STAN Tool

Selecting the Node

Understanding and overcoming
pole-zero quasi-cancellations

AMCAD Engineering
Advanced Modeling for Computer-Aided Design
eman ta zabal zazu
Universidad del País Vasco
Euskal Herriko Unibertsitatea
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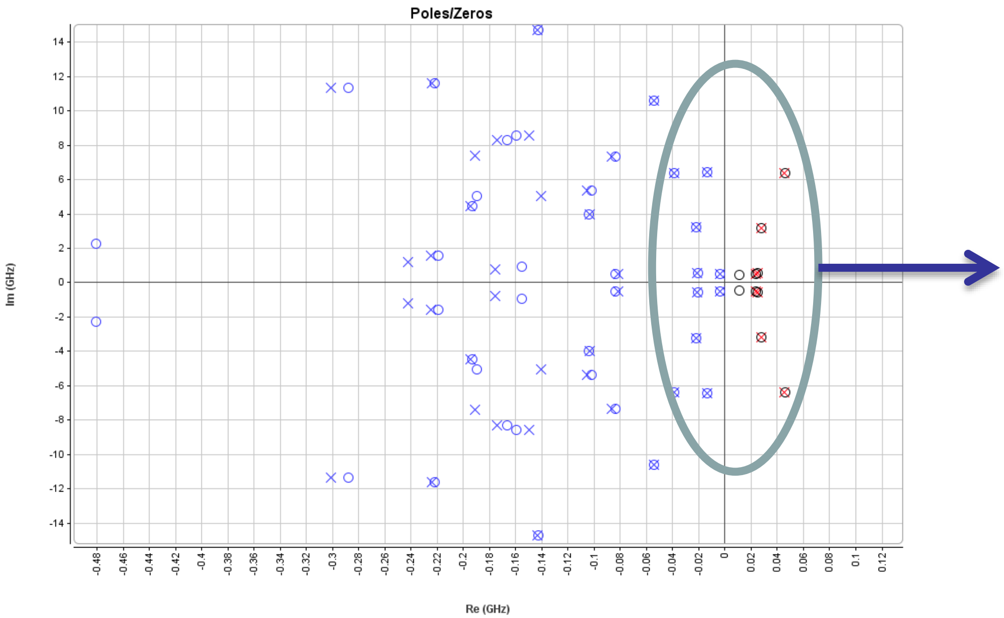
Selecting the Node

Sometimes the result of an identification provides a pole-zero map in which couples of poles and zeros are located virtually on the same position:



These are called:
pole-zero quasi-cancellations

A key question is raised in view of such a plot: **if quasi-cancellations lay on the Right Half Plane, can I always deduce that the circuit is unstable?**

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Selecting the Node

This application note tries to answer this question providing the fundamentals to understand the origin of pole-zero quasi-cancellations and the tips to get a reliable analysis that unambiguously decides on the stability/instability of the circuit in the presence of quasi-cancellations.

We will see how an appropriate selection of the analysis node can help when dealing with these quasi-cancellations.

