Projektovanje elektronskih kola

Sadržaj:

1. Uvod - osnovni pojmovi
2. Stilovi projektovanja i izrade prototipova
3. Projektovanje analognih kola
4. Osnove fizičkog projektovanja (projektovanje štampanih ploča)
5. Projektovanje digitalnih kola (vežbe)

LEDA - Laboratory for Electronic Design Automation
http://leda.elfak.ni.ac.rs/

Analiza kola

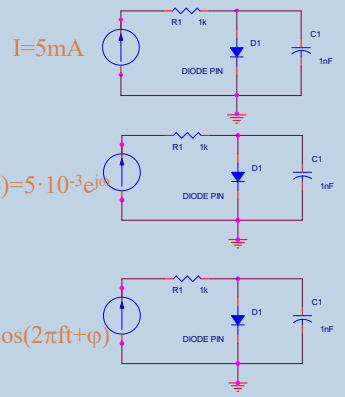
Tipovi analize?

Zavisno od vrste pobude, ima smisla analizirati ponašanje kola u

1. jednosmernom domenu (određivanje položaja jednosmerne radne tačke kola).
2. frekvencijskom domenu (frekvencijska karakteristika kola – amplitudska, fazna)
3. vremenskom domenu (talasni oblik napona/struja na izlazu kola pobuđenog impulsima poznatog talasnog oblika)

Tipovi analize kola

1. Jednosmerni domen (DC analiza)
2. Frekvencijski domen (AC analiza)
3. Vremenski domen (TR analiza)



Analiza kola

Tipovi analize?

Zavisno od vrste elemenata od kojih se kolo sastoji, različiti tip problema i metoda za analizu

1. Linearna otporna kola (R, linearni generatori, nezavisni i kontrolisani)
2. Linearna reaktivna kola (R, L, C, m, ...)
3. Nelinearna otporna (poluprovodničke komponente, R, ...)
4. Nelinearna reaktivna (poluprovodničke komponente, R, L, C,...)

Tipovi elektronskih kola

1. Linearna otporna R
2. Linearna reaktivna L, C, m, ...
3. Nelinearna otporna dioda, tranzistor, R, ...
4. Nelinearna reaktivna dioda, tranzistor, R, L, C,...

Tipovi analize kola

1. Jednosmerni domen (DC analiza)
2. Frekvencijski domen (AC analiza)
3. Vremenski domen (TR analiza)

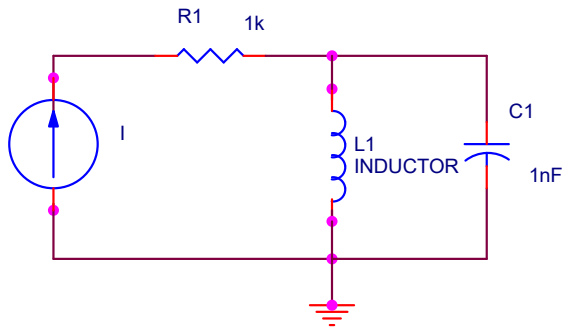
Projektovanje elektronskih kola

Analiza elektronskih kola

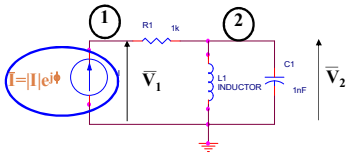
1. Uvod
2. Analiza linearnih kola u DC domenu (jednosmerni režim)
3. Analiza linearnih kola u AC domenu (frekvencijski domen)
4. Analiza linearnih kola u TR domenu (vremenski domen)
5. Analiza nelinearnih kola u DC domenu
6. Analiza nelinearnih kola u TR domenu

Analiza elektronskih kola

1. Uvod
2. Analiza linearnih kola u DC domenu (jednosmerni režim)
3. Analiza linearnih kola u AC domenu (frekvencijski domen)
4. Analiza linearnih kola u TR domenu (vremenski domen)
5. Analiza nelinearnih kola u DC domenu
6. Analiza nelinearnih kola u TR domenu



Ponašanje linearnih reaktivnih kola u frekvencijskom domenu opisuje se sistemom linearnih algebarskih jednačina sa kompleksnim koeficijentima

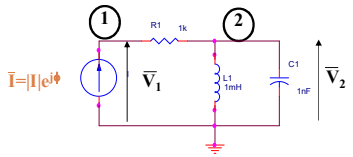


$$\frac{\bar{V}_1-\bar{V}_2}{R_1}=\bar{I}$$

$$\frac{\bar{V}_2-\bar{V}_1}{R_1}+\frac{\bar{V}_2}{j\omega\cdot L_1}+j\omega\cdot C_1\bar{V}_2=0$$

Tip kola i analize	Matematički model
2. Linearna reaktivna u AC domenu	2. Linearne algebarske jednačine sa kompleksnim koeficijentima

Matematički model	Način rešavanja sistema j-na
2. Linearne jednačine kompleksne	2. LU faktorizacija (Gauss)
3. Linearne diferencijalne jednačine	3. Numeričko integraljenje - diskretizacija - svođenje na linearne algebarske (Euler)
4. Nelinearne algebarske jednačine	4. Linearizacija - Iterativno svođenje na linearne algebarske (Newton-Kantorovič)
5. Nelinearne diferencijalne jednačine	5. Diskretizacija - svođenje na nelinearne algebarske i linearizacija - Iterativno svođenje na linearne algebarske



$$\frac{\bar{V}_1-\bar{V}_2}{R_1}=\bar{I}$$

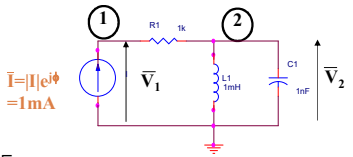
$$\frac{\bar{V}_2-\bar{V}_1}{R_1}+\frac{\bar{V}_2}{j\omega\cdot L_1}+j\omega\cdot C_1\bar{V}_2=0$$

$$\frac{1}{R_1}\bar{V}_1-\frac{1}{R_1}\bar{V}_2=\bar{I}$$

$$-\frac{1}{R_1}\bar{V}_1+\left(\frac{1}{R_1}+\frac{1}{j\omega\cdot L_1}+j\omega\cdot C_1\right)\bar{V}_2=0$$

$$10^{-3}\bar{V}_1-10^{-3}\bar{V}_2=\bar{I}$$

$$-10^{-3}\bar{V}_1+\left(10^{-3}+\frac{1}{j\omega\cdot 10^{-3}}+j\omega\cdot 10^{-9}\right)\bar{V}_2=0$$



