

IN5230

OpAmp feedback

Joar M. Østby

Okt 2024

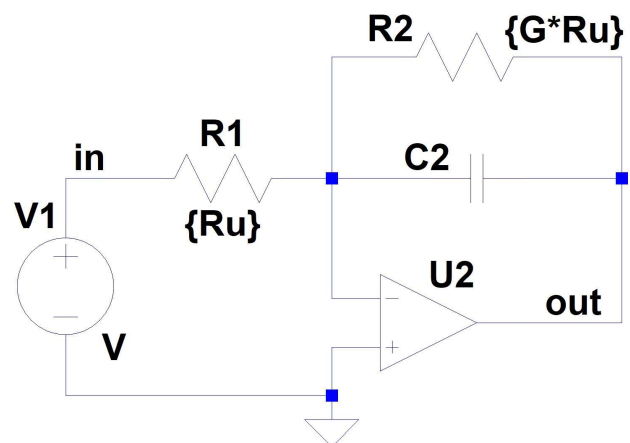
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1

Voltage to voltage

- Ru: Unit resistance
 - For reducing variations
 - Only integer number of Ru
- Gain:
 - $V_{out_max}/V_{in_max} = G \cdot R_u / R_u = G$
 - Gain independent of Ru



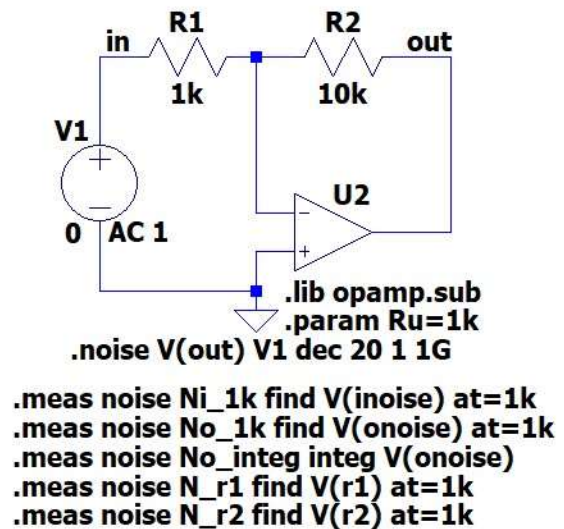
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Influence of R1 and R2 when Ru=1kΩ

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



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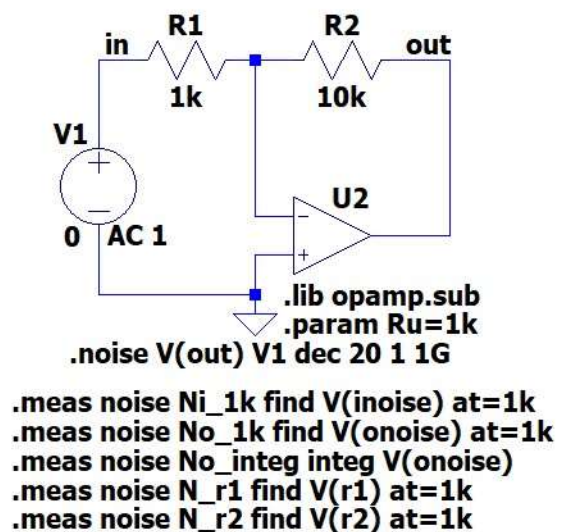
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Influence of R1 and R2, Ru=1kΩ

- 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:
 - $$V(onoise) = \sqrt{(40nV/\sqrt{Hz})^2 + (12.6nV/\sqrt{Hz})^2} = 41.95nV/\sqrt{Hz}$$

- Inoise:
 - $$V(inoise)=V(onoise)/gain=41.95nV/\sqrt{Hz}/10= 4.19nV/\sqrt{Hz}$$



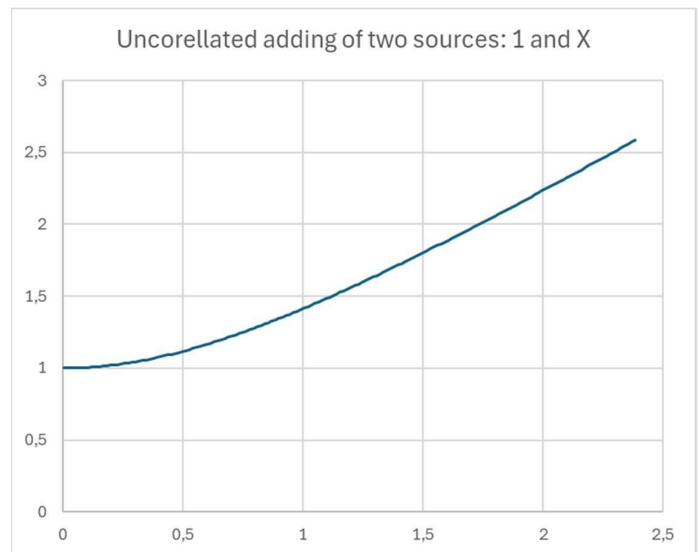
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Adding uncorrelated sources

