



# ***Elektronika*** ***uvodno predavanje***

Prof.dr.Zoran Mijanović



# ***Prof.dr.Zoran Mijanović***



- 1959. rođen u Ljubljani
- Osnovna škola “Maksim Gorki” u Titogradu (Luča, savezno takmičenje 1972. Novi Sad)
- 1977. završio Gimnaziju u Titogradu (Luča)
- 1981. diplomirao na ETF-u Titograd (9,62)
- 1981-1983 u Institutu “Mihailo Pupin”
- 1983. magistrirao na ETF Beograd
- 1984. asistent na ETF Titograd
- 1989. doktorirao na ETF Beograd
- 2000. redovni profesor
- Osnivač nekoliko firmi
- Saradnja sa privredom

# *Ciljevi izučavanja predmeta*



- Upoznati analogna elektronska kola
- Naučiti metode analize analognih kola:
  - idealni operacioni pojačavač
  - frekvencijska analiza, filteri
  - povratna sprega, stabilnost kola
  - termički račun, iskorišćenje snage
- Upoznati i analizirati prekidačka kola snage
- Pratiti savremene tehnike i tehnologije

# *Metod nastave i savladavanja gradiva*



- Predavanja
- Računske vježbe
- Rad na računaru
- Laboratorijske vježbe
- Učenje i samostalan rad
- Seminarski rad
- Konsultacije.

# *Ishodi učenja*



Nakon što student položi ovaj ispit biće u mogućnosti da:

- Analizira kola sa VFB i CFB operacionim pojačavačima;
- Izvrši frekvencijsku analizu pojačavača, aktivnih i pasivnih filtera;
- Odredi uslove oscilovanja datog kola i nađe učestanost oscilovanja;
- Dimenzioniše kolo za automatsku regulaciju amplitude oscilovanja;
- Konstruiše oscilator u 3 tačke;
- Analizira stabilnost kola sa povratnom spregom;
- Prepozna osnovne konfiguracije PLL-a i odredi osnovne parametre PLL-a;
- Termički analizira kola sa tranzistorima snage i pojačavačima snage;
- Proračuna osnovne parametre linearnog stabilizatora (ulazne i izlazne napone, strujni kapacitet);
- Prepozna osnovne konfiguracije prekidačkih izvora napajanja i nađe vezu između vremena prekidanja i izlaznog napona.



# *Literatura*



- Univerzitetski udžbenici sa ETF Beograd, Zagreb, Sarajevo, Banja Luka, ...
- Npr: Analogna integrisana kola – Slavoljub Marjanović – ETF Beograd
- Microelectronic circuits - Sedra i Smith
- [www.wikipedia.org](http://www.wikipedia.org)
- [www.etf.ac.me](http://www.etf.ac.me)



# ***Oblici provjere znanja i ocjenjivanje***



- 10 kratkih provjera znanja u terminima predavanja (ukupno 15 poena),
- Laboratorijske vježbe 10 poena
- Dvije provjere znanja po 15 poena (ukupno 30 poena),
- Seminarski rad 5 poena, i obavezan je za najvišu ocjenu,
- Završni ispit 40 poena,
- Prelazna ocjena se dobija ako se kumulativno sakupi najmanje 51 poen.

# *Seminarski radovi – vrste:*



- Naći na Internetu softverski alat za Elektroniku, ocijeniti ga i napraviti uputstvo za upotrebu
- Napraviti članak za [www.wikipedia.org](http://www.wikipedia.org)
- Napraviti neko elektronsko kolo, analizirati ga i izmjeriti karakteristike
- Predložiti ideju za poboljšanje nastave