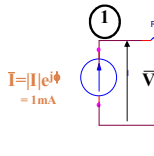
$$\frac{\bar{V}_1-\bar{V}_2}{R_1}=\bar{I}$$

$$\frac{\bar{V}_2-\bar{V}_1}{R_1}+\frac{\bar{V}_2}{j\omega\cdot L_1}+j\omega\cdot C_1\bar{V}_2=0$$

$$\begin{bmatrix}\frac{1}{R_1} & -\frac{1}{R_1}\\ -\frac{1}{R_1} & \frac{1}{R_1}+\frac{1}{j\omega\cdot L_1}+j\omega\cdot C_1\end{bmatrix}\begin{bmatrix}\bar{V}_1\\ \bar{V}_2\end{bmatrix}=\begin{bmatrix}\bar{I}\\ 0\end{bmatrix}$$

$$\underset{\sim}{Y}\cdot\underline{\bar{v}}=\underline{\bar{i}}$$

$$\begin{bmatrix}10^{-3} & -10^{-3}\\ -10^{-3} & 10^{-3}-\frac{j}{\omega\cdot 10^{-3}}+j\omega\cdot 10^{-9}\end{bmatrix}\cdot\begin{bmatrix}\bar{V}_1\\ \bar{V}_2\end{bmatrix}=\begin{bmatrix}10^{-3}\\ 0\end{bmatrix}$$

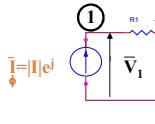


$\bar{I}=|I|e^{j\phi}$
$= 1mA$

$$\begin{bmatrix} \frac{1}{R_1} & -\frac{1}{R_1} \\ -\frac{1}{R_1} & \frac{1}{R_1}+\frac{1}{j\omega\cdot L_1}+j\omega\cdot C_1 \end{bmatrix}\begin{bmatrix} \bar{V}_1 \\ \bar{V}_2 \end{bmatrix}=\begin{bmatrix} \bar{I} \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} \frac{1}{R_1} & -\frac{1}{R_1} \\ -\frac{1}{R_1} & \frac{1}{R_1}+j(\omega\cdot C_1-\frac{1}{\omega\cdot L_1}) \end{bmatrix}\begin{bmatrix} V_{1r}+jV_{1i} \\ V_{2r}+jV_{2i} \end{bmatrix}=\begin{bmatrix} I_r+jI_i \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 10^{-3} & -10^{-3} \\ -10^{-3} & 10^{-3}+j(\omega\cdot 10^{-9}-\frac{1}{\omega\cdot 10^{-3}}) \end{bmatrix}\cdot\begin{bmatrix} V_{1r}+jV_{1i} \\ V_{2r}+jV_{2i} \end{bmatrix}=\begin{bmatrix} 10^{-3}+j0 \\ 0 \end{bmatrix}$$



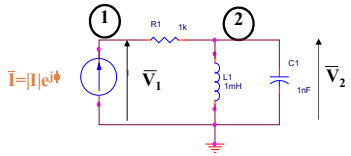
$\bar{I}=|I|e^{j\phi}$

$$\begin{bmatrix} \frac{1}{R_1} & -\frac{1}{R_1} \\ -\frac{1}{R_1} & \frac{1}{R_1}+j(\omega\cdot C_1-\frac{1}{\omega\cdot L_1}) \end{bmatrix}\begin{bmatrix} V_{1r}+jV_{1i} \\ V_{2r}+jV_{2i} \end{bmatrix}=\begin{bmatrix} I_r+jI_i \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} y_{11r}+j\cdot y_{11i} & y_{12r}+j\cdot y_{12i} \\ y_{21r}+j\cdot y_{21i} & y_{22r}+j\cdot y_{22i} \end{bmatrix}\cdot\begin{bmatrix} V_{1r}+j\cdot V_{1i} \\ V_{2r}+j\cdot V_{2i} \end{bmatrix}=\begin{bmatrix} I_r+j\cdot I_i \\ 0 \end{bmatrix}$$

$$(\underset{\sim r}{Y}+j\cdot\underset{\sim i}{Y})\cdot(\underline{v}_r+j\cdot\underline{v}_i)=\underline{i}_r+j\cdot\underline{i}_i$$

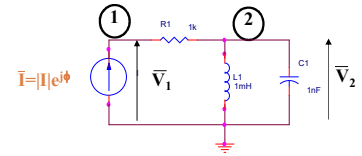
$$\begin{bmatrix} \underset{\sim r}{Y} & -\underset{\sim i}{Y} \\ \underset{\sim i}{Y} & \underset{\sim r}{Y} \end{bmatrix}\cdot\begin{bmatrix} \underline{v}_r \\ \underline{v}_i \end{bmatrix}=\begin{bmatrix} \underline{i}_r \\ \underline{i}_i \end{bmatrix};\quad \text{ili}\quad \begin{bmatrix} -\underset{\sim i}{Y} & \underset{\sim r}{Y} \\ \underset{\sim r}{Y} & \underset{\sim i}{Y} \end{bmatrix}\cdot\begin{bmatrix} \underline{v}_i \\ \underline{v}_r \end{bmatrix}=\begin{bmatrix} \underline{i}_r \\ \underline{i}_i \end{bmatrix}$$



$\bar{I}=|I|e^{j\phi}$

$$\begin{bmatrix} 10^{-3} & -10^{-3} \\ -10^{-3} & 10^{-3}+j(\omega\cdot 10^{-9}-\frac{1}{\omega\cdot 10^{-3}}) \end{bmatrix}\cdot\begin{bmatrix} V_{1r}+jV_{1i} \\ V_{2r}+jV_{2i} \end{bmatrix}=\begin{bmatrix} 10^{-3}+j0 \\ 0 \end{bmatrix}$$

$$\underset{\sim r}{Y}=\begin{bmatrix} 10^{-3} & -10^{-3} \\ -10^{-3} & 10^{-3} \end{bmatrix}\quad i\quad \underset{\sim i}{Y}=\begin{bmatrix} 0 & 0 \\ 0 & j(\omega\cdot 10^{-9}-\frac{1}{\omega\cdot 10^{-3}}) \end{bmatrix}$$

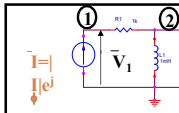


$\bar{I}=|I|e^{j\phi}$

$$\begin{bmatrix} \underset{\sim r}{Y} & -\underset{\sim i}{Y} \\ \underset{\sim i}{Y} & \underset{\sim r}{Y} \end{bmatrix}\cdot\begin{bmatrix} \underline{v}_r \\ \underline{v}_i \end{bmatrix}=\begin{bmatrix} \underline{i}_r \\ \underline{i}_i \end{bmatrix}$$

$$\left[\begin{array}{cc|cc} 10^{-3} & -10^{-3} & 0 & 0 \\ -10^{-3} & 10^{-3} & 0 & -(\omega\cdot 10^{-9}-\frac{1}{\omega\cdot 10^{-3}}) \\ \hline 0 & 0 & 10^{-3} & -10^{-3} \\ 0 & (\omega\cdot 10^{-9}-\frac{1}{\omega\cdot 10^{-3}}) & -10^{-3} & 10^{-3} \end{array}\right]\begin{bmatrix} V_{1r} \\ V_{2r} \\ V_{1i} \\ V_{2i} \end{bmatrix}=\begin{bmatrix} 10^{-3} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Red matrice 2x veći, ali je gustina matrice manja