- 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

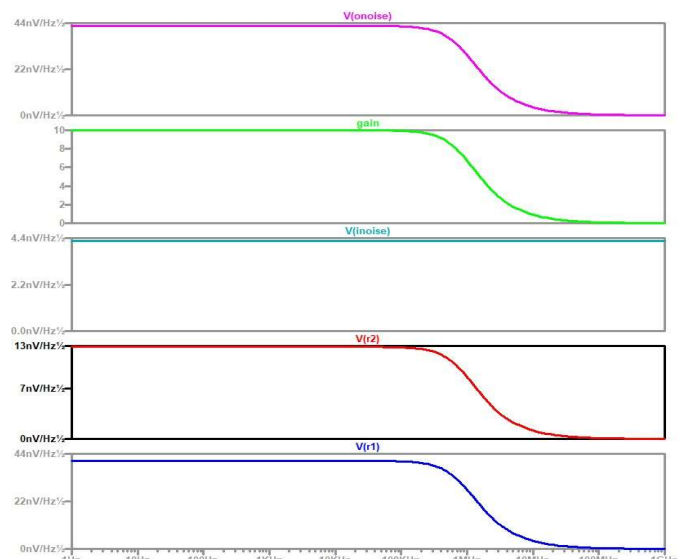
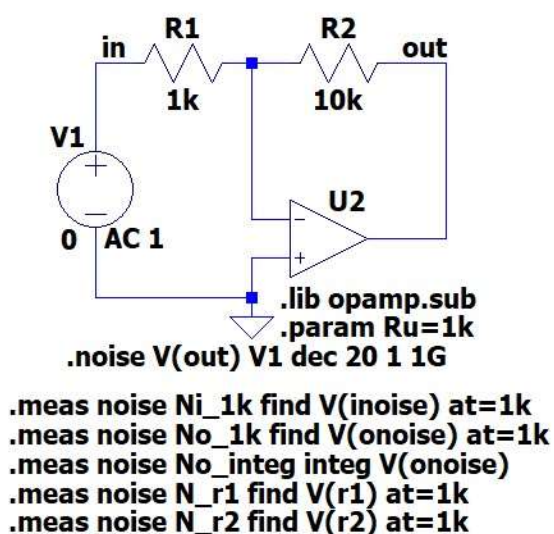


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Influence of R1 and R2 when $R_u=1k\Omega$

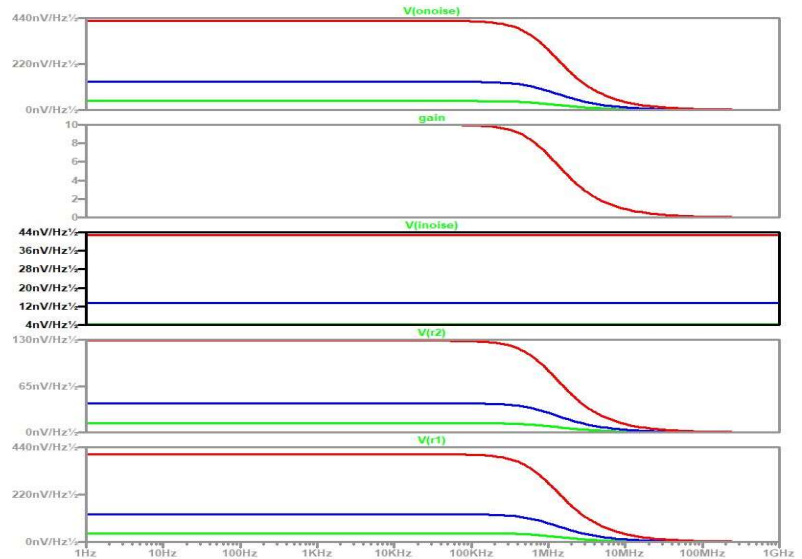
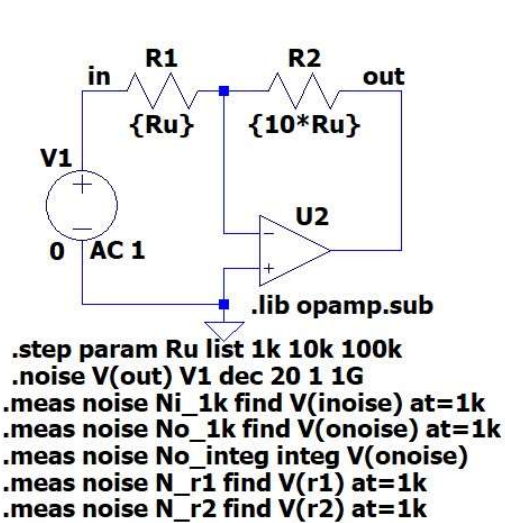


