

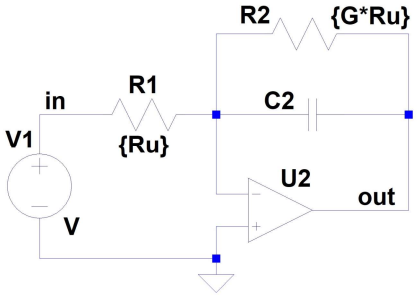
UiO : Department of Informatics
University of Oslo

IN5230
Electronic noise – estimates and countermeasures

Lecture no 7b (separate topic)
Noise in amplifiers with feedback

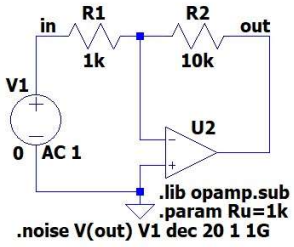
Voltage to voltage

- Ru: Unit resistance
  - For reducing variations
  - Only integer number of Ru
- Gain:
  - Vout_max/Vin_max = G·Ru/Ru=G
  - Gain independent of Ru



Influence of R1 and R2 when Ru=1kΩ

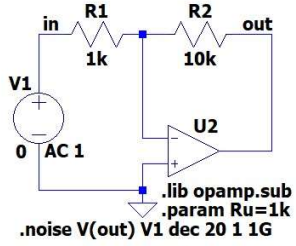
- Influence of R1 on output?
  - 10 times gain
- Influence of R2 on output?
  - 10 times resistance




```
.noise V(out) V1 dec 20 1 1G
.meas noise Ni_1k find V(inoise) at=1k
.meas noise No_1k find V(onoise) at=1k
.meas noise No_integ integ V(onoise)
.meas noise N_r1 find V(r1) at=1k
.meas noise N_r2 find V(r2) at=1k
```


Influence of R1 and R2, Ru=1kΩ

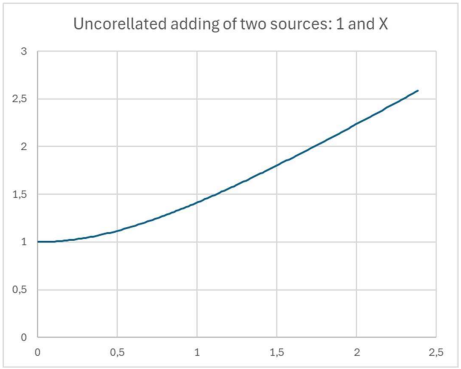
- Influence of R1 on output?
  - 10 times gain
  - ➔ 10·4nV/√Hz=40nV/√Hz
- Influence of R2 on output?
  - 10 times resistance
  - ➔√10·4nV/√Hz=3.16·4nV/√Hz= 12.6nV/√Hz
- Onoise:
  - $V(onoise) = \sqrt{\left(40nV/\sqrt{Hz}\right)^2 + \left(12.6nV/\sqrt{Hz}\right)^2}$ = 41.95nV/√Hz
- Inoise:
  - V(inoise)=V(onoise)/gain=41.95nV/√Hz/10= 4.19nV/√Hz



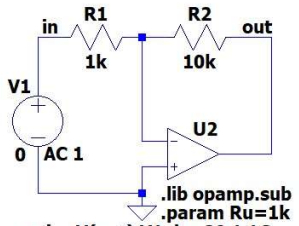

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```

Adding uncorrelated sources

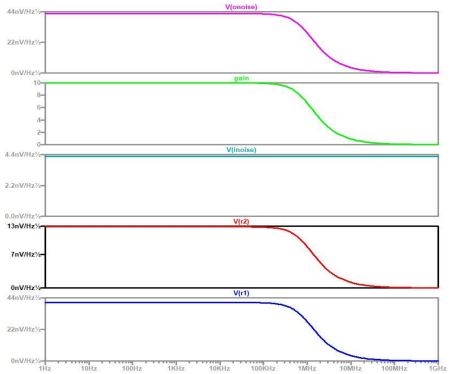
- One source = 1, other is X
- When the other source is 1 is the sum 1.4 of each
- The other source has to be 1.74 for the sum to be 2