$\bar{I}=|I|e^{j\phi}$

Za $\omega=10^3$rad/s

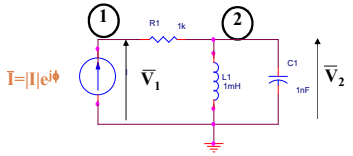
$$\begin{bmatrix} 10^{-3} & -10^{-3} & 0 & 0 \\ -10^{-3} & 10^{-3} & 0 & -(10^{-6}-1) \\ 0 & 0 & 10^{-3} & -10^{-3} \\ 0 & (10^{-6}-1) & -10^{-3} & 10^{-3} \end{bmatrix} \cdot \begin{bmatrix} v_{1r} \\ v_{2r} \\ v_{1i} \\ v_{2i} \end{bmatrix} = \begin{bmatrix} 10^{-3} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Za $\omega=10^6$rad/s

$$\begin{bmatrix} 10^{-3} & -10^{-3} & 0 & 0 \\ -10^{-3} & 10^{-3} & 0 & -(0) \\ 0 & 0 & 10^{-3} & -10^{-3} \\ 0 & (0) & -10^{-3} & 10^{-3} \end{bmatrix} \cdot \begin{bmatrix} v_{1r} \\ v_{2r} \\ v_{1i} \\ v_{2i} \end{bmatrix} = \begin{bmatrix} 10^{-3} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Za $\omega=10^9$rad/s

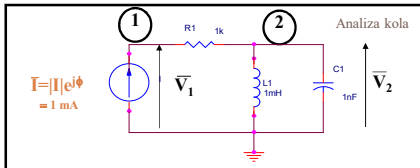
$$\begin{bmatrix} 10^{-3} & -10^{-3} & 0 & 0 \\ -10^{-3} & 10^{-3} & 0 & -(1-10^{6}) \\ 0 & 0 & 10^{-3} & -10^{-3} \\ 0 & (1-10^{6}) & -10^{-3} & 10^{-3} \end{bmatrix} \cdot \begin{bmatrix} v_{1r} \\ v_{2r} \\ v_{1i} \\ v_{2i} \end{bmatrix} = \begin{bmatrix} 10^{-3} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$



$\bar{I}=|I|e^{j\phi}$

$$\begin{bmatrix} -\underset{\sim}{Y}_i & \underset{\sim}{Y}_r \\ \underset{\sim}{Y}_r & \underset{\sim}{Y}_i \end{bmatrix} \cdot \begin{bmatrix} \underline{v}_i \\ \underline{v}_r \end{bmatrix} = \begin{bmatrix} \underline{i}_r \\ \underline{i}_i \end{bmatrix}$$

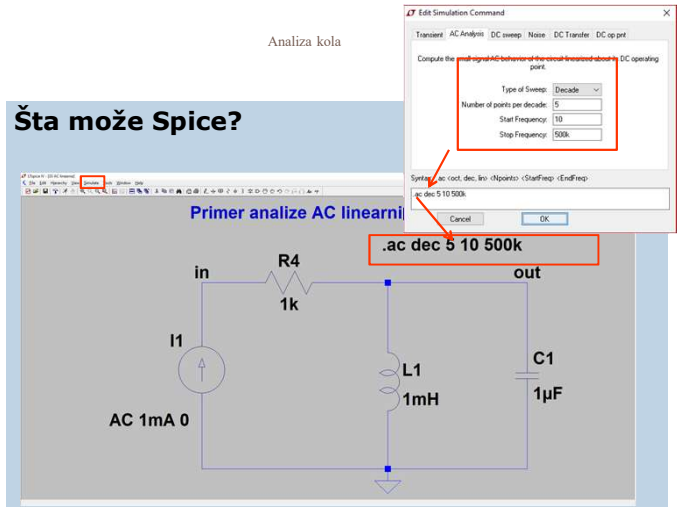
$$\left[\begin{array}{cc|cc} 0 & 0 & 10^{-3} & -10^{-3} \\ 0 & -(\omega\cdot 10^{-9}-\frac{1}{\omega\cdot 10^{-3}}) & -10^{-3} & 10^{-3} \\ \hline 10^{-3} & -10^{-3} & 0 & 0 \\ -10^{-3} & 10^{-3} & 0 & (\omega\cdot 10^{-9}-\frac{1}{\omega\cdot 10^{-3}}) \end{array}\right] \cdot \begin{bmatrix} v_{1i} \\ v_{2i} \\ v_{1r} \\ v_{2r} \end{bmatrix} = \begin{bmatrix} 10^{-3} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$



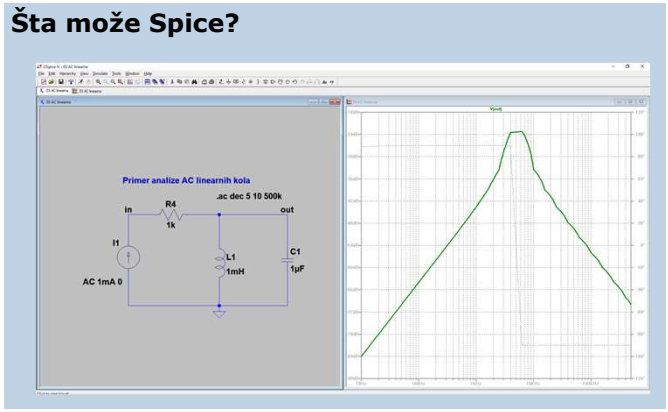
$\bar{I}=|I|e^{j\phi}$
$=1$ mA

Za $\omega=10^6$rad/s

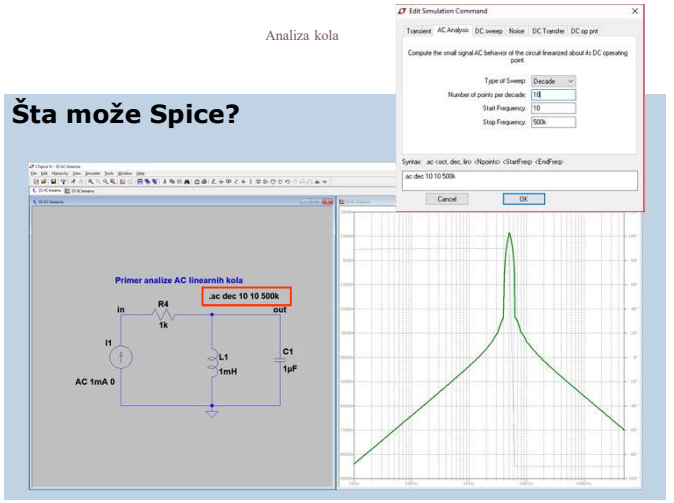
$$\begin{bmatrix} 0 & 0 & 10^{-3} & -10^{-3} \\ 0 & -(0) & -10^{-3} & 10^{-3} \\ 10^{-3} & -10^{-3} & 0 & 0 \\ -10^{-3} & 10^{-3} & 0 & (0) \end{bmatrix} \cdot \begin{bmatrix} v_{1i} \\ v_{2i} \\ v_{1r} \\ v_{2r} \end{bmatrix} = \begin{bmatrix} 10^{-3} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$