# *Neke ideje za seminarski rad*

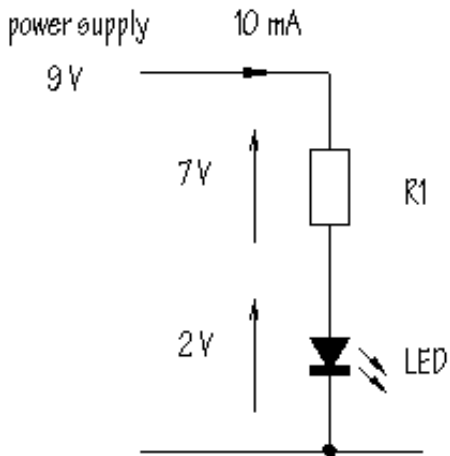


- Ovladati nekim simulacionim programom za analizu elektronskih kola poput PSPICE, TINA-TI, MULTISIM, QUICS, ...
- Ovladati nekim programom za termički proračun i dizajniranje hladnjaka poput Sauna, FloTHERM, ...
- Ovladati nekim programom za generisanje funkcija poput SoundArb, Matlab, SignalGen, T-TTG, ...
- Ovladati nekim programom za snimanje vremenskih dijagrama poput Soundcard Oscilloscope, Daqarta, Matlab, ...
- Ovladati nekim programom za proračun analognih filtera poput WeBench, FilterPro, microcap, Okawa Filter Design and Analysis, ...
- Ovladati nekim programom za dizajn induktiviteta poput irondemo, tor-demo, ...

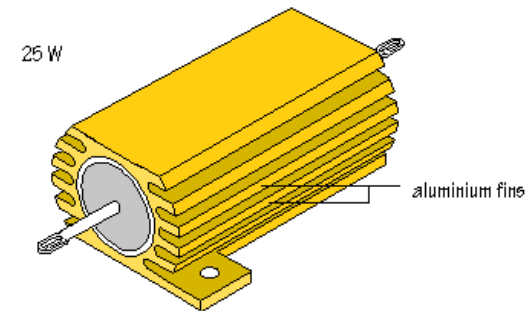
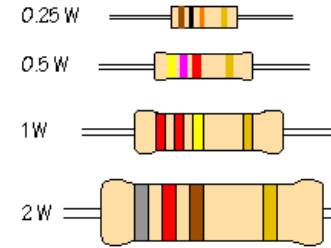
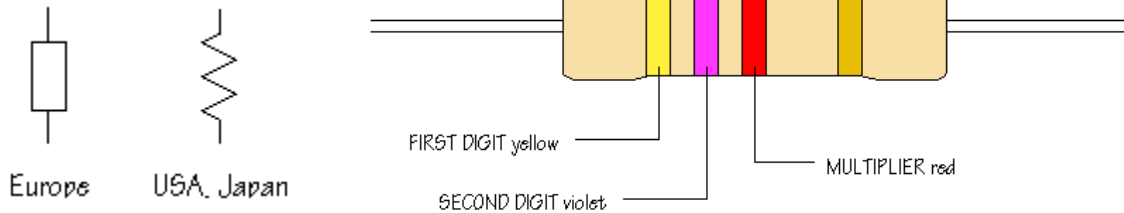
# ***Pregled osnovnih pojmova iz elektronike (podsjećanje)***



- Otpornici
- Kondenzatori
- Pojačavači
- Modeli za velike i male signale



# Otpornik



- Otpornost  $\Omega$  (kod idealnog otpornika ovo je jedina karakteristika – drugih nema)
- Snaga  $W$ , tolerancija  $\%$ , temperaturni koeficijent  $\%/^{\circ}C$ , gabariti  $mm \times mm \times mm$ , cijena  $EUR$
- Induktivnost  $H$ , kapacitivnost  $F$ , zračenje, način postavljanja, MTBF  $h$ , preopteretivost  $\%$ , izdržljivost na ubrzanja i vibracije  $g$

