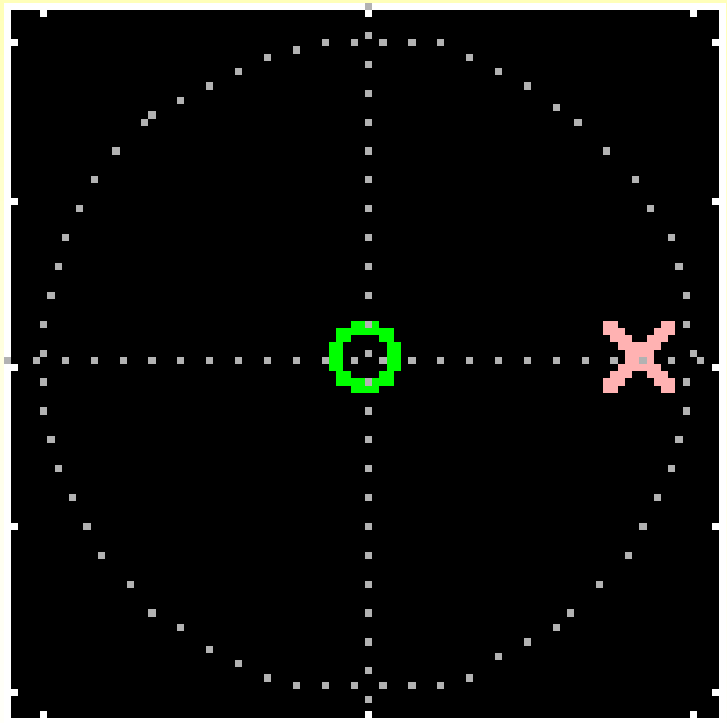
A7B31ZZS – 6. PŘEDNÁŠKA

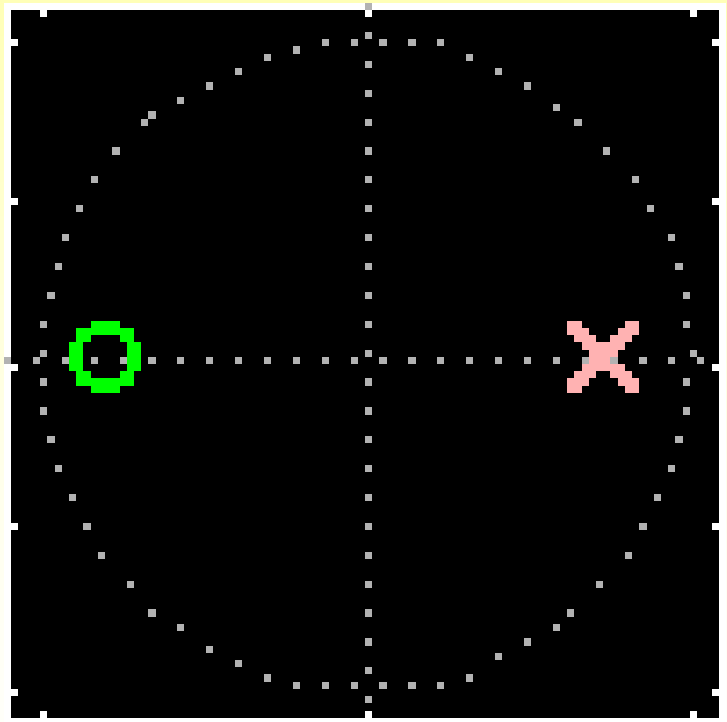
27. října 2014

- Číslicové IIR filtry vyšších řádu
  - **filtry se dvěma póly**
  - **(**filtry s více póly)
  - **řazení filtrů**
- Aplikace
  - **banka filtrů (rezonátorů)**
  - **filtrační syntézy s časově prom. filtry**
  - **formantové syntézy (samohlásky, nástroje)**
  - **potlačení šumů**

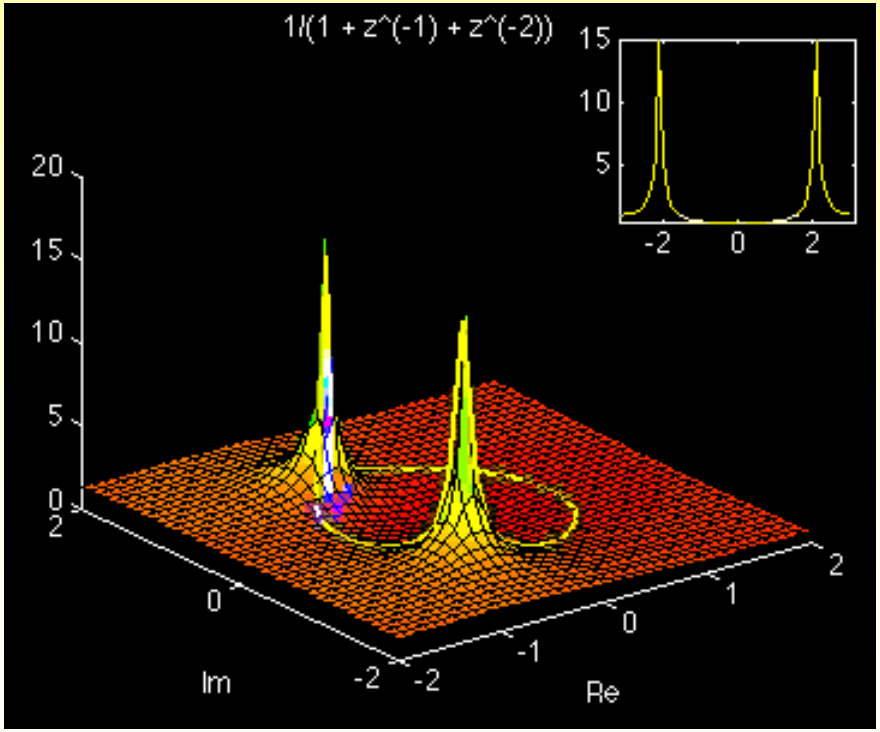
IIR filtr s jedním pólem
(pohyb pólu po reálné ose)



IIR filtr s jedním pólem a jednou nulou
(pohyb nuly a pólu po reálné ose)



Filtr se dvěma póly - rezonátor



Filtr se dvěma póly

pásmová propust IIR

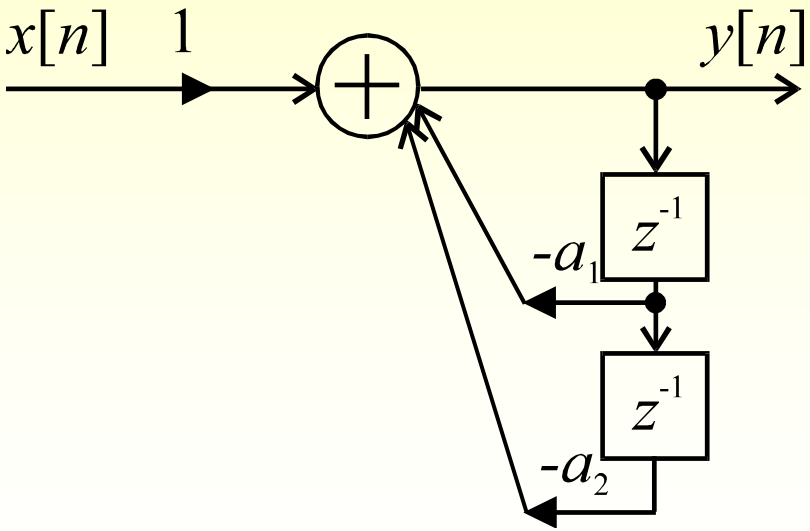
$$y[n] = x[n] - a_1 y[n-1] - a_2 y[n-2]$$

$$H(z) = \frac{z^2}{\left(z - re^{j\Theta_0}\right)\left(z - re^{-j\Theta_0}\right)} = \frac{1}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

$$\Theta_0 = 2\pi \frac{f_0}{f_s}$$

$$a_1 = -2r\cos\Theta_0$$

$$a_2 = r^2$$



Filtr se dvěma póly

pásmová propust IIR

$$H(z) = \frac{z^2}{\left(z - re^{j\Theta_0}\right)\left(z - re^{-j\Theta_0}\right)} = \frac{z^2}{z^2 - zre^{-j\Theta_0} - zre^{j\Theta_0} + r^2}$$

Filtr se dvěma póly

pásmová propust IIR

$$H(z) = \frac{z^2}{\left(z - re^{j\Theta_0}\right)\left(z - re^{-j\Theta_0}\right)} = \frac{z^2}{z^2 - zre^{-j\Theta_0} - zre^{j\Theta_0} + r^2} =$$

$$= \frac{z^2}{z^2 - zr\left(\cos\Theta_0 - j\sin\Theta_0 + \cos\Theta_0 + j\sin\Theta_0\right) + r^2}$$

Filtr se dvěma póly

pásmová propust IIR

$$H(z) = \frac{z^2}{\left(z - re^{j\Theta_0}\right)\left(z - re^{-j\Theta_0}\right)} = \frac{z^2}{z^2 - zre^{-j\Theta_0} - zre^{j\Theta_0} + r^2} =$$

$$= \frac{z^2}{z^2 - zr\left(\cos\Theta_0 - j\sin\Theta_0 + \cos\Theta_0 + j\sin\Theta_0\right) + r^2} =$$

$$= \frac{z^2}{z^2 - 2r\cos\Theta_0 z + r^2}$$

Filtr se dvěma póly

pásmová propust IIR

$$H(z) = \frac{z^2}{\left(z - re^{j\Theta_0}\right)\left(z - re^{-j\Theta_0}\right)} = \frac{z^2}{z^2 - zre^{-j\Theta_0} - zre^{j\Theta_0} + r^2} =$$

$$= \frac{z^2}{z^2 - zr\left(\cos\Theta_0 - j\sin\Theta_0 + \cos\Theta_0 + j\sin\Theta_0\right) + r^2} =$$

$$= \frac{z^2}{z^2 - 2r\cos\Theta_0 z + r^2} = \frac{z^2}{z^2 + a_1 z + a_2}$$

Filtr se dvěma póly

pásmová propust IIR

$$H(z) = \frac{z^2}{\left(z - re^{j\Theta_0}\right)\left(z - re^{-j\Theta_0}\right)} = \frac{z^2}{z^2 - zre^{-j\Theta_0} - zre^{j\Theta_0} + r^2} =$$

$$= \frac{z^2}{z^2 - zr\left(\cos\Theta_0 - j\sin\Theta_0 + \cos\Theta_0 + j\sin\Theta_0\right) + r^2} =$$

$$= \frac{z^2}{z^2 - 2r\cos\Theta_0 z + r^2} = \frac{z^2}{z^2 + a_1 z + a_2}$$

$$\Theta_0 = 2\pi\frac{f_0}{f_s} \qquad a_1 = -2r\cos\Theta_0$$

$$a_2 = r^2$$

Filtr se dvěma póly

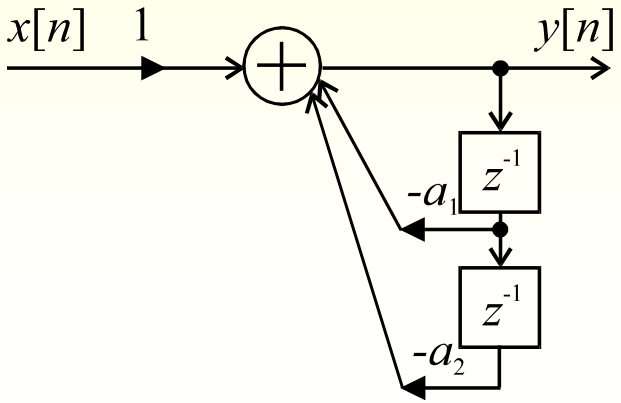
pásmová propust IIR

$$H(z) = \frac{z^2}{\left(z - re^{j\Theta_0}\right)\left(z - re^{-j\Theta_0}\right)} = \frac{z^2}{z^2 - zre^{-j\Theta_0} - zre^{j\Theta_0} + r^2} =$$

$$= \frac{z^2}{z^2 - zr\left(\cos\Theta_0 - j\sin\Theta_0 + \cos\Theta_0 + j\sin\Theta_0\right) + r^2} =$$

$$= \frac{z^2}{z^2 - 2r\cos\Theta_0 z + r^2} = \frac{z^2}{z^2 + a_1 z + a_2} = \frac{1}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

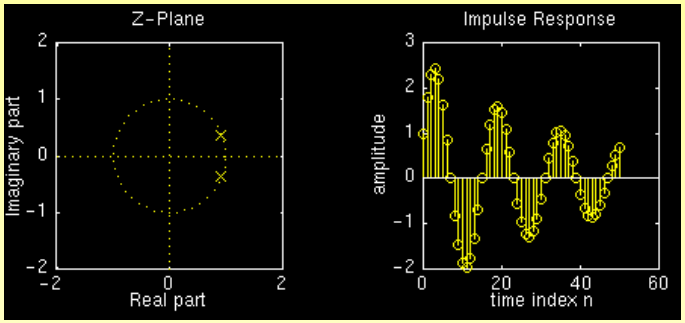
$$\Theta_0 = 2\pi \frac{f_0}{f_s} \qquad a_1 = -2r\cos\Theta_0 \qquad a_2 = r^2$$



Filtr se dvěma póly
(tlumené oscilace)

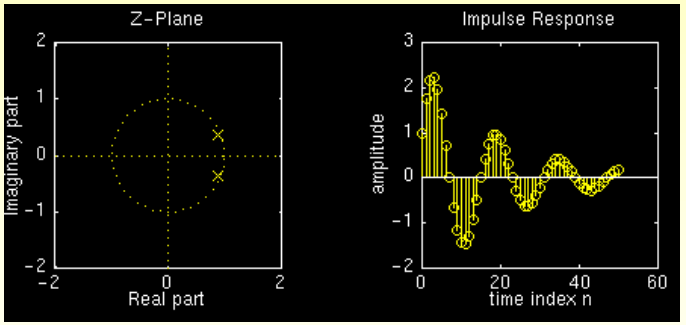
$$\Theta_0 = \frac{\pi}{8}$$

$$r = 0{,}975$$



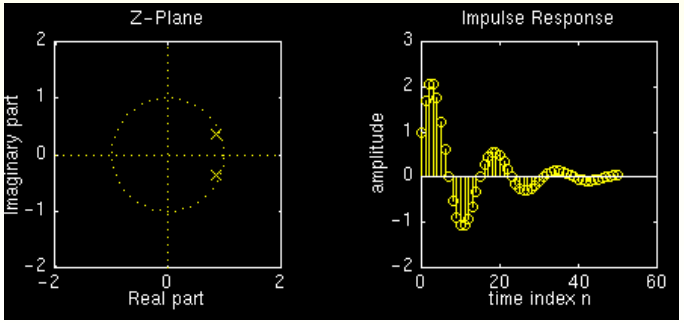
$$\Theta_0 = \frac{\pi}{8}$$

$$r = 0{,}95$$



$$\Theta_0 = \frac{\pi}{8}$$

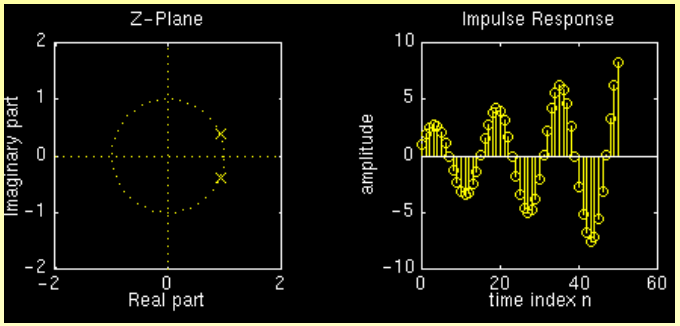
$$r = 0{,}925$$



Filtr se dvěma póly - rezonátor
(netlumené oscilace)

