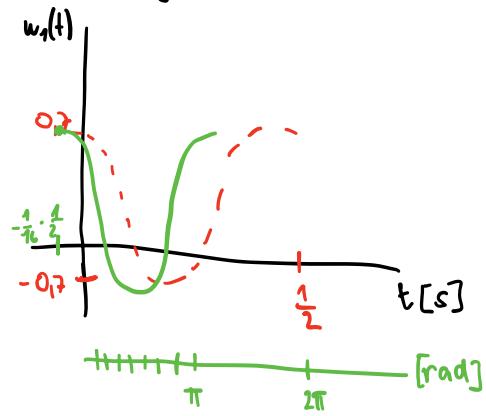
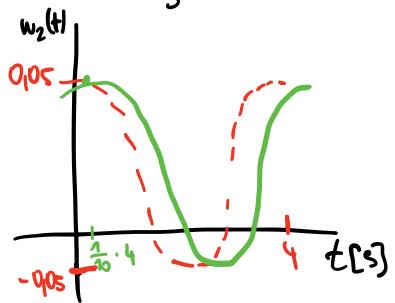


$$w(t) = 0,7 \cdot \cos\left(4\pi t + \frac{\pi}{8}\right) + 0,05 \cdot \cos\left(\frac{\pi}{2} \cdot t - \frac{\pi}{5}\right) - 0,04$$

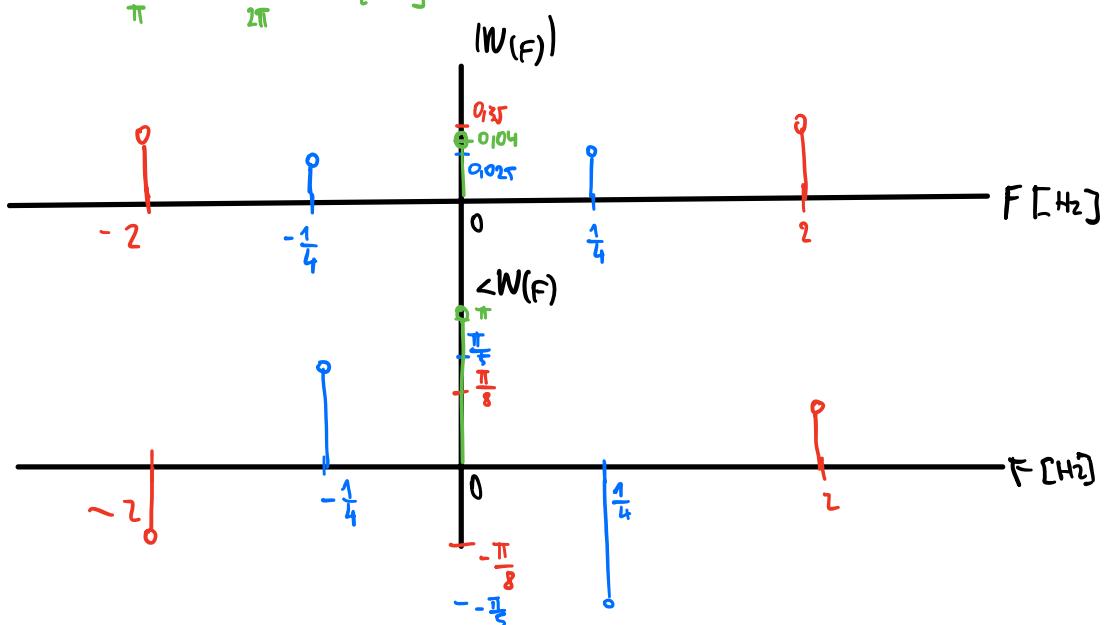
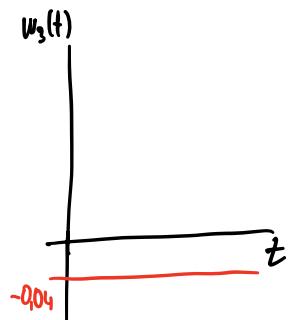
$$\begin{aligned} w_{1,\max} &= 0,7 \\ \omega_1 &= 4\pi \\ f_1 &= 2 \\ T_1 &= \frac{1}{2} \\ \varphi_1 &= \frac{\pi}{8} \text{ rad} \end{aligned}$$



$$\begin{aligned} w_{2,\max} &= 0,05 \\ \omega_2 &= \frac{\pi}{2} \\ f_2 &= \frac{1}{4} \\ T_2 &= 4 \\ \varphi_2 &= -\frac{\pi}{5} \text{ rad} \end{aligned}$$



$$c = -0,04$$



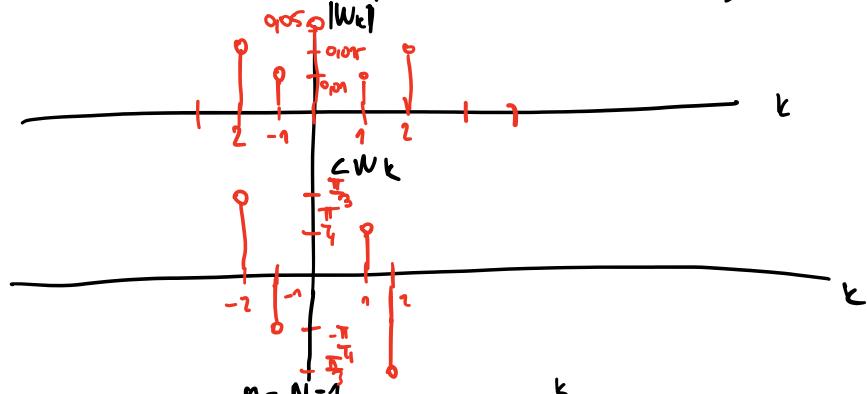
$$w[n] = 0,02 \cdot \cos\left(\frac{\pi}{4}mT_s + \frac{\pi}{4}\right) + 0,03 \cos\left(\frac{\pi}{2}mT_s - \frac{\pi}{3}\right) + 0,05$$

$$m \cdot T_s \quad T_s = 1 \quad N = 8$$

$$F_s > 2 \cdot F_{\text{max}} \text{ harm.}$$

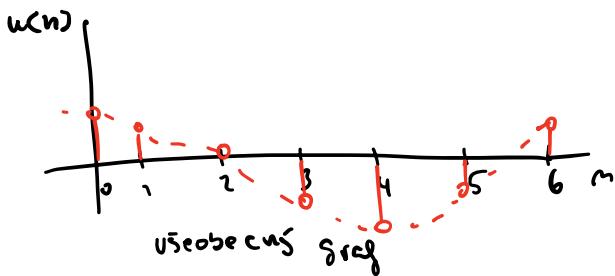
$$T_s < \frac{1}{2} T_{\text{min}} \text{ harm.}$$

$$\begin{aligned} w_1 \text{ max} &= 0,02 & w_2 \text{ max} &= 0,03 & c &= 0,05 \\ w_1 &= \frac{\pi}{4} & w_2 &= \frac{\pi}{2} & & \\ f_1 &= \frac{1}{8} & f_2 &= \frac{1}{4} & \frac{1}{4} &= \frac{k_2}{8} \\ T_1 &= 8 & T_2 &= 4 & k_2 &= 2 \\ \varphi_1 &= \frac{\pi}{4} & \varphi_2 &= -\frac{\pi}{3} & & \end{aligned}$$



DFT

$$w_k = \text{FR} \{ w[n] \} = \sum_{n=0}^{N-1} w[n] \cdot e^{-j 2\pi n \cdot \frac{k}{N}} \quad n \in \{0, N-1\} \quad k \in \{0, N-1\}$$



$$w[n] = \text{FR}^{-1} \{ w_k \} = \frac{1}{N} \sum_{k=0}^{N-1} w_k \cdot e^{j 2\pi n \frac{k}{N}}$$

$$\text{FR} \{ w \} = \{ |w_k| \} = \sqrt{\text{Re} \{ w_k \}^2 + \text{Im} \{ w_k \}^2}$$

$$\text{Fr} \{ \theta \} = \{ \angle w_k \} = \arctg \frac{\text{Im} \{ w_k \}}{\text{Re} \{ w_k \}}$$

FFT

- DIT

- DIF

$$w_k = \text{FR} \{ w[n] \} = \sum_{\text{sudl}' n=0}^{\frac{N}{2}-1} w_{\text{sudl}' n} \cdot e^{-j 2\pi n \frac{k}{\frac{N}{2}}} + e^{j 2\pi \frac{k}{\frac{N}{2}}} \cdot \sum_{\text{liedl}' n=0}^{\frac{N}{2}-1} w_{\text{liedl}' n} \cdot e^{-j 2\pi n \frac{k}{\frac{N}{2}}}$$

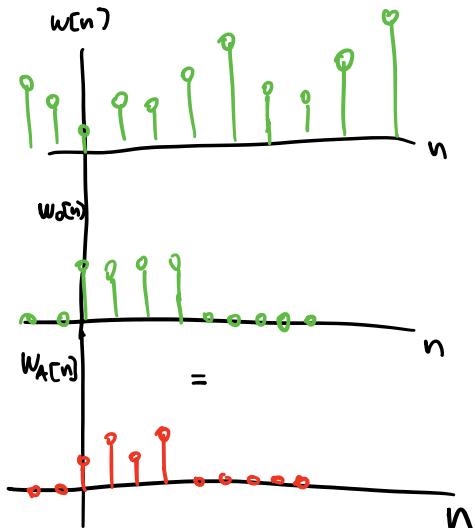
$$\begin{array}{ll} \text{DFT} & N^2 + N^2 * \\ \text{FFT} & mN + \frac{mN}{2} * N = 2^m \end{array}$$

OKENNÍ FUNKCE

$$W_A[n] = w_o[n] \cdot w[n]$$

OBDELNÍKOVÁ OKENNÍ FCE

$$w_o[n] = \begin{cases} 1 & 0 \leq n \leq N_0 - 1 \\ 0 & n < 0 \text{ v } n > N_0 - 1 \end{cases}$$



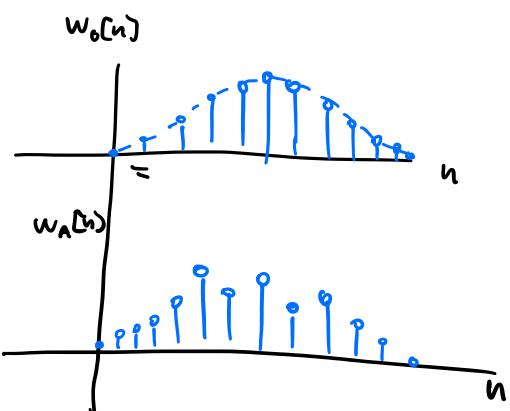
- HANNIN GOVA

$$w_o[n] = \begin{cases} 1 - \cos\left(\frac{2\pi n}{N-1}\right) & 0 \leq n \leq N-1 \\ 0 & n < 0 \text{ v } n > N-1 \end{cases}$$

- FLAT TOP

- BARLETOVÁ

- HANNOVA



PRŮMĚROVÁNÍ K

$$W_{k,K} = \frac{1}{K} \sum_{k=1}^K W_k$$

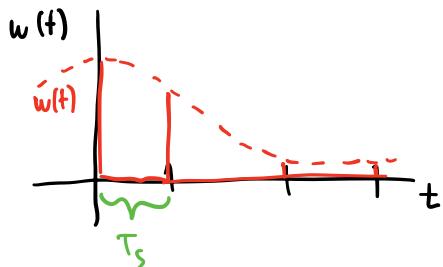
$$k = \langle 0, N-1 \rangle$$

PŘEKRYVÁNÍ SPEKTER
50% , 66,7% , 75%

ZPRACOVÁVÁNÍ SIGNALU V ZA'KLADNÍ FREKVENČNÍ OBLASTI

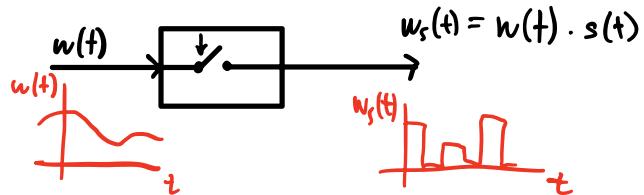
ANALOGOVÝ SIGNAL \rightarrow IMPULSNI SIGNAL \rightarrow DISKRETNÝ SIGNAL \rightarrow DIGITÁLNÝ SIGNAL

IMPULSNI SIGNAL



$$F_s > 2 \cdot F_{\text{max. harm.}}$$

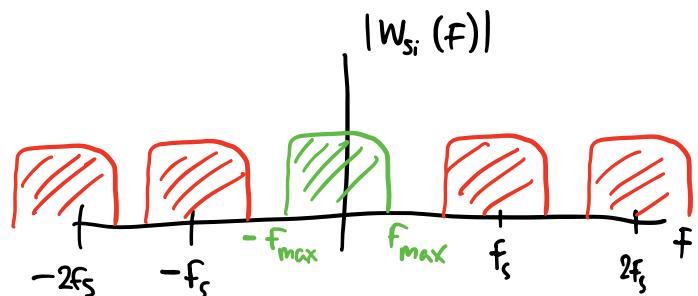
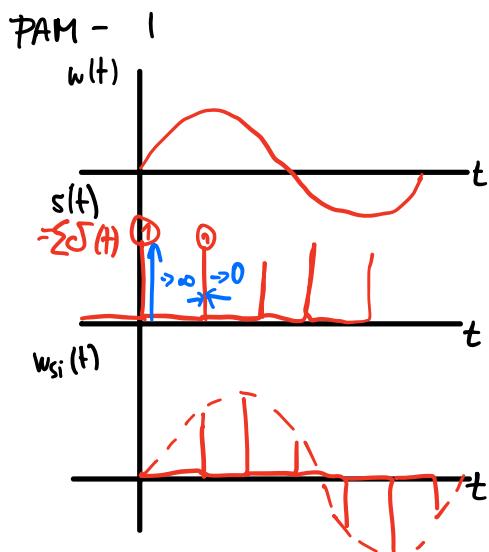
IMPULSNI AMPLITUDOVA MODULACE (PAM)



