Structured Electronic Design

Design of application-specific negative feedback amplifiers in CMOS technology (recap)

Anton J.M. Montagne

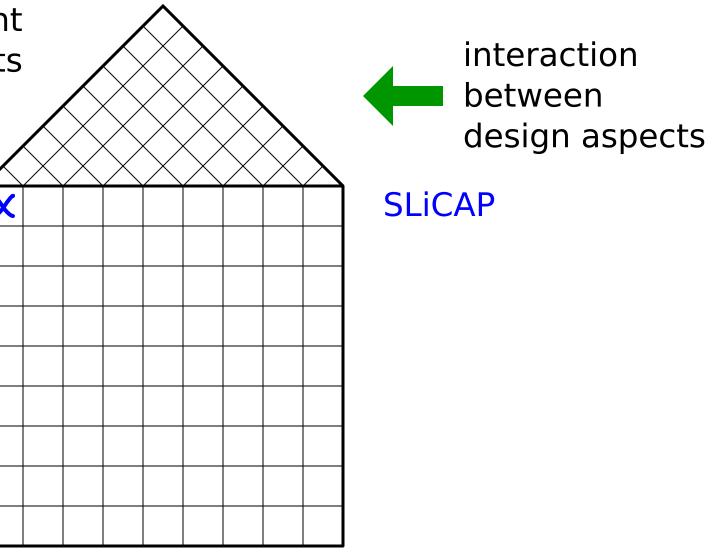
Structured Electronic Design

Step 1 Setting up the specification

Anton J.M. Montagne

Setting up specifications X

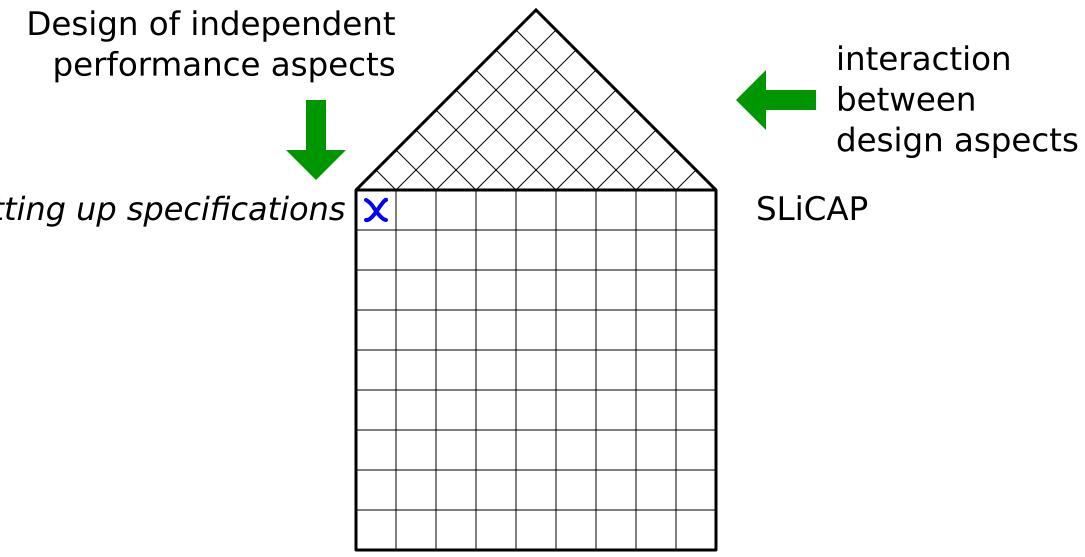
Function, performance, costs and environment





design

aspects



Design of the active antenna:

Setting up specifications X

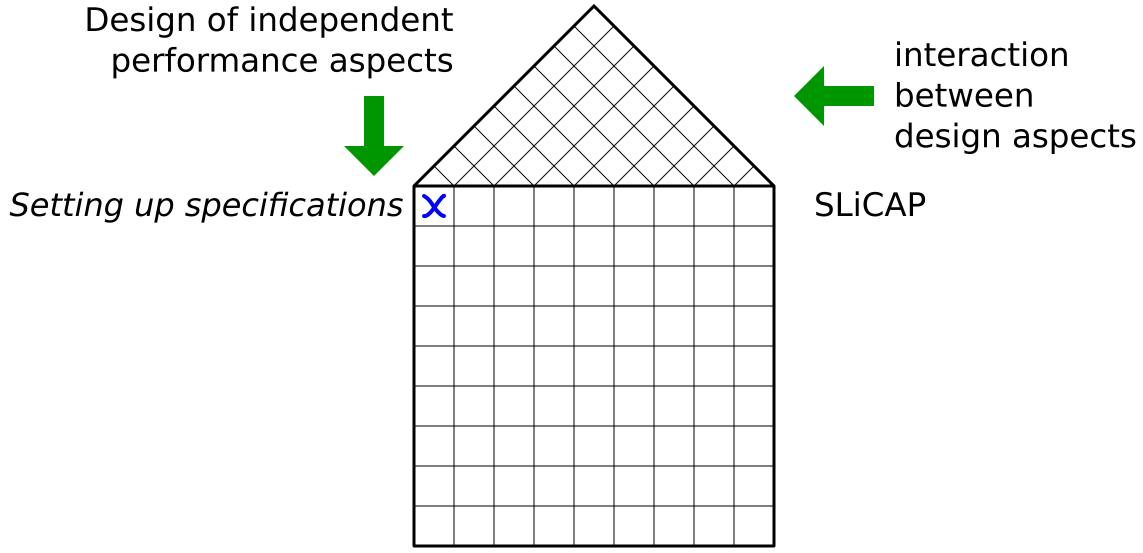
costs and environment Function, performance,



Design of the active antenna:

From the application description derive:

environment Function, performance, costs and



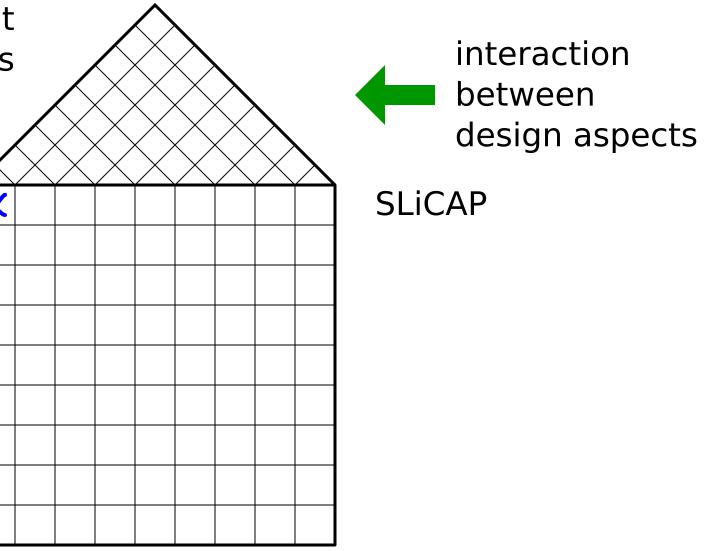


Design of the active antenna:

From the application description derive:

Functional requirements

Setting up specifications 🔀



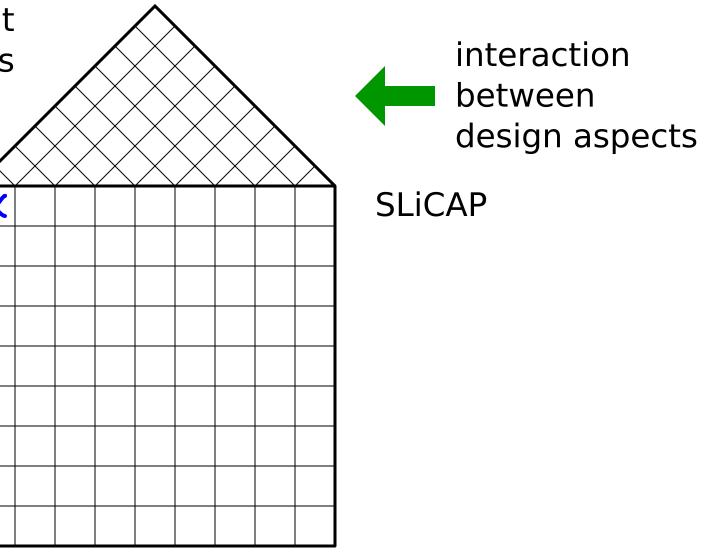


Design of the active antenna:

From the application description derive: Functional requirements

Port impedances

Setting up specifications





Design of the active antenna:

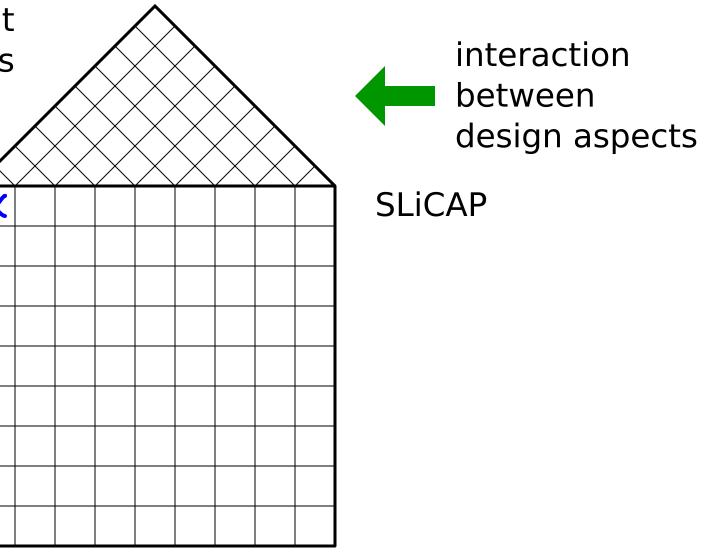
From the application description derive:

Functional requirements

Port impedances

Source-to-load transfer

Setting up specifications X





Design of the active antenna:

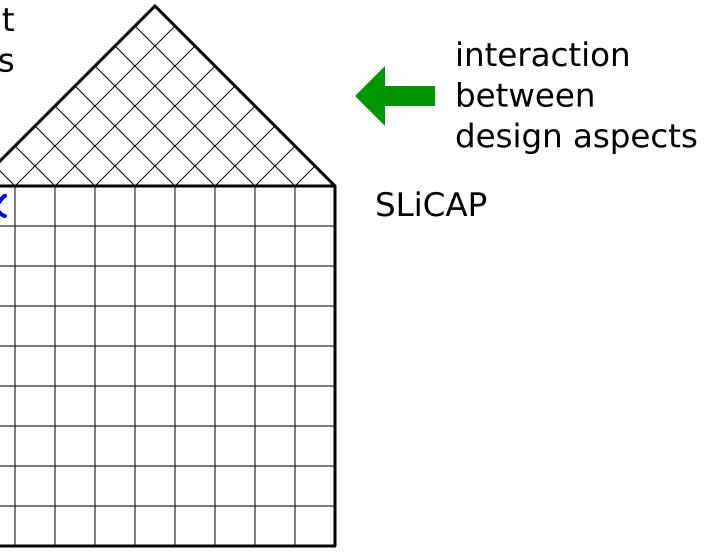
From the application description derive:

Functional requirements

- Port impedances
- Source-to-load transfer

Performance requirements (information processing capacity and quality):

Setting up specifications X





Design of the active antenna:

From the application description derive:

Functional requirements

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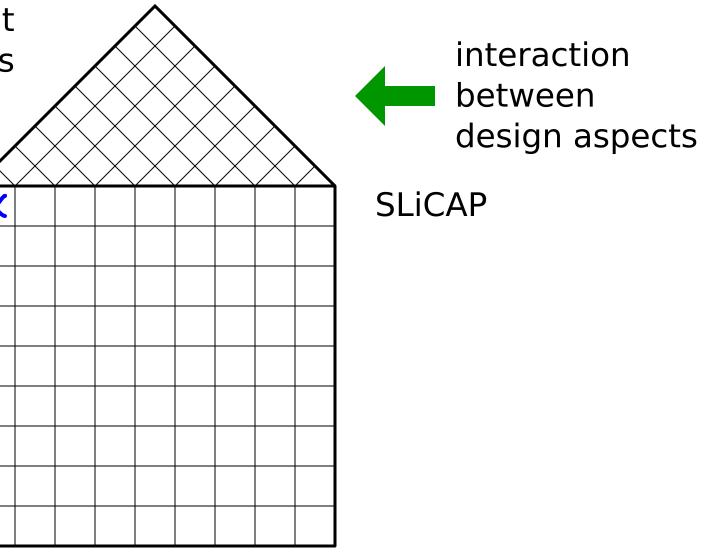
Source-to-load transfer

Performance requirements

(information processing capacity and quality):

Noise addition (temperature ofset drift)

Setting up specifications 🔀





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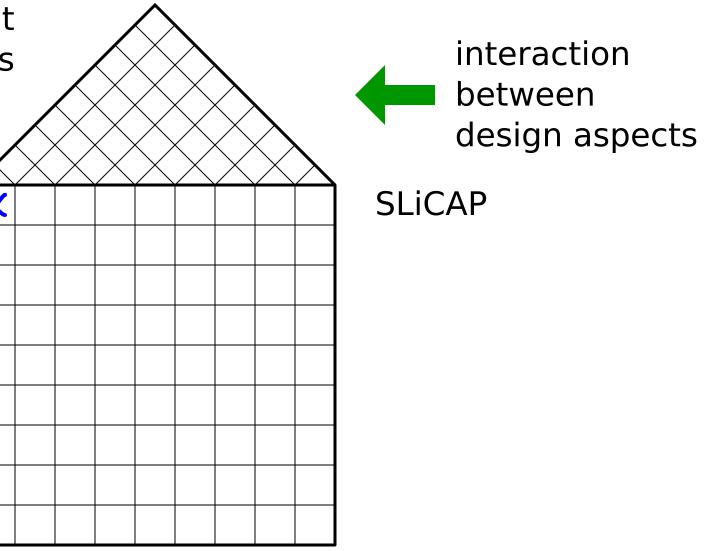
Performance requirements

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Static and dynamic signal handling capability

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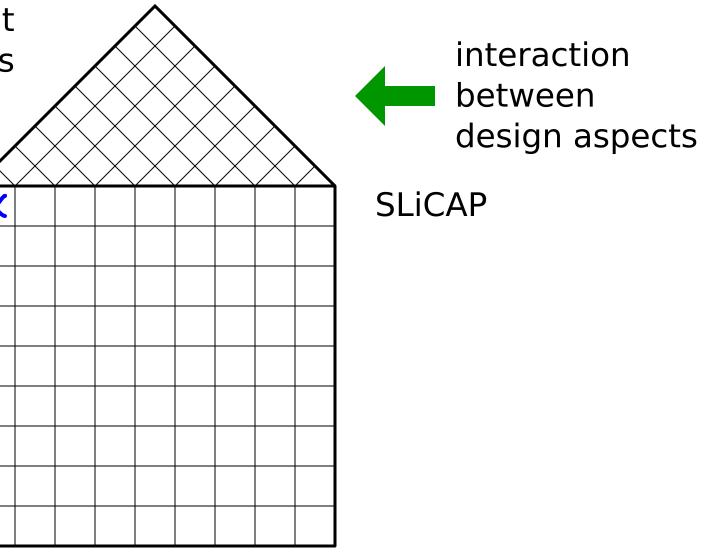
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Setting up specifications 🔀





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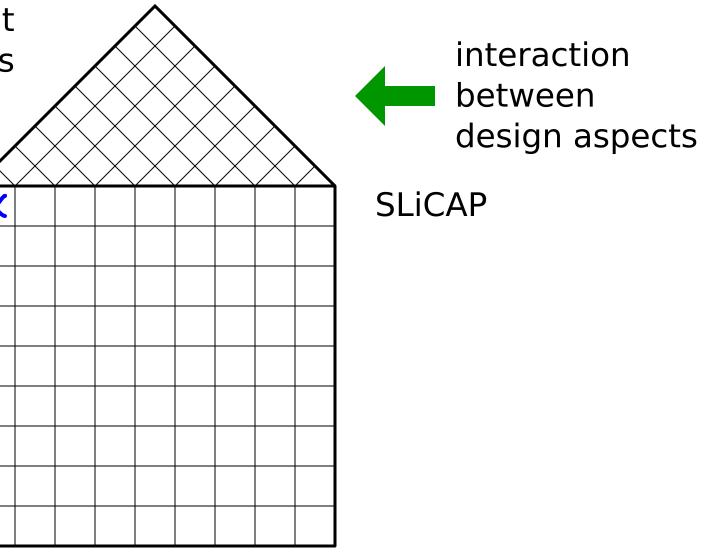
Performance requirements (information processing capacity and quality): Noise addition (temperature ofset drift)

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Inaccuracy (temperature gain drift)

Frequency or time domain response

Setting up specifications 🔀





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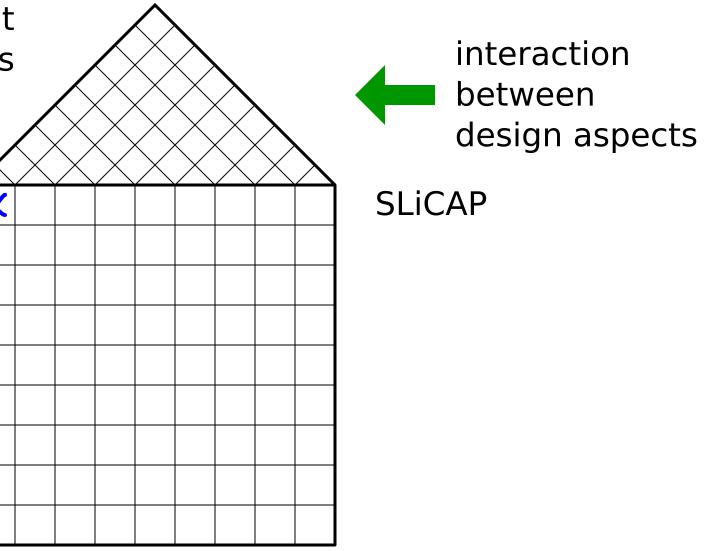
Static and dynamic signal handling capability

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Weak nonlinearity

Setting up specifications 🔀





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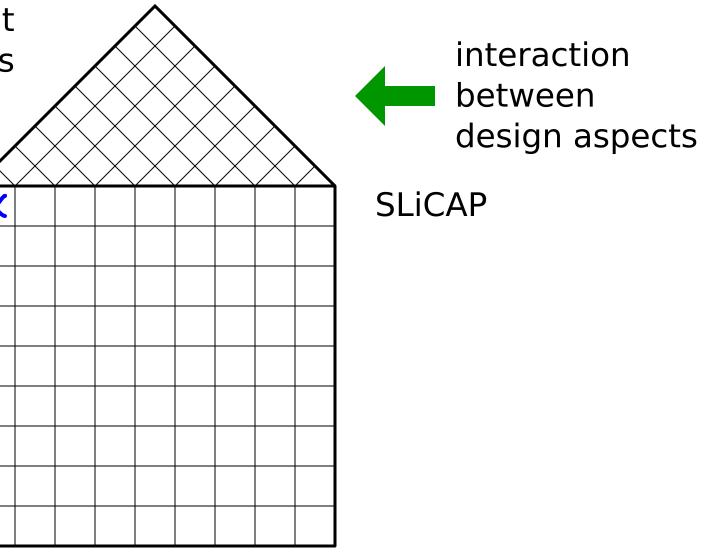
Inaccuracy (temperature gain drift)

Frequency or time domain response

Weak nonlinearity

Cost factors:

Setting up specifications 🔀





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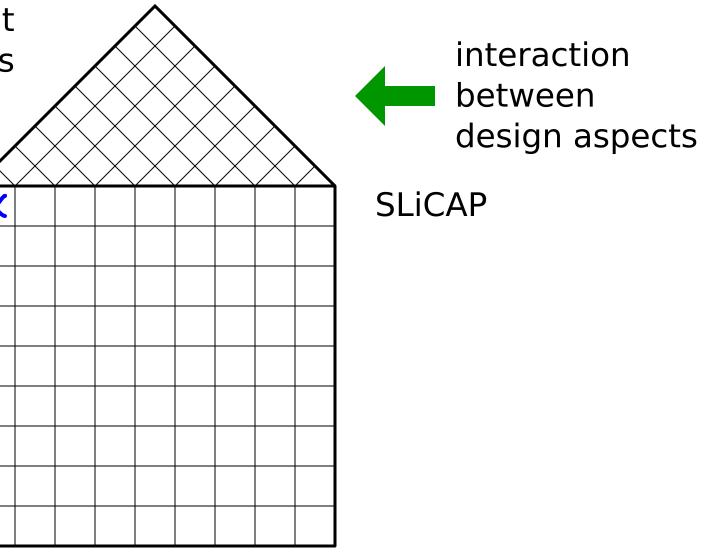
Weak nonlinearity

Cost factors:

Supply voltage

Setting up specifications 🔀

Function, performance, costs and environment





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Functional requirements

Port impedances

Source-to-load transfer

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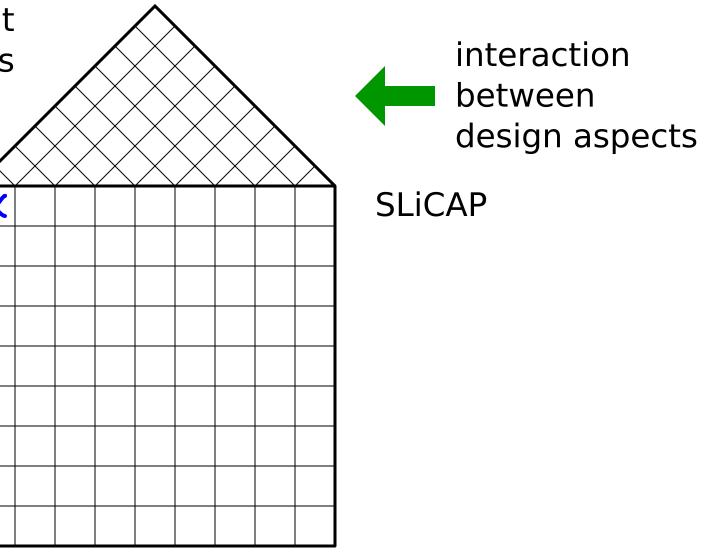
Weak nonlinearity

Cost factors:

Supply voltage

Current consumption

Setting up specifications X





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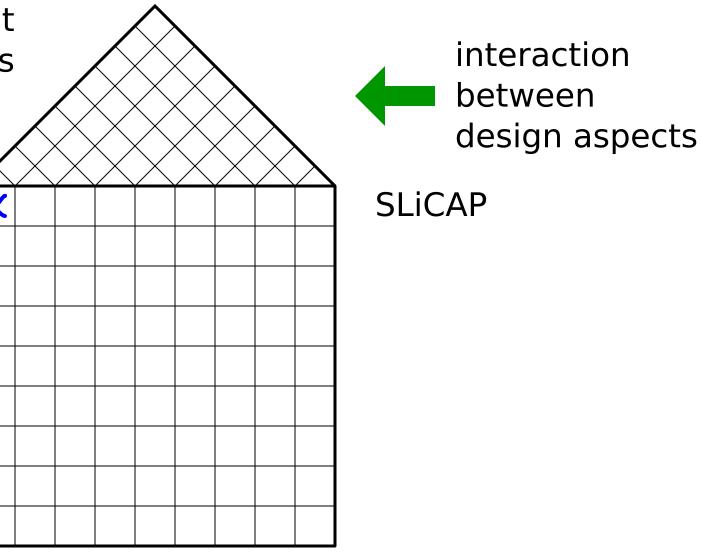
Cost factors:

Supply voltage

Current consumption

Dimensions

Setting up specifications X





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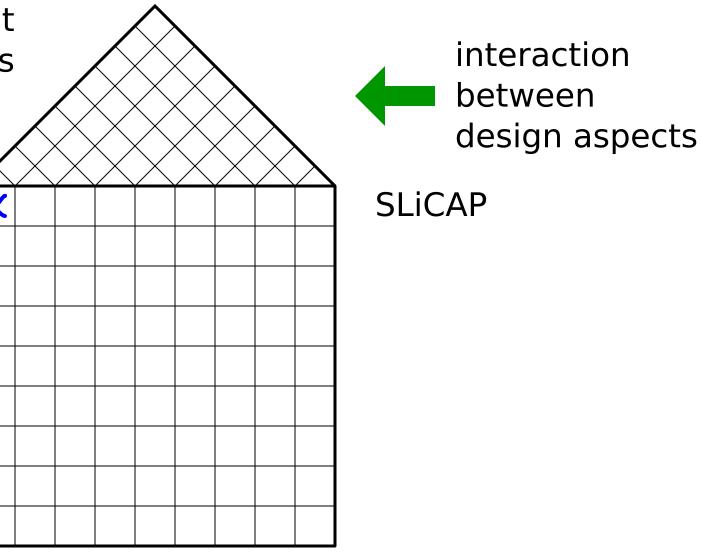
Supply voltage

Current consumption

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Operating conditions:

Setting up specifications X





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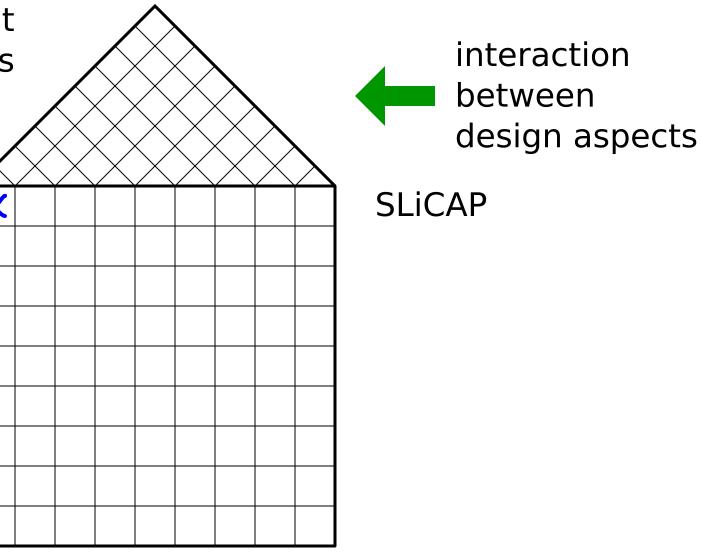
Current consumption

Dimensions

Operating conditions:

Temperature range

Setting up specifications 🔀





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Supply voltage

Current consumption

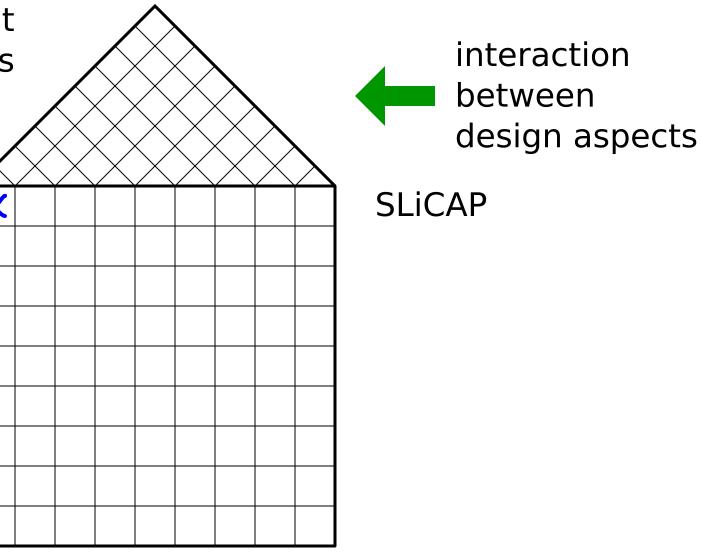
Dimensions

Operating conditions:

Temperature range

EMI, ESD

Setting up specifications X





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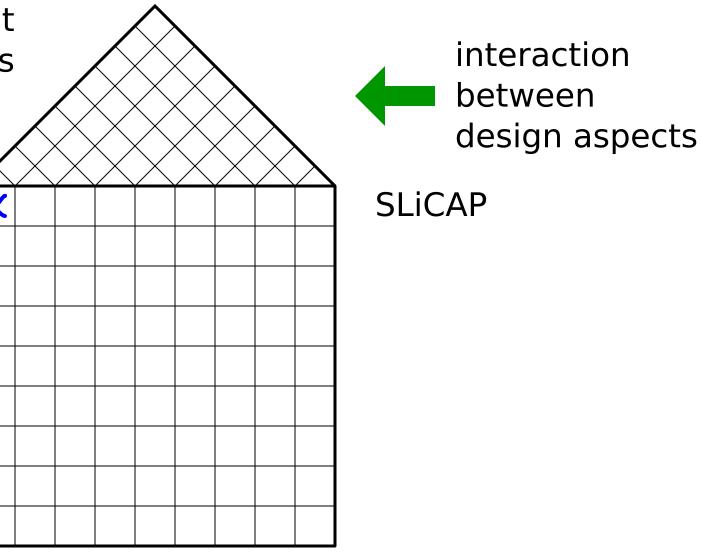
Supply voltage

Current consumption

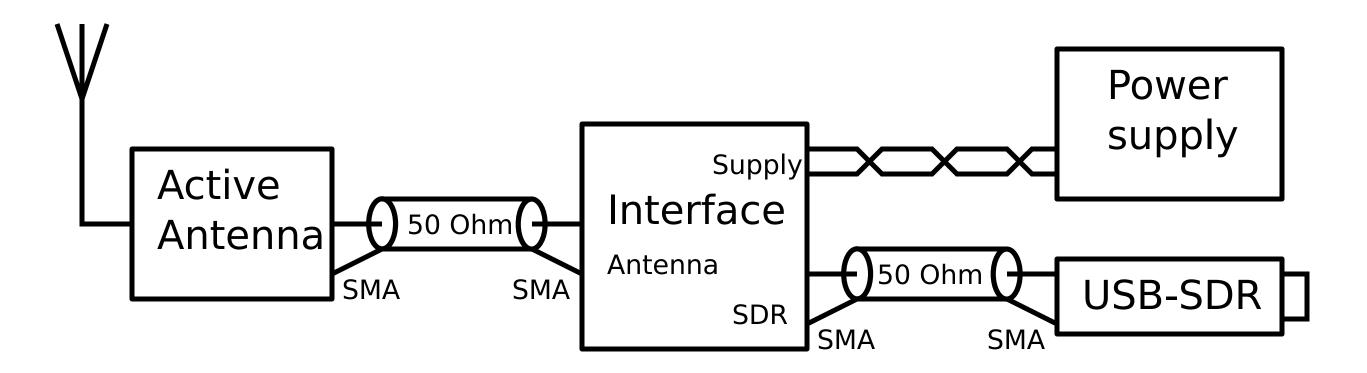
Dimensions

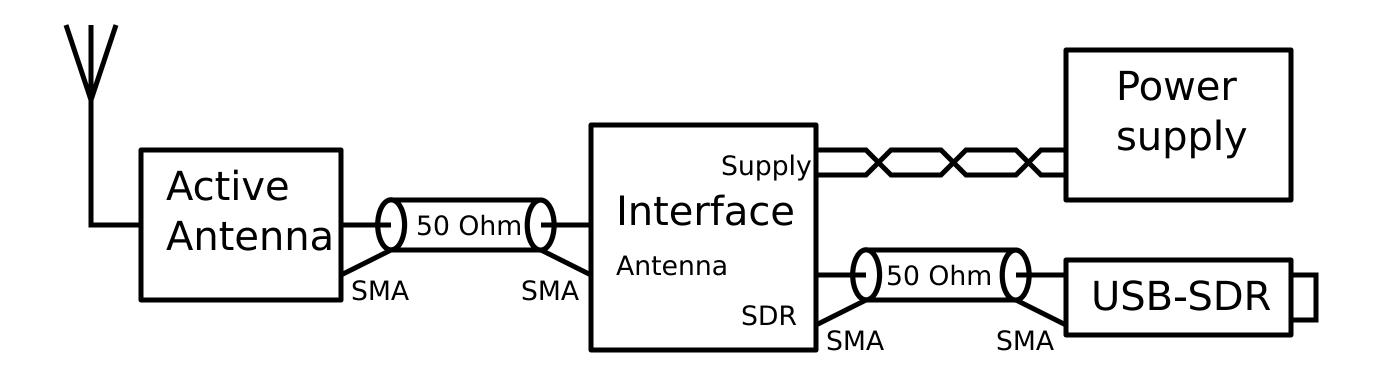
Operating conditions:

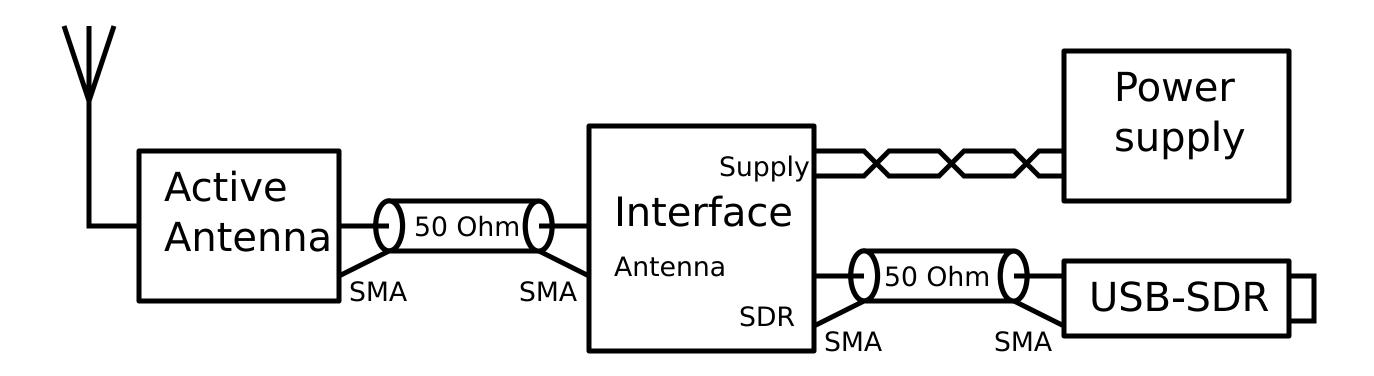
Temperature range EMI, ESD Setting up specifications X



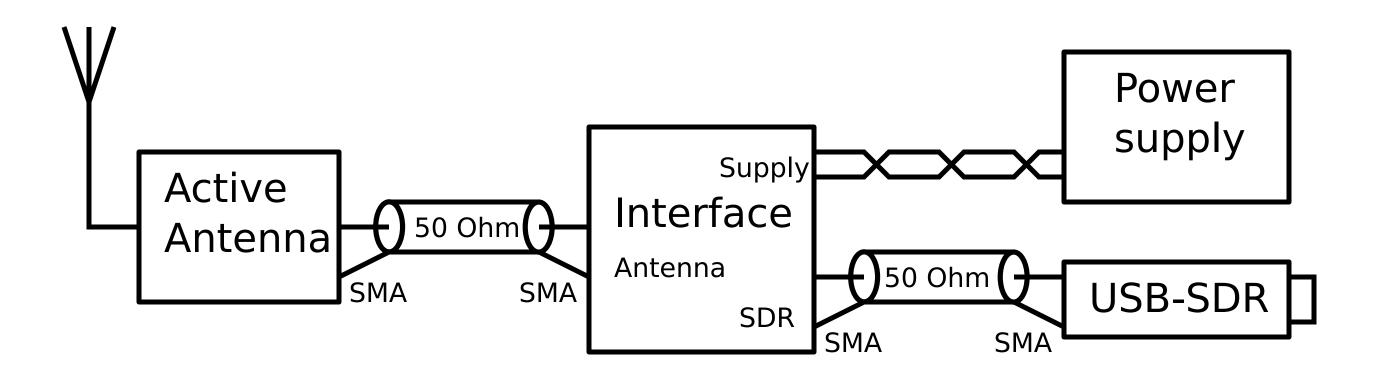






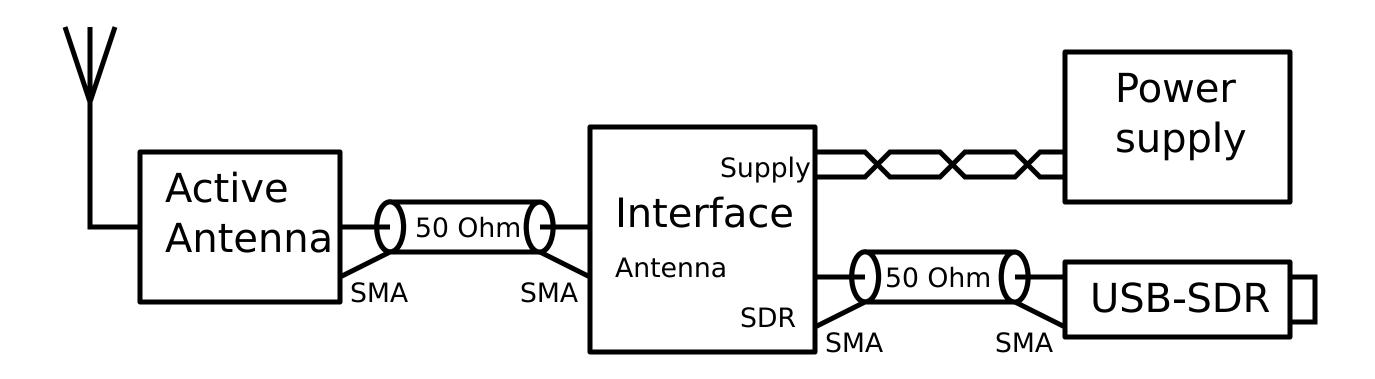


Maximum RMS input signal

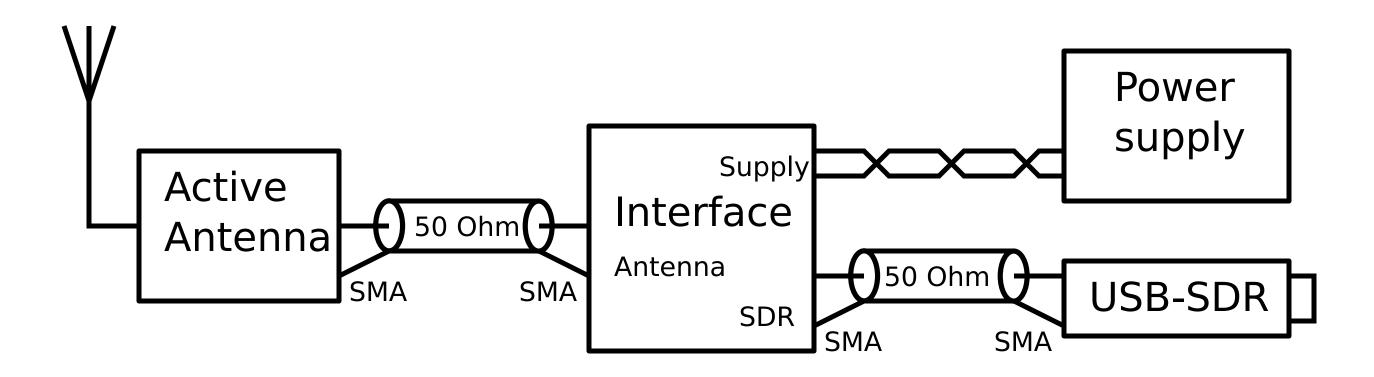


Maximum RMS input signal

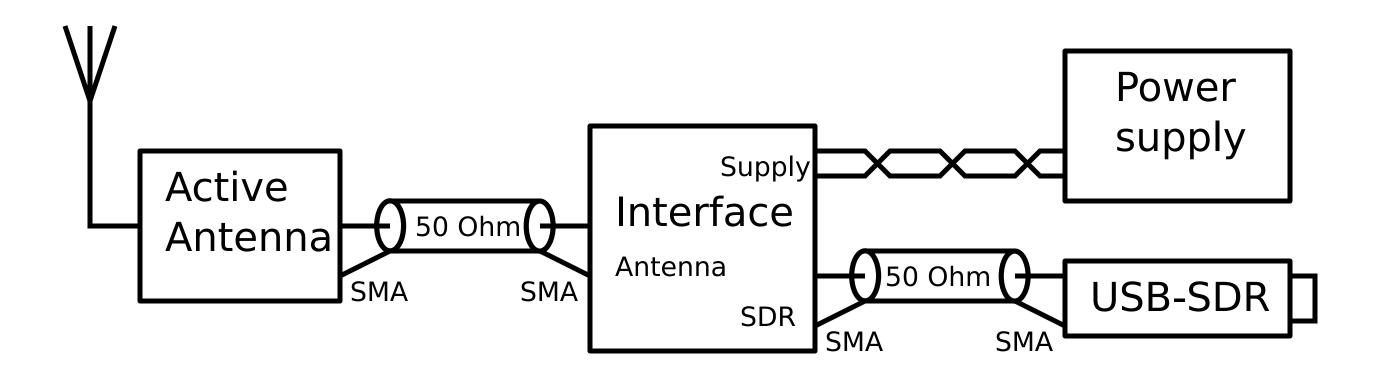
Maximum RMS output voltage across 50 Ohm



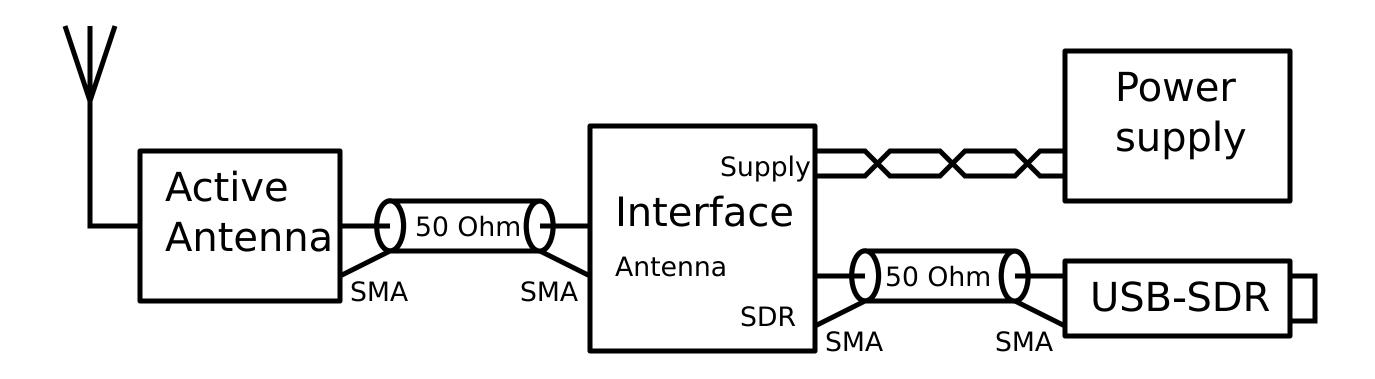
Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise



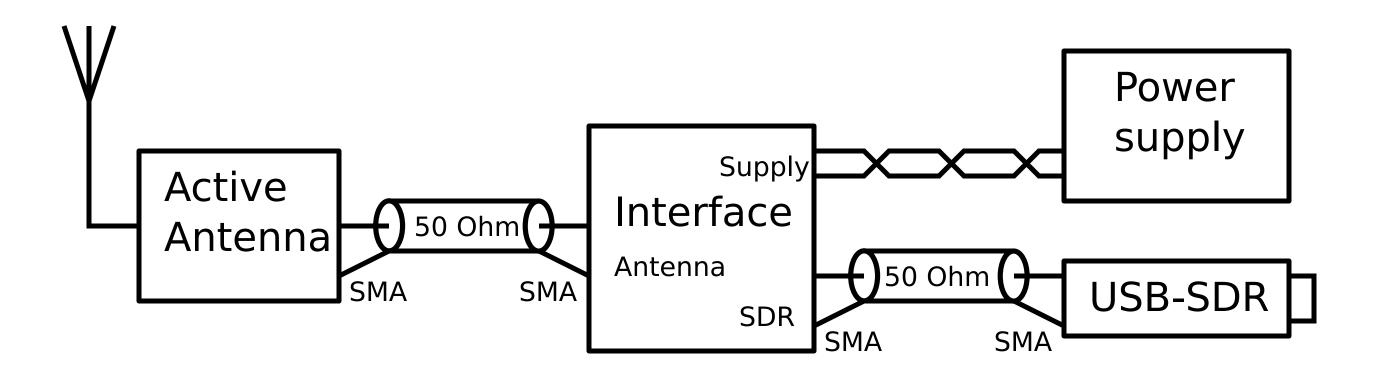
Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance



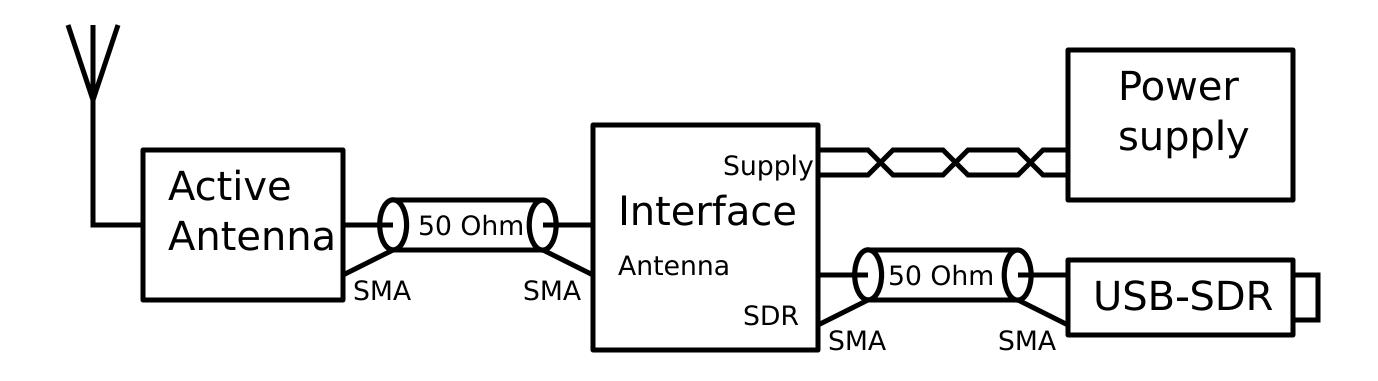
Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest



Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type

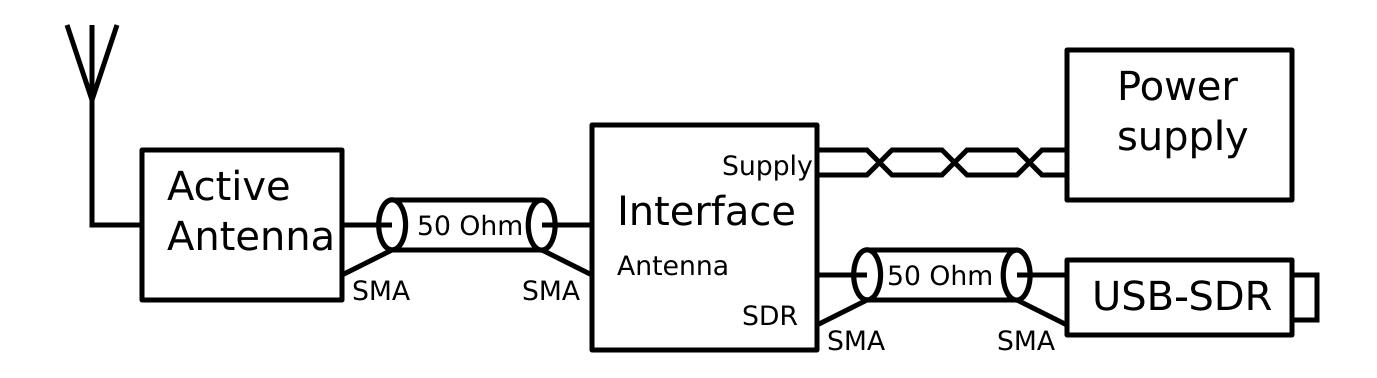


Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD



Costs

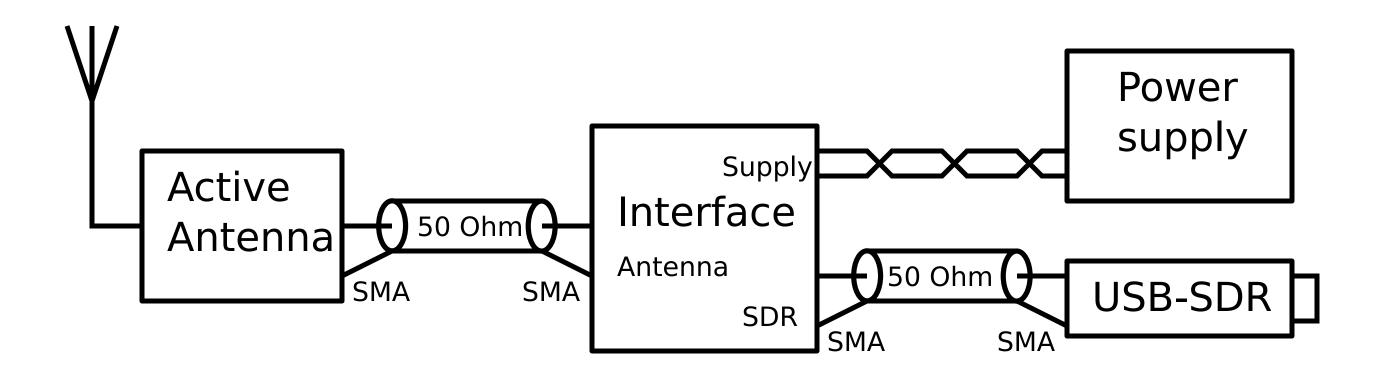
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Antenne length



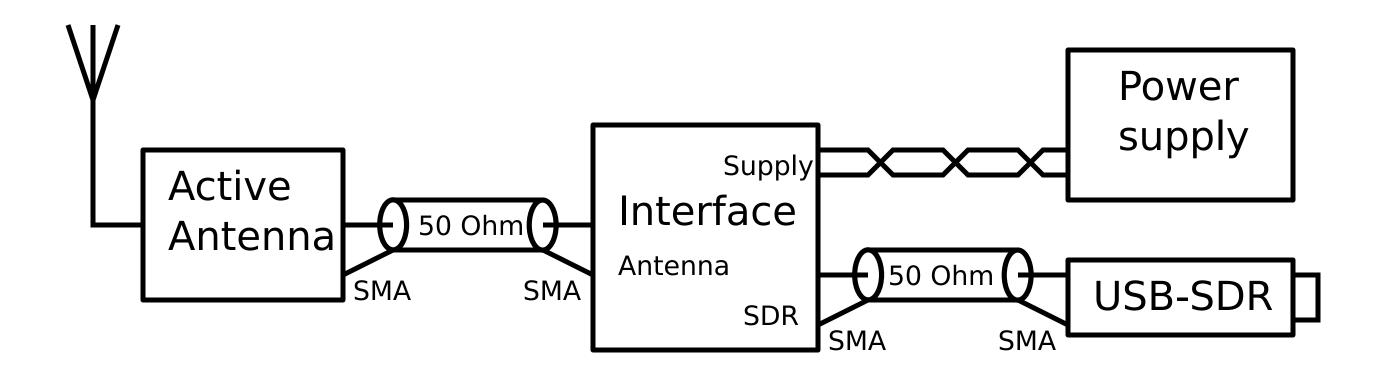
Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD

Costs

Antenne length

Supply voltage

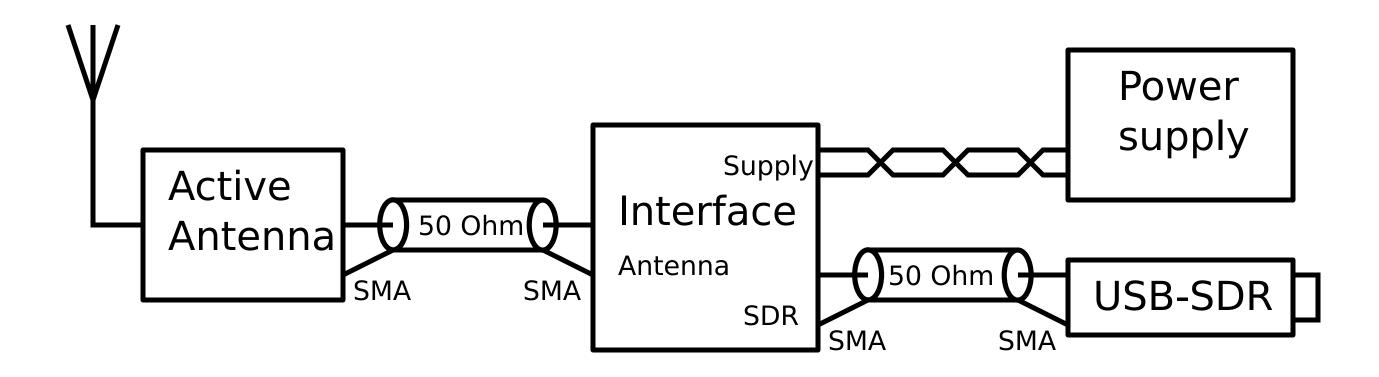
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Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD

Costs

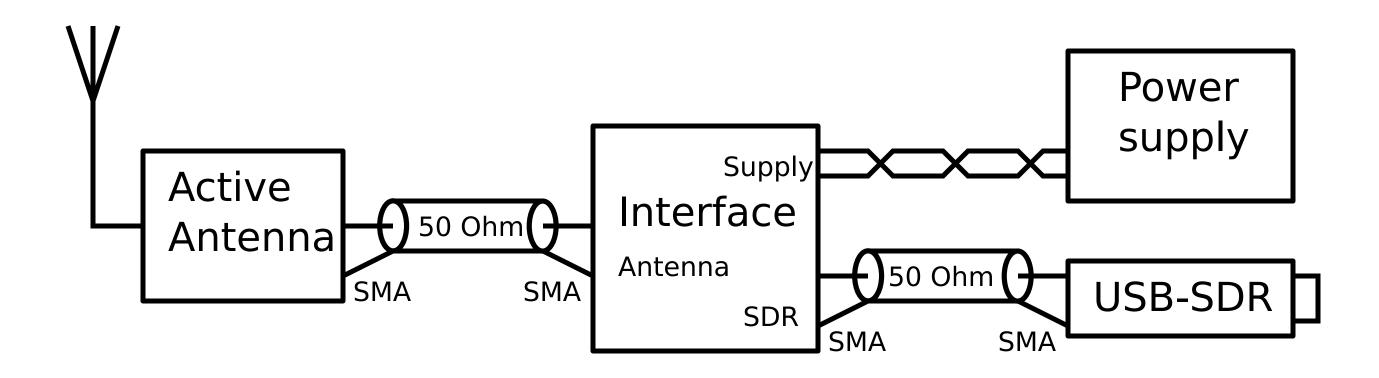
Antenne length Supply voltage Power consumption



Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD

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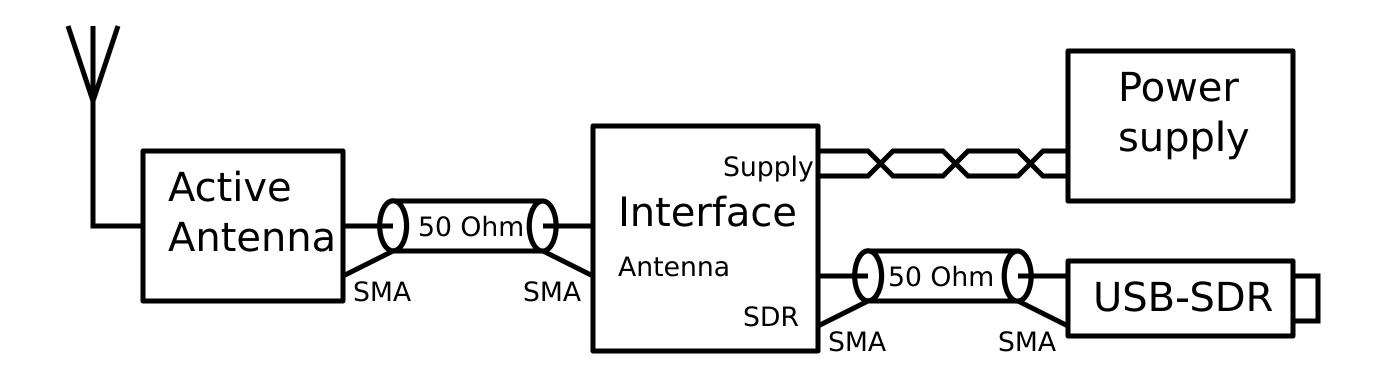
Antenne length Supply voltage Power consumption Dimensions



Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD

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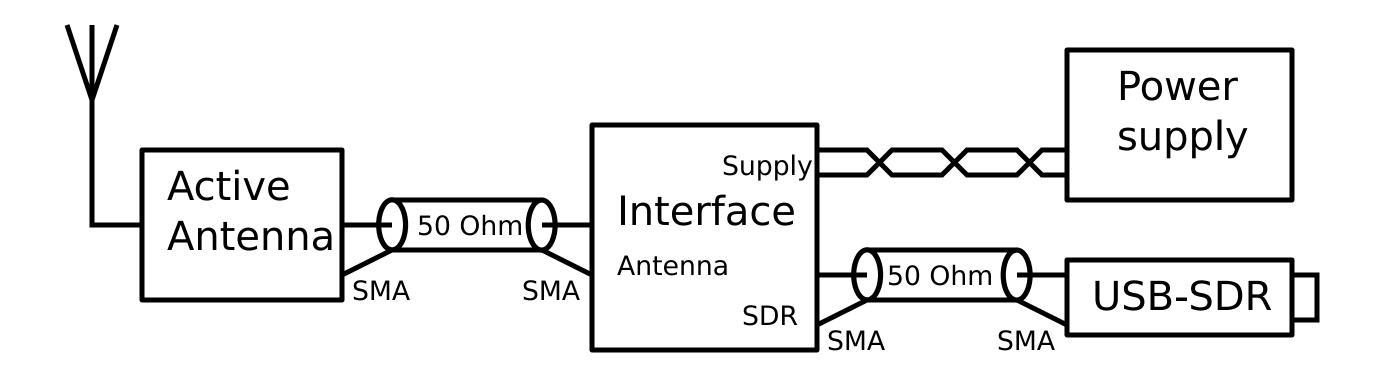
Antenne length Supply voltage Power consumption Dimensions Technology



Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD

Costs

Antenne length Supply voltage Power consumption Dimensions Technology **External components**



Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD

Costs

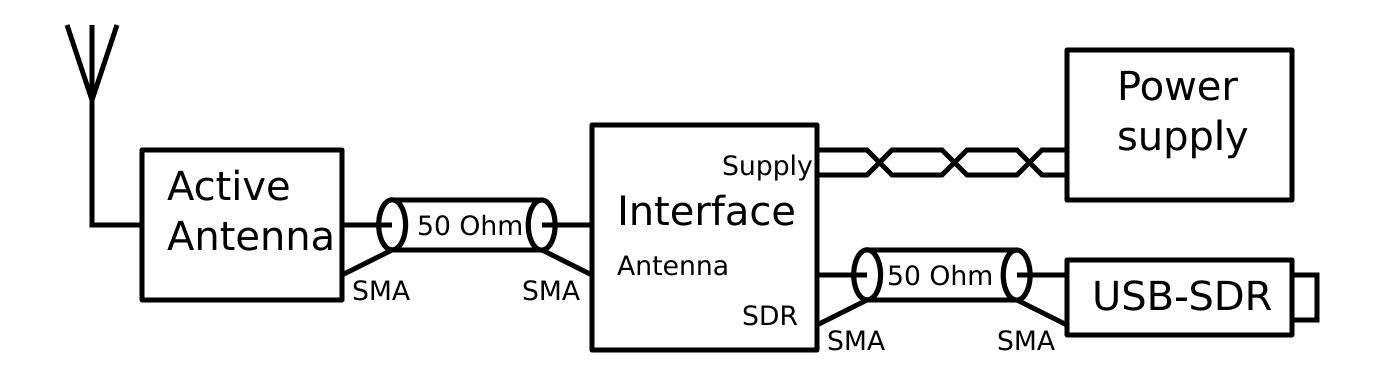
Antenne length Supply voltage Power consumption

Dimensions

Technology

External components

Package



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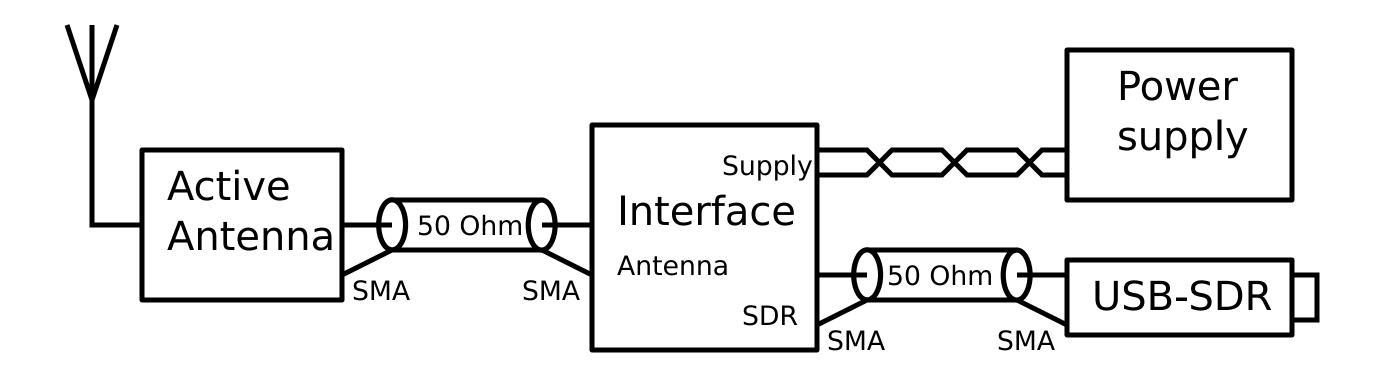
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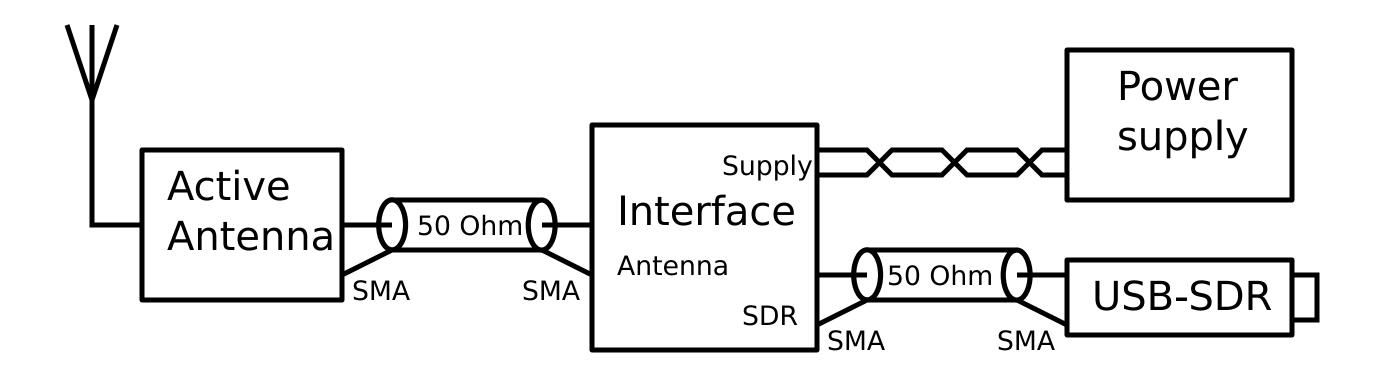
Technology

External components

Package

Operating conditions

Temperature range



Maximum RMS input signal Maximum RMS output voltage across 50 Ohm Antenna referred noise Output impedance Frequency range of interest Response type IMD

Costs

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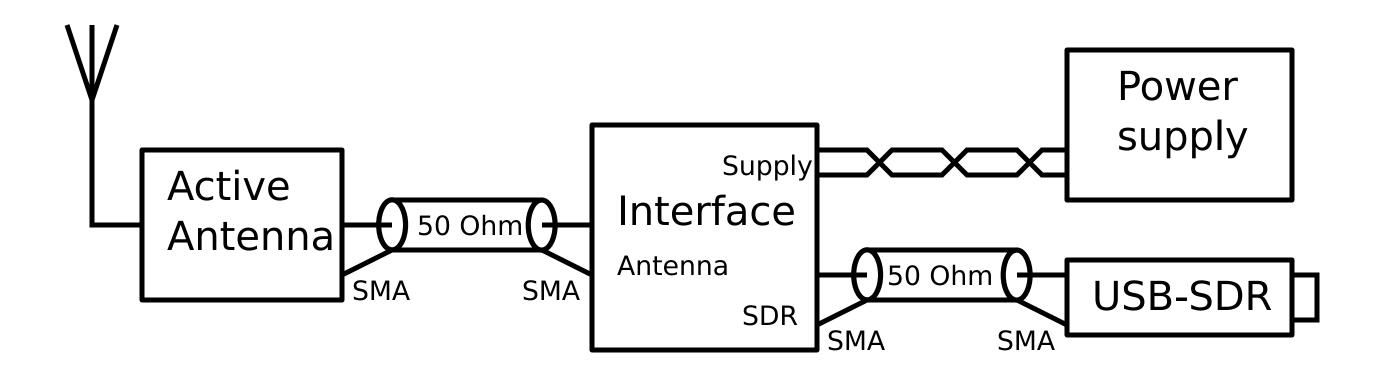
Dimensions

