DBBT
Digital Broadcasting & Broadband Technologies

Co-funded by the Erasmus+ Programme of the European Union

Procesiranje signala

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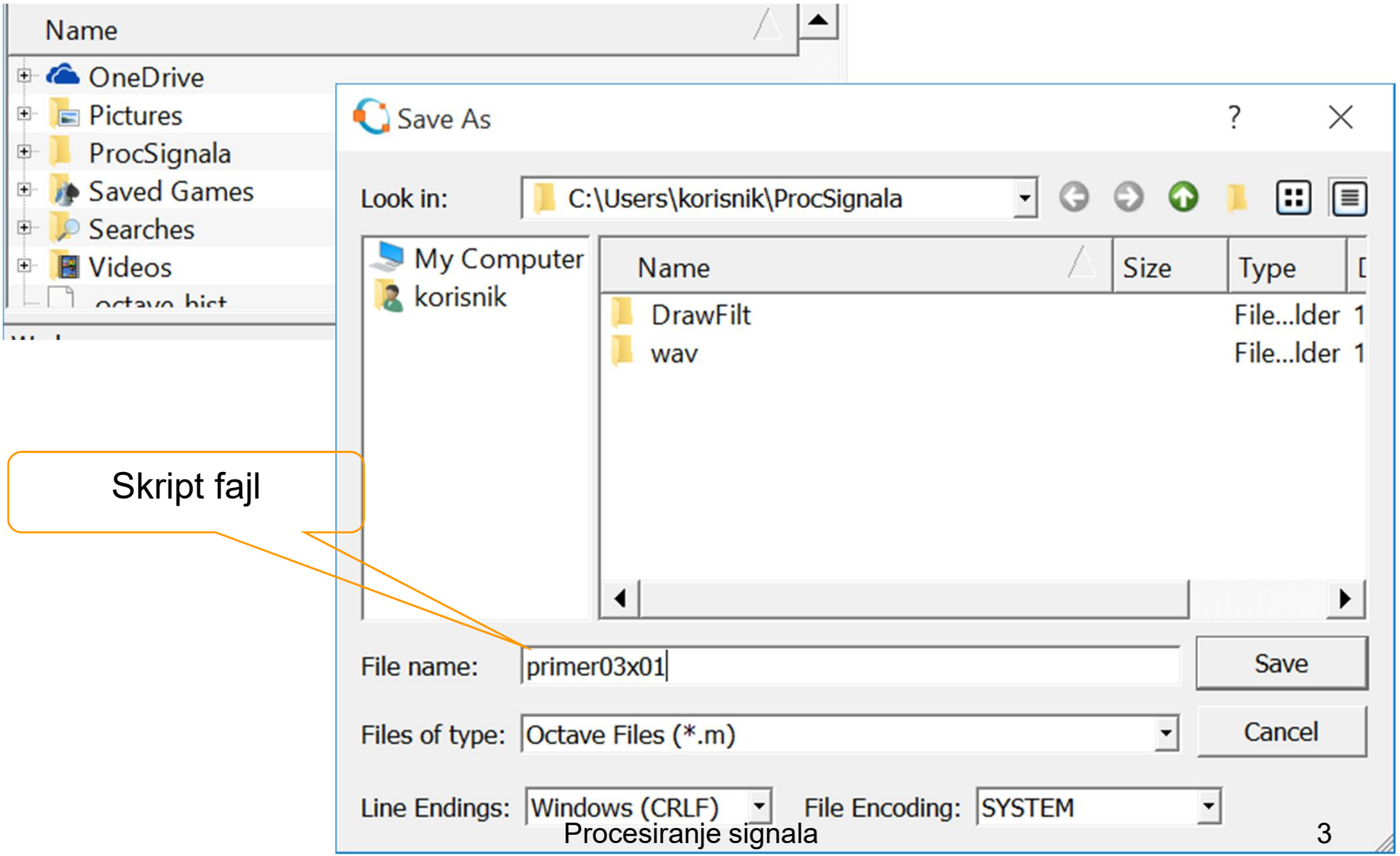
"This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein"

Sadržaj predmeta, Teorijska nastava

1. Uvodno predavanje. Upoznavanje sa planom i programom, ciljevima, ishodom i metodama.
2. Šta je procesiranje signala, istorijski pregled obrade signala, primeri primene.
3. Vizuelizacija signala (Python, Excel).
4. Kompleksni ekponencijalni diskretni signali. Primer sinteze muzičkog signala.
5. Furijeova analiza: Diskretna Furijeova transformacija (DFT) i serija (DFS). Brza Furijeova transformacija (Fast Fourier transform, FFT) i primena za spektralne analizatore i osciloskope.
6. Linearani filtri: konvolucija, idealni i realni filtri, dizajn filtra. Primena konvolucije u GPS sistemima.

…

Octave radni folder



Toolbox signal

```
>> pkg load signal
>> doc audioread
>> [y,fs]=audioread ("wav/dsp01.wav");
>> sound(y,fs)
```

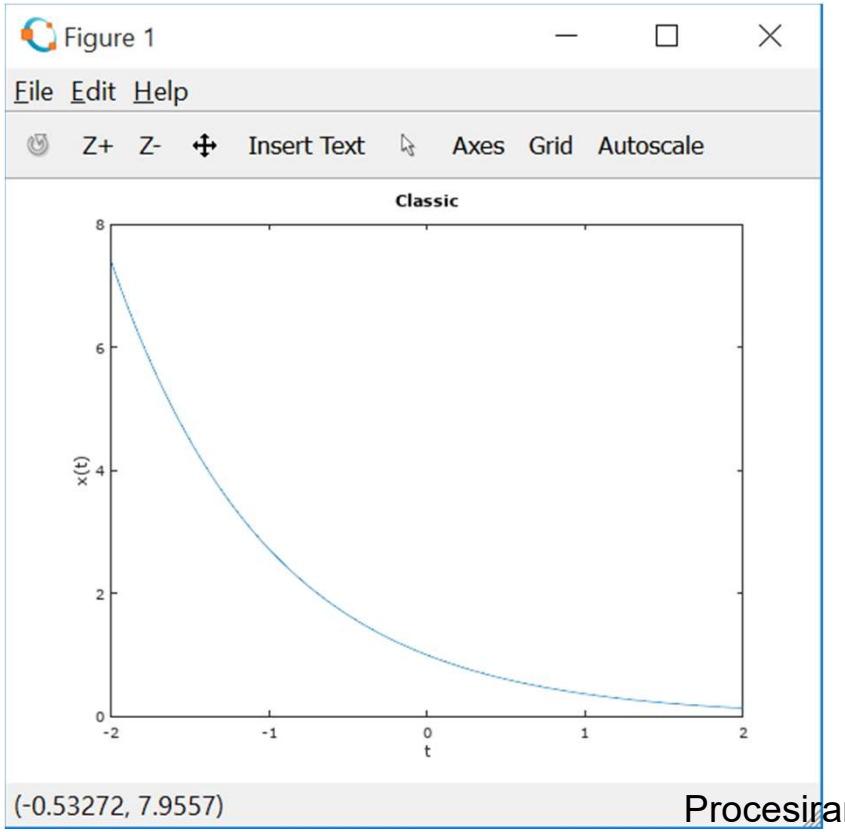
```
-- : [Y, FS] = audioread (FILENAME)
-- : [Y, FS] = audioread (FILENAME, SAMPLES)
-- : [Y, FS] = audioread (FILENAME, DATATYPE)
-- : [Y, FS] = audioread (FILENAME, SAMPLES, DATATYPE)
   Read the audio file FILENAME and return the audio data
   Y and sampling rate FS.

   The audio data is stored as matrix with rows
   corresponding to audio      frames and columns
   corresponding to channels.

   The optional two-element vector argument SAMPLES
   specifies starting and ending frames.
```

Workspace

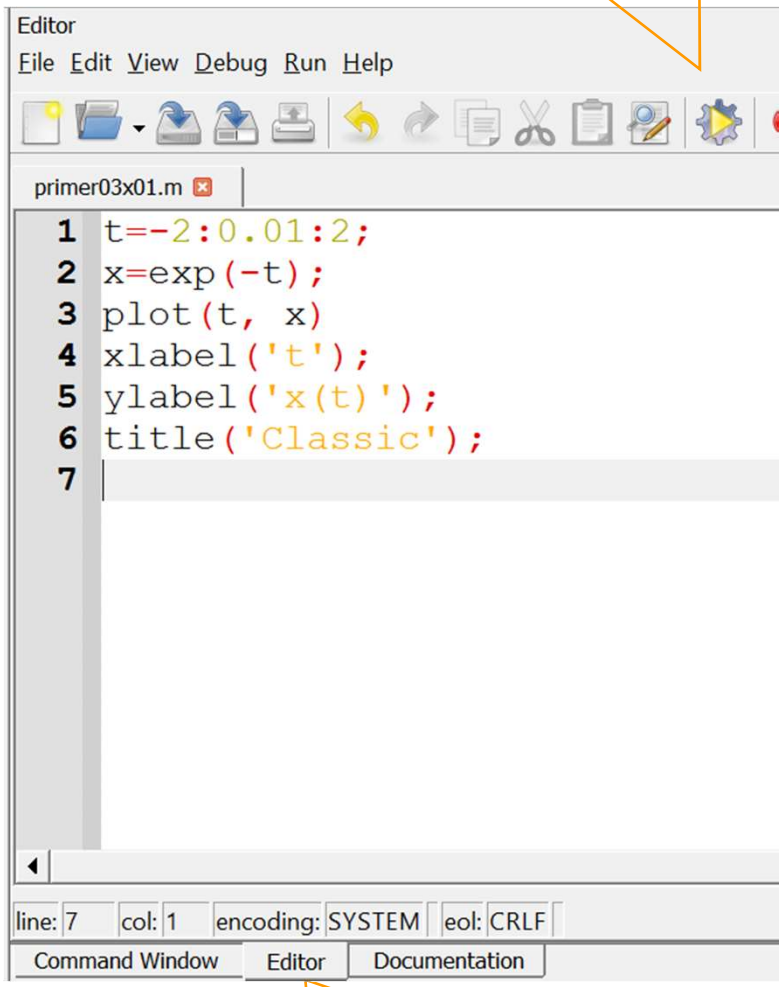
Filter

Name	Class	Dimension	Value
fs	double	1x1	44100
t	double	1x401	-2:0.01:2
x	double	1x401	[7.3891, 7...
y	double	165390x1	[0; 0; 0; 0;...