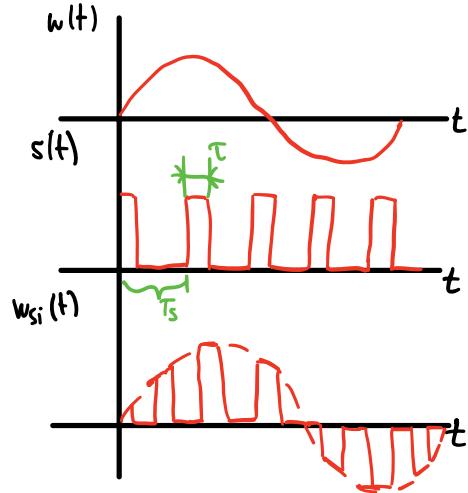
PAM - I s ideálním vzorkováním

PAM - P s přirozeným vzorkováním

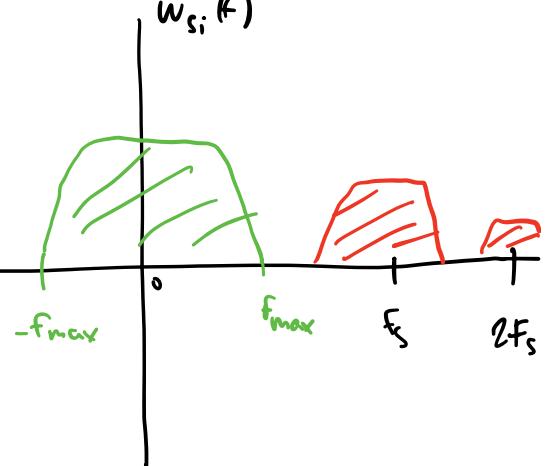
PAM - O s okamžitým vzorkováním



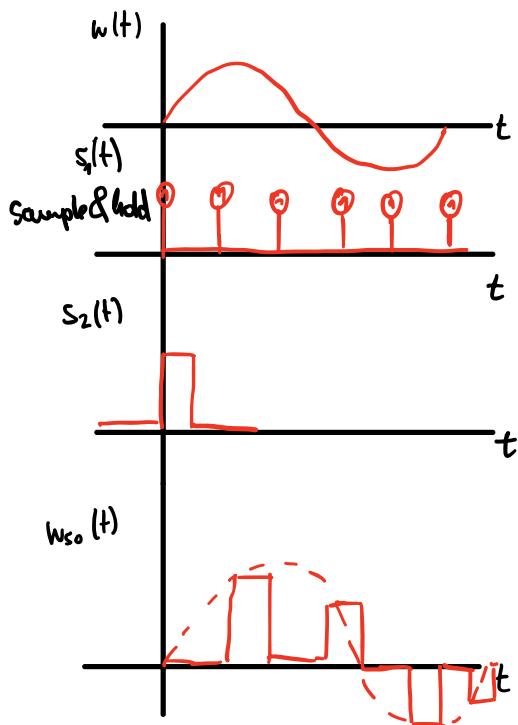
PAM - P



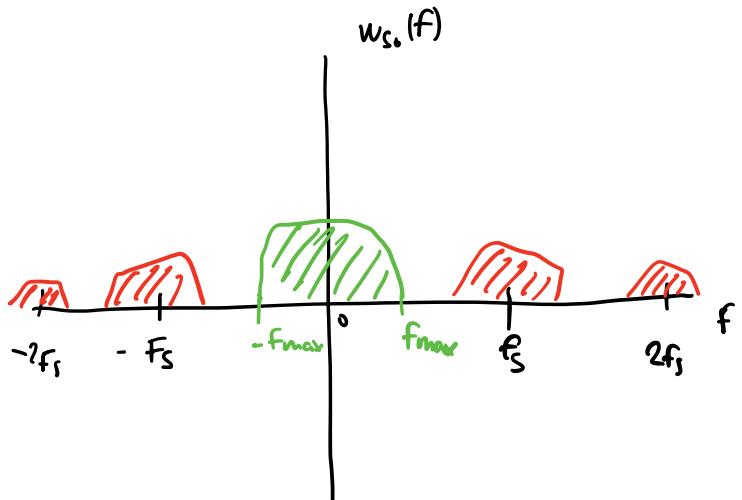
$w_{s_i}(f)$



PAM - D

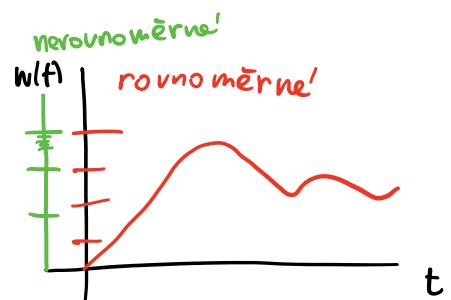


$w_{s_0}(f)$

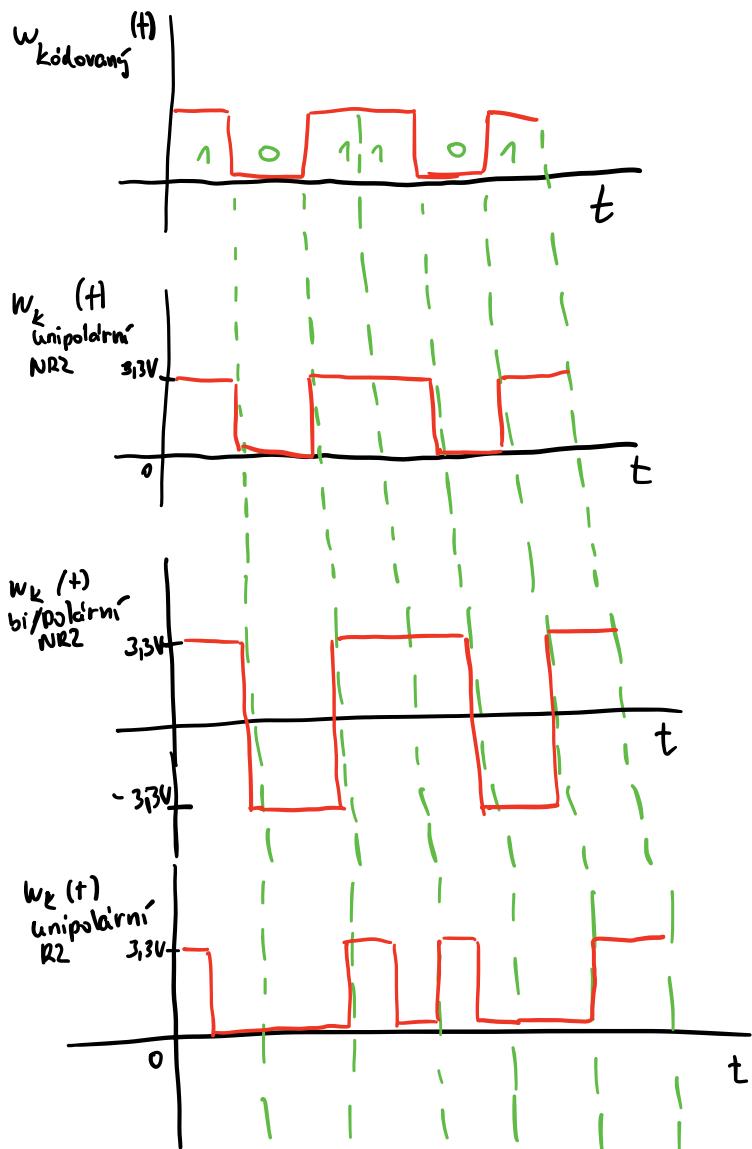


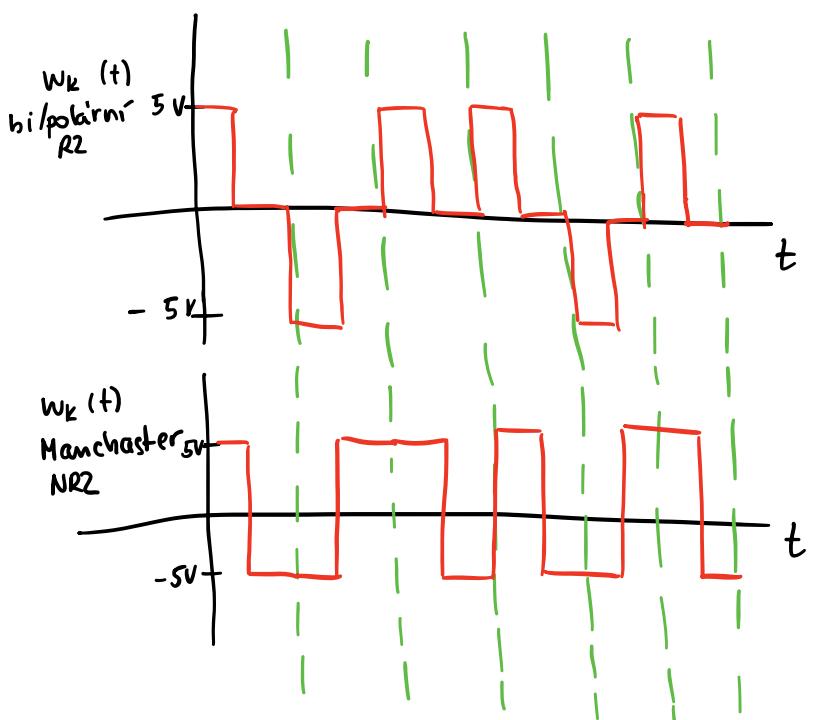
PCM Impulsní kódová modulace

- Vzorkování
- kvantování
- kódování
 - PAM
 - rovnoměrné
 - nerovnoměrné - m-low A-low
 - unipolární z průběhu původního analogového signálu
 - bipolární
 - BCD
 - Gray-kód



BCD	Gray-kód
11	10
10	11
01	01
00	00





BITOVÁ RYCHLOST

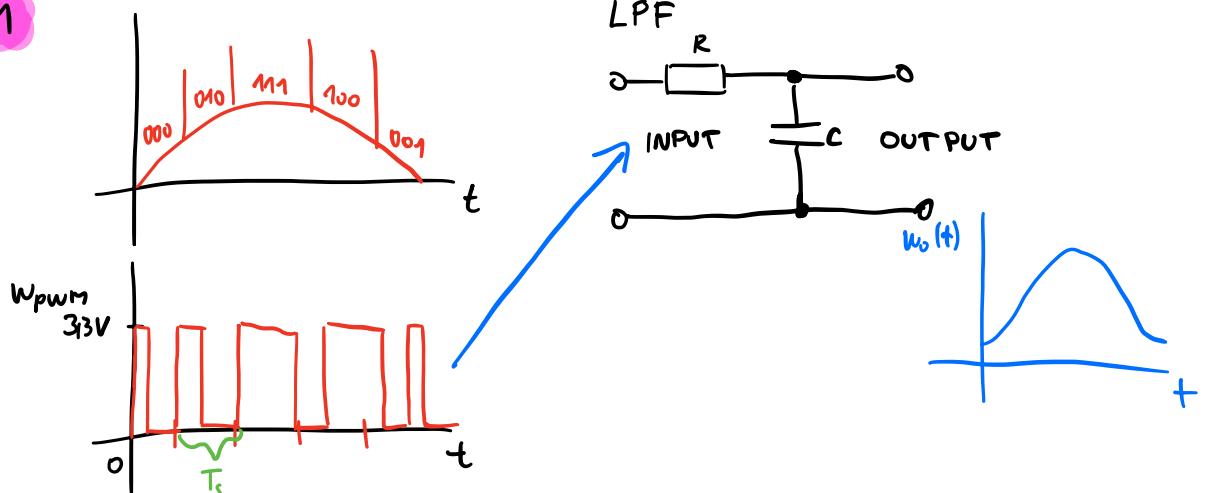
$$R = n \cdot F_s$$

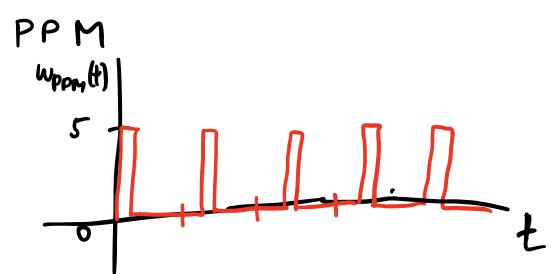
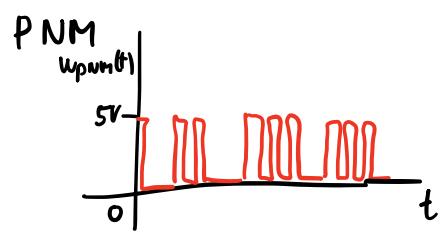
$$M = 2^n$$

$$F_s > B$$

$$B_{PCM} = n \cdot B$$

PWM





$F_c \dots$ carrier
frekvence nosné

MODULACE

$$F_c \gg 0$$

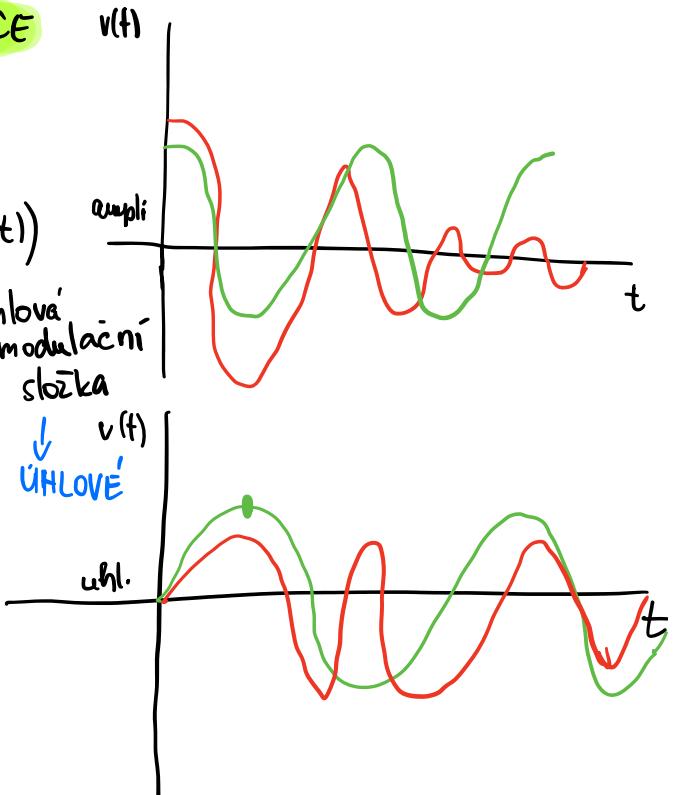
$$v(t) = R(t) \cdot \cos(w_c t + \Theta(t))$$

↑
pa'smenný
VF
modulovaný

↑
amplitudová
modulační
složka

↑
AMPLITUDOVÉ

$w_c = 2\pi F_c$



$$v(t) = \operatorname{Re} \{ g(t) e^{jw_c t} \}$$

↑
komplexní obalba

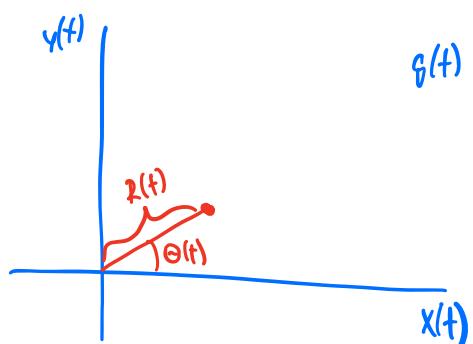
$$g(t) = R(t) \cdot e^{j\Theta(t)} = x(t) + jy(t)$$

