Sinteza električnih filtara

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Cilj predmeta

Savladati teorijske osnove
analognih električnih filtara

Korišćenje računarskih alata
za projektovanje filtara

Ishod predmeta

- Da se na osnovu zahteva za rad uređaja
  - definišu specifikacije koje filter treba da zadovolji
  - da se izabere najbolja aproksimacija
  - da se izabere tehnologiju za implementaciju.
- Koristeći alate da se
  - projektuje filter (sinteza)
  - uradi simulacija
  - uradi optimizacija

Teorijska nastava

- Uloga filtara u složenim sistemima i uređajima
- Izbor aproksimacione funkcije
- Projektovanje korišćenjem računarskih alata
- Realizacija filtara
  - aktivni sa operacionim pojačavačima
  - OTA
  - SS
  - pasivni filtri
  - univerzalna filtarska integrisana kola
  - programabilna analogna kola

Praktična nastava

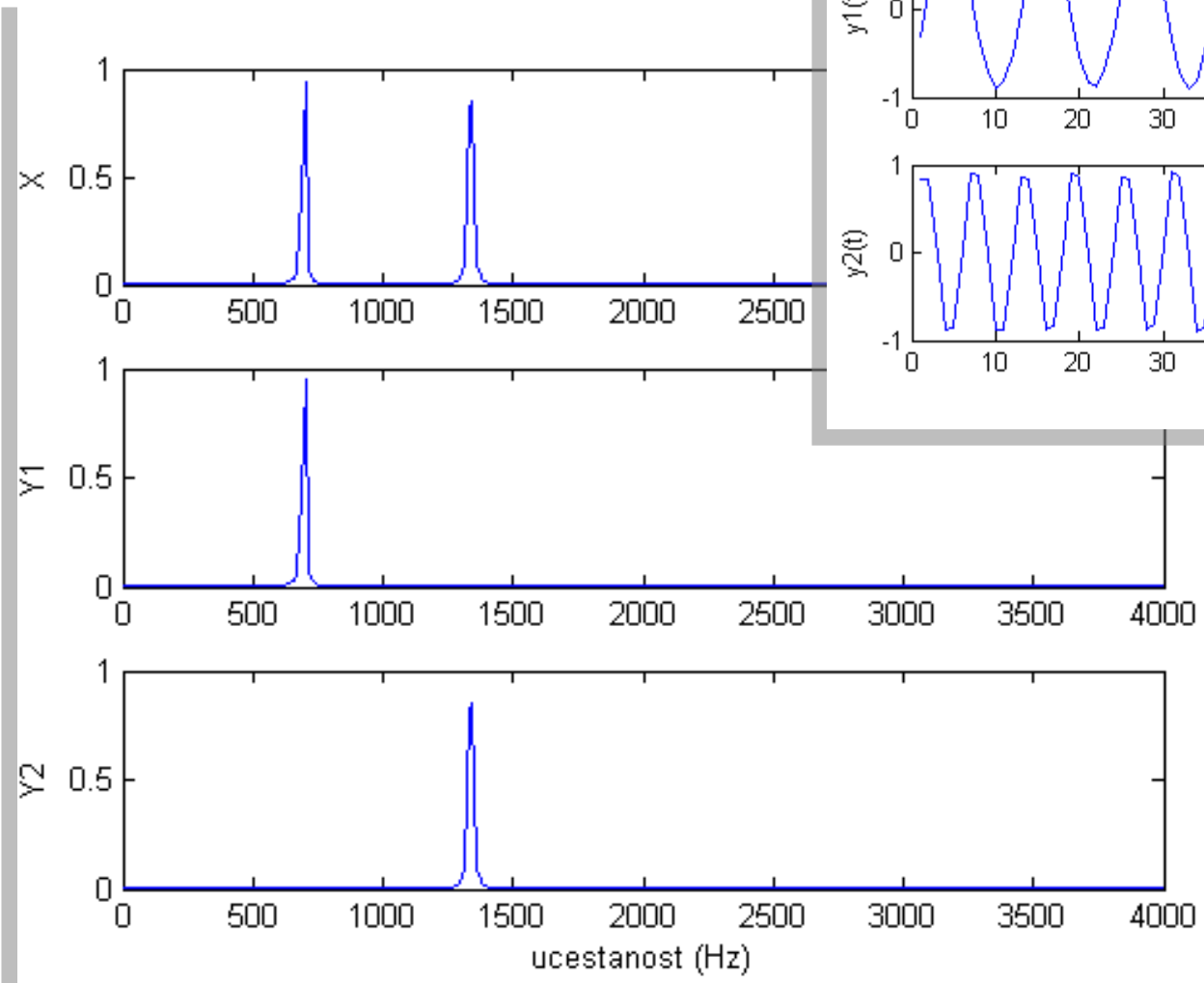
- Korišćenje standardnih računarskih alata za
  - projektovanje
  - analizu i
  - simulaciju
- rada električnih filtara

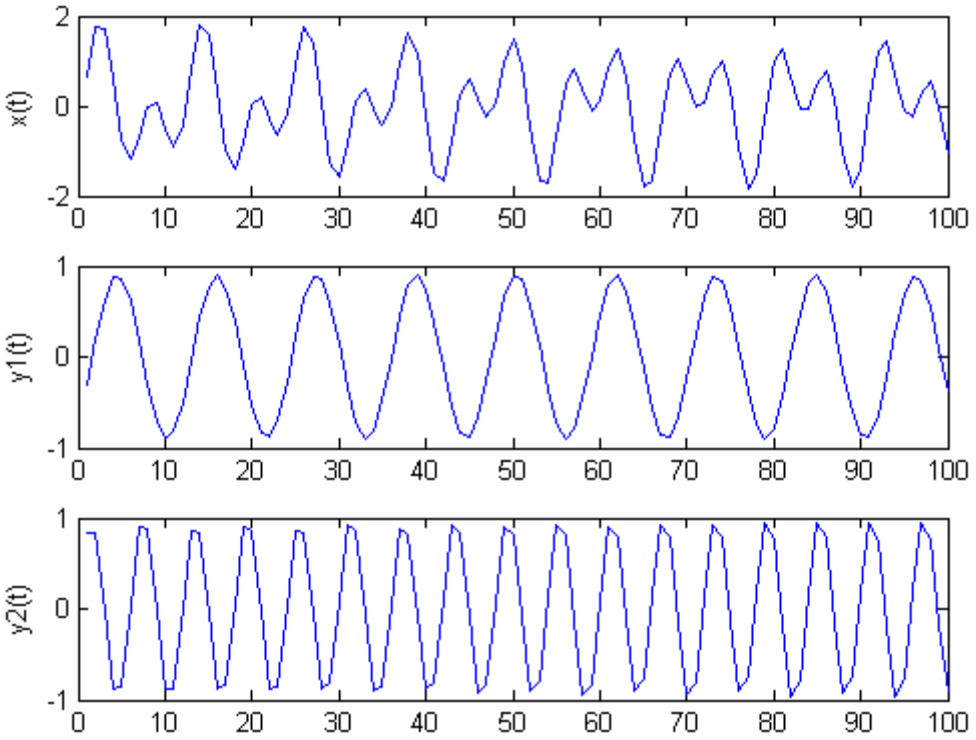
Literatura

1. M. Lutovac, D. Tosic, B. Evans,
   Filter Design for Signal Processing Using MATLAB and Mathematica,
   Prentice Hall, New Jersey, 2001
2. G. Moschytz, P. Horn,
   Active filter design handbook,
   John Wiley, New York, 1981
3. G. Daryanani,
   Principles of Active Network Synthesis and Design,
   John Wiley, New York, 1976
4. **Anadigm**, Software user manual

Telefon #2

697Hz + 1336 Hz



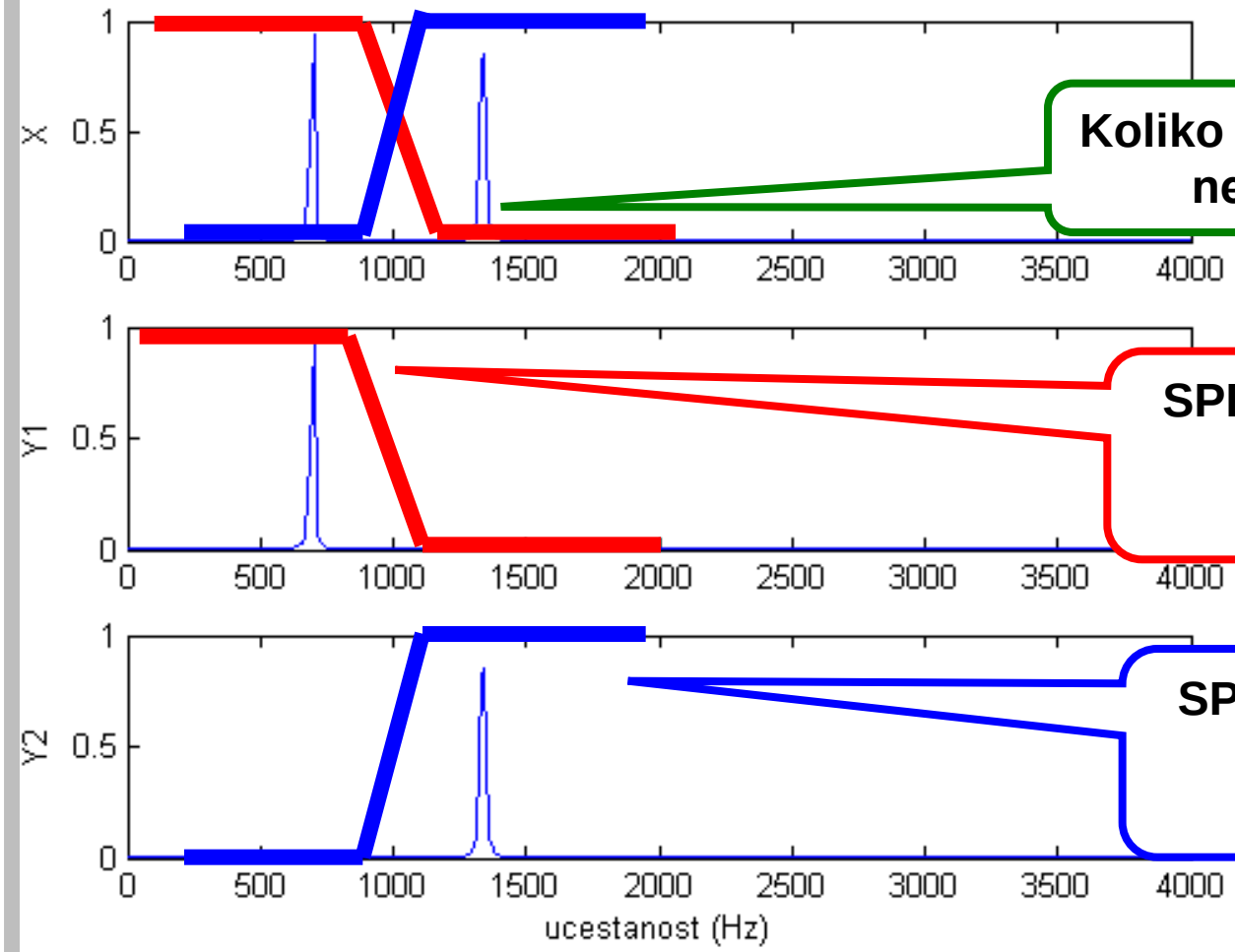


Telefon #2

697Hz + 1336 Hz

697, 770, 852, 941 Hz

1209, 1336, 1477, 1633 Hz

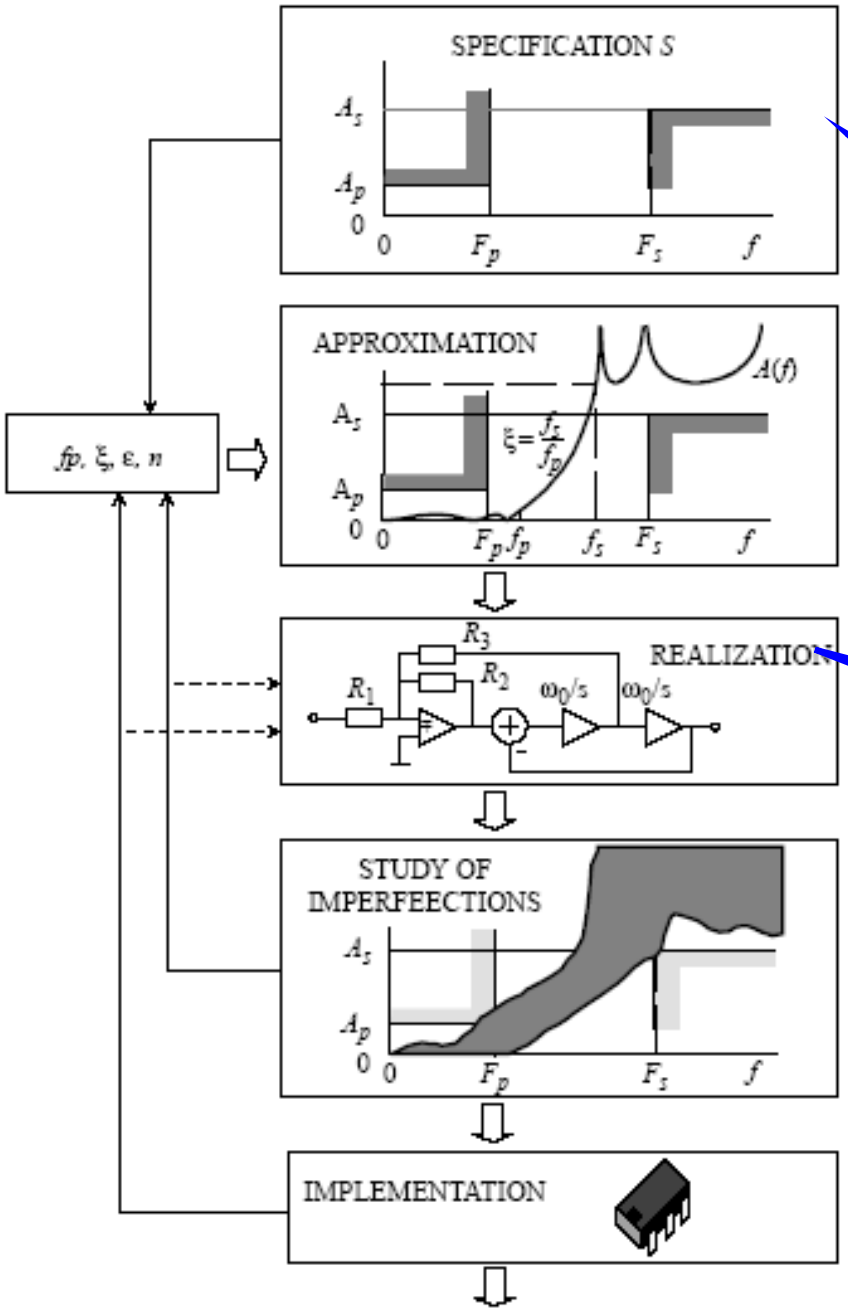


Koliko da oslabimo signal na nekoj učestanosti?