Octave primer editovanja i izvršavanja



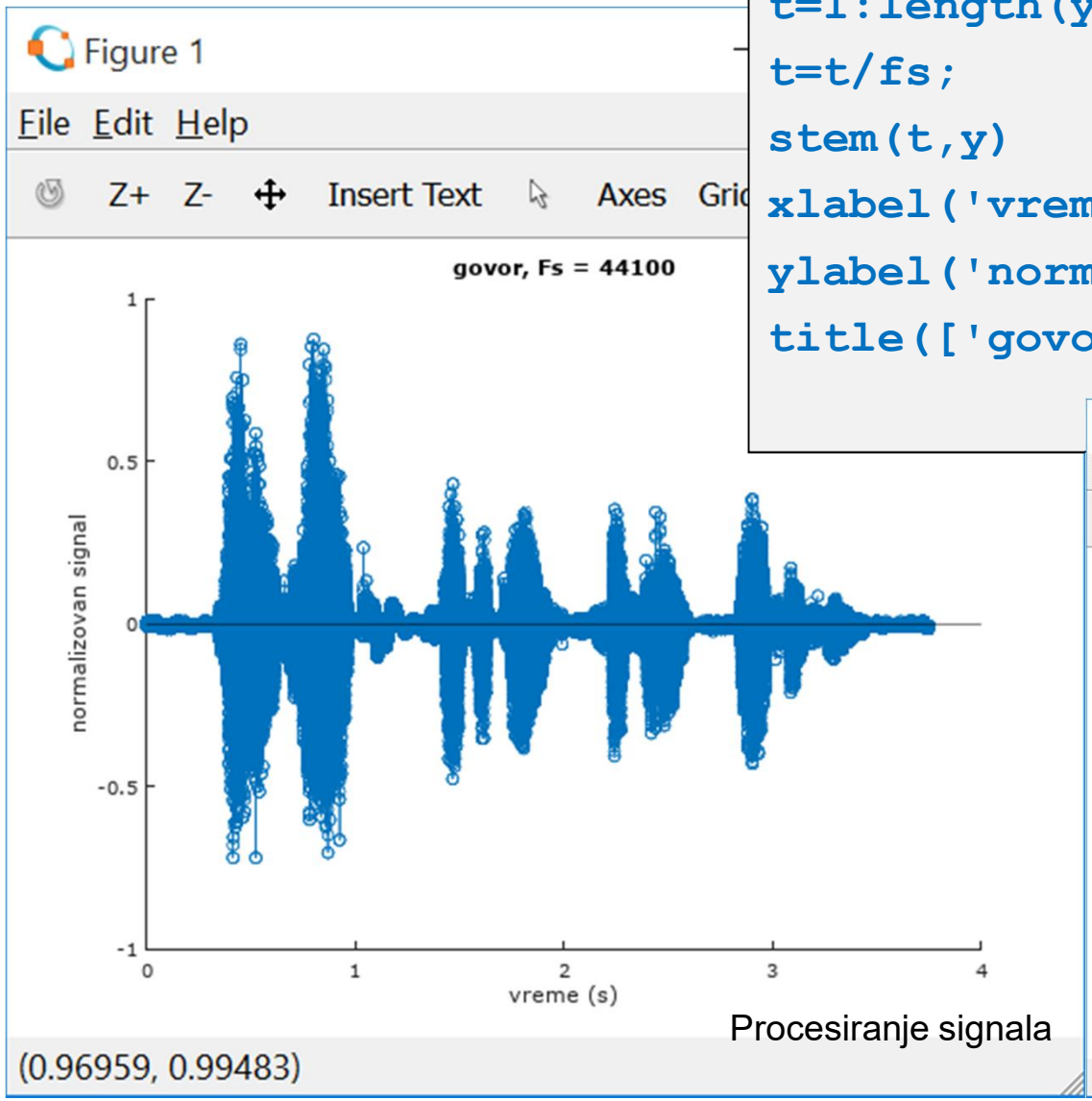
Izvrši

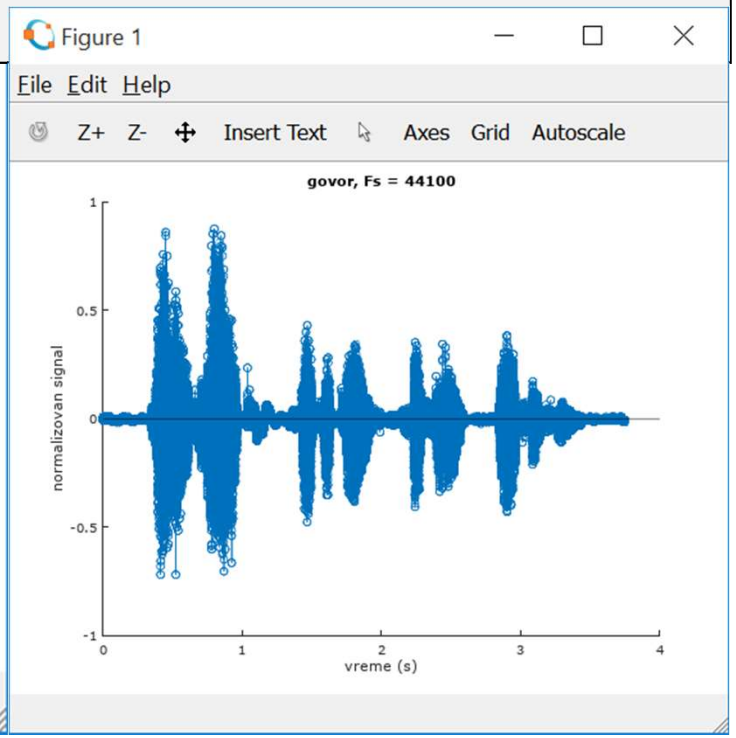


Editor

```
clear all, close all, clc
[y,fs]=audioread ("wav/dsp01.wav");
sound(y,fs)
t=1:length(y);
t=t/fs;
stem(t,y)
xlabel('vreme (s)');
ylabel('normalizovan signal');
title(['govor, Fs = ' num2str(fs)]);
```

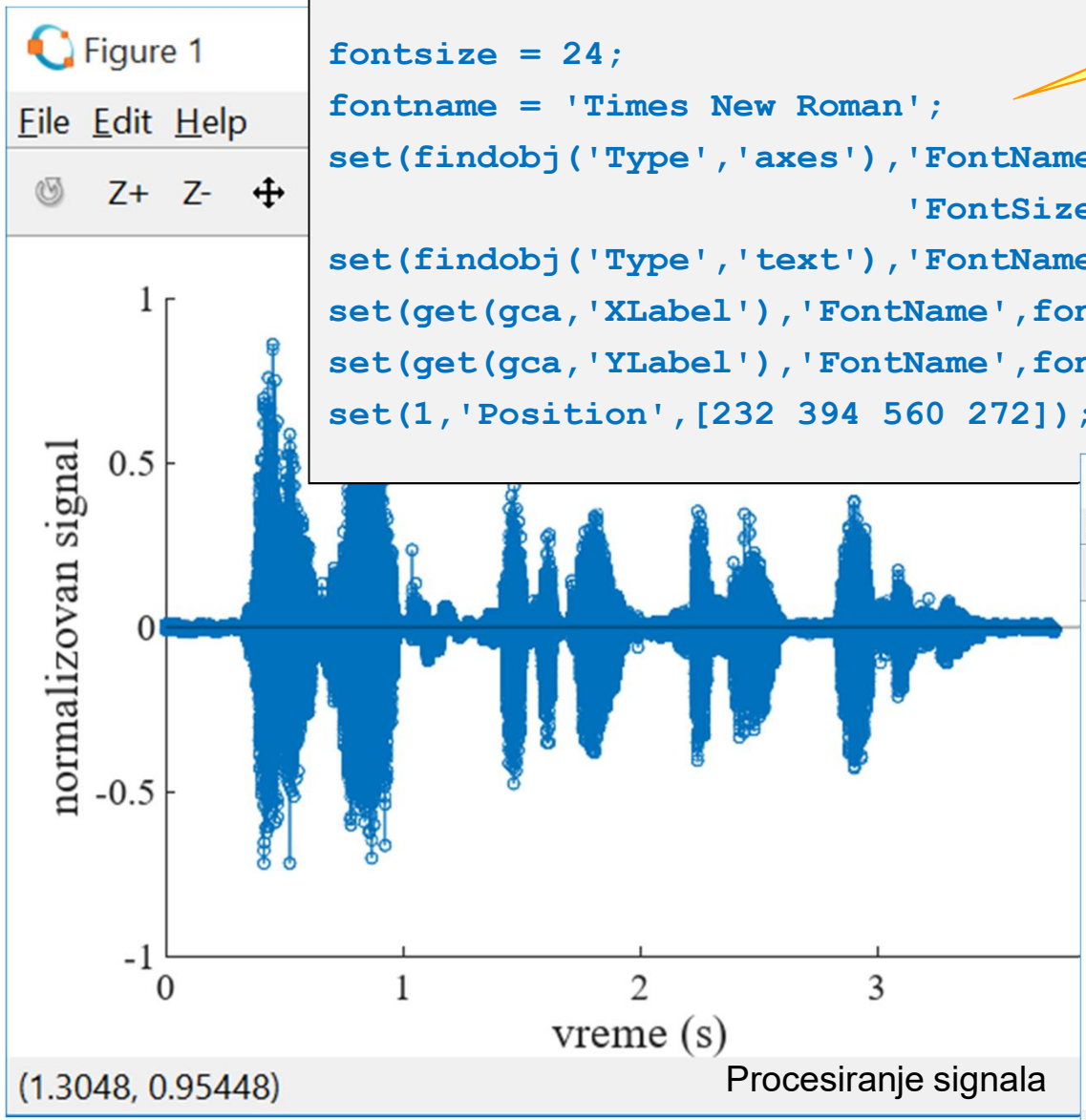
primer03x02.m

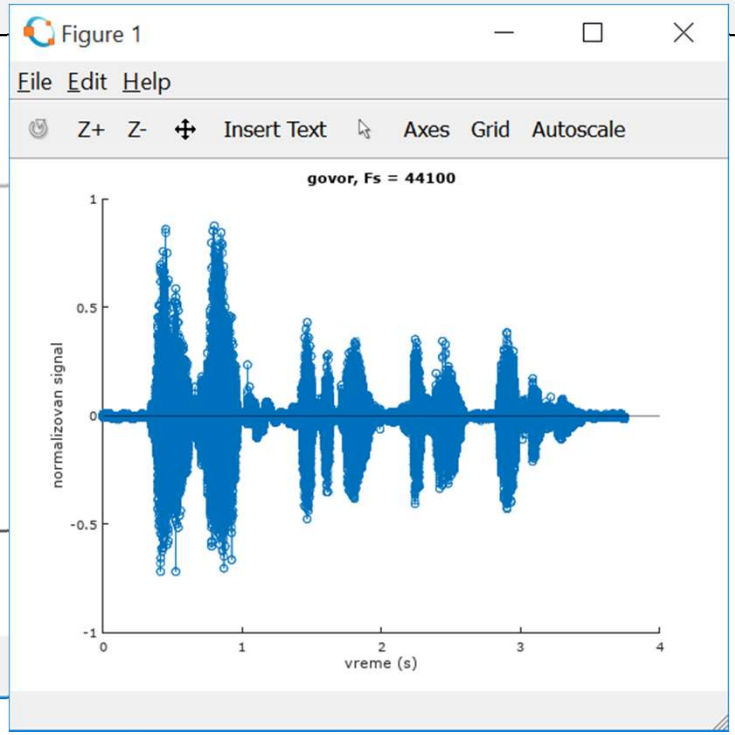




```
clear all, close all, clc
...

fontsize = 24;
fontname = 'Times New Roman';
set(findobj('Type','axes'),'FontName',fontname,...
                           'FontSize',round(fontsize*0.85));
set(findobj('Type','text'),'FontName',fontname,'FontSize',fontsize);
set(get(gca,'XLabel'),'FontName',fontname,'FontSize',fontsize);
set(get(gca,'YLabel'),'FontName',fontname,'FontSize',fontsize);
set(1,'Position',[232 394 560 272]);
```

primer03x03.m





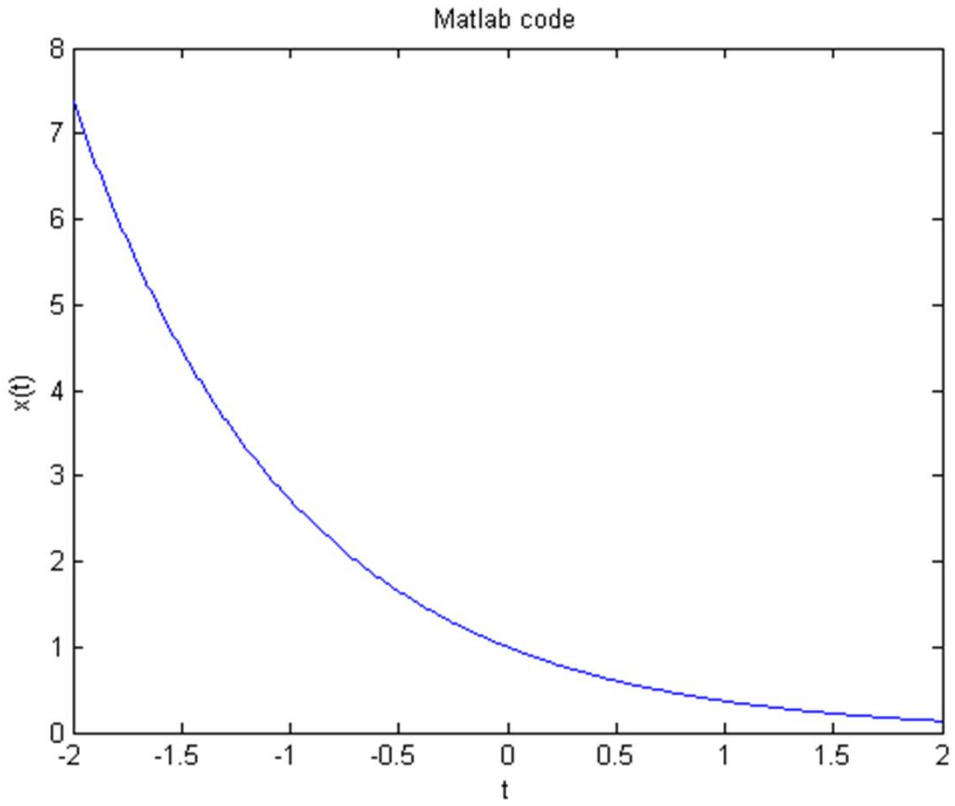
```
 # Created by Octave 4.2.1, Wed Mar 21 14:01:36 2018 GMT
   <unknown@unknown>
# name: a
# type: scalar struct
# ndims: 2
 1 1
# length: 130
...
# name: xscale
# type: sq_string
# elements: 1
# length: 6
linear
# name: xtick
# type: matrix
# rows: 1
# columns: 5
 0 1 2 3 4
```

```
a=get(gca)
save tmp.txt a
```