Document Outline

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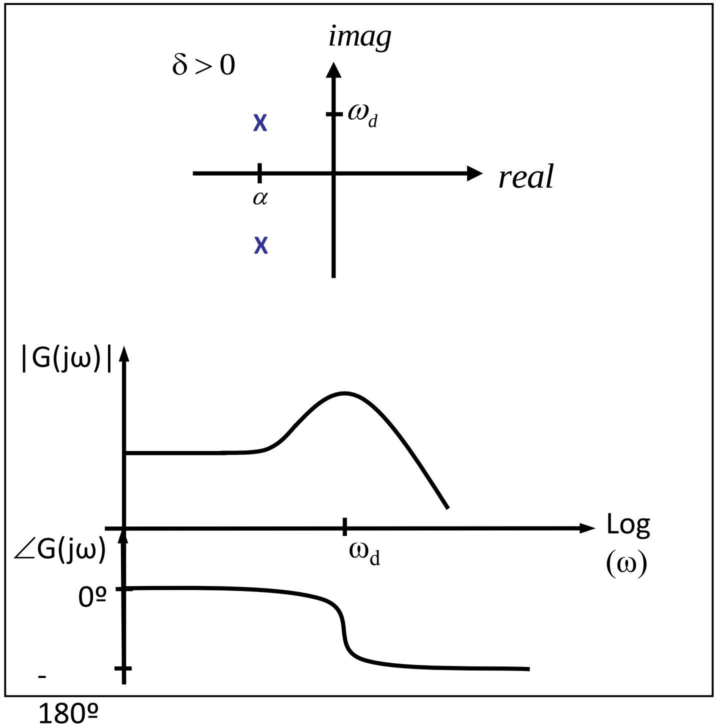
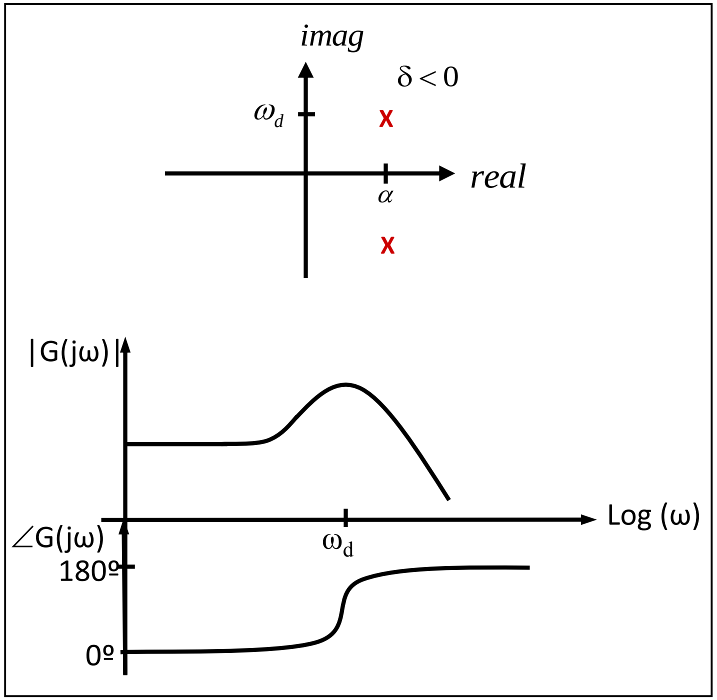
1. Basic Theory

Let us consider a pair of isolated complex conjugate **poles** $\alpha \pm j\omega_d$

$$G(s) = \frac{K\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2} \qquad \omega_d = \omega_n\sqrt{1-\delta^2} \qquad \alpha = -\delta\omega_n$$

They have an unambiguous effect on the transfer function, with a negative 180º phase jump for the stable case and a positive 180º phase jump for the unstable case.