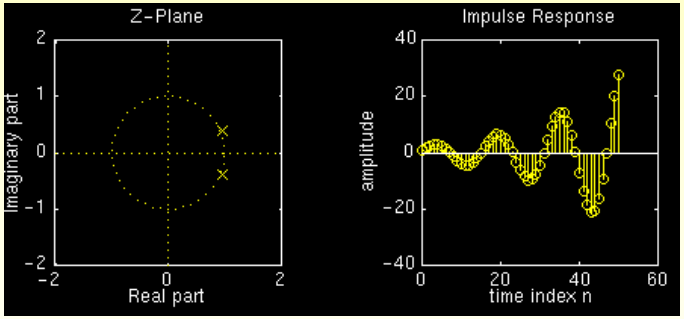
$$\Theta_0 = \frac{\pi}{8}$$

$$r = 1{,}025$$



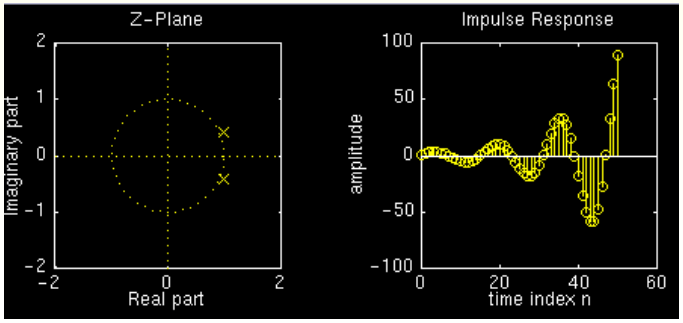
$$\Theta_0 = \frac{\pi}{8}$$

$$r = 1{,}05$$



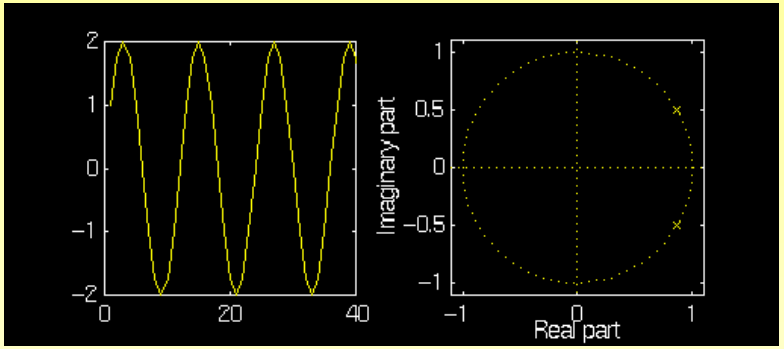
$$\Theta_0 = \frac{\pi}{8}$$

$$r = 1{,}075$$

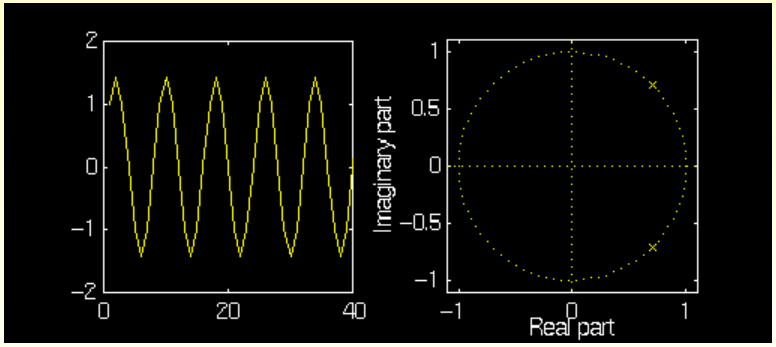


Filtr se dvěma póly - rezonátor
(konstantní koeficient a_2)

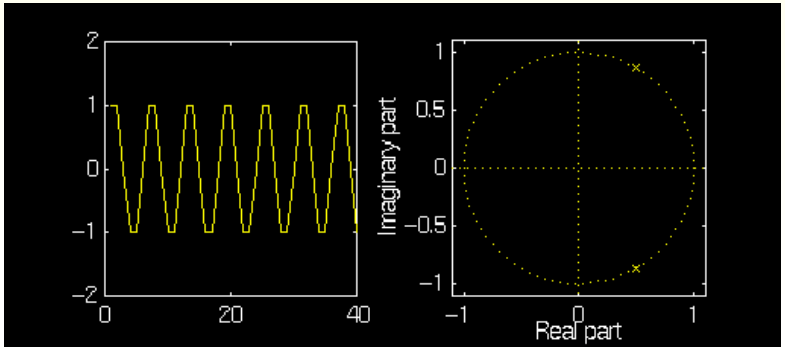
$$a_1 = -2\cos(\pi/6)$$
$$a_2 = 1$$



$$a_1 = -2\cos(\pi/4)$$
$$a_2 = 1$$

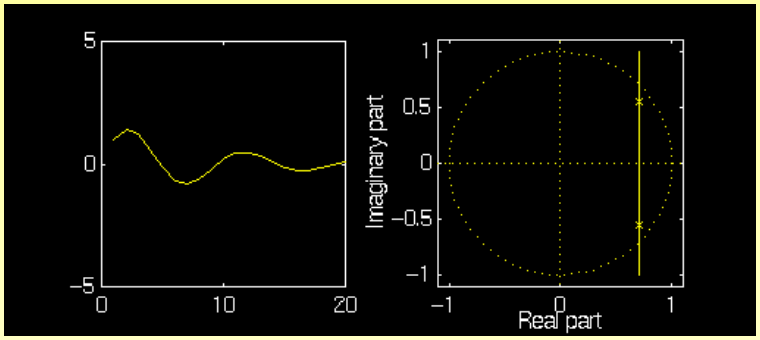


$$a_1 = -2\cos(\pi/3)$$
$$a_2 = 1$$

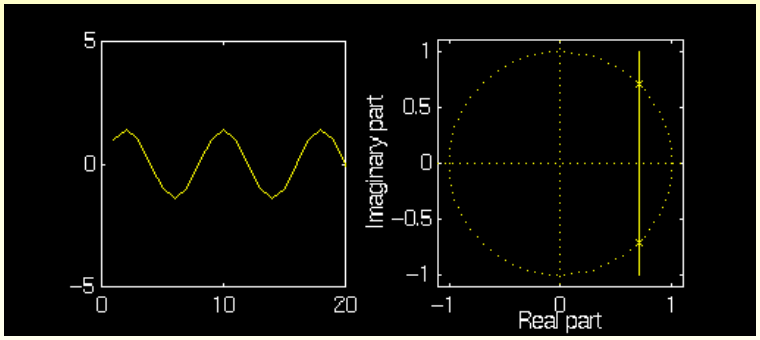


Filtr se dvěma póly - rezonátor
(konstantní koeficient a_1)

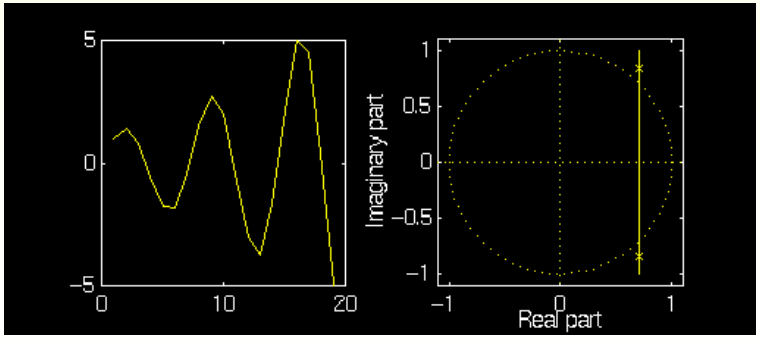
$$a_1 = -2\cos(\pi/4)$$
$$a_2 = 0{,}8$$



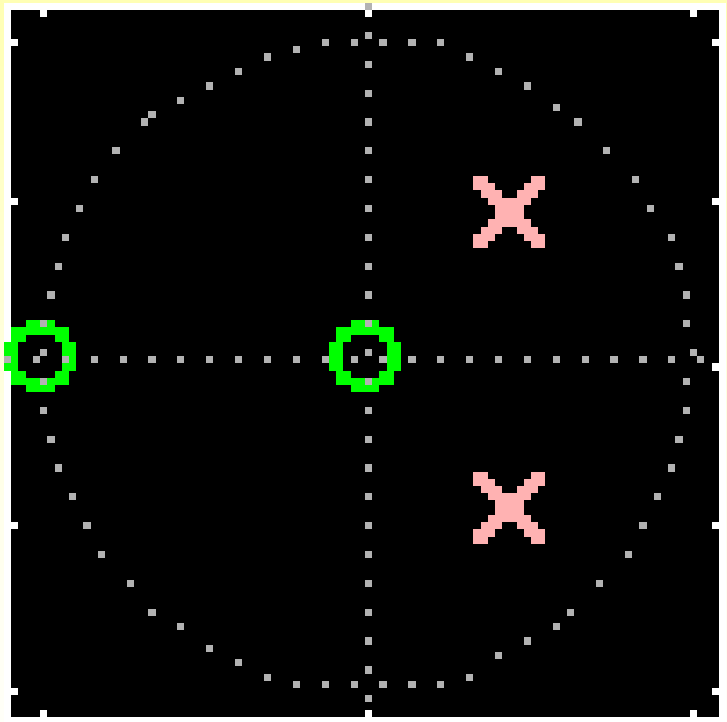
$$a_1 = -2\cos(\pi/4)$$
$$a_2 = 1$$



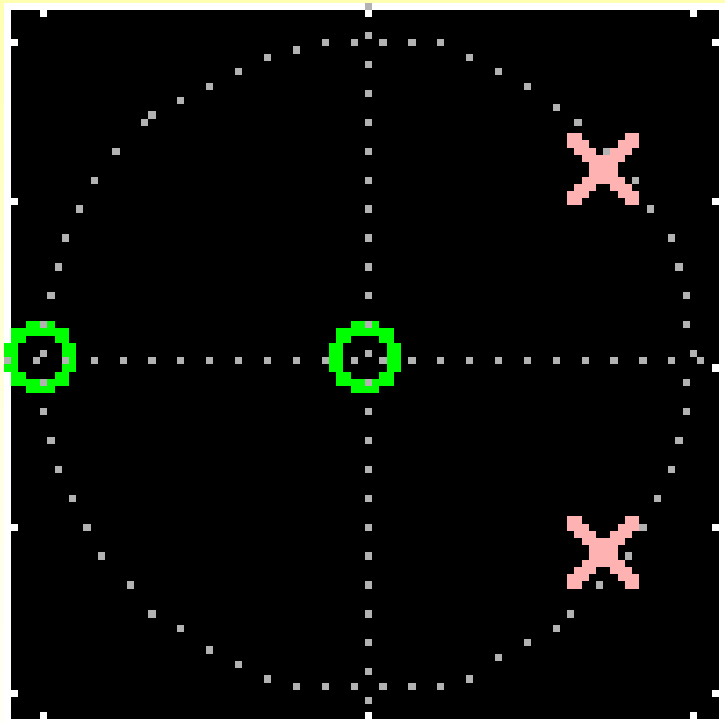
$$a_1 = -2\cos(\pi/4)$$
$$a_2 = 1{,}2$$



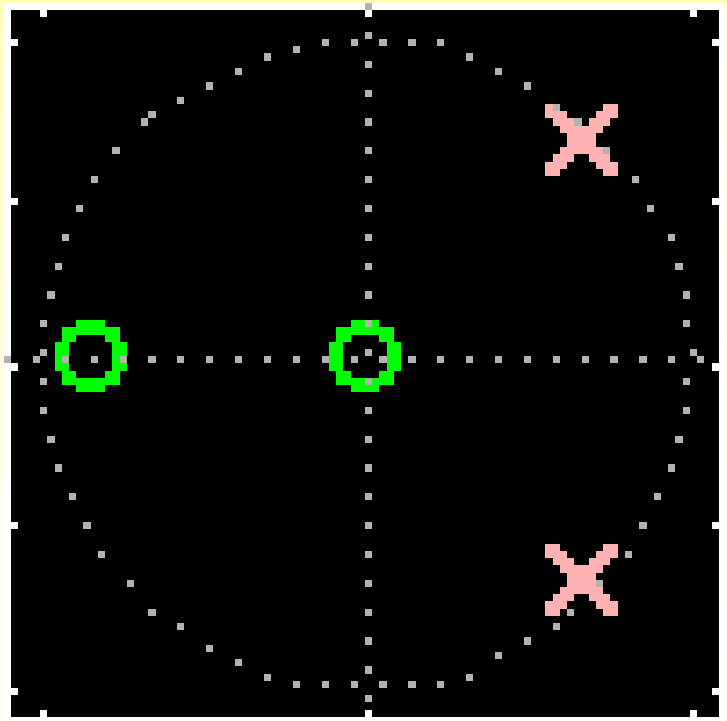
Pohyb pólů
(konstantní úhel; různý poloměr)



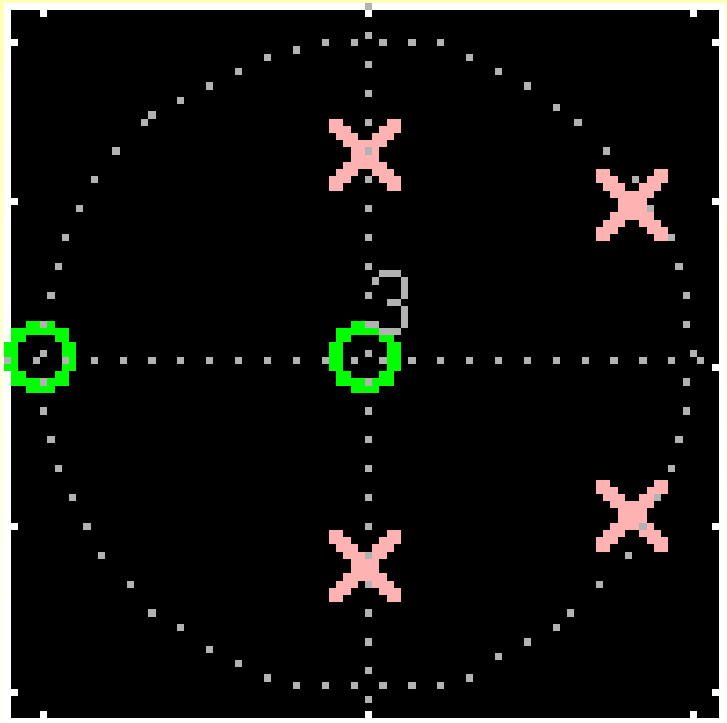
Pohyb pólů po kružnici
(různý úhel; konstantní poloměr)



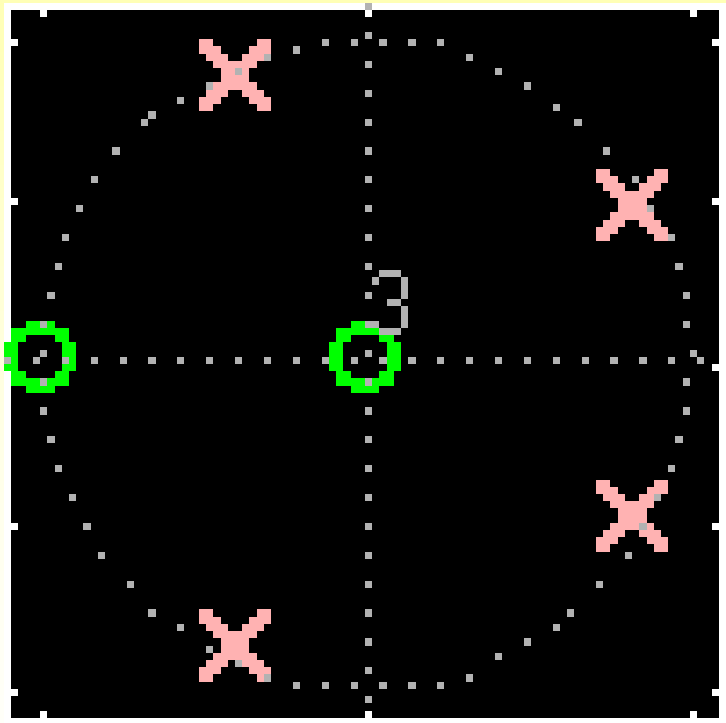
Pohyb nul IIR filtru
(po reálné ose)