SPECIFIKACIJE ZA FILTAR PROPUSNIK NISKIH UČESTANOSTI

SPECIFIKACIJE ZA FILTAR PROPUSNIK VISOKIH UČESTANOSTI

Od specifikacija do realizacije



Specifikacije

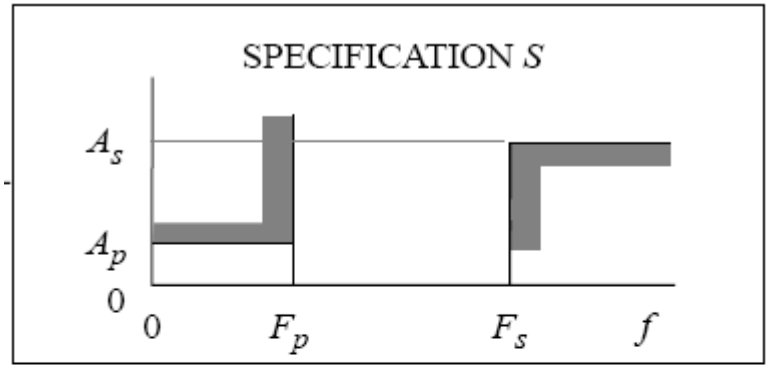
Sinteza

Specifikacije

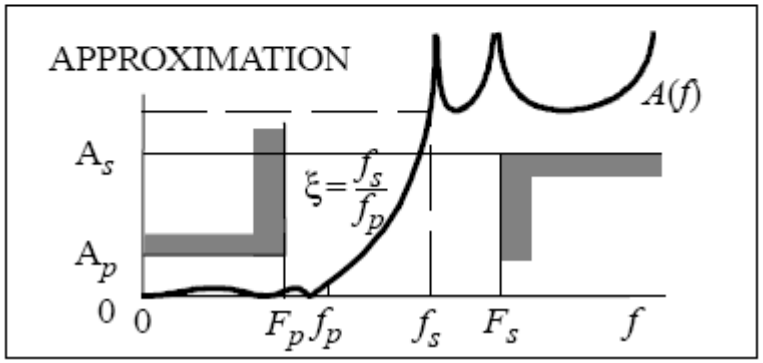
- Definišu se dozvoljene **tolerancije** u određenim frekvencijskim opsezima

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

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



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

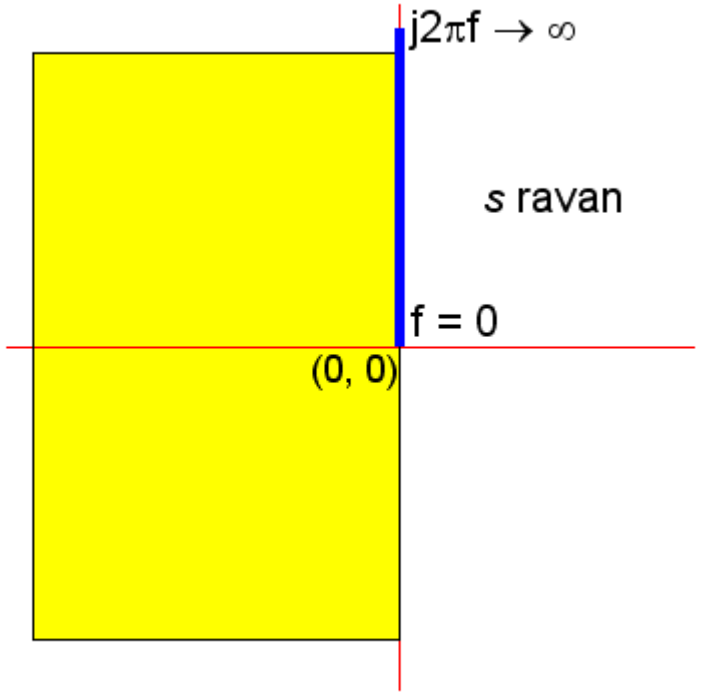


Frekvencijski odziv

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

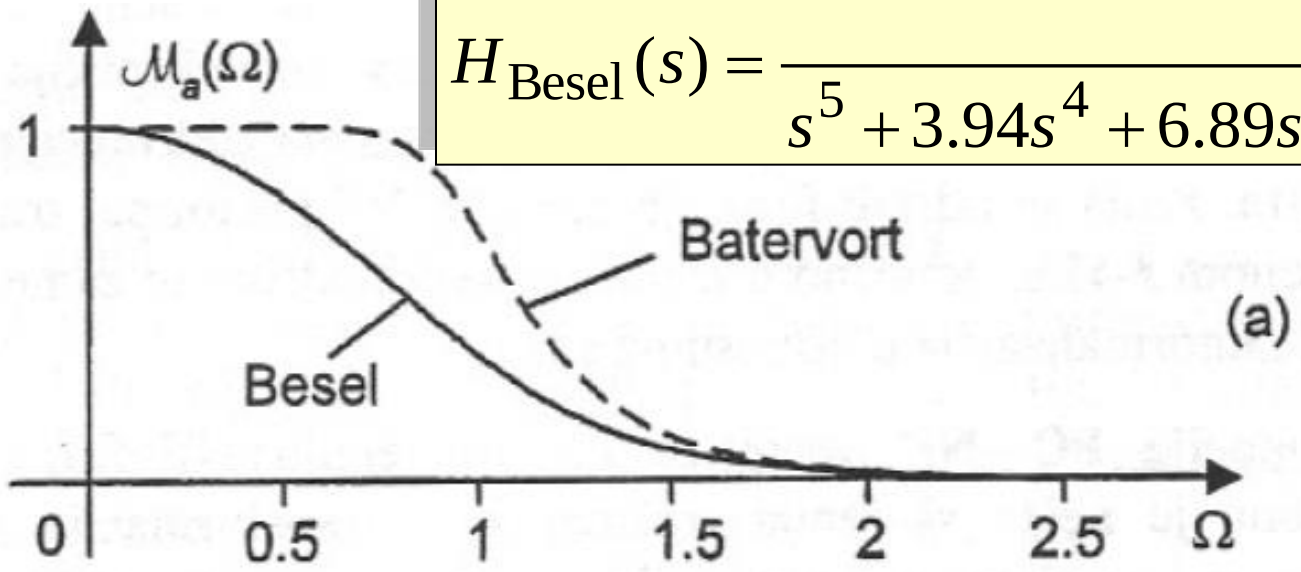
$$H(j2\pi f)$$

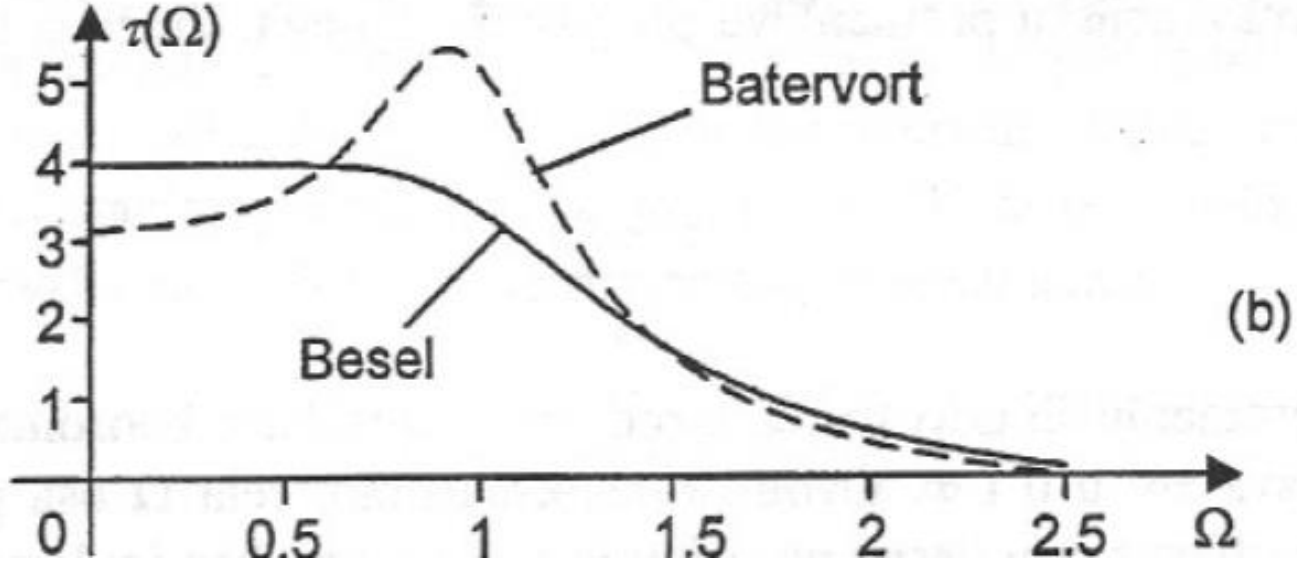
$$0 \le f \le \infty$$



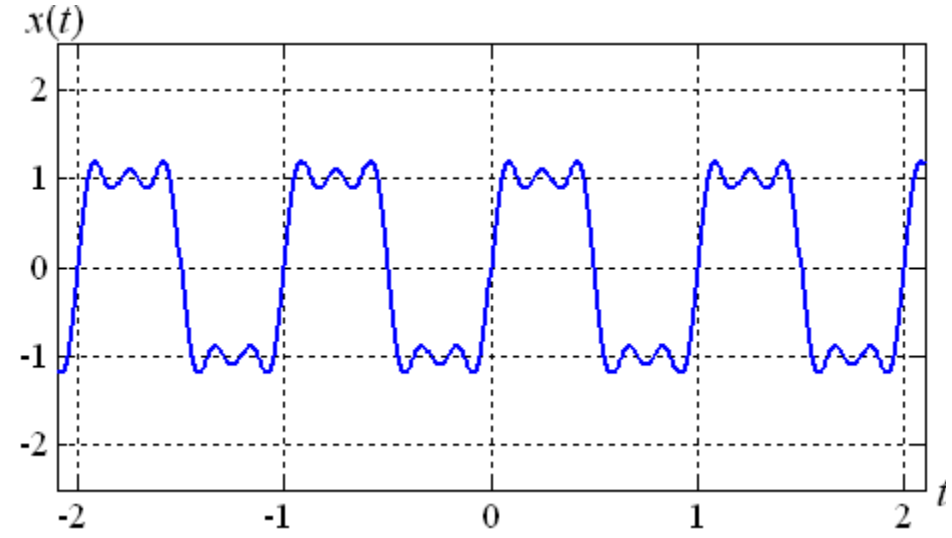
$$H_{\text{Batervort}}(s) = \frac{1}{s^5 + 3.24s^4 + 5.24s^3 + 5.24s^2 + 3.24s + 1}$$