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$R_u = 1\text{k}\Omega, 10\text{k}\Omega, 100\text{k}\Omega$



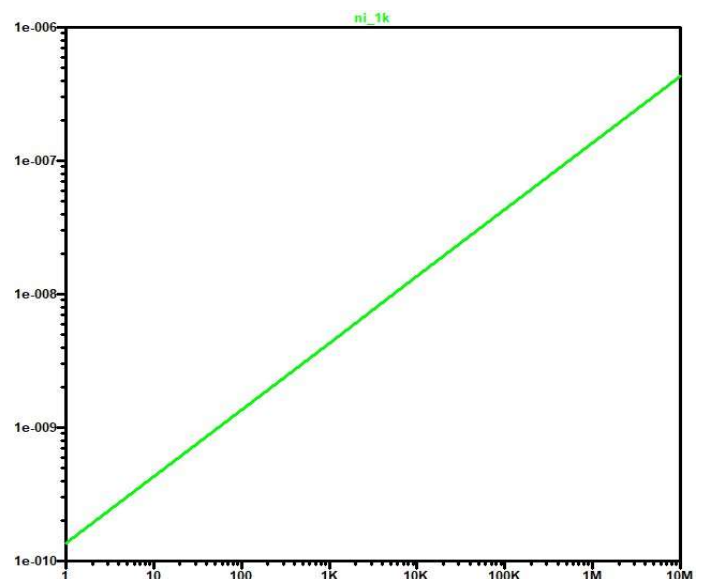
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Input noise with R_u from 1Ω to $10\text{M}\Omega$

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



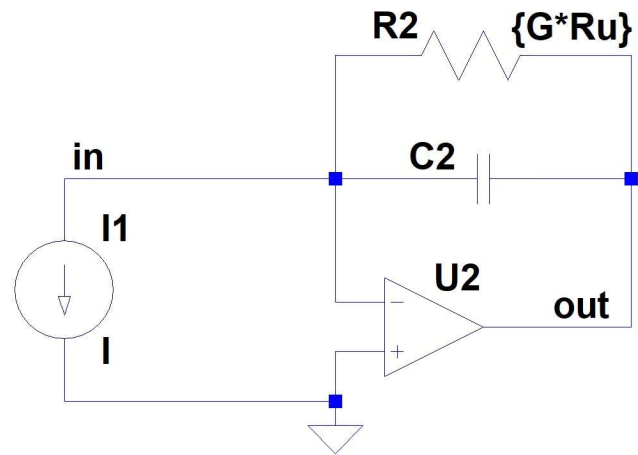
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Current to voltage

- Gain = $V_{out_max}/I_{in_max} = G \cdot R_u$
- Gain depends also on R_u !



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Current to voltage – Application example

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

I_s (nA)	0,15	1,5	15	150	1500
R (M Ω)	6666,67	666,67	66,67	6,67	0,67

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Voltage to voltage – T-network

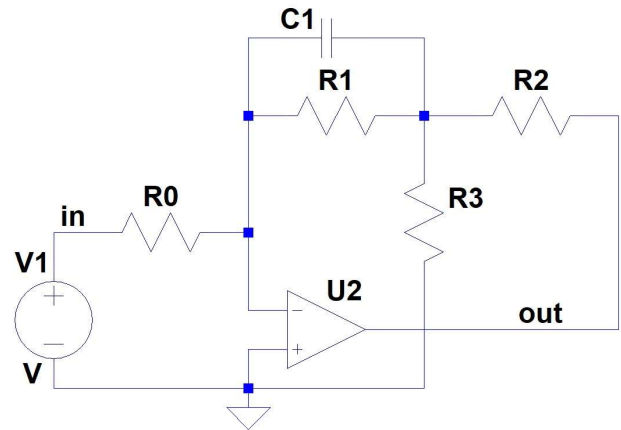
- T-networks offers an effective much higher feedback resistance

- Effective feedback resistance:

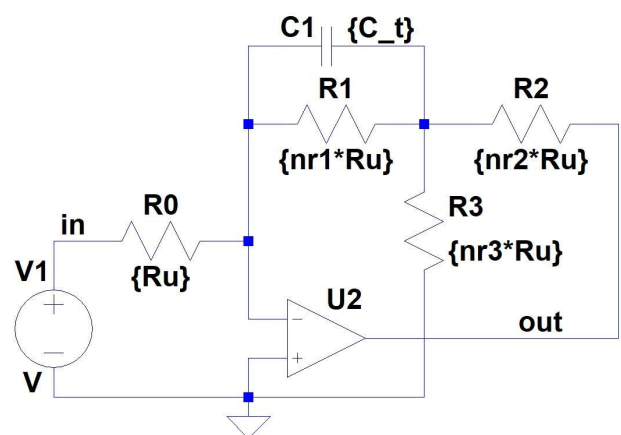
$$R_{fb} = \frac{R_1 \cdot R_2}{R_3} + R_1 + R_2$$