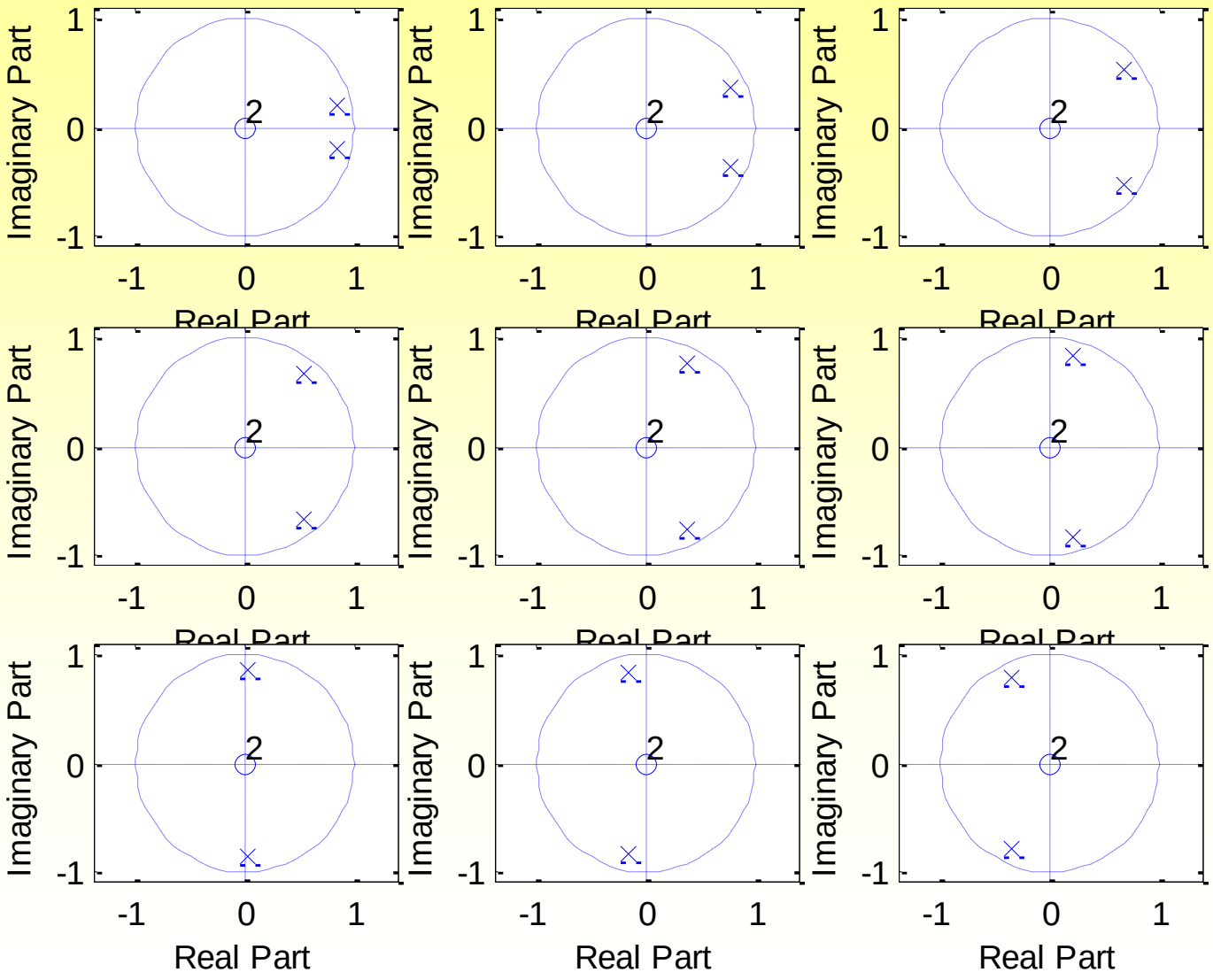
IIR s více póly
(pohyb vybraných pólů po ose)



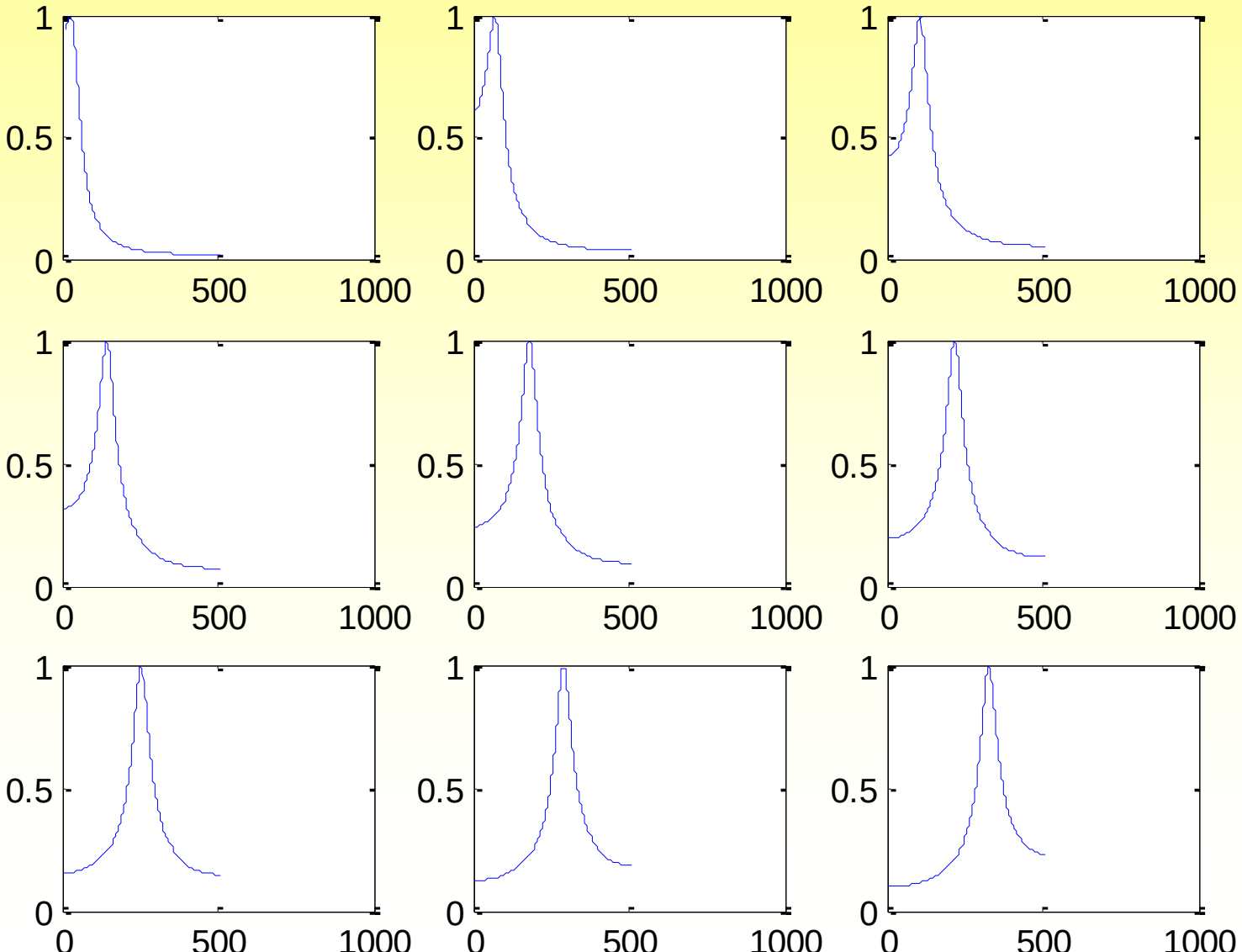
IIR s více póly
(pohyb vybraných pólů po kružnici)