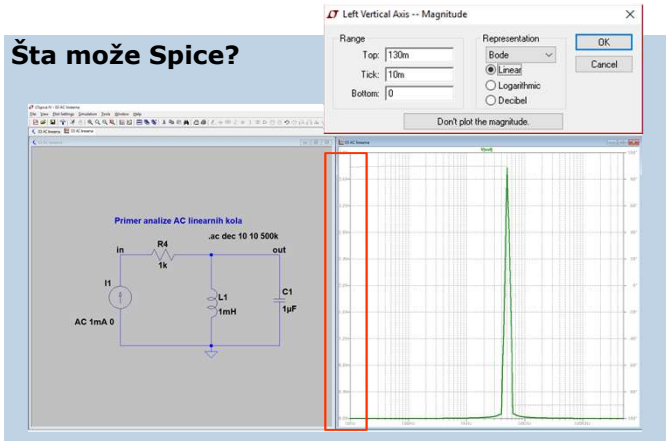
Šta može Spice?



Šta može Spice?

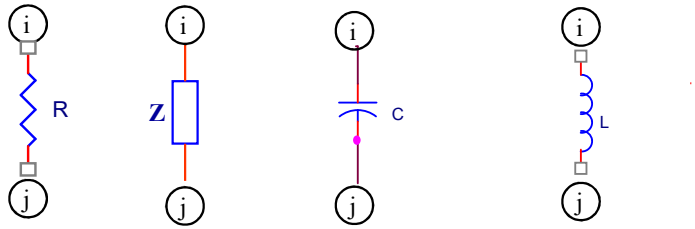


Šta može Spice?

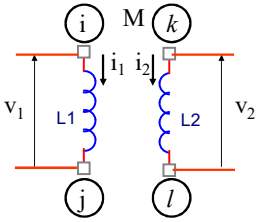


Postoji potpuna korespodencija sa elementima linearnih otpornih kola

$Z_C=1/j\omega C$ $Z_L=j\omega L$

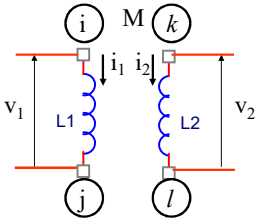


Spregnute induktivnosti



$$\mathbf{V}_1 = j\omega \mathbf{L}_1 \mathbf{i}_1 + j\omega \mathbf{M} \mathbf{i}_2$$
$$\mathbf{V}_2 = j\omega \mathbf{M} \mathbf{i}_1 + j\omega \mathbf{L}_2 \mathbf{i}_2$$
$$\begin{bmatrix} \mathbf{V}_1 \\ \mathbf{V}_2 \end{bmatrix} = \begin{bmatrix} j\omega \mathbf{L}_1 & j\omega \mathbf{M} \\ j\omega \mathbf{M} & j\omega \mathbf{L}_2 \end{bmatrix} \cdot \begin{bmatrix} \mathbf{i}_1 \\ \mathbf{i}_2 \end{bmatrix}$$

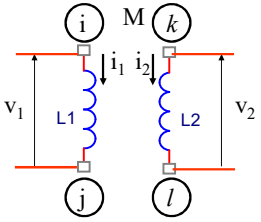
Spregnute induktivnosti



$$\begin{bmatrix} \mathbf{i}_1 \\ \mathbf{i}_2 \end{bmatrix} = \frac{1}{j\omega} \begin{bmatrix} \mathbf{L}_1 & \mathbf{M} \\ \mathbf{M} & \mathbf{L}_2 \end{bmatrix}^{-1} \cdot \begin{bmatrix} \mathbf{V}_1 \\ \mathbf{V}_2 \end{bmatrix} =$$
$$\begin{bmatrix} \mathbf{i}_1 \\ \mathbf{i}_2 \end{bmatrix} = \frac{1}{j\omega(\mathbf{L}_1\mathbf{L}_2 - \mathbf{M}^2)} \begin{bmatrix} \mathbf{L}_2 & -\mathbf{M} \\ -\mathbf{M} & \mathbf{L}_1 \end{bmatrix} \cdot \begin{bmatrix} \mathbf{V}_1 \\ \mathbf{V}_2 \end{bmatrix}$$

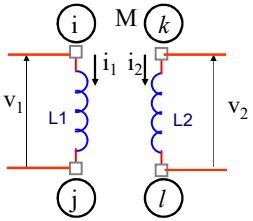
Automatizacija formulacije jednačina

Spregnute induktivnosti

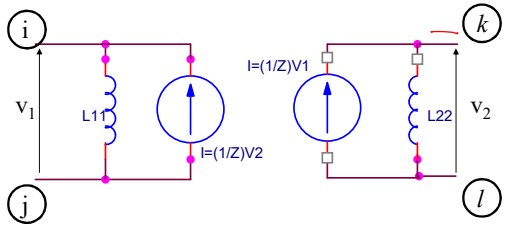


$$\mathbf{i}_1 = \frac{1}{j\omega \mathbf{L}_{11}} \mathbf{V}_1 - \frac{1}{\mathbf{Z}} \mathbf{V}_2$$
$$\mathbf{i}_2 = -\frac{1}{\mathbf{Z}} \mathbf{V}_1 + \frac{1}{j\omega \mathbf{L}_{22}} \mathbf{V}_2$$
$$\mathbf{L}_{11} = \frac{\mathbf{L}_1\mathbf{L}_2 - \mathbf{M}^2}{\mathbf{L}_2}$$
$$\mathbf{L}_{22} = \frac{\mathbf{L}_1\mathbf{L}_2 - \mathbf{M}^2}{\mathbf{L}_1}$$
$$\mathbf{Z} = j\omega \frac{\mathbf{L}_1\mathbf{L}_2 - \mathbf{M}^2}{\mathbf{M}}$$

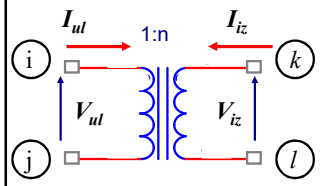
Spregnute induktivnosti



$$\mathbf{i}_1 = \frac{1}{j\omega \mathbf{L}_{11}} \mathbf{V}_1 - \frac{1}{\mathbf{Z}} \mathbf{V}_2$$
$$\mathbf{i}_2 = -\frac{1}{\mathbf{Z}} \mathbf{V}_1 + \frac{1}{j\omega \mathbf{L}_{22}} \mathbf{V}_2$$