↓
soufázová
modulační
složka

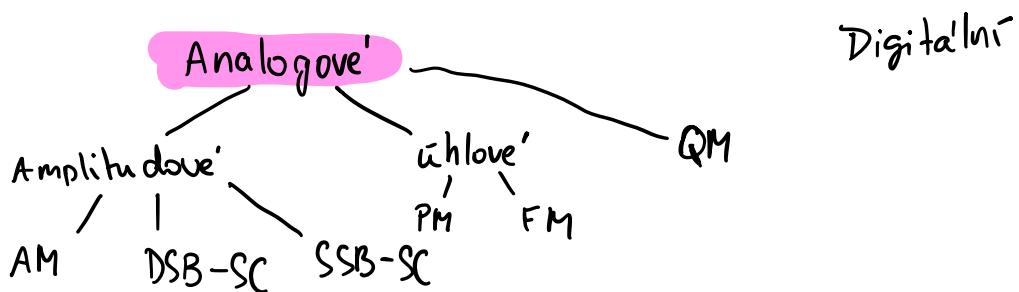
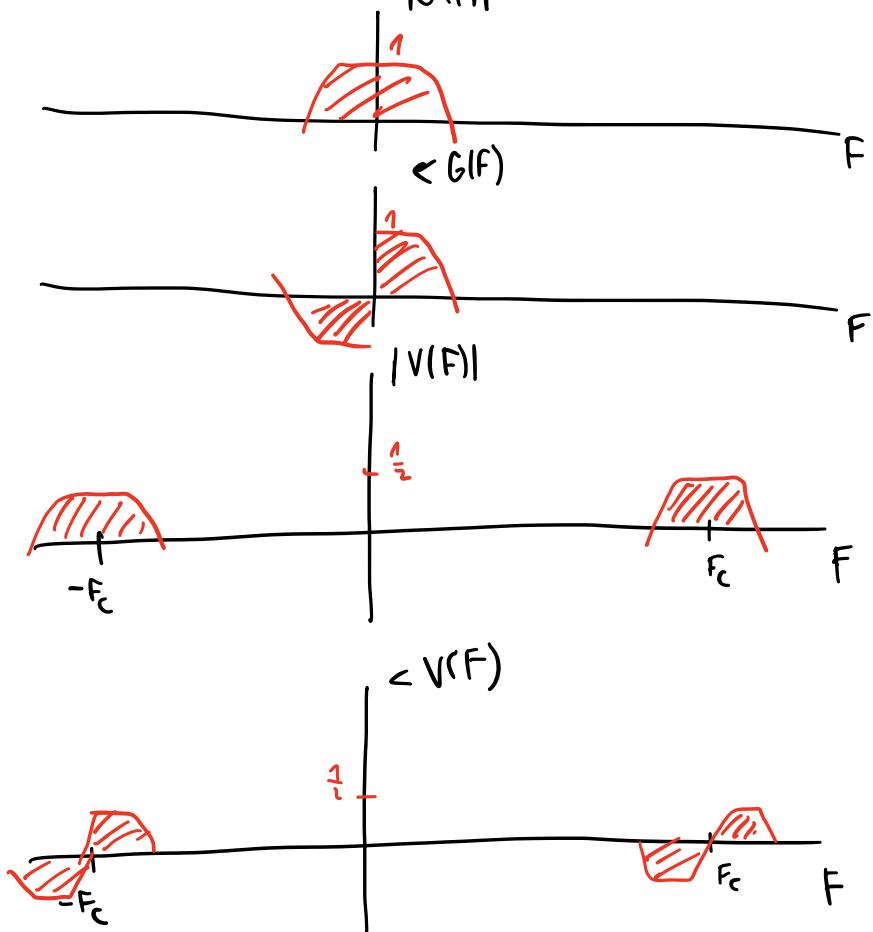
↓
kvadrantová
modulační
složka

$$R(t) = \sqrt{x^2(t) + y^2(t)}$$

$$\Theta(t) = \arctan \frac{\operatorname{Im}\{g(t)\}}{\operatorname{Re}\{g(t)\}} = \arctan \frac{y(t)}{x(t)}$$



$$V(f) = \frac{1}{2} G(F - F_c) + \frac{1}{2} \frac{G^*(F + F_c)}{|G(F)|}$$



AM MODULACE

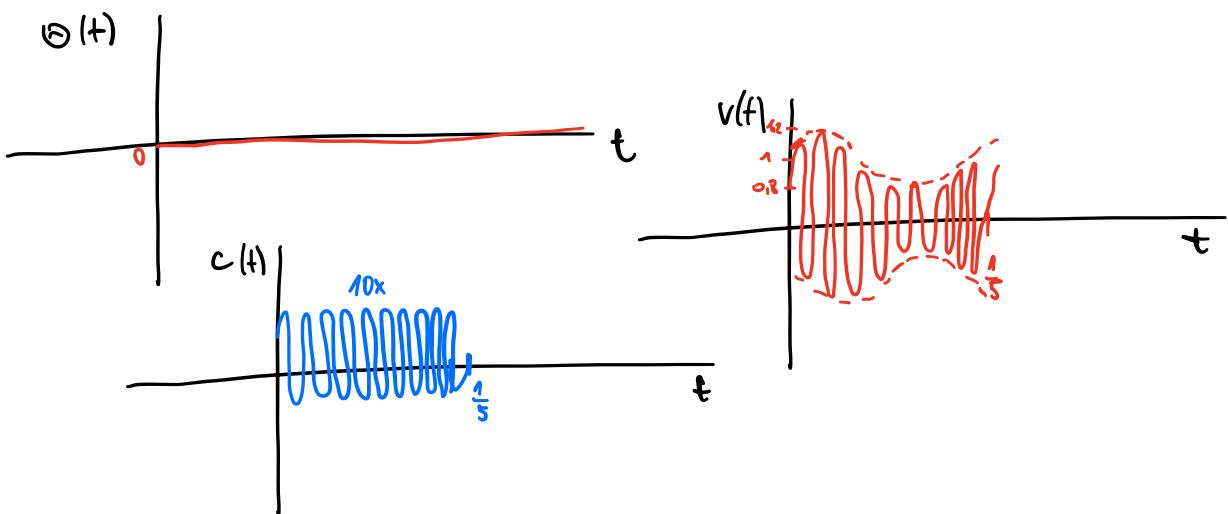
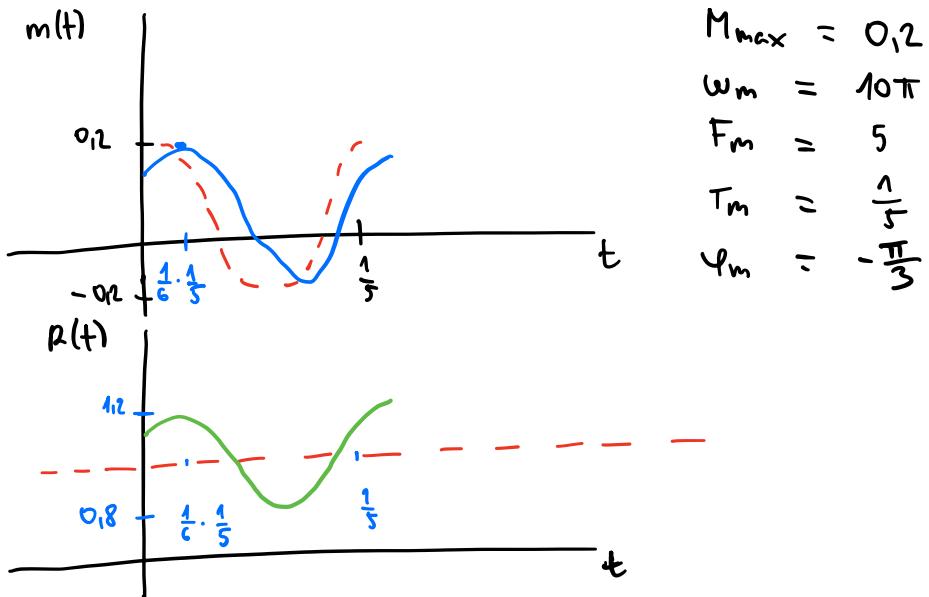
$$g(t) = 1 + m(t)$$

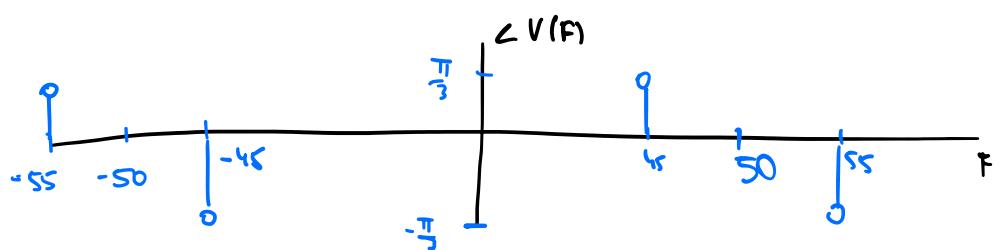
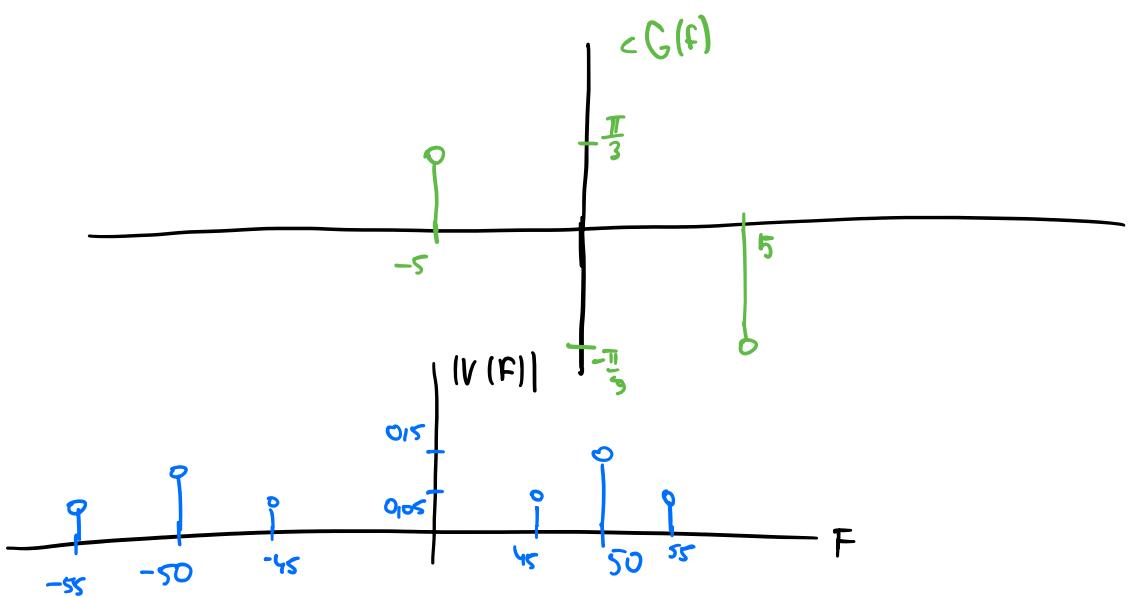
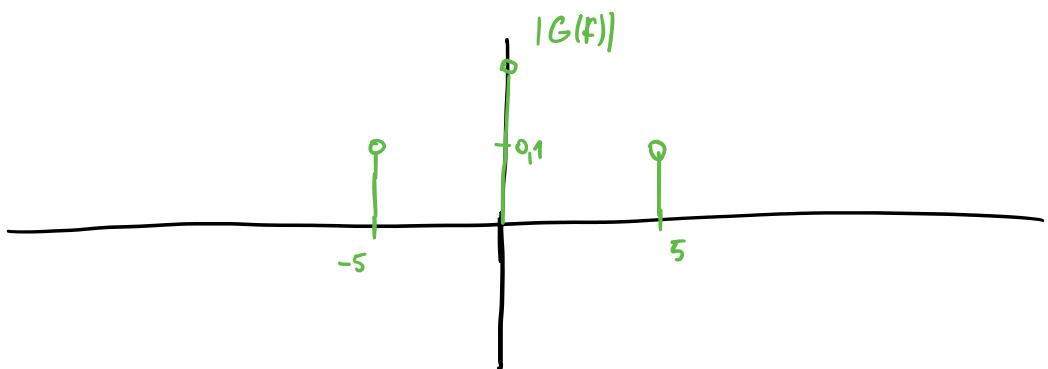
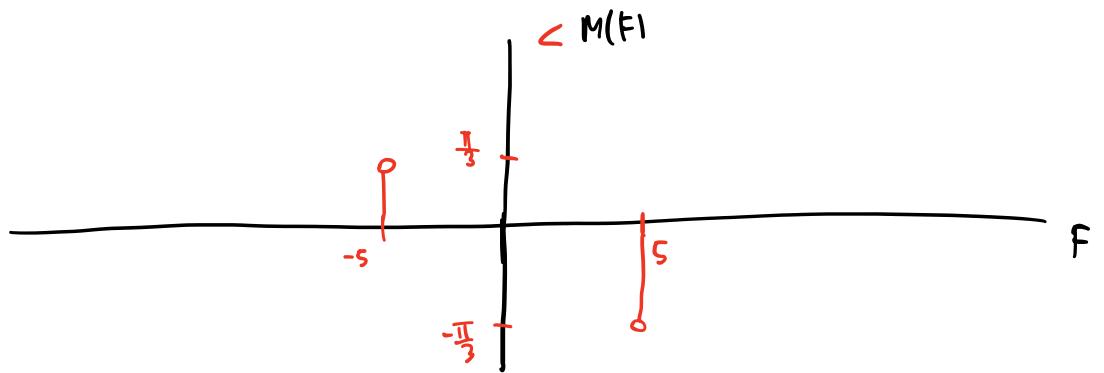
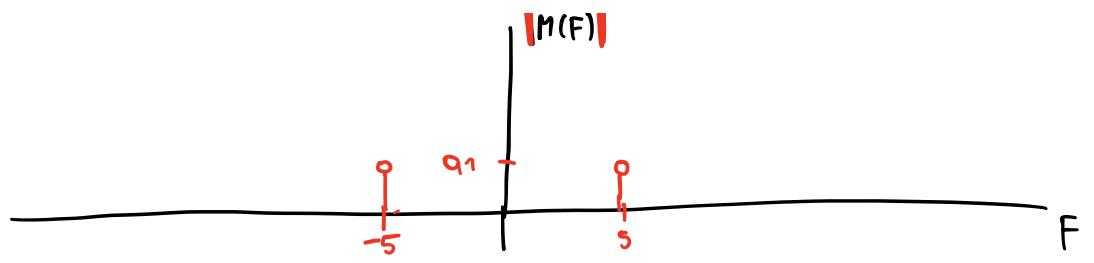
↑
informační
signál

$$\begin{aligned} R(t) &= |1+m(t)| \\ \Theta(t) &= \begin{cases} 0 & m(t) > -1 \\ \pi & m(t) < -1 \end{cases} \quad |m(t)| < 1 \\ &|m(t)| > 1 \end{aligned}$$

Informační signál → vysíláme harmonicky

$$m(t) = 0,2 \cdot \cos(10\pi t - \frac{\pi}{3}) \quad f_c = 50 \text{ Hz}$$





DSB SC potlačení moske'

OBROUSTRANÉA'

AMPLITUODNA'