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

- 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



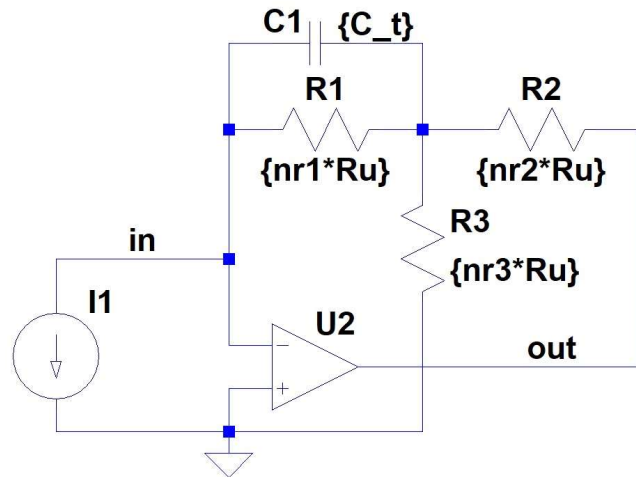
Current to voltage – T-network

- Effective feedback resistance:

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

Gain

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



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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.)

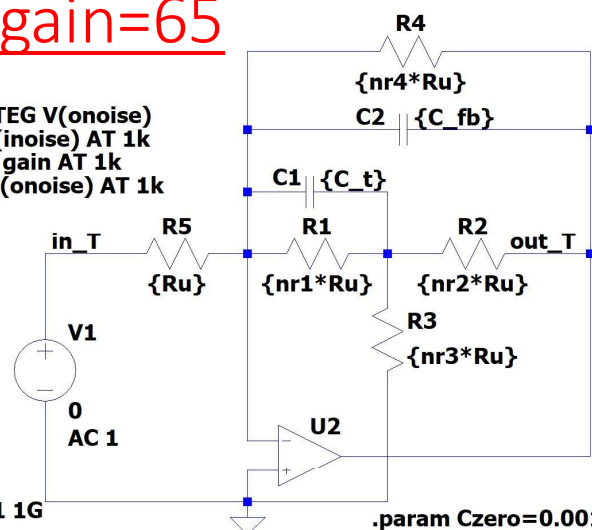
```
.meas NOISE No_integ INTEG V(onoise)
.meas NOISE Ni1k FIND V(inoise) AT 1k
.meas NOISE gain1k FIND gain AT 1k
.meas NOISE No1k FIND V(onoise) AT 1k
```

ind	R1	R2	R3	R4	Reff	#Ru
1	inf	inf	inf	65	65	65
2	32	1	1	inf	65	34
3	21	2	1	inf	65	24
4	10	5	1	inf	65	16
5	5	10	1	inf	65	16
6	2	21	1	inf	65	24
7	1	32	1	inf	65	34

```
.step param ind 1 7 1
;tran 1
.noise V(out_T) V1 dec 20 1 1G
```

```
.param nr1=table(ind,1,inf,2,32,3,21,4,10,5,5,6,2,7,1)
.param nr2=table(ind,1,inf,2,1,3,2,4,5,5,10,6,21,7,32)
.param nr3=table(ind,1,inf,2,1,3,1,4,1,5,1,6,1,7,1)
.param nr4=table(ind,1,65,2,inf,3,inf,4,inf,5,inf,6,inf,7,inf)
.param C_fb=table(ind,1,Cu,2,Czero,3,Czero,4,Czero,5,Czero,6,Czero,7,Czero)
.param C_t=table(ind,1,Czero,2,Cu,3,Cu,4,Cu,5,Cu,6,Cu,7,Cu)
```

```
.param Czero=0.001f
.param Cu=500f
.param Ru=484621
.param inf=100000
.lib opamp.sub
```