Technology

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- Temperature range EMI



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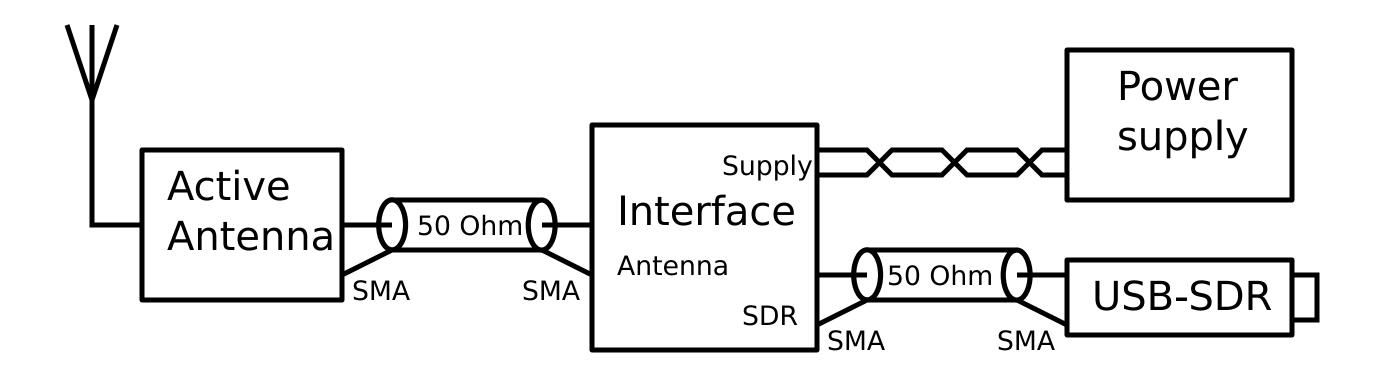
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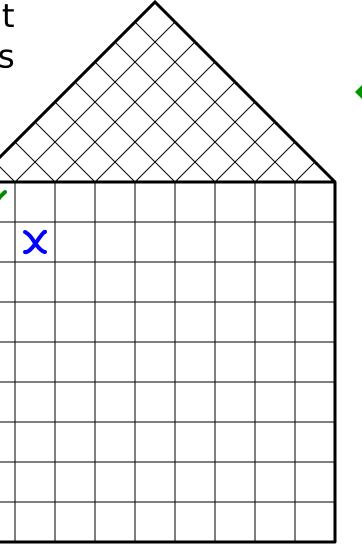
Structured Electronic Design

Step 2 Design of the amplifier type

Anton J.M. Montagne

Design of independent performance aspects Setting up specifications Design of amplifier type: A, B, C, D

> Function, performance, costs and environment Feedback configuration



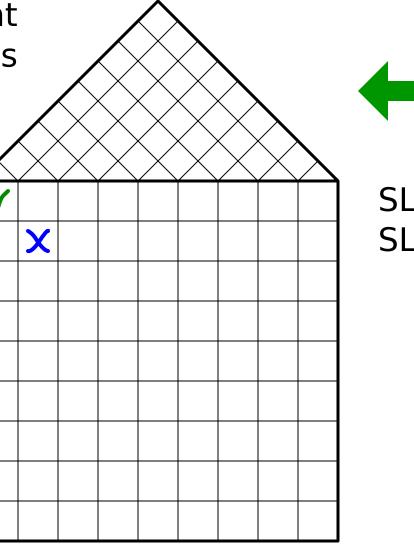
interaction between design aspects

SLiCAP SLiCAP



Design of independent performance aspects

Setting up specifications V Design of amplifier type: A, B, C, D



interaction between design aspects

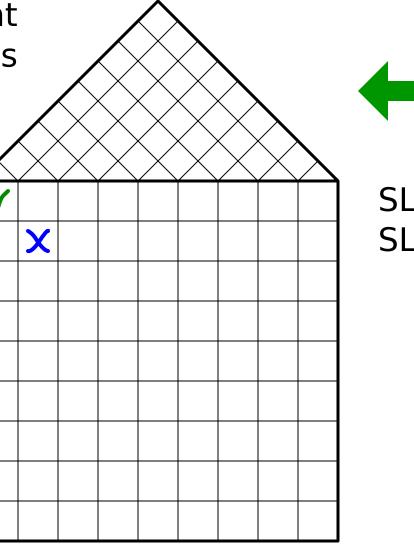
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Design of independent performance aspects

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Negative feedback can be applied if:



interaction between design aspects

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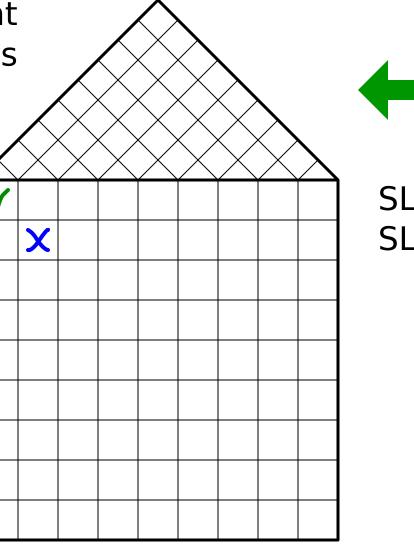
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Setting up specifications V Design of amplifier type: A, B, C, D

Negative feedback can be applied if:

Circuit dimensions are much smaller than the wavelength of the highest frequency of interest

Function, performance, costs and environment Feedback configuration



interaction between design aspects

SLiCAP SLiCAP



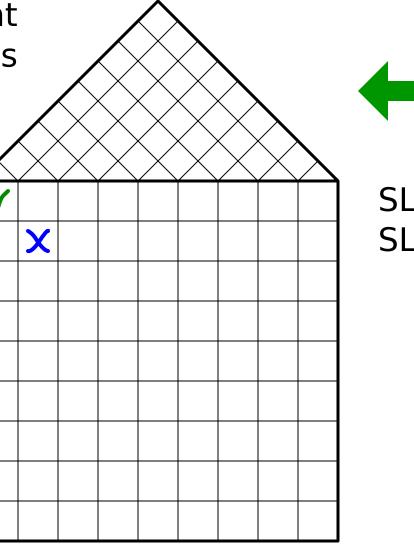
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interaction between design aspects

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Design of independent performance aspects

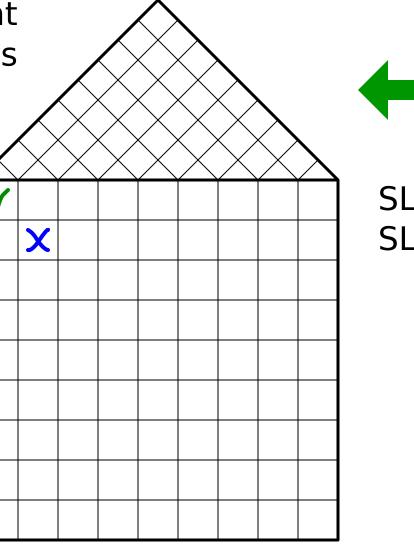
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Design of the active antenna:



interaction between design aspects

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Design of independent performance aspects

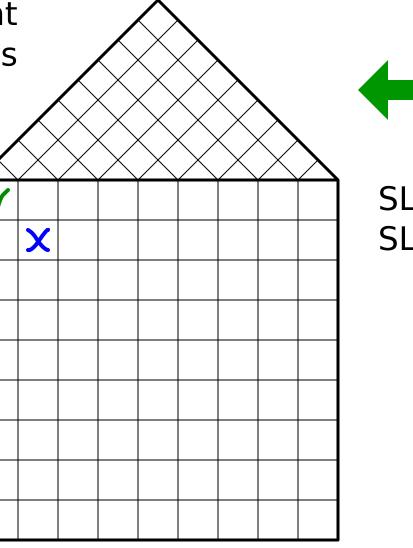
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Negative feedback can be applied if:

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Design of the active antenna:

Determine valid combinations of T1 parameters A, B, C, D



interaction between design aspects

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Design of independent performance aspects

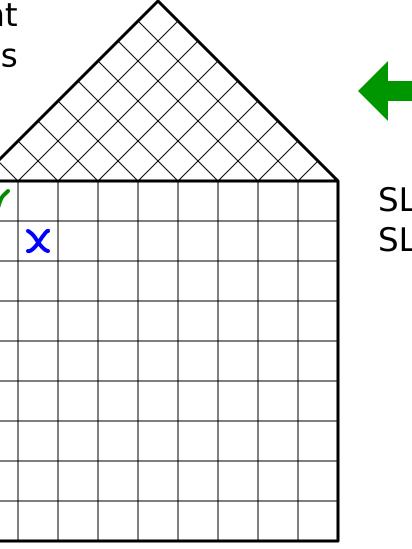
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Design of the active antenna:

Determine valid combinations of T1 parameters A, B, C, D Design feedback configurations for these combinations



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Design of independent performance aspects

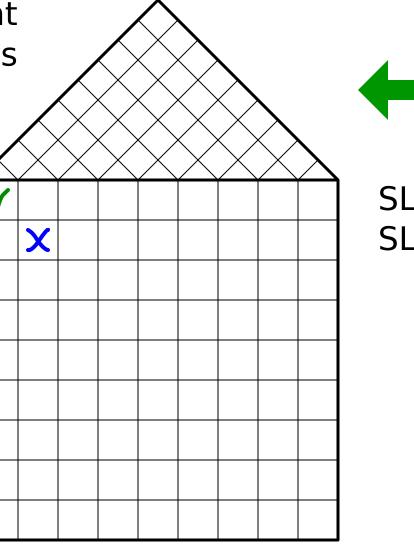
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Design of the active antenna:

Determine valid combinations of T1 parameters A, B, C, D Design feedback configurations for these combinations Discuss their feasibility (comparison table or decision matrix)



interaction between design aspects

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Design of independent performance aspects

Setting up specifications V Design of amplifier type: A, B, C, D

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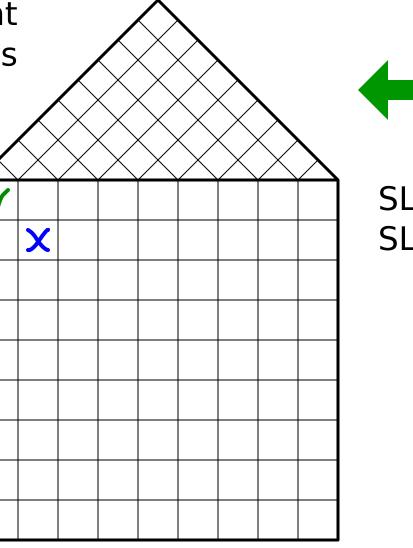
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interaction between design aspects

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Design of independent performance aspects

Setting up specifications V Design of amplifier type: A, B, C, D

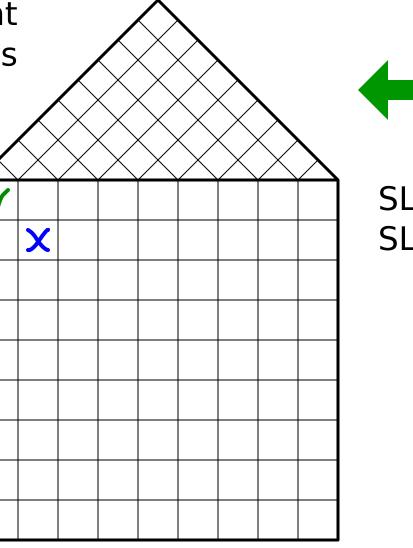
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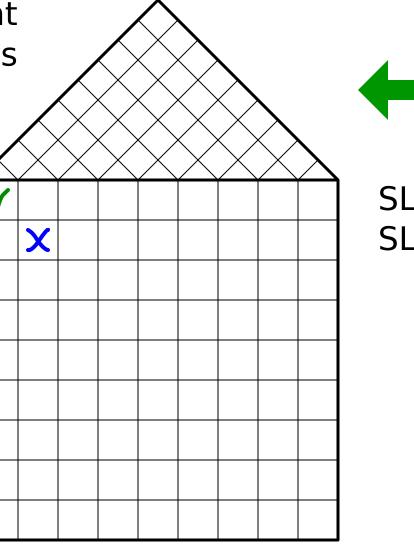
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> Result is a functional design or concept design which is assumed feasible

Design studies level fo detailing depends on experience *Function, performance, costs and environment* Feedback configuration



interaction between design aspects

SLiCAP SLiCAP



Design of independent performance aspects

Setting up specifications V Design of amplifier type: A, B, C, D

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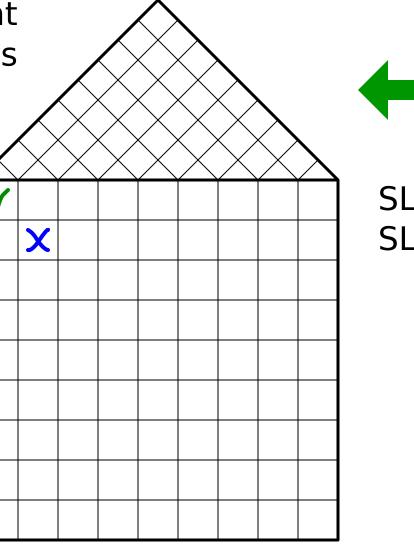
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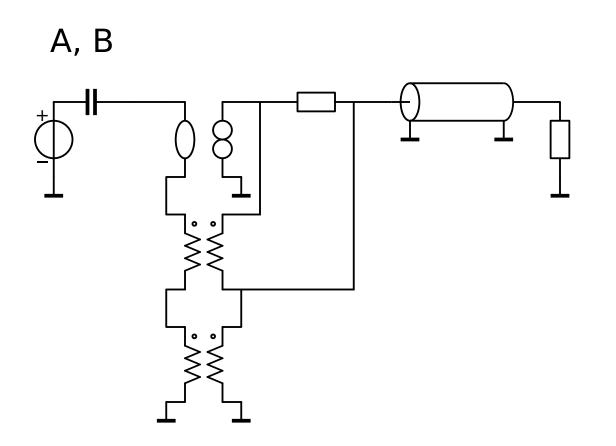
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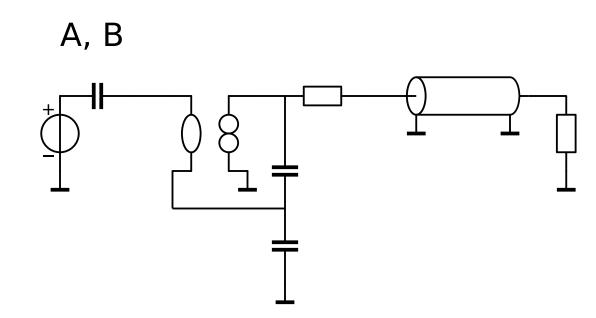


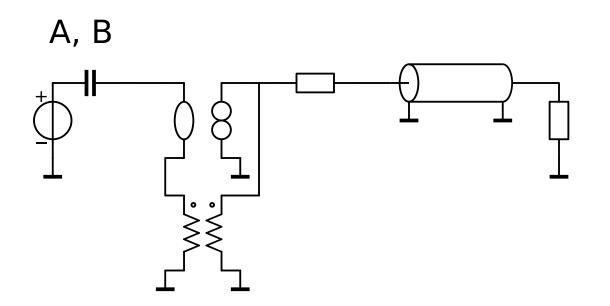
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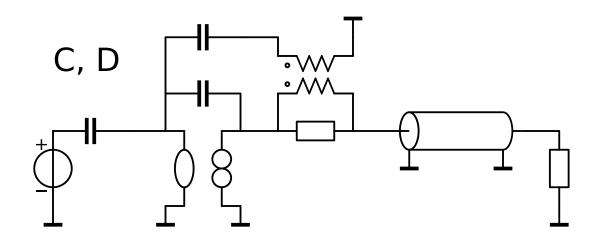
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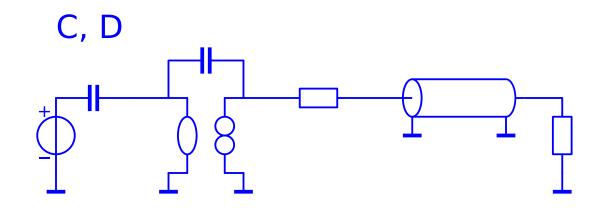


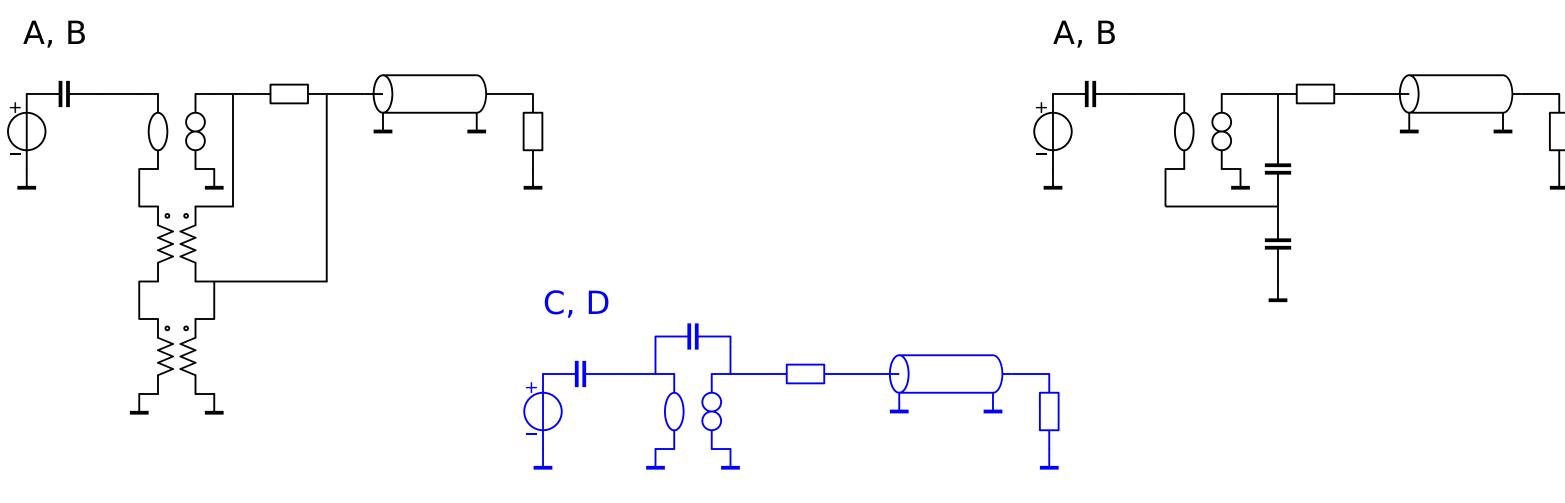














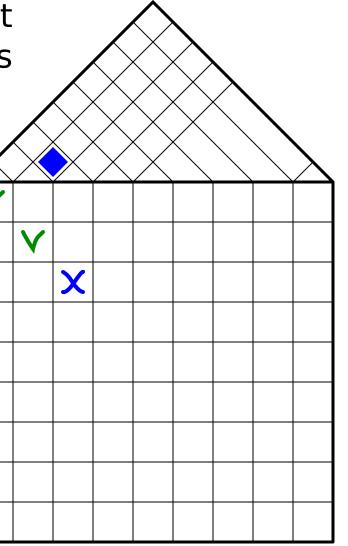
Structured Electronic Design

Step 3 Feasibility of the noise requirements

Anton J.M. Montagne

Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

> *Function, performance, costs and environment* Feedback configuration Controller input stage



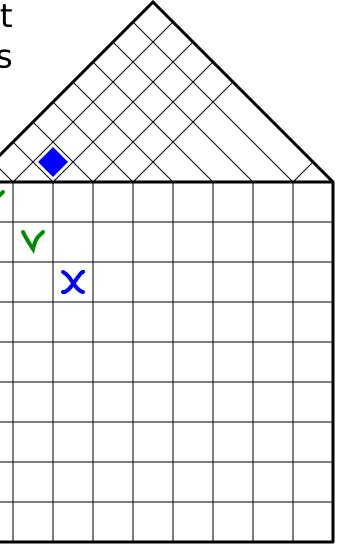
interaction between design aspects

SLiCAP SLiCAP SLiCAP



Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

Design of the feedback network and the input stage of the controller



interaction between design aspects

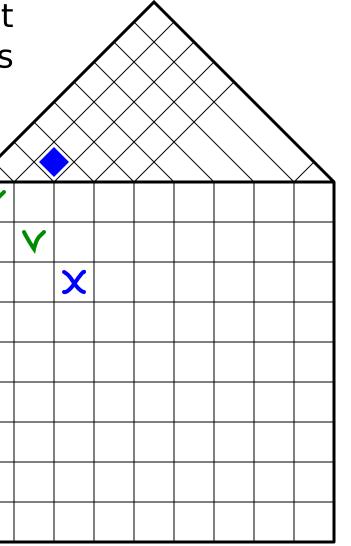
SLiCAP SLiCAP SLiCAP



Setting up specifications ▼ Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

Design of the feedback network and the input stage of the controller

If the frequency range of temperature variations overlaps with that of the signal, equivalent input offset and bias variations have to be considered as input noise sources.



interaction between design aspects

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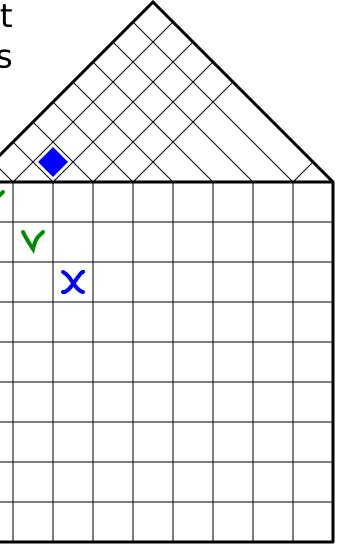


Setting up specifications ▼ Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

Design of the feedback network and the input stage of the controller

If the frequency range of temperature variations overlaps with that of the signal, equivalent input offset and bias variations have to be considered as input noise sources.

Otherwise, the influence of temperature variations can be dealt with at a later stage of the design.



interaction between design aspects

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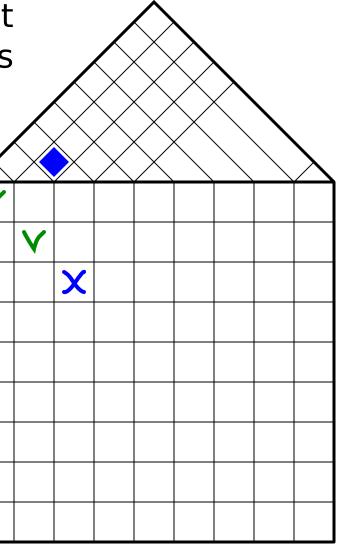
Setting up specifications ▼ Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

Design of the feedback network and the input stage of the controller

If the frequency range of temperature variations overlaps with that of the signal, equivalent input offset and bias variations have to be considered as input noise sources.

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Design of the active antenna:



interaction between design aspects

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Setting up specifications ▼ Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

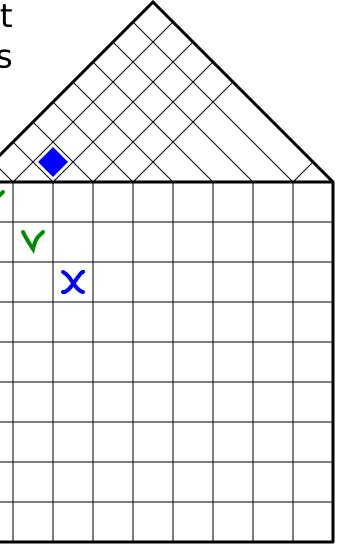
Design of the feedback network and the input stage of the controller

If the frequency range of temperature variations overlaps with that of the signal, equivalent input offset and bias variations have to be considered as input noise sources.

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Design of the active antenna:

Design a CS stage with sufficiently low noise performance



interaction between design aspects

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Setting up specifications ▼ Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

Design of the feedback network and the input stage of the controller

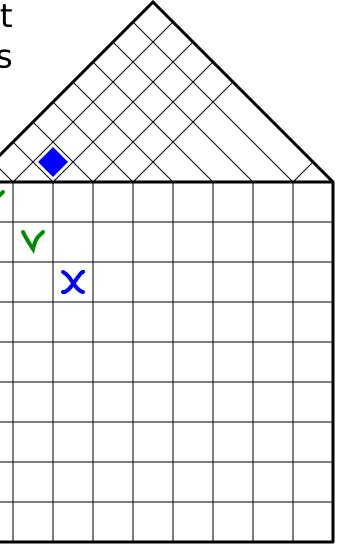
If the frequency range of temperature variations overlaps with that of the signal, equivalent input offset and bias variations have to be considered as input noise sources.

Otherwise, the influence of temperature variations can be dealt with at a later stage of the design.

Design of the active antenna:

Design a CS stage with sufficiently low noise performance

Determine valid ranges for: $I_{DS},\,W,\,L,\,M$



interaction between design aspects

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Feedback configuration Controller input stage

Setting up specifications ▼ Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications

Design of the feedback network and the input stage of the controller

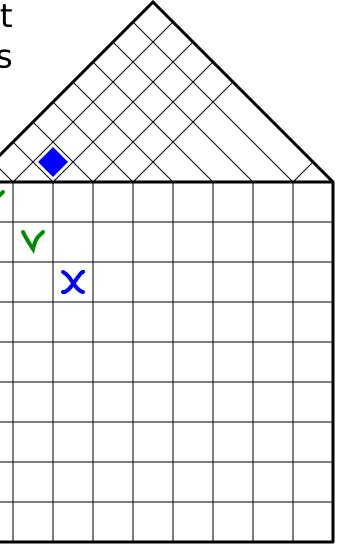
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Design of the active antenna:

Design a CS stage with sufficiently low noise performance

Determine valid ranges for: I_{DS}, W, L, M

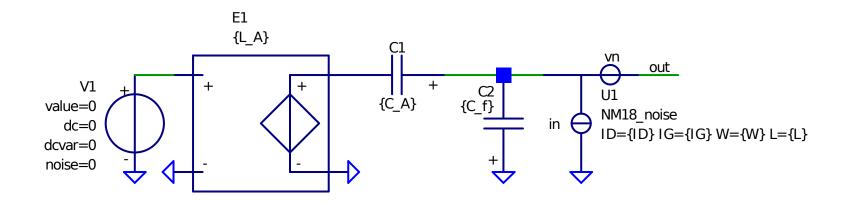


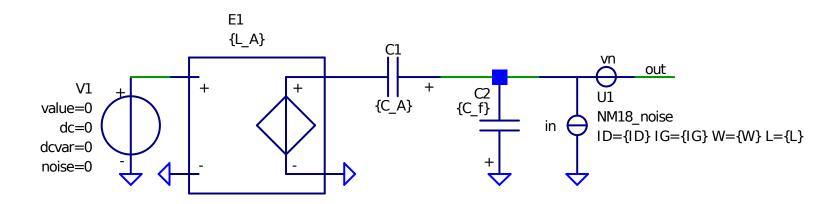
interaction between design aspects

SLiCAP SLiCAP SLiCAP

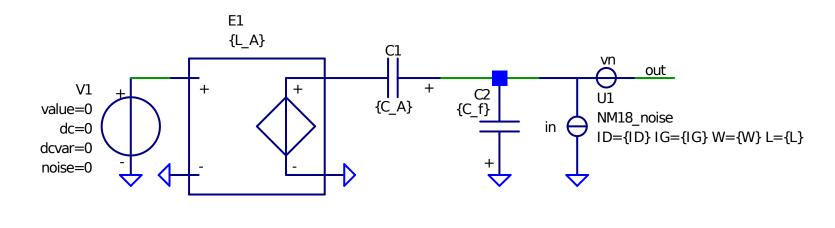


Feedback configuration Controller input stage





Source-referred noise at the output of E1:

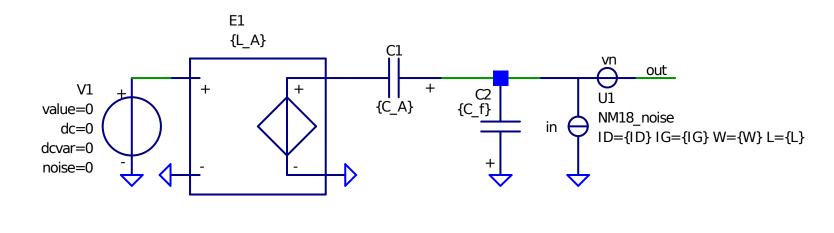


Source-referred noise at the output of E1:

 $S_{v_n} = \frac{4kTn}{g_m}$

$$f_{\ell} = \alpha f_T = \alpha \frac{g_m}{2\pi c_{iss}}$$
 α : process parameter

$$\frac{d\Gamma}{d\Gamma}\left(1+\frac{c_{iss}}{C_s}\right)^2\left(1+\frac{f_\ell}{f}\right)$$



Source-referred noise at the output of E1:

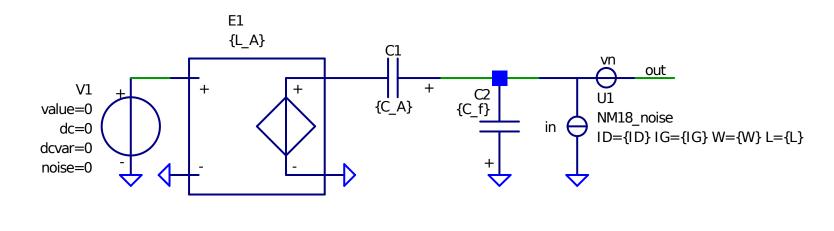
 $S_{v_n} = \frac{4kTn}{g_m}$

$$f_\ell = \alpha f_T =$$

1/f noise:

$$\frac{\Gamma}{L} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $= \alpha \frac{g_m}{2\pi c_{iss}} \quad \alpha: \text{ process parameter}$ $S_{v_{n_f}} = \frac{2kTn\Gamma\alpha}{\pi fc_{iss}} \left(1 + \frac{c_{iss}}{C_s}\right)^2$



Source-referred noise at the output of E1:

 $S_{v_n} = \frac{4kTn}{g_m}$

$$f_\ell = \alpha f_T =$$

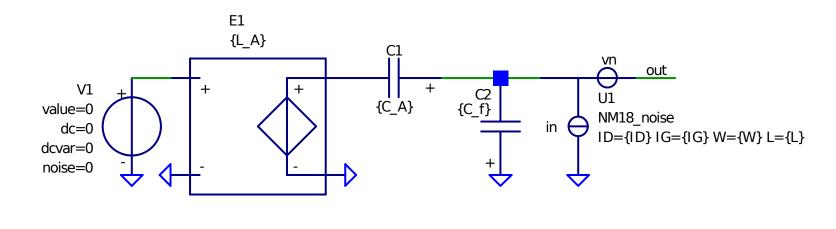
1/f noise:

Lowest 1/f if: $c_{iss} = C_s$

$$\frac{\Gamma}{2} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $= \alpha \frac{g_m}{2\pi c_{iss}}$ α : process parameter

$$S_{v_{n_f}} = \frac{2kTn\Gamma\alpha}{\pi fc_{iss}} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$



Source-referred noise at the output of E1:

 $S_{v_n} = \frac{4kTn}{g_m}$

$$f_\ell = \alpha f_T =$$

1/f noise:

Lowest 1/f

Foor noise:

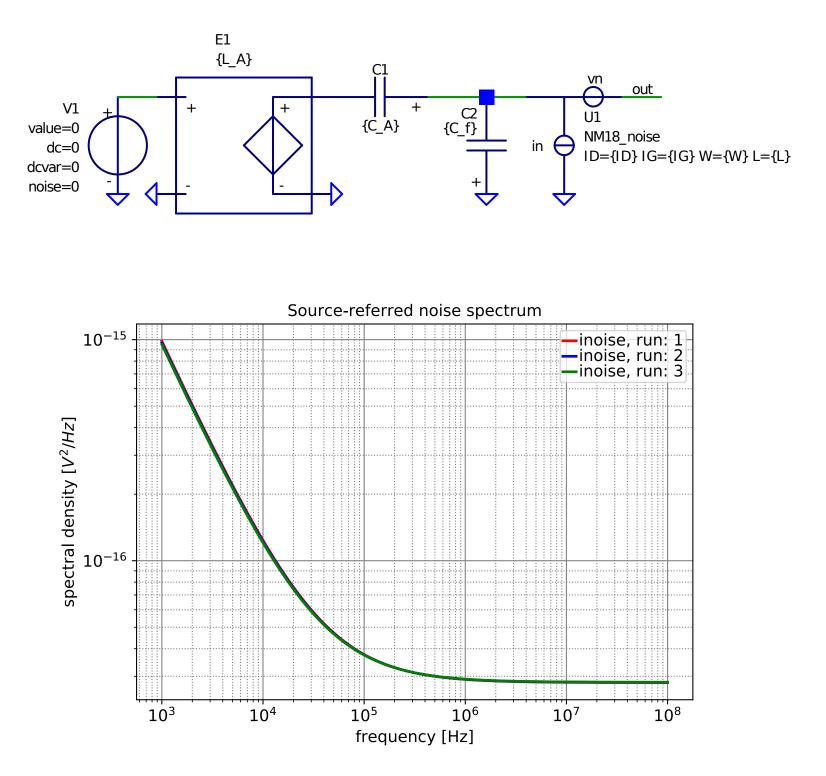
$$\frac{\Gamma}{2} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $= \alpha \frac{g_m}{2\pi c_{iss}}$ α : process parameter

$$S_{v_{n_f}} = \frac{2kTn\Gamma\alpha}{\pi fc_{iss}} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$