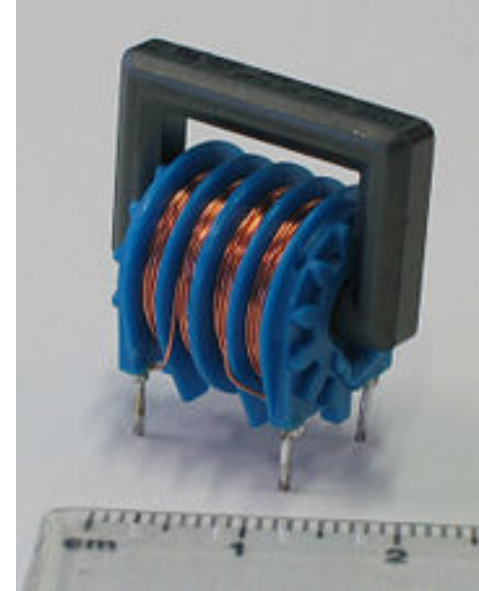
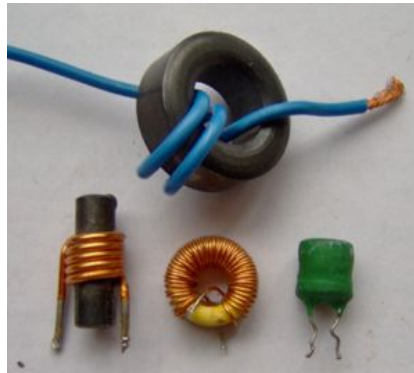
# Kondenzator



- Kapacitivnost  $F$  (jedina karakteristika kod idealnog kondenzatora)
- Probojni napon  $V$ , tangens gubitaka  $\delta$ , tolerancija  $\%$ , temperaturni koeficijent  $\%/^{\circ}C$ , gabariti  $mm \times mm \times mm$ , cijena  $EUR$
- Bipolarnost, vremenska konstanta  $s$ , vrsta izolacije, induktivnost  $H$ , otpornost  $\Omega$ , zračenje, način postavljanja, MTBF  $h$ , ispitni napon  $V$ , izdržljivost na ubrzanja i vibracije  $g$

# Induktivitet (prigušnica)

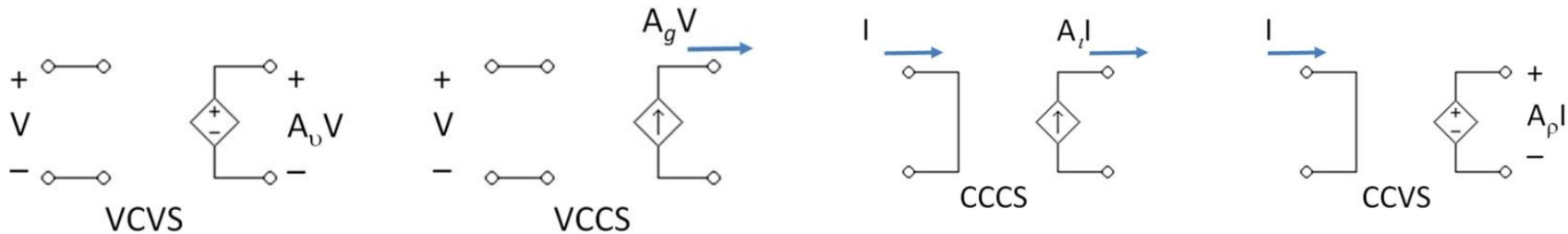
<http://en.wikipedia.org/wiki/Inductor#Formula>  
e



- Idealno samo induktivnost  $H$
- Dozvoljena struja  $A$ , faktor dobrote  $Q$ , tolerancija  $\%$ , temperaturni koeficijent  $\%/^{\circ}C$ , gabariti  $mm \times mm \times mm$ , cijena  $EUR$
- Otpornost  $\Omega$ , kapacitivnost  $F$ , zračenje, način postavljanja, MTBF  $h$ , ispitni napon  $V$ , izdržljivost na ubrzanja i vibracije  $g$