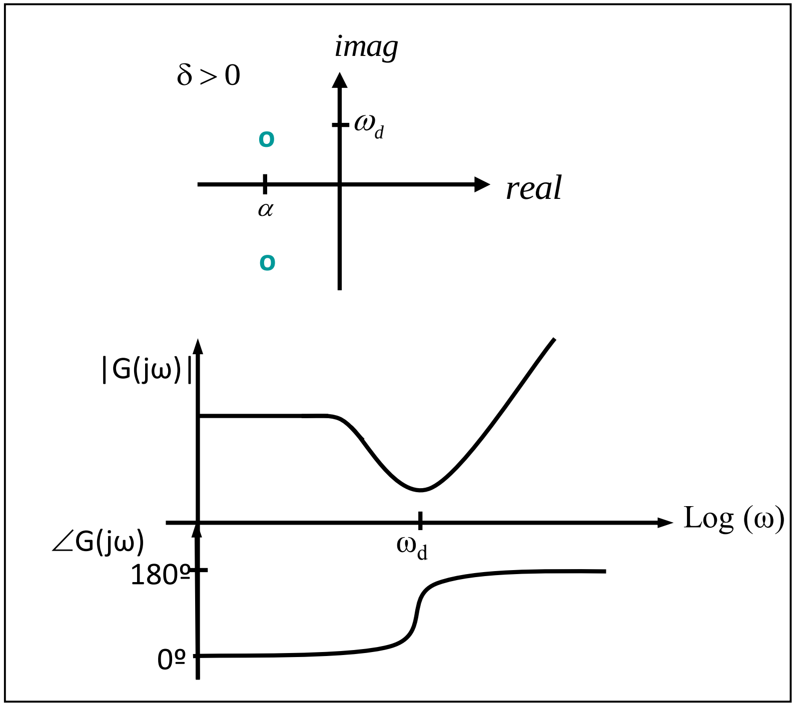


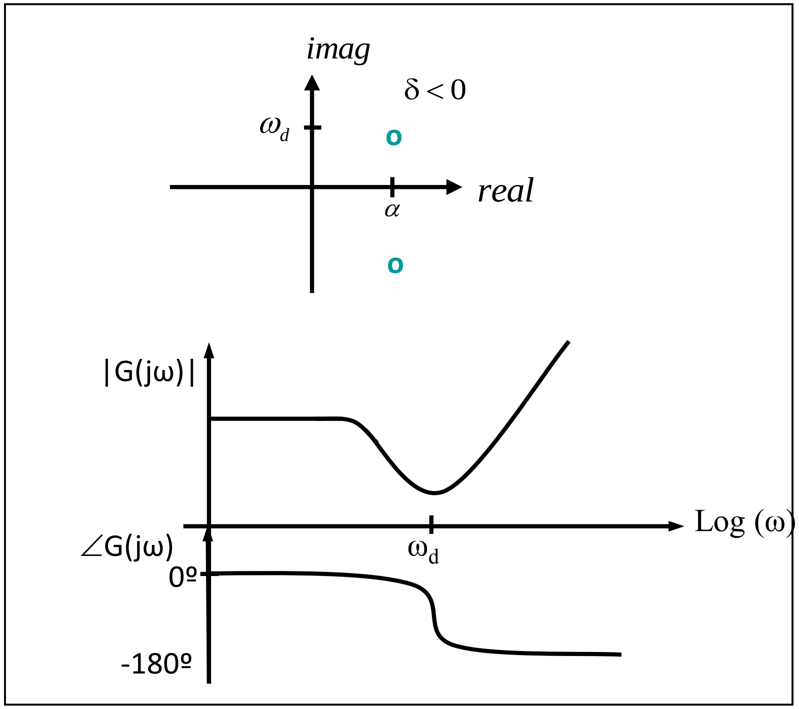
1. Basic Theory

Let us consider now a pair of isolated complex conjugate **zeros** $\alpha \pm j\omega_d$

$$G(s) = s^2 + 2\delta\omega_n s + \omega_n^2 \qquad \omega_d = \omega_n\sqrt{1-\delta^2} \qquad \alpha = -\delta\omega_n$$