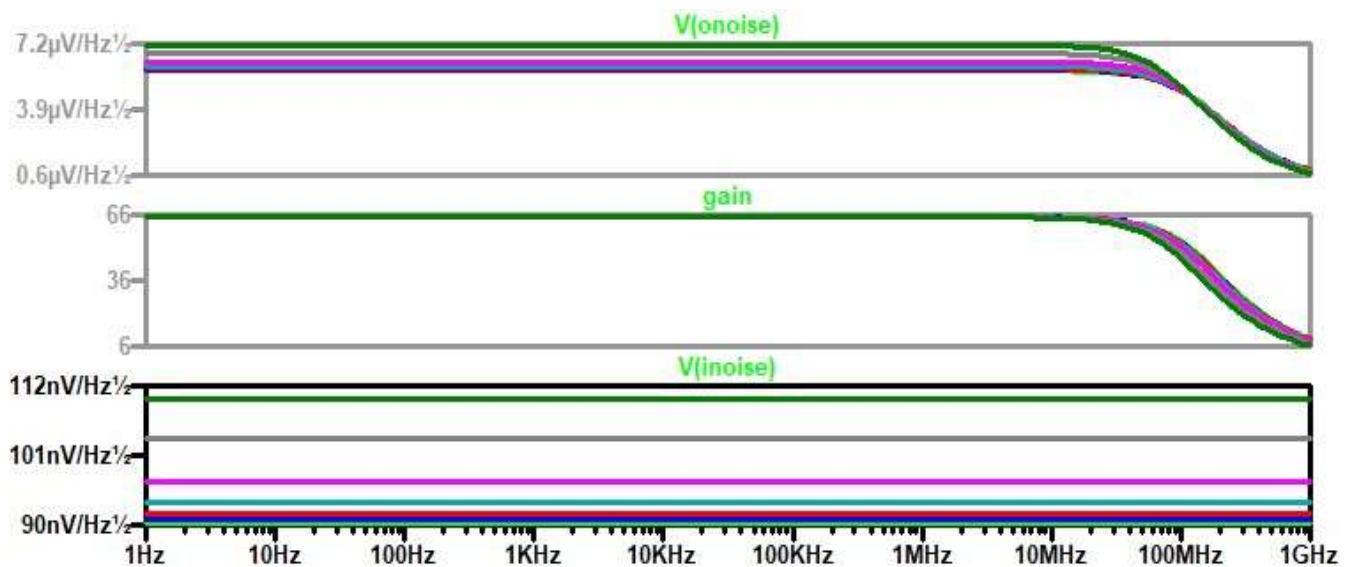


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V to V – String & T-net – gain=65

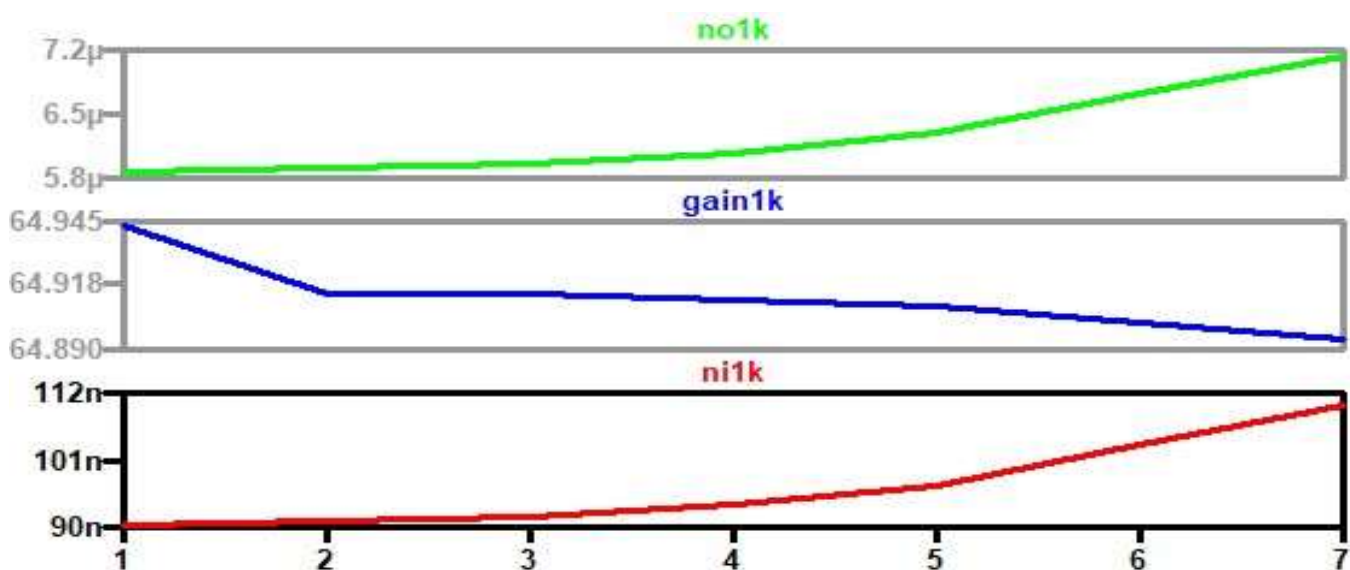


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V to V – String & T-net – gain=65. Spot noise at 1kHz



