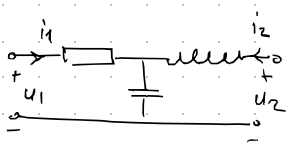
2. ELEMENTI EL KRUGOVA

- dvopoli → R → možemo napraviti 4-pole

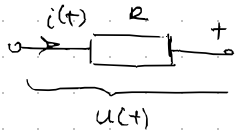


- četveropoli → transformatori

↳ mogu se proširiti na n-teropole

Dvopolni elementi R, L, C

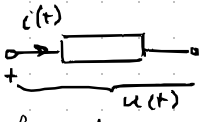
Primjer:



$R = 5\,k\Omega$

$u = -10V$

▶ otpor (R)



odnosi $i(t)$ i $u(t)$

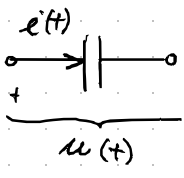
↳ zakonitost ne ovisi o smjeru

$U = I \cdot R$

ako $i(t)$ i $u(t)$ nisu istog usmjerenja → $i(t) = -2mA$

→ formule mora pratit sliku!!

▶ kapacitet (C)



$$i(t) = C\frac{du(t)}{dt}$$

↳ skladišti ("pamti") što je bilo prije

proizvoljan trenutak

$$u(t) = \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = u_C(0) + \frac{1}{C}\int_{0}^{t} i(\tau)d\tau$$

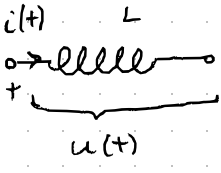
doprinos struje na kapacitetu od 0 do t

- ako u nekom x trenutku želimo spojit neki novi element

↳ $u_{C(x)} + \frac{1}{C}\int_{x}^{t} i(\tau)d\tau$

pasivni element: $E(t) = C\frac{u^2}{2} \geq 0$

▶ induktivitet (L)



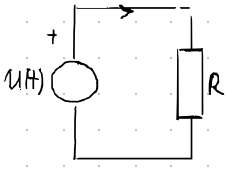
$$i(t) = \frac{1}{L}\int_{-\infty}^{t} u(\tau)d\tau = i_L(0) + \frac{1}{L}\int_{0}^{t} u(\tau)d\tau$$

$$u(t) = L\frac{di(t)}{dt}$$

pasivni element: $E(t) = \frac{1}{2}Li(t) \geq 0$

→ aktivni dvopoli: Naponski i Strujni izvor

Primjer:

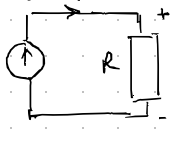


$\rightarrow I = \frac{U}{R}$

R	U	I
1 kΩ	10V	10mA
10 kΩ	10V	1mA

=> Struja kroz naponski izvor ovisi o elementu ili mreži priključenoj na njega

Primjer: Strujni izvor:

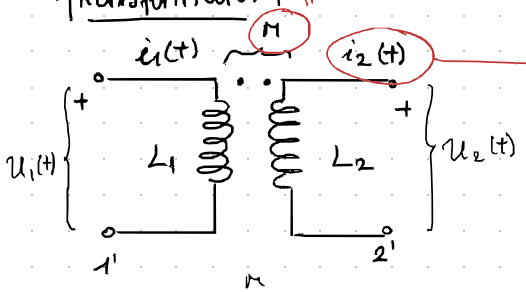


$U = I \cdot R$

-> Napon na strujnom izvoru ovisi o elementu ili mreži priključenoj na njega

Četveropolni elementi

→ **transformator** — međuinduktivitet



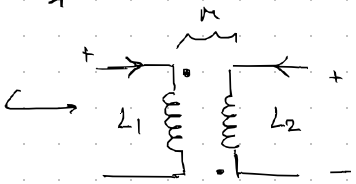
primar

$$u_1(t) = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

jer struja i_2 prolazi kroz L_2 pa se inducira dodatni napon

* dvopol → 1 jednadžba → jedan napon

četveropol → 2 jednadžbe → 2 napona

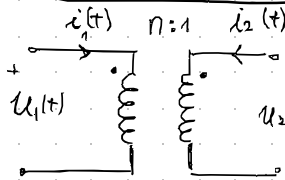


– ako se zamijene točkice → minus (–) ispred M

$$u_1(t) = L_1 \frac{di_1}{dt} - M \frac{di_2}{dt}$$

$$\rightarrow k = \frac{M}{\sqrt{L_1 L_2}} \qquad 0 < |k| < 1 \text{ , } k = 1 \text{ perfektni transformator}$$