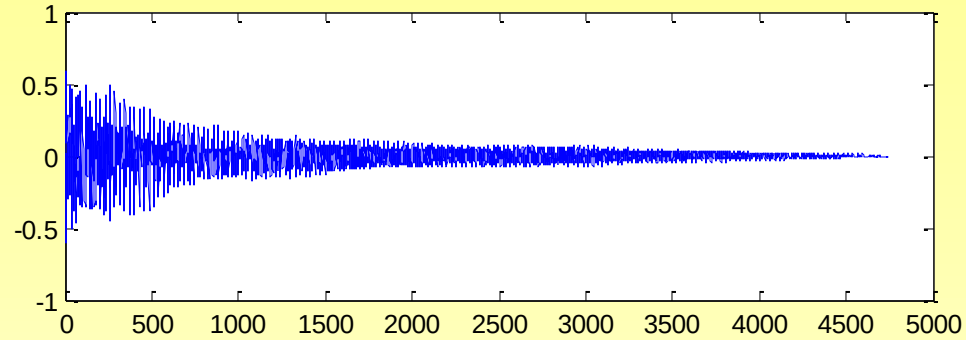
z-rovina rezonátorů

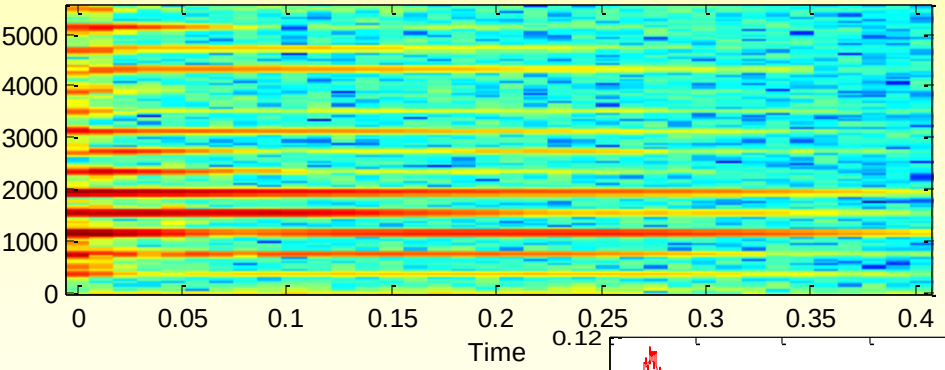


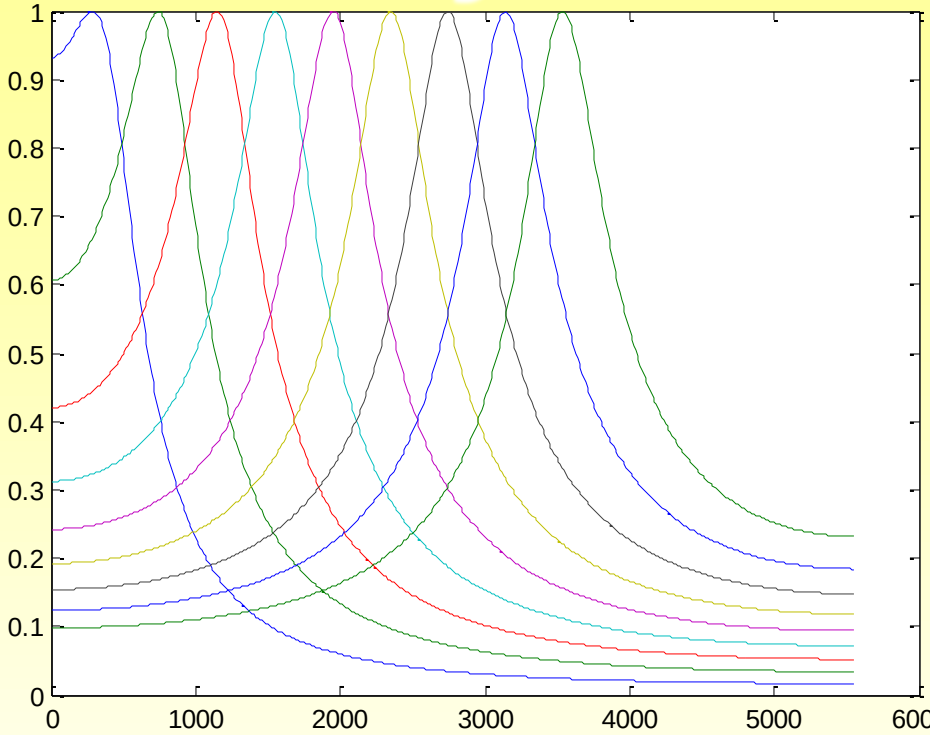
Amplitudové charakteristiky rezonátorů

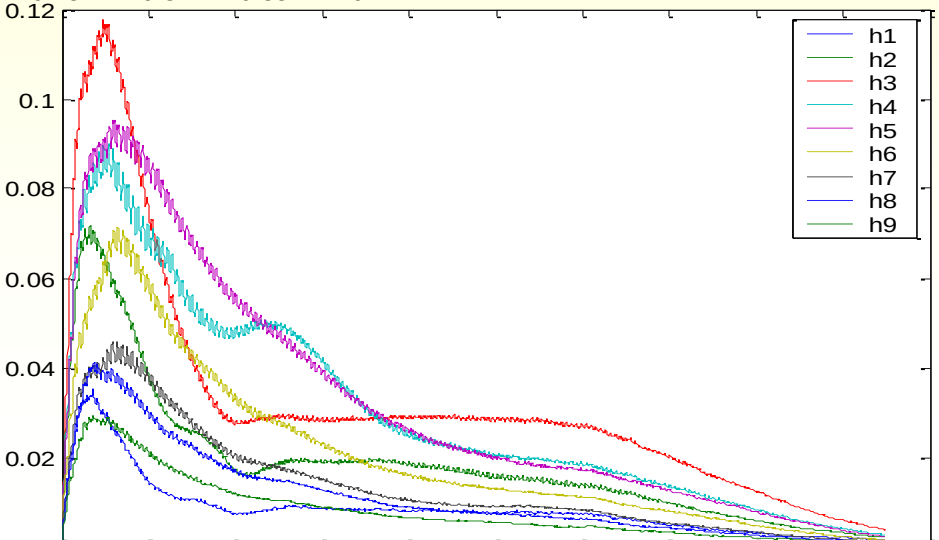


Analýza harmonických

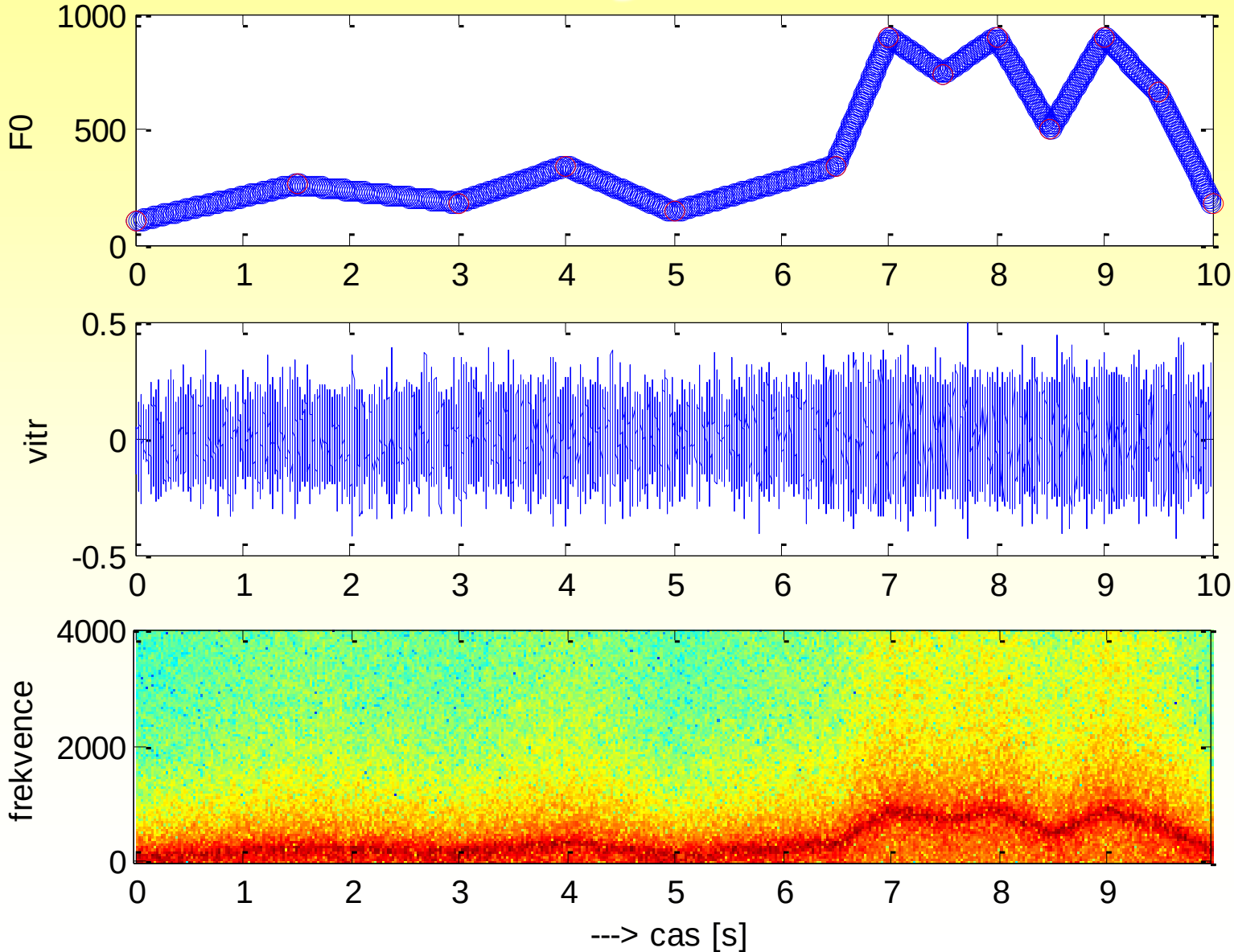








Filtrační syntéza větru



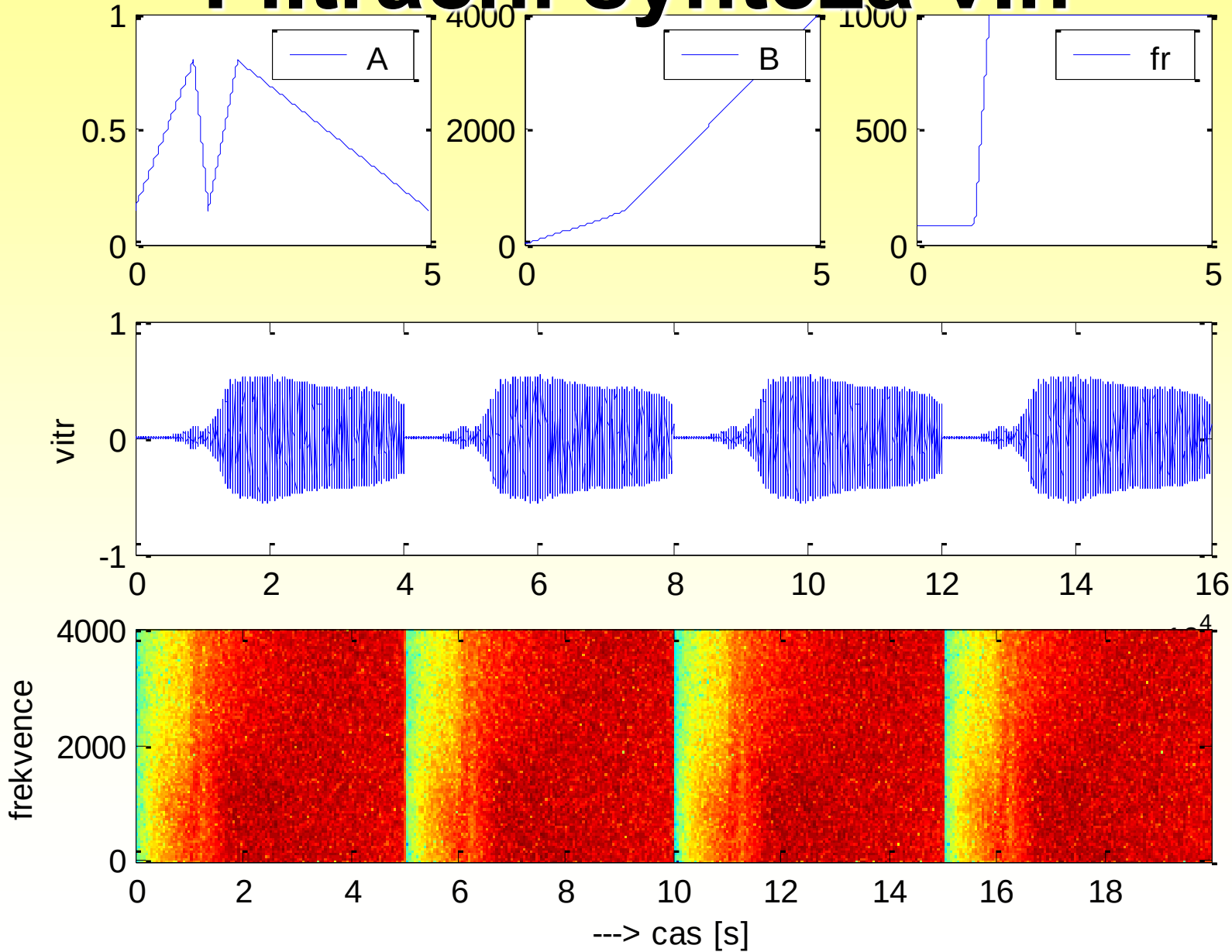
Filtrační syntéza větru

```
clear,
fs   =  8000;          % vzorkovaci frekvence [Hz]
doba =  10;            % doba trvani tonu [s]
x=2*rand(1,fs*doba)-1;  % generovani bileho sumu
nT=0:1/fs:doba-1/fs;    % casova osa

% souradnice ridicich bodu sily vetru
X=[0 .15 .3 .4 .5 .65 .7 .75 .8 .85 .9 .95 1];
Y=[0 .2  .1 .3 .05 .3  1 .8   1  .5  1 .7 .1];
Fmin=100; Fmax=900;
y=(Fmax-Fmin)*Y+Fmin;

% casovy prubeh interpolovane ridici frekvence
fr=interp1(X,y,nT/nT(end));
```

Filtrační syntéza větru

```
% navrh rezonatoru
B    = 100;                          % sirka pasma rezonatoru
R    = 1-B*pi/fs;                    % vypocet polomer polu
a    =-2*R*cos(2*pi*fr/fs);          % vypocet koeficientu
b0=(1-R)*sqrt(R*(R-4*cos(2*pi*fr/fs)+2)+1);   %
norm.koeficient
y=zeros(1,length(x));
for n=3:length(x)
    y(n)=b0(n)*x(n)-a(n)*y(n-1)-(R.^2)*y(n-2);
end
```

Filtrační syntéza vln



Filtrační syntéza vln

```
% souradnice ridicich bodu
X  =[0 .2 .25 .35 1];       % casova osa
Y_A=[0  .8 .15  .8  .1];    % amplituda
Y_B=[0  320  400 600 4000];  % sirka pasma
Y_f=[80 80 1000 1000 1000]; % rezonancni frekvence

% casovy prubeh interpolovane ridici amplitudy
G=interp1(X,Y_A,nT/nT(end));
% casovy prubeh interpolovane sirky pasma
B=interp1(X,Y_B,nT/nT(end));
% casovy prubeh interpolovane ridici rezonancni f
fr=interp1(X,Y_f,nT/nT(end));
```

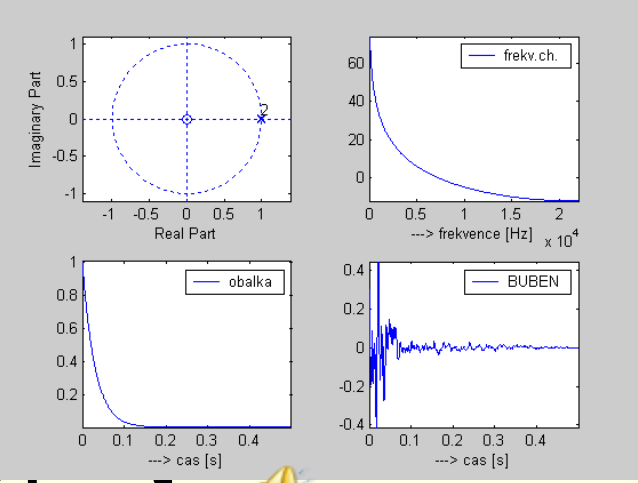
Filtrační syntéza vln

```
x=2*rand(1,fs*doba)-1;

for n=3:length(x)
   R(n)    = 1-B(n)*pi/fs;      % vypocet polomer polu
   a(n)    =-2*R(n)*cos(2*pi*fr(n)/fs); % vypocet koeficientu
   b0(n)=(1-R(n))*sqrt(R(n)*(R(n)-4*cos(2*pi*fr(n)/fs)+2)+1);
% norm.koeficient
   y(n)=G(n)*(b0(n)*x(n)-a(n)*y(n-1)-(R(n).^2)*y(n-2));
end
```