MATLAB skript - primer

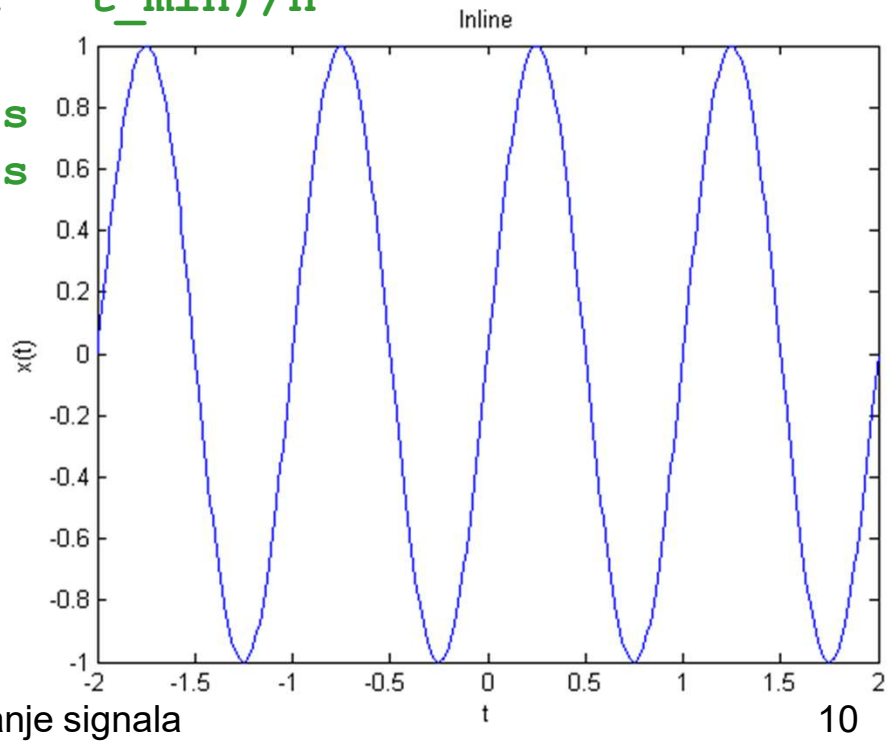
Definiše se vreme

```
t=-2:0.01:2;
x=exp(-t);
plot(t, x)
xlabel('t');
ylabel('x(t)');
title('Classic');
```



Inline function object

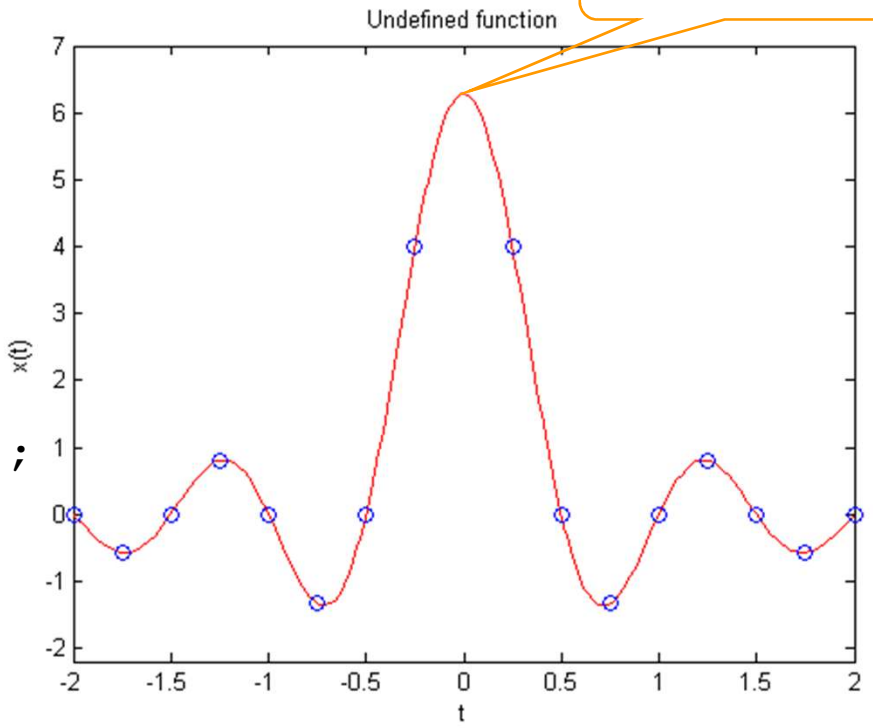
```
signal='sin(2*pi*t)'; % string with the function
time='t';             % string with variable
x=inline(signal, time);
t_min = -2; t_max =  2;
plotRange = [t_min t_max]; % the x-axis limits
N = 100; % step size is (t_max - t_min)/n
fplot(x, plotRange, n, 'b-')
xlabel('t');      % label x-axis
ylabel('x(t)');   % label y-axis
title('Inline ');% add title
```



Define a function before specifying the time

Signal that is not defined at a point

```
signal='(1./t).*sin(2*pi*t)';
time = 't';
x = inline(signal, time);
t1 = -2; t2 = 2;
x1 = -2.2; x2 = 7;
plotRange = [t1 t2 x1 x2];
fplot(x,plotRange,100,'r-')
xlabel('t'); ylabel('x(t)');
title('Signal with singularity');
hold on
  t = -2:0.25:2;
  x = (1./t).*sin(2*pi*t);
  plot(t,x,'o')
hold off
```



Not defined

$$x(t) = \frac{1}{t}\sin(2\pi t)$$

Not defined
at t=0

Limit of the signal exists

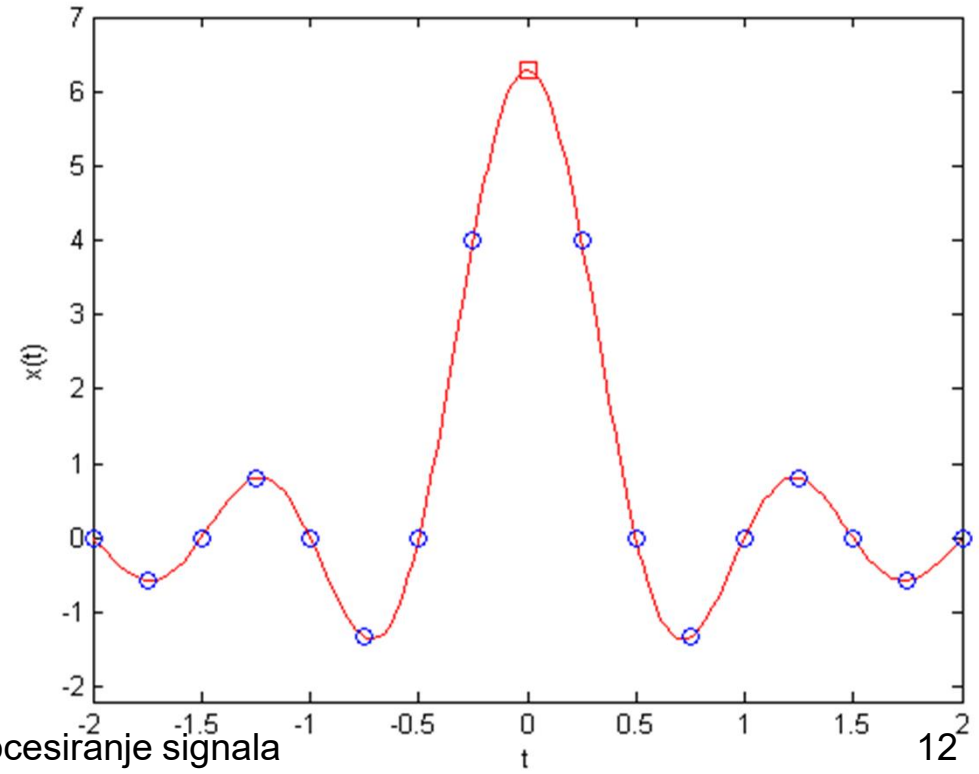
```
syms t x
x = eval(signal)
t = eval(time)
t0 = 0;
x1 = subs(x,t,t0)
x2 = limit(x,t,t0)
hold on
plot(t0,double(x2),'sr')
hold off
```