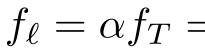
if:
$$c_{iss} = C_s$$

$$S_{v_n} = \frac{4kTn\Gamma}{g_m} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$



Source-referred noise at the output of E1:

 $S_{v_n} = \frac{4kTn}{g_m}$



1/f noise:

Lowest 1/f

Foor noise:

Antenna-referred noise:

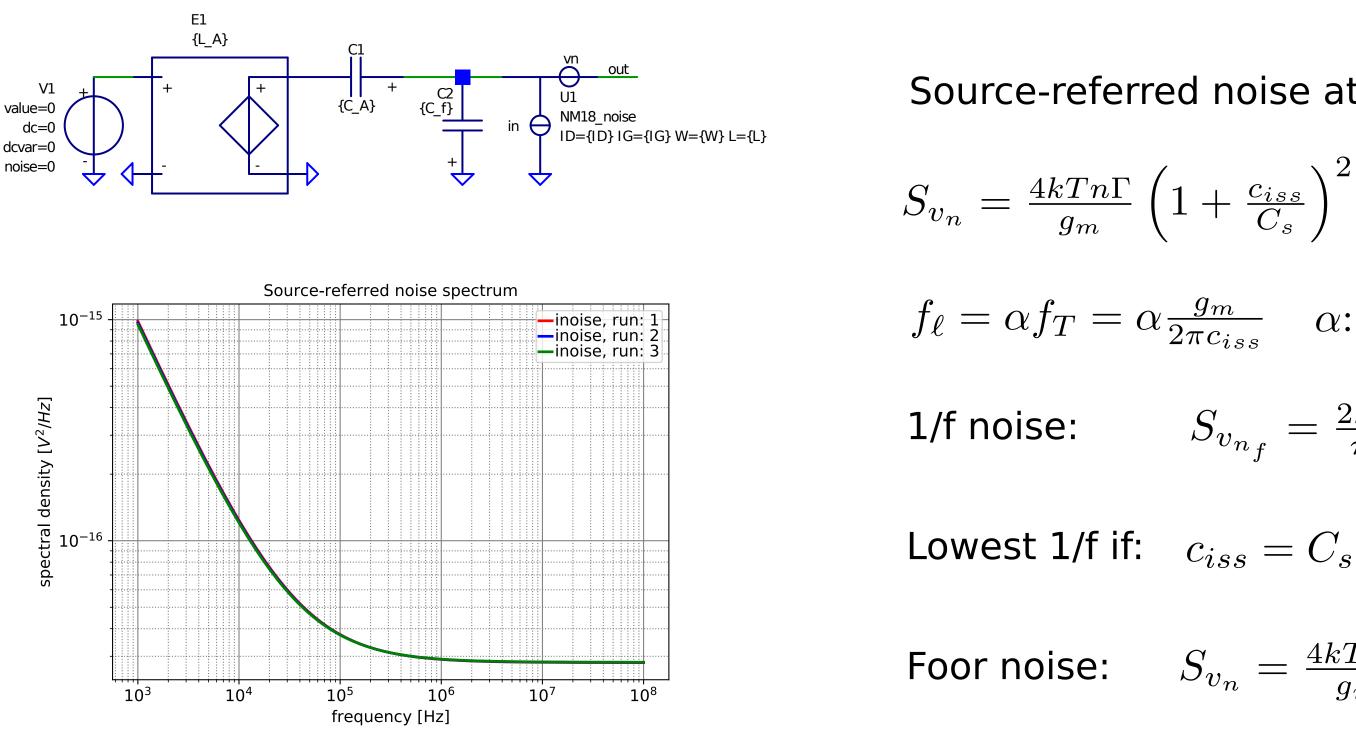
$$\frac{\Gamma}{2} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $f_{\ell} = \alpha f_T = \alpha \frac{g_m}{2\pi c_{iss}}$ α : process parameter

$$S_{v_{n_f}} = \frac{2kTn\Gamma\alpha}{\pi fc_{iss}} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$

if:
$$c_{iss} = C_s$$

$$S_{v_n} = \frac{4kTn\Gamma}{g_m} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$



Antenna-referred noise:

 $1: W = 1.20e-3, L = 1.25e-6, ID = 1.39e-03, S_f = 2.81e-17, f_ell = 3.41e+4, Ciss = 1.03e-11, IC=2.27e+0.$

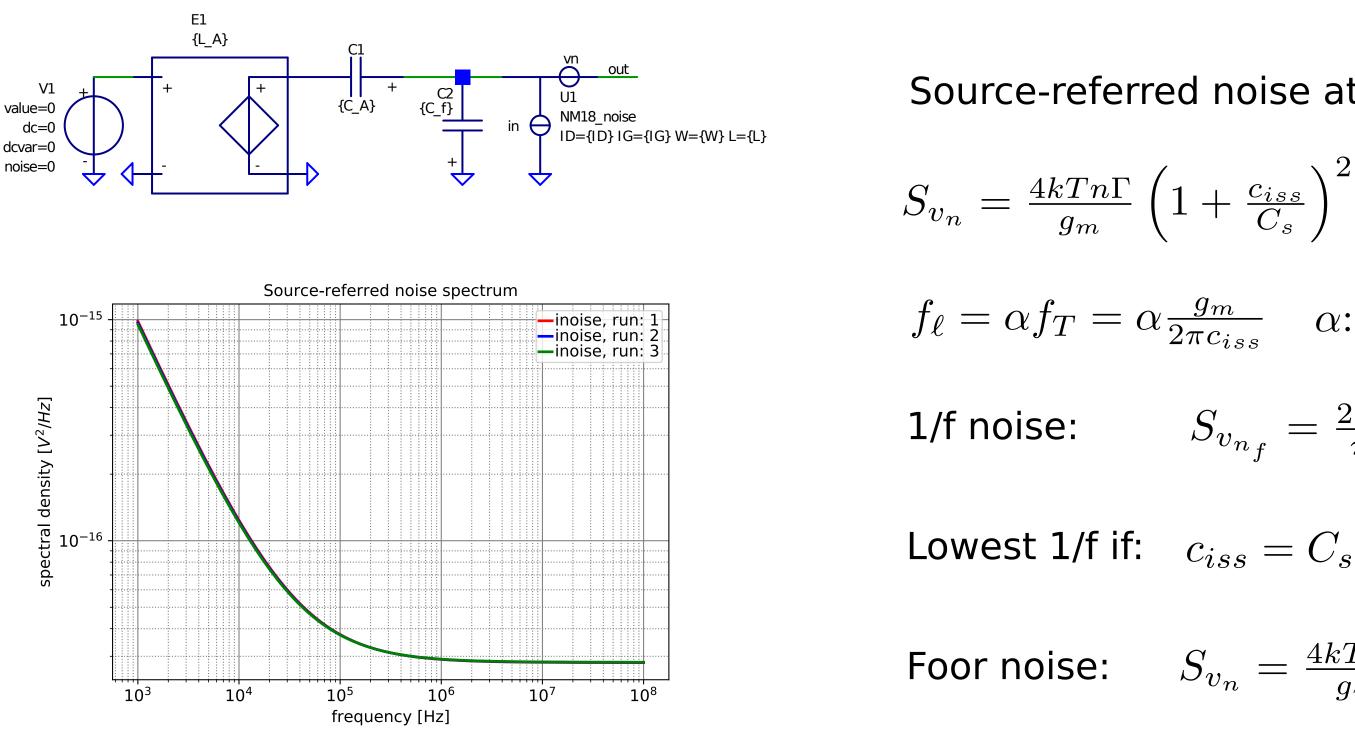
Source-referred noise at the output of E1:

$$\frac{\Gamma}{2} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $f_{\ell} = \alpha f_T = \alpha \frac{g_m}{2\pi c_{iss}}$ α : process parameter

$$S_{v_{n_f}} = \frac{2kTn\Gamma\alpha}{\pi fc_{iss}} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$

$$S_{v_n} = \frac{4kTn\Gamma}{g_m} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$



Antenna-referred noise:

1: W = 1.20e-3, L = 1.25e-6, ID = 1.39e-03, S f = 2.81e-17, f ell = 3.41e+4, Ciss = 1.03e-11, IC=2.27e+0.2 : W = 9.00e-4, L = 1.71e-6, ID = 2.13e-03, S_f = 2.82e-17, f_ell = 3.34e+4, Ciss = 1.03e-11, IC=6.31e+0.

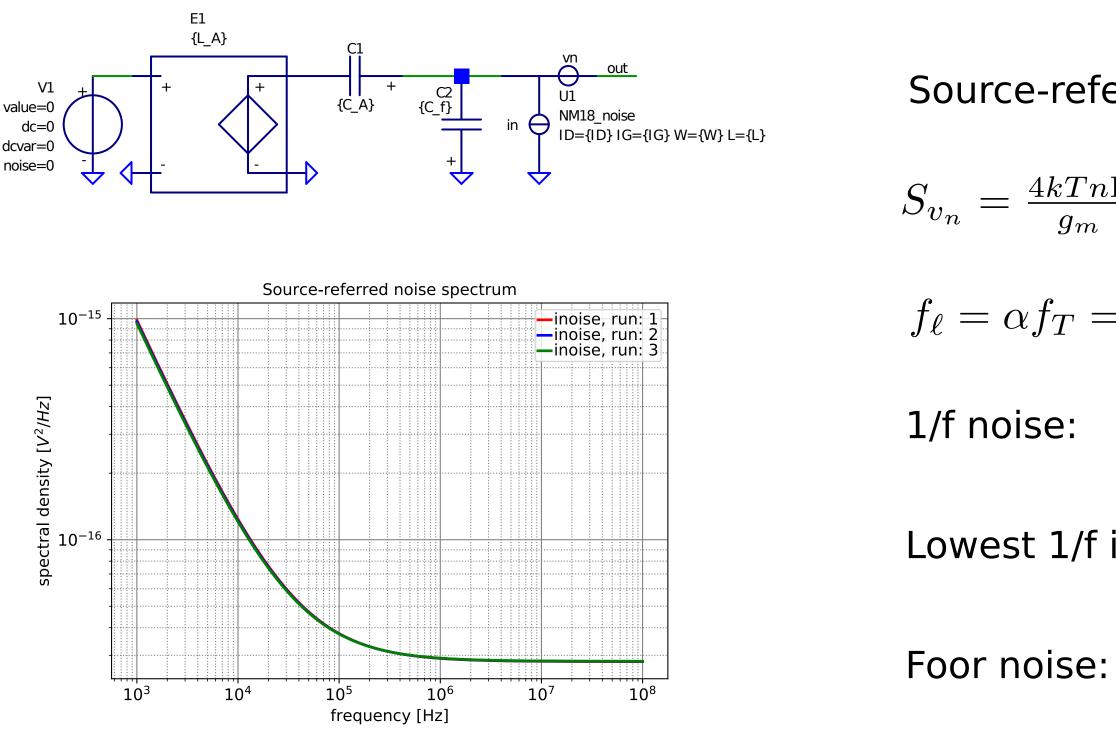
Source-referred noise at the output of E1:

$$\frac{\Gamma}{2} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $f_{\ell} = \alpha f_T = \alpha \frac{g_m}{2\pi c_{iss}}$ α : process parameter

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Source-referred noise at the output of E1:

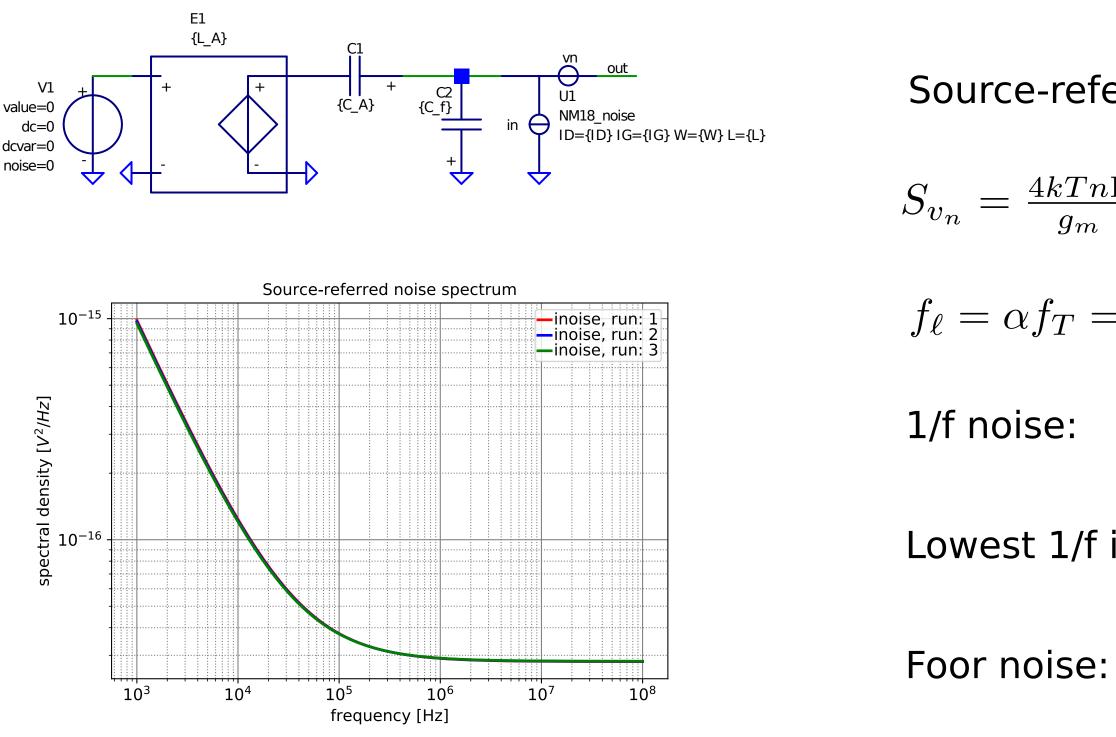
$$\frac{\Gamma}{2} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $f_{\ell} = \alpha f_T = \alpha \frac{g_m}{2\pi c_{iss}}$ α : process parameter

$$S_{v_{n_f}} = \frac{2kTn\Gamma\alpha}{\pi fc_{iss}} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$

Lowest 1/f if: $c_{iss} = C_s$

$$S_{v_n} = \frac{4kTn\Gamma}{g_m} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$



Antenna-referred noise:

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Source-referred noise at the output of E1:

$$\frac{\Gamma}{2} \left(1 + \frac{c_{iss}}{C_s} \right)^2 \left(1 + \frac{f_\ell}{f} \right)$$

 $f_{\ell} = \alpha f_T = \alpha \frac{g_m}{2\pi c_{iss}}$ α : process parameter

$$S_{v_{n_f}} = \frac{2kTn\Gamma\alpha}{\pi fc_{iss}} \left(1 + \frac{c_{iss}}{C_s}\right)^2$$

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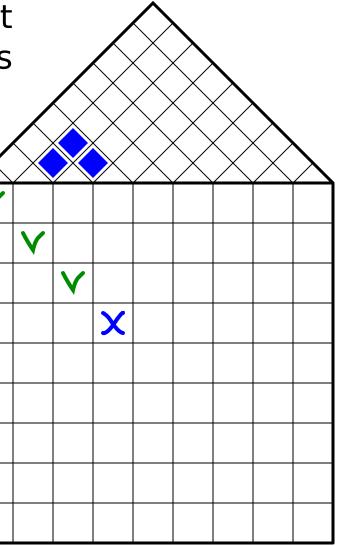
Structured Electronic Design

Step 4 Feasibility load drive requirements

Anton J.M. Montagne

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

> *Function, performance, costs and environment* Feedback configuration Controller input stage



interaction between design aspects

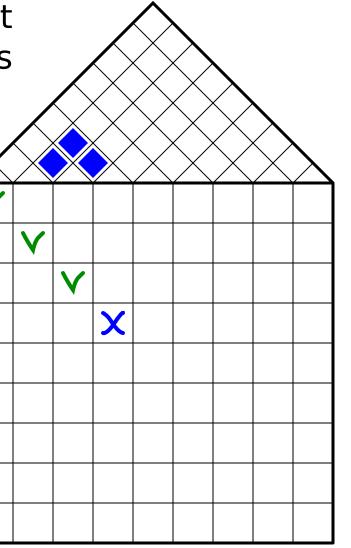
SLiCAP SLiCAP SLiCAP LTspice



Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

Design of the feedback network and the output stage of the controller

Function, performance, costs and environment Feedback configuration Controller input stage Controller output stage



interaction between design aspects

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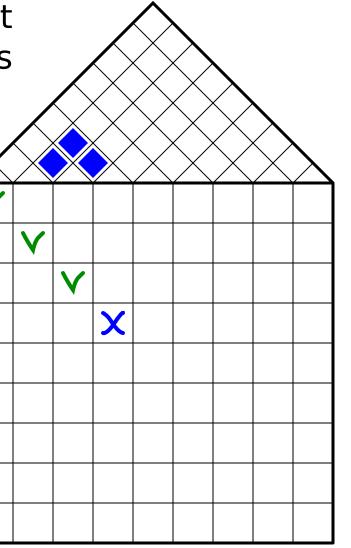


Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

Design of the feedback network and the output stage of the controller

Design of the active antenna:

Function, performance, costs and environment Feedback configuration Controller input stage Controller output stage



interaction between design aspects

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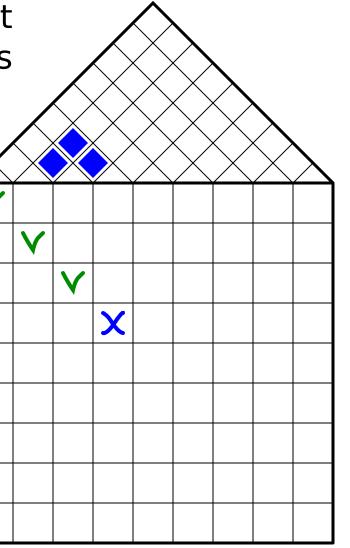
Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

Design of the feedback network and the output stage of the controller

Design of the active antenna:

Design a CS stage with sufficient static and dynamic drive capability

Function, performance, costs and environment



interaction between design aspects

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Feedback configuration Controller input stage Controller output stage

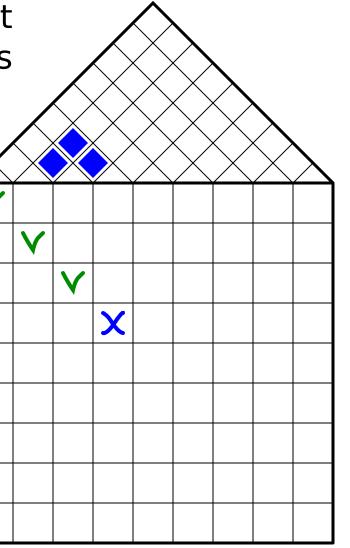
Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

Design of the feedback network and the output stage of the controller

Design of the active antenna:

Design a CS stage with sufficient static and dynamic drive capability

Determine valid ranges for: $I_{DS}, \, V_{DS}, \, W, \, L, \, M$



interaction between design aspects

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Feedback configuration Controller input stage Controller output stage

Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

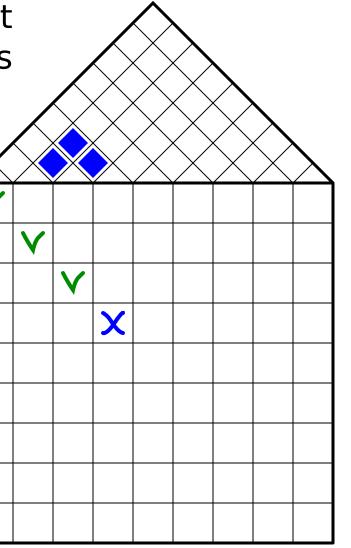
Design of the feedback network and the output stage of the controller

Design of the active antenna:

Design a CS stage with sufficient static and dynamic drive capability

Determine valid ranges for: I_{DS}, V_{DS}, W, L, M

The performance-to-cost ratio can be improved through application of balancing:



interaction between design aspects

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⁻eedback configuration Controller input stage Controller output stage

Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

Design of the feedback network and the output stage of the controller

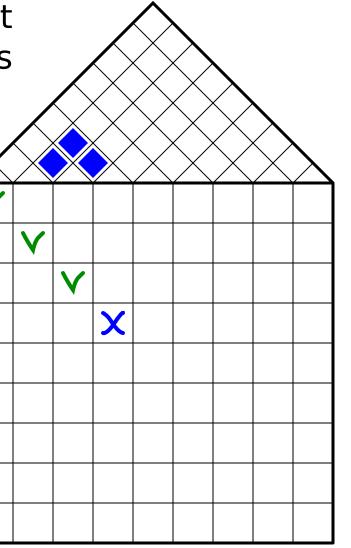
Design of the active antenna:

Design a CS stage with sufficient static and dynamic drive capability

Determine valid ranges for: I_{DS}, V_{DS}, W, L, M

The performance-to-cost ratio can be improved through application of balancing:

Complementary-parallel or push-pull stage.



interaction between design aspects

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Feedback configuration Controller input stage Controller output stage

Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements

Design of the feedback network and the output stage of the controller

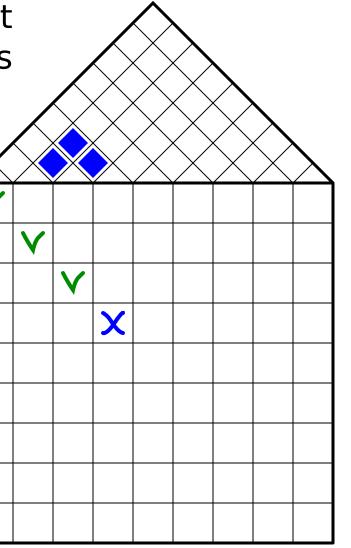
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Complementary-parallel or push-pull stage.

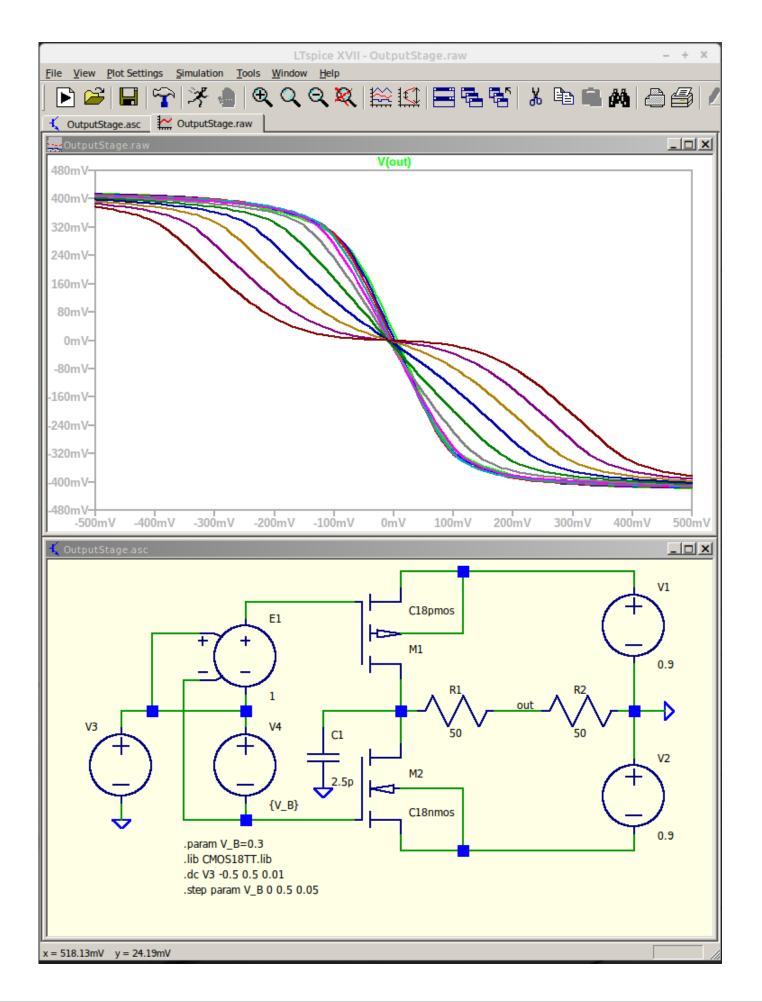


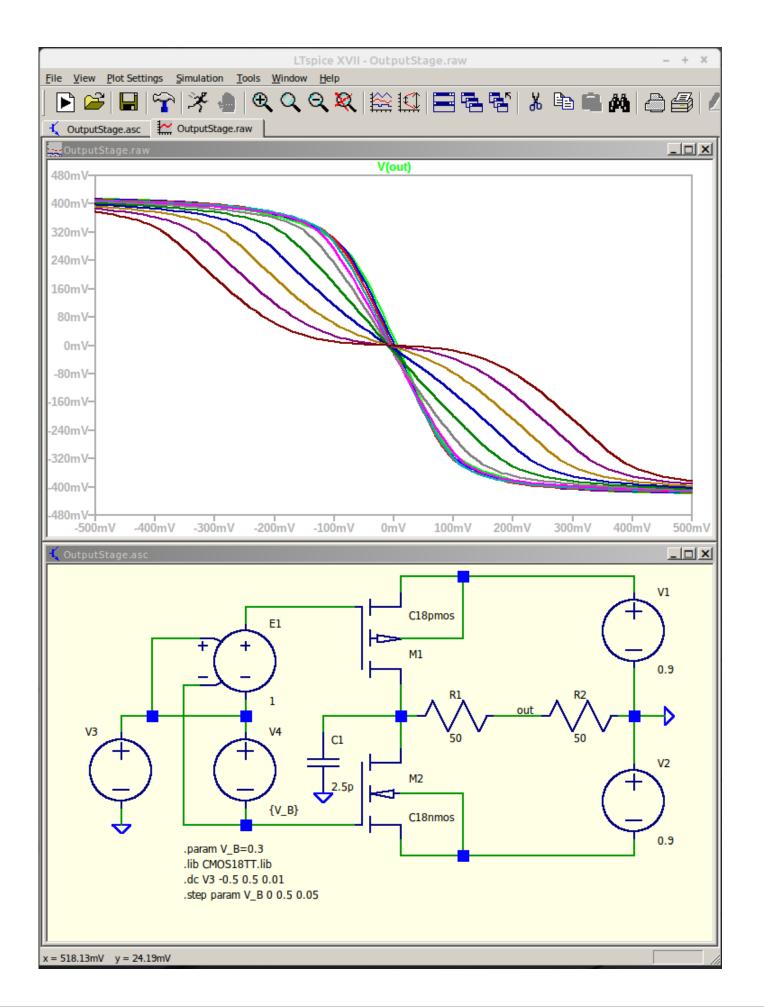
interaction between design aspects

SLiCAP SLiCAP SLiCAP LTspice

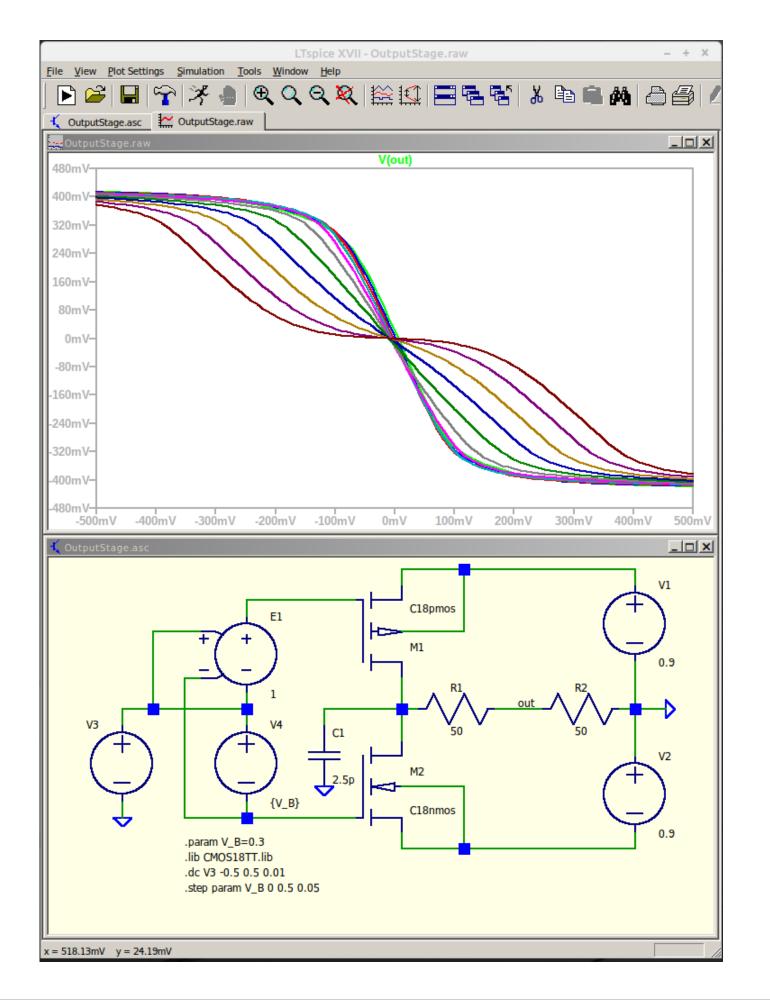


Feedback configuration Controller input stage Controller output stage

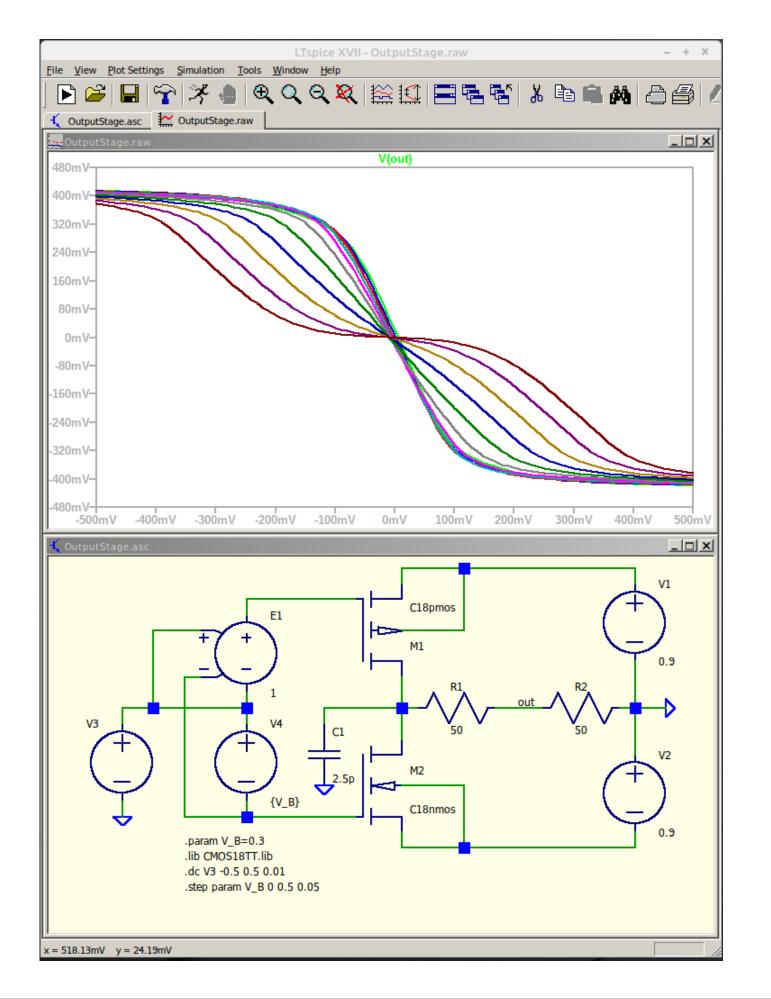




Smallest value for L: 180nm

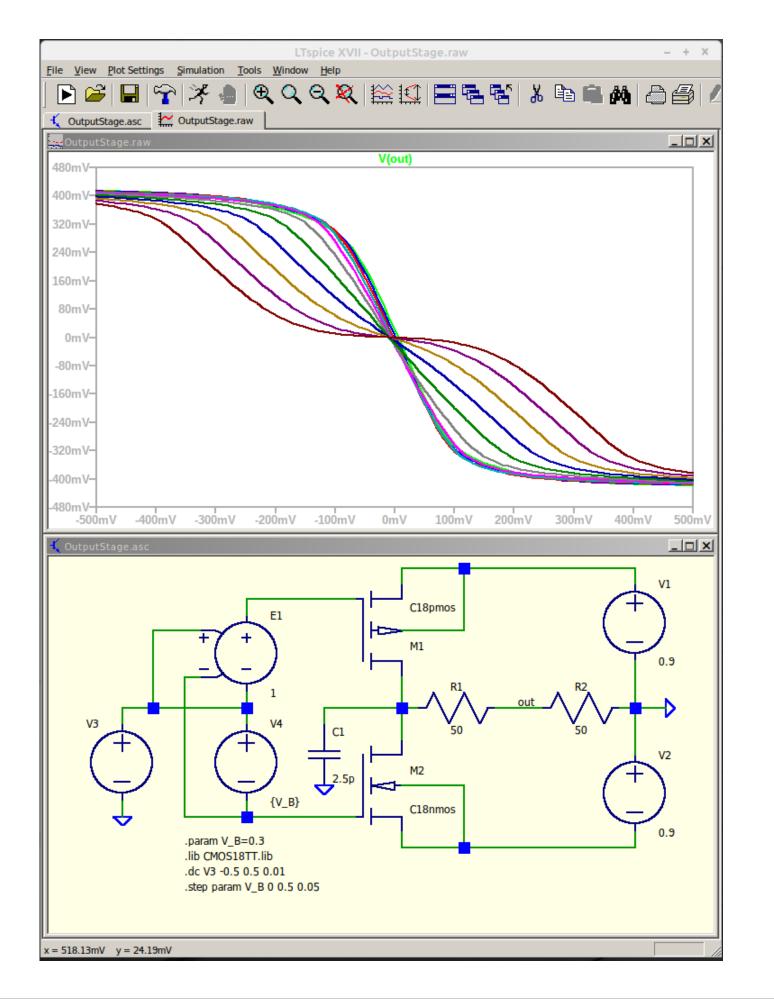


Smallest value for L: 180nm Wpmos/Wnmos = 1/mobility_ratio



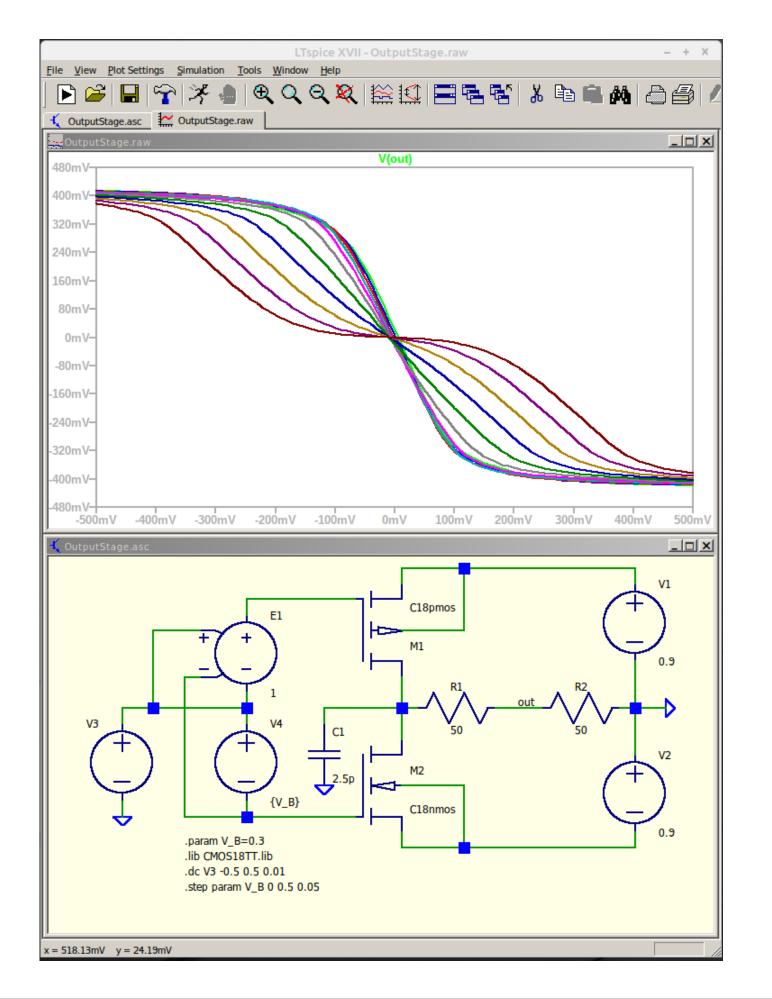
Smallest valu Wpmos/Wnm Determine W be driven wit