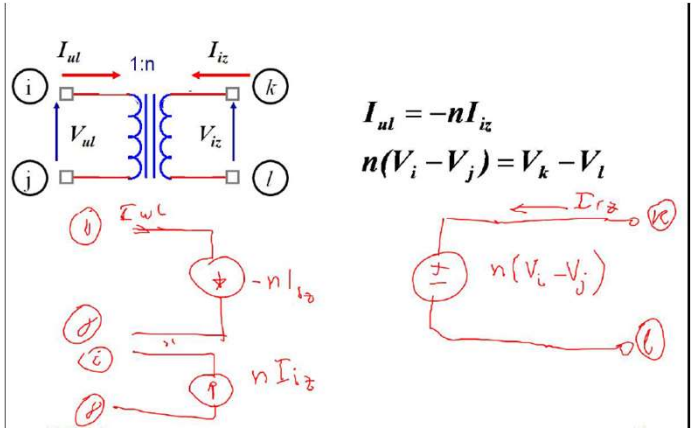


Transformator



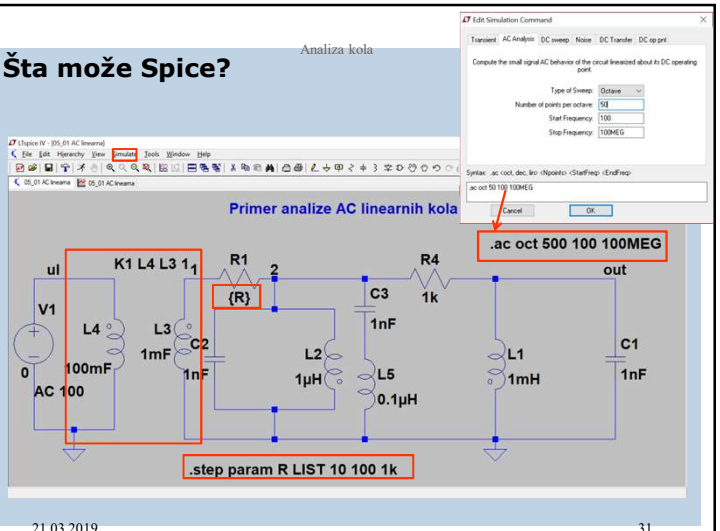
$$I_{ul} = -nI_{iz}$$
$$n(V_i - V_j) = V_k - V_l$$

Transformator

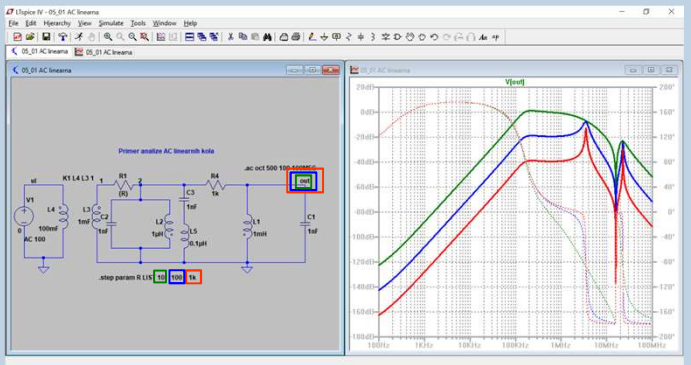


$$I_{ul} = -nI_{iz}$$
$$n(V_i - V_j) = V_k - V_l$$

Šta može Spice?



Šta može Spice?

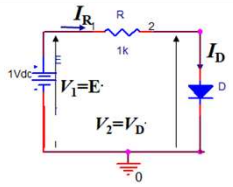


Kako se predstavljaju nelinearne komponente:
- Diode
- BJT
- MOST

pri AC analizi?

Predstavljaju se modelima za male signale
(kako mali signal vidi nelinearnu karakteristiku)

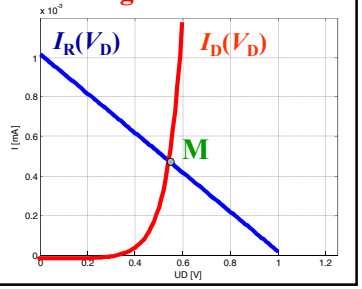
-Dioda u elektronskom kolu



Model diode – nelinearan – za velike signale

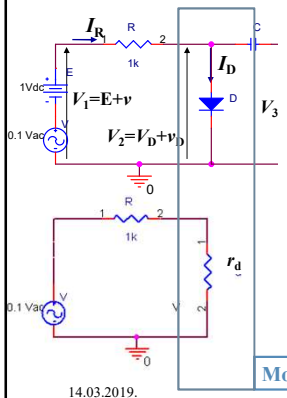
$$\frac{E - V_D}{R} = I_R$$

$$I_D = I_S\left(e^{\frac{V_D}{V_T}} - 1\right)$$

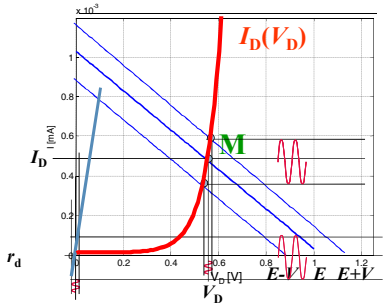


Dioda

-Dioda u elektronskom kolu



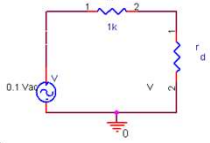
Grafička interpretacija problema

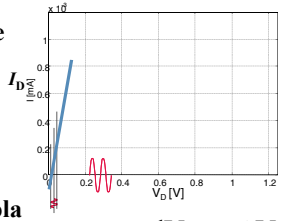


Model za male signale

Dioda

VAŽNO model za male signale





koristi se u analizi ponašanja kola pobuđenih malim naizmeničnim signalima.

Tada se svi elementi kola zamenjuju *dinamičkim parametrima*

Dinamički parametar diode jeste *unutrašnja otpornost* diode u radnoj tački.

$$r_d = \frac{dV_D}{dI_D} \approx \frac{\Delta V_D}{\Delta I_D}$$

$$r_d = \frac{1}{\frac{dI_D}{dV_D}} \approx \frac{1}{\frac{I_S e^{V_D/V_T}}{V_T}}$$