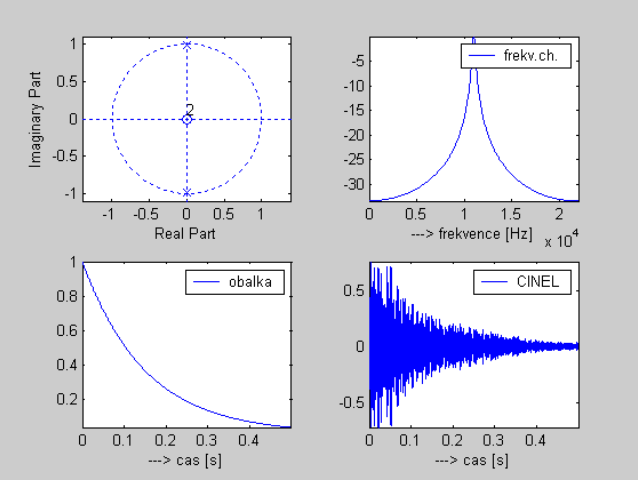
Filtrační syntéza

Aplikace s šumem rezonátory a obálkami

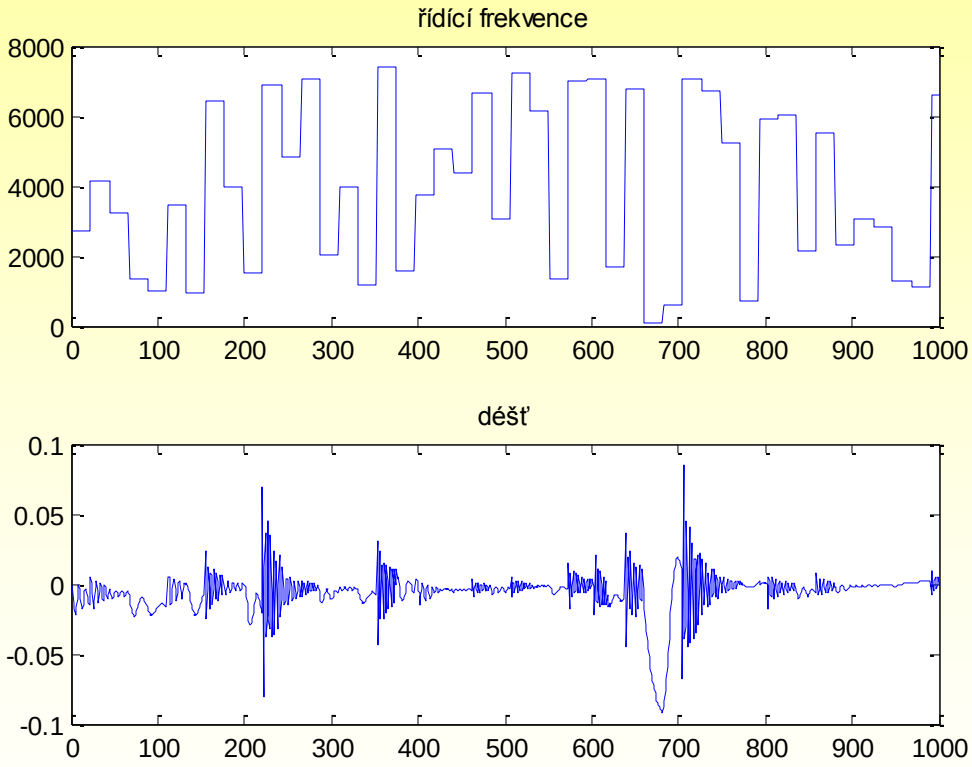
- buben



- činel

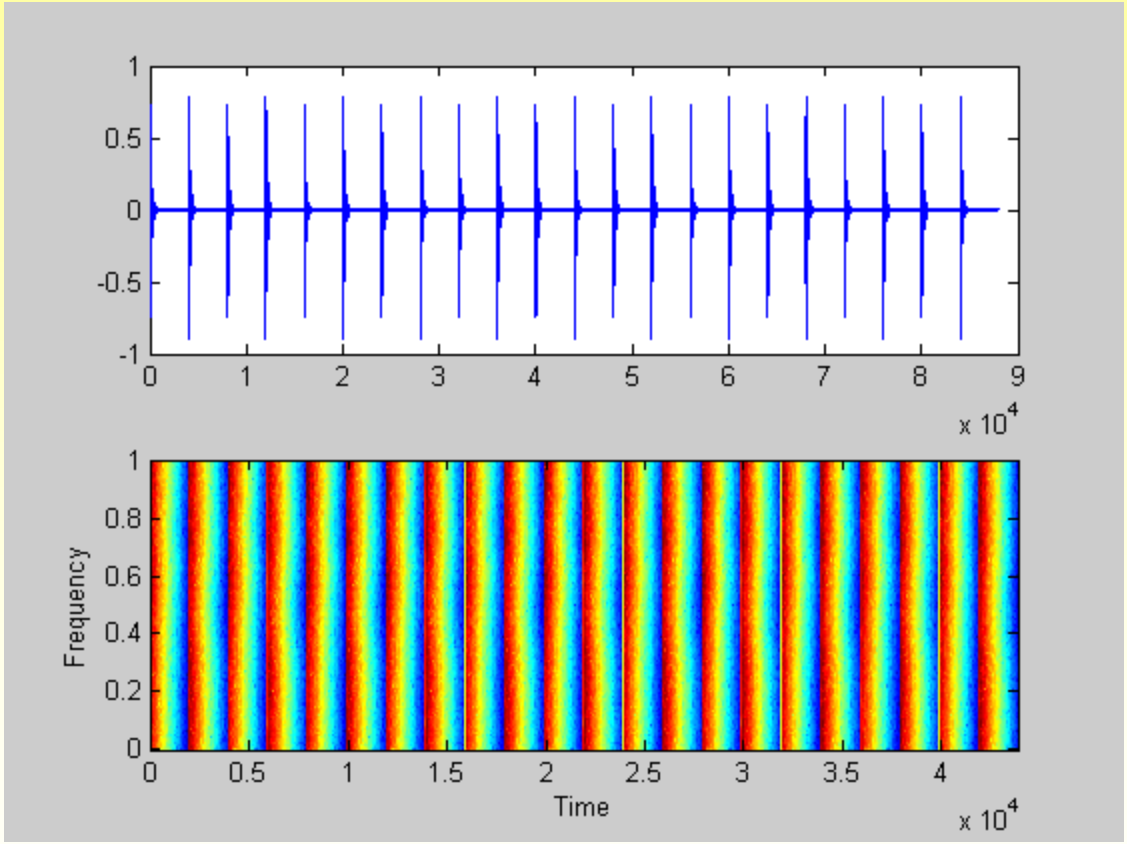


Filtrační syntéza



Filtrační syntéza

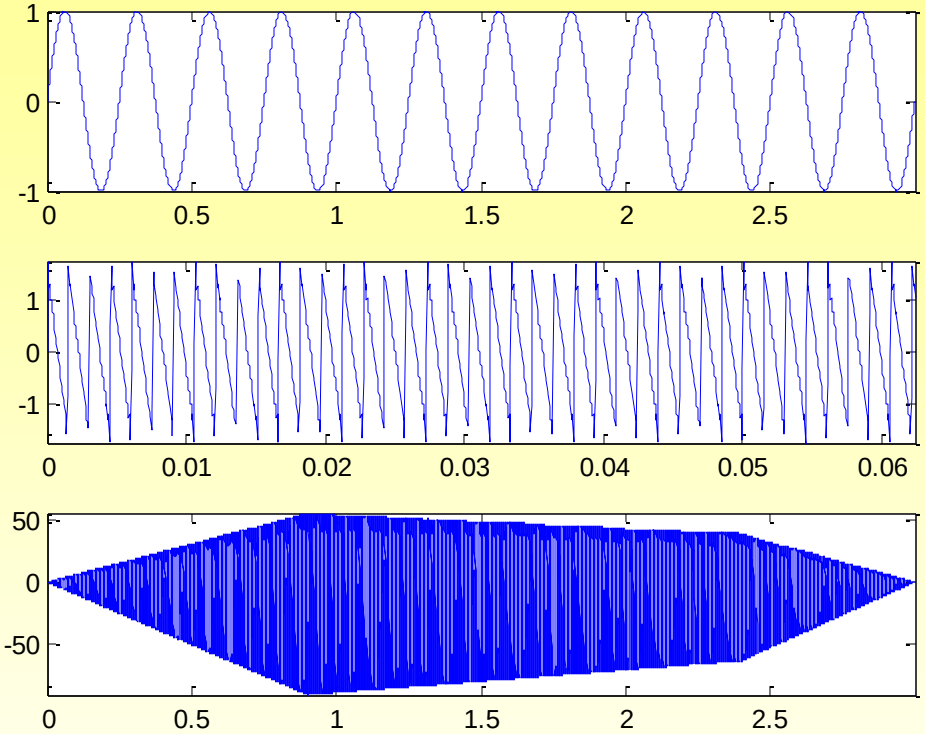
hodiny

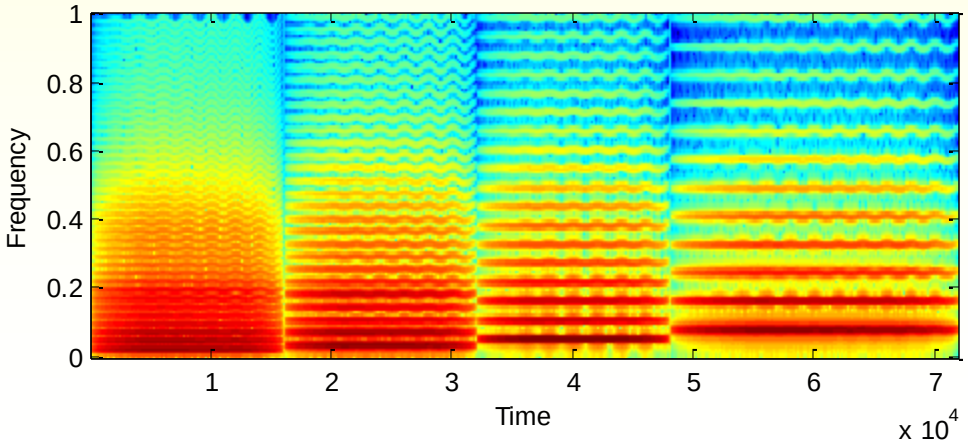


Fr=3500; B = 550;
Fr=3000; B = 750;

Filtrační syntéza

housle

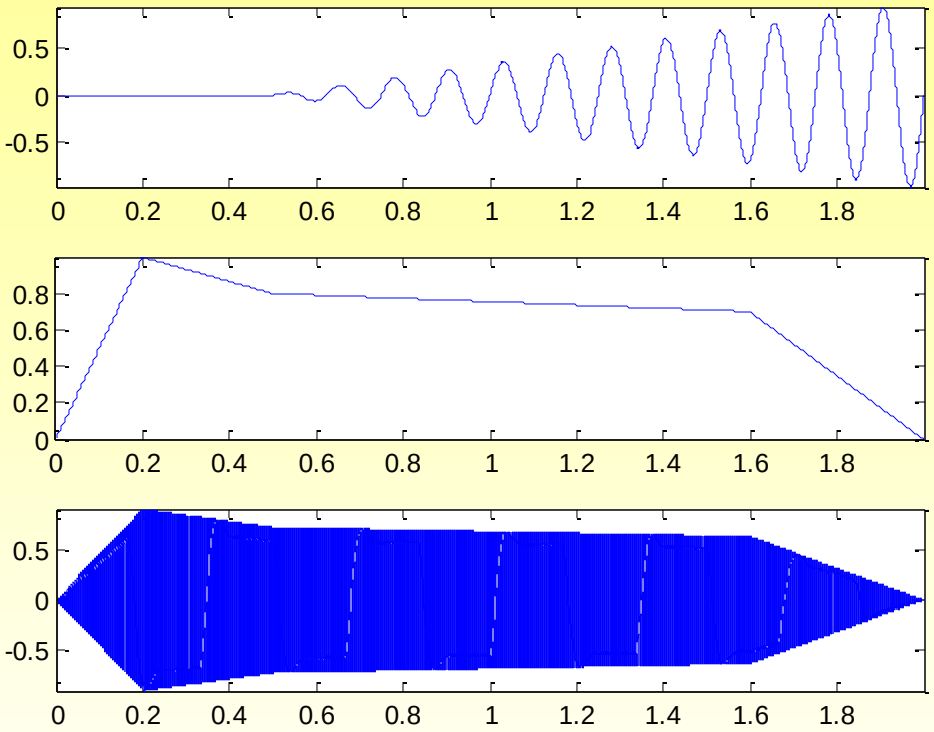





```
% filtr (model housli)
%%%%%%%%%%%%%%
F = [500, 1500, 3000, 4000];
BW = [300, 200, 700, 1500];
```

Filtrační syntéza

klarinet




```
% navrh rezonatoru
fr   =  900;        % rezonancni frekvence
B    = 1200;        % sirka pasma rezonatoru
```