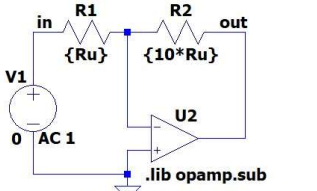
Influence of R1 and R2 when Ru=1kΩ



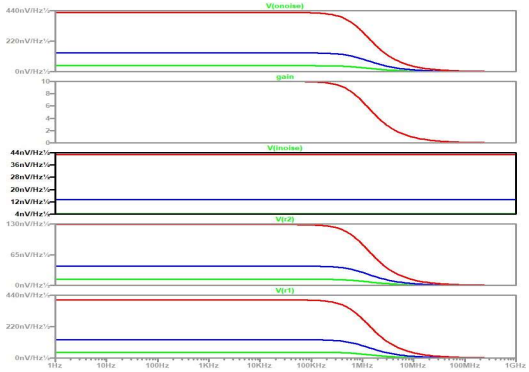

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.meas noise No_integ integ V(onoise)
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```



Ru=1kΩ, 10kΩ, 100kΩ

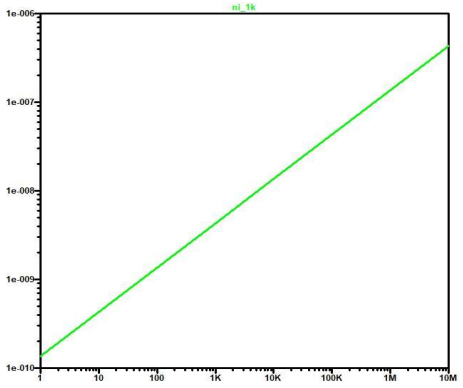



```
.step param Ru list 1k 10k 100k
.noise V(out) V1 dec 20 1 1G
.meas noise Ni_1k find V(inoise) at=1k
.meas noise No_1k find V(onoise) at=1k
.meas noise No_integ integ V(onoise)
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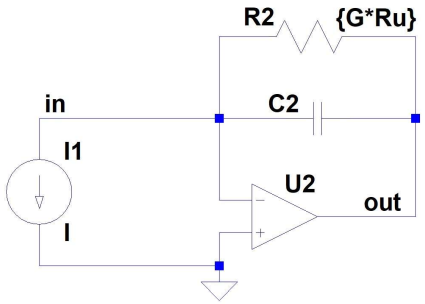
Input noise with Ru from 1Ω to 10MΩ

- Gain=10 for all cases
- Ru: Noise – power trade-off
  - Smaller Ru gives less noise but consumes more power



Current to voltage

- Gain = Vout_max/lin_max= G*Ru
- Gain depends also on Ru!



Current to voltage – Application example

- Challenging with a resistor string if the input signals varies over many decades