MODULACE

$$g(t) = m(t)$$

$$R(t) = |m(t)|$$

$$\Theta(t) \begin{cases} 0 & m(t) \geq 0 \\ \pi & m(t) < 0 \end{cases}$$

SSB - SC

$$g(t) = m(t) \pm j\hat{m}(t)$$

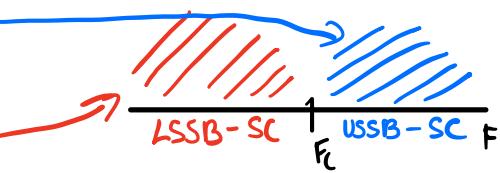
Hilbertova transformace

$$\cos(x) \rightarrow \sin(x)$$

$$\sin(x) \rightarrow -\cos(x)$$

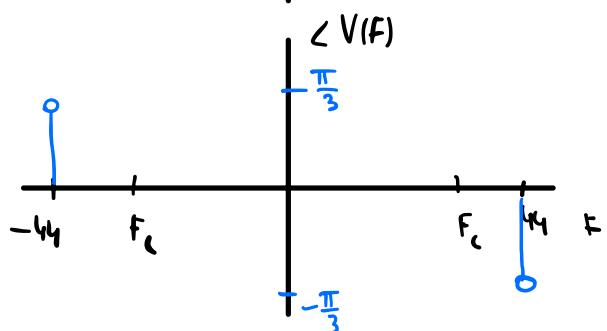
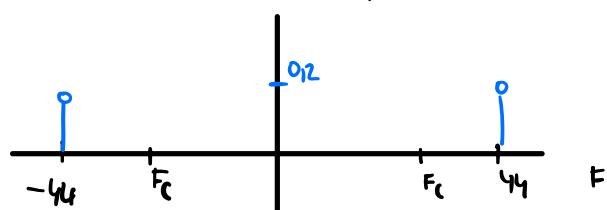
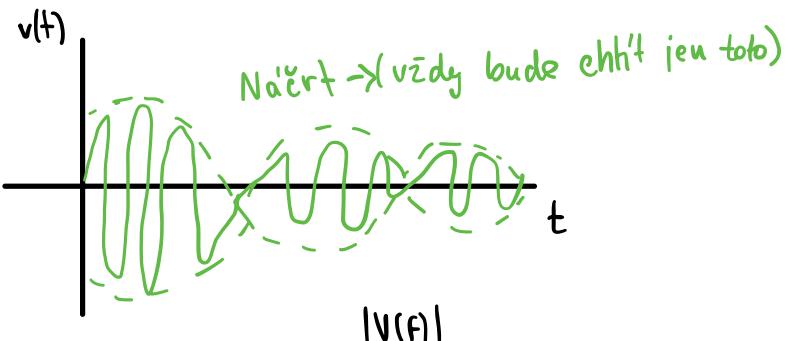
$$R(t) = \sqrt{m^2(t) + \hat{m}^2(t)}$$

$$\vartheta(t) = \arctg \frac{\pm \hat{m}(t)}{m(t)}$$



$$m(t) = 0.4 \cdot \cos\left(8\pi t - \frac{\pi}{3}\right)$$

USSB-SC $40\text{Hz} = F_c$



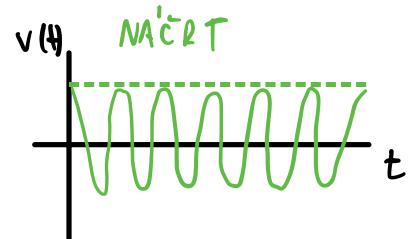
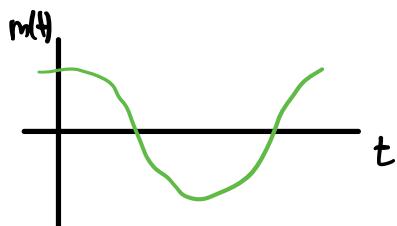
ÚHLOVÁ MODULACE

$$v(t) = R(t) \cdot \cos(\omega_c t + \Theta(t))$$

$$R(t) = C = 1$$

$$g(t) = e^{j D_p m(t)}$$

$$R(t) = 1$$



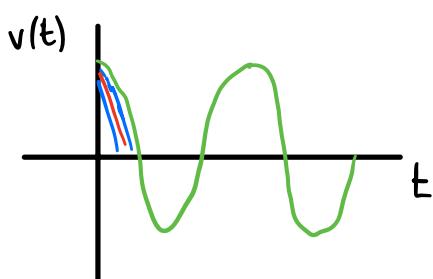
PM fázová

$$g(t) = e^{j D_p m(t)}$$

D_p ... index fázovej modulace

$$R(t) = 1$$

$$\Theta(t) = D_p \cdot m(t)$$



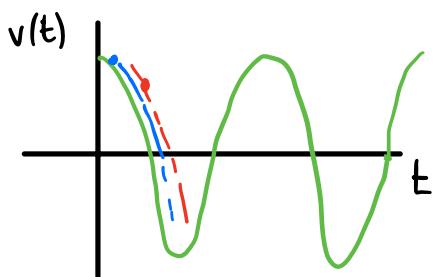
FM frekvenčná

$$g(t) = e^{j D_f \int_{-\infty}^{t_0} m(t) dt}$$

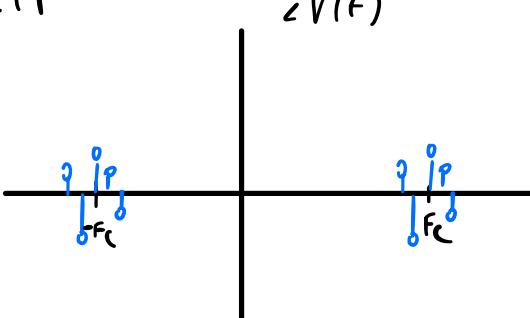
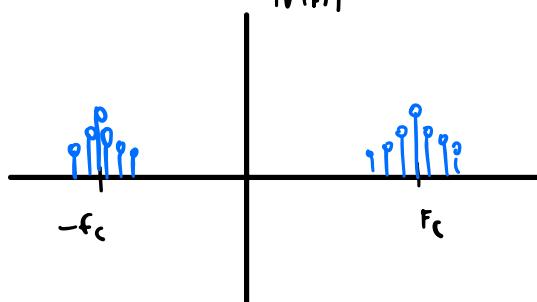
D_f ... index frekvenčnej modulace

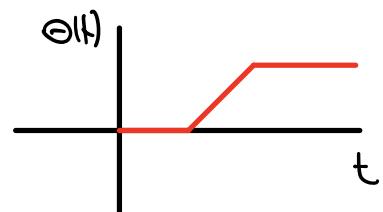
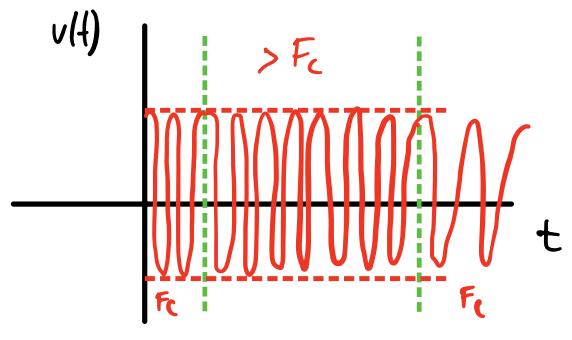
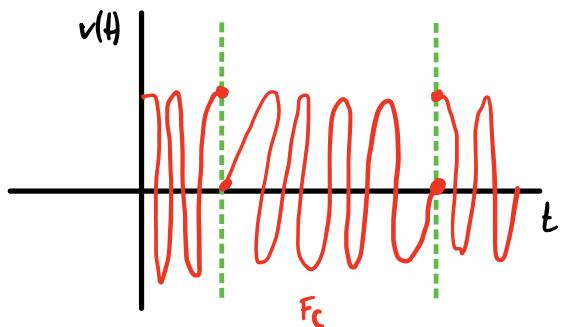
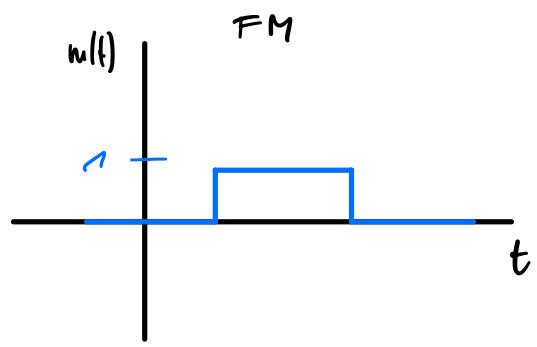
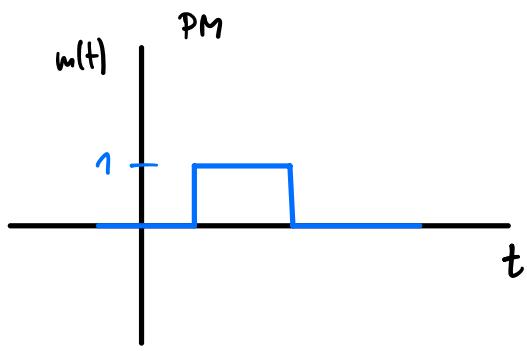
$$R(t) = 1$$

$$\Theta(t) = D_f \cdot \int_{-\infty}^{t_0} m(t) dt$$



NÁČRTY





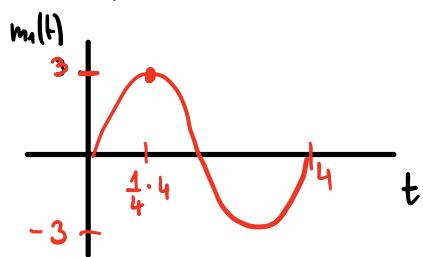
QPM MODULACE

$$m_1(t) = 3 \cos \left(\frac{\pi}{2}t - \frac{\pi}{2} \right) \quad m_2(t) = 5 \cos \left(\frac{\pi}{4}t + \frac{\pi}{3} \right)$$

$$g(t) = m_1(t) + j m_2(t)$$

$$R(t) = \sqrt{m_1^2(t) + m_2^2(t)}$$

$$\Theta(t) = \arctan \frac{m_2(t)}{m_1(t)}$$



$$M_{1,\max} = 3$$

$$\omega_1 = \frac{\pi}{2}$$

$$F_1 = \frac{1}{4}$$

$$T_1 = 4$$

$$\varphi_1 = -\frac{\pi}{2}$$

$$F_C = 10H_2$$

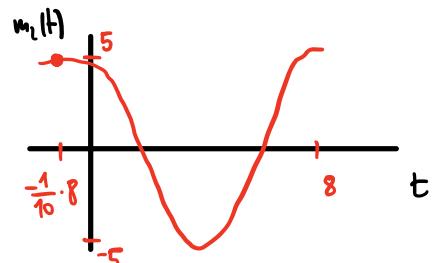
$$M_{2,\max} = 5$$

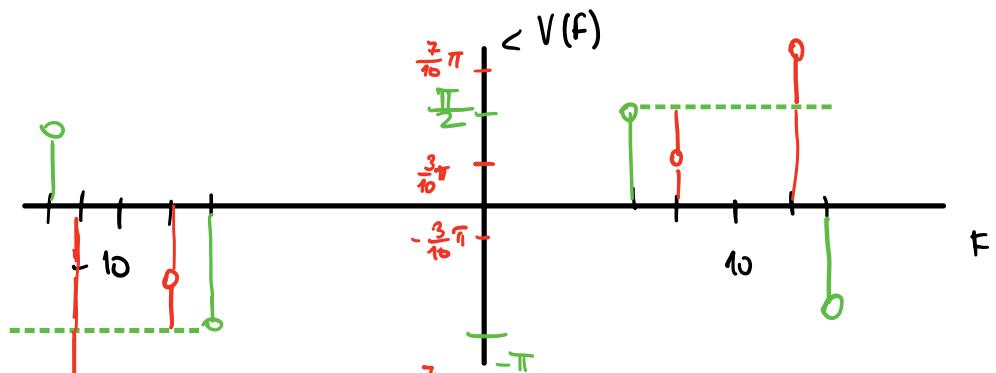
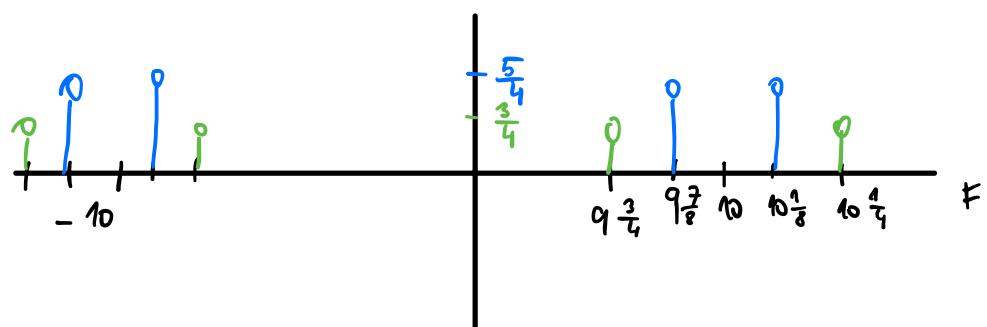
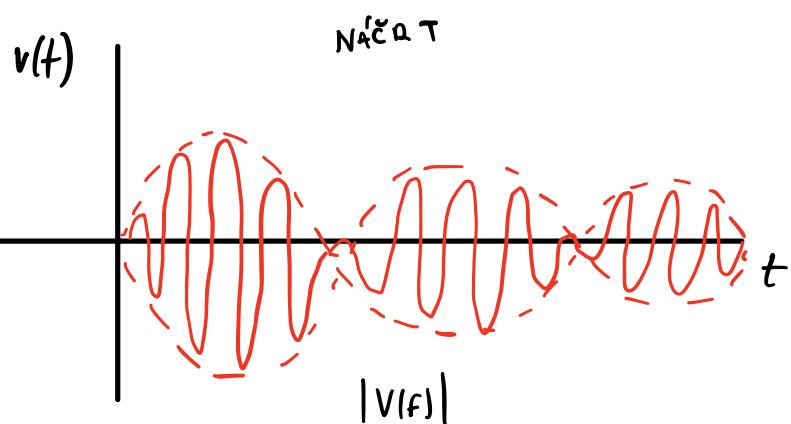
$$\omega_2 = \frac{\pi}{4}$$

$$F_2 = \frac{1}{8}$$

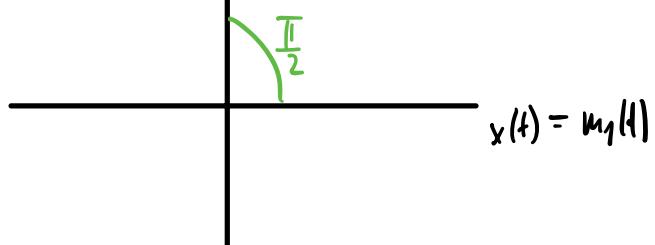
$$T_2 = 8$$

$$\varphi_2 = \frac{\pi}{5}$$

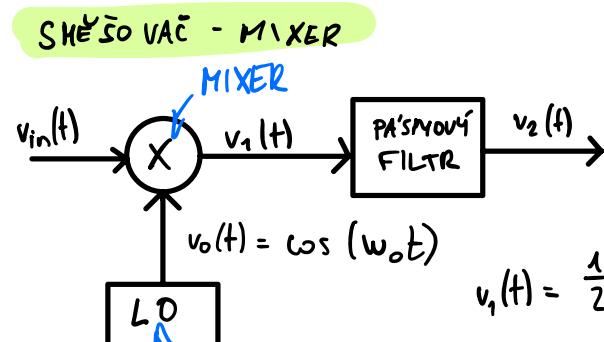




$$y(t) = m_2(t) g(t)$$



SYSTE'MY PRO ZPRACOVÁ'NI SIGHA'LU



$$v_{in}(t) = \operatorname{Re} \left\{ g(t) \cdot e^{i\omega t} \right\}$$

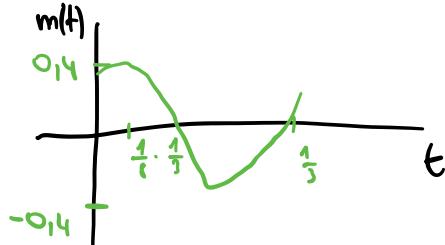
$$v_1(t) = \operatorname{Re} \left\{ g(t) \cdot e^{i\omega t} \right\} \cdot \cos(\omega_0 t)$$

$$v_1(t) = \frac{1}{2} \operatorname{Re} \left\{ g(t) \cdot e^{i(\omega_c + \omega_0)t} \right\} + \frac{1}{2} \operatorname{Re} \left\{ g^*(t) e^{i(\omega_c - \omega_0)t} \right\}$$

