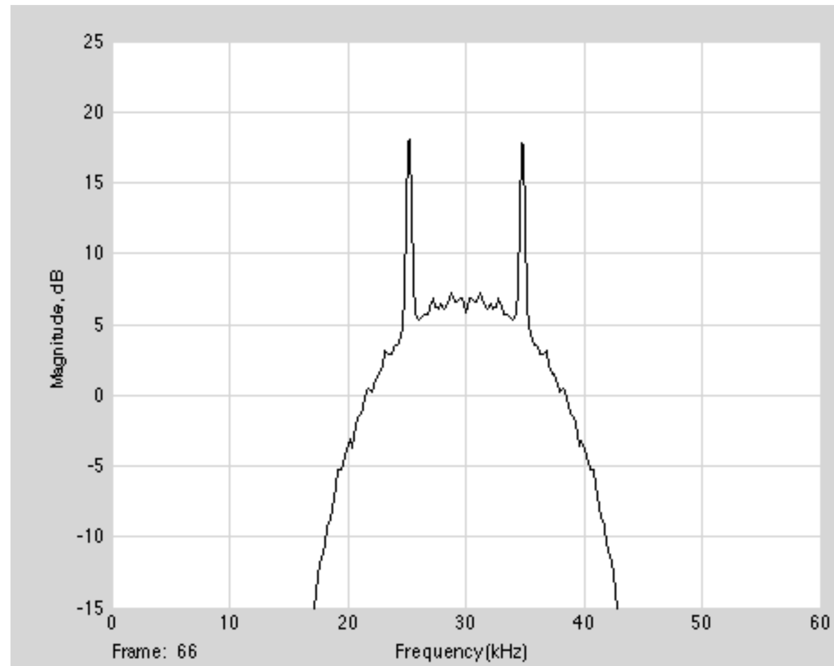
where

$$S_i(f) = \mathcal{F}\{s_i(t)\} = \frac{1}{2}\sqrt{\frac{2E_b}{T_b}} \left[\mathrm{sinc}(T_b(f + f_i)) + \mathrm{sinc}(T_b(f - f_i)) \right] e^{-j(\pi f T_b + \Theta_i)}, \quad i = 1, 2.$$

(Proakis)

BFSK spectrum as a function of Δf – part 1 (Rb = 9600 bps and f_c = 30 kHz. Matlab model)

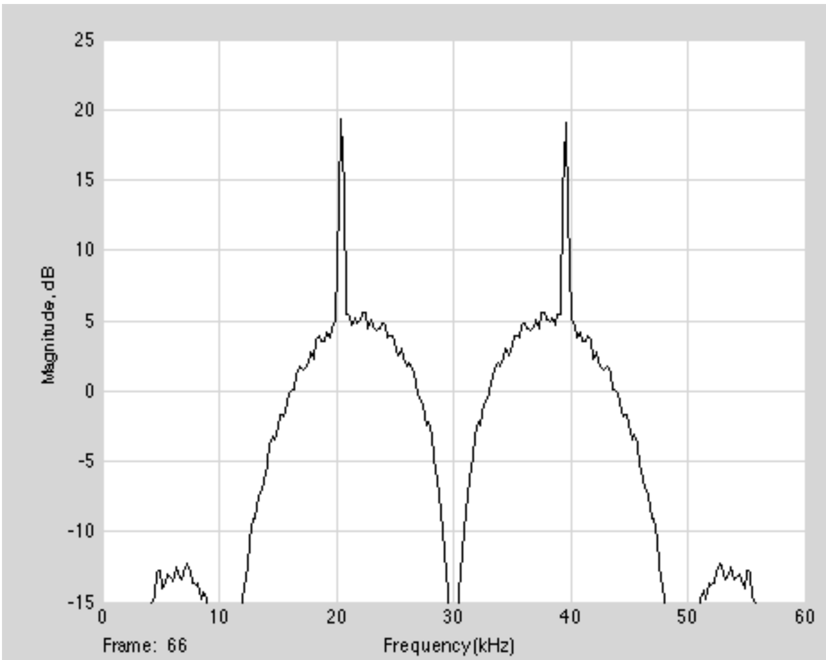




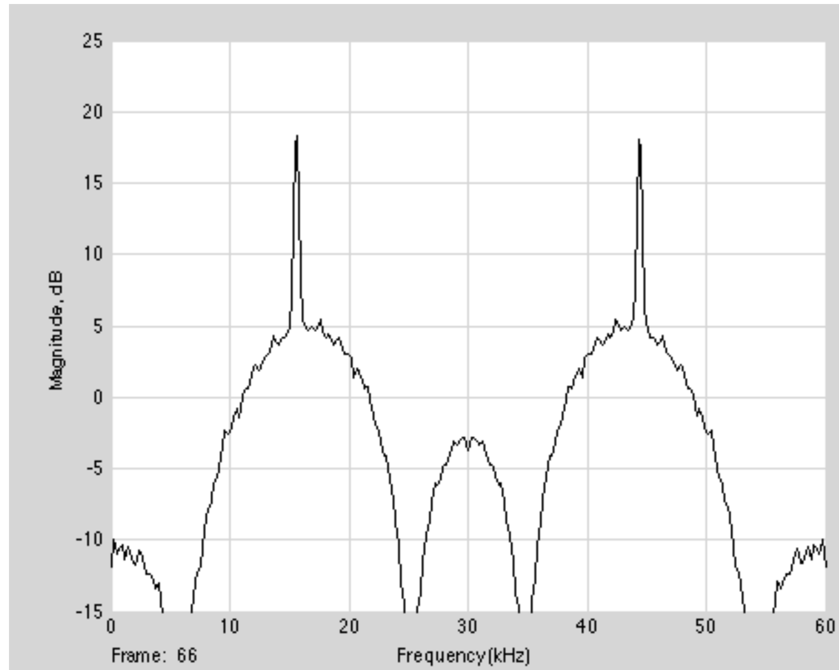
Δf = Rb/2=4800 Hz

Δf = Rb=9600 Hz

BFSK spectrum as a function of Δf – part 2 (Rb = 9600 bps and f_c = 30 kHz. Matlab model)