Define two symbolic variables

Find limit of the symbolic expression

$$x_1 = x(0) = NaN$$

$$x_2 = \lim_{t \to 0} x(t) = 2\pi$$



Simplify an expression

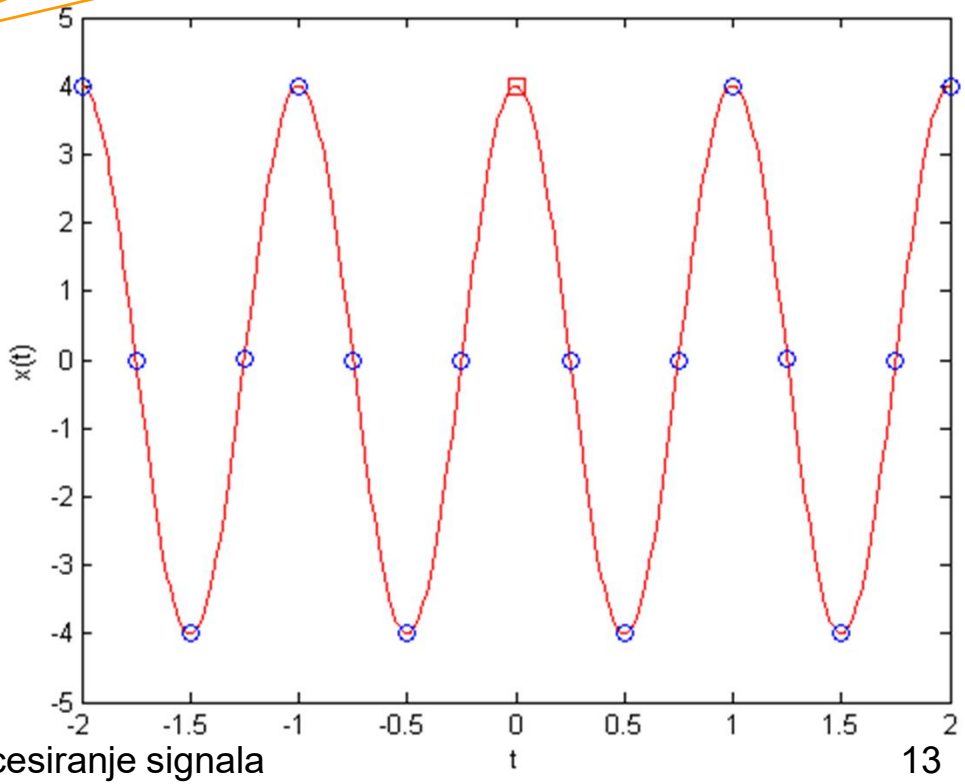
Define two symbolic variables

Simplify a symbolic expression

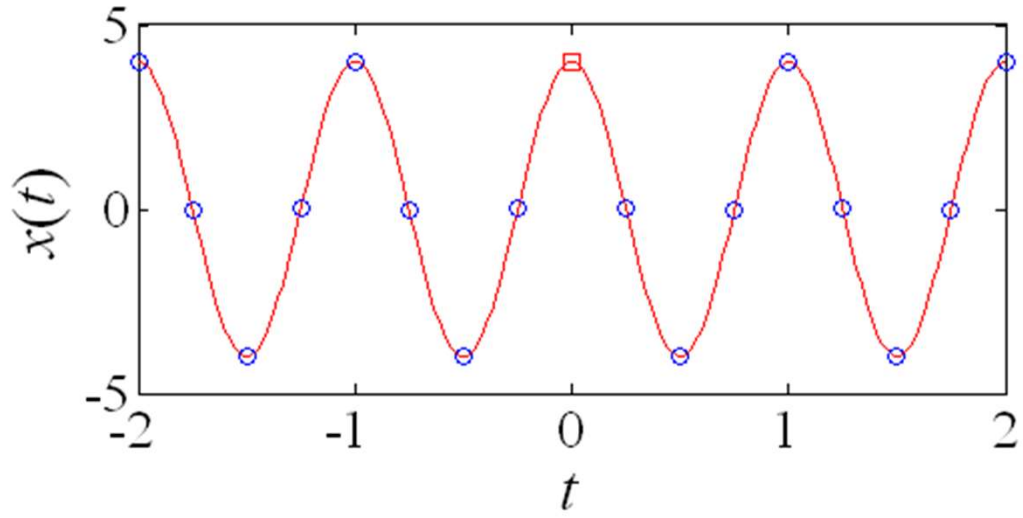
```
syms t x
x = eval(signal)
t = eval(time)
t0 = 0;
x1 = subs(x,t,t0)
x_simp = simplify(x)
x2 = subs(x_simp,t,t0)
hold on
plot(t0,double(x2),'sr')
hold off
```

$$x(t) = \left(\frac{(t+1)^2}{t} - \frac{(t-1)^2}{t} \right) \cos(2\pi t)$$

$$x_{\text{simp}}(t) = 4\cos(2\pi t)$$

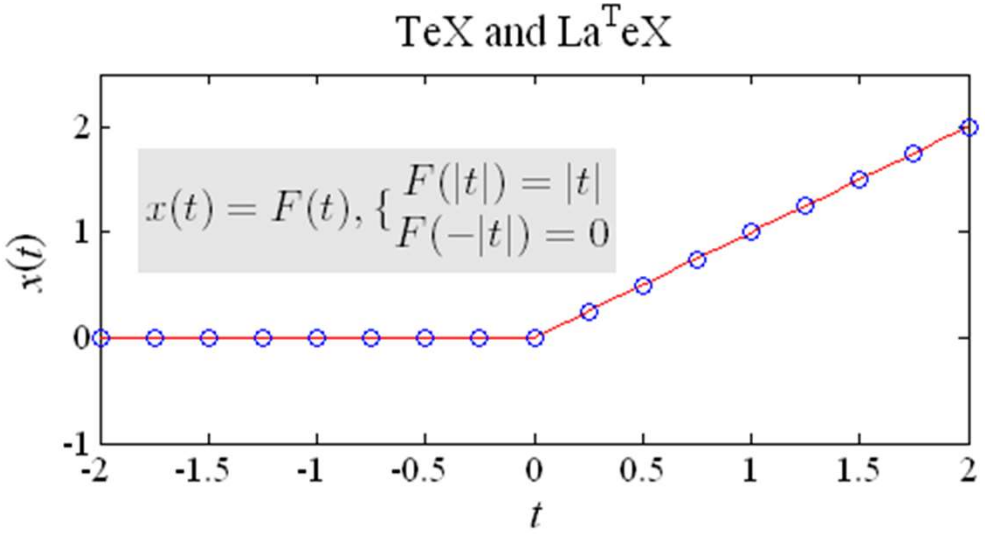


Refine figure typsetting




```
fontsize = 24;
fontname = 'Times New Roman';
set(findobj('Type','axes'),'FontName',fontname,...
                           'FontSize',round(fontsize*0.85));
set(findobj('Type','text'),'FontName',fontname,'FontSize',fontsize);
set(get(gca,'XLabel'),'FontName',fontname,'FontSize',fontsize);
set(get(gca,'YLabel'),'FontName',fontname,'FontSize',fontsize);
set(1,'Position',[232 394 560 272]);
```

LaTeX mathematical expressions

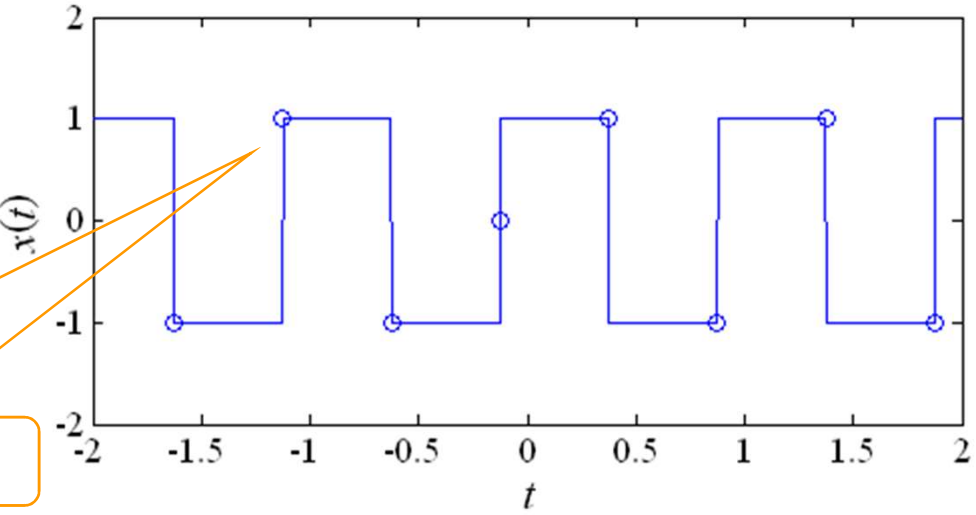



```
signal='t.*(t>0)';
time='t';
x=inline(signal,time);
t1=-2; t2=2;
x1=-1; x1=2.5;
plotRange=[t1 t2 x1 x2];
fplot(x,plotRange,100,'r-')
xlabel('\it t');
ylabel('{\itx}({\itt})');
tn = -2:0.25:2;
xn = feval(x, tn);
hold on, plot(tn,xn,'o'), hold off
texstr='$x(t)=F(t),\{\begin{array}{cl}F(|t|)=|t|\\F(-|t|)=0\end{array}$'
text('string',texstr,'interpreter','latex',...
   'FontSize',24,'pos',[-1.8 1.2],'BackgroundColor',[.9 .9 .9])
```

Anonymous function

$$x(t) = \mathrm{F}(\sin(2\pi t + \pi/4))$$

$$\mathrm{F}(0) = 0, \mathrm{F}(|a|) = 1, \mathrm{F}(-|a|) = -1$$



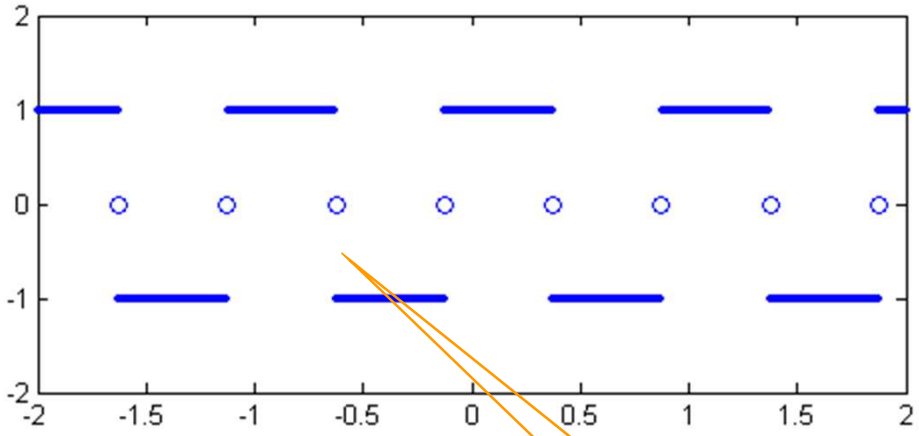
It should be 0, not 1

```
x= @(t) ((sin(2*pi*t+pi/4))>0)-((sin(2*pi*t+pi/4))<0);
fplot(x, [-2 2 -2 2],1000,'b-')
xlabel('\it t'); ylabel('{\itx}({\itt})');
t1 = [-13 -9 -5 -1 3 7 11 15]/8;
x1 = feval(x, t1);
hold on, plot(t1,x1,'bo'), hold off
```

Correct plot of the signal

$$x(t) = \mathrm{F}\left(\sin\left(2\pi t + \pi/4\right)\right)$$

$$\mathrm{F}(0) = 0, \mathrm{F}(|a|) = 1, \mathrm{F}(-|a|) = -1$$




```
x= @(t) ((sin(2*pi*t+pi/4))>0)-((sin(2*pi*t+pi/4))<0);
f = @(t) (t>0) - (t<0);
fplot(x,[-2 2 -2 2],1000,'b.')
t1 = [-13 -9 -5 -1 3 7 11 15]/8;
sym xsin
xsin = 'sin(2*pi*t+pi/4)'
for ind = 1:length(t1)
 xs(ind)=eval(simplify(subs(xsin,sym(t1(ind),'r'))));
end
x2 = feval(f, xs);
hold on, plot(t1,x2,'ob'), hold off
```

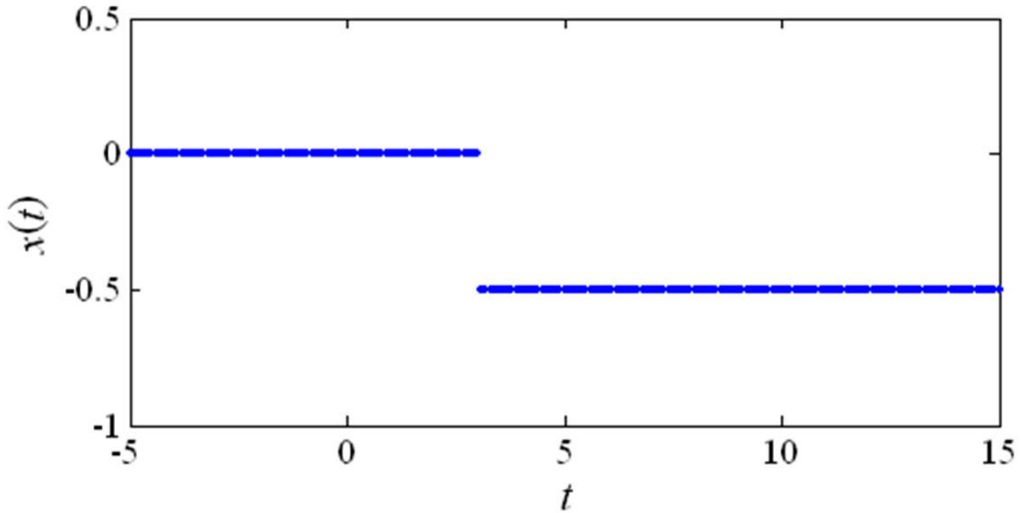
Correct values

Unit step signal

$$u(t) = \begin{cases} 1, & t > 0 \\ 0, & t \le 0 \end{cases}$$

$$x(t) = -\frac{1}{2} u(t-3)$$

```
signal = 't>0';
time = 't';
x = inline(signal,time);
k = (-5:0.1:15)';
plot(k,-(1/2)*x(k-3),'b.')
```