komplexné sdruženie

$$m(t) = 0,4 \cdot \cos \left(6\pi t - \frac{\pi}{4} \right)$$

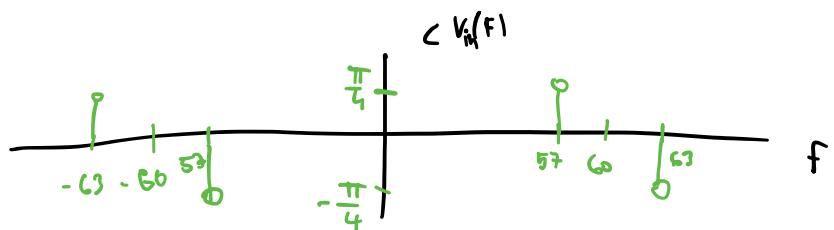
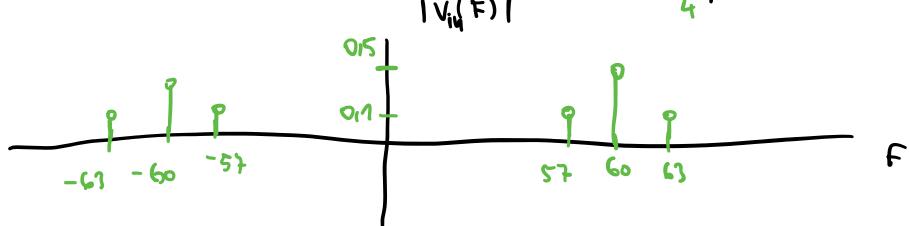
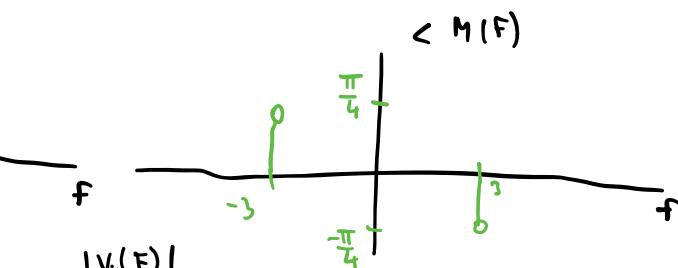
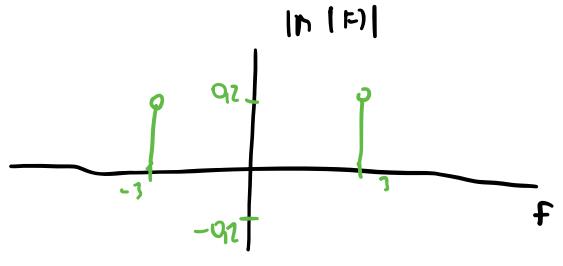
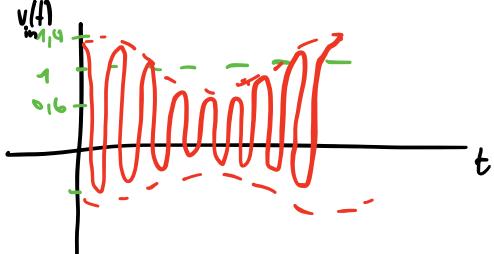
AM $f_c = 60 \text{ Hz}$ $f_o = 10 \text{ Hz}$

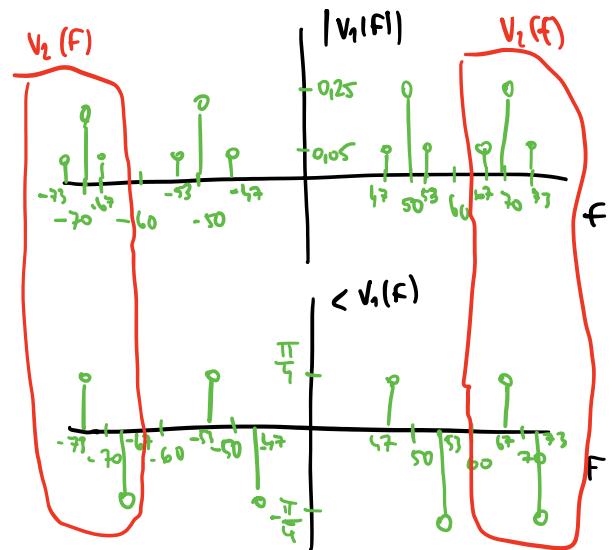
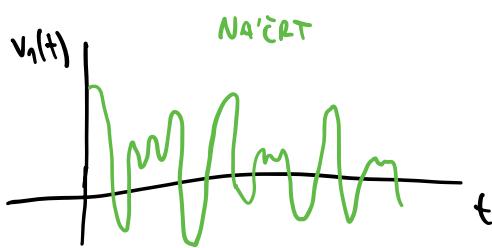


$$M_{\max} = 0,14 \quad \omega = 6\pi \quad f = 3 \quad T = \frac{1}{3}$$

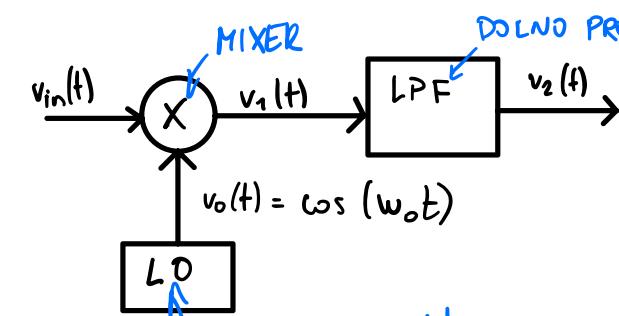
$$\varphi = -\frac{\pi}{4}$$

$$f_2 = 70 \text{ Hz}$$



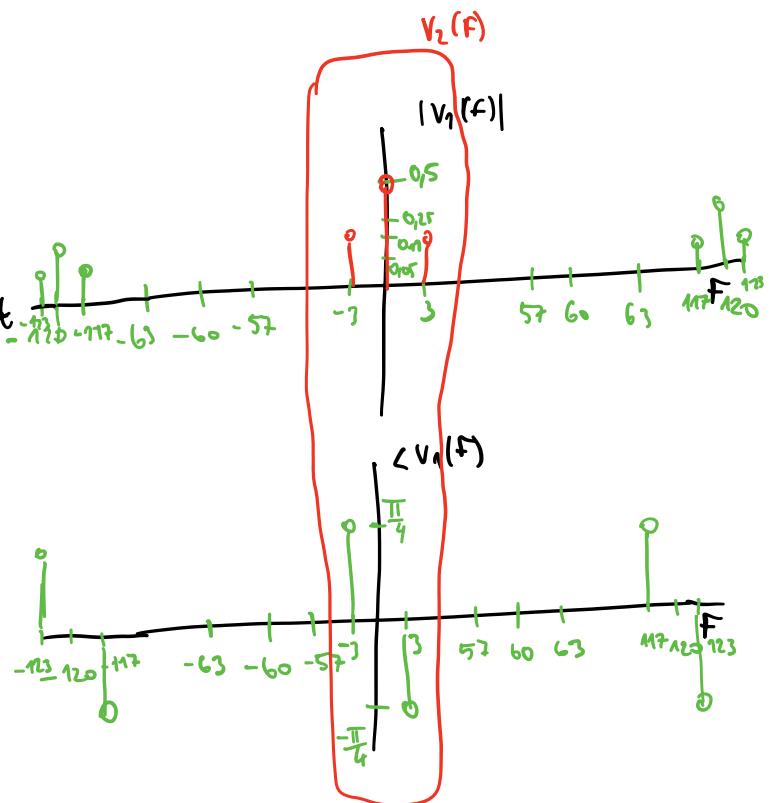
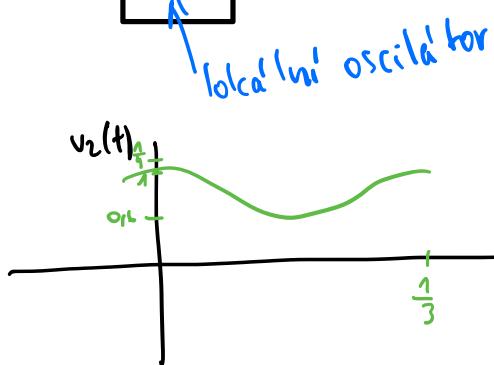


MULTIPLIKATIVNÍ PROJEKTOR

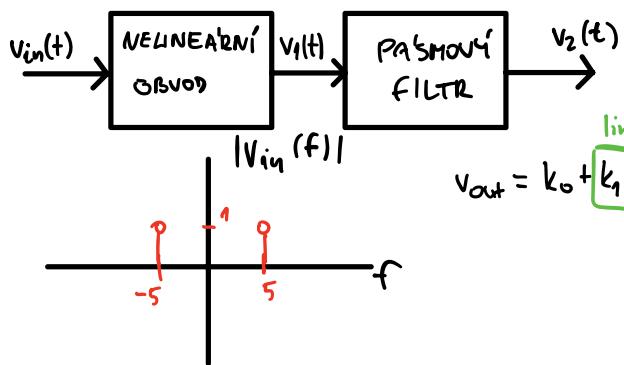


$$v_1(t) = R(t) \cdot \cos(\omega_c t + \Theta(t)) \cdot \cos(\omega_o t)$$

$$v_2(t) = \frac{1}{2} R(t)$$



NAJÍSBIČ FREKVENCE



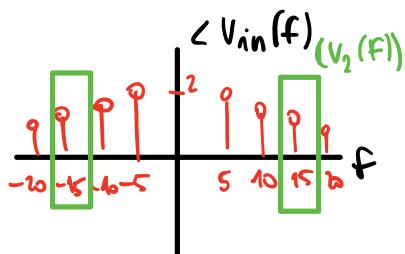
$$v_{in}(t) = R(t) \cdot \cos(\omega_c t + \Theta(t))$$

$$v_{in}(t) = C \cdot R^{\text{nonlinear}}(t) \cdot \cos(n \cdot \omega_c t + n \cdot \Theta(t))$$

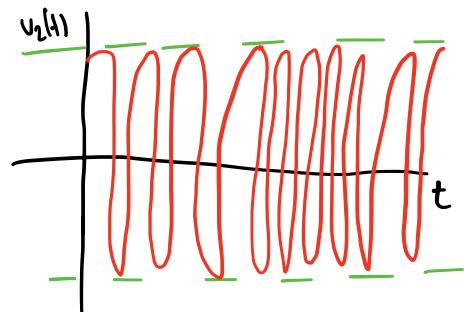
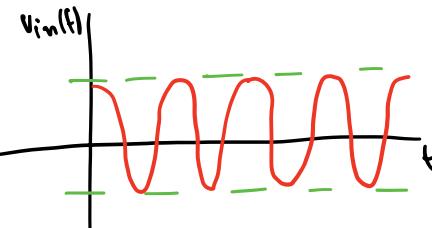
použití: 'ultra-linear amplitude modulation'

$$v_{out} = k_0 + k_1 v_{in} + k_2 v_{in}^2 + k_3 v_{in}^3 + \dots = \sum_{n=0}^{\infty} k_n \cdot v_{in}^n$$

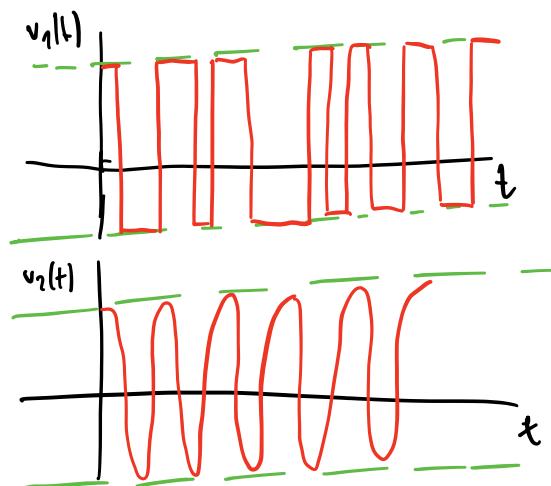
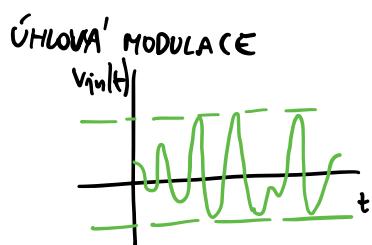
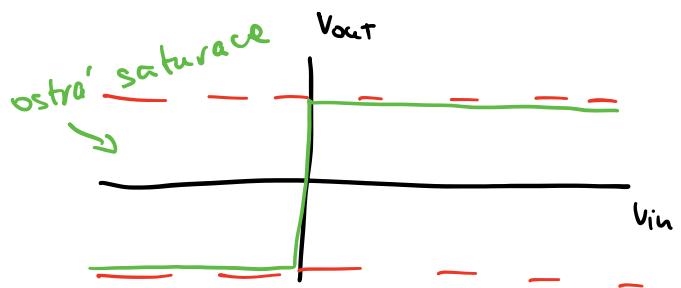
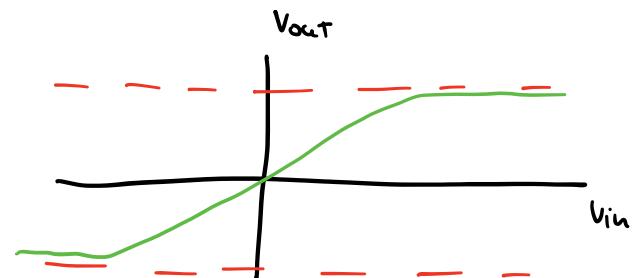
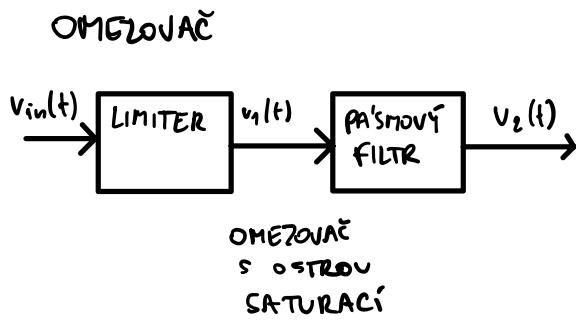
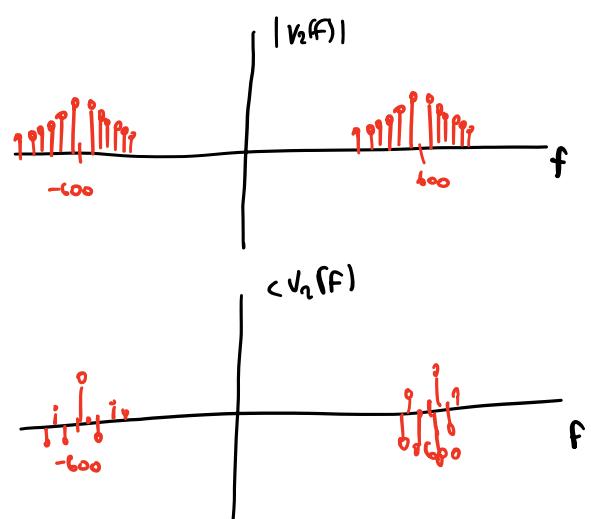
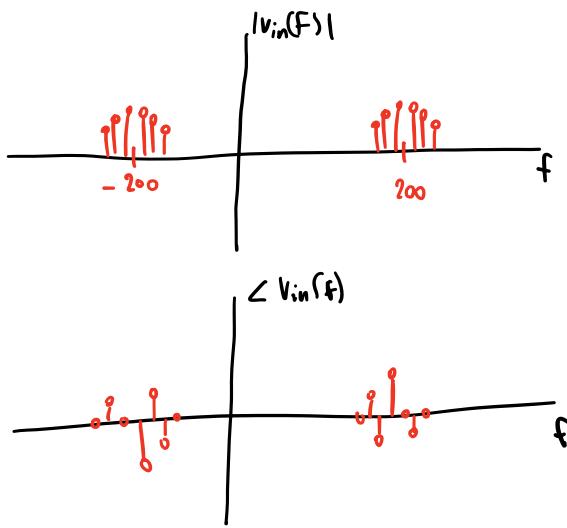
lineární