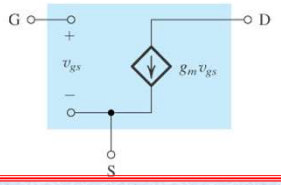
$$r_d \approx \frac{V_T}{I_D}$$

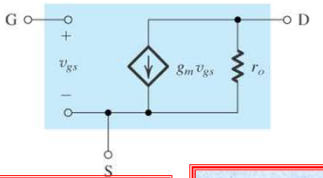
Dioda Spice model

Diode SPICE parameters

Symbol	Name	Parameter	Units	Default
I_S	IS	Saturation current (diode equation)	A	1E-14
R_S	RS	Parsitic resistance (series resistance)	Ω	0
n	N	Emission coefficient, 1 to 2	-	1
τ_D	TT	Transit time	s	0
$C_D(0)$	CJO	Zero-bias junction capacitance	F	0
φ_0	VJ	Junction potential	V	1
m	M	Junction grading coefficient	-	0.5
-	-	0.33 for linearly graded junction	-	-
-	-	0.5 for abrupt junction	-	-
E_g	EG	Activation energy:	eV	1.11
-	-	Si: 1.11	-	-
-	-	Ge: 0.67	-	-
-	-	Schottky: 0.69	-	-
p_I	XTI	IS temperature exponent	-	3.0
-	-	pn junction: 3.0	-	-
-	-	Schottky: 2.0	-	-
k_f	KF	Flicker noise coefficient	-	0
a_f	AF	Flicker noise exponent	-	1
FC	FC	Forward bias depletion capacitance coefficient	-	0.5
BV	BV	Reverse breakdown voltage	V	∞
IBV	IBV	Reverse breakdown current	A	1E-3

Model MOS tranzistora za male signale





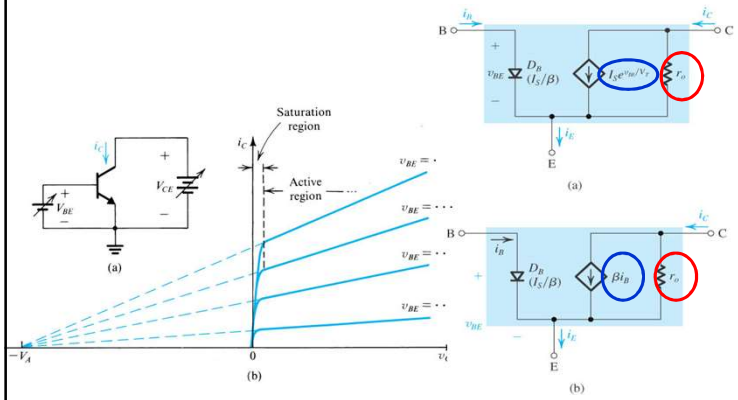
$$g_m = \mu_n C'_{ox} \frac{W}{L}(V_{GS} - V_t) = \frac{2I_D}{(V_{GS} - V_t)} = \frac{2I_D}{V_{OV}}$$

$$r_o = \frac{V_A}{I_D}$$

$$\left(g_m r_o \equiv \mu = \frac{\partial I_D}{\partial V_{GS}} \frac{\partial V_{DS}}{\partial I_D} = \frac{\partial V_{DS}}{\partial V_{GS}} = \frac{2V_A}{(V_{GS} - V_t)} \right) \quad (r_o \equiv R_i)$$

MOS tranzistor Spice model

Tranzistor



BJT Spice model

Pri AC analizi sve komponente se zamenjuju linearnim modelima!

- AC podrazumeva analizu LINEARNIH kola
- Sadrže reaktivne komponente (L i C)

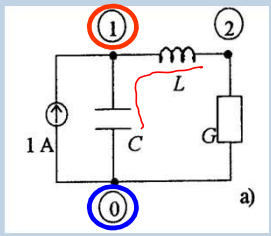
Njih opisuje sistem linearnih algebarskih jednačina sa kompleksnim koeficijentima.

Rešavaju se LU faktorizacijom (Gaus)

Izazovi i specifičnosti AC analize?

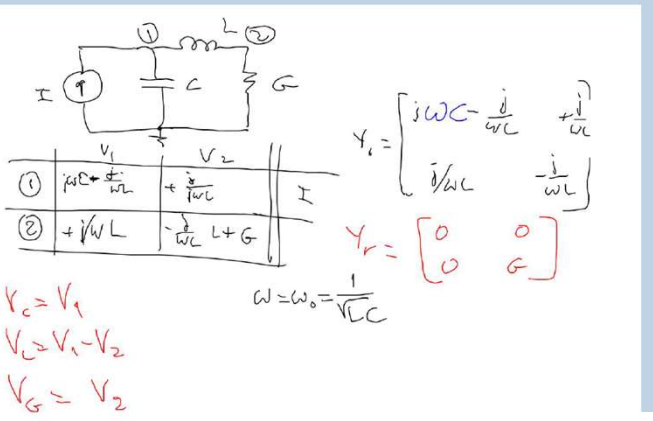
Izazovi i specifičnosti AC analize?

Primer



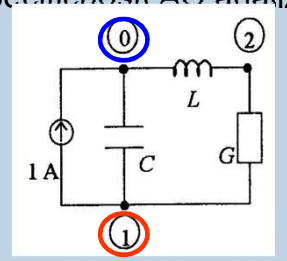
$$\begin{bmatrix} j\omega C - j\frac{1}{\omega L} & j\frac{1}{\omega L} \\ j\frac{1}{\omega L} & G - j\frac{1}{\omega L} \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

Izazovi i specifičnosti AC analize?



Izazovi i specifičnosti AC analize?

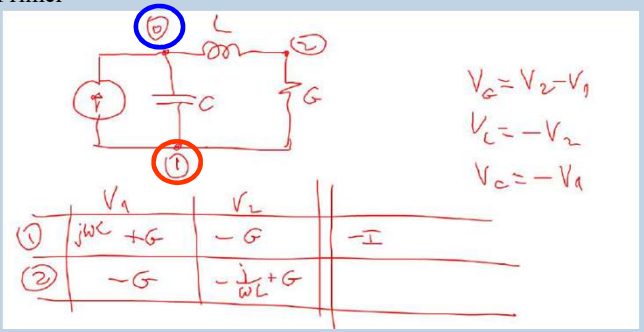
Primer



$$\begin{bmatrix} j\omega \cdot C + G & -G \\ -G & G - \dfrac{j}{\omega \cdot L} \end{bmatrix} \begin{bmatrix} \overline{V_1} \\ \overline{V_2} \end{bmatrix} = \begin{bmatrix} -\overline{I} \\ 0 \end{bmatrix}$$

Izazovi i specifičnosti AC analize?

Primer



Karakteristike analize u AC domenu:

Analiza od f_d do f_g

Voditi računa o veličini koraka i veličini propusnog opsega kola koje se analizira.

Svi modeli poluprovodničkih komponenata su linearni i malosignalni. U Spice-u uvek se najpre obavi DC analiza, da bi se odredio položaj radne tačke, a zatim se izračunavaju parametri modela.