- Smallest value for L: 180nm
- Wpmos/Wnmos = 1/mobility_ratio
- Determine W and M such that the load can be driven with a sufficiently small drive (V3)



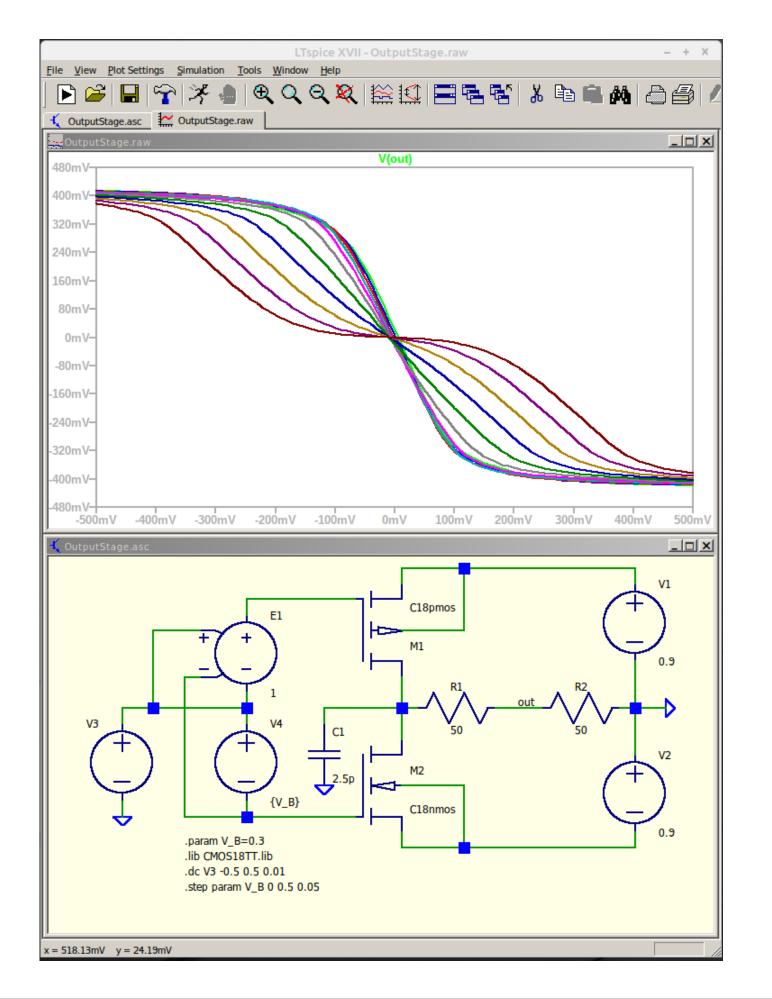
PMOS: W=40u, M=10

- Smallest value for L: 180nm
- Wpmos/Wnmos = 1/mobility_ratio
- Determine W and M such that the load can be driven with a sufficiently small drive (V3)



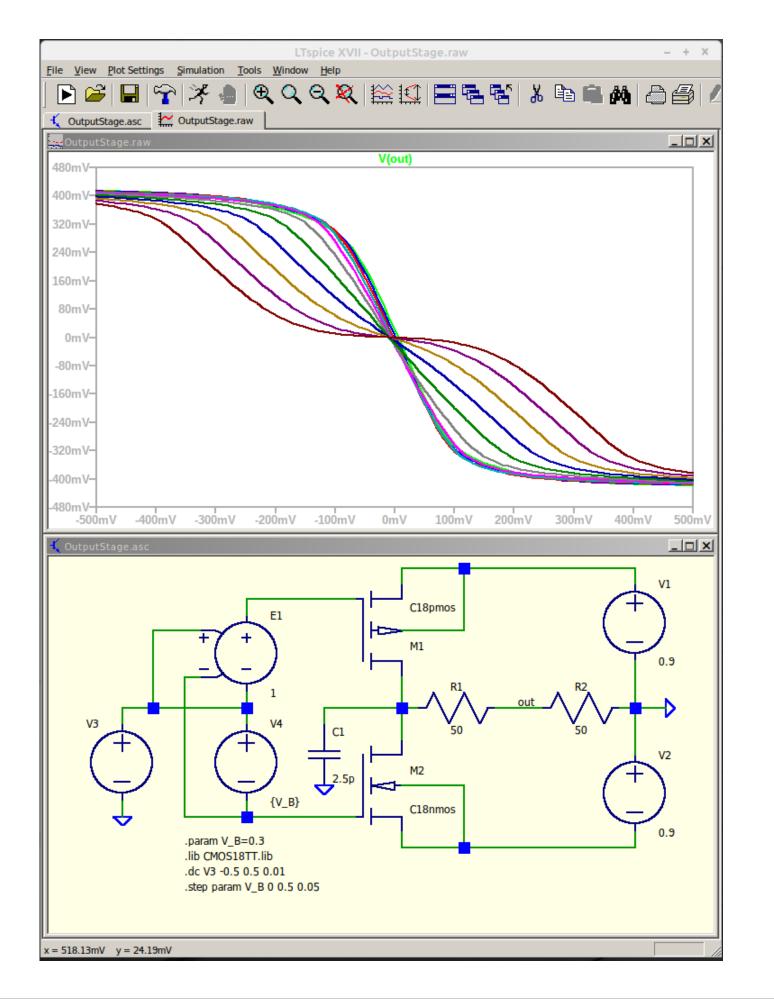
PMOS: W=40u, M=10 NMOS: W=40u, M=3

- Smallest value for L: 180nm
- Wpmos/Wnmos = 1/mobility_ratio
- Determine W and M such that the load can be driven with a sufficiently small drive (V3)



PMOS: W=40u, M=10 NMOS: W=40u, M=3Bias voltage 0.2V

- Smallest value for L: 180nm
- Wpmos/Wnmos = 1/mobility_ratio
- Determine W and M such that the load can be driven with a sufficiently small drive (V3)

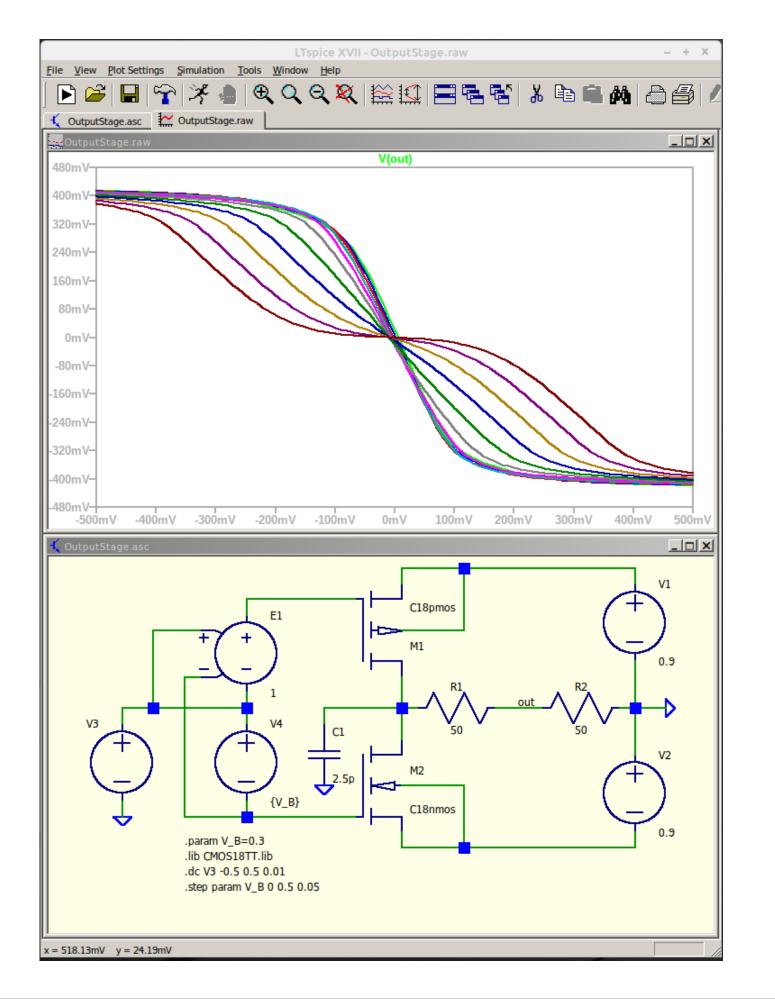


PMOS: W=40u, M=10 NMOS: W=40u, M=3Bias voltage 0.2V Quiescent current 1mA

```
Smallest value for L: 180nm
```

```
Wpmos/Wnmos = 1/mobility_ratio
```

```
Determine W and M such that the load can
be driven with a sufficiently small drive (V3)
```

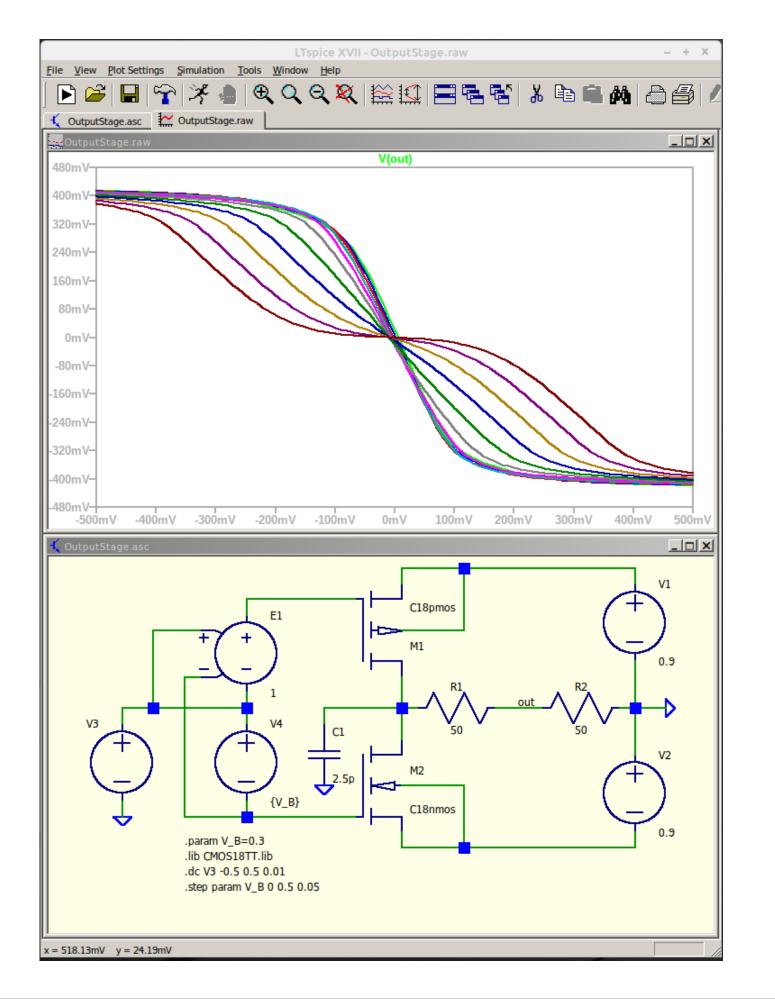


PMOS: W=40u, M=10 NMOS: W=40u, M=3Bias voltage 0.2V Quiescent current 1mA Drive requirement +/- 0.2V

```
Smallest value for L: 180nm
```

```
Wpmos/Wnmos = 1/mobility_ratio
```

```
Determine W and M such that the load can
be driven with a sufficiently small drive (V3)
```



PMOS: W=40u, M=10 NMOS: W=40u, M=3Bias voltage 0.2V Quiescent current 1mA Drive requirement +/- 0.2V

```
Smallest value for L: 180nm
```

```
Wpmos/Wnmos = 1/mobility_ratio
```

```
Determine W and M such that the load can
be driven with a sufficiently small drive (V3)
```

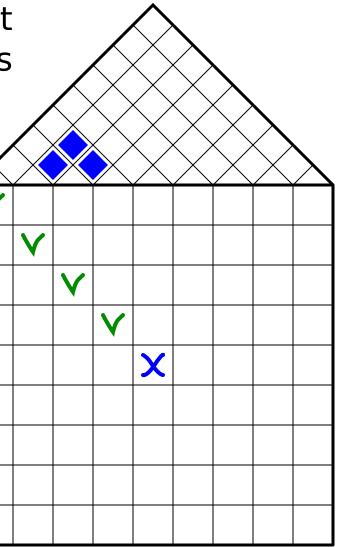
Structured Electronic Design

Step 5 Design of mid-band accuracy and bandwidth

Anton J.M. Montagne

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth

> *Function, performance, costs and environment* Feedback configuration Controller input stage Controller output stage



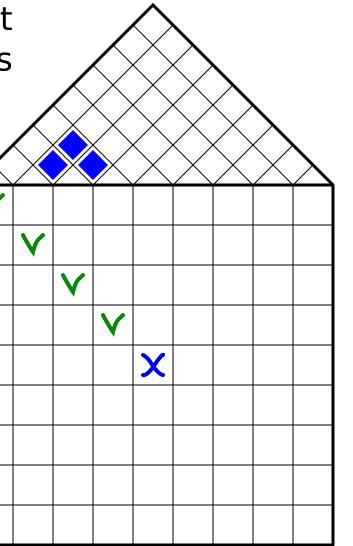
interaction between design aspects

SLiCAP SLiCAP SLiCAP LTspice SLiCAP



Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth

Design of the number of stages of the controller



interaction between design aspects

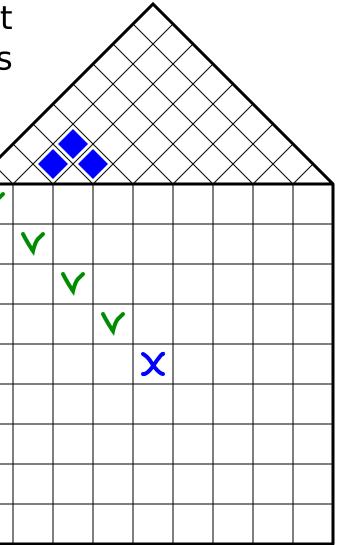
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth

Design of the number of stages of the controller

Determine the number of stages required for a sufficiently large mid-band (or DC) loop gain and loop gain-poles product.



interaction between design aspects

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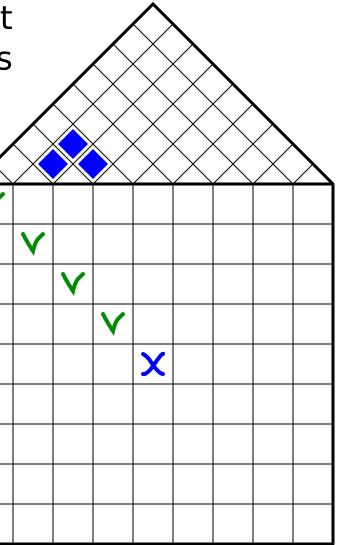


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Design of the active antenna:



interaction between design aspects

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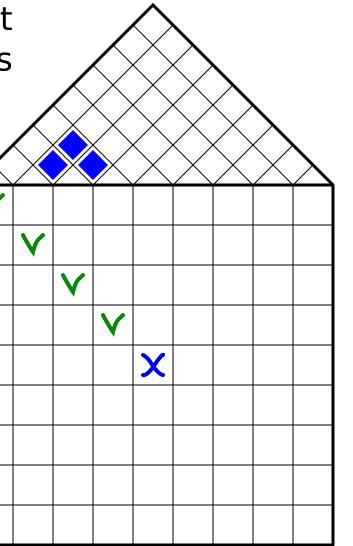
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Determine the number of stages required for a sufficiently large mid-band (or DC) loop gain and loop gain-poles product.

Design of the active antenna:

Use the asymptotic gain feedback model to verify the loop gain and the loop gain-poles product of the two-stage solution.



interaction between design aspects

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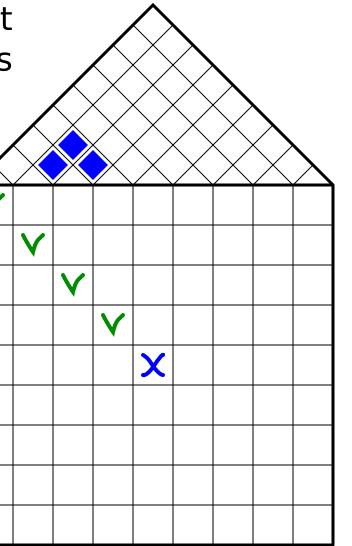
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Design of the active antenna:

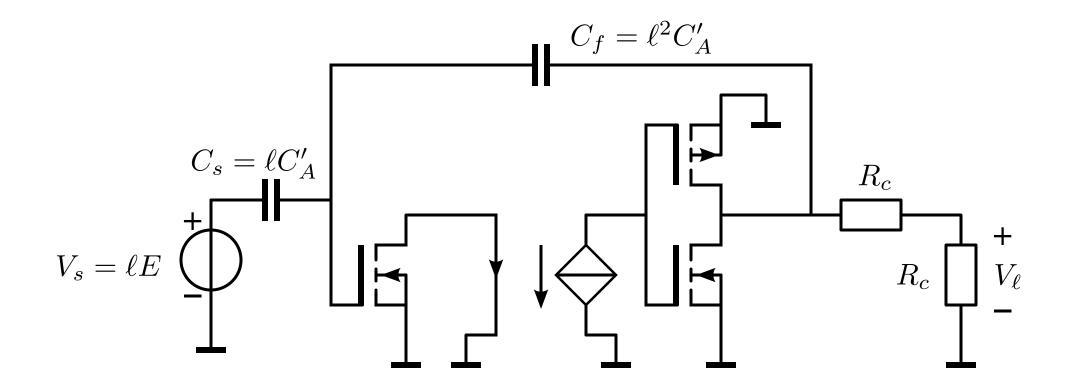
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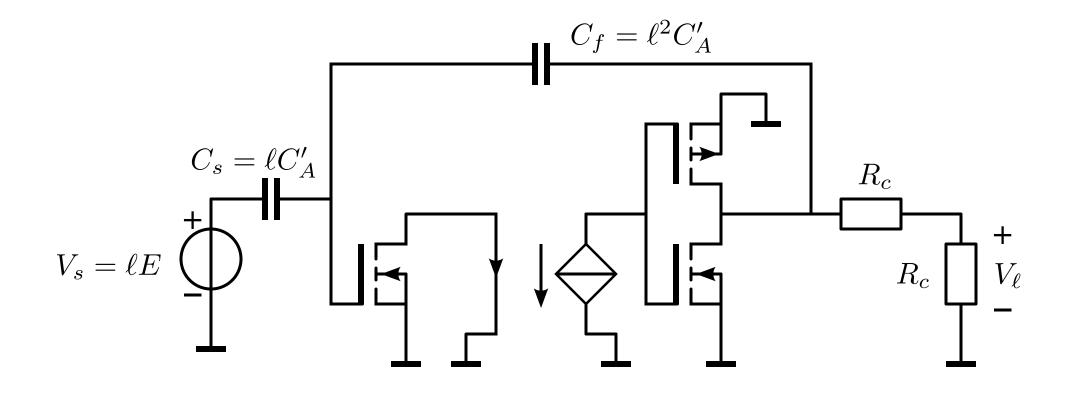


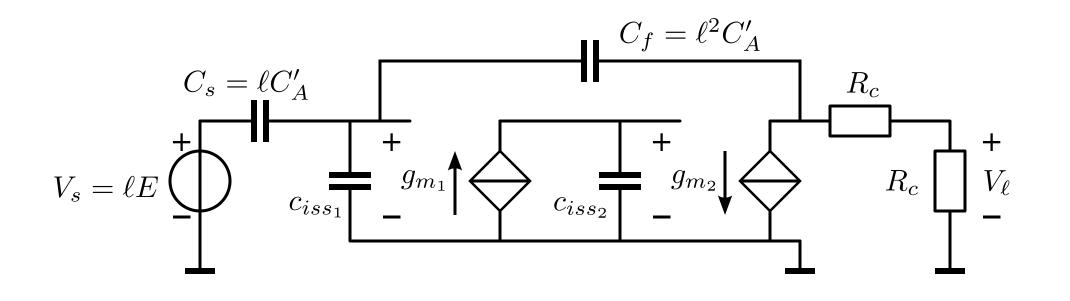
interaction between design aspects

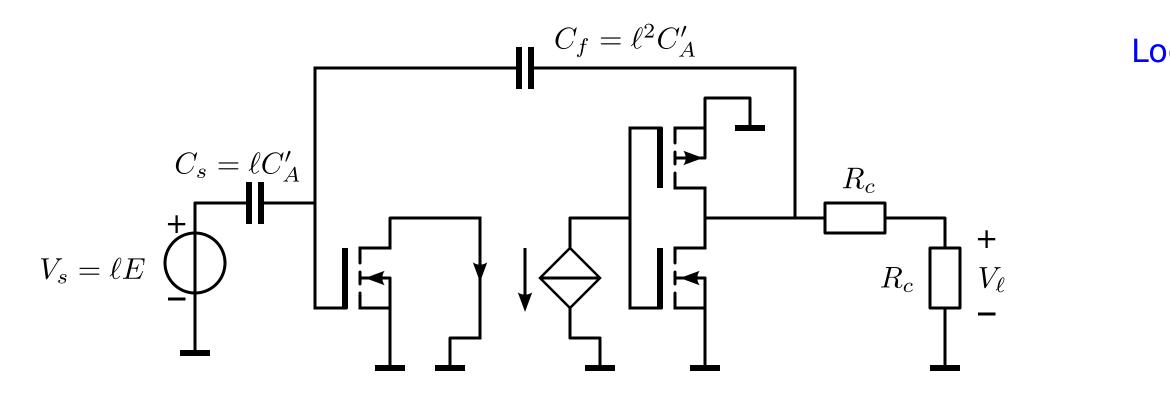
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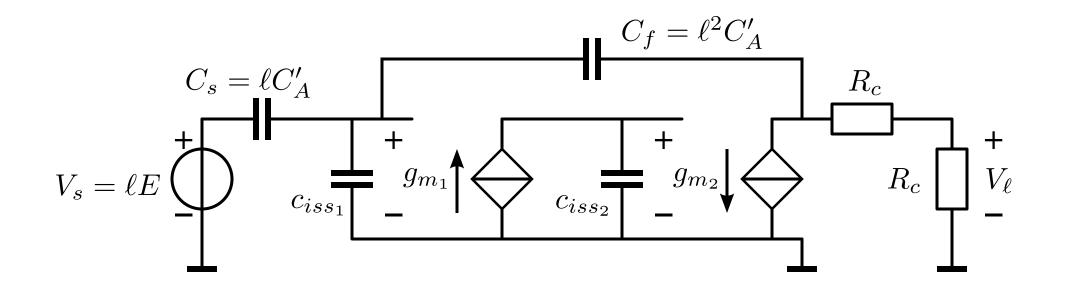




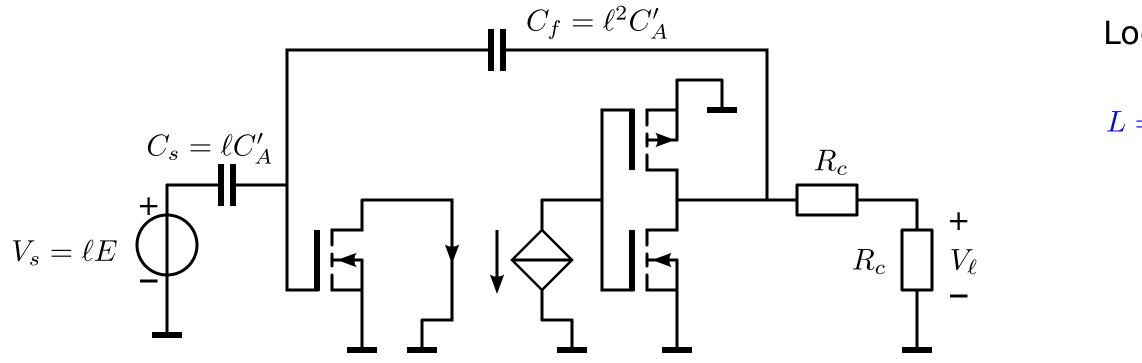


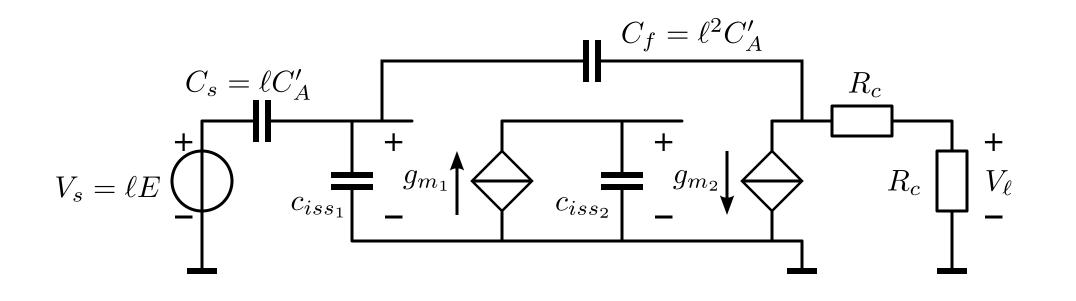






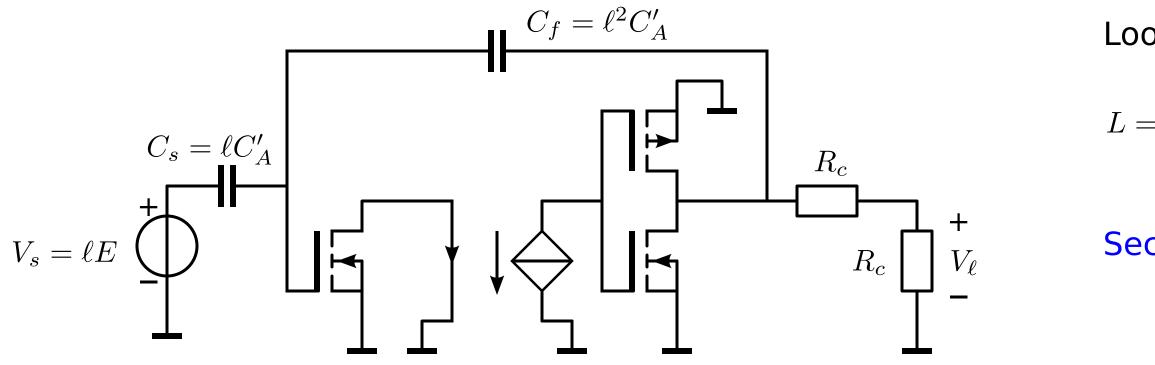
Loop gain, ref: g_{m_1}

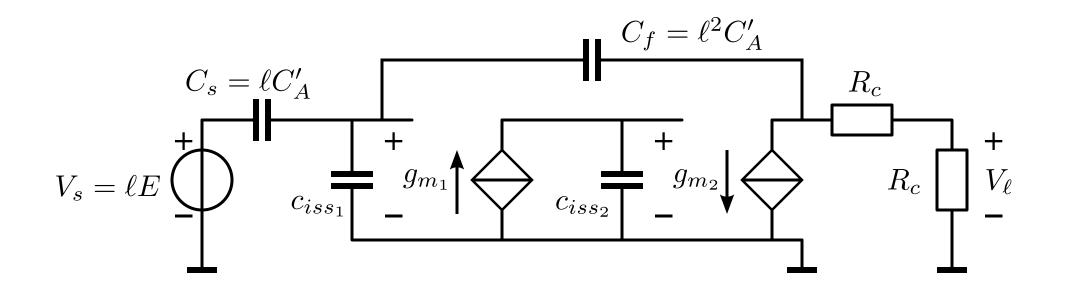




Loop gain, ref: g_{m_1}

 $L = -\frac{2g_{m_1}g_{m_2}R_c\frac{C_f}{C_f + C_s + c_{iss_1}}}{sc_{iss_2}\left(1 + s2R_c\frac{C_f\left(C_s + c_{iss_1}\right)}{C_f + C_s + c_{iss_1}}\right)}$