PŘÍKLAD



NÁČRTY

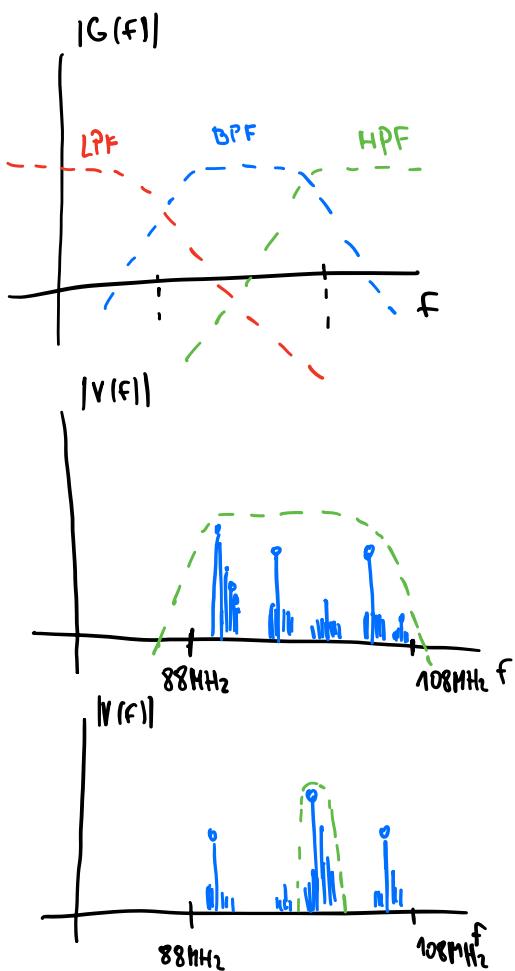


$$v_{in(t)} = R(t) \cos(\omega_c t + \Theta(t))$$

$$v_2(t) = k \cdot \cos(\omega_c(t) + \Theta(t))$$

FILTRY

- širokopa'smový BPF
- úzkopa'smový NBPF



ZESILOVACÉ

$$v_{out}(t) = A \cdot v_{in}(t) \quad \text{lineární zesilovač}$$

$$v_{out}(t) = k_0 + k_1 \cdot v_{in}(t) + k_2 \cdot v_{in}^2(t) + \dots + k_n v_{in}^n(t) \quad \text{ne-lineární}$$

THD

$$v_{in}(t) = A_0 \cos(\omega_0 t)$$

$$v_{out}(t) = v_0 + \frac{|V_{in}(f)|}{|V_{out}(f)|} v_1 \cos(\omega_0 t + \varphi_1) + v_2 \cos(2\omega_0 t + \varphi_2) + \dots + v_n \cos(n\omega_0 t + \varphi_n)$$



$$\text{THD} = \sqrt{\sum_{n=2}^{\infty} v_n^2} / v_1 \cdot 100 \%$$

IMD

$$v_{in}(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)$$

$$k_1(A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t))$$

$$k_2(A_1^2 \cos^2(\omega_1 t) + A_2^2 \cos^2(\omega_2 t)) \approx 2 \cdot A_1 \cdot A_2 \cos(\omega_1 t) \cdot \cos(\omega_2 t)$$

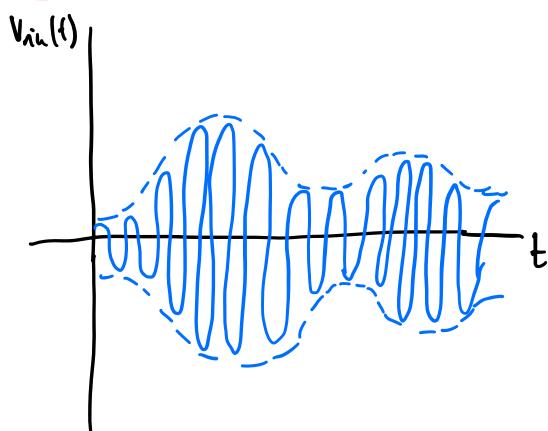
$$= A^2 + 2AB + B^2$$

$$= A^2 + 2AB^2 + 2A^2B + B^3$$

$$(A+B)^2$$

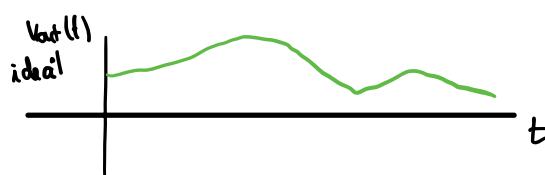
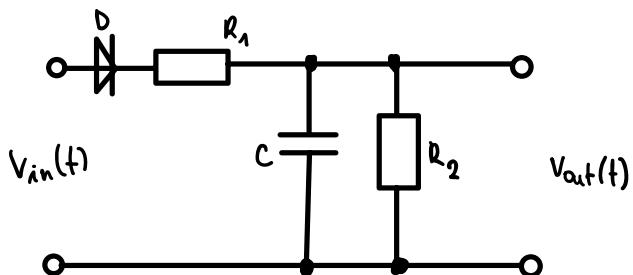
$$(A+B)^3$$

DETEKTOR OBRAČKY

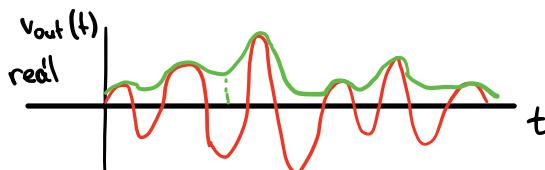


$$v_{in}(t) = R(t) \cdot \cos(\omega_c t + \Theta(t))$$

$$v_{out}(t) = k \cdot R(t)$$



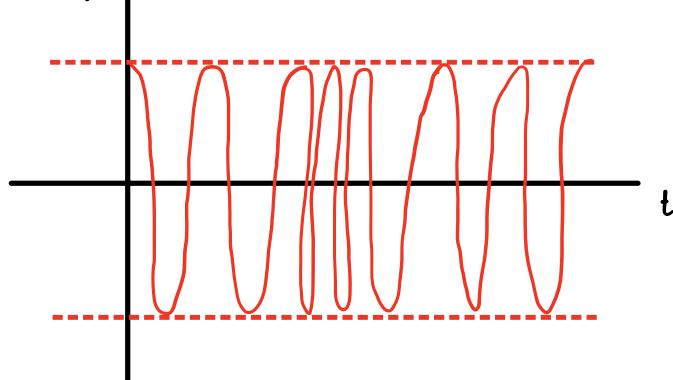
— kondenzátor se vybije
— signál



DETEKTOR FM SIGNALU

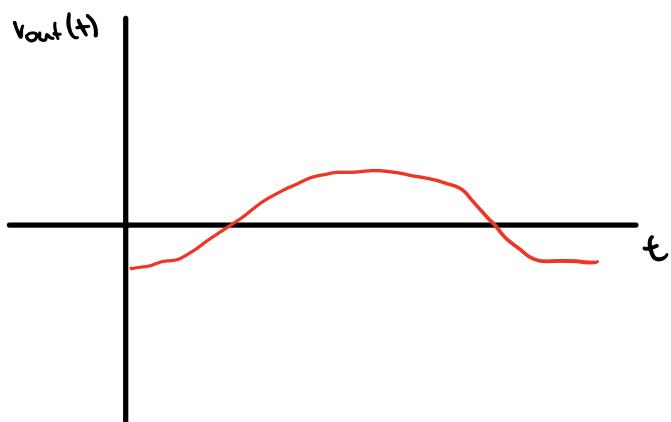
$$v_{in}(t) = R(t) \cdot \cos(\omega_c t + \Theta(t))$$

$$v_{in}(t)$$



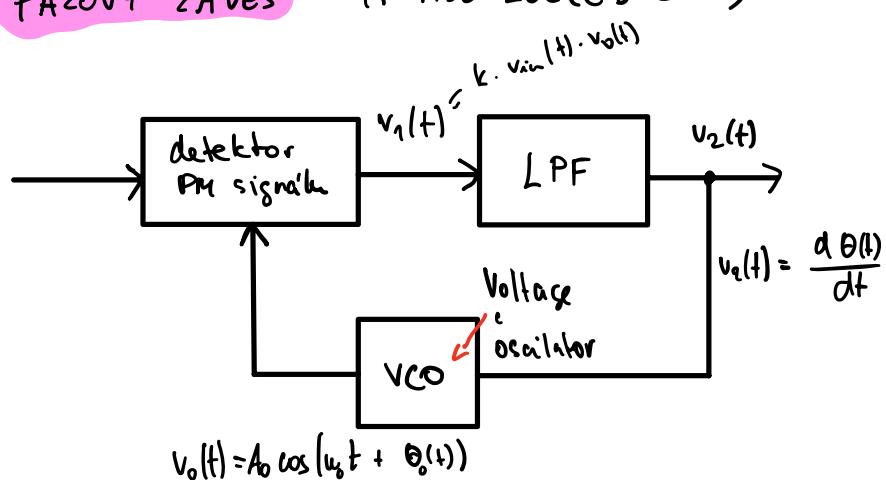
$$v_{out}(t) \approx k \cdot \frac{d\Theta(t)}{dt}$$

- konverze FM - AM
- průchod nutku
- určení fázového posunu



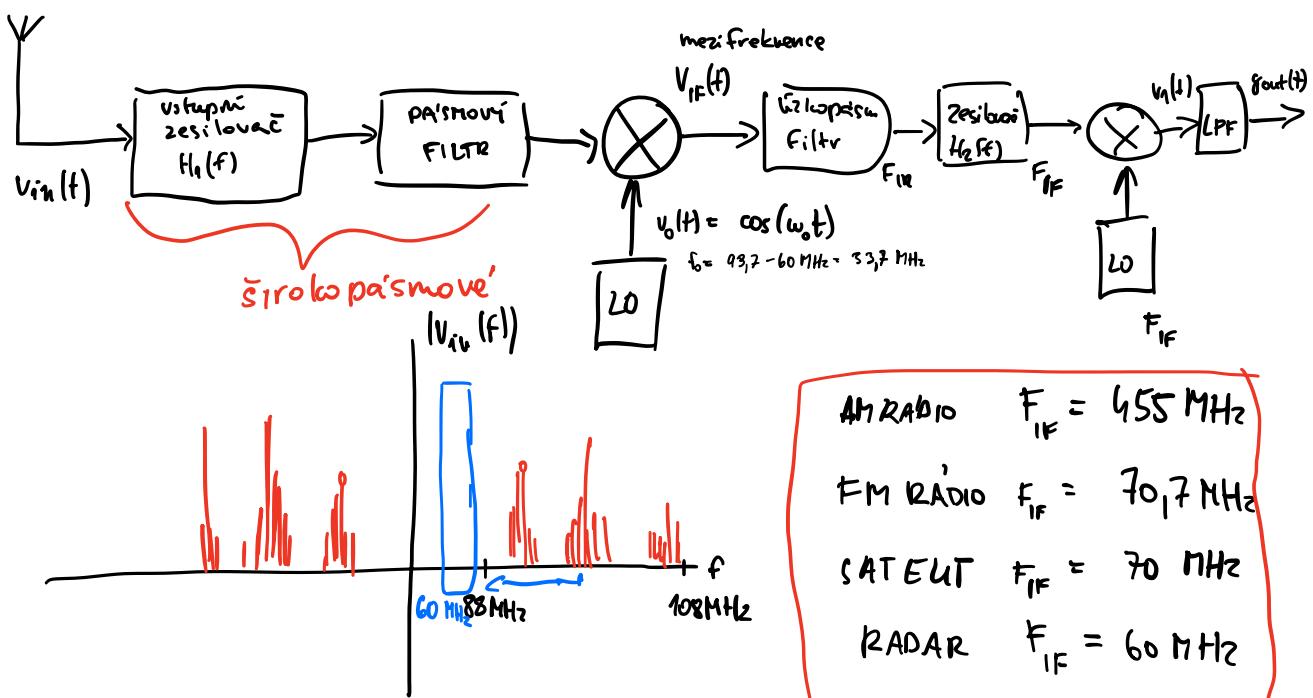
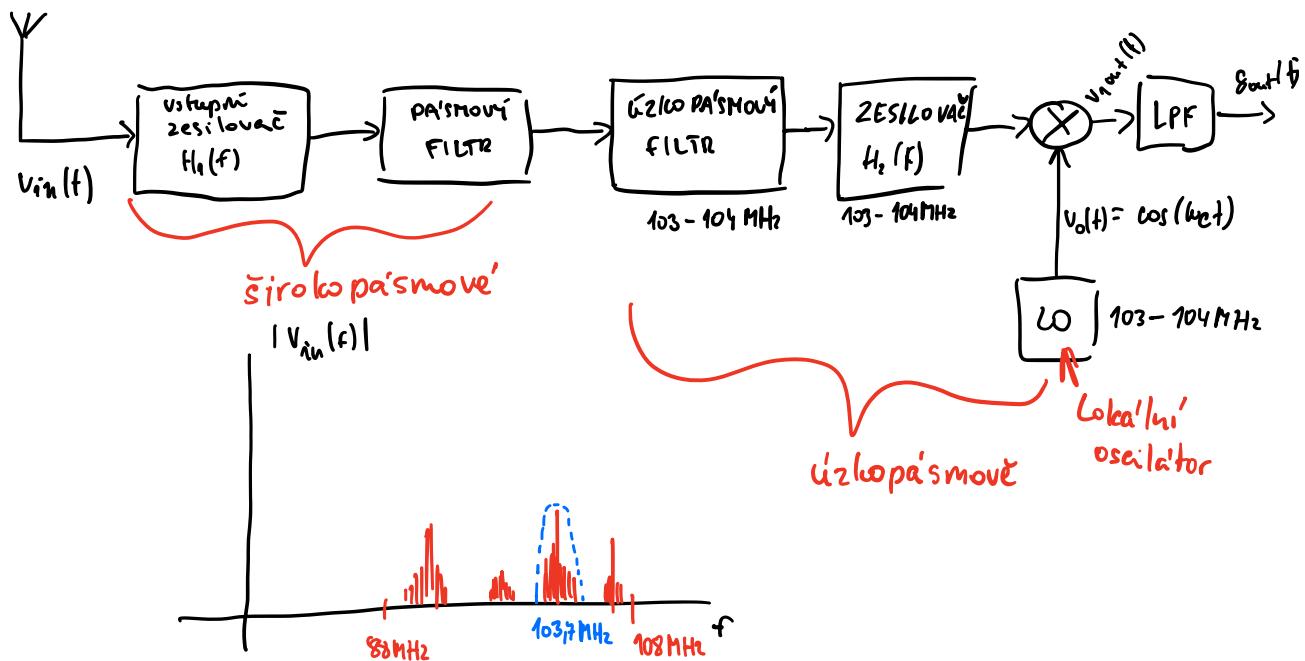
FÁZOVÝ ZA'VĚS

(PHASE LOCKED LOOP)