→ **idealni transformator** $M = \sqrt{L_1 L_2}$



$$u_1(t) = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \quad / \cdot \frac{1}{\sqrt{L_1}} \Rightarrow \frac{u_1}{\sqrt{L_1}} = \sqrt{L_1} \frac{di_1}{dt} + \frac{M}{\sqrt{L_1}} \frac{di_2}{dt}$$

$$u_2(t) = M \frac{di_1}{dt} + L_2 \frac{di_2}{dt} \quad / \cdot \frac{1}{\sqrt{L_2}} \Rightarrow \frac{u_2}{\sqrt{L_2}} = \frac{M}{\sqrt{L_2}} \frac{di_1}{dt} + \sqrt{L_2} \frac{di_2}{dt}$$

$$\frac{u_1}{\sqrt{L_1}} = \sqrt{L_1} \frac{di_1}{dt} + \sqrt{L_2} \frac{di_2}{dt}$$

$$\frac{u_2}{\sqrt{L_2}} = \sqrt{L_1} \frac{di_1}{dt} + \sqrt{L_2} \frac{di_2}{dt}$$

$$= \rightarrow \frac{u_1}{\sqrt{L_1}} = \frac{u_2}{\sqrt{L_2}} \rightarrow \boxed{\frac{u_1}{u_2} = \sqrt{\frac{L_1}{L_2}}}$$

• n – omjer transformacije $\Rightarrow u_1(t) = n \cdot u_2(t)$, $i_1(t) = \frac{-1}{n} i_2(t)$

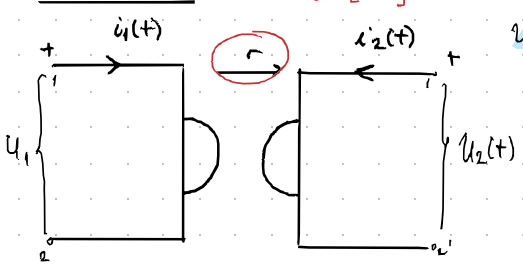
– idealni transformator – pasivni četveropol bez gubitaka

$E(t) = 0$ → ne pohranjuje energiju

→ **Girator** pozitivna i realna konstanta [Ω]

$$u_1(t) = r \cdot i_2(t)$$

$$u_2(t) = -r \cdot i_1(t)$$

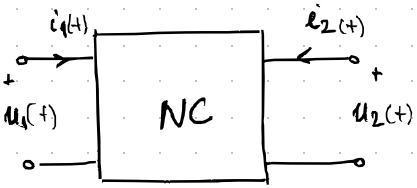


* pasivni četveropol bez gubitaka

$E(t) = 0$

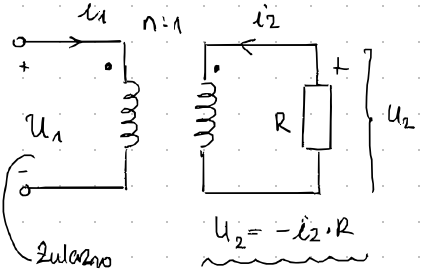
→ Negativni konvertor

$u_1(t) = k_1 \cdot u_2(t)$ $\quad i_2(t) = k_2 \, i_1(t)$ $\quad k = k_1 k_2$



▶ Važno svojstvo idealnog transformatora, giratora i neg. konvertora je transformacija otpora (impedancije)

IDEALNI TRANSFORMATOR



$u_1 = n \, u_2$

$i_1 = -\frac{1}{n} i_2$

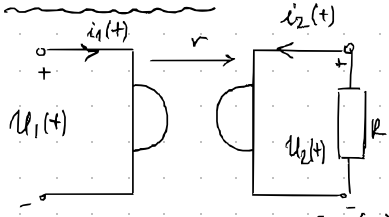
$Z_{ul} = \frac{u_1}{i_1} = \frac{n \, u_2}{-\frac{1}{n} i_2} = -\frac{n^2 u_2}{i_2}$

$u_2 = -i_2 \cdot R$

$\boxed{Z_{ul} = -n^2 \cdot R}$!

Idealnim transf. moguće je promijeniti vrijednost otpora

GIRATOR



$u_1 = r \cdot i_2(t)$

$u_2 = -r \, i_1(t)$

$Z_{ul} = \frac{u_1}{i_1}$

$Z_{ul} = \frac{u_1}{i_1} = \frac{r \, i_2(t)}{i_1(t)} = r \cdot \frac{\frac{u_2(t)}{-R}}{i_1(t)}$

$Z_{ul} = \frac{r \cdot (-r) \, i_1(t)}{-R \, i_1(t)}$

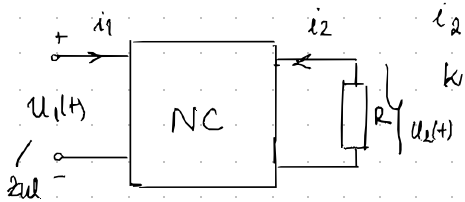
$u_2(t) = i_2(t) \cdot (-R)$

$\boxed{Z_{ul} = \frac{r^2}{R}}$!