# Idealni pojačavač



- Karakteriše se **vrstom** i **iznosom** pojačanja
- Vrste pojačanja:
  - Naponsko  $A_v$  (napon u napon)
  - Transadmitansno  $A_g$  (napon u struju)
  - Strujno  $A_i$  (struja u struju)
  - Transimpedansno  $A_r$  (struja u napon)
- <http://en.wikipedia.org/wiki/Amplifier>
- Ulazne/izlazne impedanse su ili beskonačno ili nula

# Realni pojačavač se opisuje sa znatno više parametara



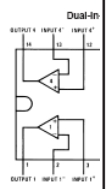
National Semiconductor May 1999

## LM124/LM224/LM324/LM2902 Low Power Quad Operator

**General Description**  
The LM124 series consists of four independent, high gain internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.  
Application areas include transducer amplifiers, DC gain boosters and all the conventional op amp circuits which can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15 power supplies.

**Unique Characteristics**  
■ In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.  
■ The unity gain cross frequency is temperature compensated.  
■ The input bias current is also temperature compensated.

### Connection Diagram



### Absolute Maximum Ratings (Note 12)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage,  $V^+$   
Differential Input Voltage  
Input Voltage  
Input Current  
 $V_{IO} < -0.3V$  (Note 5)  
Power Dissipation (Note 4)  
Molded DIP  
Cavity DIP  
Small Outline Package  
Output Short-Circuit to GND (One Amplifier) (Note 5)  
 $V^+ \leq 15V$  and  $T_A = 25^\circ C$   
Operating Temperature Range  
LM324/LM324A  
LM224/LM224A  
LM124/LM124A  
Storage Temperature Range  
Lead Temperature (Soldering, 10 seconds)  
Soldering Information  
Dual-In-Line Package  
Soldering (10 seconds)  
Small Outline Package  
Vapor Phase (60 seconds)  
Infrared (15 seconds)  
See AN-450 "Surface Mounting Methods and Their Devices."  
ESD Tolerance (Note 13)

**Electrical Characteristics**  
 $V^+ = +5.0V$ , (Note 7), unless otherwise stated

Parameter	Conditions
Input Offset Voltage (Note 8)	$T_A = 25^\circ C$
Input Bias Current (Note 9)	$V_{IO} = 0V, V_{CM} = 0V, T_A = 25^\circ C$
Input Offset Current (Note 9)	$V_{IO} = 0V, V_{CM} = 0V, T_A = 25^\circ C$
Input Common-Mode Voltage Range (Note 10)	$V^+ = 30V, (LM2902, V^+ = 28V), T_A = 25^\circ C$
Supply Current	Over Full Temperature Range $R_L = \infty$ On All Op Amps $V^+ = 30V, (LM2902, V^+ = 28V), V_{IO} = 5V$
Large Signal Voltage Gain	$V^+ = 15V, R_{L2} = 2k\Omega, (V_{IO} = 1V \text{ to } 11V), T_A = 25^\circ C$
Common-Mode Rejection Ratio	DC, $V_{CM} = 0V$ to $V^+ - 1.5V, T_A = 25^\circ C$

### Electrical Characteristics (Continued)

$V^+ = +5.0V$ , (Note 7), unless otherwise stated

Parameter	Conditions	LM124A				LM224A				LM324A				Units
		Min	Typ	Max		Min	Typ	Max		Min	Typ	Max		
Power Supply Rejection Ratio	$V^+ = 5V$ to $30V$ (LM2902, $V^+ = 5V$ to $28V$ ), $T_A = 25^\circ C$													
Amplifier-to-Amplifier Coupling (Note 11)	$f = 1 \text{ kHz}$ to $20 \text{ kHz}, T_A = 25^\circ C$ (Input Referred)													
Output Current	Source $V_{IO} = 1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													
	Sink $V_{IO} = 1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													
Short Circuit to Ground (Note 5)	(Note 5) $V^+ = 15V, T_A = 25^\circ C$													
Input Offset Voltage (Note 8)	$R_L = 0\Omega$													
Input Offset Current (Note 9)	$V_{IO} = -V_{IO}, V_{CM} = 0V$													
Input Offset Current (Note 9)	$R_L = 0\Omega$													
Input Bias Current (Note 9)	$V_{IO} = 0V$													
Input Common-Mode Voltage Range (Note 10)	$V^+ = +30V$ (LM2902, $V^+ = 28V$ )													
Large Signal Voltage Gain	$V_{IO} = +15V$ ( $V_{IO} = 1V$ to $11V$ ) $R_L \geq 2k\Omega$													
Output Voltage Swing	$V_{OH} = 30V$ (LM2902, $V^+ = 28V$ ) $V_{OL} = 5V, R_L = 10k\Omega$													
	Source $V_{IO} = 2V$													
	Sink $V_{IO} = +1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													