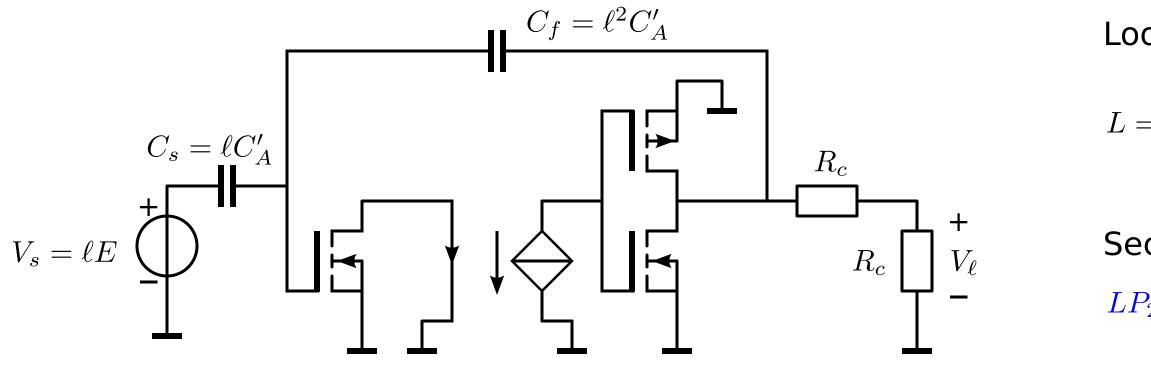


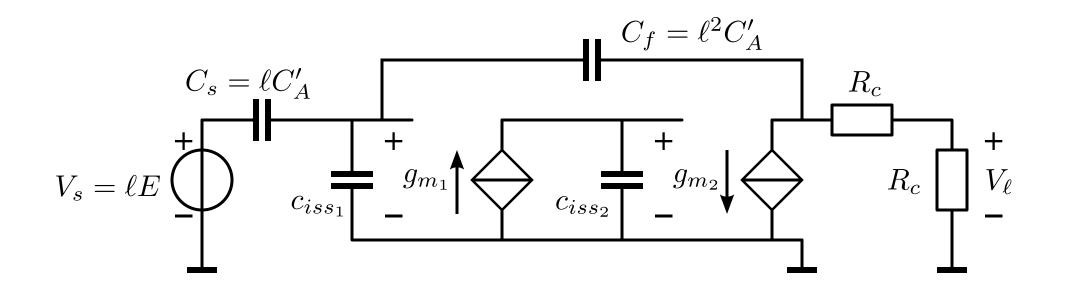


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Second-order loop gain-poles product:



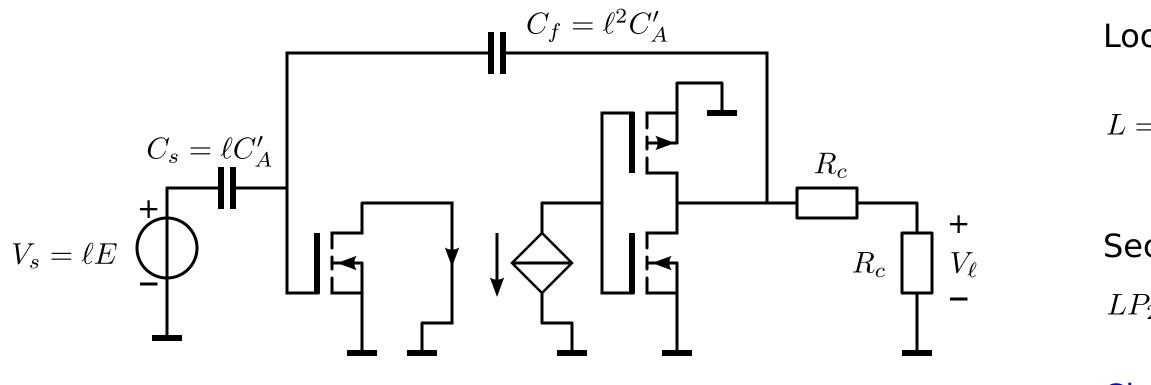


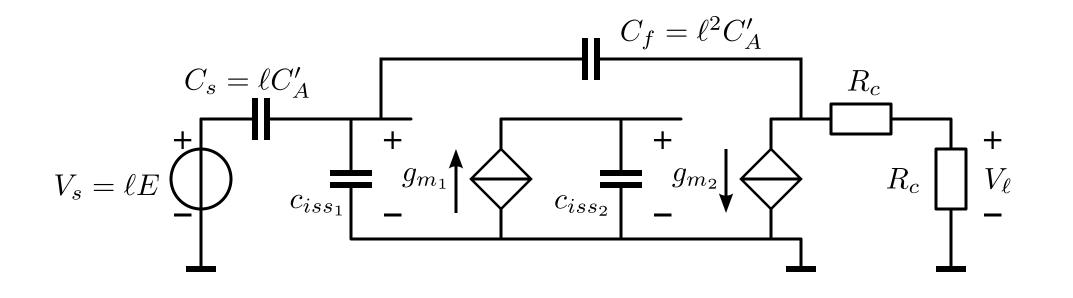
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$$= -\frac{2g_{m_{1}}g_{m_{2}}R_{c}\frac{C_{f}}{C_{f}+C_{s}+c_{iss_{1}}}}{sc_{iss_{2}}\left(1+s2R_{c}\frac{C_{f}\left(C_{s}+c_{iss_{1}}\right)}{C_{f}+C_{s}+c_{iss_{1}}}\right)}$$

Second-order loop gain-poles product:

$$P_2 = \frac{g_{m_1}g_{m_2}}{c_{iss_2}(C_s + c_{iss_1})}$$





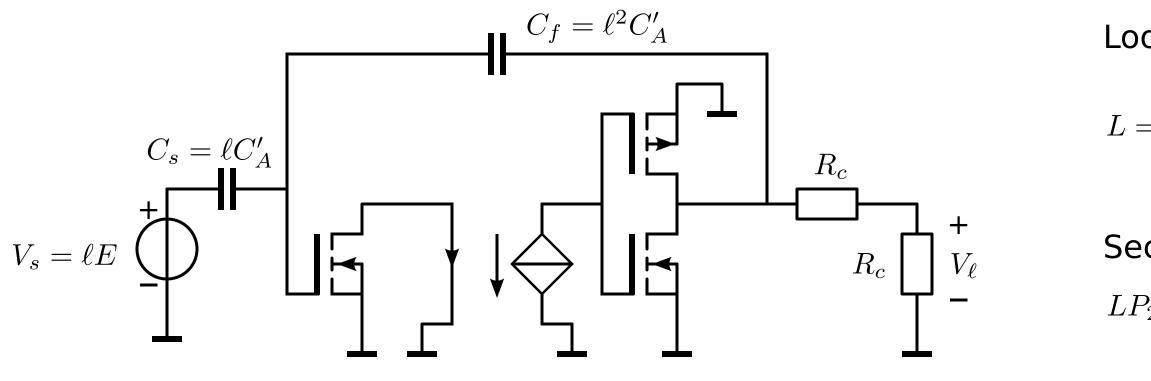
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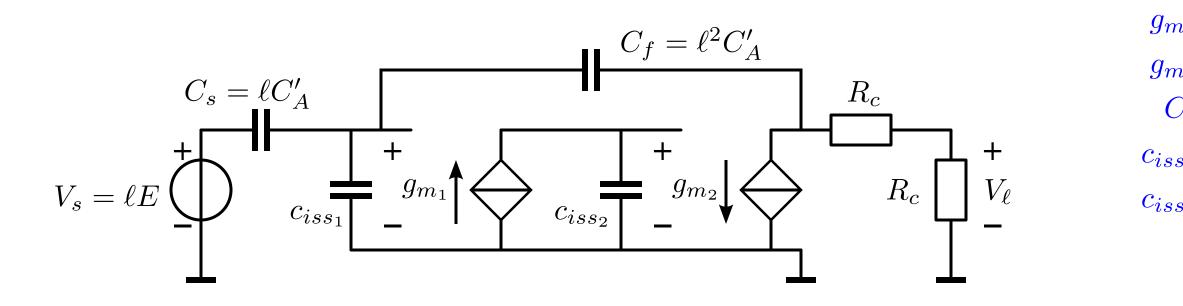
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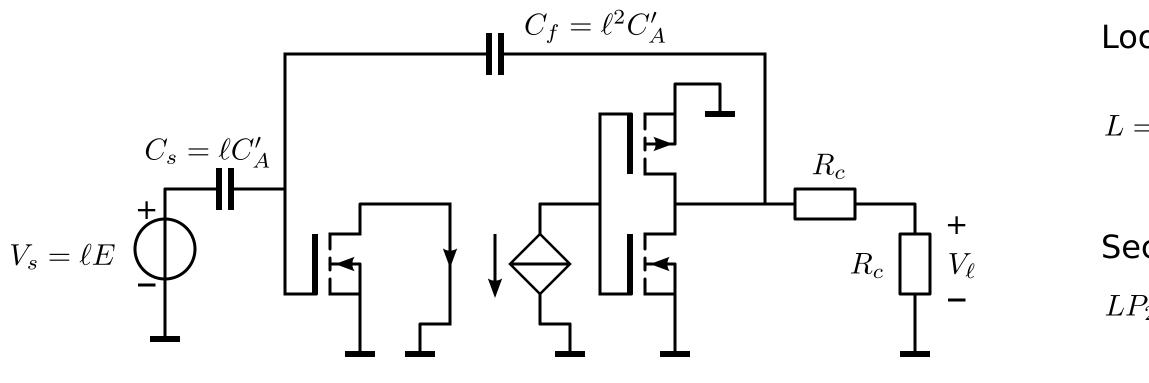
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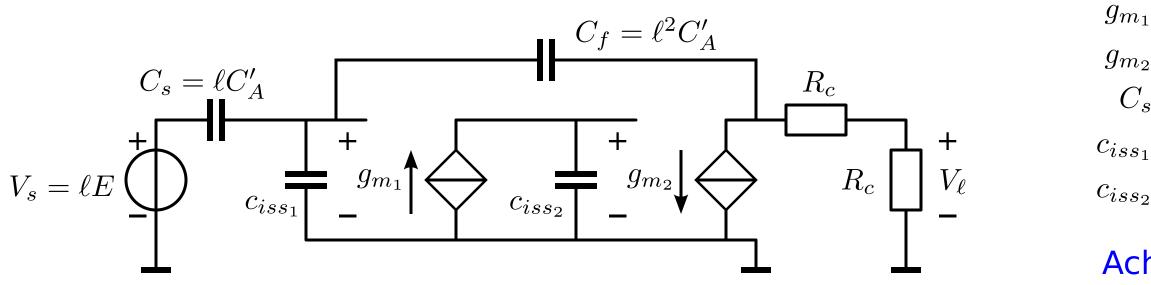
Circuit element values:

$$a_{11} = 23m$$

 $a_{22} = 28m$
 $C_s = 5p$
 $a_{s_1} = 1p$
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Loop gain, ref: g_{m_1}

$$= -\frac{2g_{m_1}g_{m_2}R_c\frac{C_f}{C_f + C_s + c_{iss_1}}}{sc_{iss_2}\left(1 + s2R_c\frac{C_f\left(C_s + c_{iss_1}\right)}{C_f + C_s + c_{iss_1}}\right)}$$

Second-order loop gain-poles product:

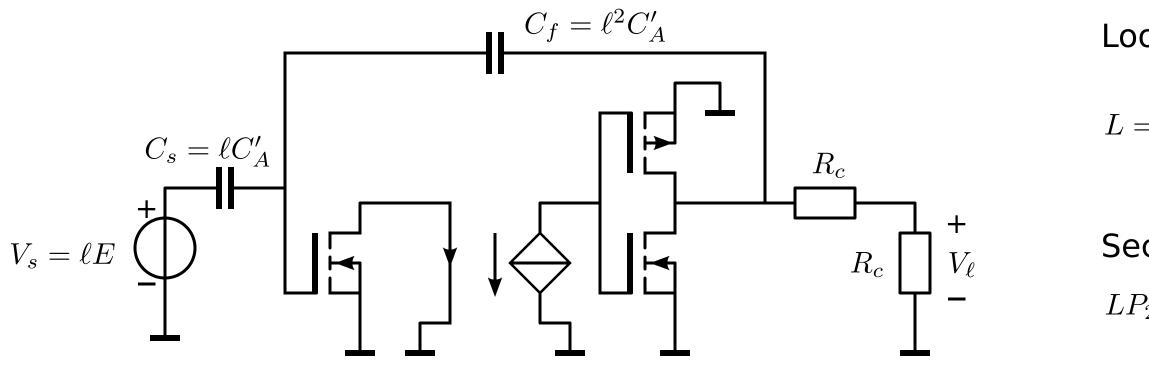
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Achievable MFM bandwidth:





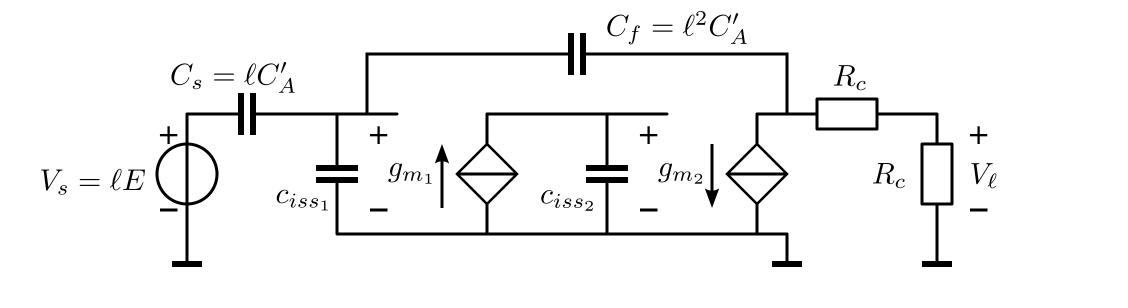


 g_m

C

 c_{iss}

 c_{iss_2}



Loop gain, ref: g_{m_1}

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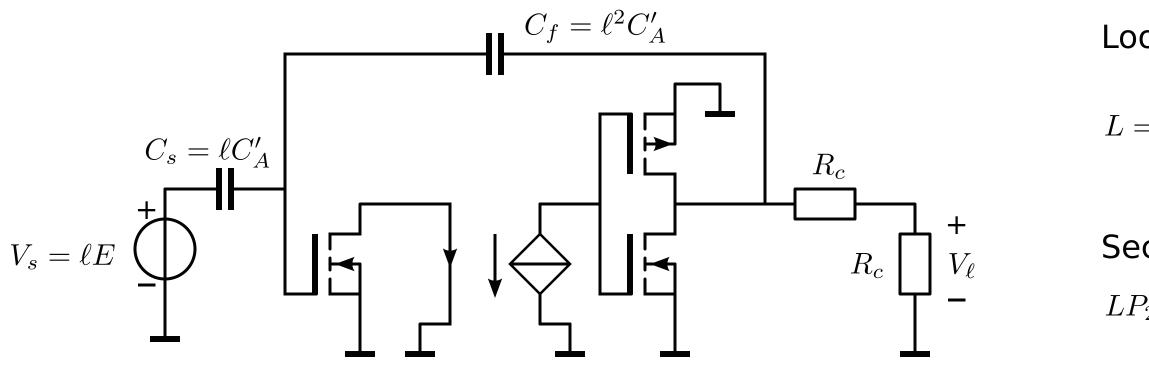
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Achievable MFM bandwidth:

 $B_f = \frac{1}{2\pi}\sqrt{LP_2} = 1.5 \text{GHz}$



 $C_s = \ell C'_A$

 $V_s = \ell E$

+

 c_{iss_1}

 g_{m_1}

 $C_f = \ell^2 C'_A$

 g_{m_2}

+

 c_{iss_2}

 R_c

 R_c

 V_{ℓ}





 g_m

C

 c_{iss}

 c_{iss}

 B_f

Loop gain, ref: g_{m_1}

$$= -\frac{2g_{m_{1}}g_{m_{2}}R_{c}\frac{C_{f}}{C_{f}+C_{s}+c_{iss_{1}}}}{sc_{iss_{2}}\left(1+s2R_{c}\frac{C_{f}\left(C_{s}+c_{iss_{1}}\right)}{C_{f}+C_{s}+c_{iss_{1}}}\right)}$$

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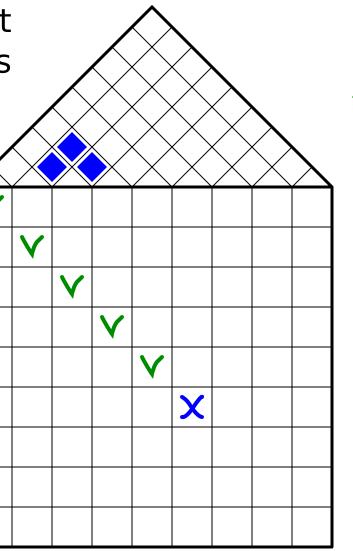
Structured Electronic Design

Step 6 Design of frequency response (frequency compensation)

Anton J.M. Montagne

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response

> *Function, performance, costs and environment* Feedback configuration Controller input stage Controller output stage Loop gain poles product PZ pattern



interaction between design aspects

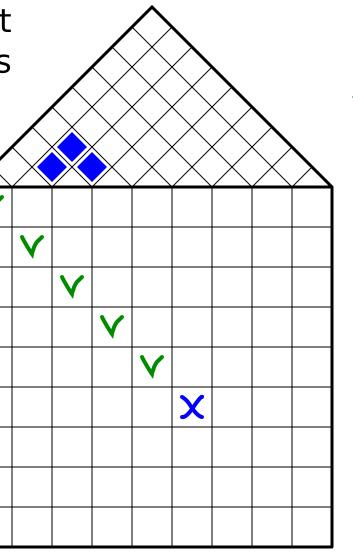
SLiCAP SLiCAP SLiCAP LTspice SLiCAP SLiCAP



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Frequency compensation

stage ration stage product pattern environment performance onfigui input output Loop gain poles PZ Controller costs and Controll Function, Feedbacl



interaction between design aspects

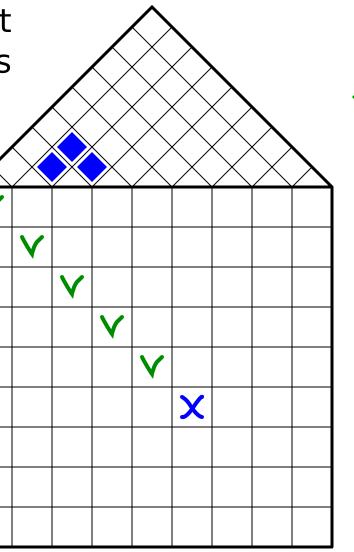
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Correct the pole-zero pattern of the uncompensated amplifier without affecting other performance aspects.



interaction between design aspects

SLiCAP SLiCAP SLiCAP LTspice SLiCAP SLiCAP

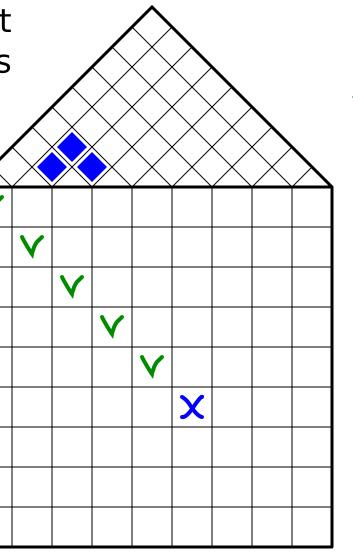


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The preferred method for low interaction is phantom zero compensation.



interaction between design aspects

SLiCAP SLiCAP SLiCAP LTspice SLiCAP SLiCAP



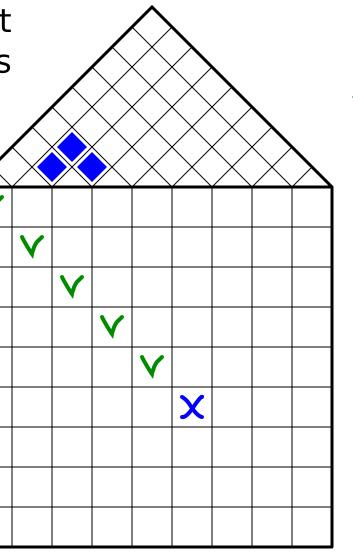
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Design of the active antenna:



interaction between design aspects

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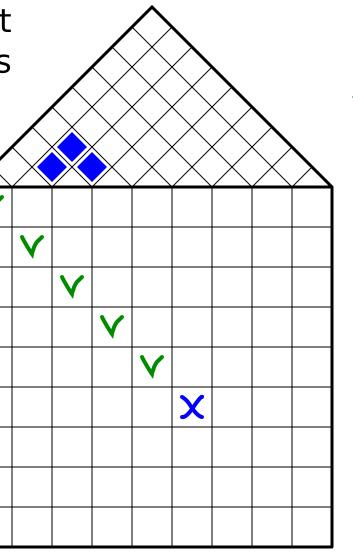
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Design of the active antenna:

Correct the frequency characteristic using a phantom zero at the input of the amplifier.



interaction between design aspects

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stage pattern stage product ration utput input ΡZ es bo gain Φ Controll Controll Feedba Loop

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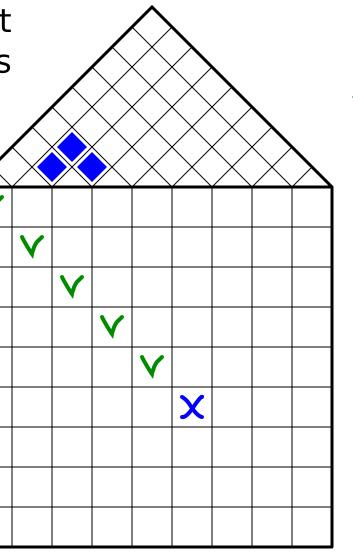
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SLiCAP SLiCAP SLiCAP LTspice SLiCAP SLiCAP



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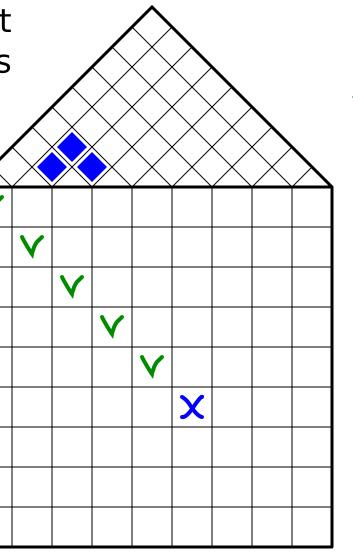
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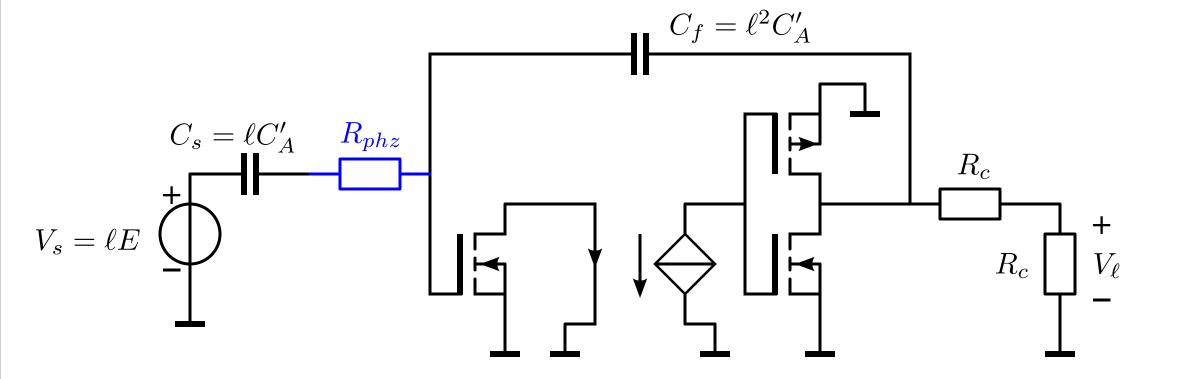


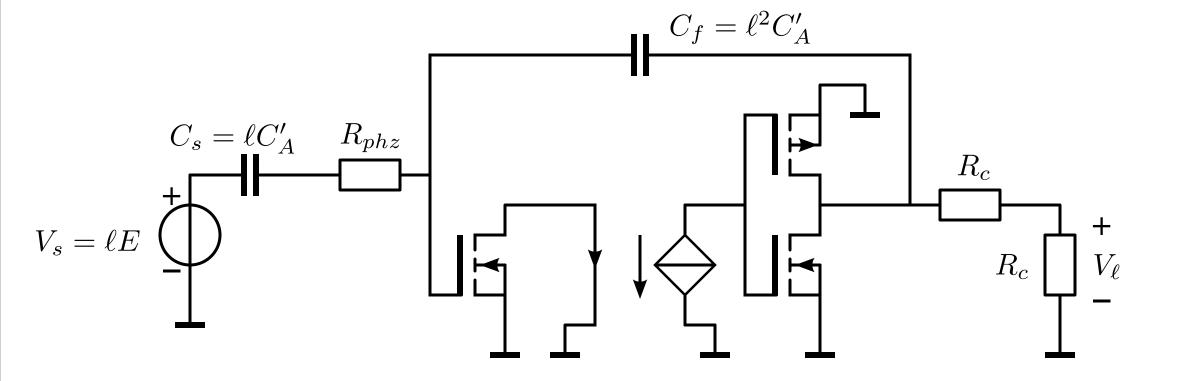
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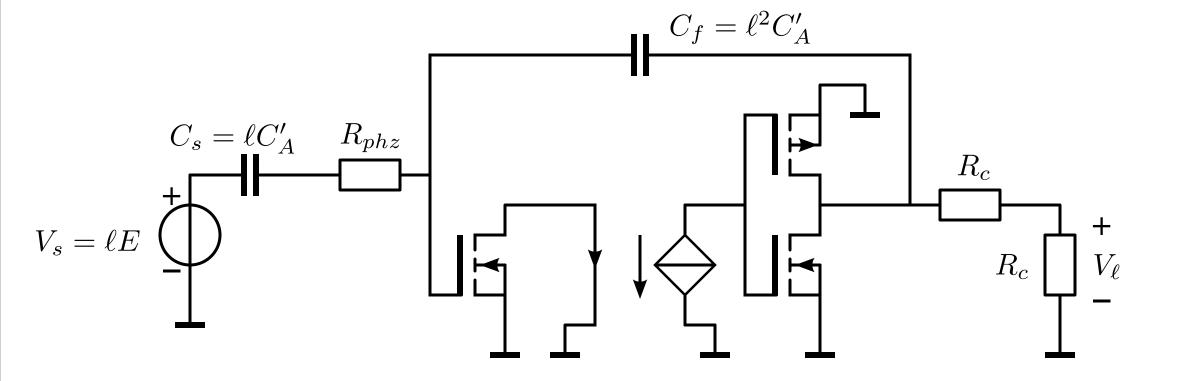


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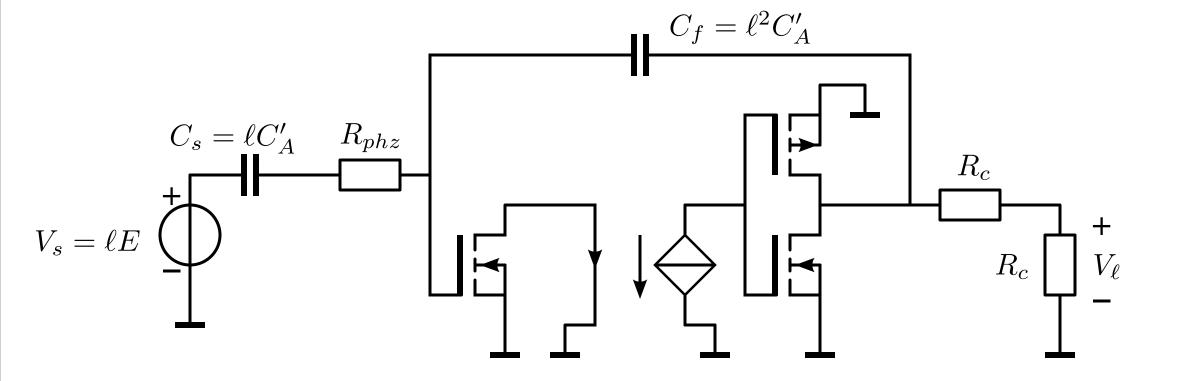


Circuit element values:



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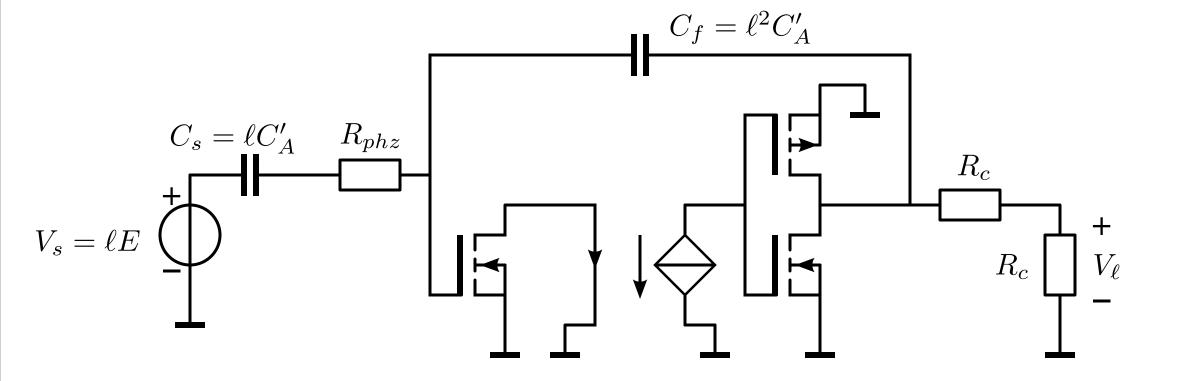
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Achievable MFM bandwidth:

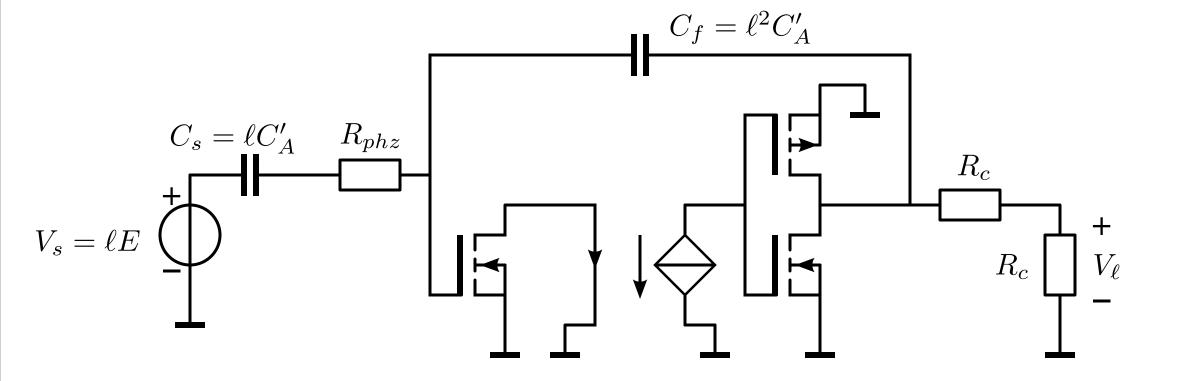


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 $B_f = \frac{1}{2\pi} \sqrt{LP_2} = 1.5 \text{GHz}$



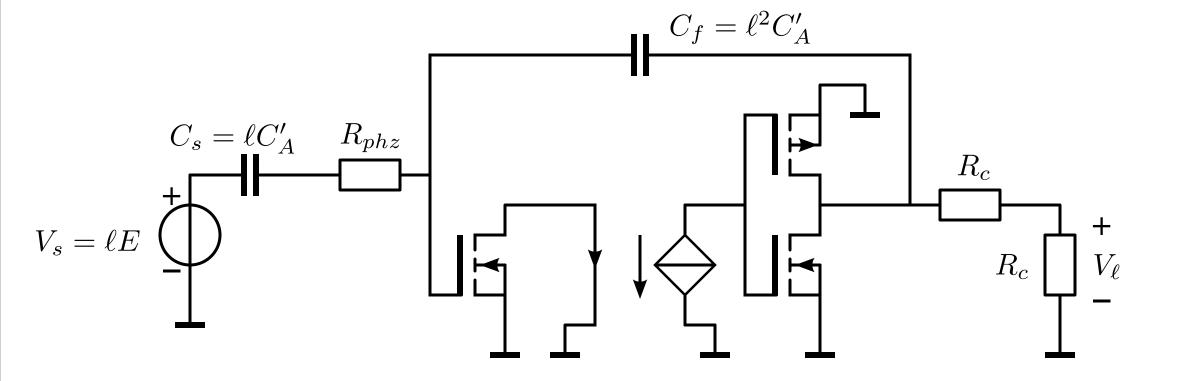
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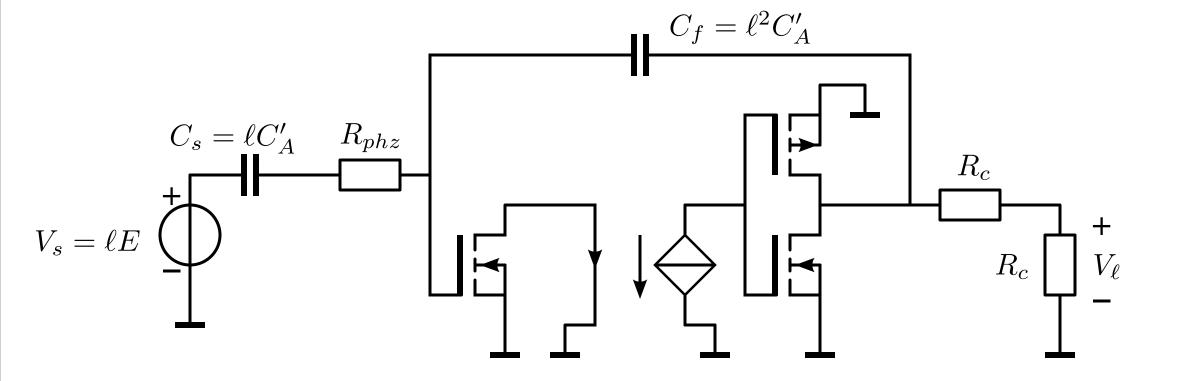
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Sum of the poles:

 $p_1 = 0, p_2 = -\frac{C_f + C_s + c_{iss_1}}{4\pi R_c C_f (C_s + c_{iss_1})} = -450 \text{MHz}$



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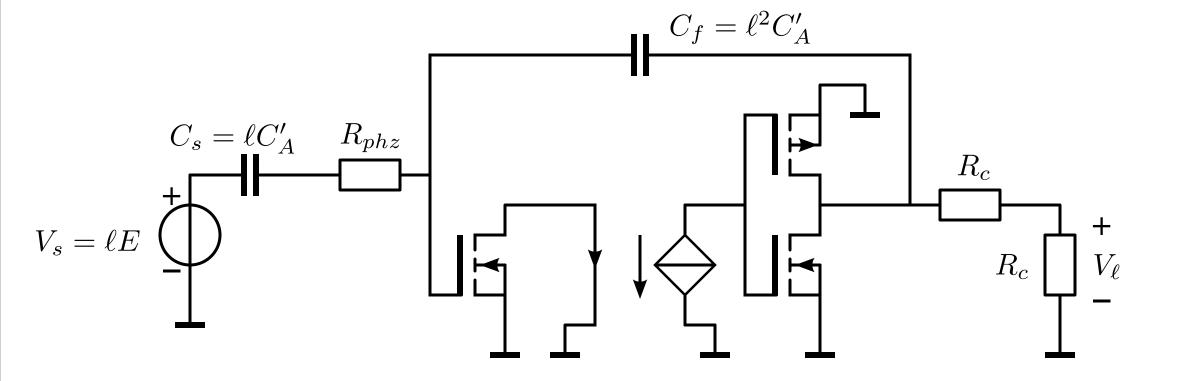
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Frequency of the phantom zero



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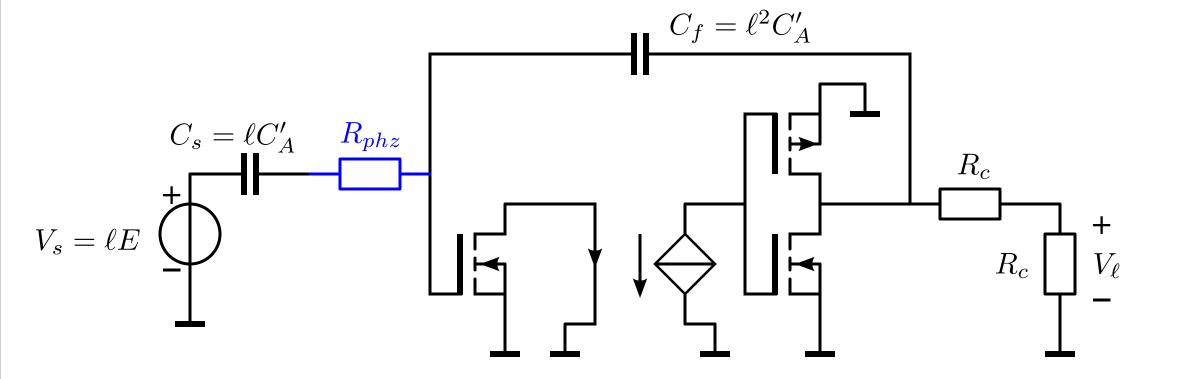
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Frequency of the phantom zero

$$z = -\frac{B_f^2}{\sqrt{2}B_f + p_1 + p_2} = -\frac{1}{2\pi R_{phz}C_s} = -1$$
GHz

Phantom-zero compensation



Circuit element values:

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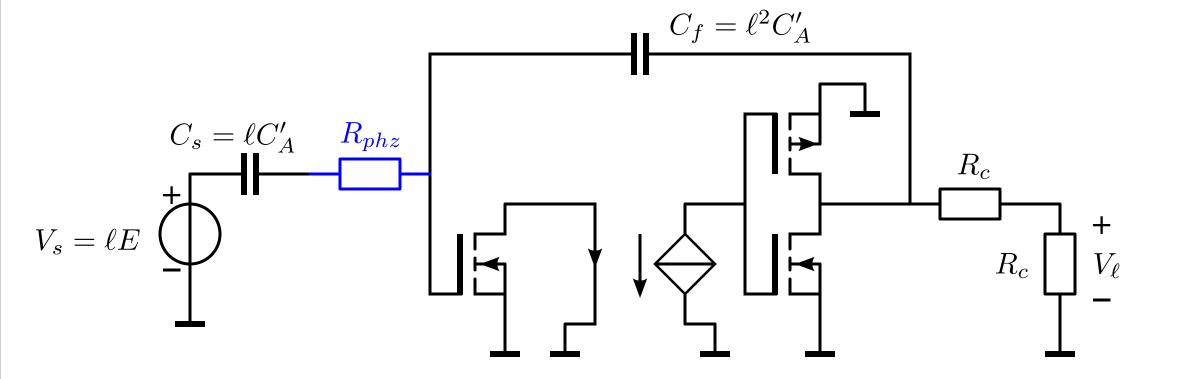
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Value of the compensation resistor

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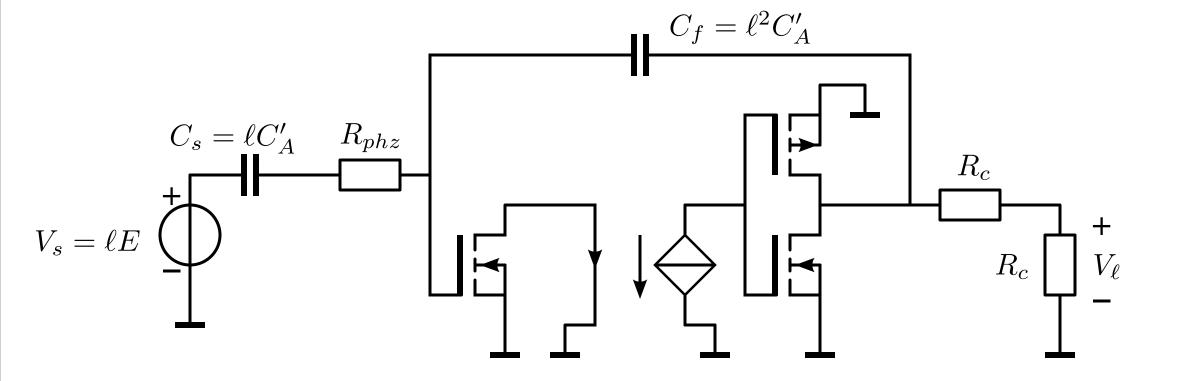
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GHz

Value of the compensation resistor

$$R_{phz} = -\frac{1}{2\pi z C_s} = 30\Omega$$

Phantom-zero compensation



Circuit element values:

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Achievable MFM bandwidth:

$$B_f = \frac{1}{2\pi} \sqrt{LP_2} = 1.5 \text{GHz}$$

Sum of the poles:

$$p_1 = 0, \, p_2 = -\frac{C_f + C_s + c_{iss_1}}{4\pi R_c C_f (C_s + c_{iss_1})} = -450 \text{MHz}$$

Frequency of the phantom zero

$$z = -\frac{B_f^2}{\sqrt{2}B_f + p_1 + p_2} = -\frac{1}{2\pi R_{phz}C_s} = -1$$
GHz

Value of the compensation resistor

$$R_{phz} = -\frac{1}{2\pi z C_s} = 30\Omega$$

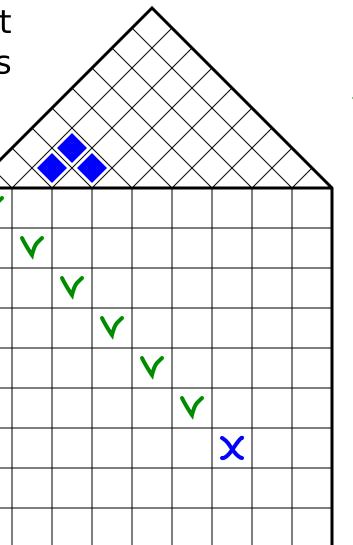
Structured Electronic Design

Step 7 Design of the biasing concept (ideal bias sources)

Anton J.M. Montagne

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

> pattern stage stage structure product environment configuration performance ⁻ input output Loop gain poles ΡZ Bias Controlle Controller costs and Feedback Function,



interaction between design aspects

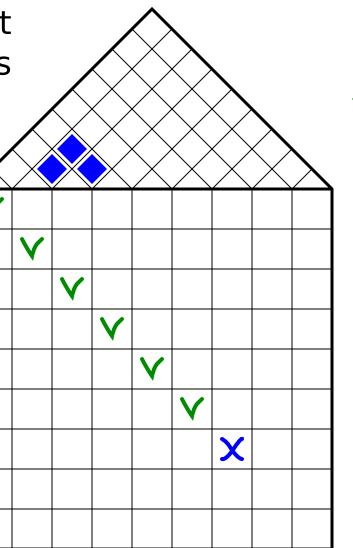
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> design aspects

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

stage pattern structure environment onfiguration stage product performance input output ΡZ Loop gain poles Bias Controlle Controller costs and Function, Feedback



interaction between design aspects

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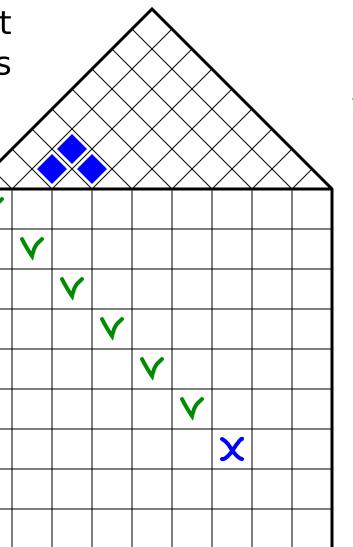


Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

Connect the circuit to the power supply

pattern stage stage structure product ration environment performance onfigui tput input ΡZ Loop gain poles Bias no costs and Controller Controll Function, Feedbac



interaction between design aspects

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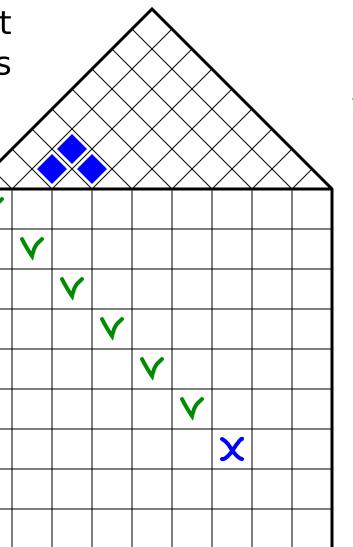
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply

pattern stage structure stage product ration environment performance nfigu itput input ΡZ Loop gain poles Bias costs and Controller Controll Function, Feedba



interaction between design aspects

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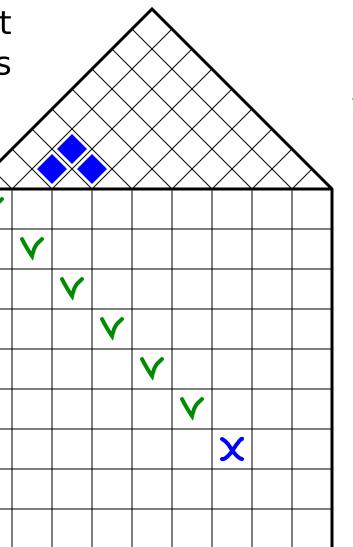


Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources

pattern stage structure stage product ration environment performance nfigu tput input ΡZ -oop gain poles Bias costs and Controller Controll Function, Feedba



interaction between design aspects

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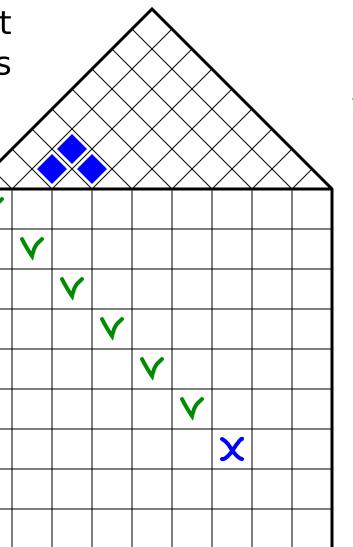


Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources Apply error reduction techniques to improve biasing stability

pattern stage structure stage ration product environment performance nfigu tput input ΡZ poles Bias gain costs and Controlle Controll Function, Feedba Loop



interaction between design aspects

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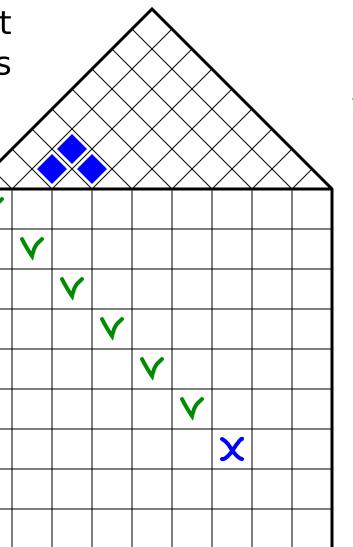
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Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources Apply error reduction techniques to improve biasing stability

Design of the active antenna:



interaction between design aspects

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pattern stage structure stage ration product tput input ΡZ **B**S Bias gain Controlle Controll Feedba Loop

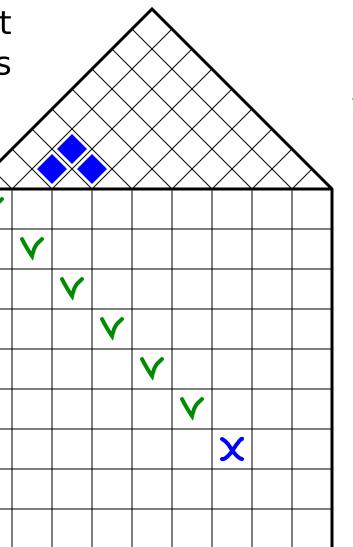
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Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources Apply error reduction techniques to improve biasing stability

Design of the active antenna:

1.8V supply



interaction between design aspects

SLiCAP SLiCAP SLiCAP LTspice SLiCAP SLiCAP LTspice



pattern stage structure stage product ration nfigu tput input poles ΡZ Bias gain Controlle Controll Feedba Loop

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

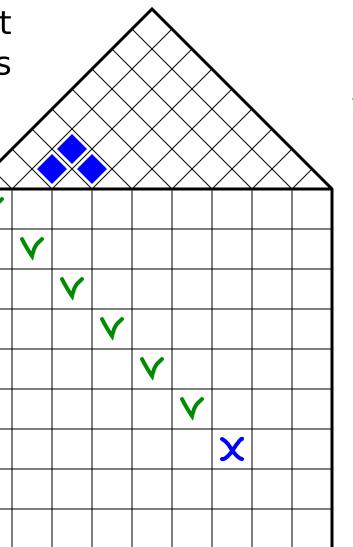
Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources Apply error reduction techniques to improve biasing stability

Design of the active antenna:

1.8V supply Redirected current sources

stage pattern structure stage ration product environment performance tput input ΡZ **B**S Bias bo costs and gain Ē Controll Function, Controll Feedba Loop



interaction between design aspects

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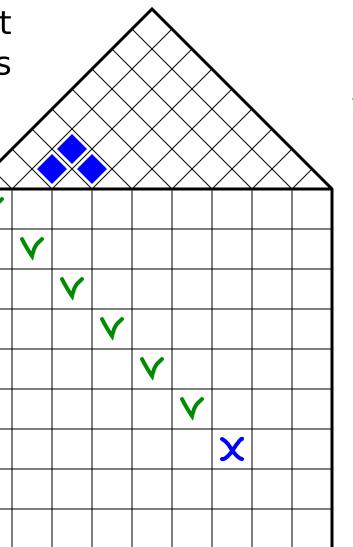
Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources Apply error reduction techniques to improve biasing stability

Design of the active antenna:

1.8V supply Redirected current sources AC coupling



interaction between design aspects

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pattern stage structure stage product ration nfigu tput input ΡZ **B**S Bias bole gain Ē Controll Controll Feedba Loop

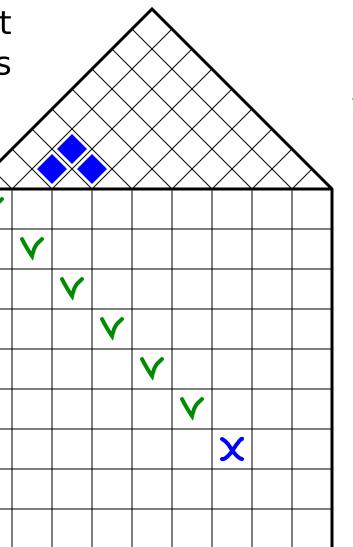
Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources Apply error reduction techniques to improve biasing stability

Design of the active antenna:

1.8V supplyRedirected current sourcesAC couplingOver-all negative-feedback biasing



interaction between design aspects

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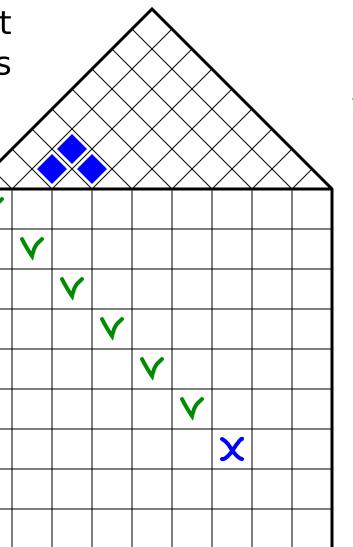
Setting up specifications V Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources)

Biasing concept

Connect the circuit to the power supply Redirect bias current sources over the power supply Minimize the number of floating voltage sources Apply error reduction techniques to improve biasing stability

Design of the active antenna:

1.8V supplyRedirected current sourcesAC couplingOver-all negative-feedback biasing

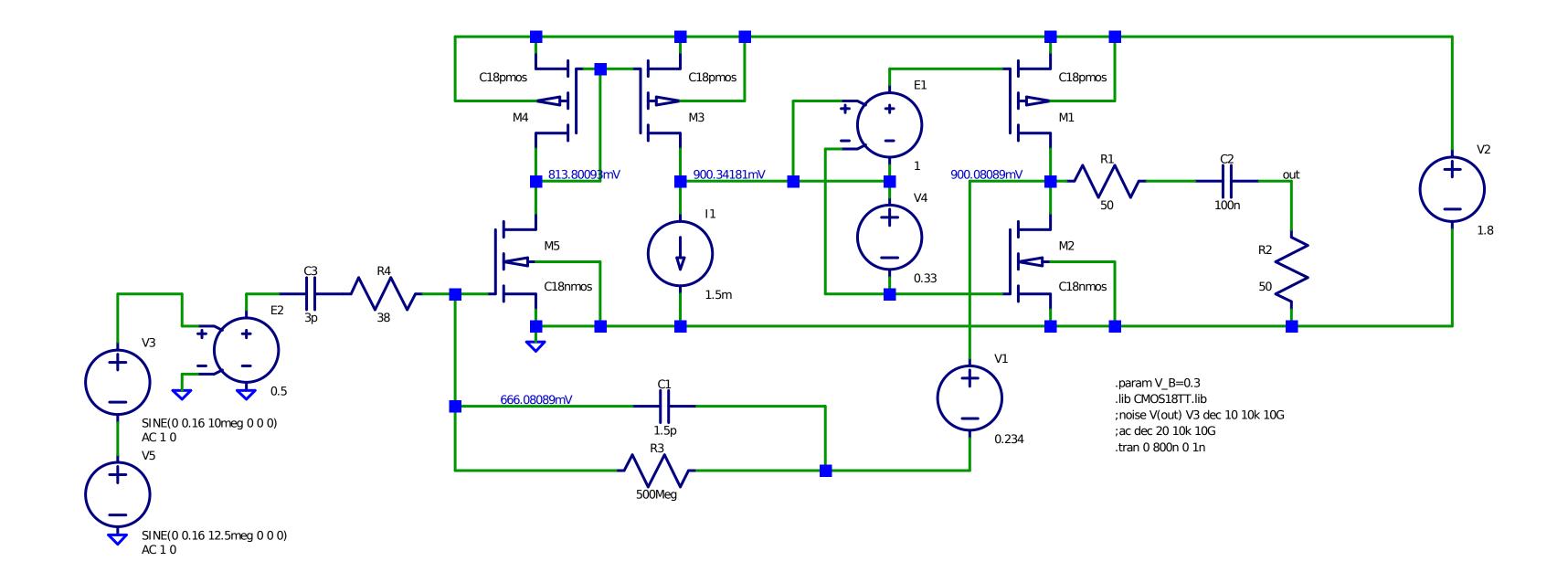


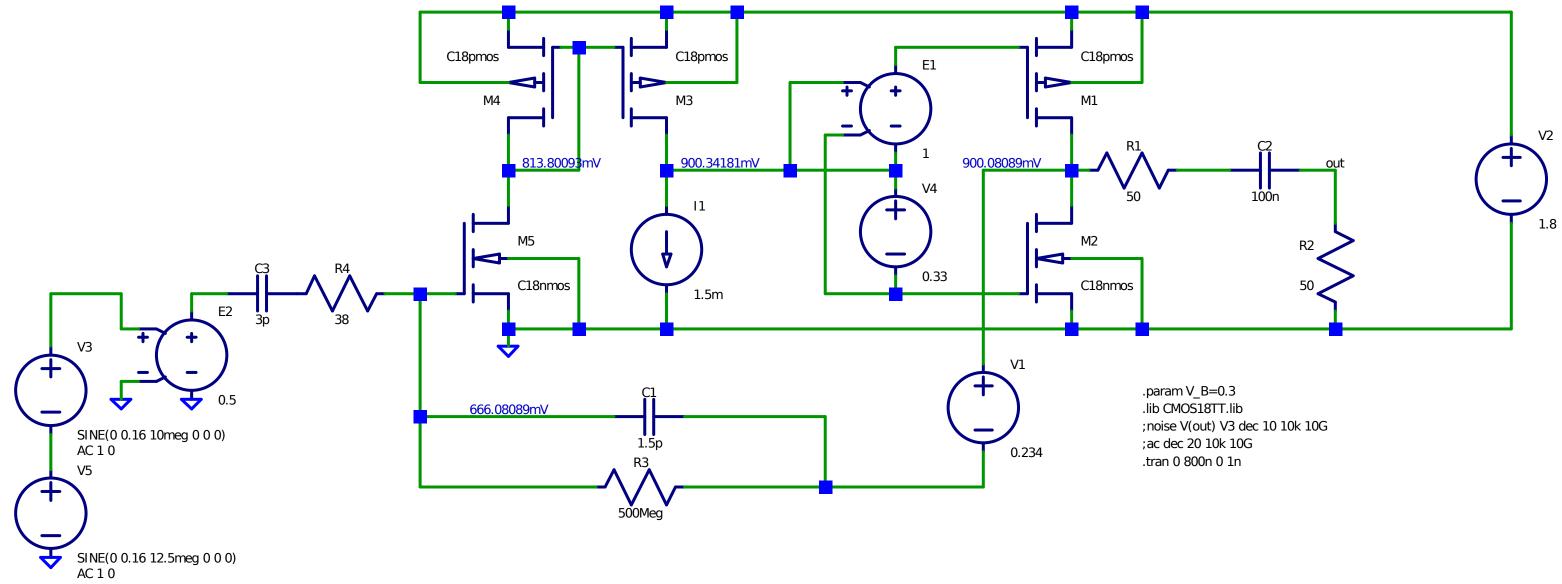
interaction between design aspects

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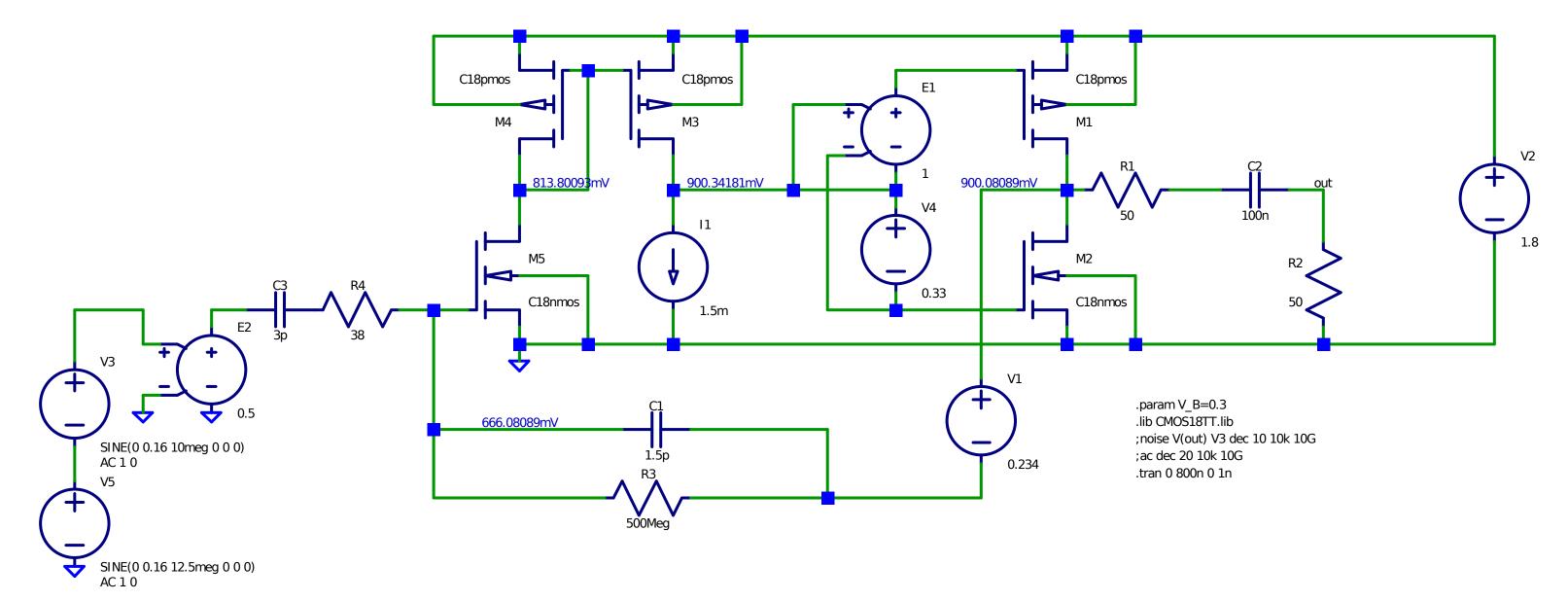
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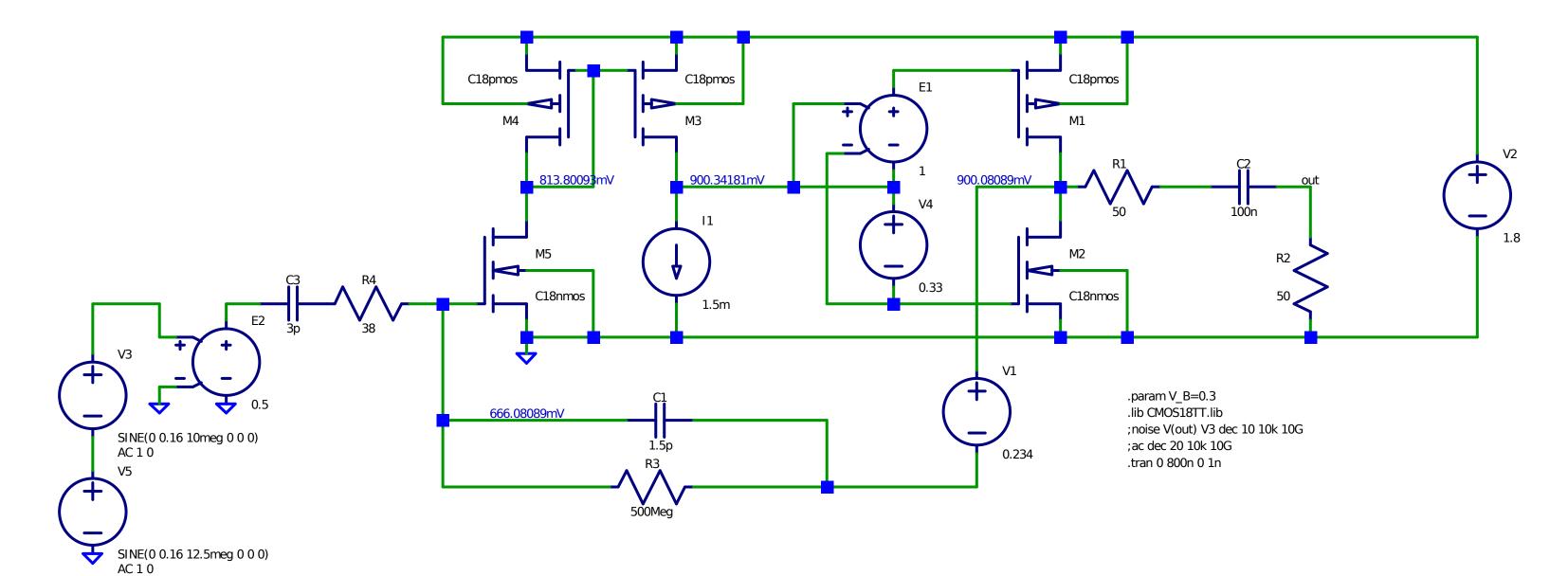




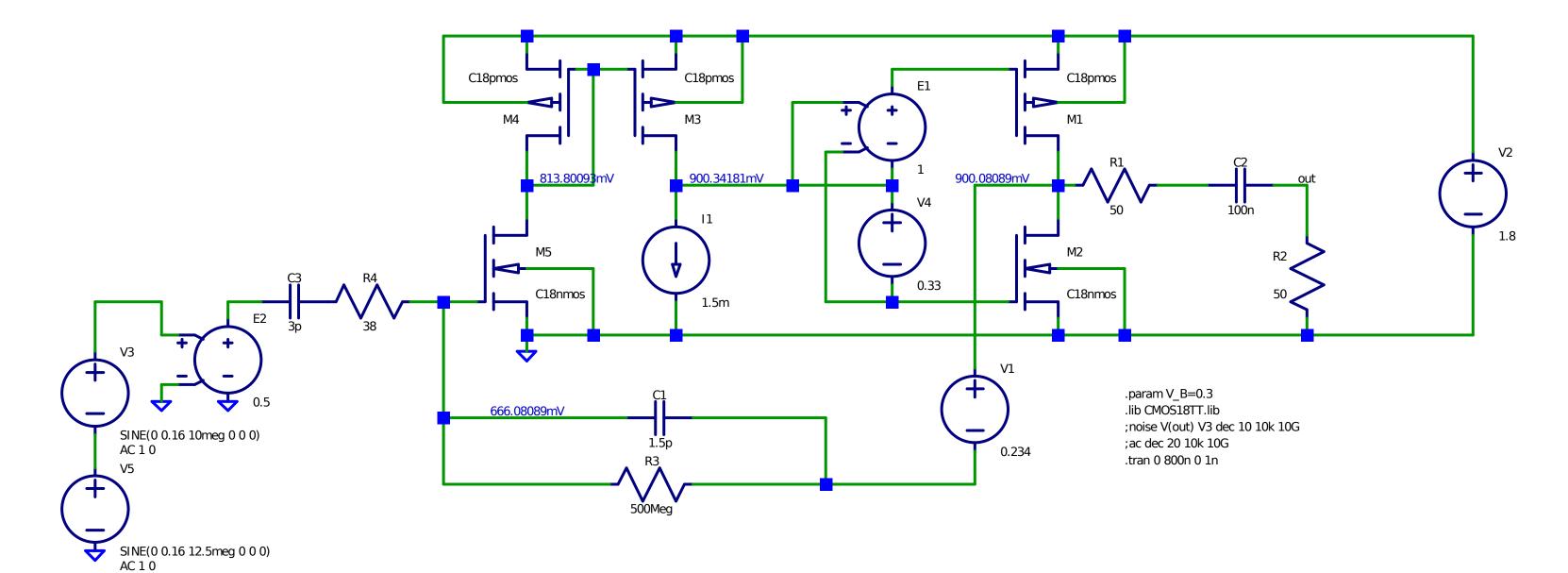
Single supply



Single supply Bias current sources redirected via supply and combined

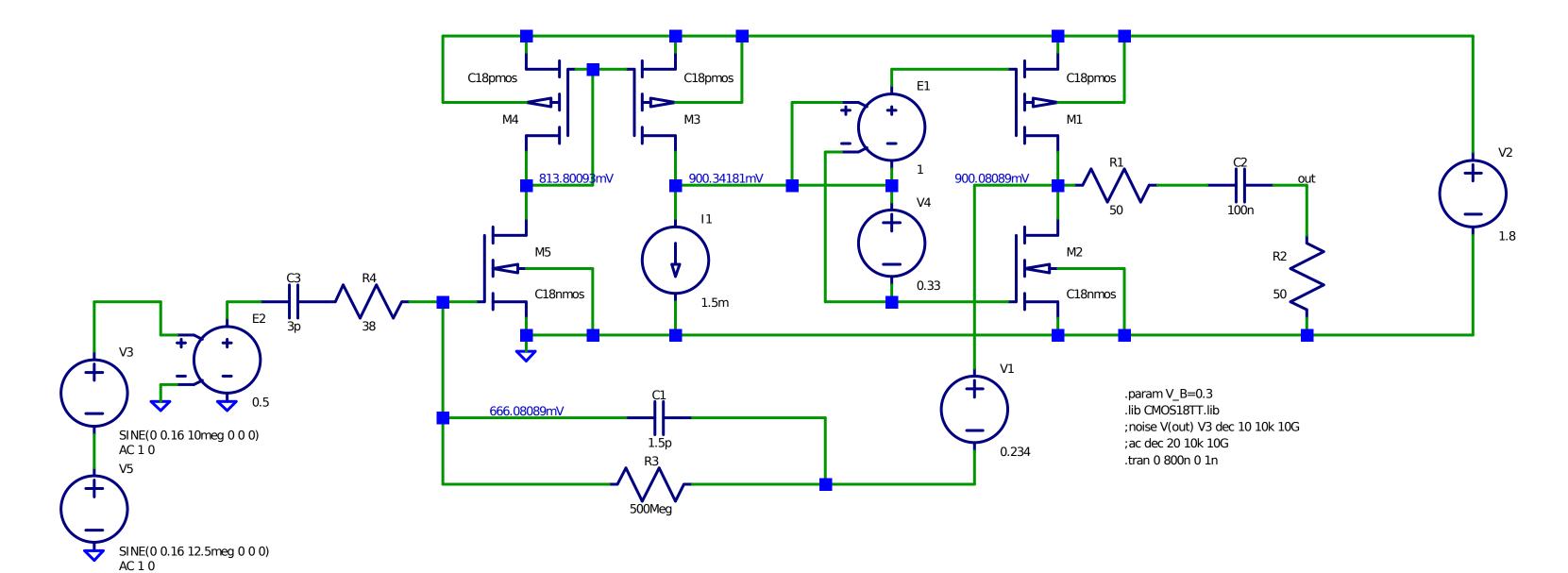


Single supply Bias current sources redirected via supply and combined AC coupling and over-all negative feedback biasing