Δf = 2Rb=19200 Hz

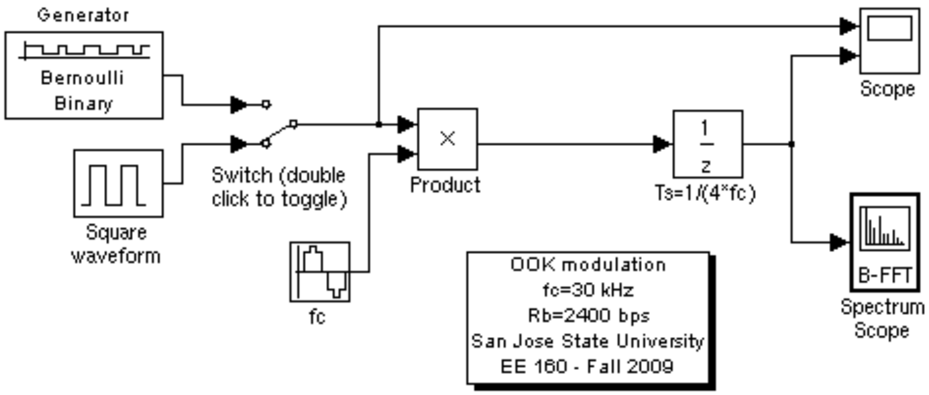


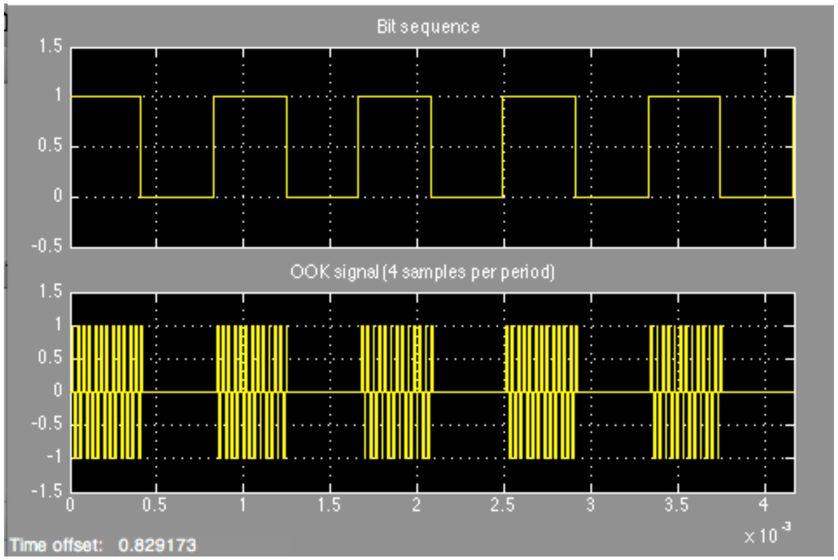
Δf = 3Rb= 28800 Hz

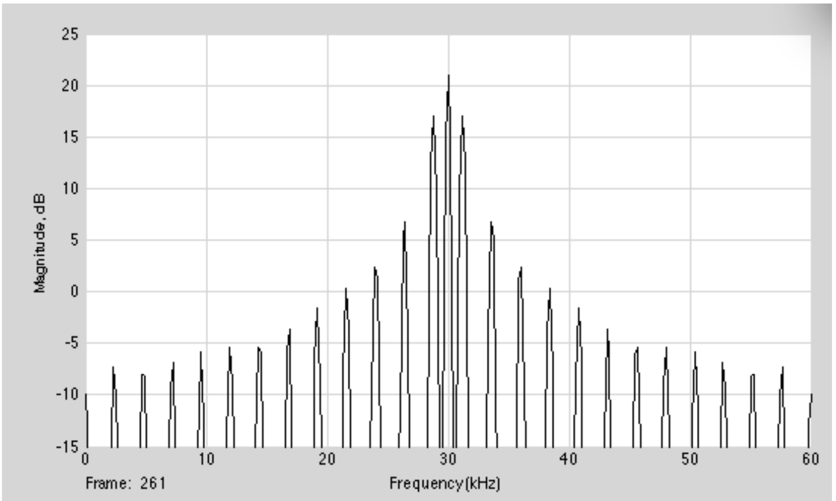
Simulink models of OOK, ASK and FSK

- Canvas under folder *files/Matlab/Digital Modulation*
- There are six modulations available:
  - OOK and GOOK (Gaussian-filtered OOK)
  - ASK and GASK (Gaussian-filtered ASK)
  - FSK and GFSK (Gaussian-filtered FSK)
- The models have a manual switch (double-click to change the toggle position) to select between
  - Square waveform generator as in the laboratory
  - Random bits source

Example: OOK with square waveform







Example: OOK with random bits