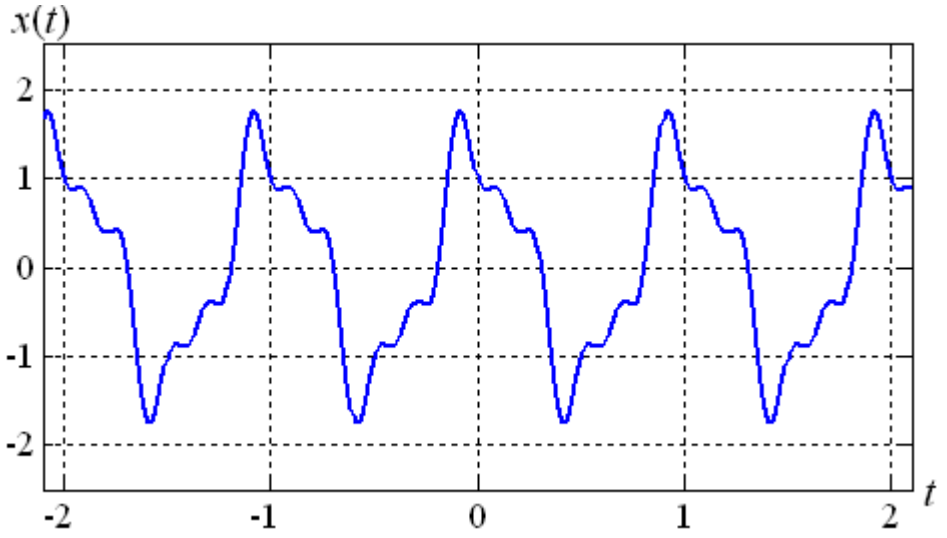
$$H_{\text{Besel}}(s) = \frac{1}{s^5 + 3.94s^4 + 6.89s^3 + 6.78s^2 + 3.81s + 1}$$

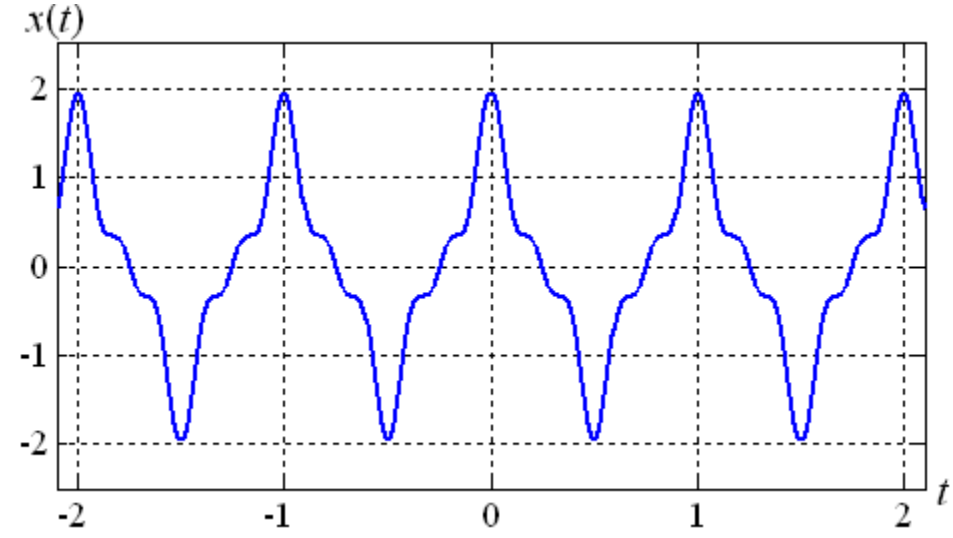


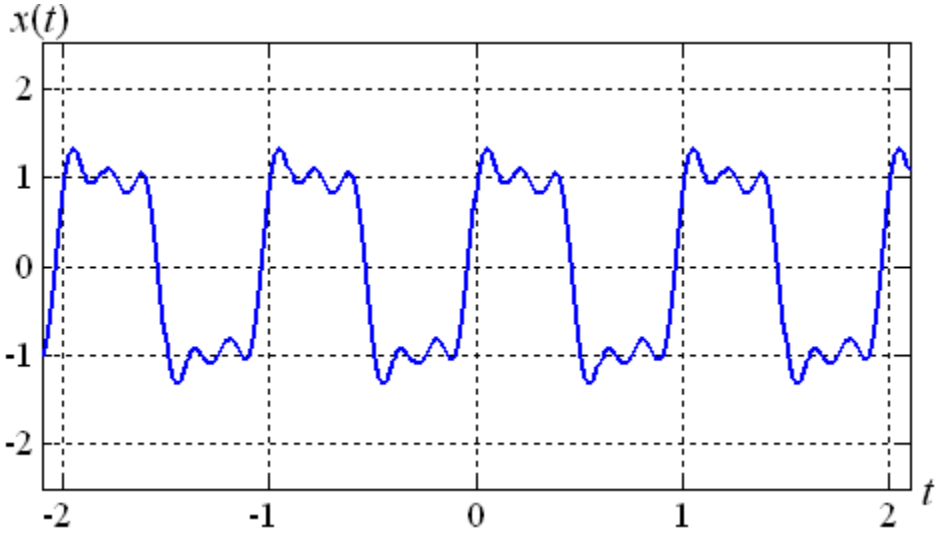


Uticaj fazne karakteristike

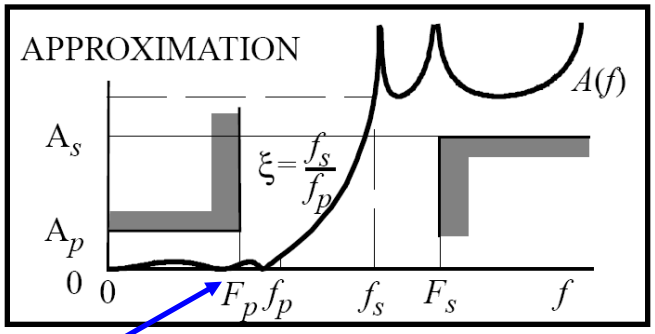




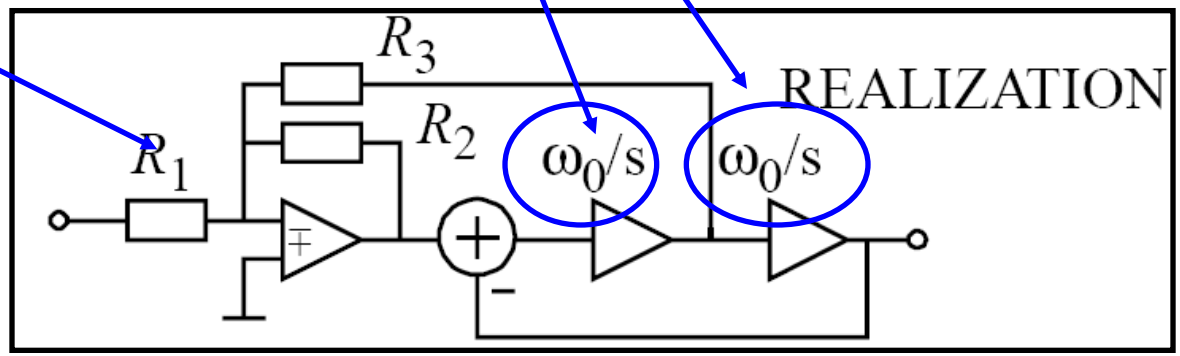




Sinteza



- Naći funkciju prenosa takvu da je racionalna funkcija po *s*
  što nižeg reda i
  da amplitudska karakteristika zadovoljava specifikacije
- da se koristi minimalan broj elemenata u realizaciji



Analogni filtar

- **Analogni filtar** je električno kolo koje se koristi da pojača ili oslabi sinusoidalne signale ili signale koji zauzimaju određeni frekvencijski opseg
- Opseg učestanosti u kome se signali pojačavaju ili propuštaju bez većih slabljenja naziva se **propusni opseg**
- Opseg učestanosti u kome se signali značajnije slabe, naziva se **nepropusni opseg**
- **Specifikacije** su zahtevi u pogledu minimalnog dozvoljenog ili maksimalnog slabljenja ili pojačanja signala, u nekom opsegu učestanosti, a granice opsega su granične učestanosti
- **Projektovanje (sinteza)** analognog filtra je proces u kome konstruišemo kolo, odnosno izračunavamo vrednosti elemenata tako da to kolo zadovolji specifikacije

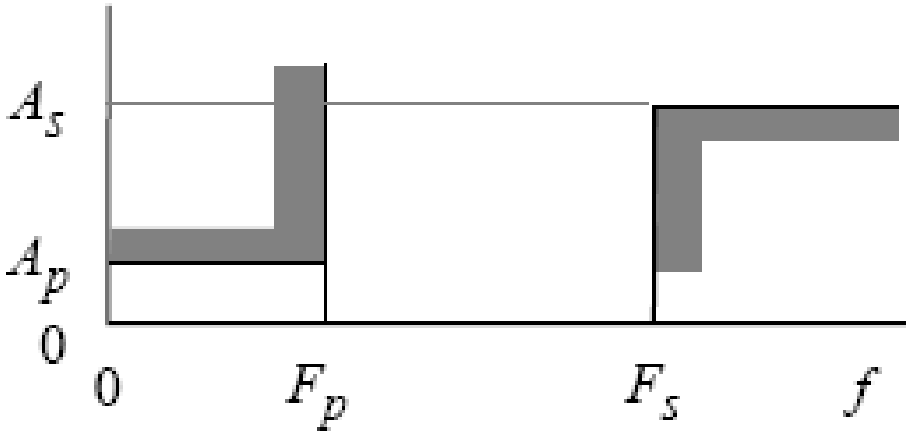
Projektovanje - sinteza

- Projektovanje se sastoji od
  - Aproksimacije
  - Realizacije
  - Analiza nesavršenosti
  - Implementacije
- Broj električnih kola koji može da se napravi a da zadovolji specifikacije je beskonačan
- Kako izabrati optimalno rešenje?

Filtar propusnik niskih učestanosti

- Propušta sinusoidalne signale čija je učestanost u opsegu $0 \leq f \leq f_p$
- Slabi signale čija je učestanost $f \geq Fs > Fp$
  to je analogni lowpass filter
- Opseg učestanosti $0 \leq f \leq f_p$ je propusni opseg
- Opseg učestanosti $f \geq Fs > Fp$ je nepropusni opseg
- *Fp* je granica propusnog opsega (*passband edge frequency*)
- *Fs* je granica nepropusnog opsega (*stopband edge frequency*)
- Slabljenje u propusnom opsegu ne sme biti veće izvan opsega 0 – *Ap* u dB
- Slabljenje u nepropusnom opsegu ne sme biti manje od *As* u dB, *As>0*
- *Ap* je *maximum passband attenuation*
- *As* is the *minimum stopband attenuation*
- Lista *S*={*Fp,Fs, Ap, As*} je **specifikacija** *lowpass* filtra

Tolerancije karakteristike slabljenja



$$A(f) = -20\log(\delta(f))$$

$S=\{Fp,Fs, Ap, As\}$

$0 \le A(f) \le A_p$ za $0 \le f \le F_p$

Propusni opseg

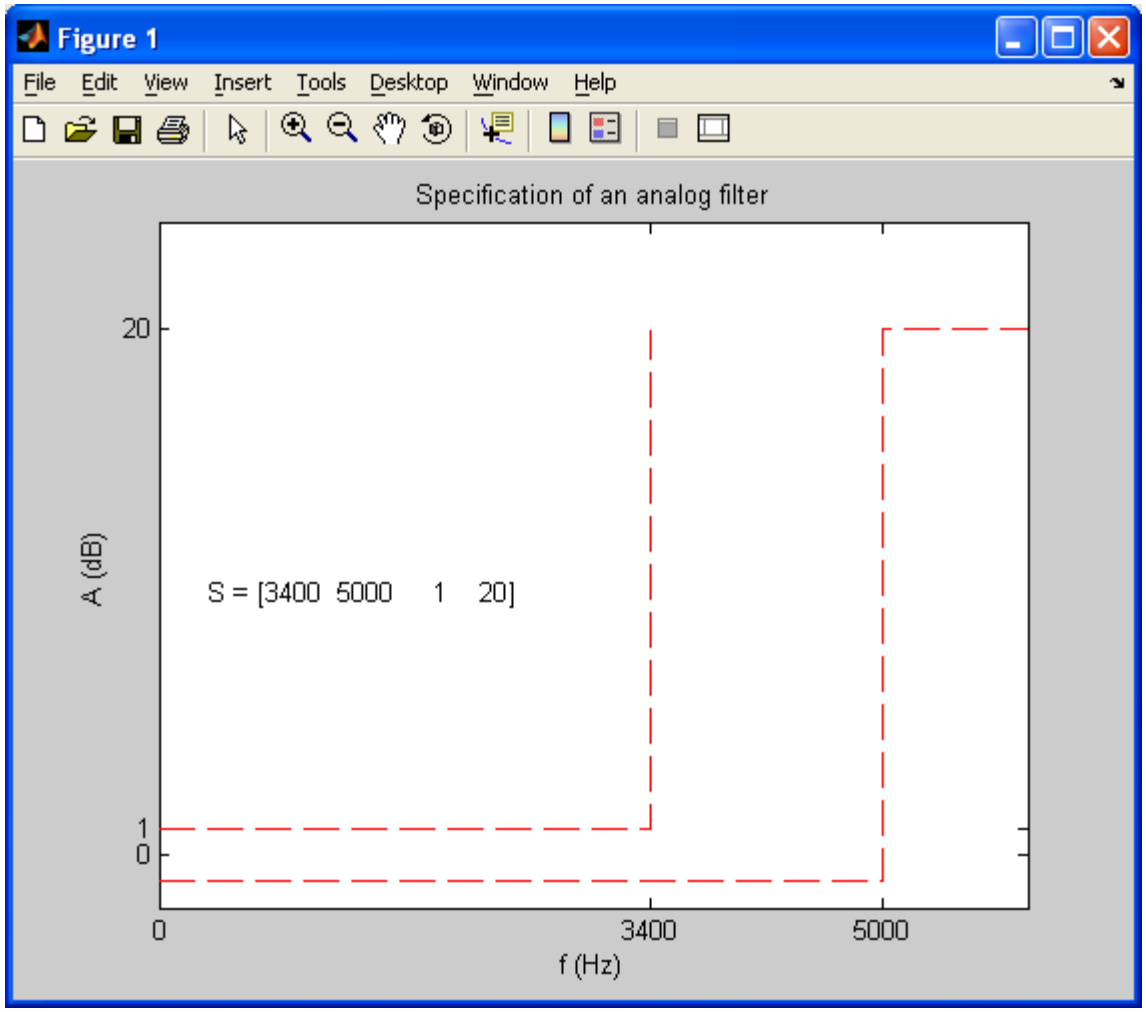
$A_s \le A(f) \le +\infty$ za $F_s \le f < +\infty$