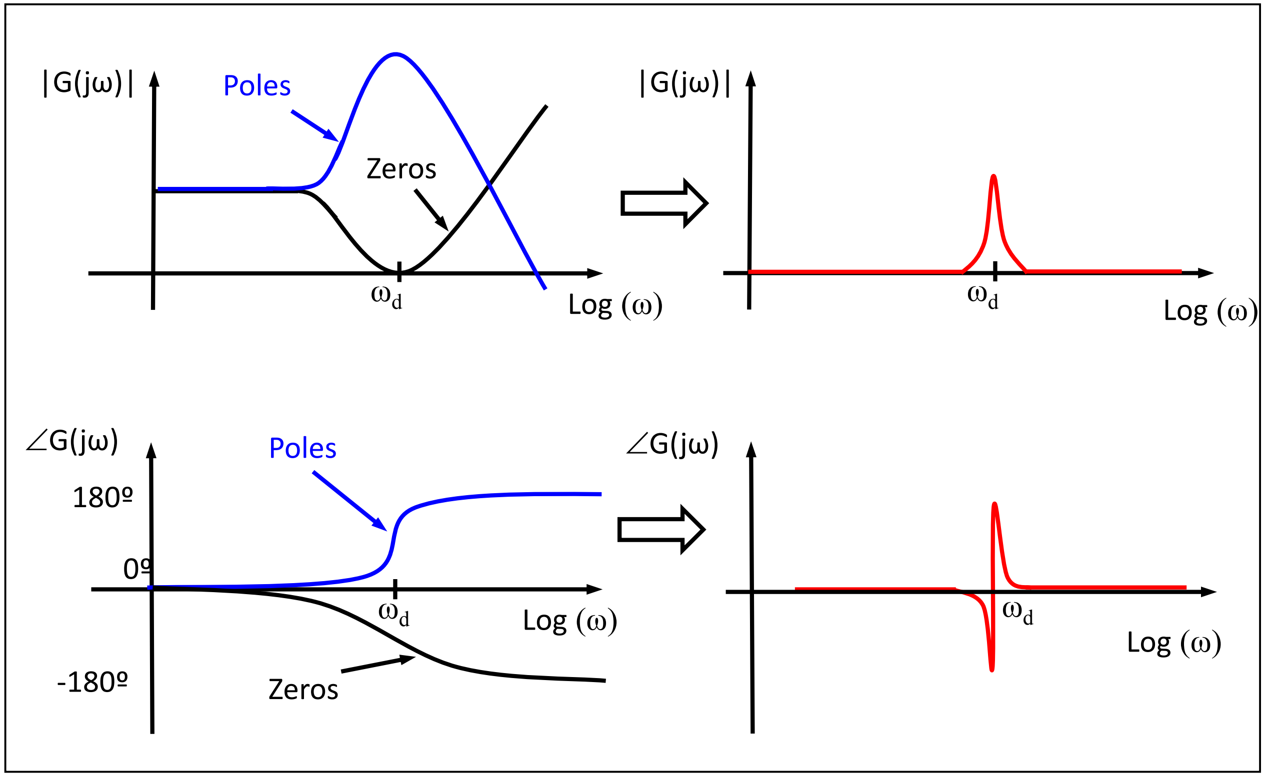
They also have an unambiguous effect on the transfer function. Now the LHP zeros cause a positive 180º phase jump and the RHP zeros cause a negative 180º phase jump.

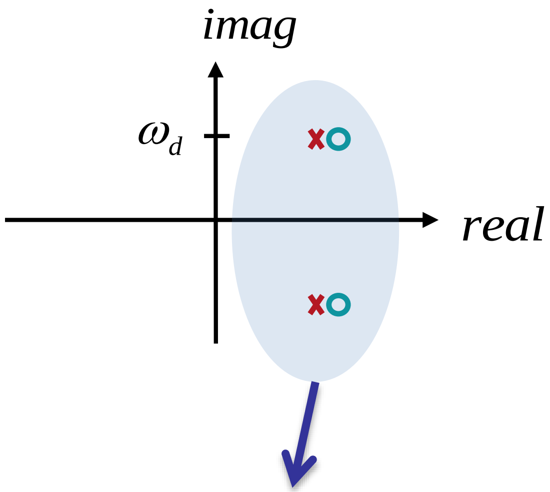




1. Basic Theory

Consequently, the presence of poles and zeros located very close on the complex plane compensate both effects and results in very tiny variations in the transfer function.