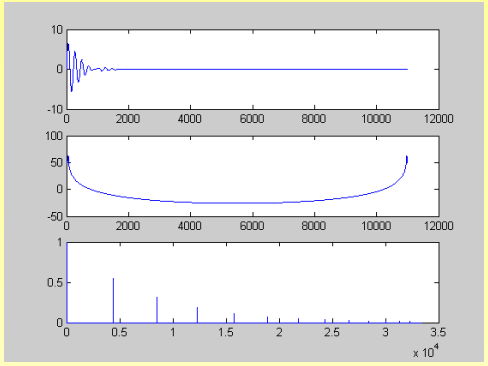
Syntéza strojů

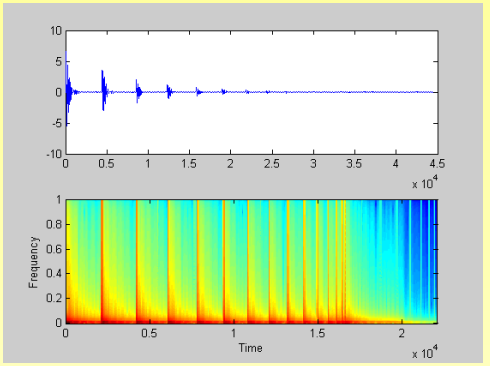
vlak

letadlo

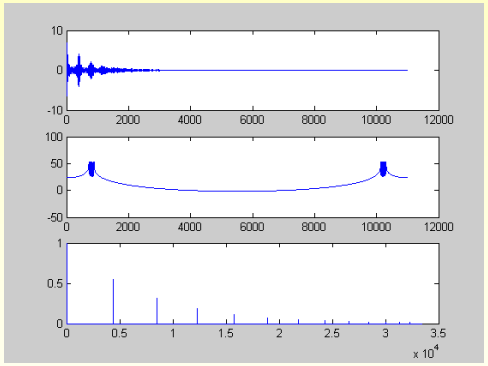
Syntéza materiálu

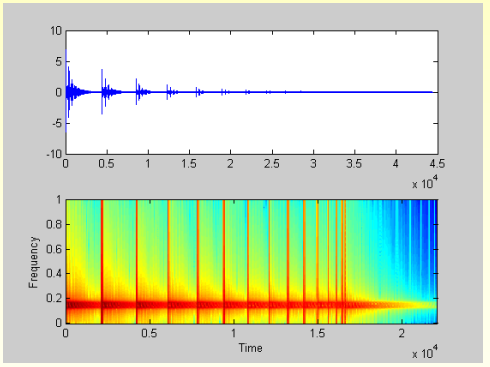
dřevo



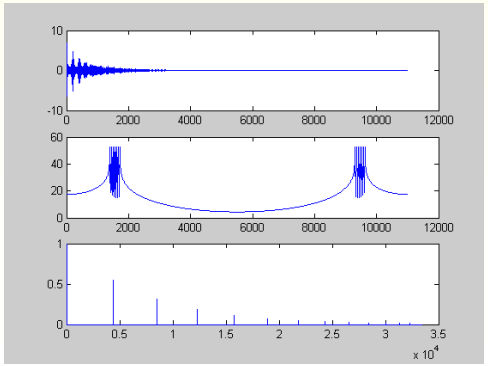


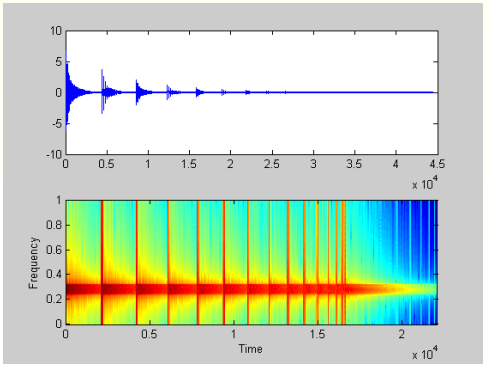
- kov



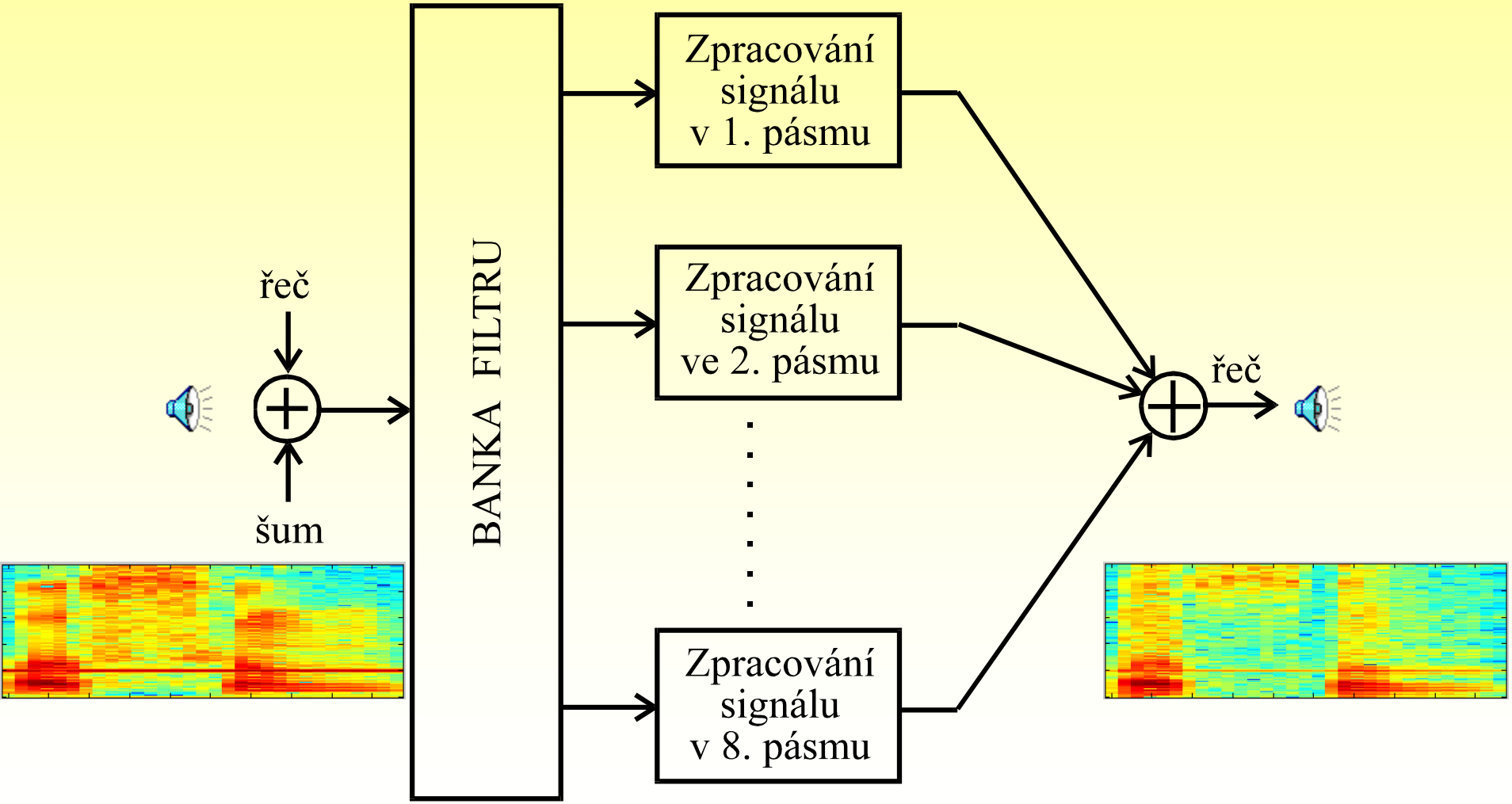


- sklo

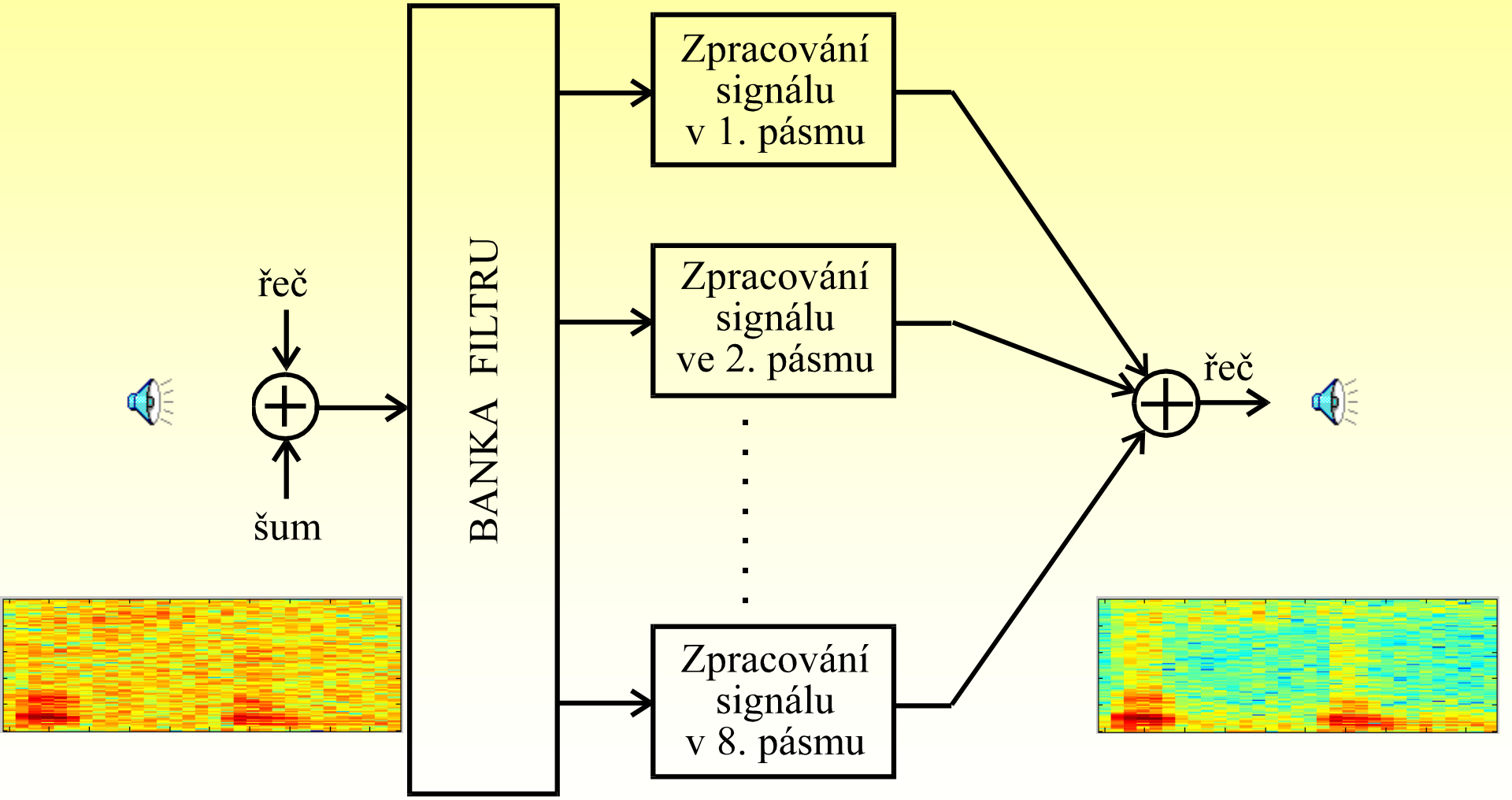




Potlačení šumu v řeči bankou filtrů

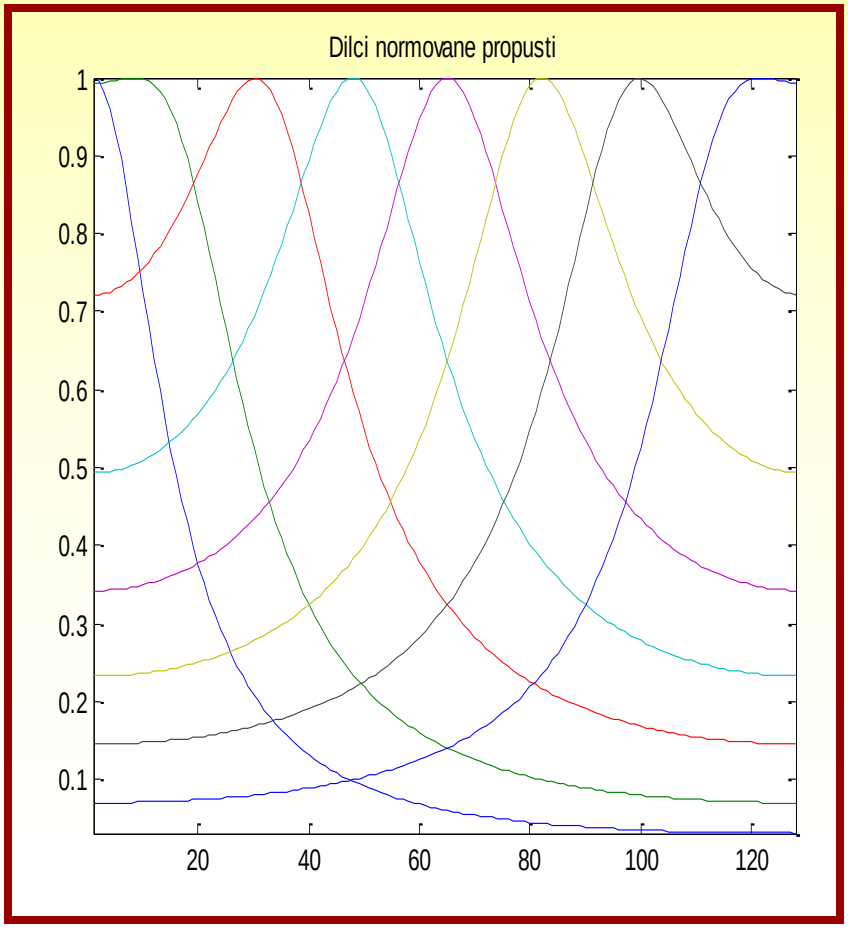


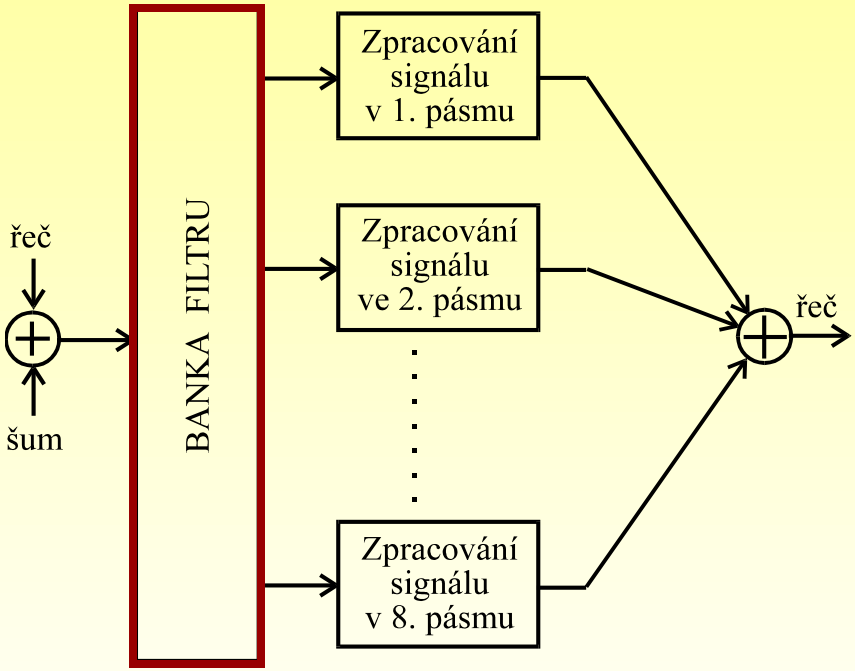
Potlačení šumu v řeči bankou filtrů

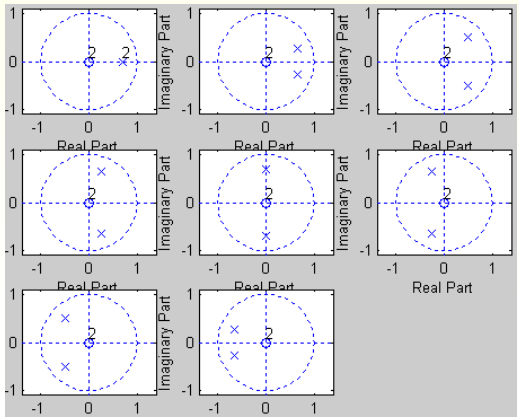


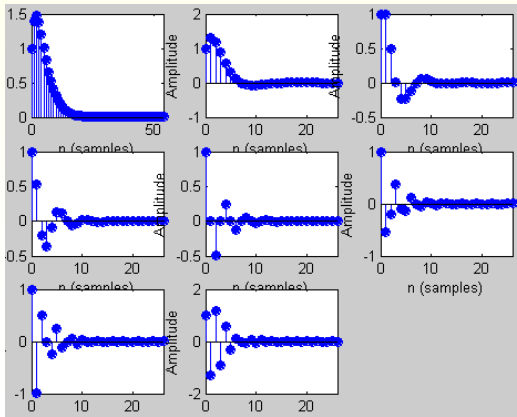
Potlačení šumu v řeči bankou filtrů

banka filtrů



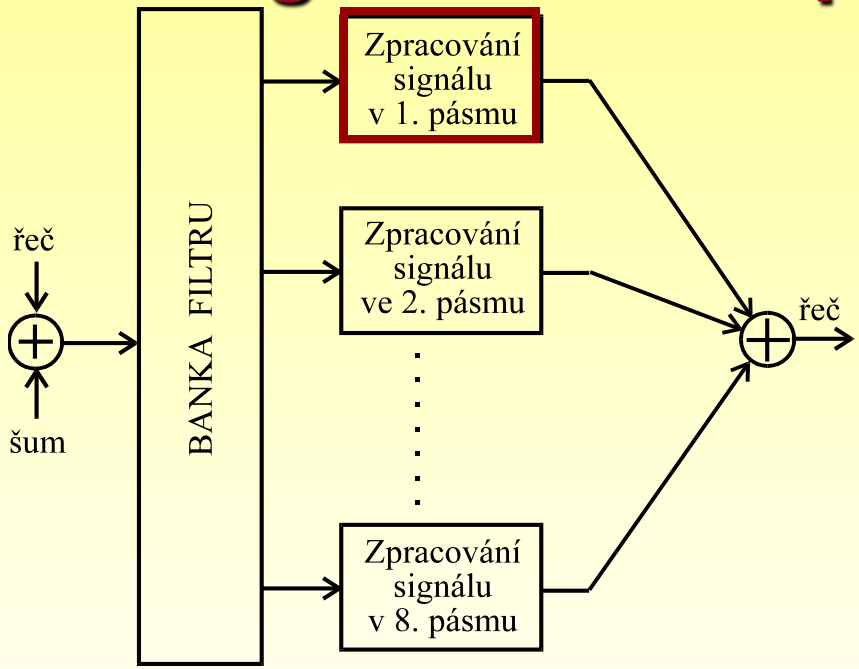


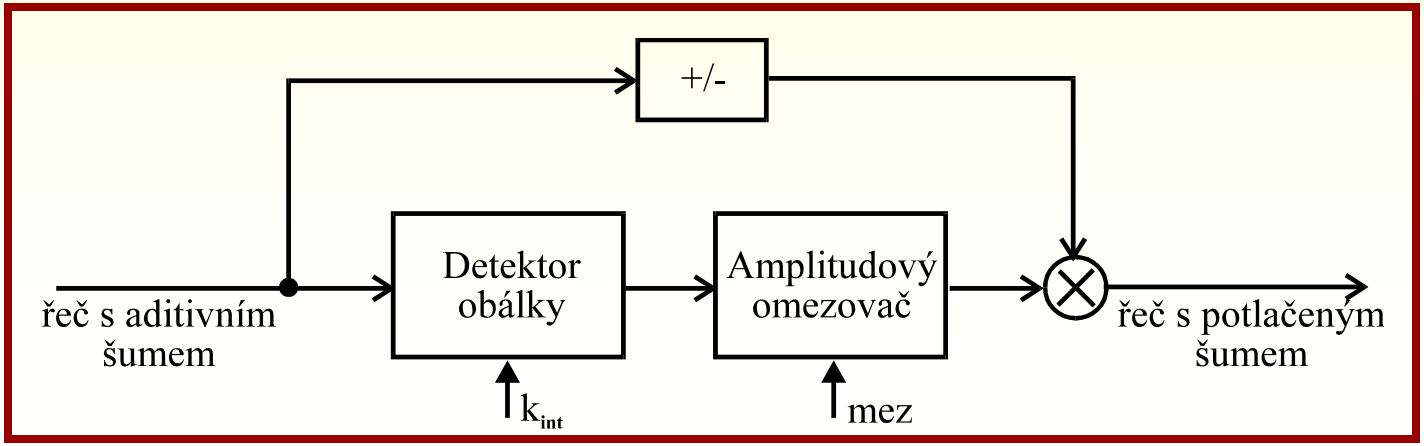




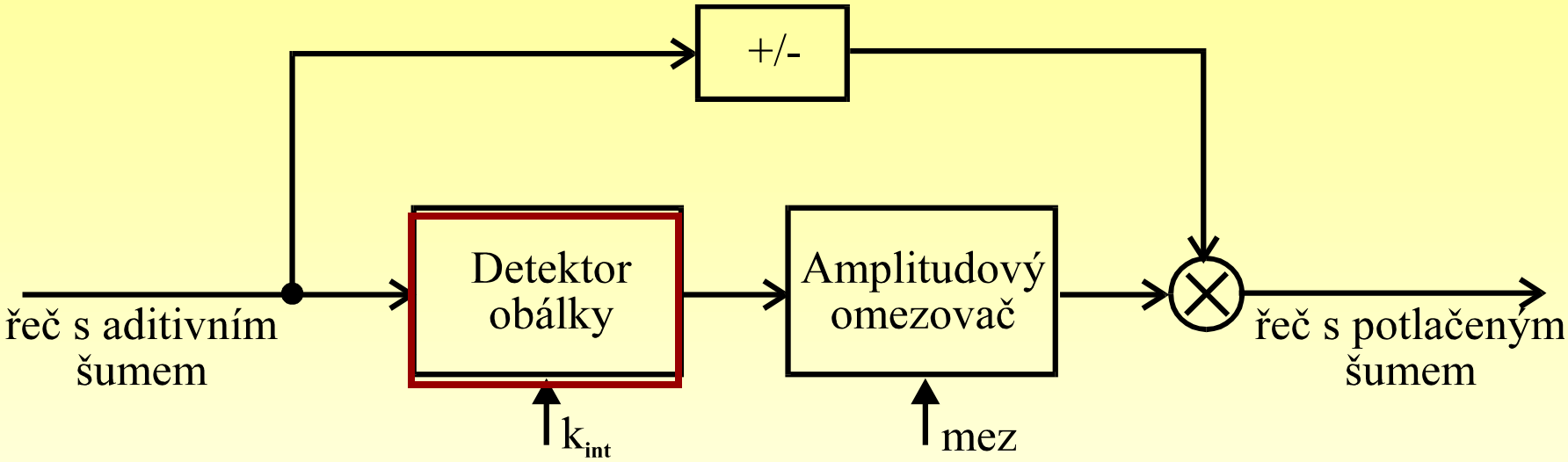
Potlačení šumu v řeči bankou filtrů

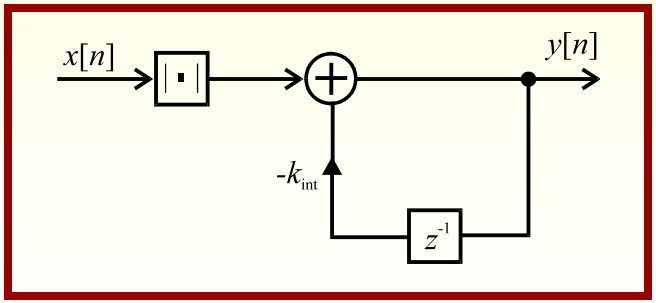
zpracování signálů v i-tém pásmu