Nepropusni opseg

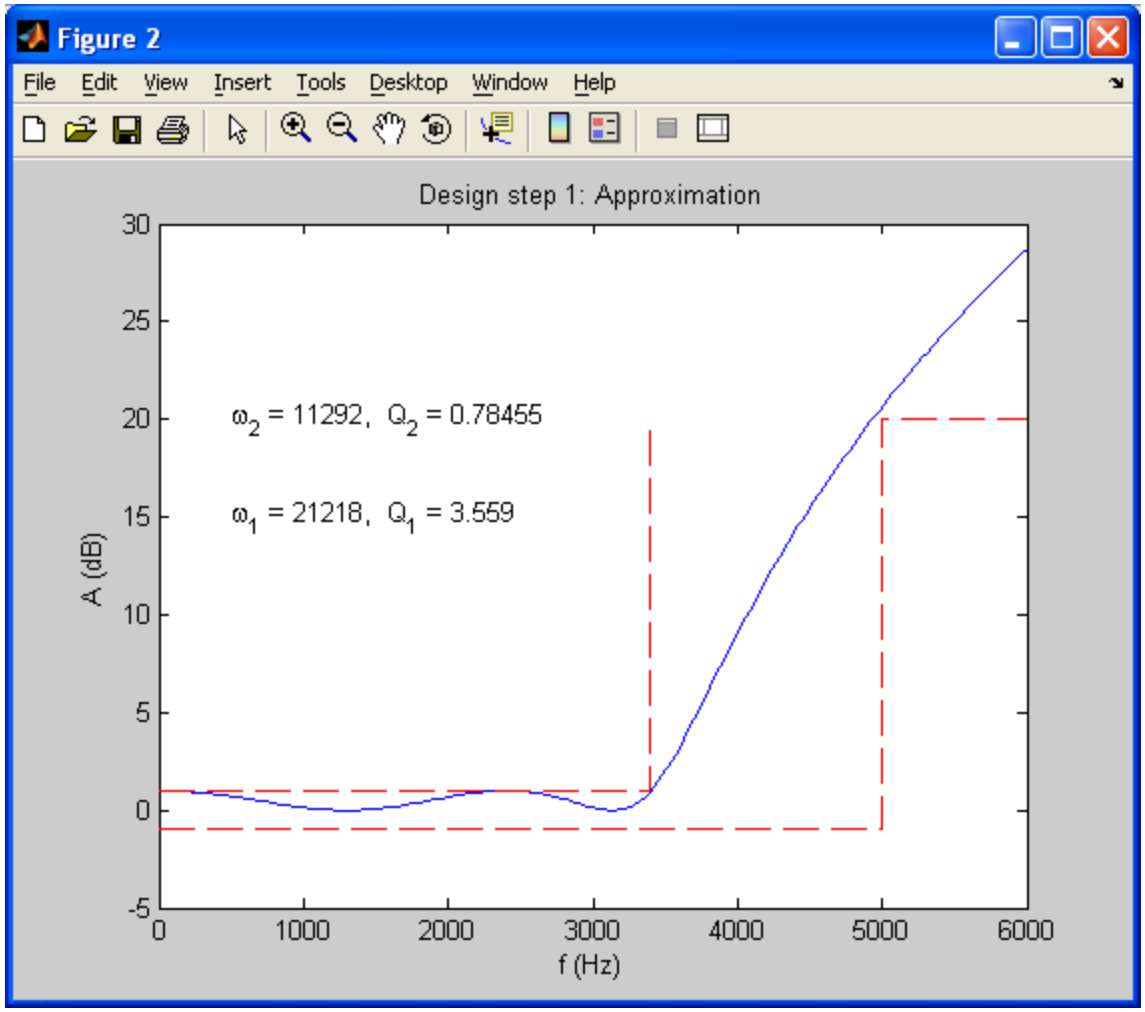
Primer projektovanja

- Specifikacije
- 1: aproksimacija – izbor Čebiševljeve
- 2: realizacija – kaskada bikvada
- 3: analiza nesavršenosti – zaokruživanje vrednosti
- Ponavljanje projektovanja ako nije zadovoljen spek
  - 1: aproksimacija
  - 2: realizacija
  - 3: analiza nesavršenosti
- 4: implementacija
- MATLAB i dokumentacija

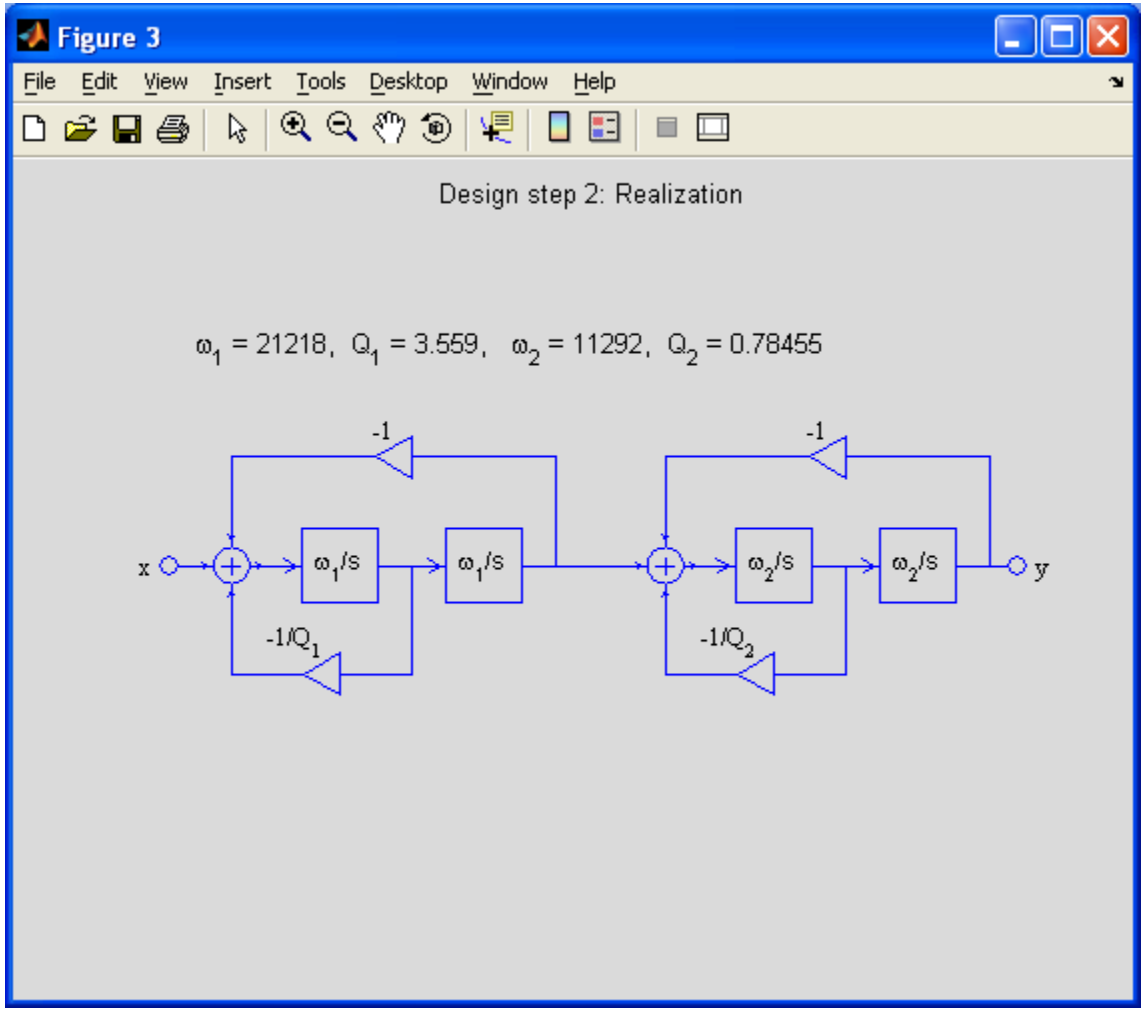
Start sa specifikacijama



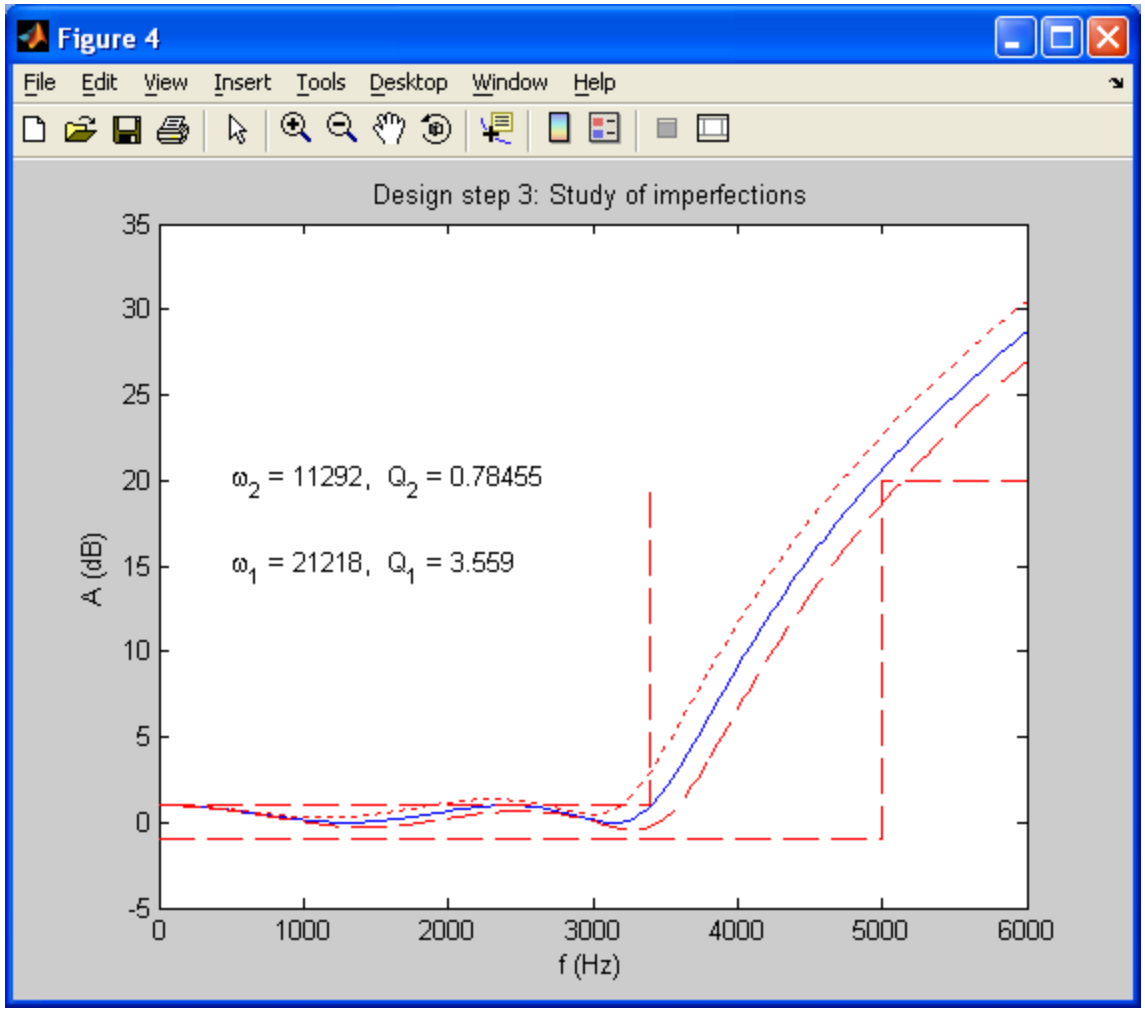
1: aproksimacija
Izbor Čebiševljeve aproksimacije tip I