Pole-zero quasi-cancellation

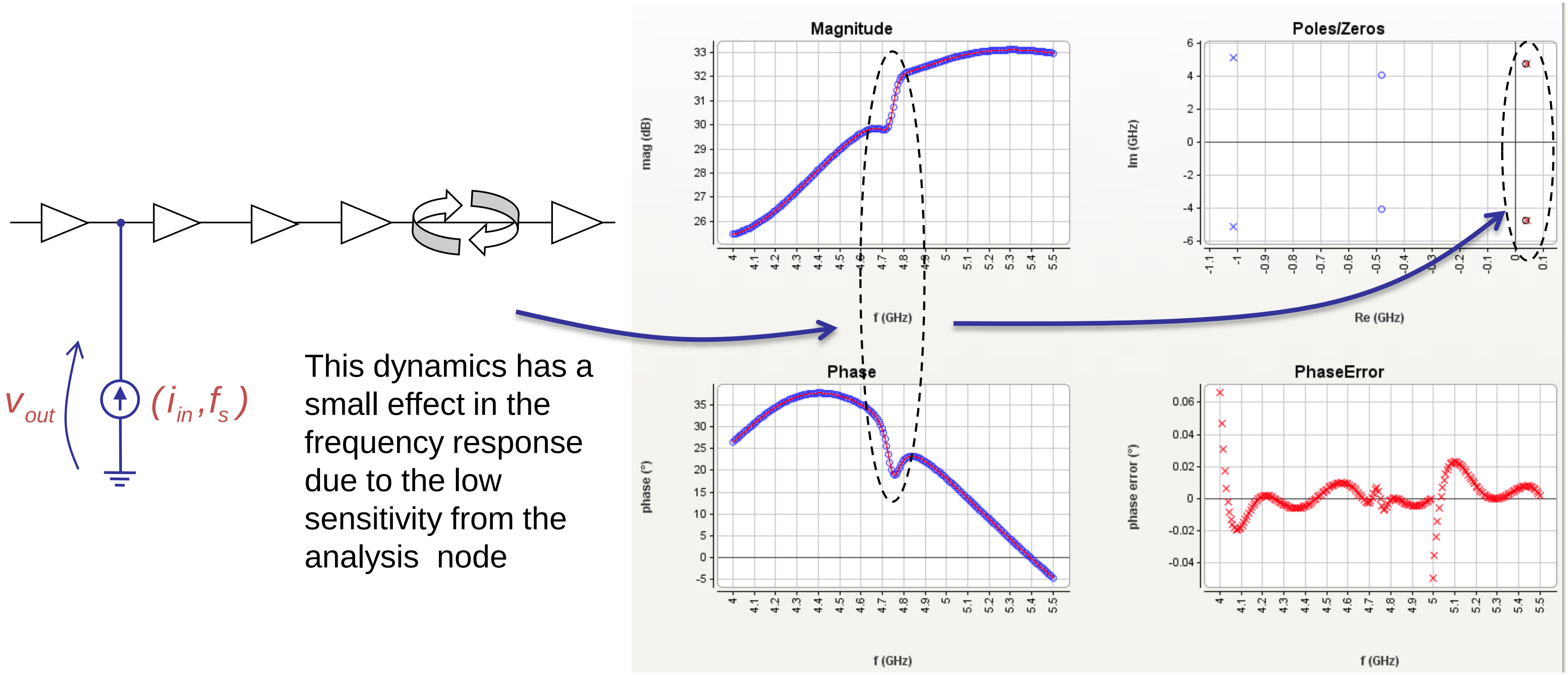
The closest the tiniest !

In the limit case of pole and zero overlying perfectly, we have an **exact pole-zero cancellation** and there is no appreciable effect on the transfer function

Document Outline

2.1 Physical quasi-cancellations

When part of the circuit dynamics is electrically isolated from the node selected for the analysis, poles representing this dynamics appear quasi-cancelled by zeroes and the effect of this dynamics on the transfer function is very slight.