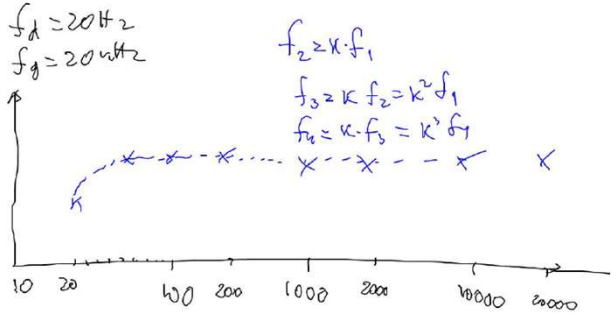
Izbor koraka frekvencije

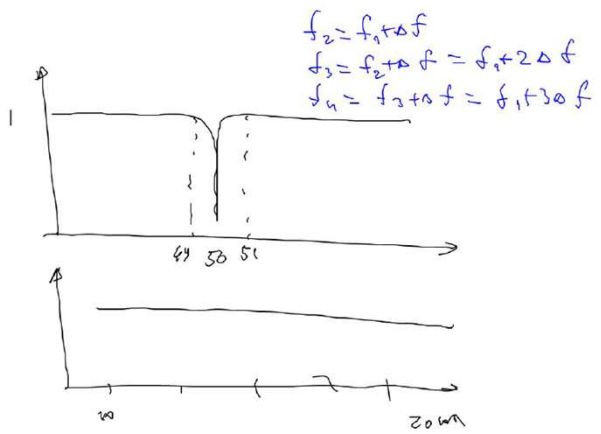
Logaritamska skala

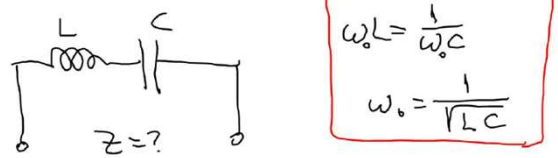
Broj tačaka po dekadi/oktavi

Linearna skala

$\Delta_f = (f_g - f_d)/N$





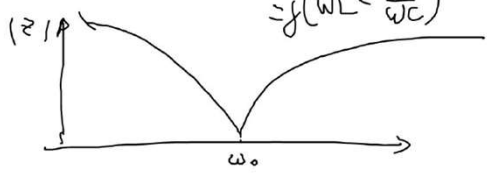


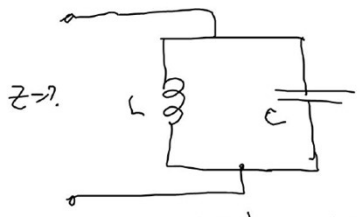
$$\omega_0 L = \frac{1}{\omega_0 C}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$Z = j\omega L + \frac{1}{j\omega C} = j\omega L - j\frac{1}{\omega C} =$$

$$= j\left(\omega L - \frac{1}{\omega C}\right)$$

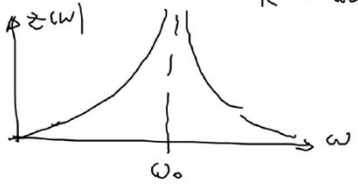




$$Z = \frac{Z_L \cdot Z_C}{Z_L + Z_C}$$

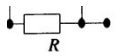
$$= \frac{j\omega L \cdot \frac{1}{j\omega C}}{j\omega L - j\frac{1}{\omega C}}$$

$$= \frac{\frac{L}{C}}{j\left(\omega L - \frac{1}{\omega C}\right)}$$

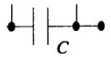


Analiza VF kola - parazitni efekti

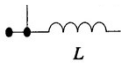
R



C

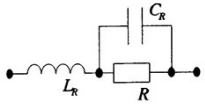


L

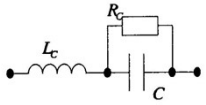


Analiza VF kola - parazitni efekti

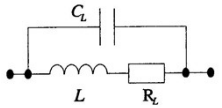
R



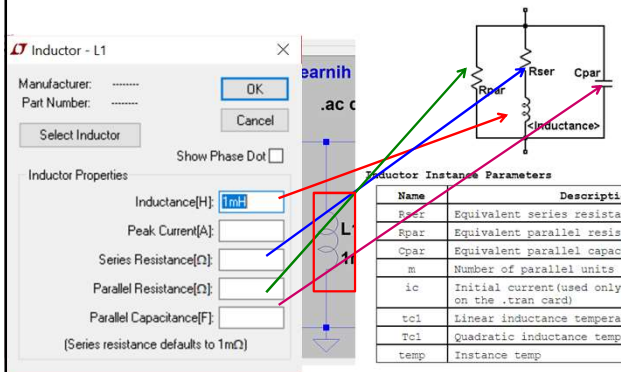
C



L



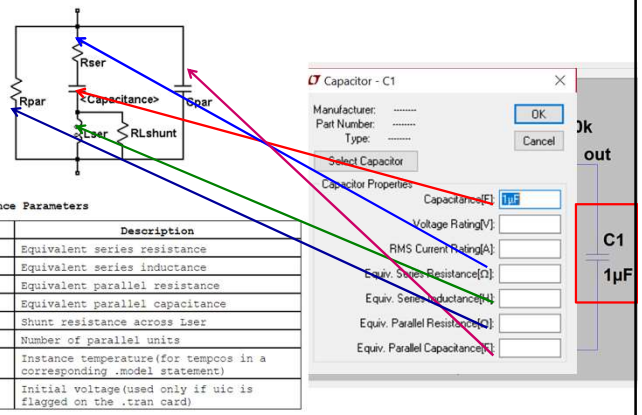
Analiza VF kola - parazitni efekti LTSpice



Inductor Instance Parameters

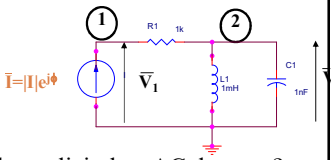
Name	Description
Rser	Equivalent series resistance
Rpar	Equivalent parallel resistance
Cpar	Equivalent parallel capacitance
m	Number of parallel units
ic	Initial current (used only if uic flagged on the .tran card)
tc1	Linear inductance temperature coeff.
Tc1	Quadratic inductance temperature coeff.
temp	Instance temp

Analiza VF kola - parazitni efekti LTSpice



Capacitor Instance Parameters

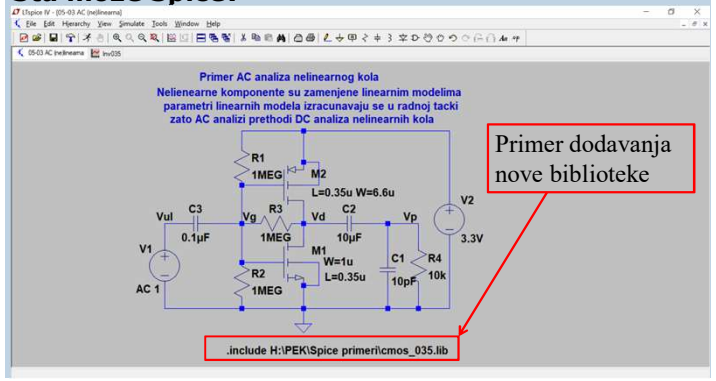
Name	Description
Rser	Equivalent series resistance
Lser	Equivalent series inductance
Rpar	Equivalent parallel resistance
Cpar	Equivalent parallel capacitance
RLshunt	Shunt resistance across Lser
m	Number of parallel units
temp	Instance temperature (for tempcos in a corresponding .model statement)
ic	Initial voltage (used only if uic is flagged on the .tran card)