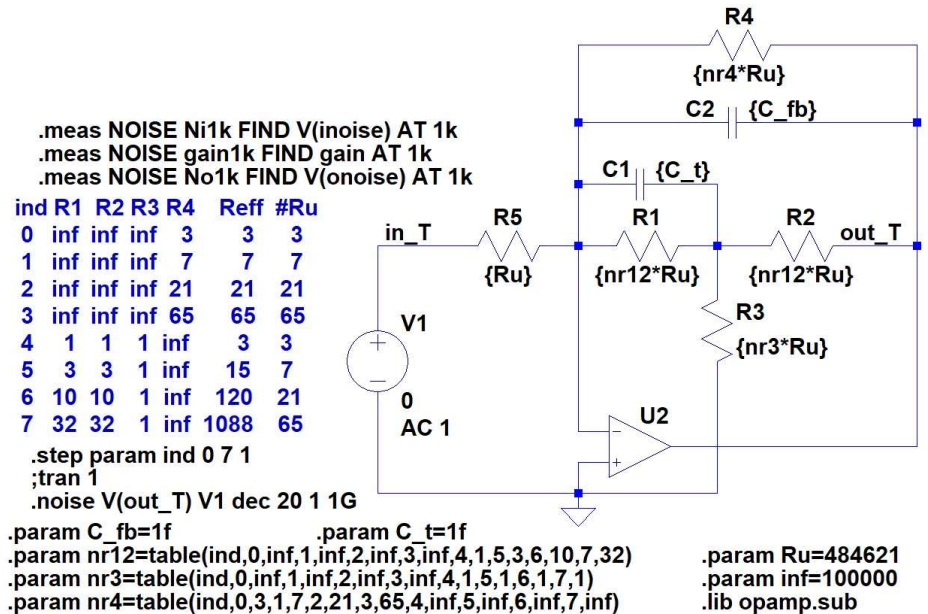
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V to V – String & T-net – Multiple gain levels

- 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)

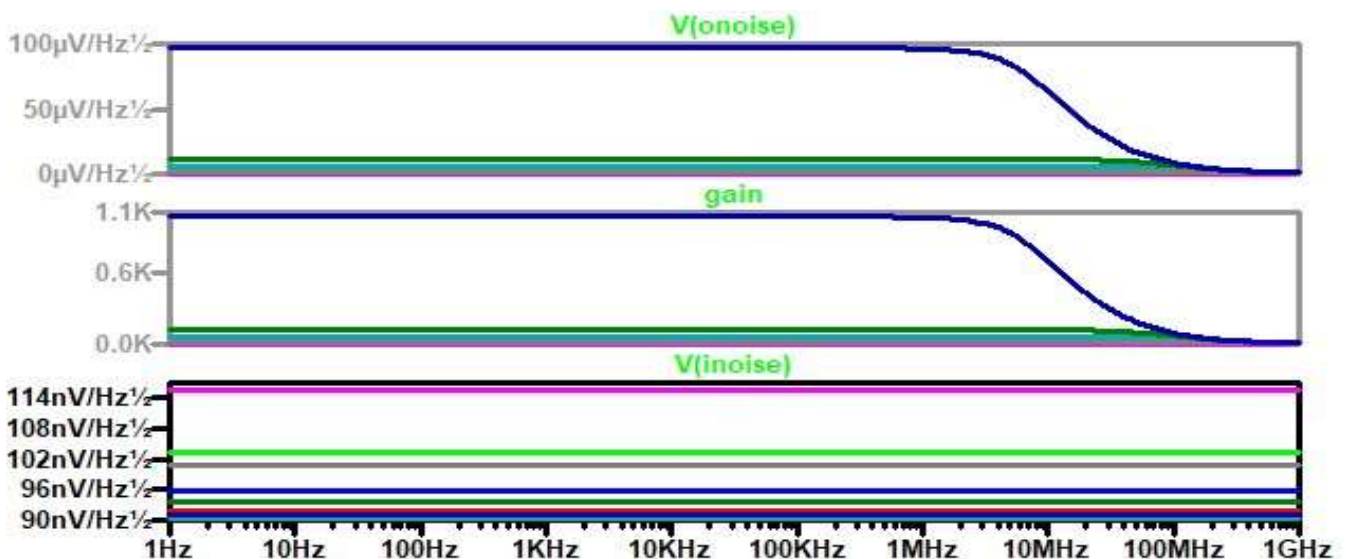


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V to V – String & T-net – Multiple gain levels



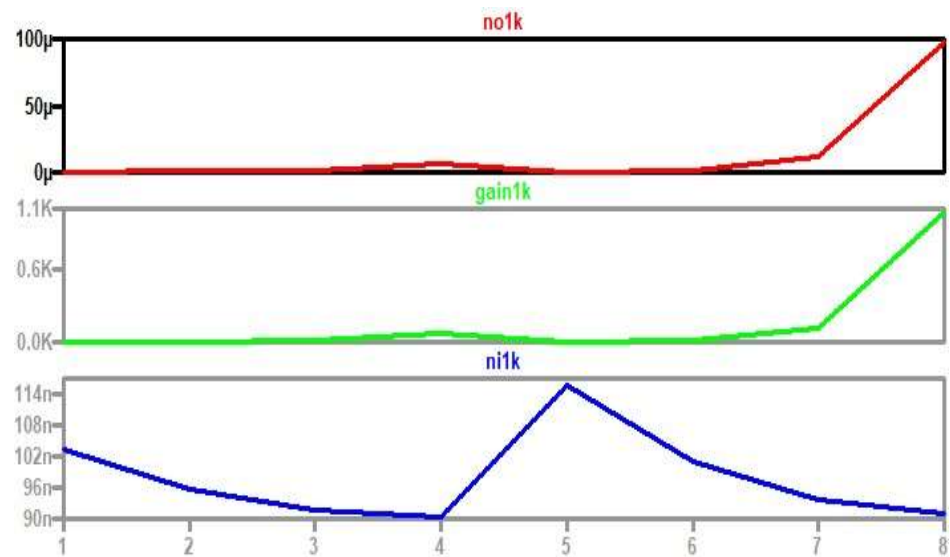
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V to V – String & T-net – Multiple gain levels