Sinusoidalni signal

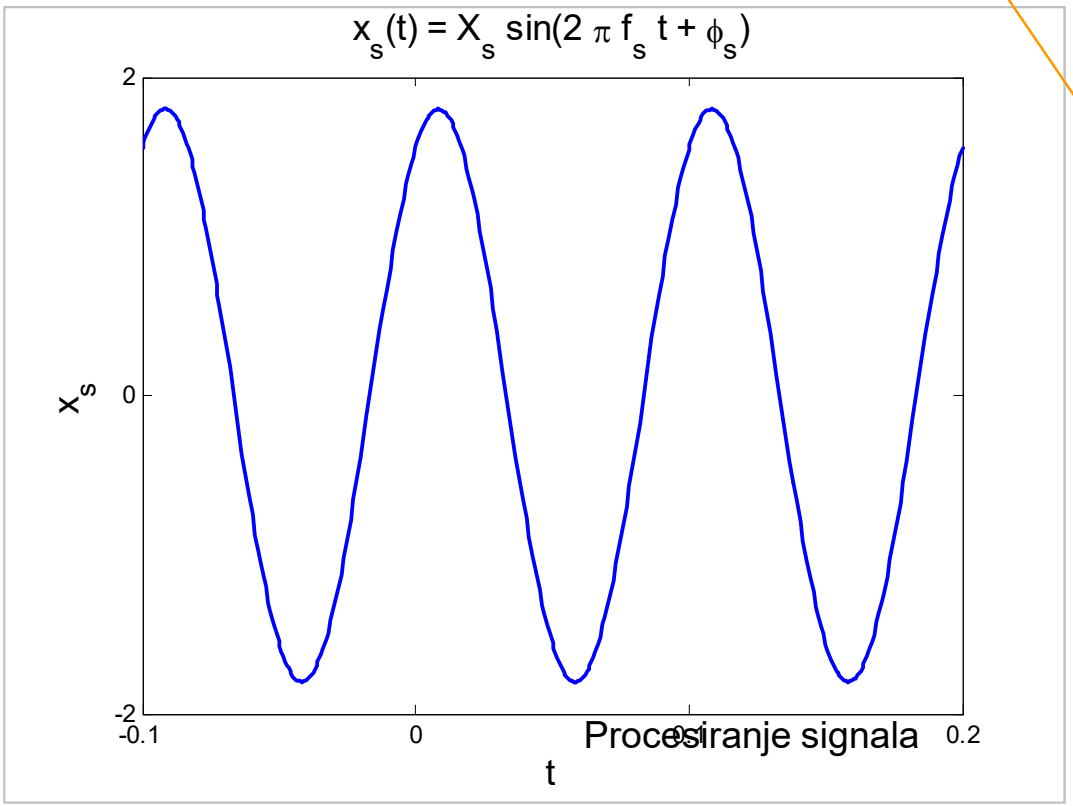
$$x_s(t) = X_s \sin(2\pi f_s t + \phi_s)$$

Amplituda

Faza u radijanima

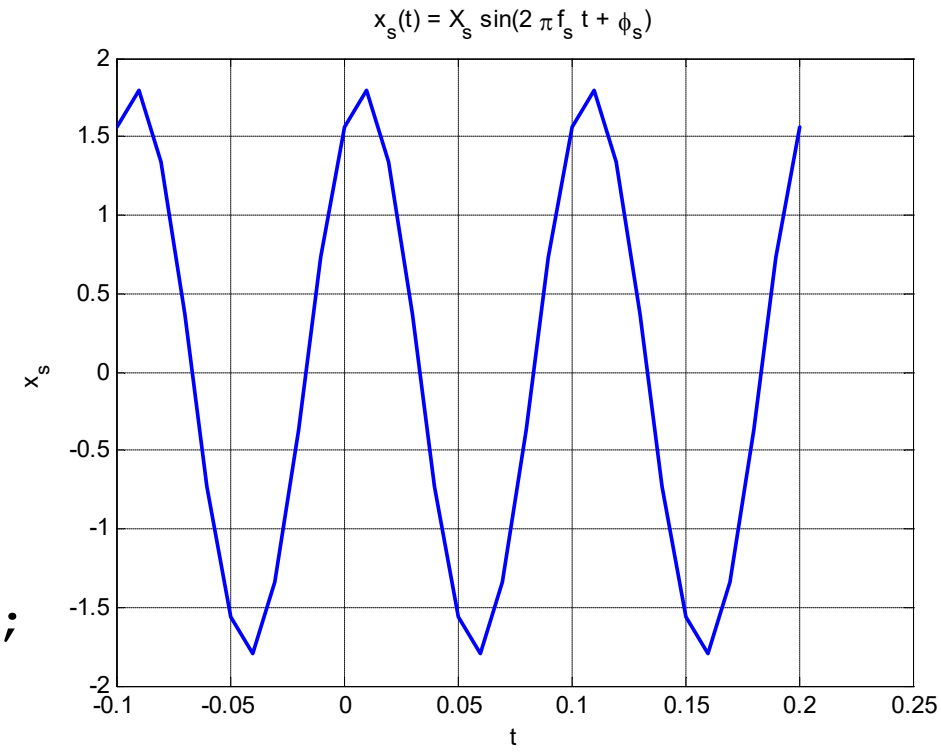
Vreme u sekundama (s)

Frekvencija u Hertz (Hz)



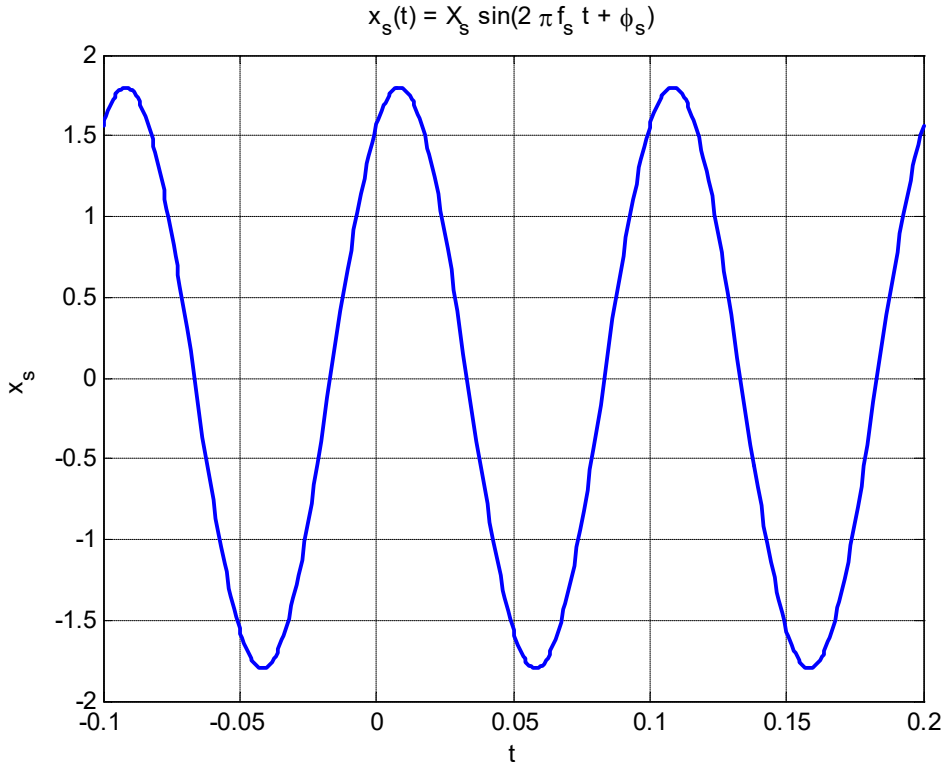
MATLAB kod za sin signal

```
Xs  = 1.8;
fs = 10;
fi = pi/3;
t1 = -0.1;
tstep = 0.01;
t2 = 0.2;
t = t1:tstep:t2;
x = Xs*sin(2*pi*fs*t+fi);
plot(t, x)
xlabel('t')
ylabel('x_s')
title('x_s(t) = X_s sin(2 \pi f_s t + \phi_s)')
grid on
```



MATLAB kod za kontinualne

```
Xs  = 1.8;
fs = 10;
fi = pi/3;

t1 = -0.1;
t2 = 0.2;
t = [t1, t2];
```

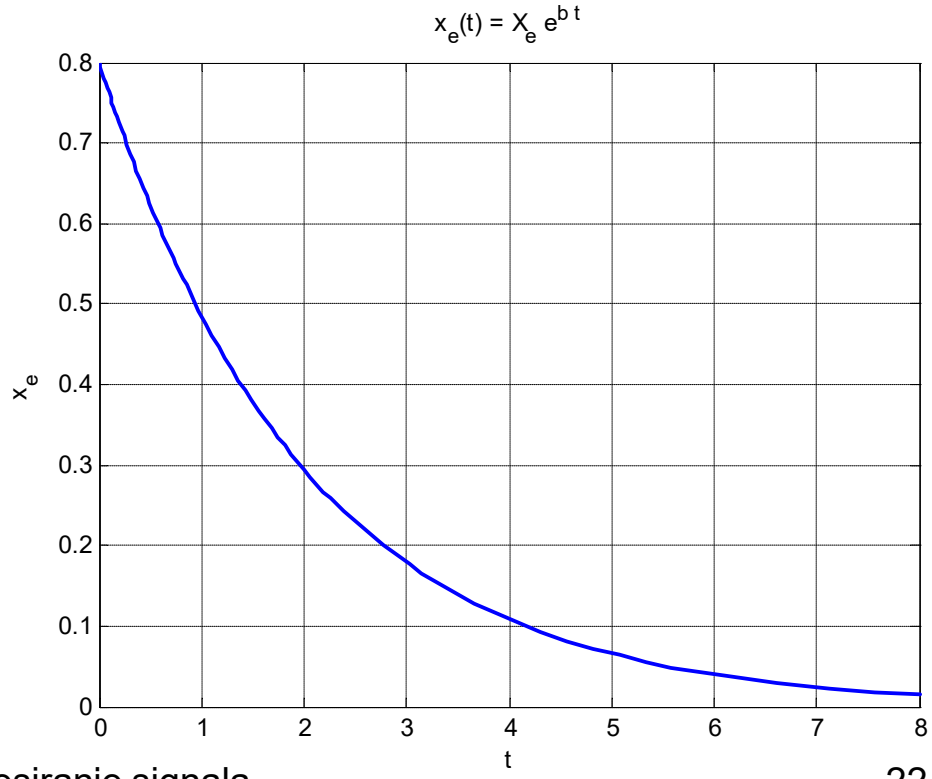



```
x = inline('Xs*sin(2*pi*fs*t+fi)','t','Xs','fs','fi');
fplot(x,t,2e-3,1,'-',Xs,fs,fi)
xlabel('t'); ylabel('x_s'); grid on
title('x_s(t) = X_s sin(2 \pi f_s t + \phi_s)')
```