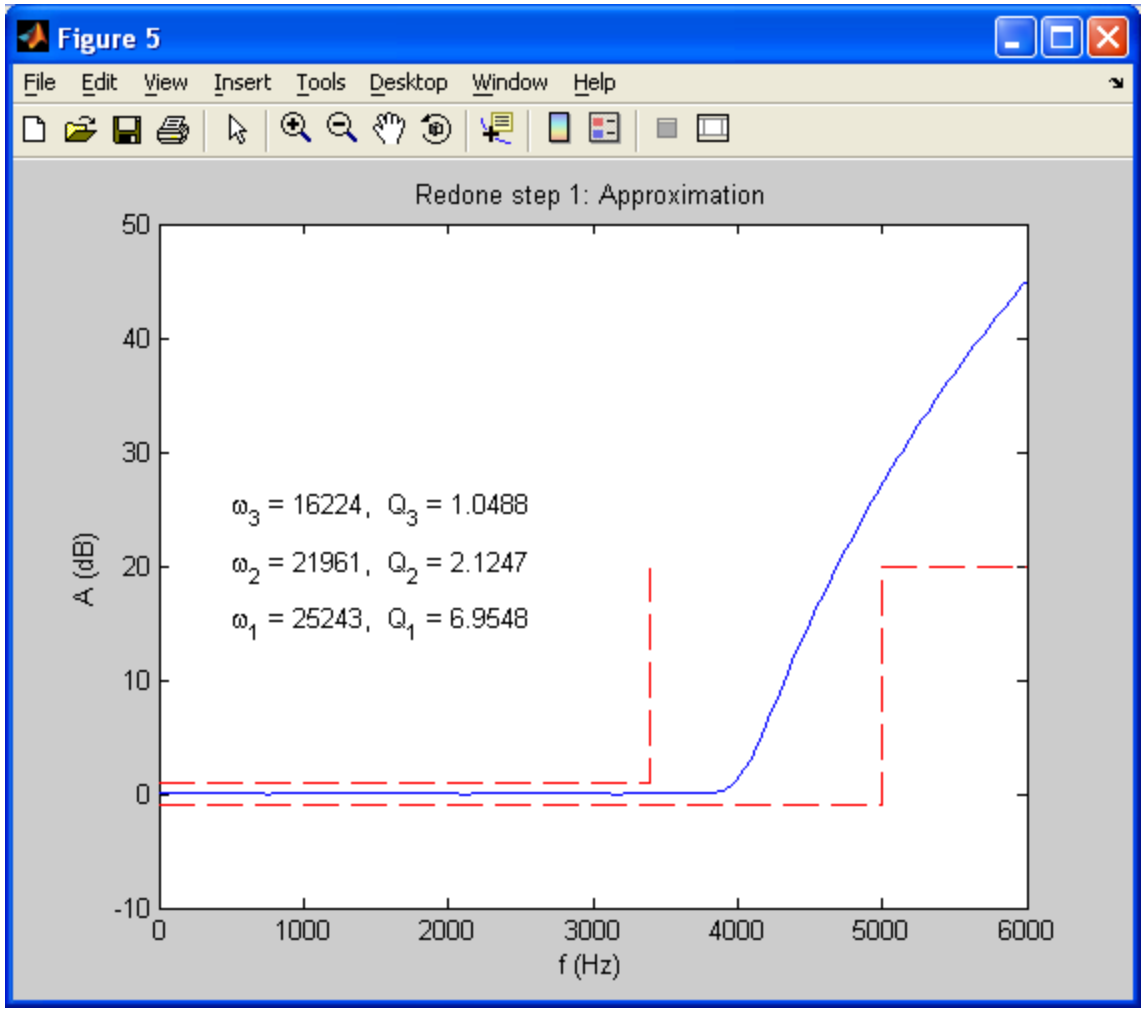
2: realizacija (sinteza)
Kaskada programabilnih sekcija drugog reda (biquads)



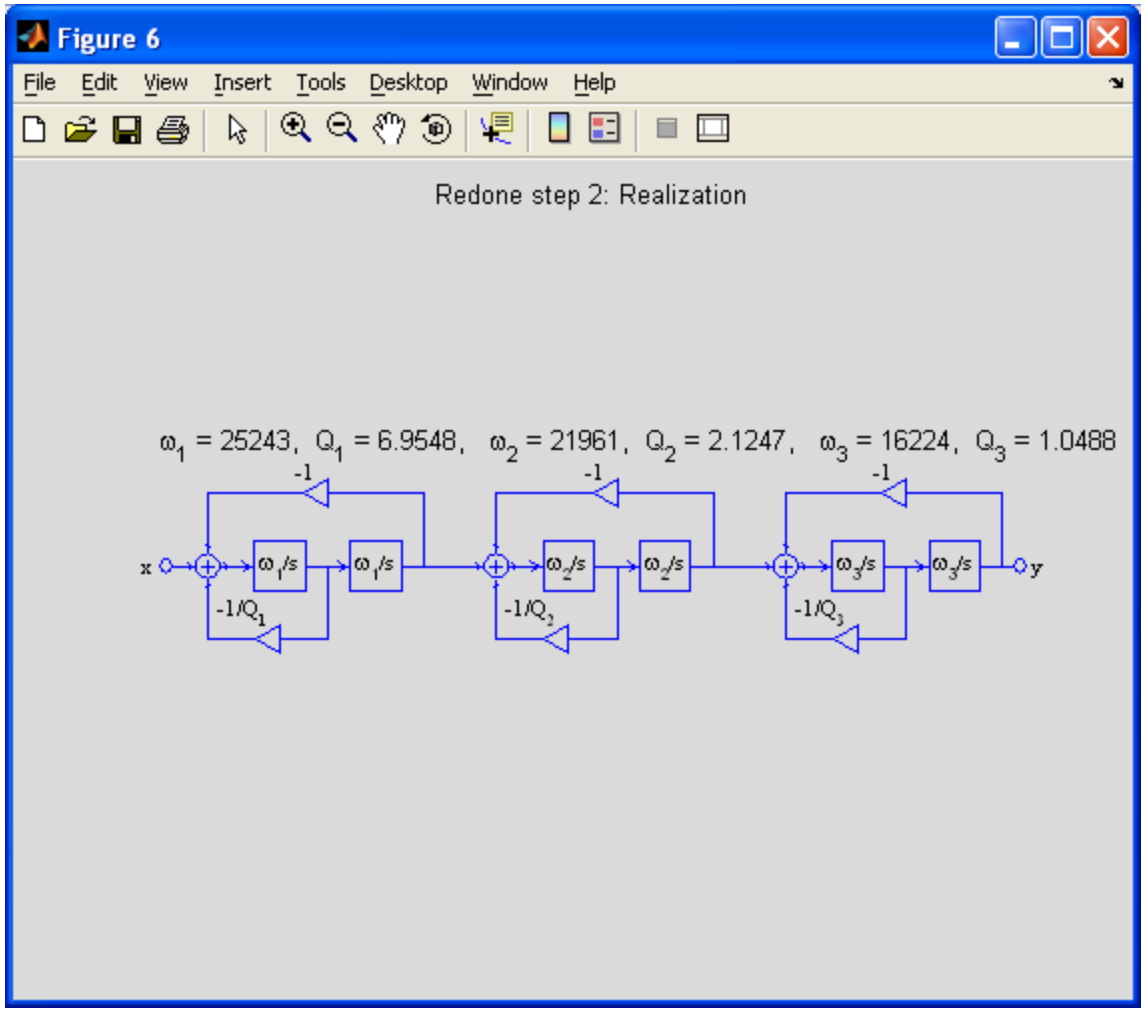
3: Analiza nesavršenosti analiza osetljivosti



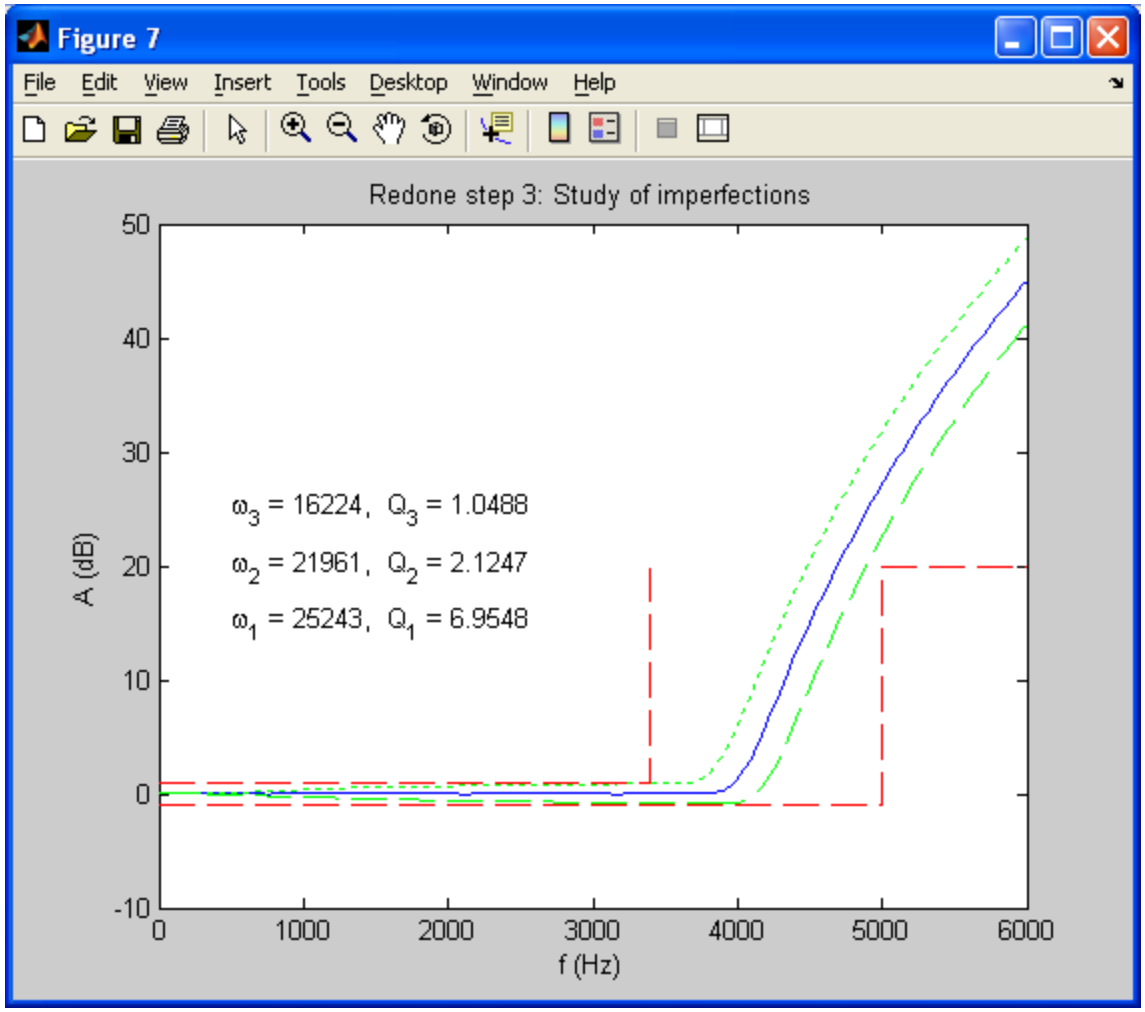
Ponovo 1: aproksimacija povećanje reda funkcije prenosa