- 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



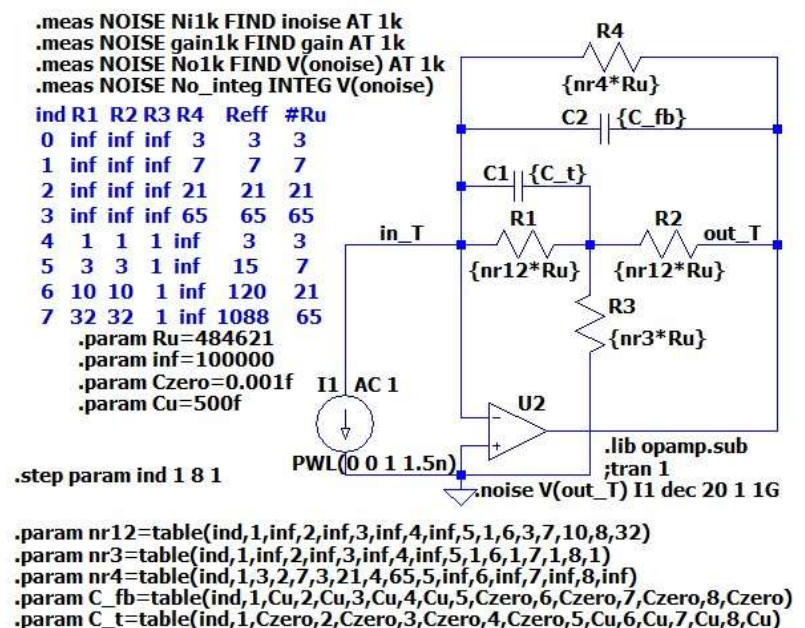
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I to V – String & T-net – Multiple gain levels

- Same as previous but current to voltage

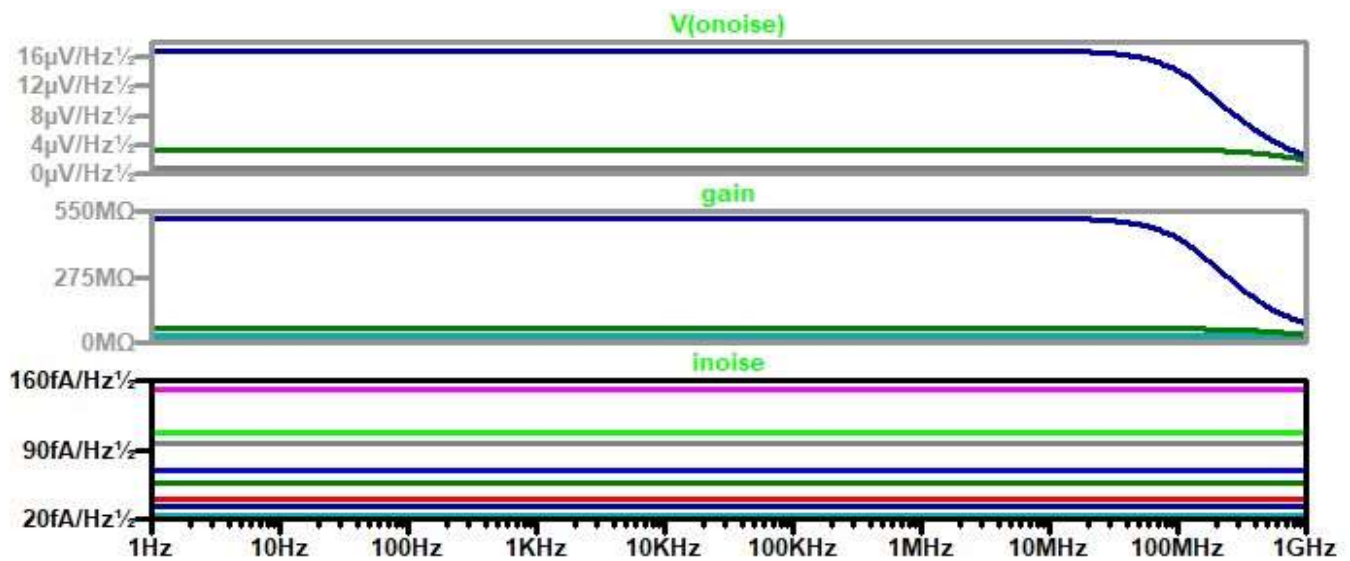


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I to V – String & T-net – Multiple gain levels