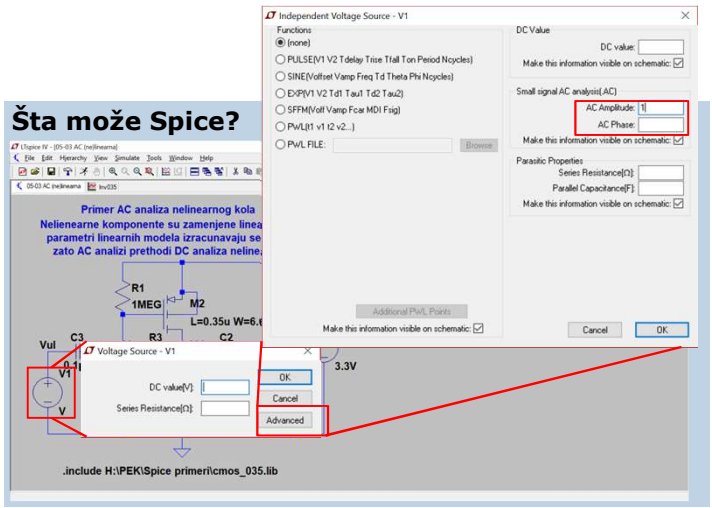
Spice:
Koje parametre treba zadati da bi se kolo analiziralo u AC domenu?

- Tip analize: AC
- Parametri generatora: magnituda i faza
- Donja granična frekvencija
- Gornja granična frekvencija
- Broj tačaka:
  - Linearno
  - Logaritamski
    - (po dekadi)
    - (po oktavi)

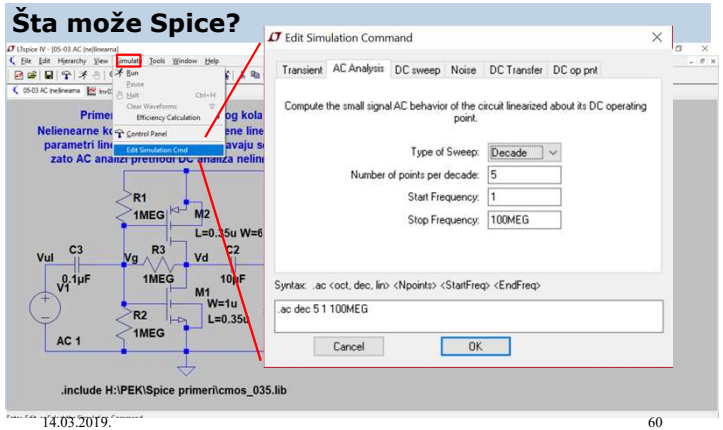
Šta može Spice?



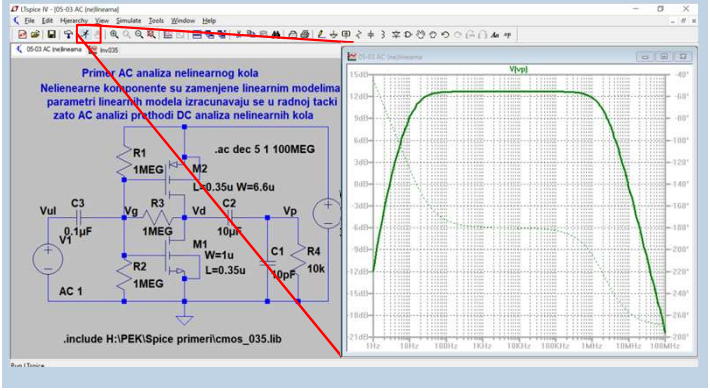
Šta može Spice?



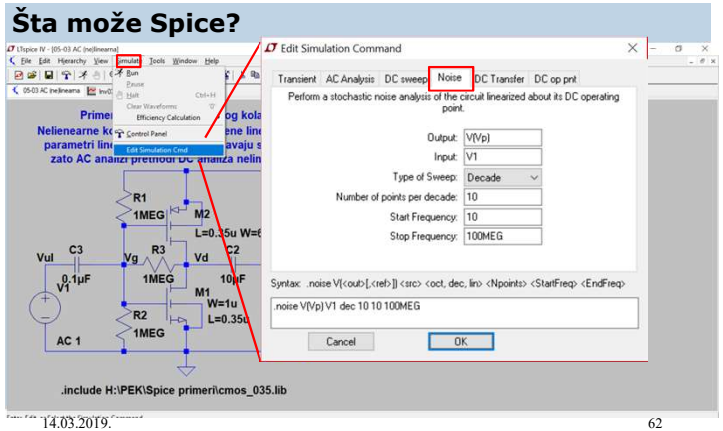
Šta može Spice?



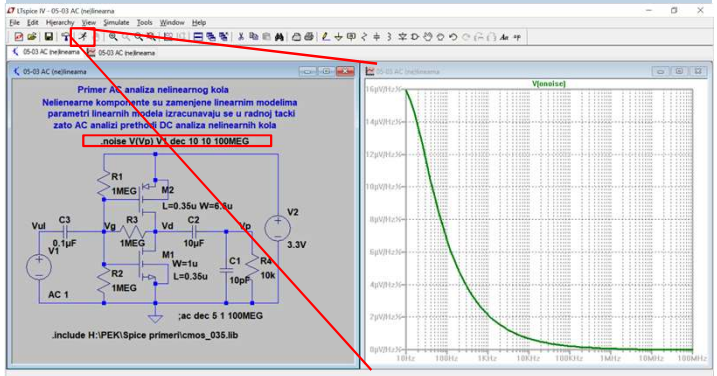
Šta može Spice?



Šta može Spice?



Šta može Spice?



Analiza linearnih kola u AC domenu

Šta treba da znamo?

Elementarno (za potpis)

Šta se dobija kao rezultat analize u frekvencijskom domenu?

Osnovna (za 6)

1. **Koje parametre treba zadati da bi se u programu Spice analiziralo kolo u frekvencijskom domonu?**
2. **Kakvi se modeli poluprovodničkih komponenta koriste pri AC analizi?**

Ispitna pitanja

a) **Koliko puta se formira i rešava sistem jednačina pri jednoj analizi kola u AC režimu ukoliko se traži analiza u 4 tačke po dekadi u opsegu od 5Hz do 50kHz/Koliko puta se formira i rešava sistem jednačina pri jednoj analizi kola u AC režimu ukoliko se traži analiza u 2 tačke po oktavi u opsegu od 5Hz do 50kHz?**

b) **Koji su karakteristični problemi vezani za zadavanje koraka u AC analizi?**

c) **Koji su karakteristični problemi vezani za rezonantnu frekvenciju u AC analizi? Kako ih izbeći?**