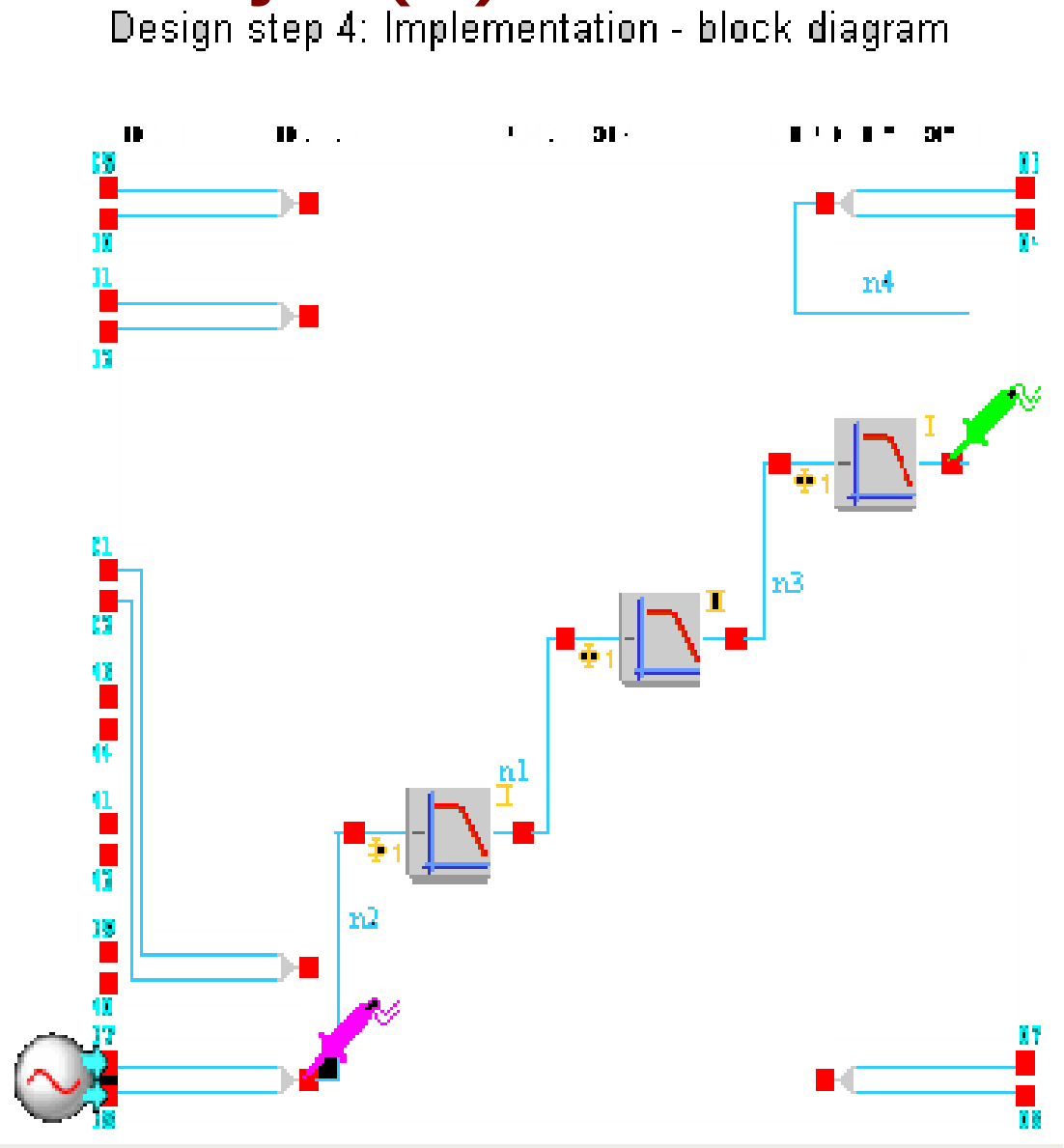
Ponovo 2: realizacija



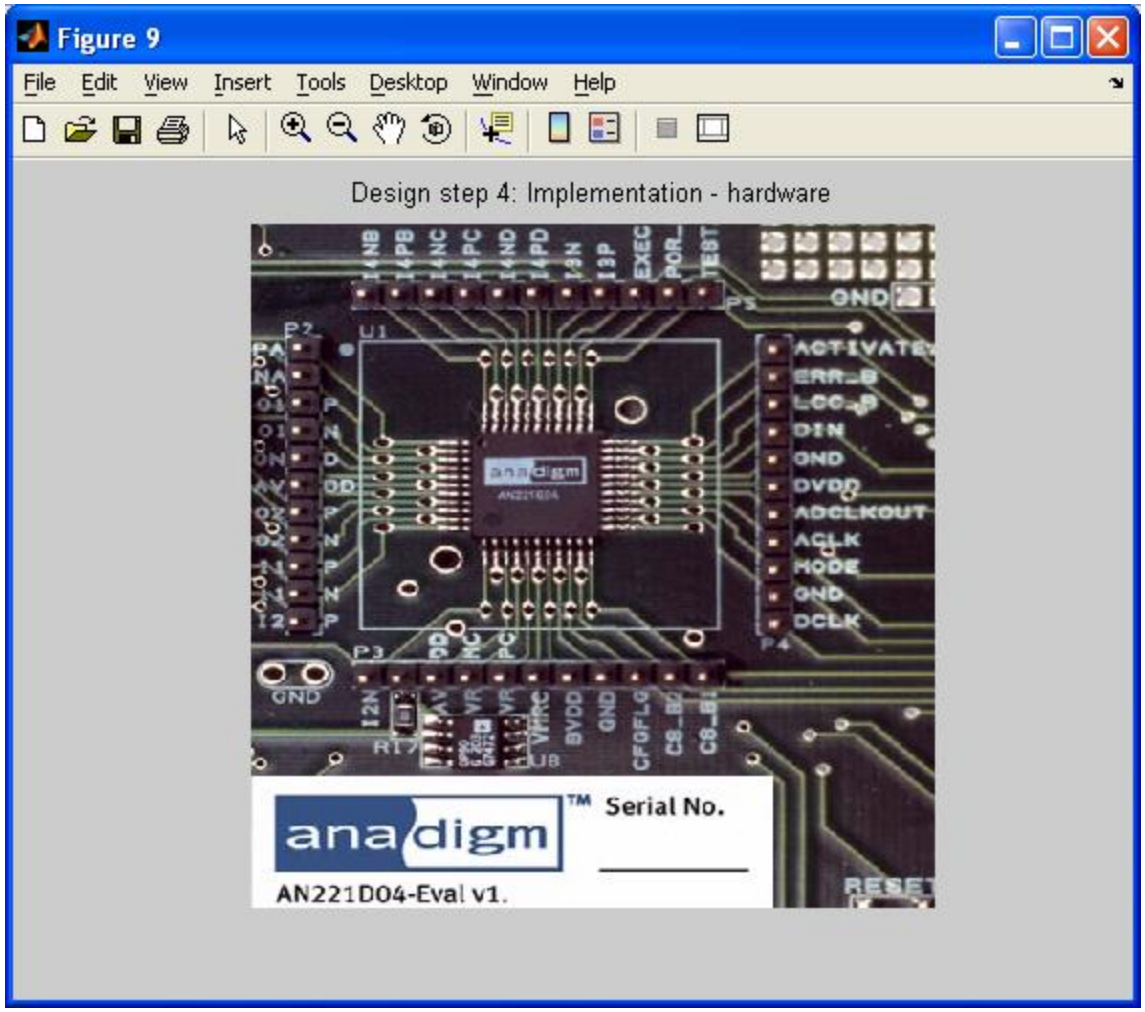
Ponovo 3: analiza nesavršenosti



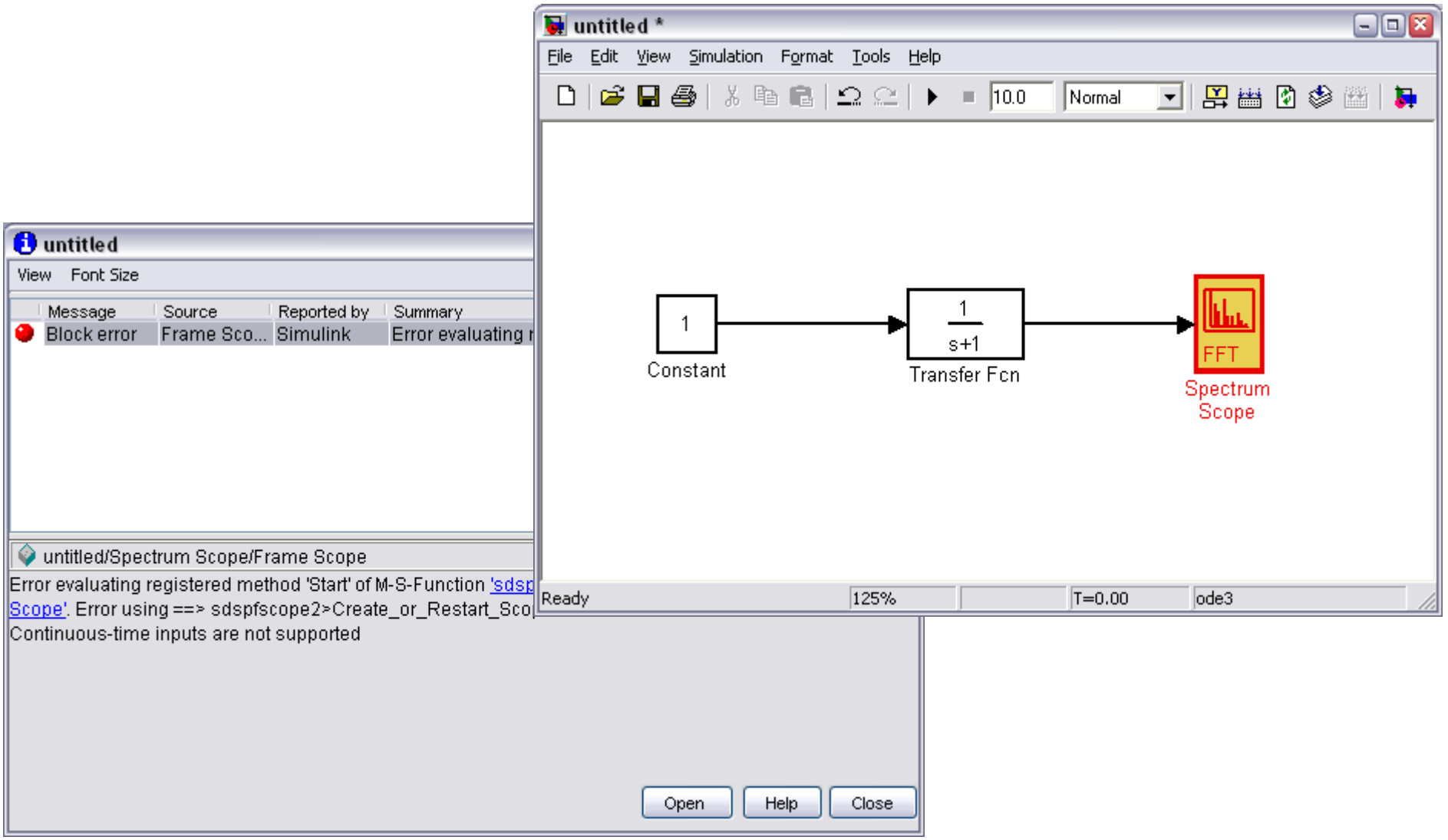
4: implementacija (1)



4: implementacija (2)

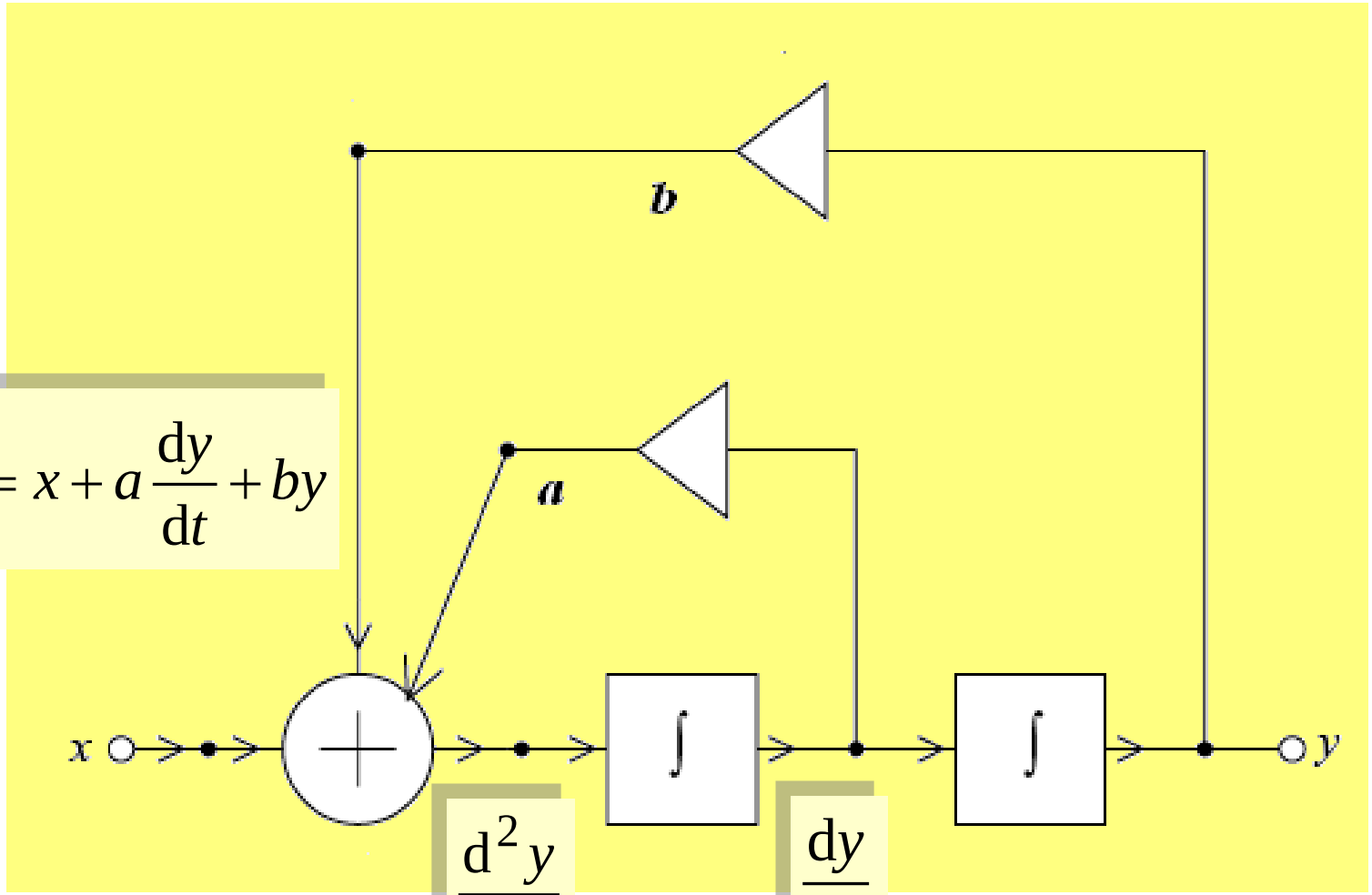


Simulink ne podržava analizator spektra za kontinualne signale

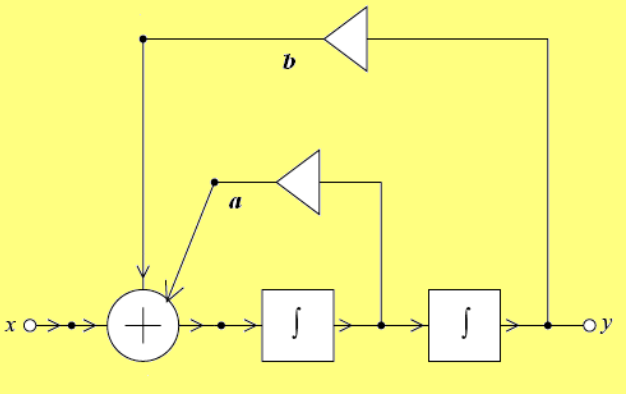


Kontinualni sistemi

$$\frac{\mathrm{d}^2 y}{\mathrm{d}t^2} = x + a\frac{\mathrm{d}y}{\mathrm{d}t} + by$$