Single supply

Bias current sources redirected via supply and combined AC coupling and over-all negative feedback biasing Two or three remaining floating voltage sources



Single supply

Bias current sources redirected via supply and combined AC coupling and over-all negative feedback biasing Two or three remaining floating voltage sources

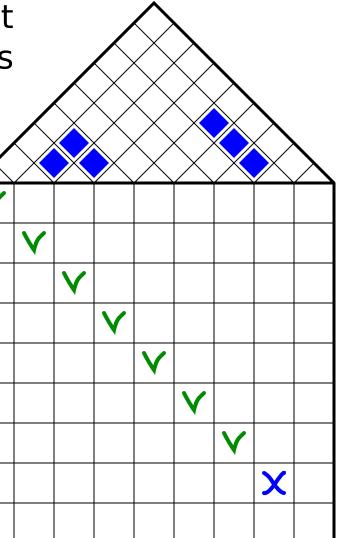
Structured Electronic Design

Step 8 Design of the sufficiently low weak nonlinearity (ideal bias sources)

Anton J.M. Montagne

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

> Function, performance, costs and environment



interaction between design aspects

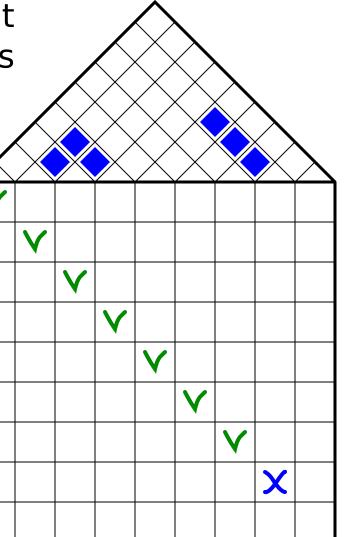
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> design aspects

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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio



interaction between design aspects

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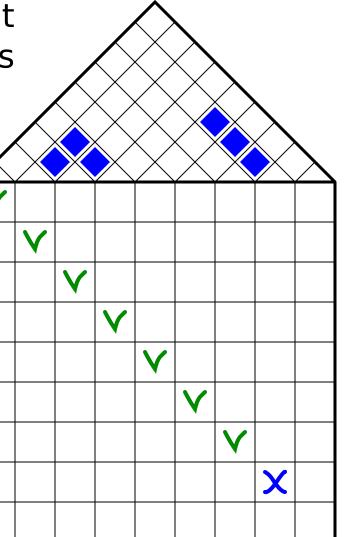
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio

Verify the biasing (operating point of all devices)



interaction between design aspects

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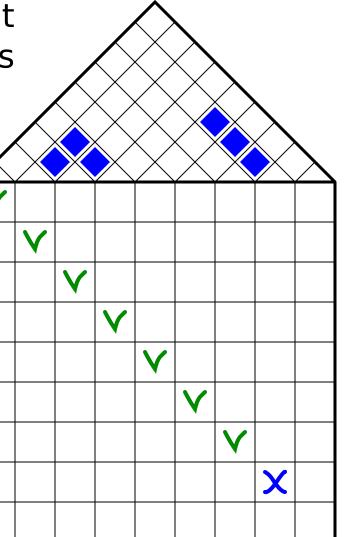
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio

Verify the biasing (operating point of all devices) Verify all performance aspects Function, performance, costs and environment



interaction between design aspects

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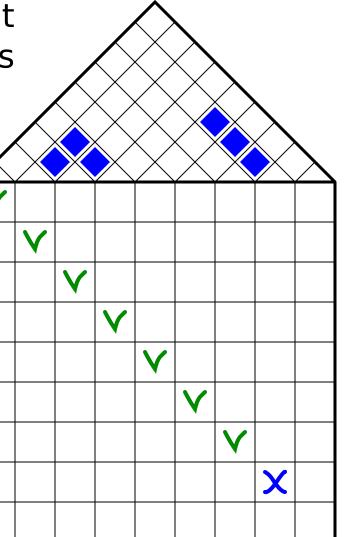
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio

Verify the biasing (operating point of all devices) Verify all performance aspects The weak nonlinearity can be reduced by: Function, performance, costs and environment



interaction between design aspects

SLiCAP SLiCAP SLiCAP LTspice SLiCAP SLiCAP LTspice LTspice

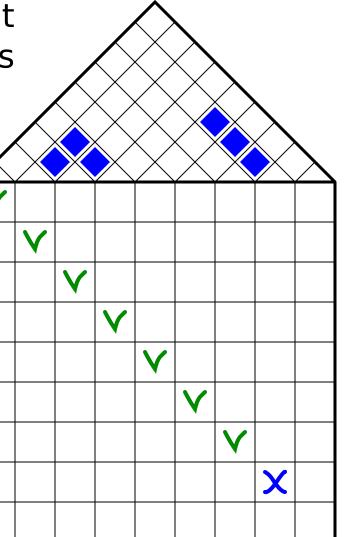
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio

Verify the biasing (operating point of all devices)
Verify all performance aspects
The weak nonlinearity can be reduced by:
Decreasing the differential-error-to-gain ratio per stage



interaction between design aspects

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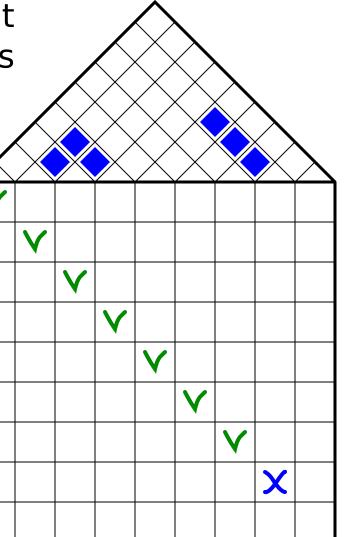
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio

Verify the biasing (operating point of all devices) Verify all performance aspects The weak nonlinearity can be reduced by: Decreasing the differential-error-to-gain ratio per stage Modify the operating conditions and/or device geometry



interaction between design aspects

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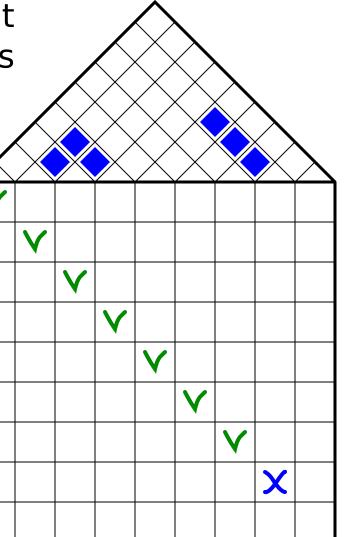
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio

Verify the biasing (operating point of all devices) Verify all performance aspects The weak nonlinearity can be reduced by: Decreasing the differential-error-to-gain ratio per stage Modify the operating conditions and/or device geometry Increase the number of stages



interaction between design aspects

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> design aspects

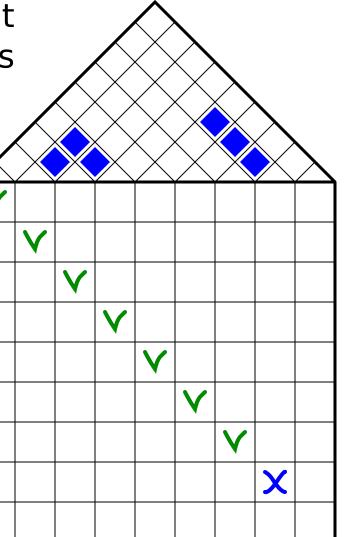
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Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

Differential-error-to-gain ratio

Verify the biasing (operating point of all devices)
Verify all performance aspects
The weak nonlinearity can be reduced by:
Decreasing the differential-error-to-gain ratio per stage
Modify the operating conditions and/or device geometry
Increase the number of stages

Design of the active antenna:



interaction between design aspects

SLiCAP SLiCAP SLiCAP LTspice SLiCAP SLiCAP LTspice LTspice

> design aspects

stage structure gain ratio attern stage ration oduct input PA Bias to bo errol gain Φ Controll Controll Feedba Differential doo

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity

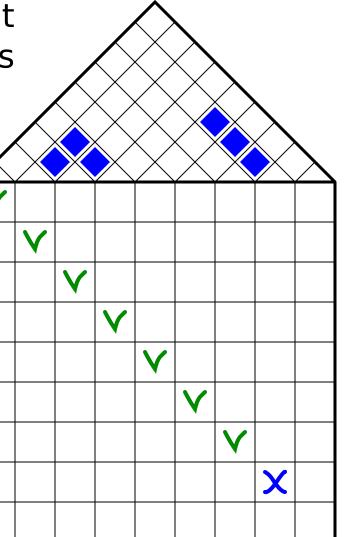
Differential-error-to-gain ratio

Verify the biasing (operating point of all devices)
Verify all performance aspects
The weak nonlinearity can be reduced by:
Decreasing the differential-error-to-gain ratio per stage
Modify the operating conditions and/or device geometry
Increase the number of stages

Design of the active antenna:

Verification showed sufficiently low distortion

Function, performance, costs and environment



interaction between design aspects

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> design aspects

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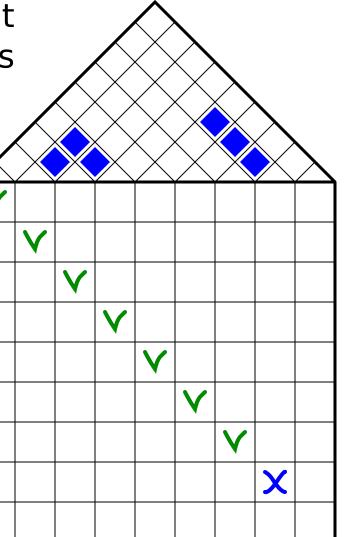
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Differential-error-to-gain ratio

Verify the biasing (operating point of all devices)
Verify all performance aspects
The weak nonlinearity can be reduced by:
Decreasing the differential-error-to-gain ratio per stage
Modify the operating conditions and/or device geometry
Increase the number of stages

Design of the active antenna:

Verification showed sufficiently low distortion



interaction between design aspects

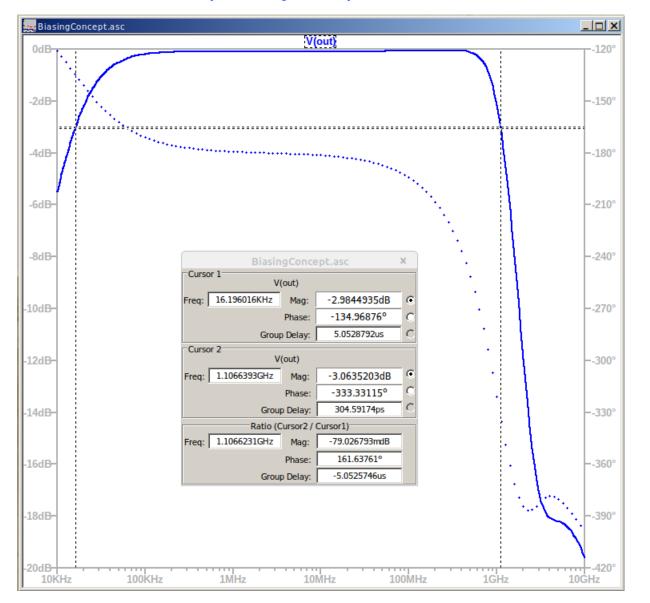
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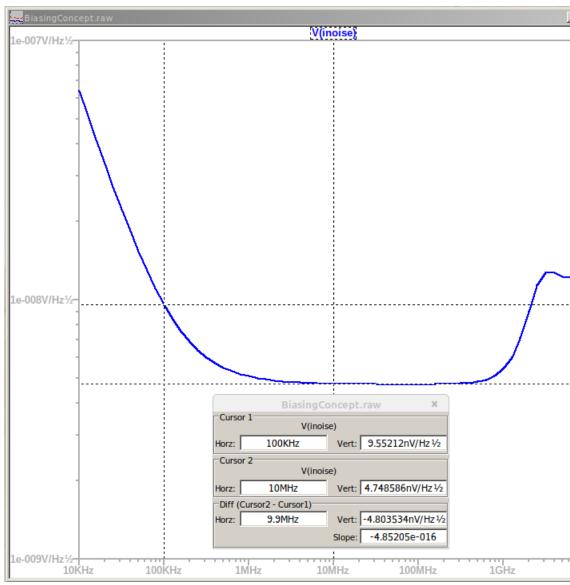
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Check performance

Frequency response

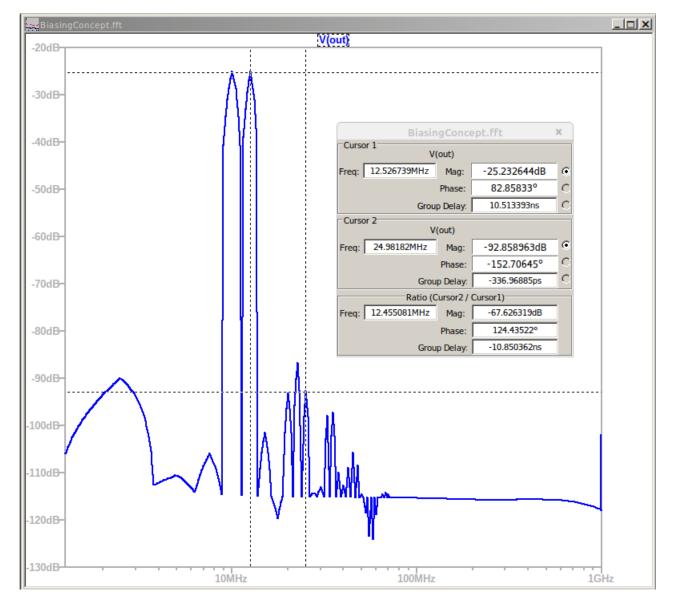


Antenna referred noise



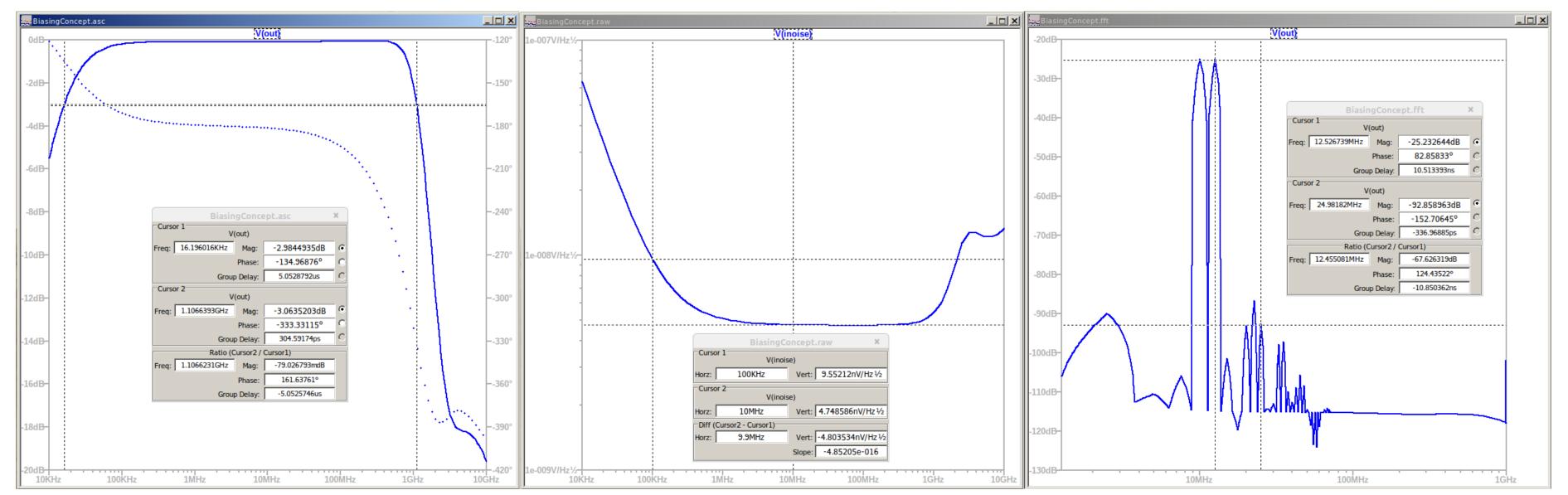


IMD



Frequency response

Antenna referred noise



IMD

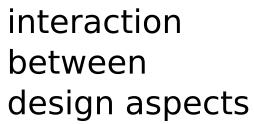
Structured Electronic Design

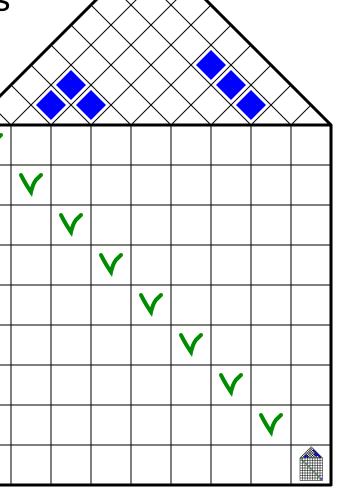
Step 9 Design of the bias sources

Anton J.M. Montagne

Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity Specification of bias sources

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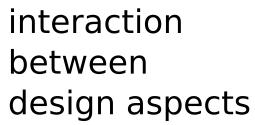


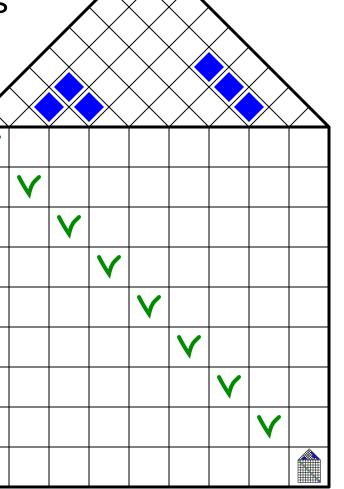




Same procedure for each bias source Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity Specification of bias sources

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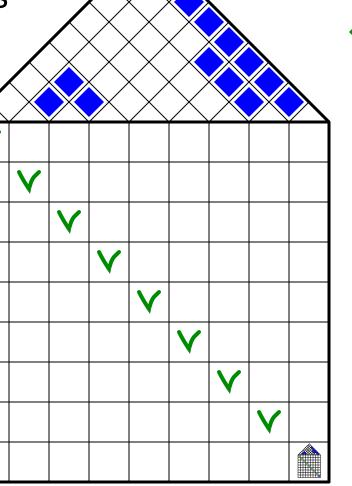


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Same procedure for each bias source Setting up specifications Design of amplifier type: A, B, C, D Feasibility of noise (temperature drift) specifications Feasibility of static and dynamic drive requirements Design of midband accuracy and amplifier bandwidth Design of the frequency response Design of the biasing (ideal sources) Design of sufficiently low weak nonlinearity Specification of bias sources

Function, performance, costs and environment



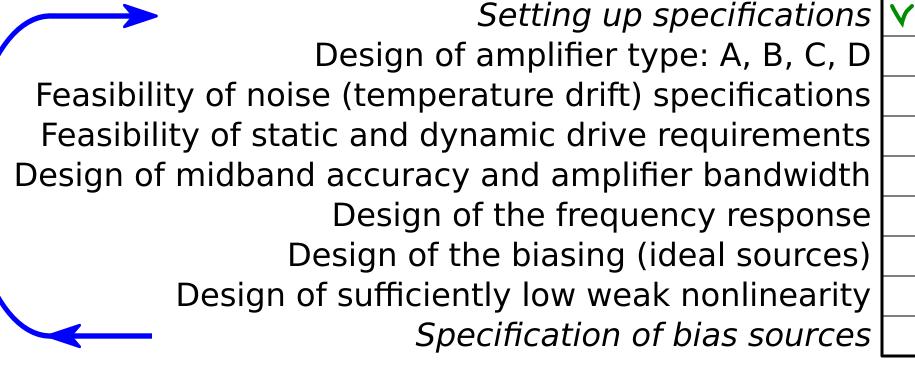


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> design aspects

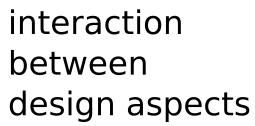
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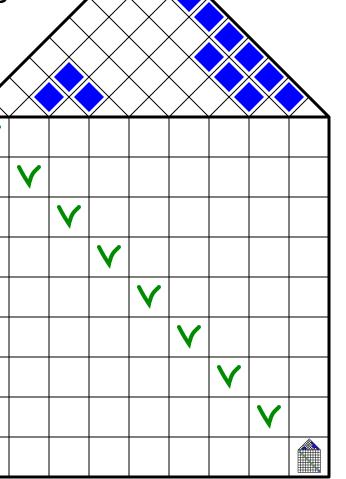
Same procedure for each bias source



Design of bias sources

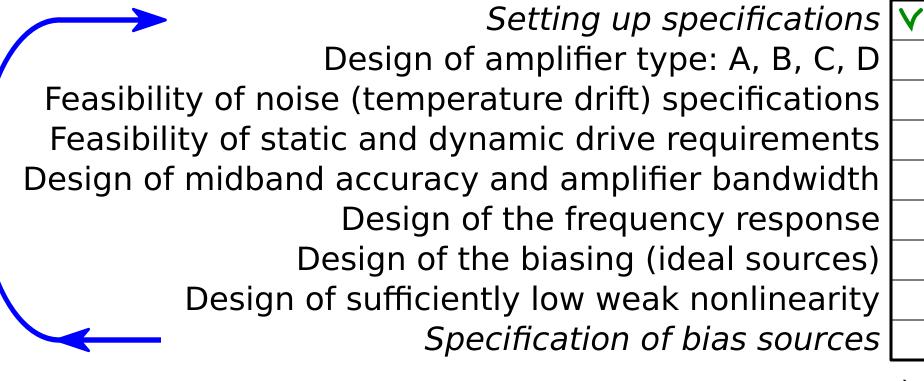
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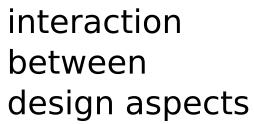
Same procedure for each bias source

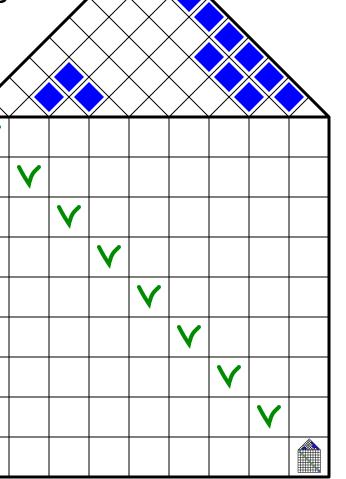


Design of bias sources

Find an operating mechanism:

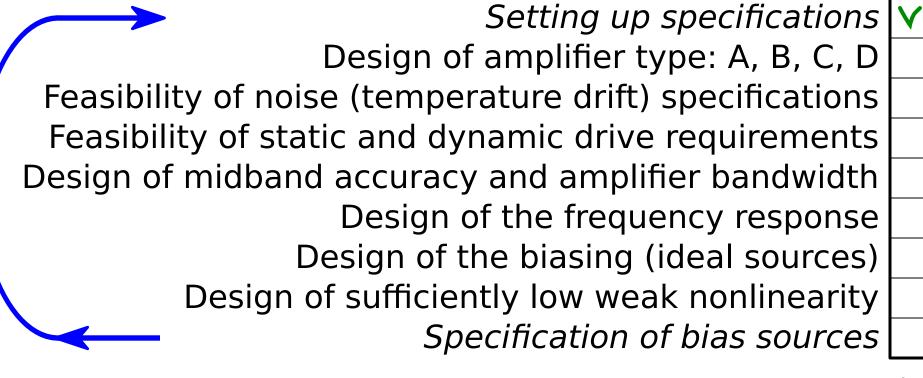
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Same procedure for each bias source

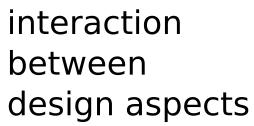


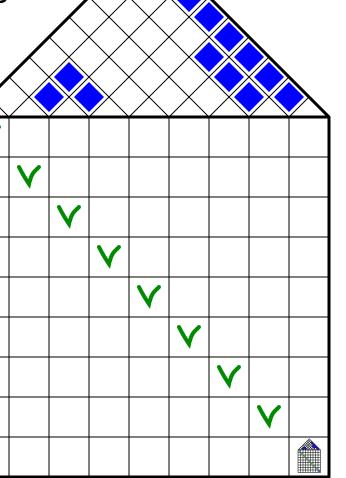
Design of bias sources

Find an operating mechanism:

Element with voltage or current source character

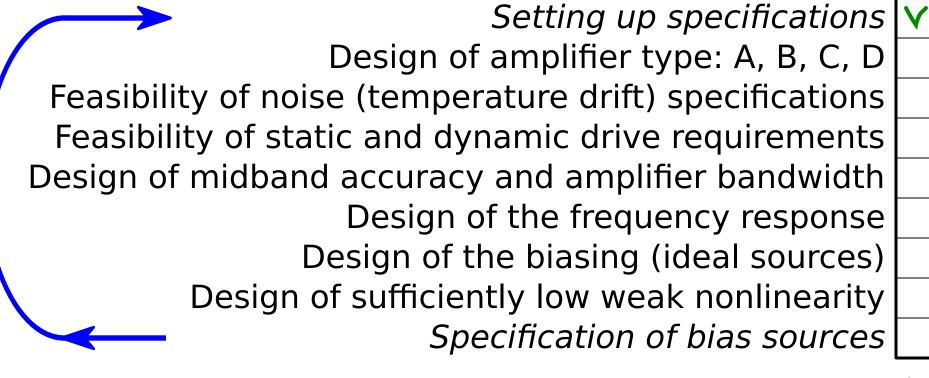
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Same procedure for each bias source

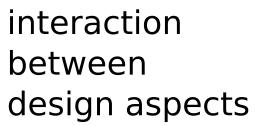


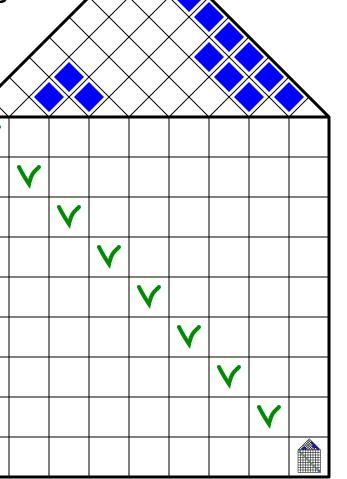
Design of bias sources

Find an operating mechanism:

Element with voltage or current source character Study in which way performence aspects can be affected by design

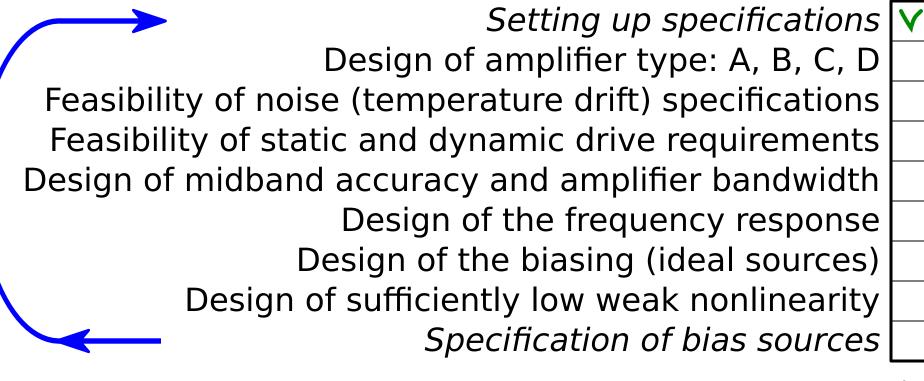
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Same procedure for each bias source

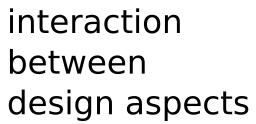


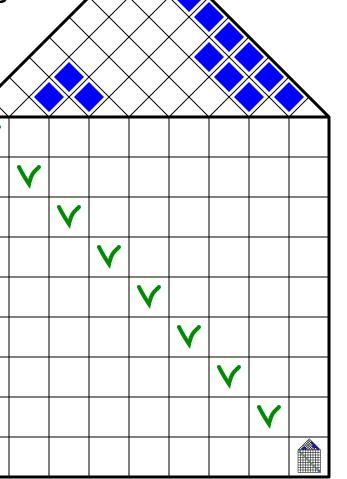
Design of bias sources

Find an operating mechanism:

Element with voltage or current source character Study in which way performence aspects can be affected by design

If necessary: improve performance versus costs through application of error-reduction techniques



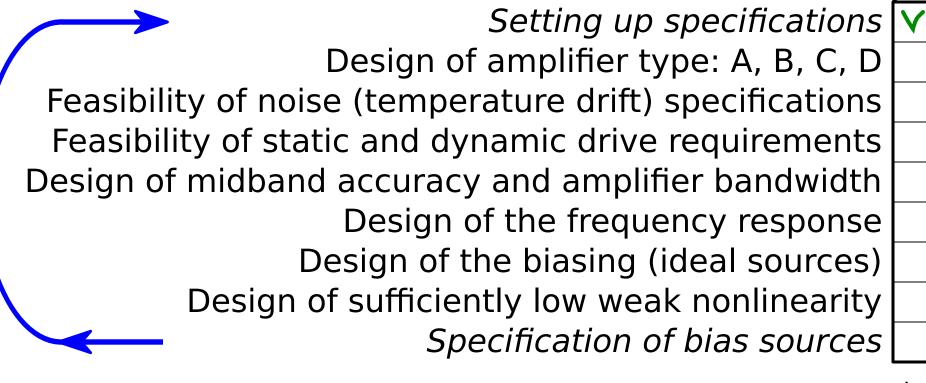


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> design aspects

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Same procedure for each bias source



Design of bias sources

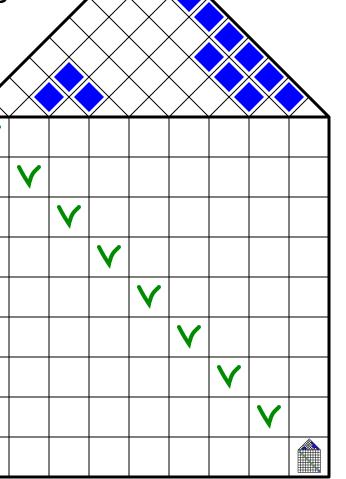
Find an operating mechanism:

Element with voltage or current source character Study in which way performence aspects can be affected by design

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