### Electrical Characteristics

$V^+ = +5.0V$ , (Note 7), unless otherwise stated

Parameter	Conditions
Input Offset Voltage (Note 8)	$T_A = 25^\circ C$
Input Bias Current (Note 9)	$V_{IO} = 0V, V_{CM} = 0V, T_A = 25^\circ C$
Input Offset Current (Note 9)	$V_{IO} = 0V, V_{CM} = 0V, T_A = 25^\circ C$
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Large Signal Voltage Gain	$V^+ = 15V, R_{L2} = 2k\Omega, (V_{IO} = 1V \text{ to } 11V), T_A = 25^\circ C$
Common-Mode Rejection Ratio	DC, $V_{CM} = 0V$ to $V^+ - 1.5V, T_A = 25^\circ C$

### Electrical Characteristics (Continued)

$V^+ = +5.0V$ , (Note 7), unless otherwise stated

Parameter	Conditions	LM124/LM224				LM324				LM2902				Units
		Min	Typ	Max		Min	Typ	Max		Min	Typ	Max		
Common-Mode Rejection Ratio	DC, $V_{CM} = 0V$ to $V^+ - 1.5V, T_A = 25^\circ C$													
Power Supply Rejection Ratio	$V^+ = 5V$ to $30V$ (LM2902, $V^+ = 5V$ to $28V$ ), $T_A = 25^\circ C$													
Amplifier-to-Amplifier Coupling (Note 11)	$f = 1 \text{ kHz}$ to $20 \text{ kHz}, T_A = 25^\circ C$ (Input Referred)													
Output Current	Source $V_{IO} = 1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													
	Sink $V_{IO} = 1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													
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Input Offset Voltage (Note 8)	$R_L = 0\Omega$													
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Large Signal Voltage Gain	$V_{IO} = +15V$ ( $V_{IO} = 1V$ to $11V$ ) $R_L \geq 2k\Omega$													
Output Voltage Swing	$V_{OH} = 30V$ (LM2902, $V^+ = 28V$ ) $V_{OL} = 5V, R_L = 10k\Omega$													
	Source $V_{IO} = 2V$													
	Sink $V_{IO} = +1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													

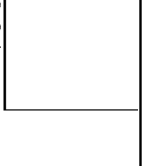
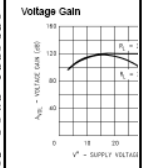
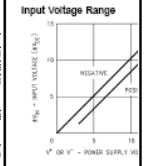
Note 4: For operating at high temperatures, the LM324/LM224A/LM2902 must be derated by a factor of 80°C/W which applies for the device soldered in a printed circuit board, operating in a rated base to a +150°C maximum junction temperature. The dissipation in the lead of a free potted or surface of a device to reduce the power which is dissipated in the integrated circuit.  
Note 5: Short circuits from the output to  $V^+$  can cause excessive heating and eventual destruction current is approximately 40 mA independent of the magnitude of  $V^+$ . All values of supply voltage dissipation ratings and cause eventual destruction. Destructive dissipation can result from an input common-mode voltage at any of the input leads to drive a transistor becoming forward biased and thereby acting as input diode clamps. In addition to this IC trip, this transistor action can cause the output voltage of the op-amp to go to the  $V^+$  or  $V^-$  or an input is driven negative. This is not destructive and normal output states will be established greater than -0.3V (at 25°C).  
Note 6: These specifications are limited to -55°C to +125°C for the LM124/LM124A, with  $T_A \leq 485^\circ C$ , the LM324/LM224A temperature specifications are limited to 0°C to +170°C.  
Note 7:  $V_{IO} = 0A$ ,  $R_L = 0\Omega$  with  $V^+$  from 5V to 30V, and over the full input common-mode range.  
Note 8: The direction of the input current is out of the IC due to the PNP input stage. This current reading change reads on the input line.  
Note 9: The input common-mode voltage of either input signal voltage should not be above common-mode voltage range in  $V^+ - 1.5V$  (at 25°C), but either or both inputs can go to +52V  $V^+$ .  
Note 11: Due to proximity of external components, insure that coupling is not originating via a detected as this type of capacitance increases at higher frequencies.  
Note 12: Refer to RETS124XK for LM124A military specifications and refer to RETS124K for