Primena Laplasove transformacije



$$\frac{\mathrm{d}^2 y}{\mathrm{d}t^2} = x + a\frac{\mathrm{d}y}{\mathrm{d}t} + by$$

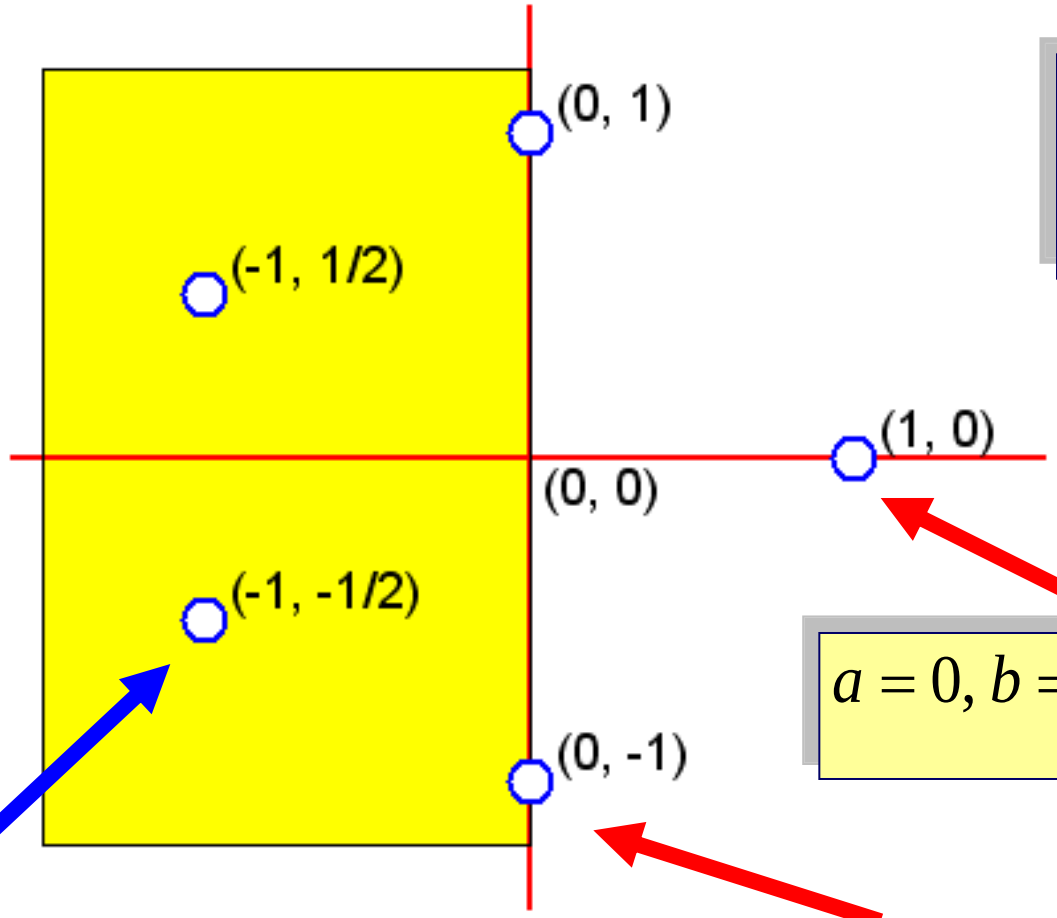
$$s^2\, Y(s) = X(s) + a\, s\, Y(s) + b\, Y(s)$$

$$(s^2 - a\, s - b)Y(s) = X(s)$$

$$\frac{Y(s)}{X(s)} = \frac{1}{s^2 - a\, s - b}$$

Funkcija prenosa

Polovi funkcije prenosa u *s* ravni



$$\frac{1}{s^2 - as - b}$$

$$a = 0, b = 1 \rightarrow \lim_{t \to +\infty} y(t) = \pm\infty$$

$$\mathrm{Re}(\mathrm{pol}) < 0 \rightarrow \lim_{t \to +\infty} y(t) = 0$$

$$a = 0, b = -1 \rightarrow y(t) = \sin(t)$$

Transformacije

- Laplasova transformacija impulsnog odziva

$$H(s) = \int_{-\infty}^{\infty} h(t) e^{-st} \mathrm{d}t$$

Funkcije prenosa

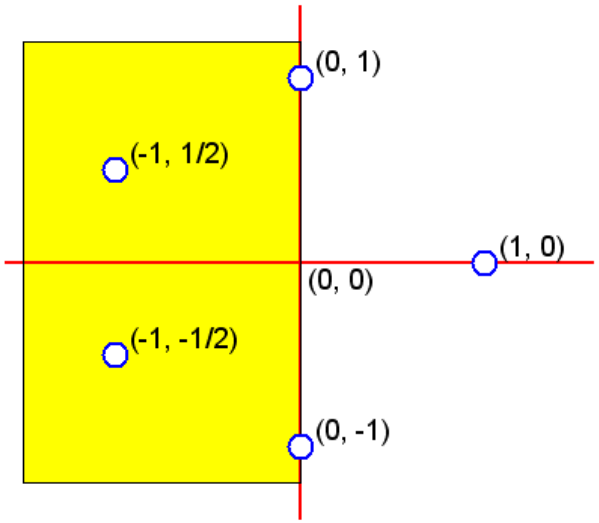
- Racionalna funkcija kompleksne frekvencije $s=\delta+j\Omega$

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

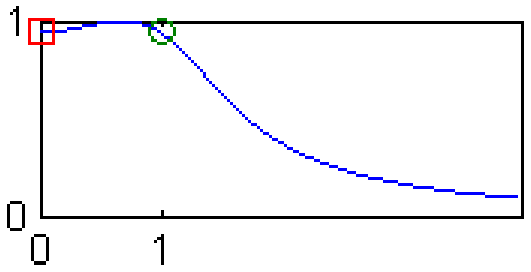
Polovi funkcije prenosa

- Leva polovina kompleksne s ravni

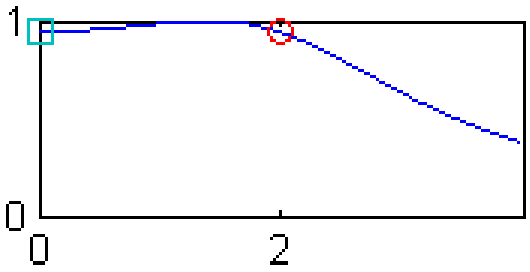
$$H(s) = \frac{C(s)}{D(s)}$$



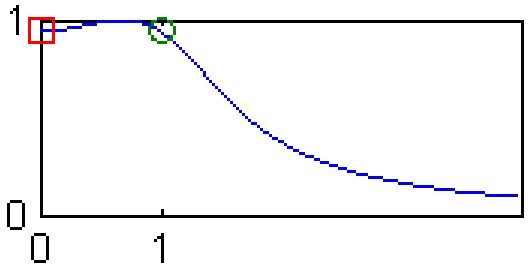
Frekvencijske transformacije



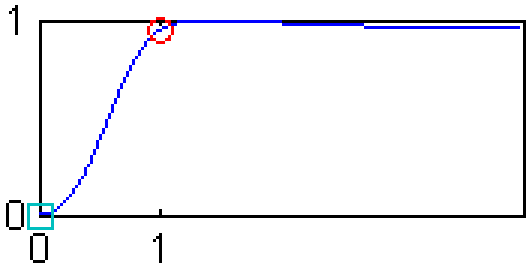
$$s \rightarrow \frac{s}{\Omega_n}$$

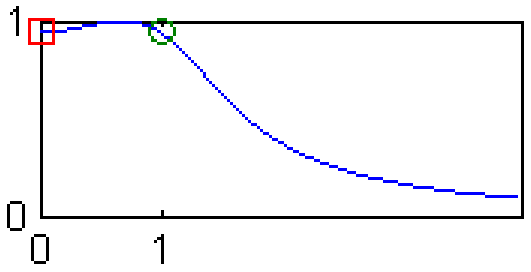


$$s \rightarrow j\Omega$$

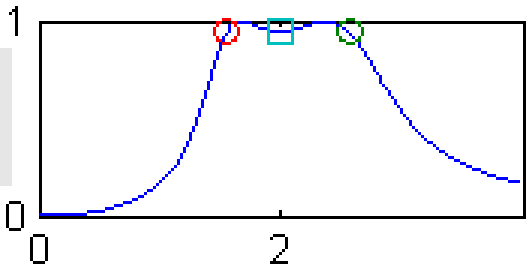


$$s \rightarrow \frac{1}{s}$$

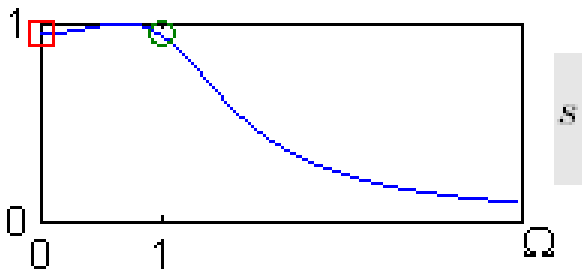




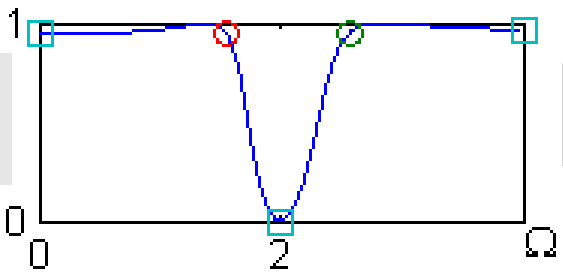
$$s \rightarrow \frac{s^2 + \Omega_0^2}{s}$$



$$\Omega_0 = \sqrt{\Omega_{p1}\Omega_{p2}}$$



$$s \rightarrow \frac{s}{s^2 + \Omega_0^2}$$



$$\Omega_0 = \sqrt{\Omega_{a1}\Omega_{a2}}$$

Transformacije NF prototipa

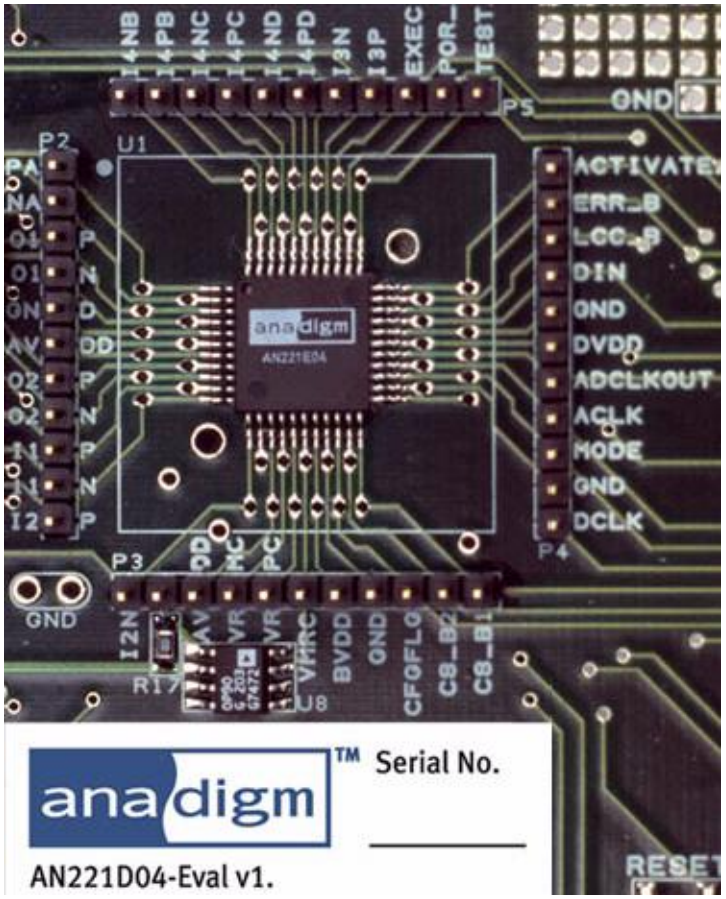
- Transformacija NF-NF prototip $s \rightarrow s/\Omega_n$
- Transformacija VF-NF prototip $s \rightarrow 1/s$
- Transformacija PO-NF prototip $s \rightarrow (s2+ \Omega_0^2)/s$
- Transformacija NO-NF prototip $s \rightarrow s/(s2+ \Omega_0^2)$