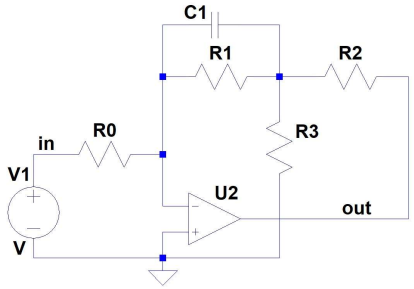
Is (nA)	0,15	1,5	15	150	1500
R (MOhm)	6666,67	666,67	66,67	6,67	0,67

Voltage to voltage – T-network

- T-networks offers an effective much higher feedback resistance
- Effective feedback resistance:

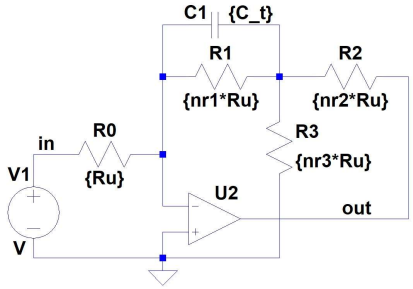
$$R_{fb} = \frac{R_1 \cdot R_2}{R_3} + R_1 + R_2$$

$$V_{out} = \frac{R_{fb}}{R_0} V_{in}$$



- https://www.ti.com/lit/an/sboa284/sboa284.pdf?ts=1726536544210&ref_url=https%253A%252F%252Fwww.google.com%252F

Voltage to voltage – T-network



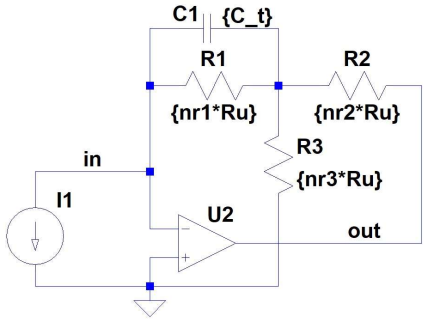
Current to voltage – T-network

- Effective feedback resistance:

$$R_{fb} = \frac{R_1 \cdot R_2}{R_3} + R_1 + R_2$$

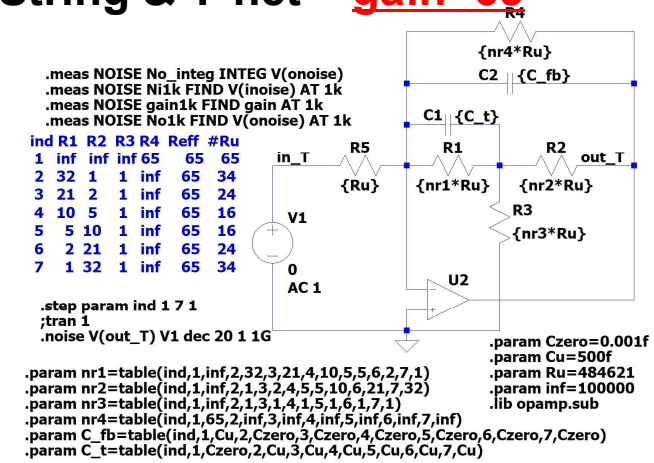
Gain

$$V_{out} = R_{fb} I_{in}$$

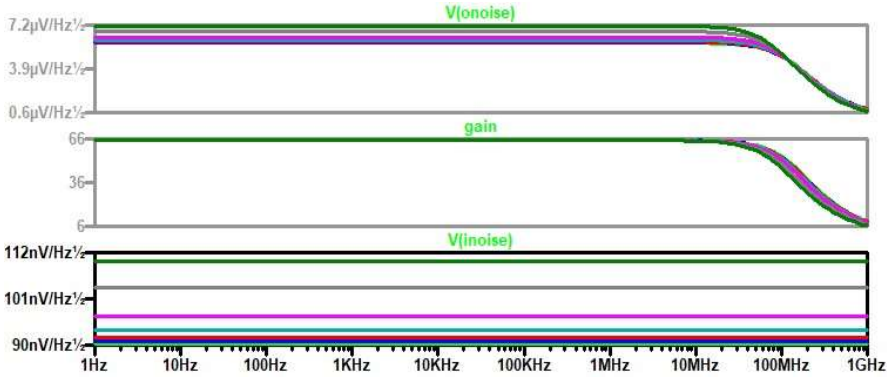


V to V – String & T-net – gain=65

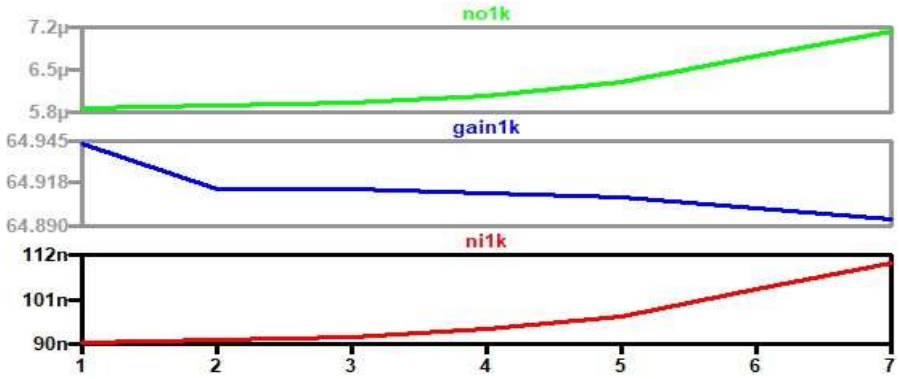
- 8 configurations
  - 1 standard