### Electrical Characteristics (Continued)

$V^+ = +5.0V$ , (Note 7), unless otherwise stated

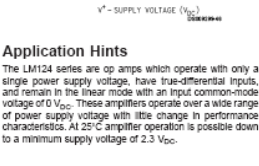
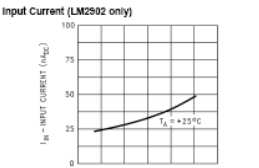
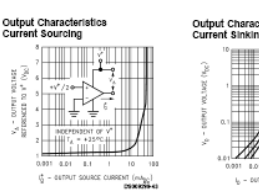
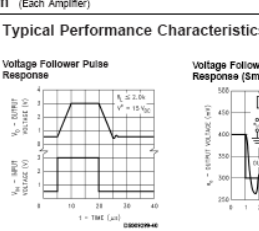
Parameter	Conditions	LM124/LM224				LM324				LM2902				Units
		Min	Typ	Max		Min	Typ	Max		Min	Typ	Max		
Common-Mode Rejection Ratio	DC, $V_{CM} = 0V$ to $V^+ - 1.5V, T_A = 25^\circ C$													
Power Supply Rejection Ratio	$V^+ = 5V$ to $30V$ (LM2902, $V^+ = 5V$ to $28V$ ), $T_A = 25^\circ C$													
Amplifier-to-Amplifier Coupling (Note 11)	$f = 1 \text{ kHz}$ to $20 \text{ kHz}, T_A = 25^\circ C$ (Input Referred)													
Output Current	Source $V_{IO} = 1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													
	Sink $V_{IO} = 1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													
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Output Voltage Swing	$V_{OH} = 30V$ (LM2902, $V^+ = 28V$ ) $V_{OL} = 5V, R_L = 10k\Omega$													
	Source $V_{IO} = 2V$													
	Sink $V_{IO} = +1V, V_{CM} = 0V, V^+ = 15V, V_{IO} = 2V, T_A = 25^\circ C$													

### Typical Performance

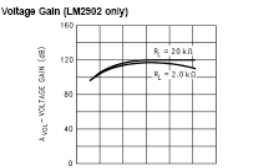
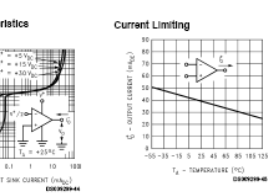
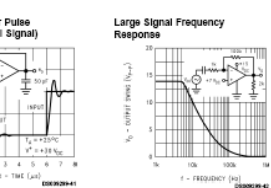