Primer transformacije

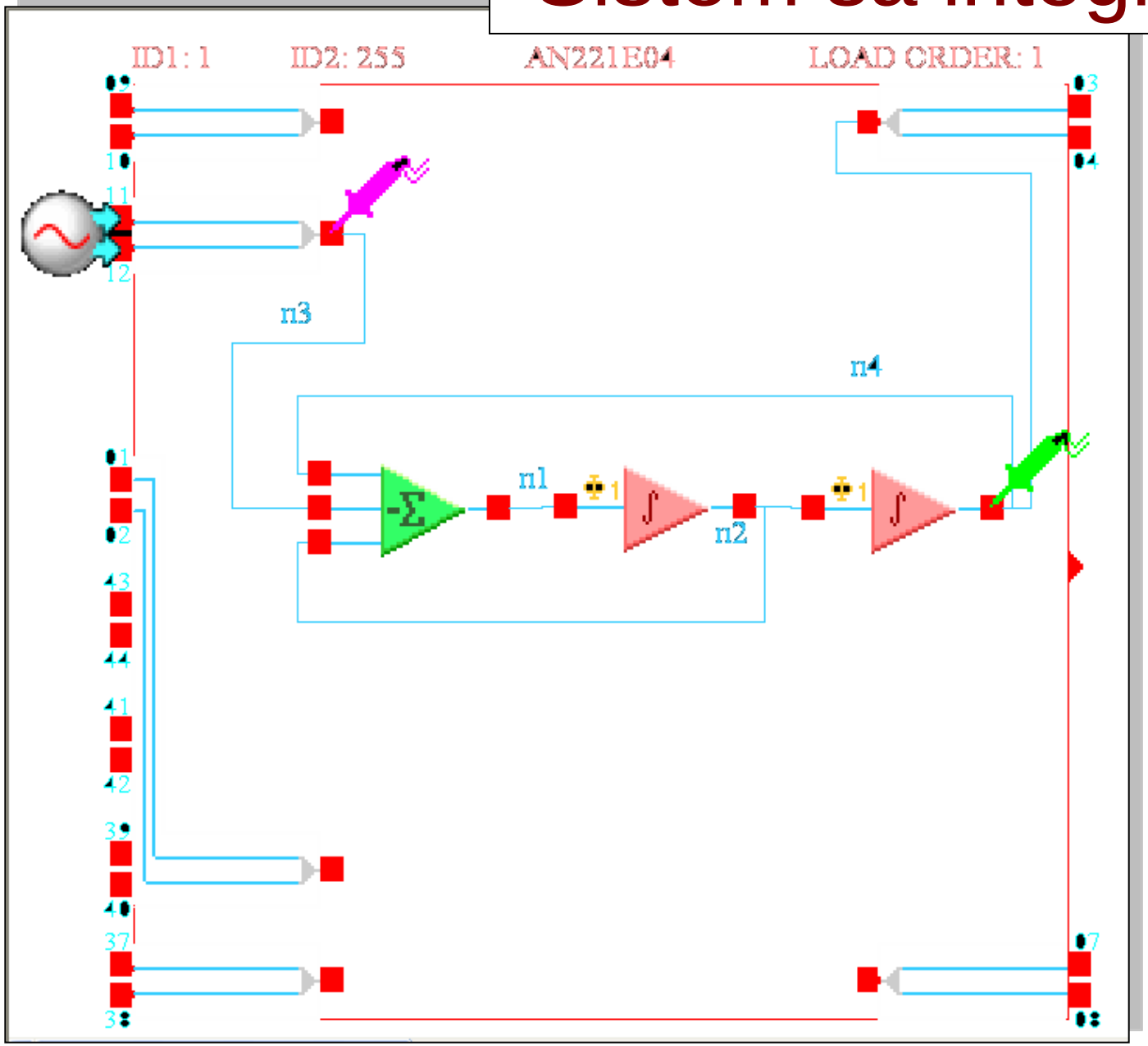
$$H_{\mathrm{NF}} = \left.\frac{1}{s^2+2s+3}\right|_{s\to\frac{s^2+1}{s}} \rightarrow H_{\mathrm{PO}} = \frac{s^2}{s^4+2s^3+5s^2+2s+3}$$

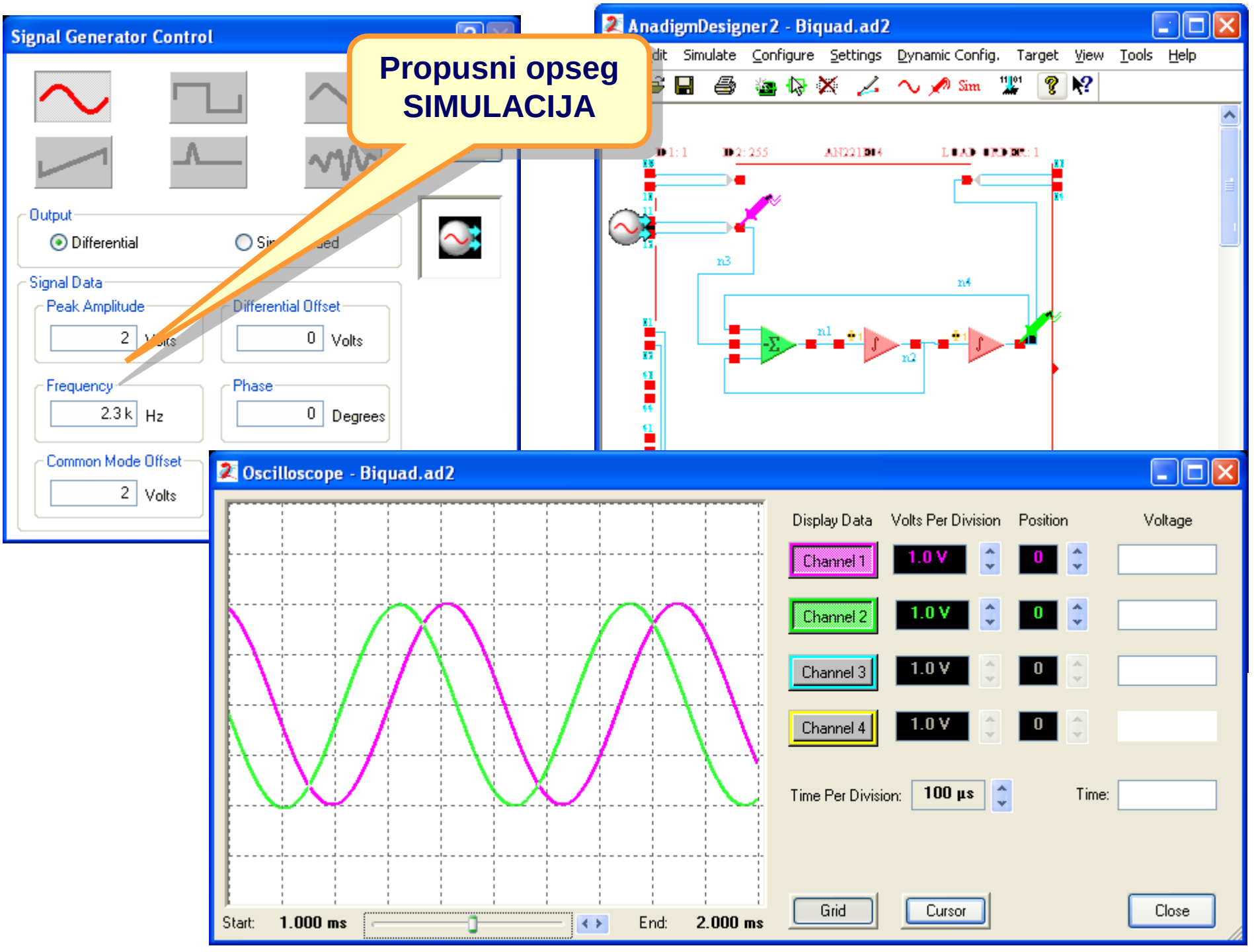
H je racionalna funkcija

Hardverska implementacija



Sistem sa integratorima




Propusni opseg
SIMULACIJA
Signal Generator Control
Output
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Signal Data
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Differential Offset
0
Volts
Frequency
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Hz
Phase
0
Degrees
Common Mode Offset
2
Volts
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Edit
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Configure
Settings
Dynamic Config.
Target
View
Tools
Help
Sim
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n2
n3
n4
Oscilloscope - Biquad.ad2
Display Data
Volts Per Division
Position
Voltage
Channel 1
1.0 V
0
Channel 2
1.0 V
0
Channel 3
1.0 V
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Channel 4
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Time:
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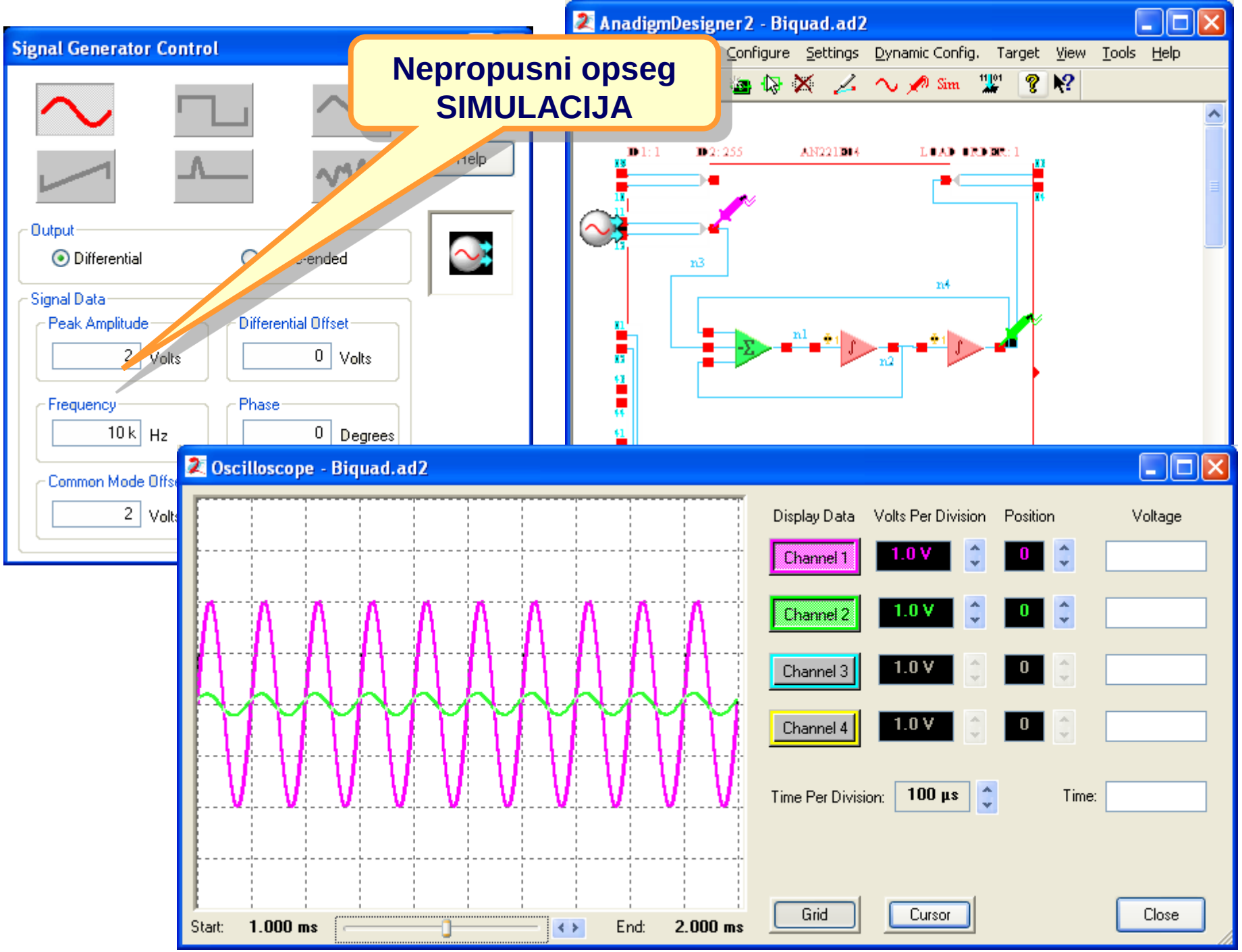
End:
2.000 ms
Grid
Cursor
Close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Channel 4
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Time:
Start:
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End:
2.000 ms
Grid
Cursor
Close

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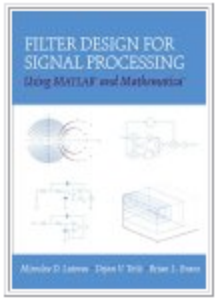

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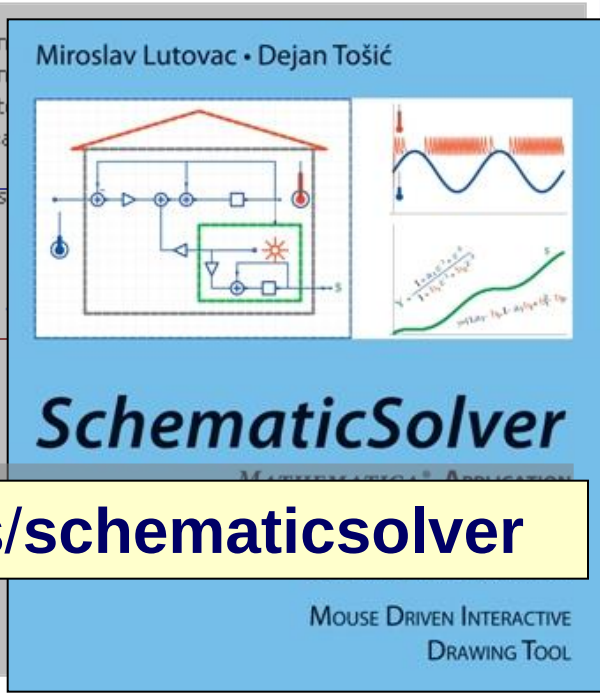

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