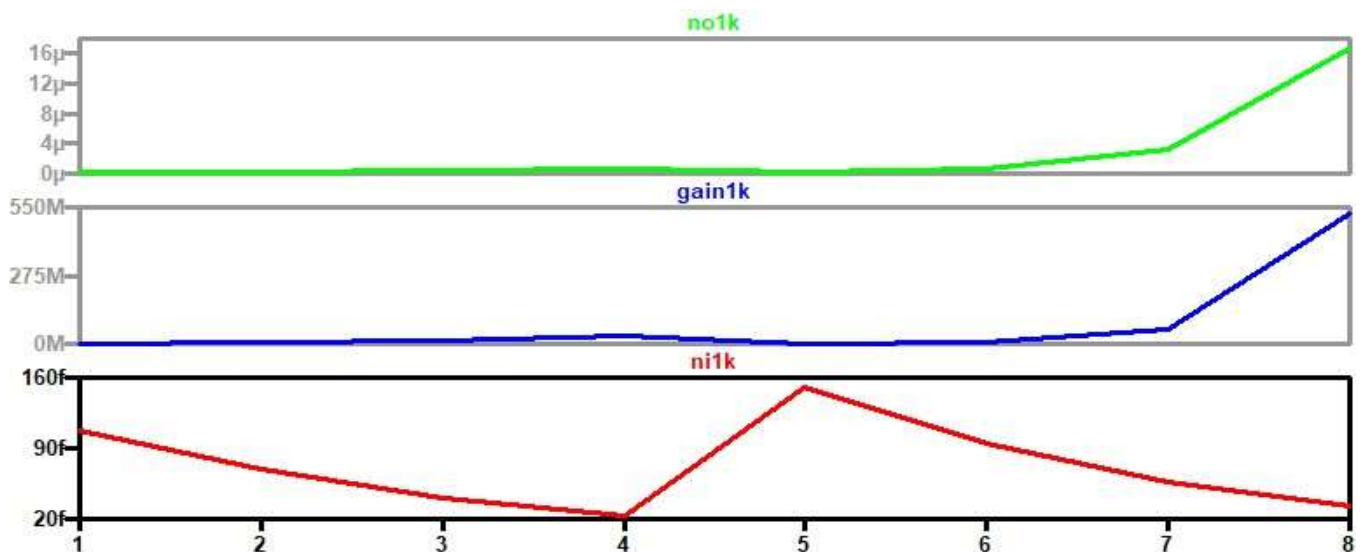


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I to V – String & T-net – Multiple gain levels

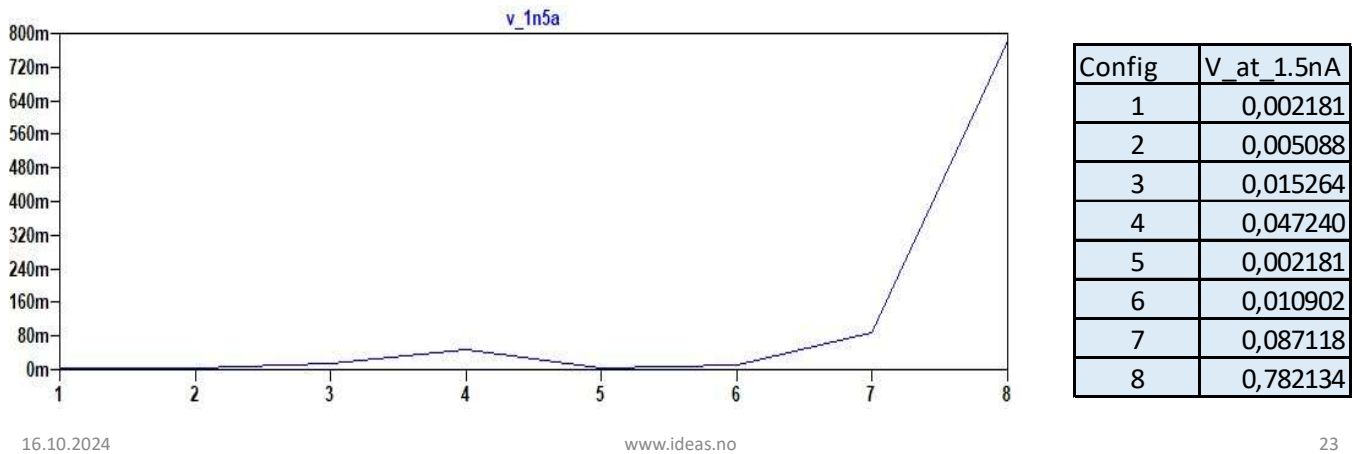


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1.5nA to V – String & T-net – Multiple gain levels



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

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