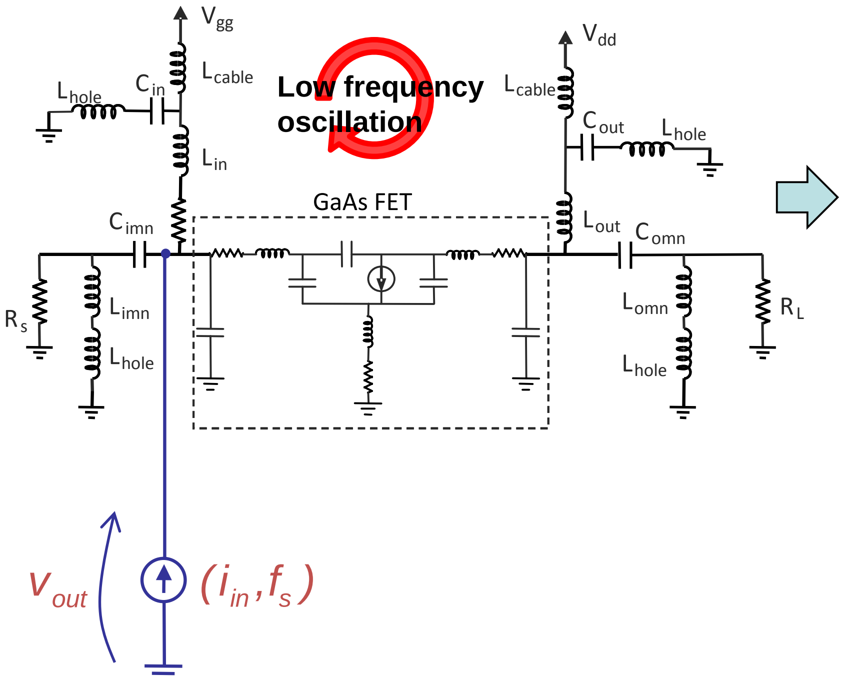


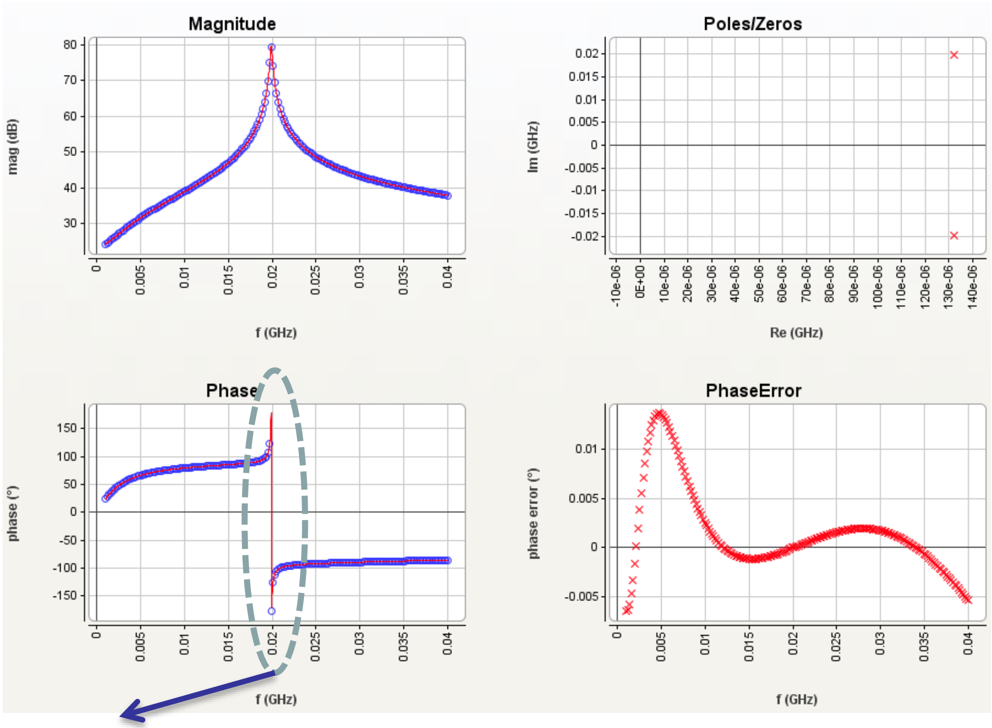
When this happens, we say that the analysis node has very low sensitivity to that dynamics (low degree of observability and/or controllability)

2.1 Physical quasi-cancellations

Example: amplifier with low frequency oscillation involving elements of the bias networks

If we select as analysis node the gate of the transistor → high sensibility → the critical poles are not quasi-cancelled by zeros. The effect on the transfer function is unmistakable, with a positive jump of 180º in the phase