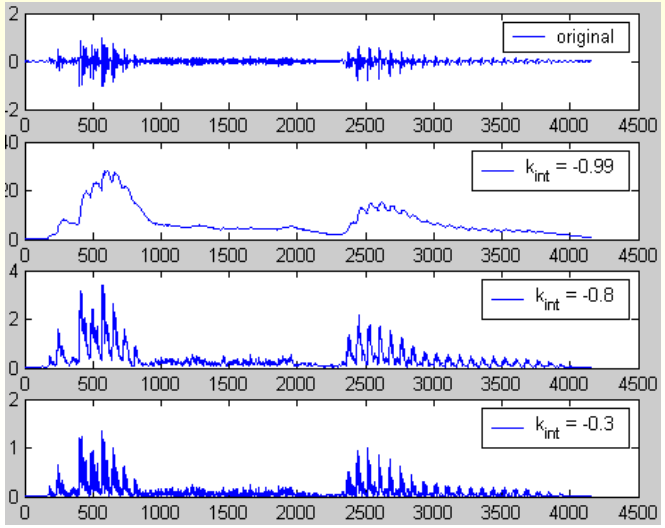




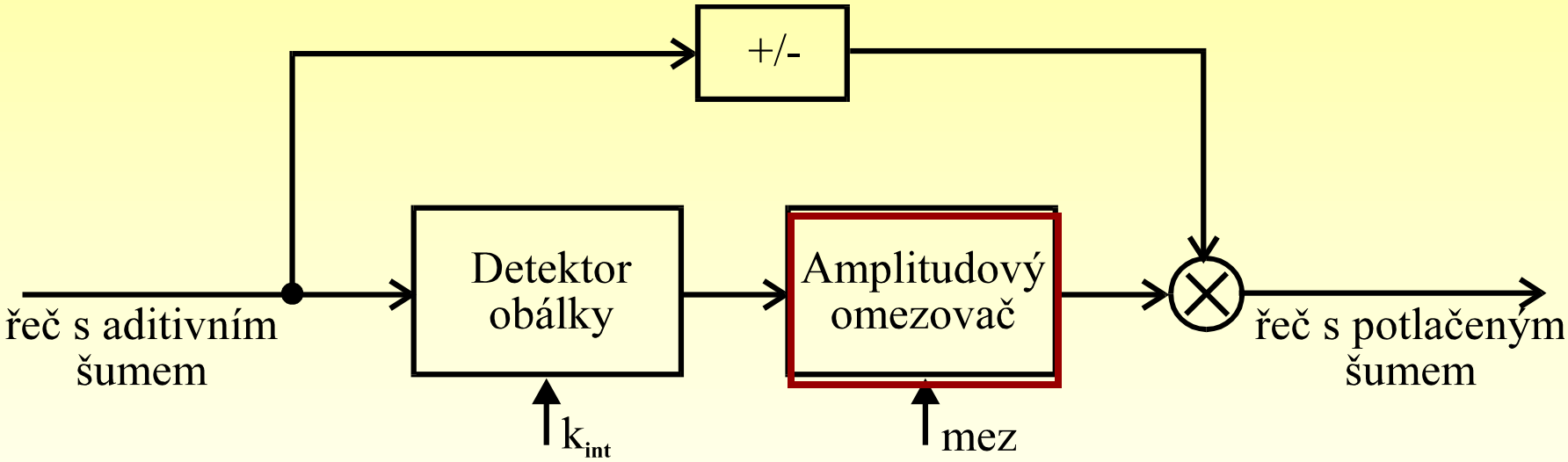
Potlačení šumu v řeči bankou filtrů

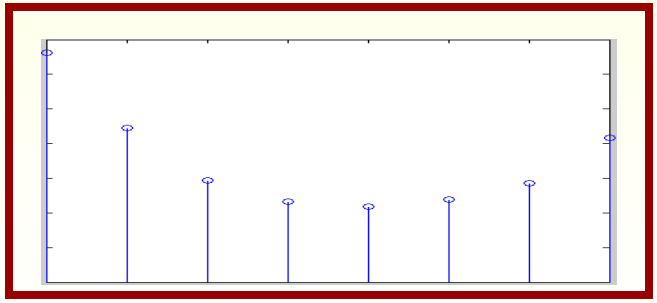




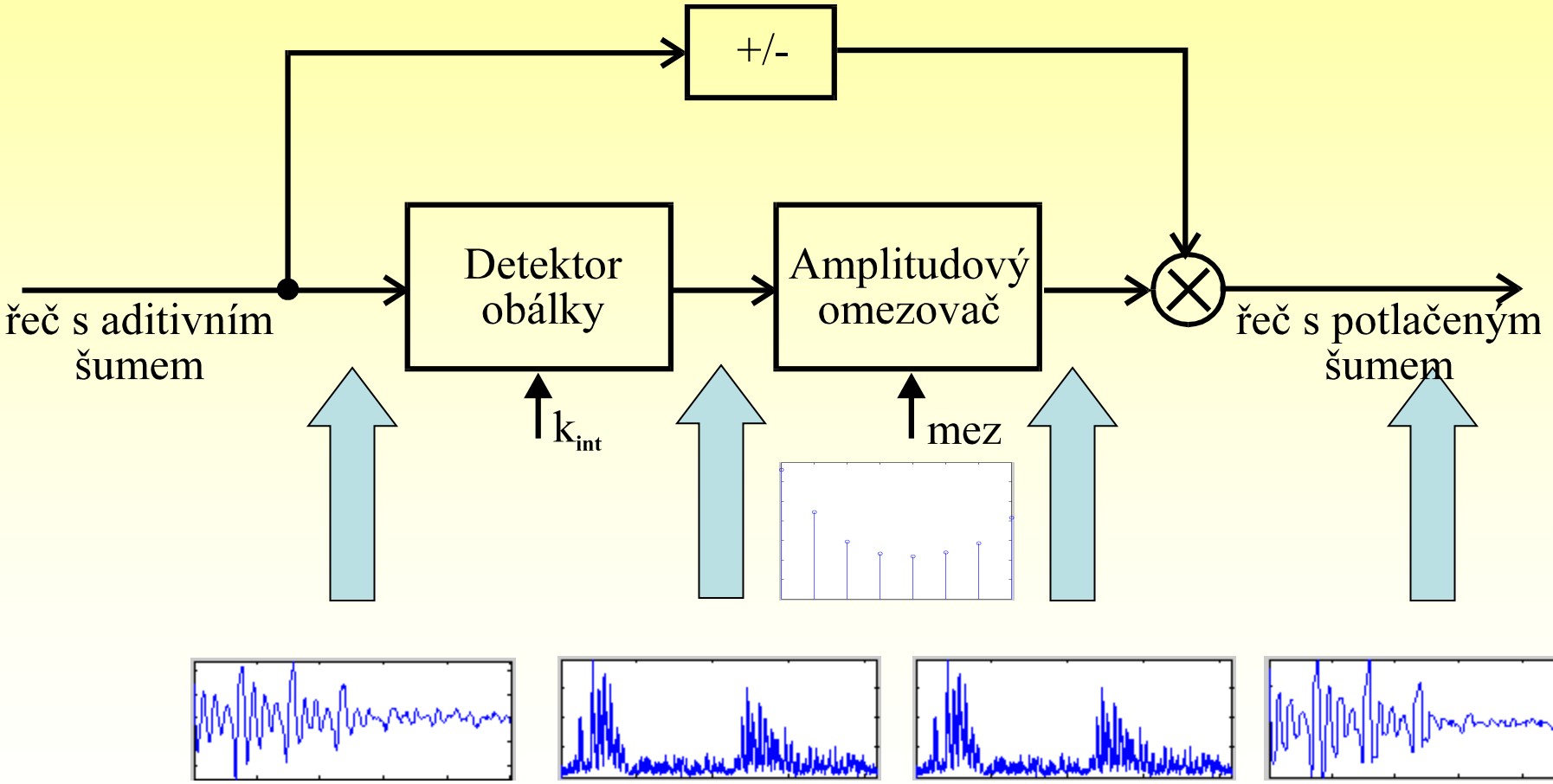


Potlačení šumu v řeči bankou filtrů

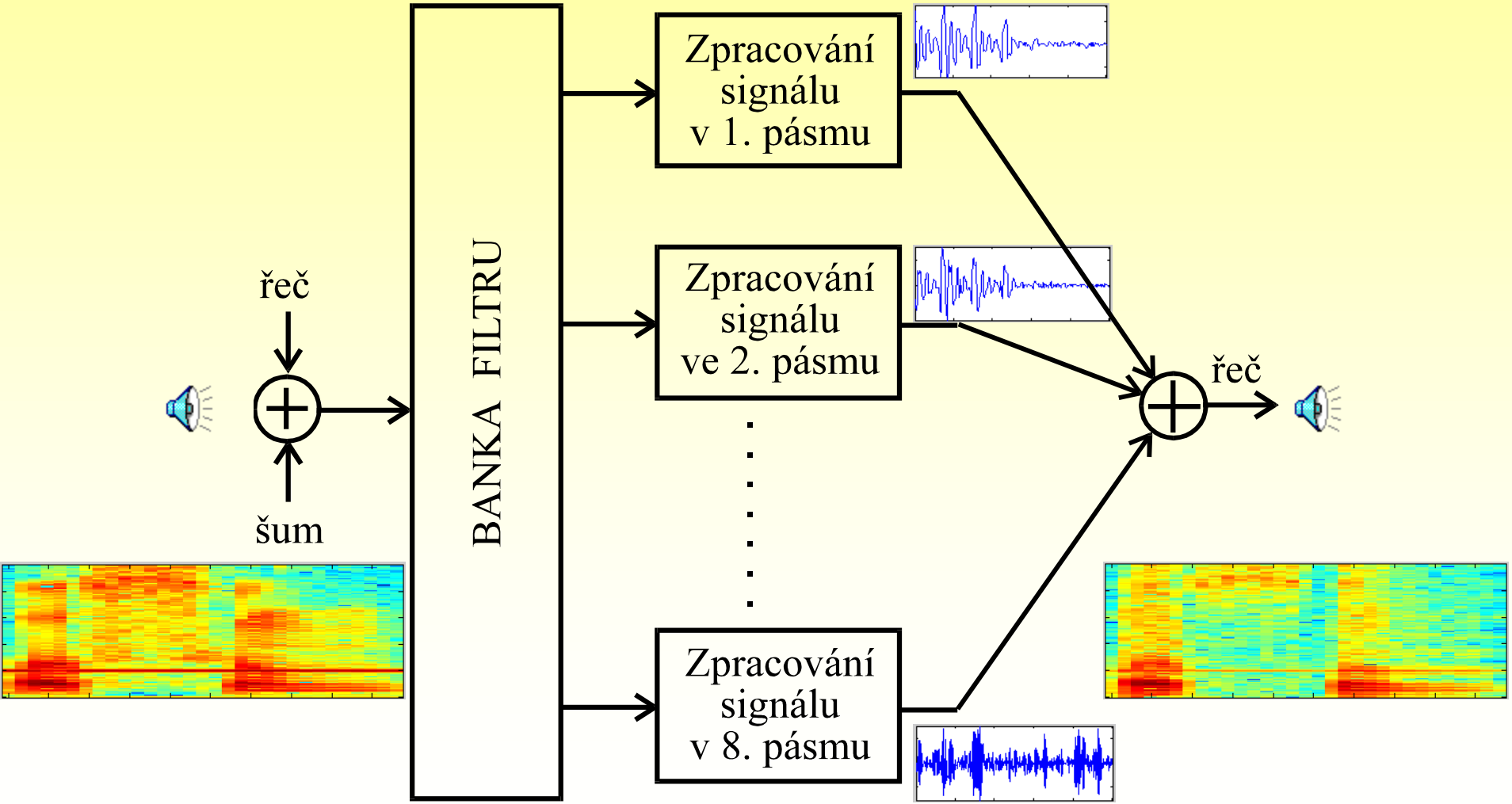




Potlačení šumu v řeči bankou filtrů



Potlačení šumu v řeči bankou filtrů



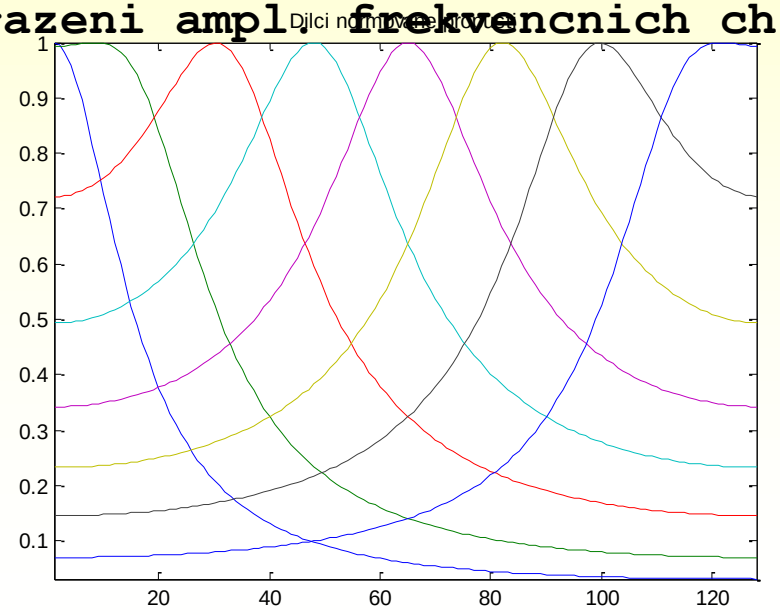
Potlačení šumu v řeči bankou filtrů III
(generování rušení)

```
%%%%%%%%%%%%%%%%%% GENEROVANI SUMU %%%%%%%%%%%%%%%%%%%%
k_noise= 0.1;

sig=input('1 = sinusove ruseni; 2 = nahodny sum ... ')

if sig==2,
   noise=k_noise*randn(length(xc),1);
end;
if sig==1,                                  % rusivy signal 800H z
   noise=sqrt(2)*k_noise*sin(2*pi*(0:length(xc)-1)*800/8000)';
end;
x=xc+noise;

'cinitel odstupu signalu k sumu'
snr=10*log10(sum(xc.^2)/sum(noise.^2))
```

Potlačení šumu v řeči bankou filtrů IV

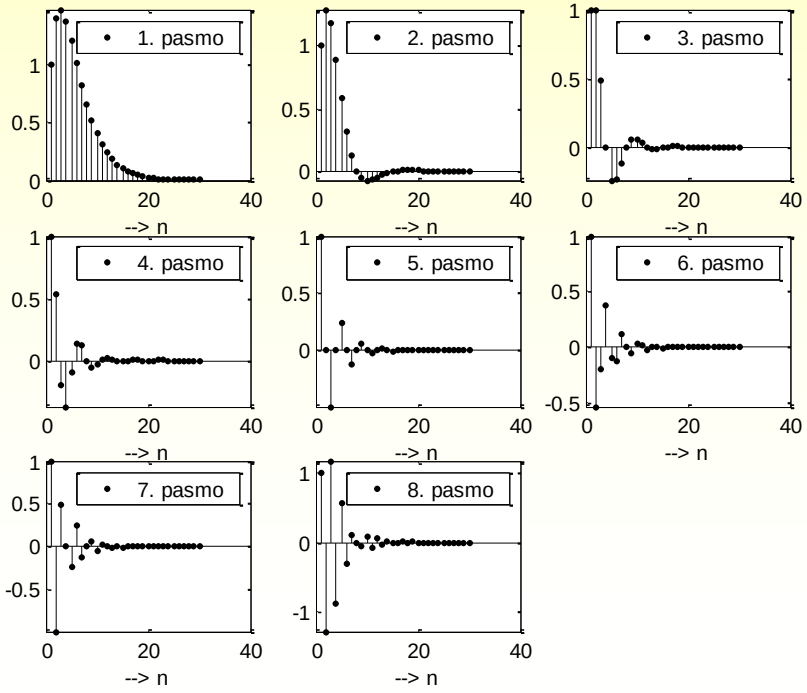
(banka filtrů)