Girator invertira impedanciju ↳ $Z \uparrow \sim R \downarrow$

- ako bi izlaz ostavili otvoren → $Z_{ul} = 0\,\Omega$ $(R = \infty)$
- izlaz spojimo kratko ⟶ $Z_{ul} = \infty\,\Omega$ $(R = 0)$

NEGATIVNI KONVERTOR



$u_1 = k_1 \, u_2(t)$

$i_2(t) = k_2 \, i_1(t)$

$k = k_1 \cdot k_2$

$Z_{ul} = \frac{u_1}{i_1}$ $\quad u_2 = -i_2 \cdot R$

$Z_{ul} = \frac{k_1 u_2(t)}{i_1(t)} = k_1 \cdot \frac{u_2(t)}{i_2(t) \cdot \frac{1}{k_2}}$

$Z_{ul} = k_1 \cdot k_2 \cdot (-R)$

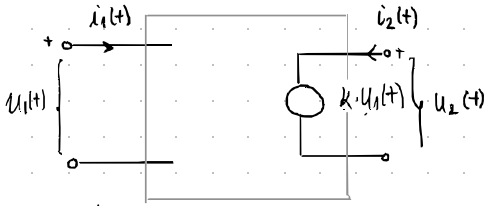
$\Rightarrow \boxed{Z_{ul} = -k_1 k_2 R}$!

→ NC mijenja predznak otporu R

Ovisni izvori – aktivni četveropoli

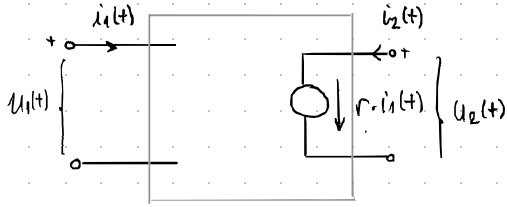
– daju uvjetni napon → naponski izvor je ovisan o nekoj struji ili naponu u mreži

– Naponski ovisni naponski izvor (NONI)



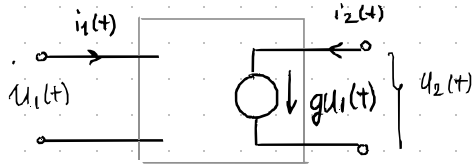
$u_2 = k u_1 \quad u_1 = 0$

– Strujno ovisni naponski izvor (SONI)



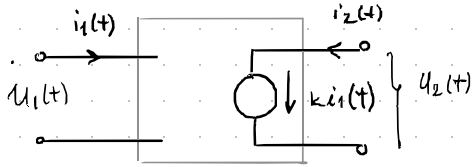
$u_2 = i_1 \cdot r \quad a_1 = 0$

– Naponski ovisni strujni izvor (NOSI)



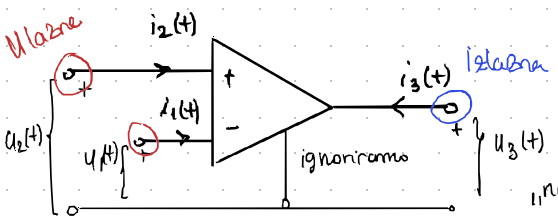
$u_2(t) = g u_1(t)$

– Strujno ovisni strujni izvor (SOSI)



$i_2 = k i_1$

Operacijsko pojačalo → 3 priključka



Definicijske jednadžbe

1) $u_3 = A(u_2 - u_1)$ $\quad A \to \infty$ (pojačanje)

2) $i_2 = i_1 = 0$

„naponsko pojačalo" jer je uvjet $u_3 = A(u_2 - u_1)$

→ u realnim uvjetima:

- pojačanje A je cca 10^4 ; nije konstantno nego frekvencijski ovisno
- $i_1 \neq i_2 \neq 0$
- tipičan ulazni otpor je $5 \times 10^5 \Omega$, a izlazni 300Ω

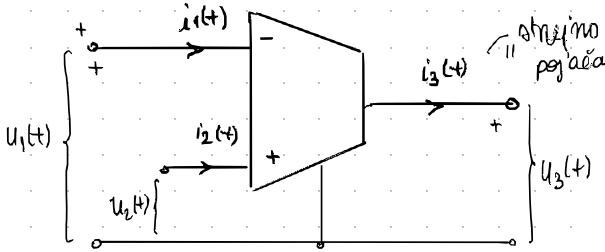
▶ princip prividnog kratkog spoja – pojednostavljuje analizu krugova s op. pojačalom

$u_2 - u_1 = \frac{u_3}{A}$ $\quad u_3$ – konačan, $A = \infty$ ↳ $u_2 = u_1$

jer na strujе i_1 i i_2 jednake 0

Strujno pojačalo

element s 3 priključka



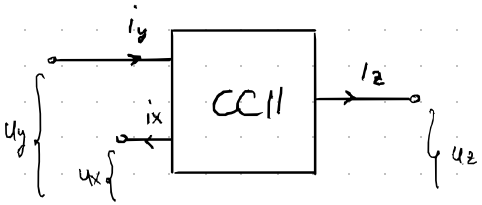
"strujno pojačalo" $\rightarrow i_3 = g_m(u_2 - u_1)$

$g_m \neq \infty$

$i_2 = i_1 = 0$

- ulazni i izlazni otpori su beskonačni

Strujni pojačnomik



$u_x = u_y$

$i_y = 0 \quad i_z = i_x$