  - 7 T-variations
  - 3 pairs mirrored
- Gain of 65 for all
- 65 to 16 unit resistors
- (The large Ru is due to later I-to-V. For V-to-V it should be very significantly smaller.)



V to V – String & T-net – gain=65

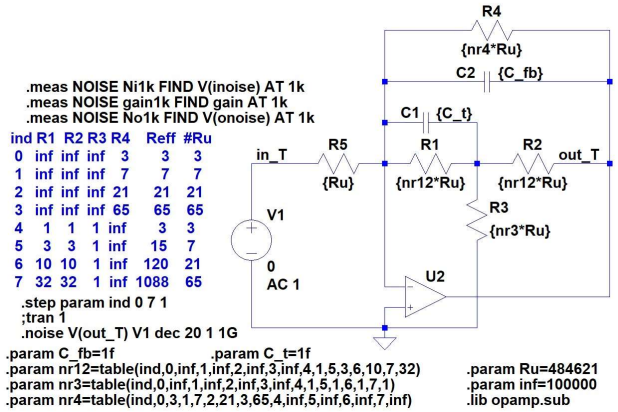


V to V – String & T-net – gain=65. Spot noise at 1kHz

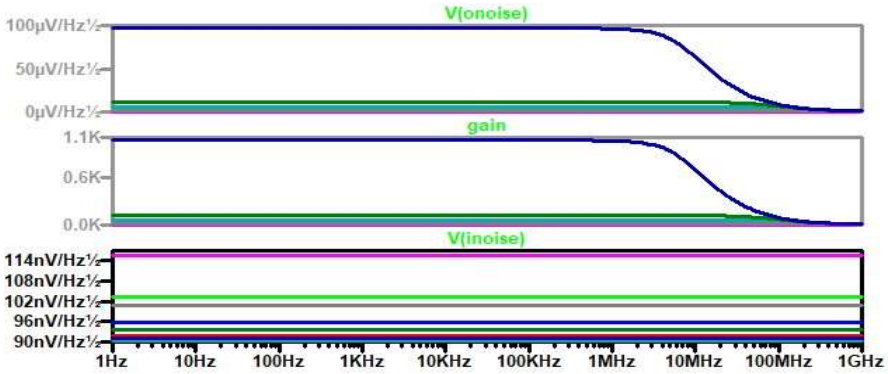


V to V – String & T-net – Multiple gain levels

- For T-network: Four gain steps exponentially distributed up to maximum achievable gain
- Compare with R-string with same number of unit resistors (3, 7, 21 and 65)

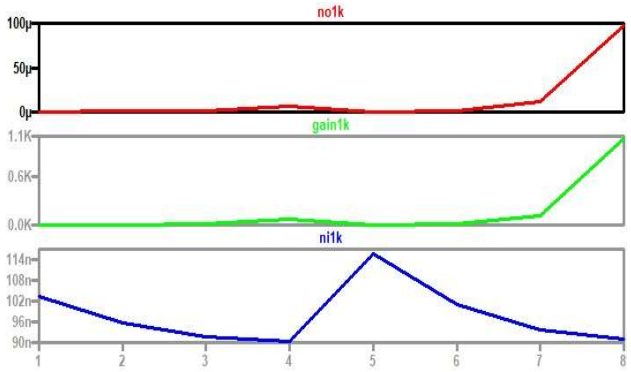


V to V – String & T-net – Multiple gain levels

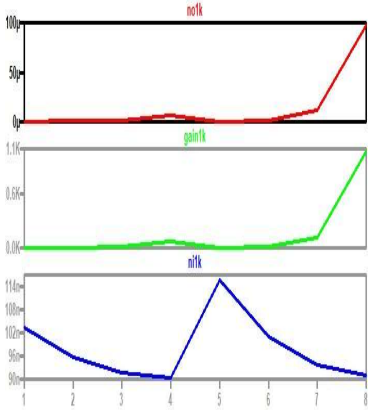


V to V – String & T-net – Multiple gain levels

- X-axis: Different configurations
- All measured at 1kHz
- No1k largest for 4 and 8. But gain is larger at 4 and 8. Hence ni1k is minimum at 4 and 8



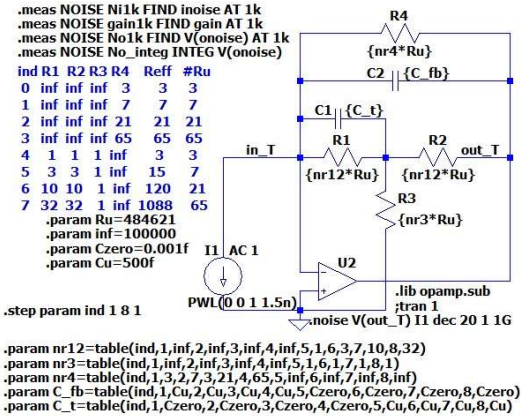