Eksponencijalni signal

$$x_e(t) = X_e \, \mathrm{e}^{bt}$$

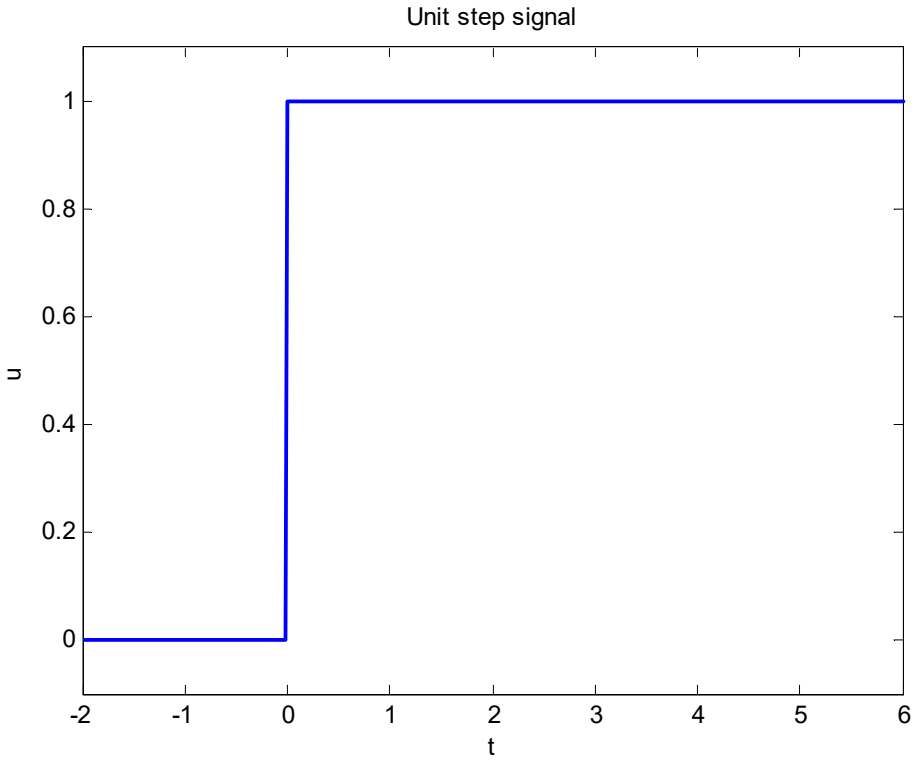
```
x = inline('Xe*exp(b*t)','t','Xe','b');

Xe  = 0.8;
b = -0.5;

t1 = 0;
t2 = 8;
t = [t1, t2];

fplot(x,t,2e-3,1,'-',Xe,b)
xlabel('t')
ylabel('x_e')
title('x_e(t) = X_e e^{b t}')
grid on
```



Unit step signal
Jedinična odskočna funkcija

$$u(t) = \begin{cases} 1, & t > 0 \\ 0, & t \leq 0 \end{cases}$$

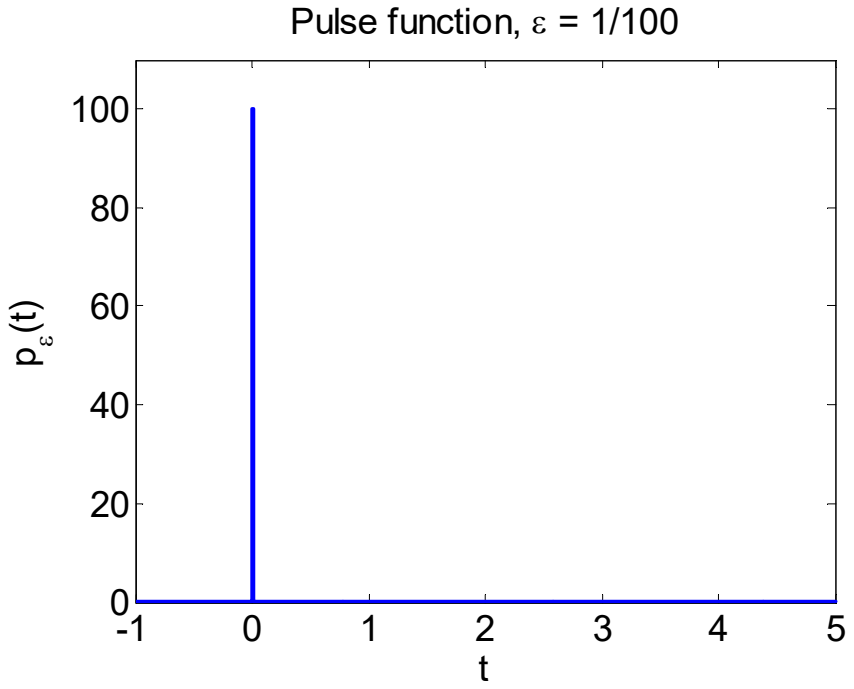
```
x = inline('t>0', 't');

t1 = -2;
t2 = 6;
t = [t1, t2];

fplot(x, t)

xlabel('t')
ylabel('u')
title('Unit step signal')
axis([t -0.1 1.1])
```



Pulse signal
Jedinični impulsni signal

$$p_\varepsilon(t) = \begin{cases} \dfrac{1}{\varepsilon}, & 0 < t \le \varepsilon \\ 0, & \text{otherwise} \end{cases}$$

```
x = inline('(1/e)*((t>0)&(t<=e))','t','e');

e = 1/100;
t1 = -1;
t2 = 5;
t = [t1, t2];

fplot(x,t,1e-5,1000,'-',e)

set(gca,'FontSize',16)
xlabel('t')
ylabel('p_\epsilon(t)')
axis([t -0.1 1.1/e])
title('Pulse function, \epsilon = 1/100')
```



Unit impulse signal (Dirac delta)

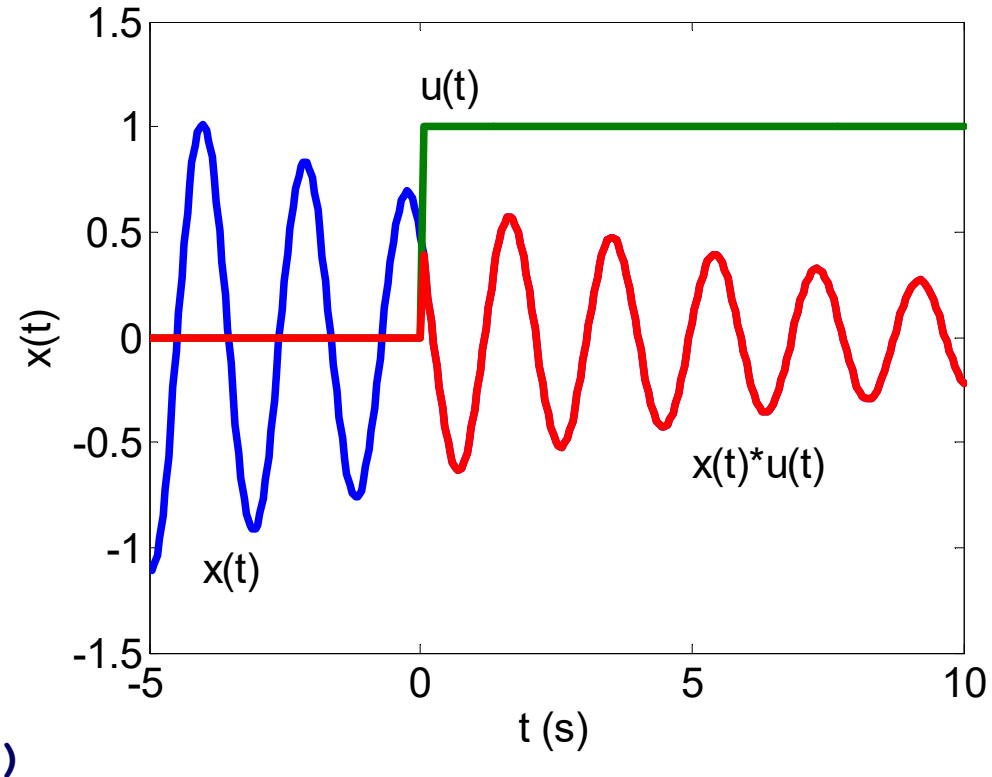
$$\delta(t) = \lim_{\varepsilon \to 0} p_{\varepsilon}(t)$$

$$\delta(t) = 0, \quad t \neq 0$$

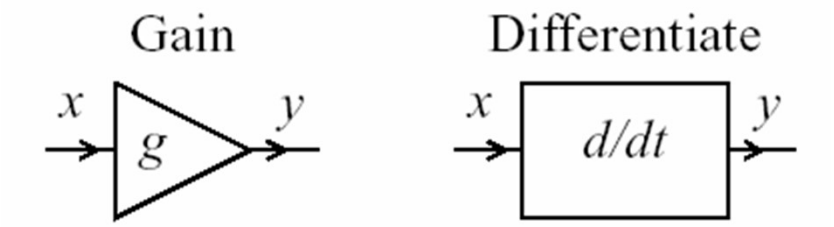
$$\int_{-\infty}^{\infty} \delta(t)\,\mathrm{d}t = 1$$

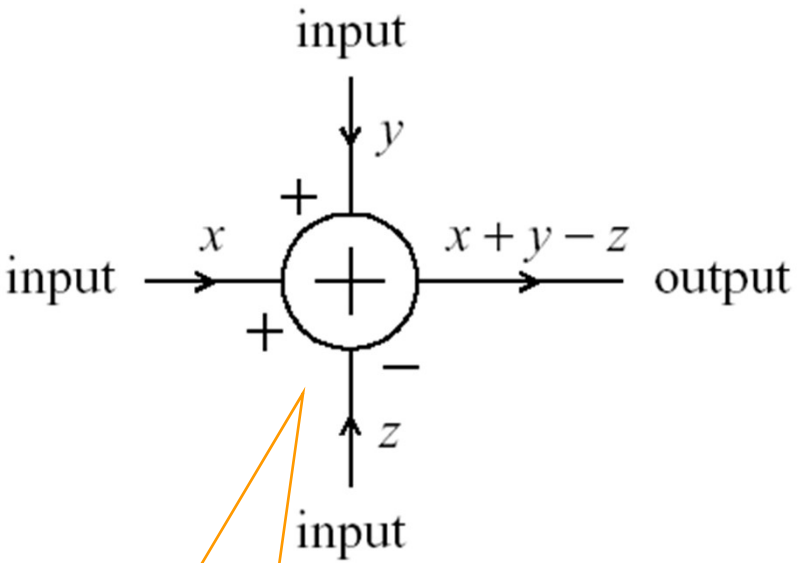
Kauzalan signal u MATLAB-u

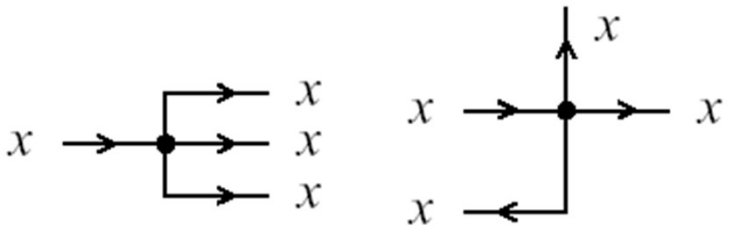
```
B = 0.02;
a = 0.1;
f = 0.53;
phi = 3*pi/4;
t = -5:0.05:10;
x = B^a*exp(-a*t).*sin(...
    2*pi*f*t+phi);
xu = x.*(t>0);
u = (t>0);
plot(t,x,t,u,t,xu)
ylabel('x(t)')
xlabel('t (s)')
text(0,1.2,'u(t)')
text(-4,-1.1,'x(t)')
text(5,-.6,'x(t)*u(t)')
axis([t(1) t(end) -1.5 1.5])
```