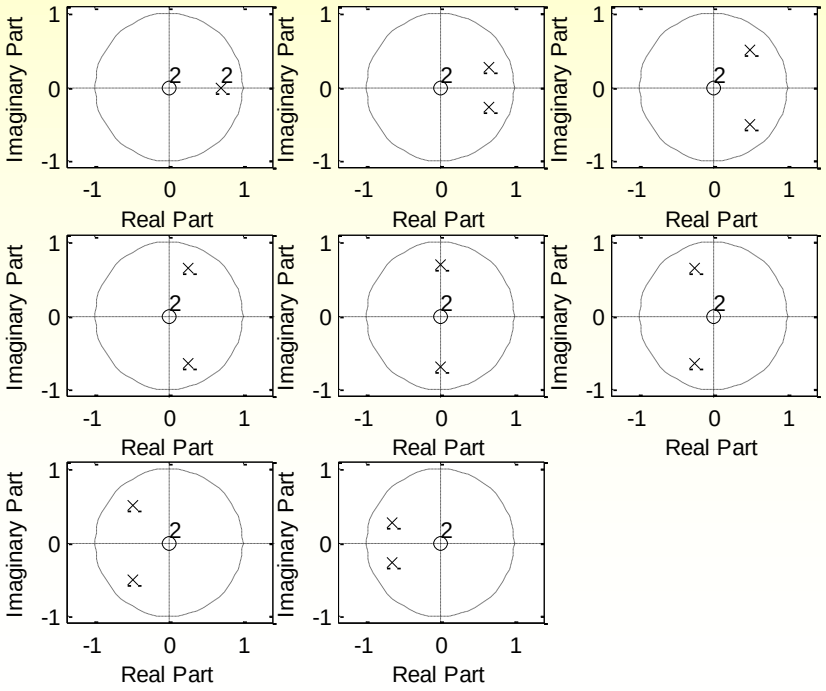
```
f_s=8;                              % vzorkovaci frekvence [kHz]
P=8;                                % pocet propusti
f_r=f_s/(2*P)*(0:P-1);              % vypocet rezonancnich frekvenci
R=0.7;                              % polomer polu
b=-2*R*cos(2*pi*f_r/f_s);           % vypocet koeficientu rezonatoru
for i=1:P                           % normovani charakteristik
    Ha(:,i)=(freqz(1,[1 b(i) R.^2],128));
    Ham(i)=max(abs(Ha(:,i)));   % vypocet normovacich koef.
    Han(:,i)=(freqz(1/Ham(i),[1 b(i) R.^2],128));
end;
plot(abs(Han)); axis tight          % zobrazeni ampl. frekvencnich ch.
title('Dilci normovane propusti')
```



Potlačení šumu v řeči bankou filtrů
(banka filtrů)

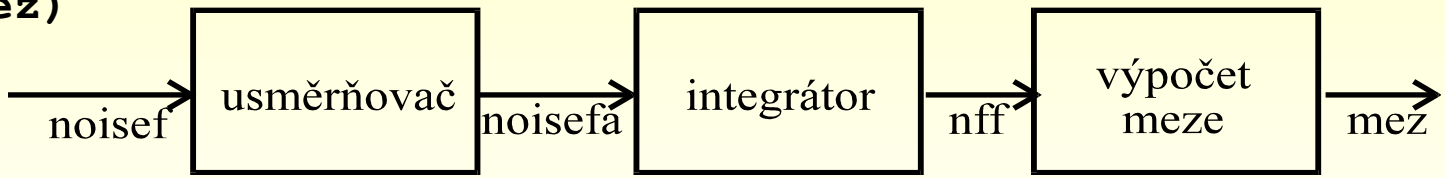
```
for k=1:P           % zobrazeni impulsnich charakteristik
    subplot(3,3,k), impz([1 0 0],[1 b(k) R.^2])
end;

% zobrazeni z-roviny
for k=1:P
    subplot(3,3,k), zplane([1 0 0],[1 b(k) R.^2])
end;
```

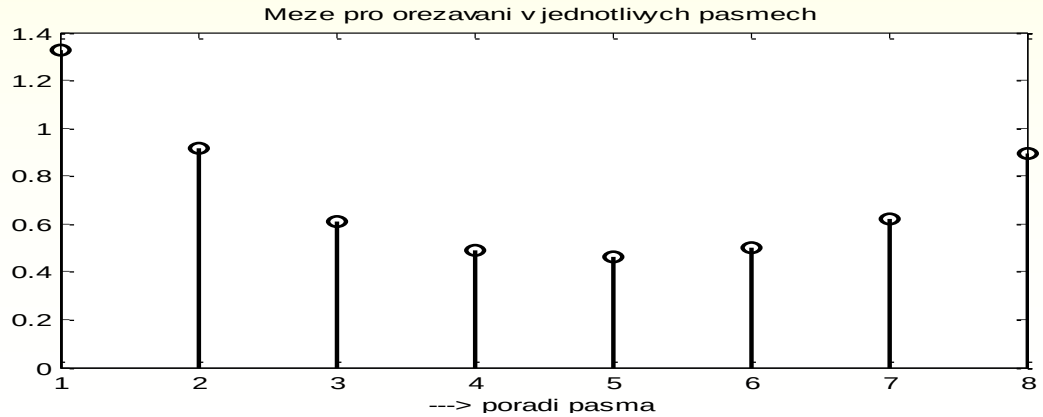




Potlačení šumu v řeči bankou filtrů
(stanovení mezí v pásmech)

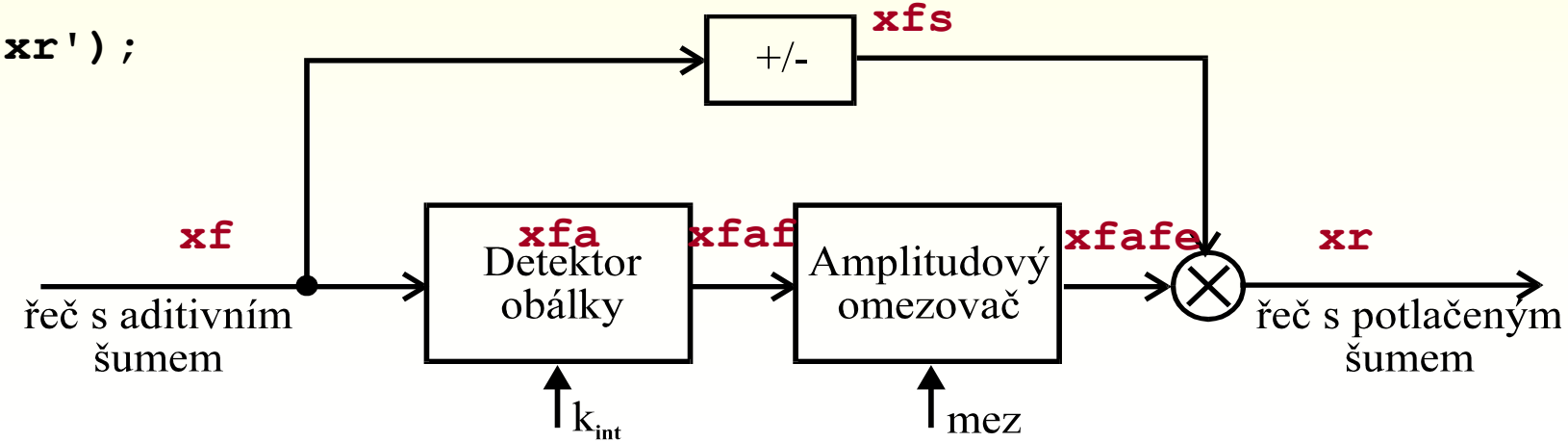
```
%%%%%% FILTRACE A VYPOCET MEZE PRO OREZAVANI %%%%%%
k_noise= 0.1; k_int  = 0.8;
for i=1:P
   noisef(:,i)=filter(1/Ham(i),[1 b(i) R.^2],noise(1:1000));
                                                    % filtrace
   noisefa(:,i)=abs(noisef(:,i));                   % usmerneni
   nff(:,i)=filter(1,[1 -k_int],noisefa(:,i));      % obalka
   mez(i)=mean(abs(nff(:,i)));   % vypocet mezi ve vsech pasmech
end;
stem(mez)
```



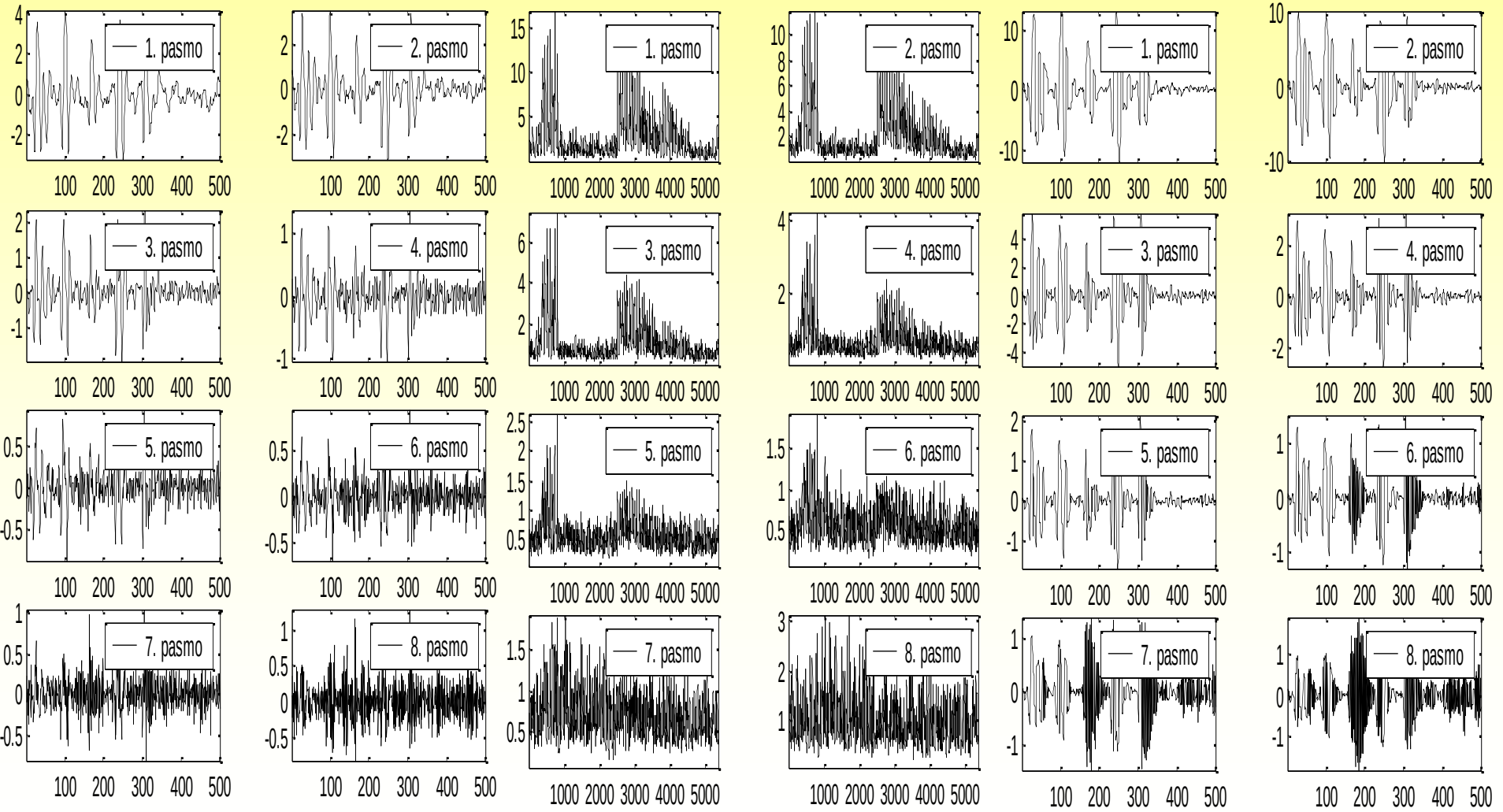


Potlačení šumu v řeči bankou filtrů
(filtrace a rozklad do pásem)

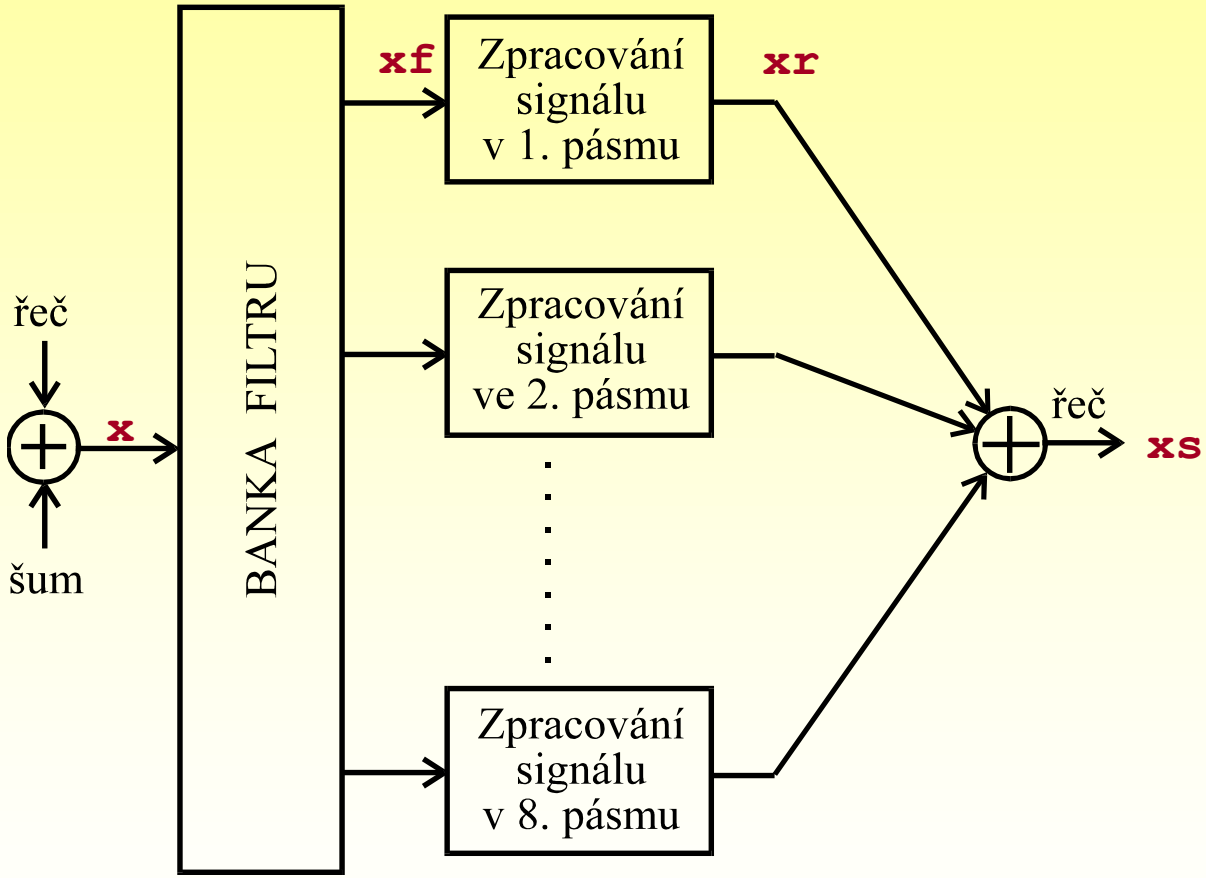
```
%%%%%%%%%%%%% POTLACENI SUMU BANKOU FILTRU %%%%%%%%%%%%%
%%% FILTRACE A ROZKLAD DO PASEM - VYPOCET OBALEK %%%%%%%
for i=1:P
    xf(:,i)=filter(1/Ham(i),[1 b(i) R.^2],x);   % filtrace
    xfs(:,i)=sign(xf(:,i)+0.00001);             % znamenko
    xfa(:,i)=abs(xf(:,i));                      % usmerneni
    xfaf(:,i)=filter(1,[1 -k_int],xfa(:,i)); % obalka
    subplot(4,2,i), plot(xfaf(:,i)); axis tight
    xfafe(:,i)=abs(xfaf(:,i)-mez(i));           % oriznuti
    xr(:,i)=xfafe(:,i).*xfs(:,i);
    subplot(4,2,i), plot(xf(500:1000,i))
    subplot(4,2,i), plot(xr(500:1000,i)); axis tight
end;
xs=sum(xr');
```



Potlačení šumu v řeči bankou filtrů



Potlačení šumu v řeči bankou filtrů



Potlačení šumu v řeči bankou filtrů

```
for i=1:3 soundsc(x); pause(1), soundsc(xs); pause(1);end;
subplot(211); specgram(x); subplot(212); specgram(xs);
```