PŘIJÍMAC

- kaskádové (a dělný)
- super heterodyne



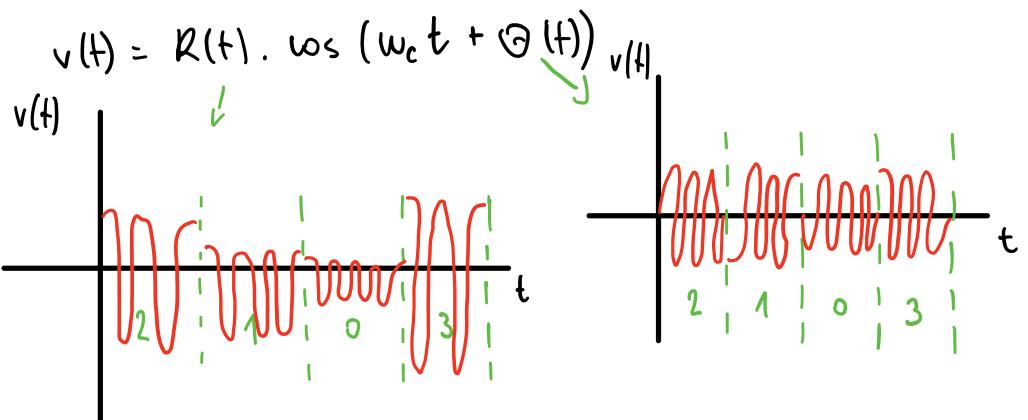
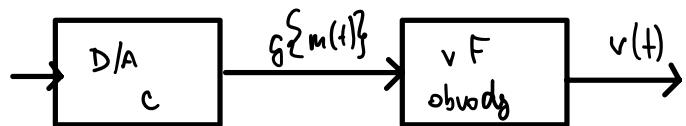
$$m(t) = 0.7 \cdot \cos \left(4\pi t - \frac{\pi}{3} \right) \text{ Am}$$

$$f_c = 60 \text{ Hz}$$

$$f_{IF} = 25 \text{ Hz}$$

DIGITÁLNÍ ZPRACOVÁNÍ PAŠMOVÉHO SIGNALU

$$m(t) \in \{1,0,1,1,0\} \quad v(t) = \operatorname{Re} \left\{ g(t) \cdot e^{jw_c t} \right\}$$



bitová rychlosť

$$R = \frac{1}{T_b} \quad [\text{bit} \cdot \text{s}^{-1}]$$

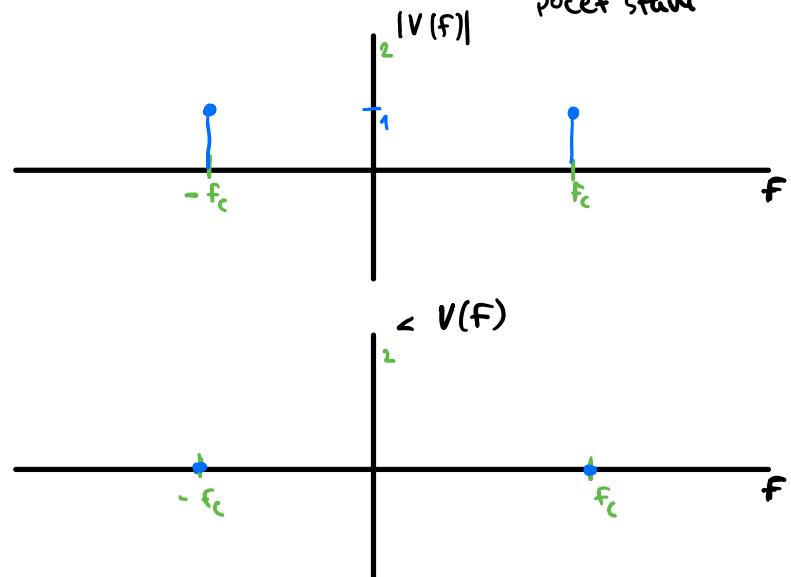
T_b ... prenos 1 bitu - perioda [s]

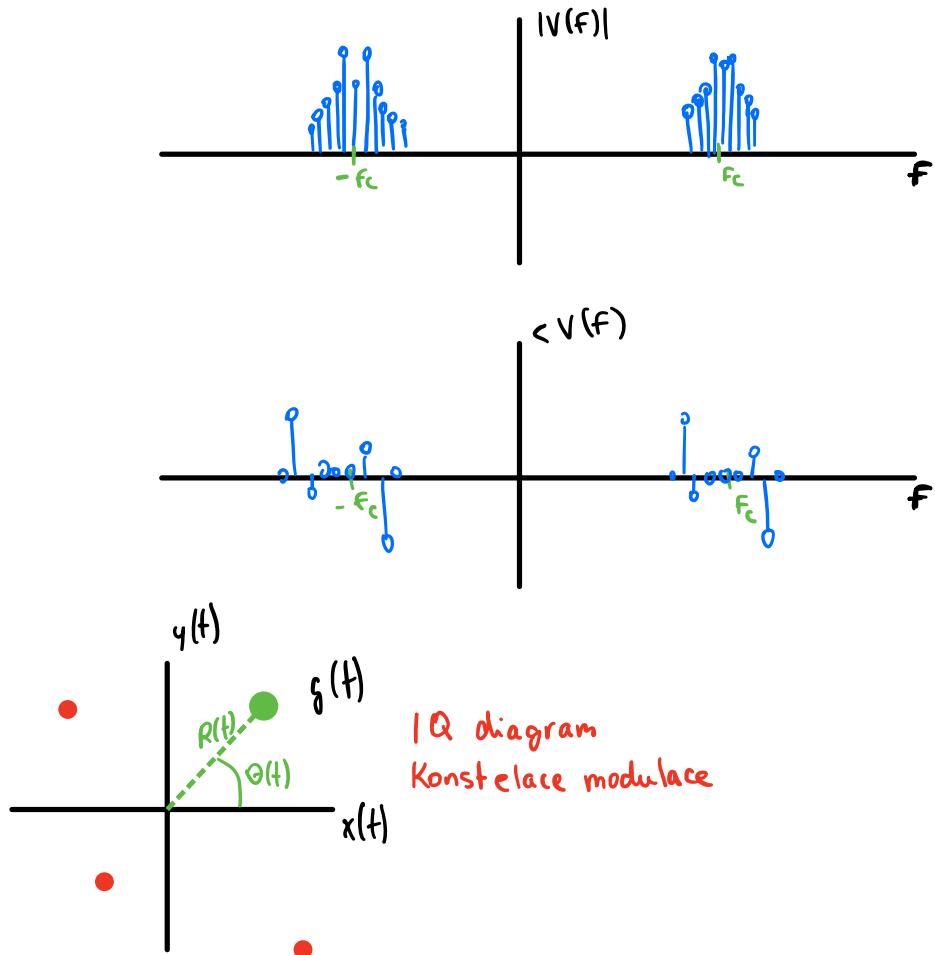
rychlosť prenosu

$$D = \frac{R}{n} \quad [\text{digit} \cdot \text{s}^{-1}]$$

n ... počet bitov

$$M = 2^n \quad \begin{matrix} \text{počet stav} \\ \text{u} \end{matrix}$$

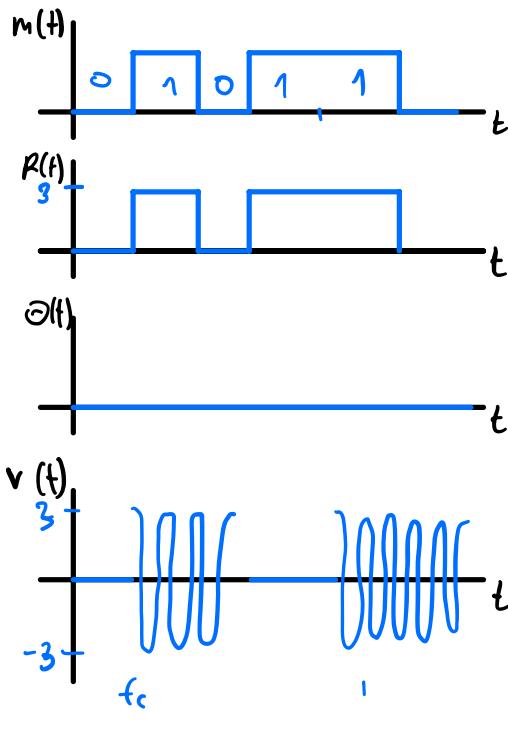
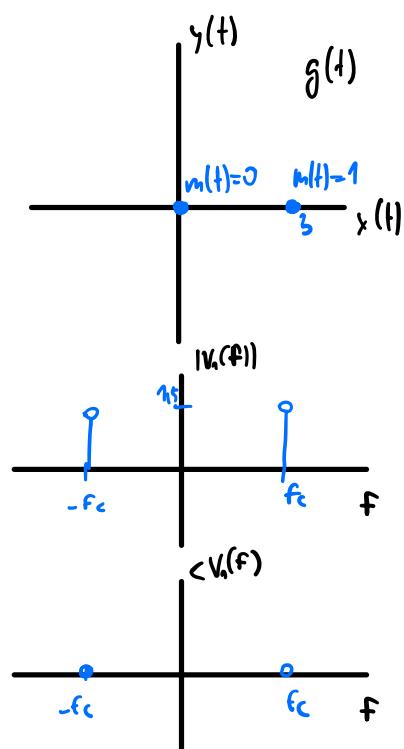




- BINARNÍ ZPRACOVÁNÍ SIGNALU
BINARY SIGNALING 0, 1, 0, 1, 1, 1, 1, 1
- VÍCE STAVOVÉ ZPRACOVÁNÍ SIGNALU
MULTILEVEL SIGNALING 5 1 15 1

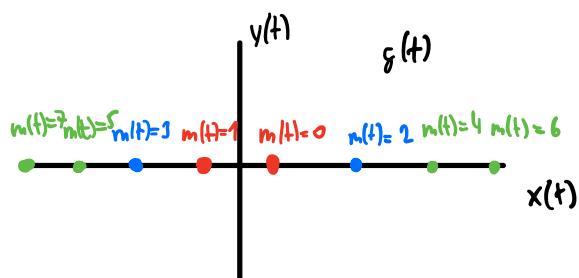
MODULACE

ON-OFF KEYING
KLÍČOVÁNÍ



ASK - AMPLITUDOVÉ KLÍČOVÁNÍ

$$d_n \in \{ \pm 1, \pm 3, \pm 5, \pm 7 \}$$



2-ASK binární

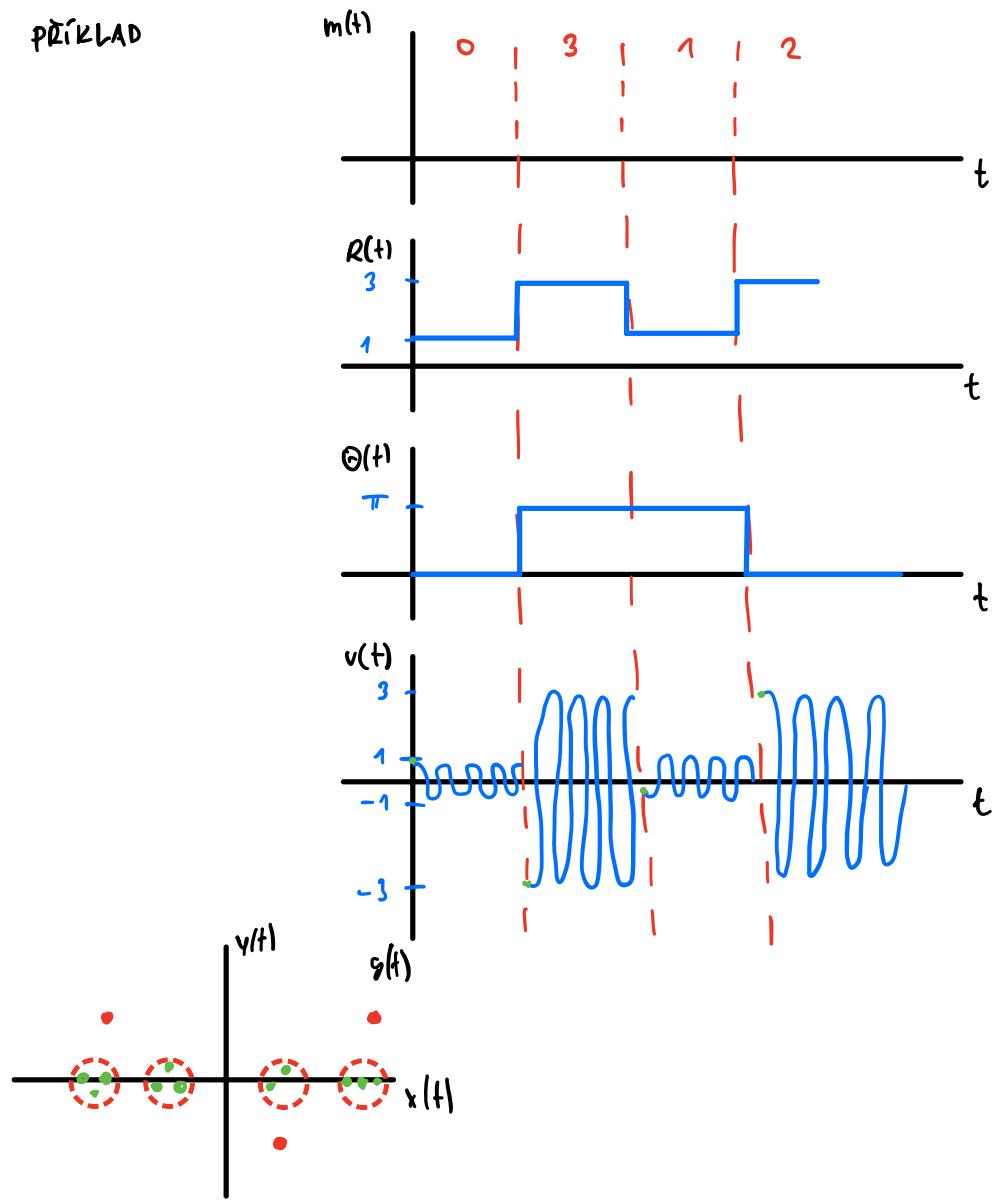
4-ASK

8-ASK

⋮

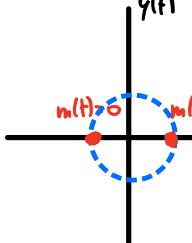
M-ASK

PŘÍKLAD

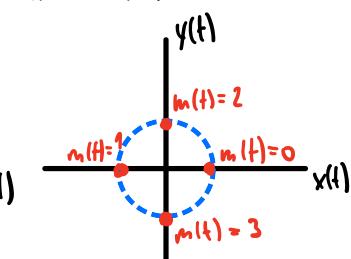


PSK - fazové kódování

B-PSK
 $d_n \in \{1, -1\}$

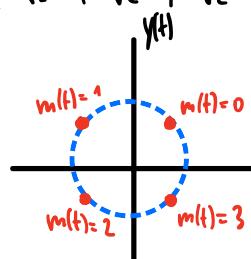


4PSK



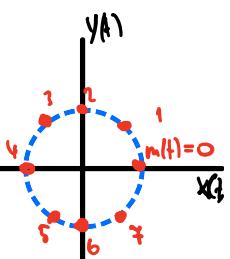
Q-PSK

$$d_n \in \left\{ \frac{1+i}{\sqrt{2}}, \frac{1-i}{\sqrt{2}}, \frac{-1+i}{\sqrt{2}}, \frac{-1-i}{\sqrt{2}} \right\}$$