Elementi blok dijagrama





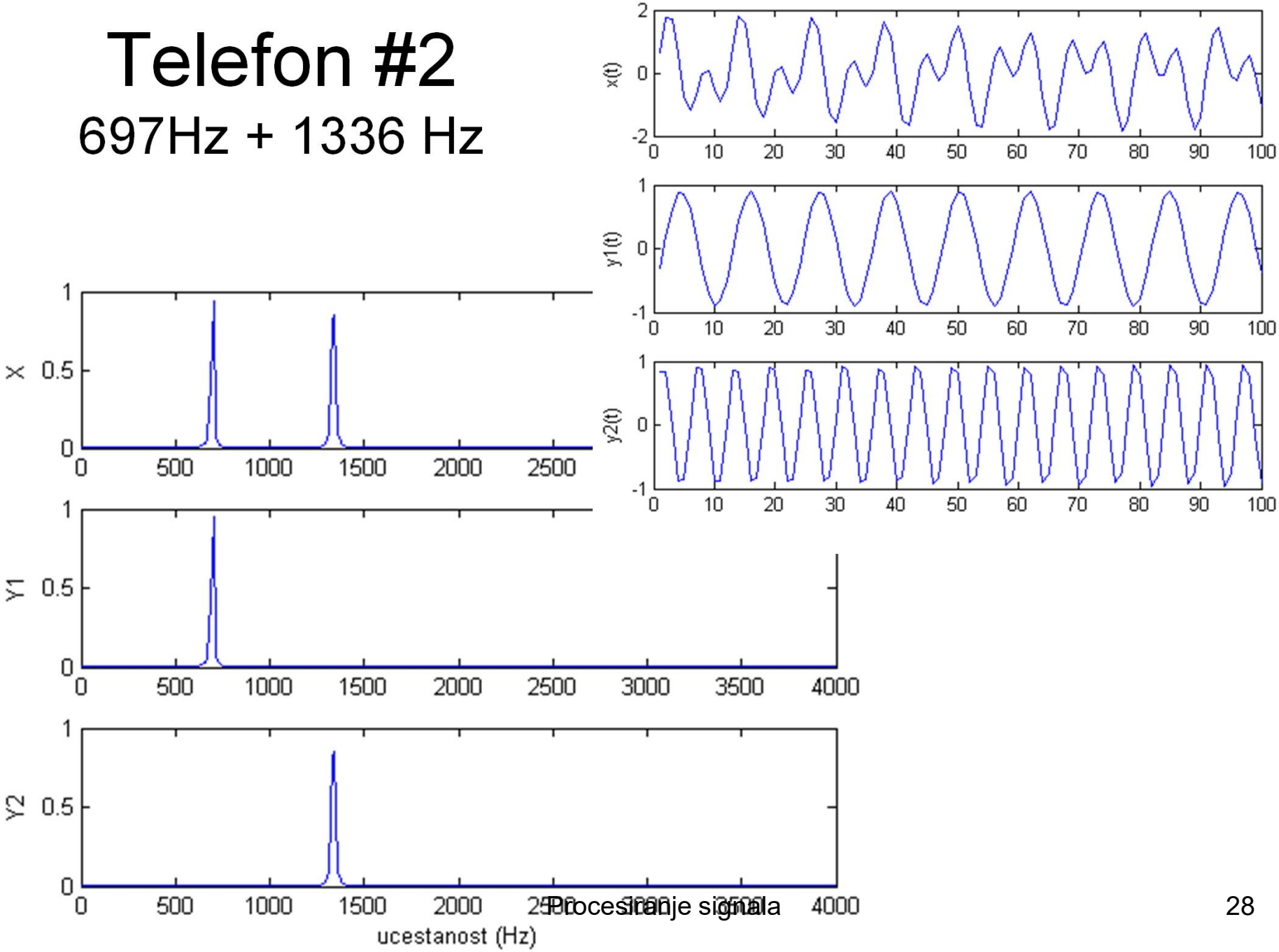


Summing point

Takeoff point

Telefon #2

697Hz + 1336 Hz

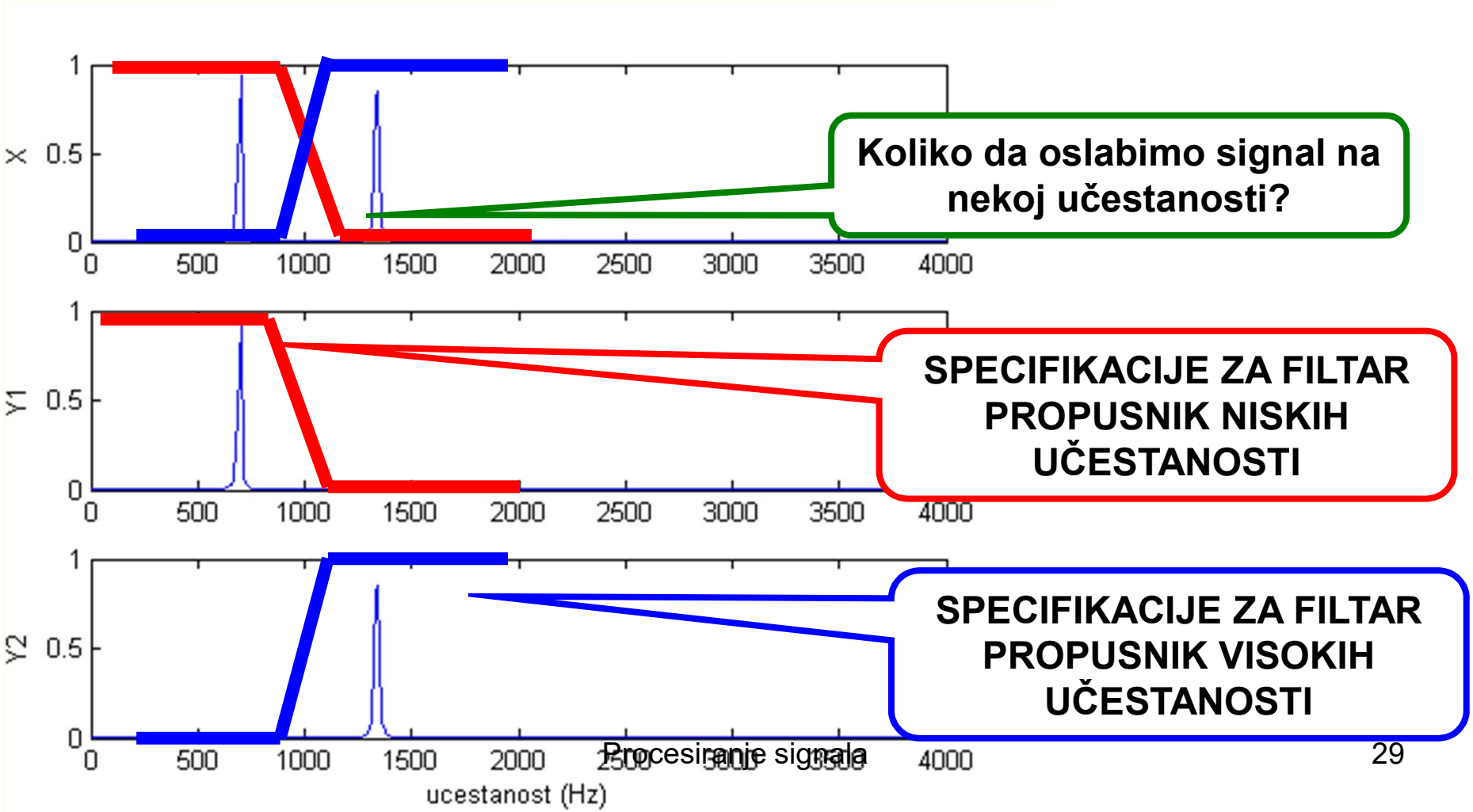


Telefon #2

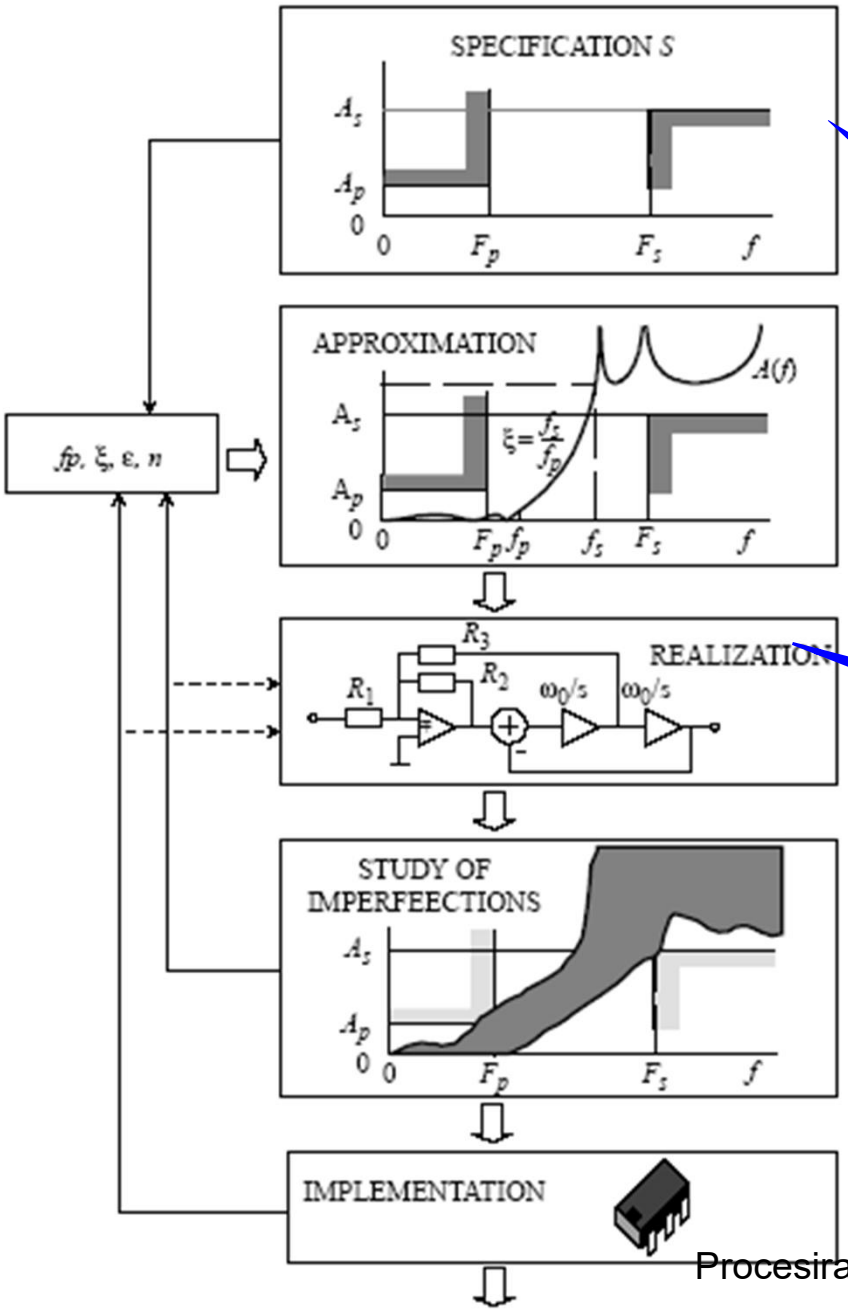
697Hz + 1336 Hz

697, 770, 852, 941 Hz

1209, 1336, 1477, 1633 Hz



Od specifikacija do realizacije



Specifikacije

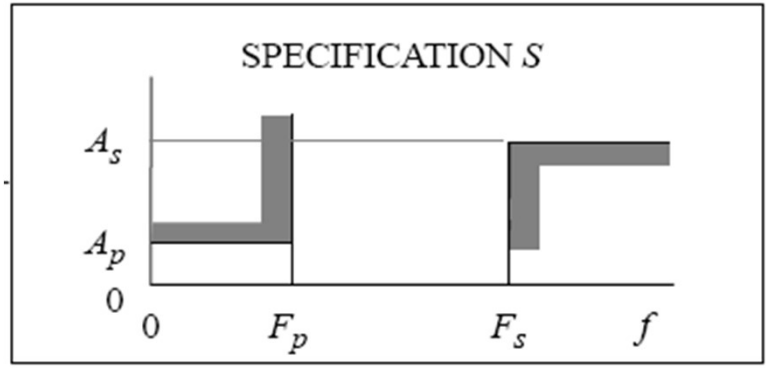
Sinteza

Specifikacije

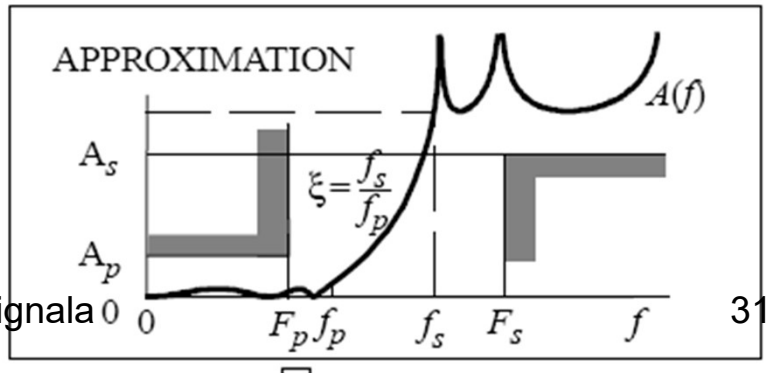
- Definišu se dozvoljene **tolerancije** u određenim frekvencijskim opsezima