### Electrical Characteristics (Continued)

Note 13: Human body model, 1.5 kΩ in series with 100 pF



### Typical Performance Characteristics (Continued)

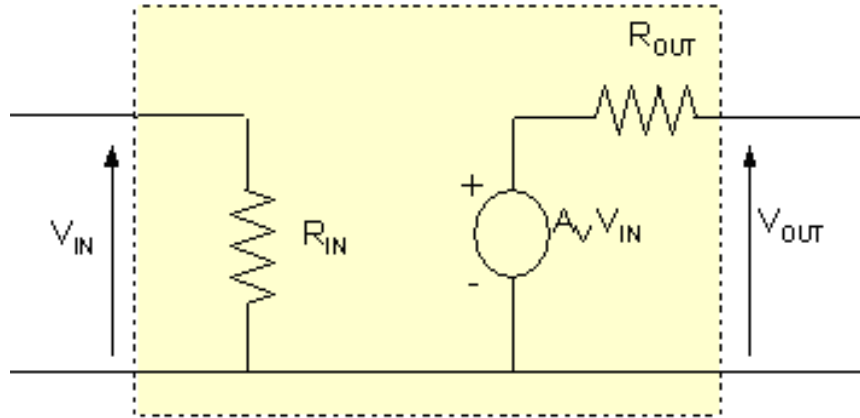


### Application Hints

The LM124 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0  $V_{CM}$ . These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25°C amplifier operation is possible down to a minimum supply voltage of 2.3 Vcc.

The pinouts of the package have been designed to simplify PC board layouts. Inverting inputs are adjacent to outputs for all of the amplifiers and the outputs have also been placed at the corners of the package (pins 1, 7, 8, and 14). Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a

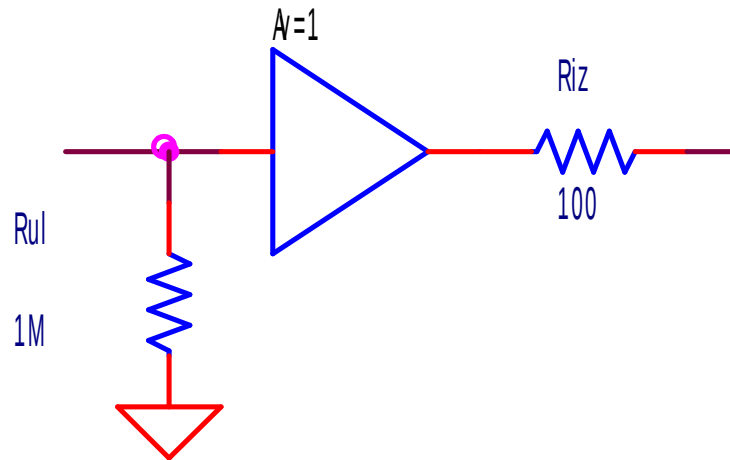
# Realni pojačavač



- Može se predstaviti Teveninovima ili Nortonovim modelom
  - Teveninov model: naponsko pojačanje, ulazna i izlazna impedansa.
  - Nortonov model: strujno pojačanje,  $R_{ul}$  i  $R_{iz}$
- Tipične vrijednosti kod realnog naponskog pojačavača su:
  - Naponsko pojačanje  $A_v$  (100'000)
  - Ulazna otpornost  $R_{ul}$  (Momi)
  - Izlazna otpornost  $R_{iz}$  (omi)
- Masa je zajednička za ulaz i izlaz.
- Opseg ulaznog napona i opseg izlaznog napona zavise od napona napajanja pojačavača (od  $-V_{ee}+2V$  do  $V_{cc}-2V$ ).



# Odnos ulazne/izlazne otpornost je značajan koliko i pojačanje



- Pogledajmo primjer sa jediničnim pojačavačem.
- Na prvi pogled, pojačanje 1 nije korisno, jer je izlazni napon jednak ulaznom.