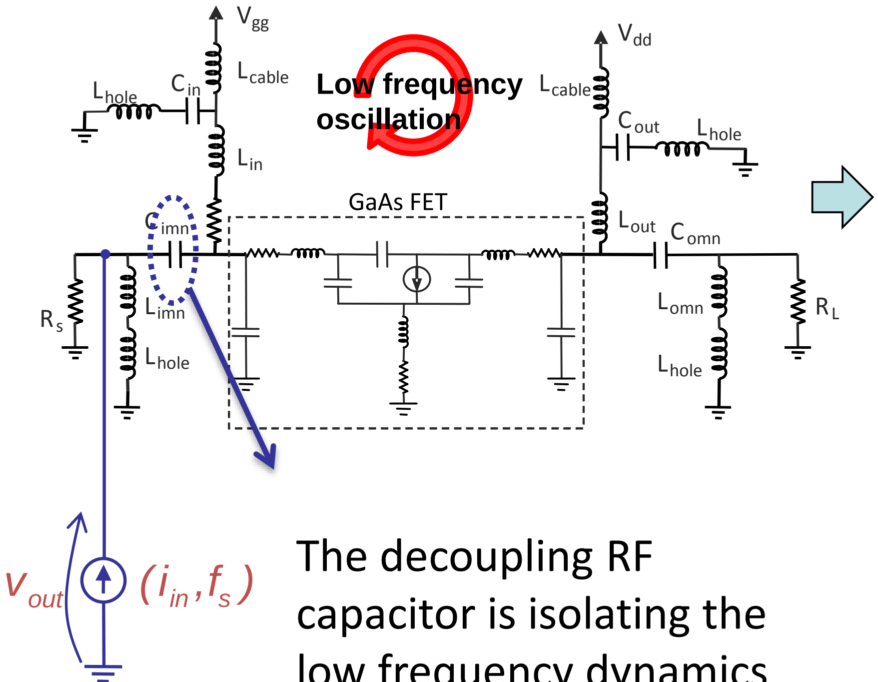


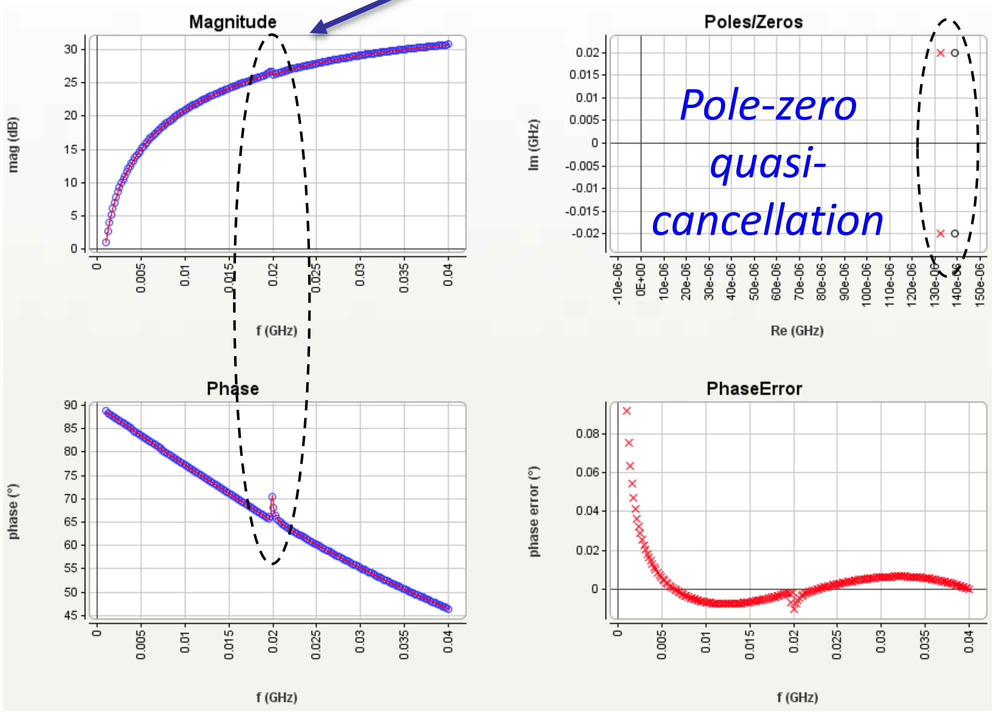
Positive jump of 180º in the phase revealing the presence of the RHP complex conjugate poles

2.1 Physical quasi-cancellations

Example: amplifier with low frequency oscillation involving elements of the bias networks

If the analysis node is before the RF decoupling capacitor → low sensitivity → critical poles are quasi-cancelled by zeros. The effect on the transfer function is very slight.