$H(s)$ je racionalna funkcija kompleksne frekvencije
$s=\delta+j\omega$, $s= j2\pi f$

$$a(f) = -20\log(|H(j2\pi f)|)$$

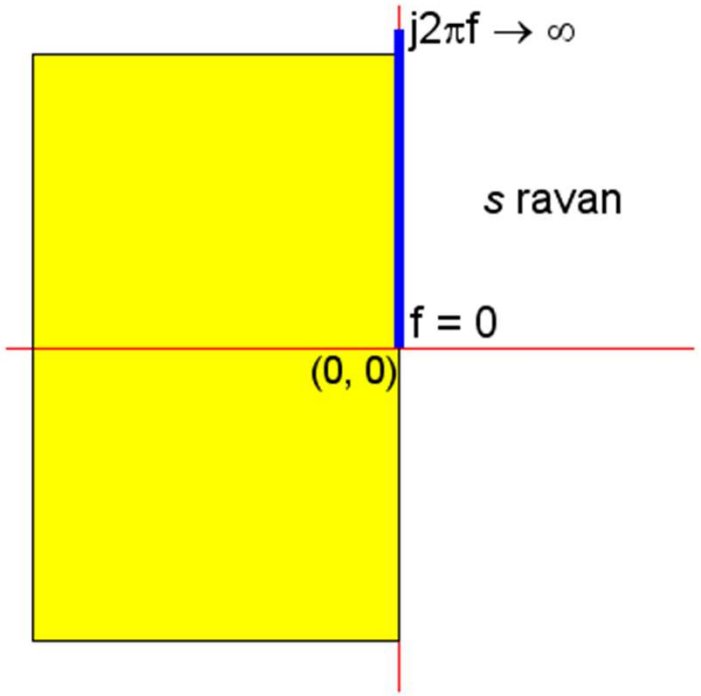


$$H(s) = \frac{\sum_{k=0}^{M} c_k s^k}{\sum_{k=0}^{N} d_k s^k} = \frac{C(s)}{D(s)}$$



Frekvencijski odziv

$$H(s) = \frac{\sum_{k=0}^{M} c_k s^k}{\sum_{k=0}^{N} d_k s^k} = \frac{C(s)}{D(s)}$$

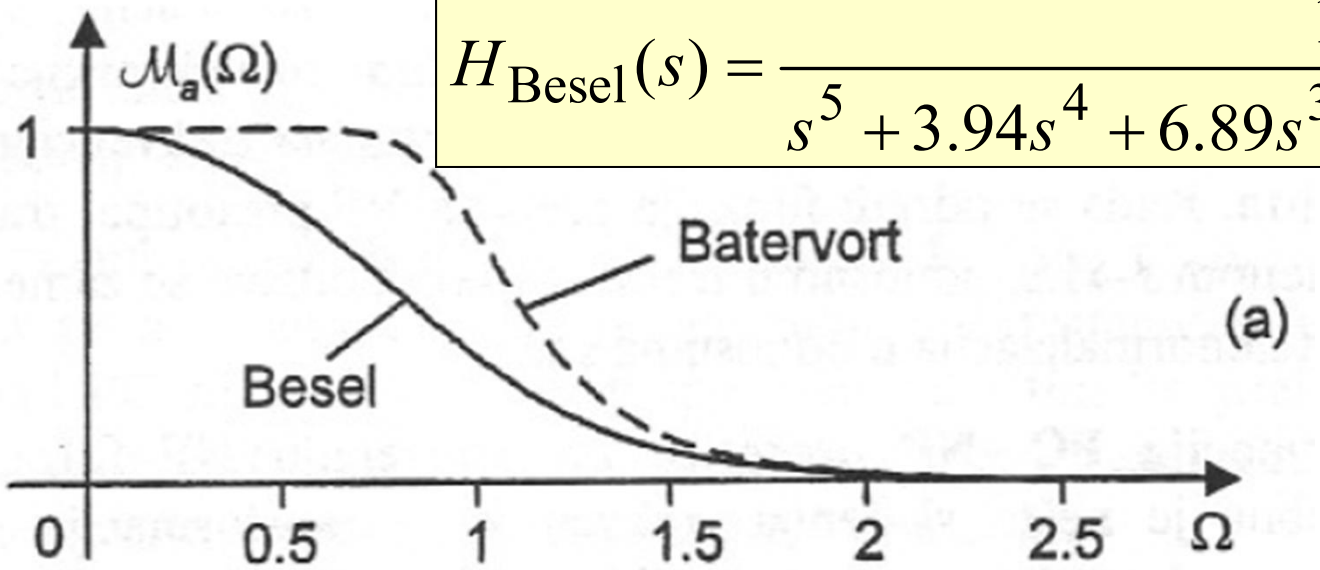


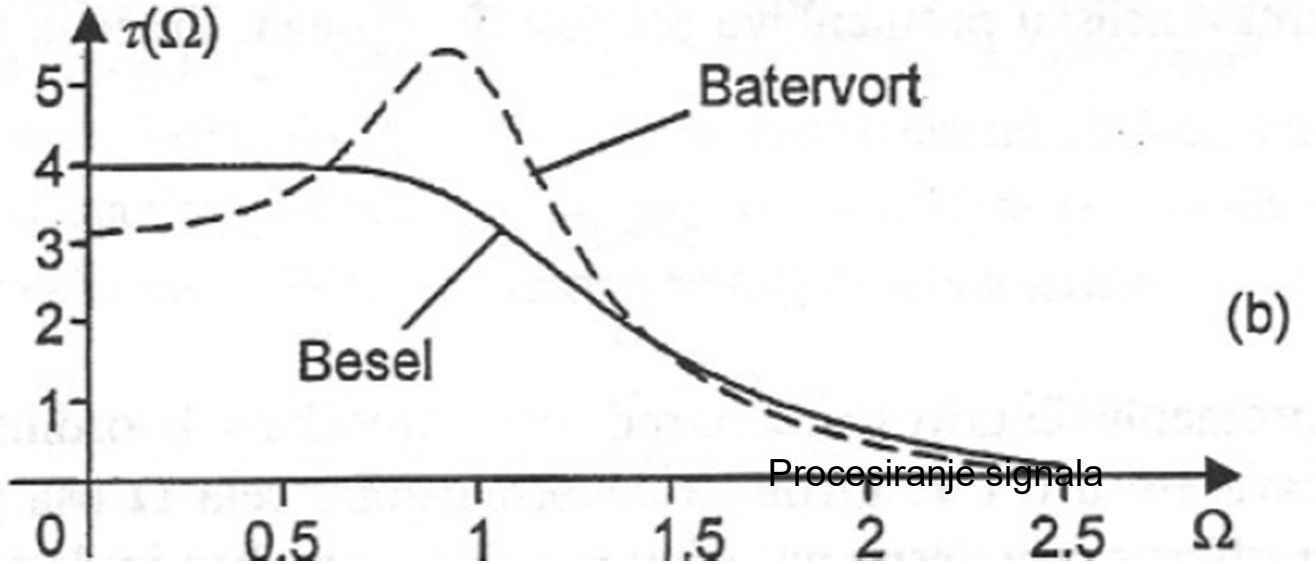
$$H(j2\pi f)$$

$$0 \le f \le \infty$$

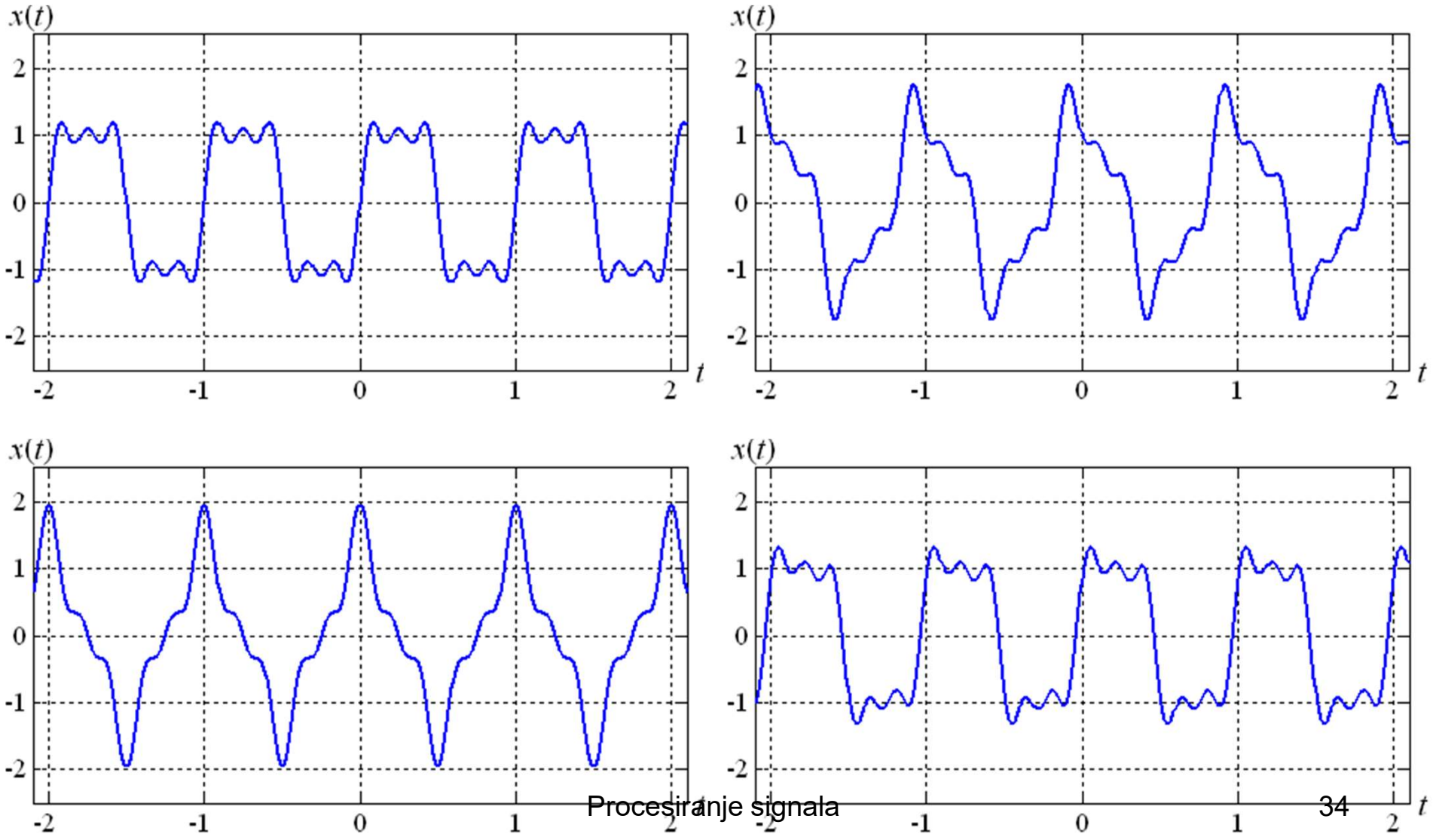
$$H_{\text{Batervort}}(s) = \frac{1}{s^5 + 3.24s^4 + 5.24s^3 + 5.24s^2 + 3.24s + 1}$$

$$H_{\text{Besel}}(s) = \frac{1}{s^5 + 3.94s^4 + 6.89s^3 + 6.78s^2 + 3.81s + 1}$$





Uticaj fazne karakteristike



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