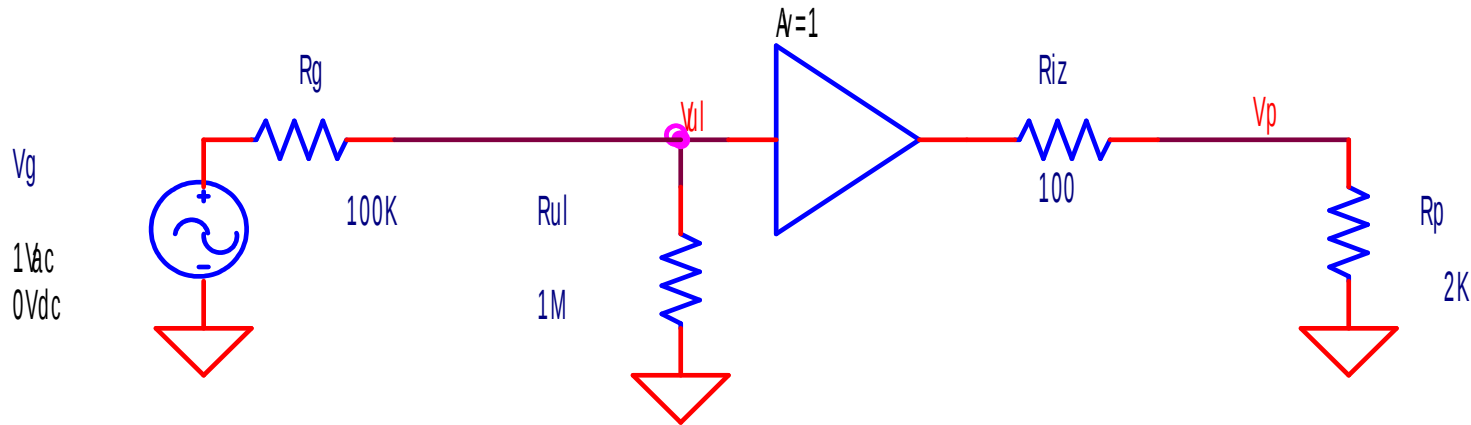


# Ali kada imamo visokoomski izvor i niskoomski potrošač...



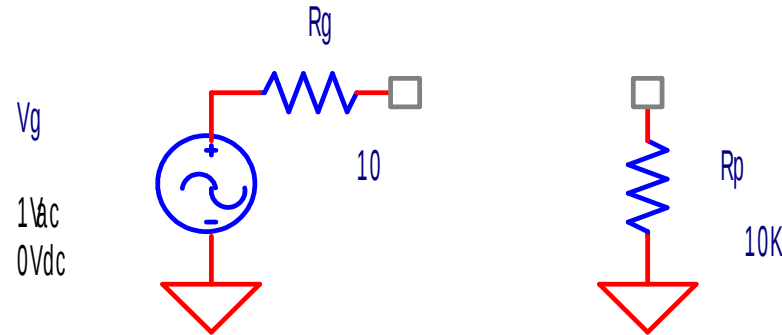
- Direktnim spajanjem izvora i potrošača formira se razdjelnik napona.
- Koliko ćemo dobiti na potrošaču  $V_p = ?$  [V]

# Umetanjem jediničnog pojačavača dobijamo...



- Dva razdjelnika napona, na ulazu i na izlazu pojačavača
- Prvi razdjelnik pravi na ulazu  $V_u = ?$  [V]
- Drugi razdjelnik pravi na potrošaču  $V_p = ?$  [V]
- Šta se dobilo umetanjem ovog pojačavača?

# *Ima situacija kada je ovakav pojačavač štetan*



- Kada je  $R_g \ll R_p$ , umetanjem pojačavač se ne dobija ništa.
- Štaviše, pojačavač unosi šum, izobličenja, limitiranje signala, traži napajanje, ...



# ***Analysis of Amplifier Systems***

# *Simulacija elektronskih kola*



- Omogućava provjeru dizajna brzo i jeftino.
- Nije uvijek efikasna (ponekad postoje problemi konvergencije), a ponekad daje neočekivano glupe rezultate.
- Veoma je korisna, ali samo ako znamo šta očekujemo.
- Najpoznatiji simulacioni programi:
  - SPICE
  - Multisim
  - QUCS
- Virtuelni instrumenti (Labview)
  - Mjerenje na realnom i/ili simuliranom sistemu