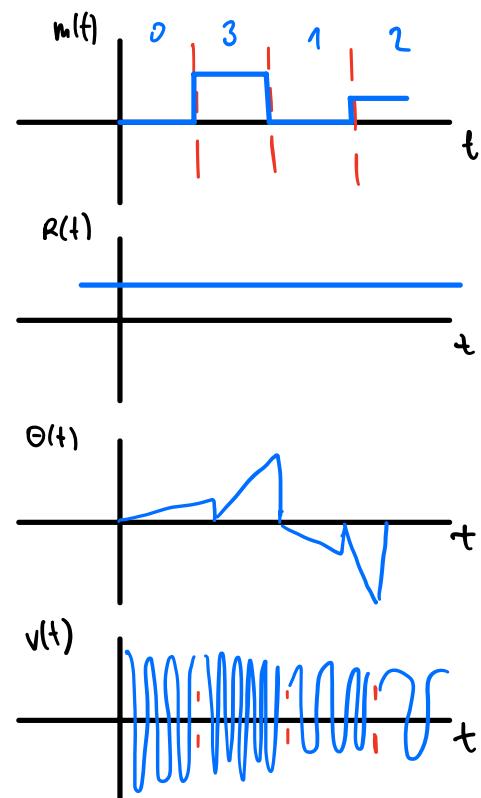
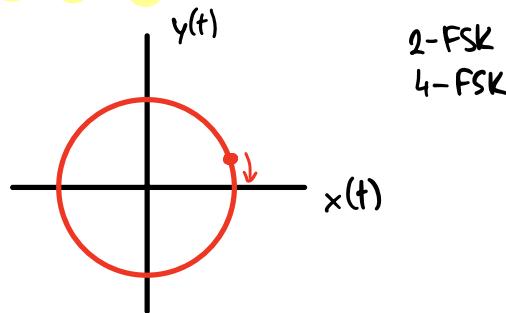
8-PSK

$$d_n \in d_n \cdot 4\text{-PSK} + d_n \cdot Q\text{-PSK}$$



DPSK

FSK - frekvenční klíčování



Pokračování = PB

QAM - Kvadraturní amplitudová modulace

4-QAM

16-QAM

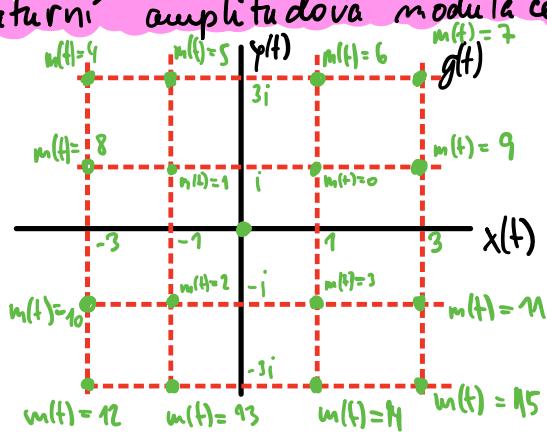
32-QAM

64-QAM

:

256-QAM

:

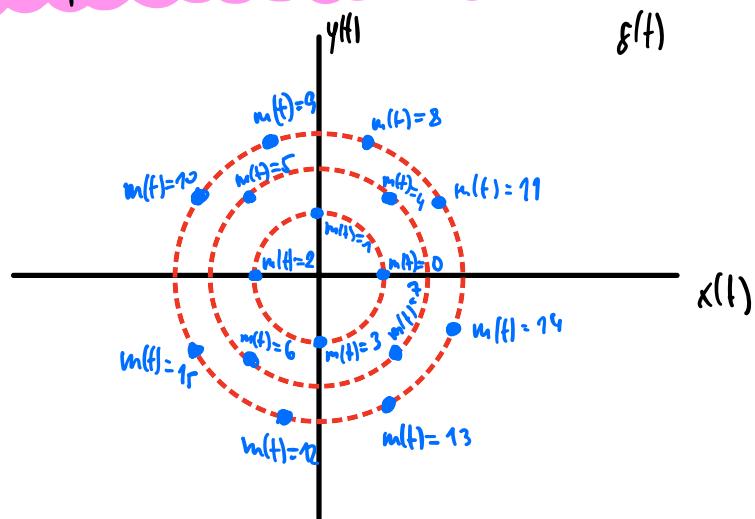


APSK - Amplitudově fazové kódování

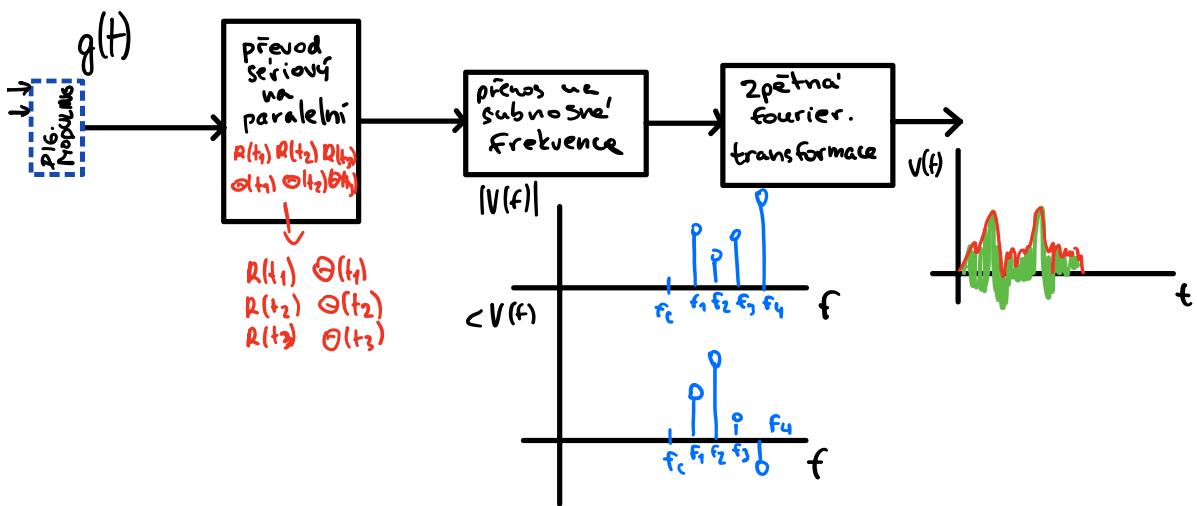
8-APSK

16-APSK

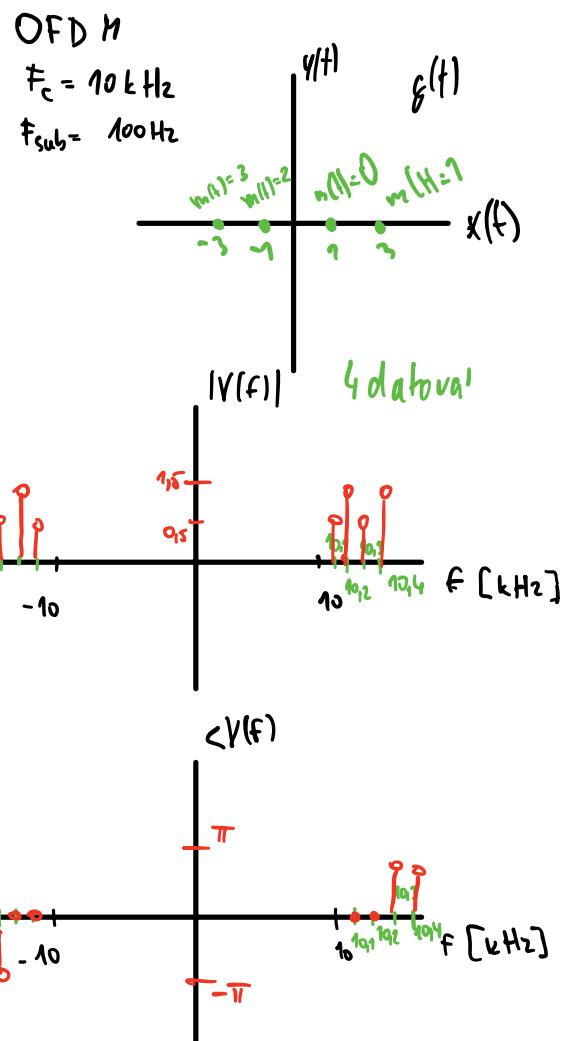
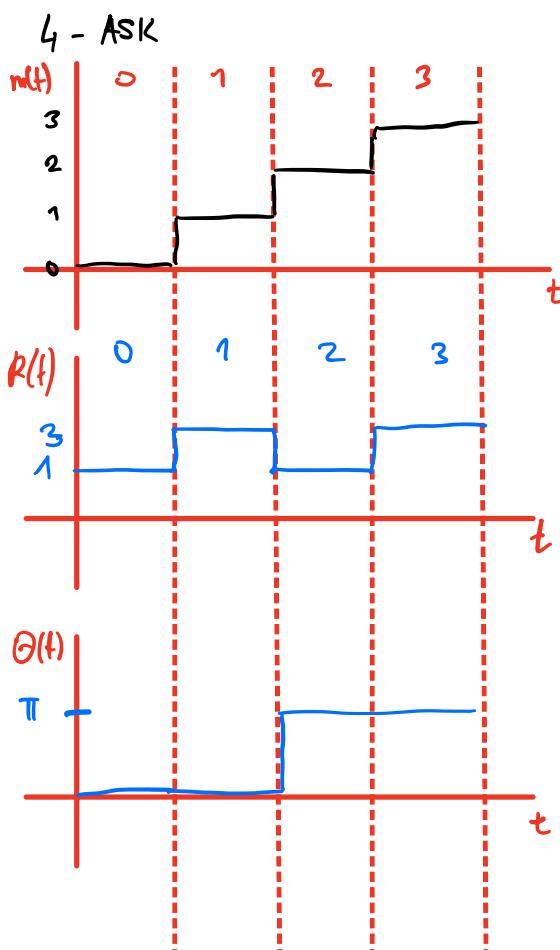
:

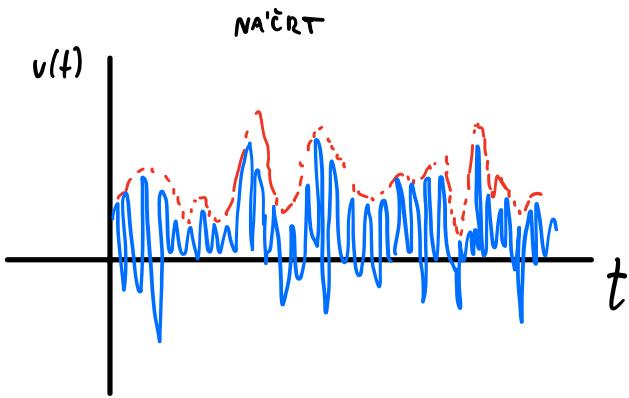


OFDM - Orthogonal frequency division multiplexing



Příklad





vf

2,4 GHz
5,86 GHz
wifi, bluetooth

v průmyslu
ZIGBEE
Sigfox
LoRa IoT

Broadcasting

TV	OFDM
DVB-T T2	pozemní QPSK - 64 QAM 8L → 256QAM 16L, 32L
DVB-S S2	satelitní QPSK 8PSK, 16PSK, 32PSK
DVB-C	babylon 16, 32, 256 QAM

DAB, DAB⁺ DQPSK

mpeg 2

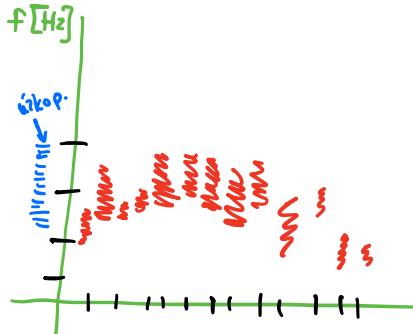
mpeg 4

reed-solomonov kód

FEC 1 vnitřní
FEC 2 vnější

Analyza a parametry zvukového signálu

- mikrofón
- akustické kamery
- vibrační senzory
- hlukoměr



Zpracování

- Filtrace
- FT
- Spektrogram
 - širokopásmové detailní
 - úzkopásmové 5-10 ms
- křížová korelace
- rytmus signálu
- kepspektrální analýza
- oktafonická analýza
- waveletová analýza

Analyza

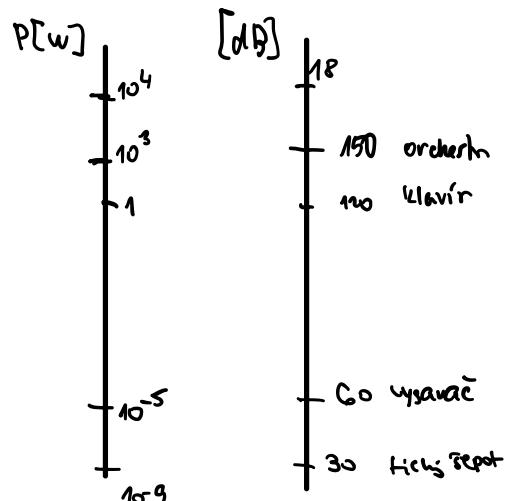
- nízka - oscilace, energie, těžistě, počet průtoků muzik
- střední - množství význam - nota, rytmus, výškovatona
- vysoká - tónina, akordy, melodie

$$L_w = 10 \log \cdot \frac{P}{P_0} \quad [\text{dB}]$$

informační $P_0 = 10^{-12}$

$$L_p = 20 \log \frac{P}{P_0} \quad [\text{dB}]$$

$P_0 = 2 \cdot 10^{-5} \text{ Pa}$



Generování a analýza řeči

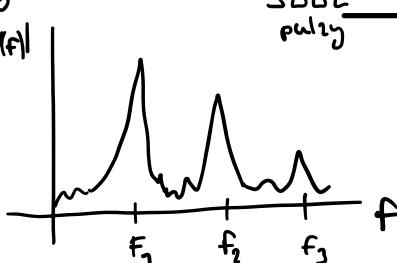
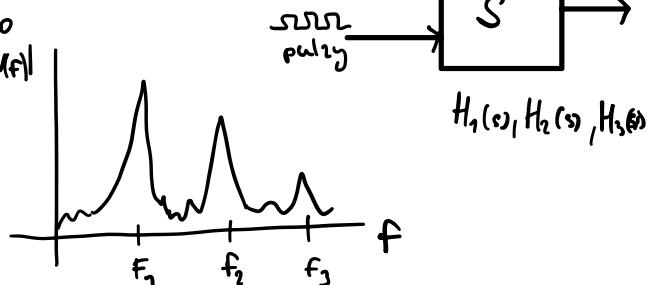
| 30ms |
| 10ms |

základní dominantní frekvence F_0

duté 300-400 Hz

muz 120 Hz

žena 210 Hz

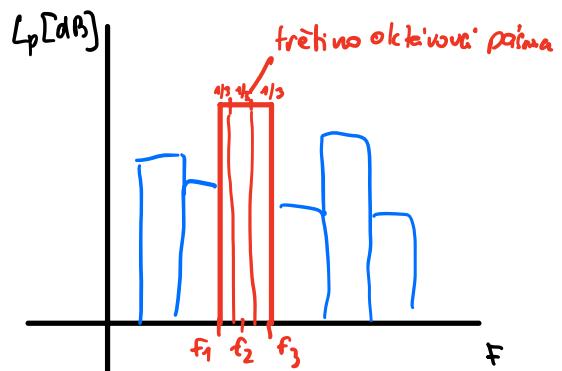


OKTAVOVÁ FREKVENCNÍ ANALÝZA

10 oktav

$$\frac{f_2}{f_1} = 2$$

f_m	f_1	f_2	f_c	f_i
31,5	22	44	22	2,8
63	44	88	28	35
125	88	176	3,5	44
250	176	353		
500	353	707		
1000	707	1414		



KEPSTRALNÍ ANALÝZA

- analýza řeči