V to V – String & T-net – Multiple gain levels



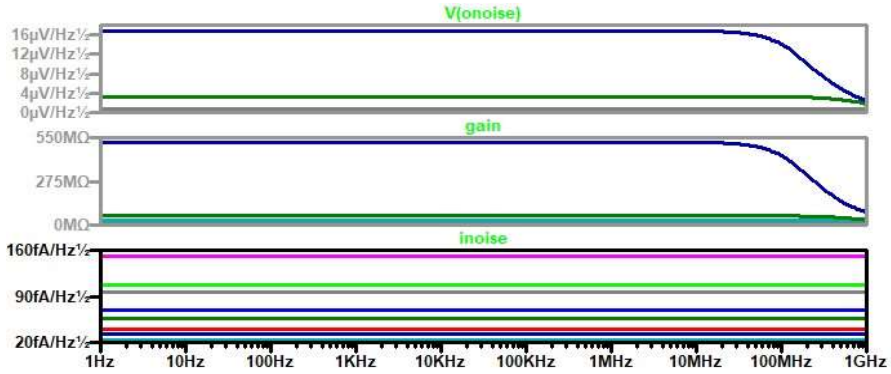
	Reff	#Ru	Output noise nV/sqrt(Hz)	Gain Gain	Input noise fV/sqrt(Hz)
1	3	3	155	1 450 000	107
2	7	7	237	3 390 000	70
3	21	21	410	10 170 000	40
4	65	65	722	31 490 000	23
5	3	3	219	1 450 000	151
6	15	7	694	7 267 000	96
7	120	21	3 250	58 080 000	56
8	1088	65	16 800	521 000 000	32

I to V – String & T-net – Multiple gain levels

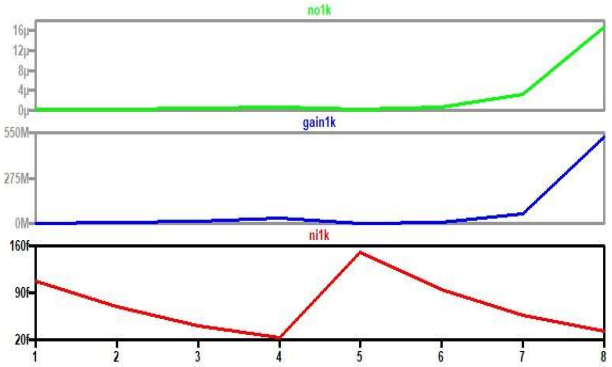
- Same as previous but current to voltage



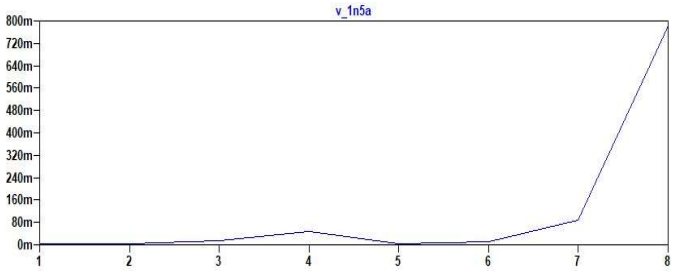
I to V – String & T-net – Multiple gain levels



I to V – String & T-net – Multiple gain levels



1.5nA to V – String & T-net – Multiple gain levels



Config	V_at_1.5nA
1	0,002181
2	0,005088
3	0,015264
4	0,047240
5	0,002181
6	0,010902
7	0,087118
8	0,782134

I to V – String & T-net – Multiple gain levels

- Integrated output noise
- Bandwidth
  - No C-filtering
  - Opamp GBW