The decoupling RF capacitor is isolating the low frequency dynamics from the analysis node

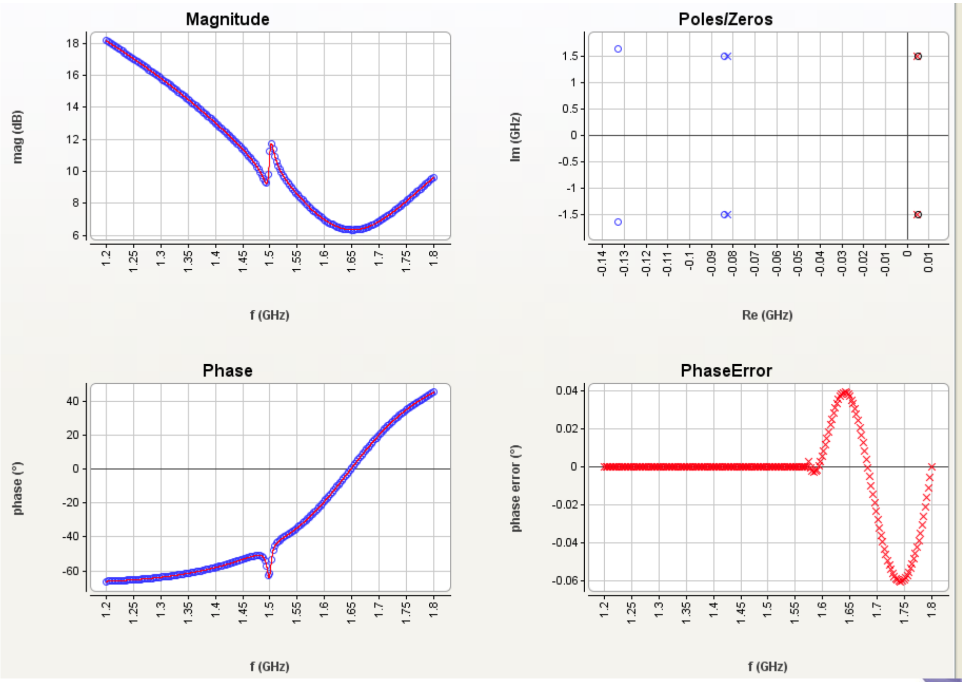
2.1 Physical quasi-cancellations

In summary, we call **“physical” quasi-cancellation**, this kind of quasi-cancellation that is reflecting the low sensitivity of part of the circuit dynamics from the analysis node (or branch)

IMPORTANT:

1 – If properly used, STAN identification is powerful enough to detect the slightest resonances

2 – If a physical quasi-cancelation appears in the RHP the circuit is unstable



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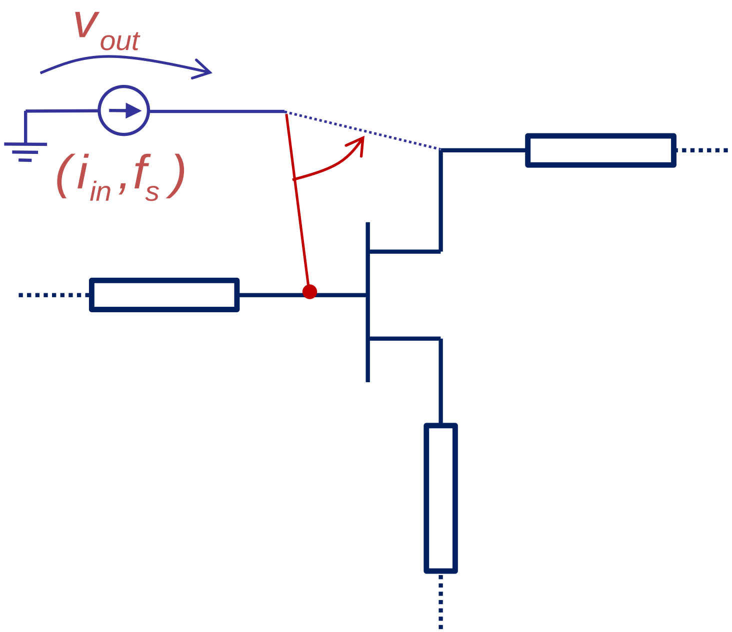
2.1 Physical quasi-cancellations

Recommendation

In general, connect the current source the closest to the input and/or output of the active devices (gate and drain, base and collector…) to get the best sensitivity.

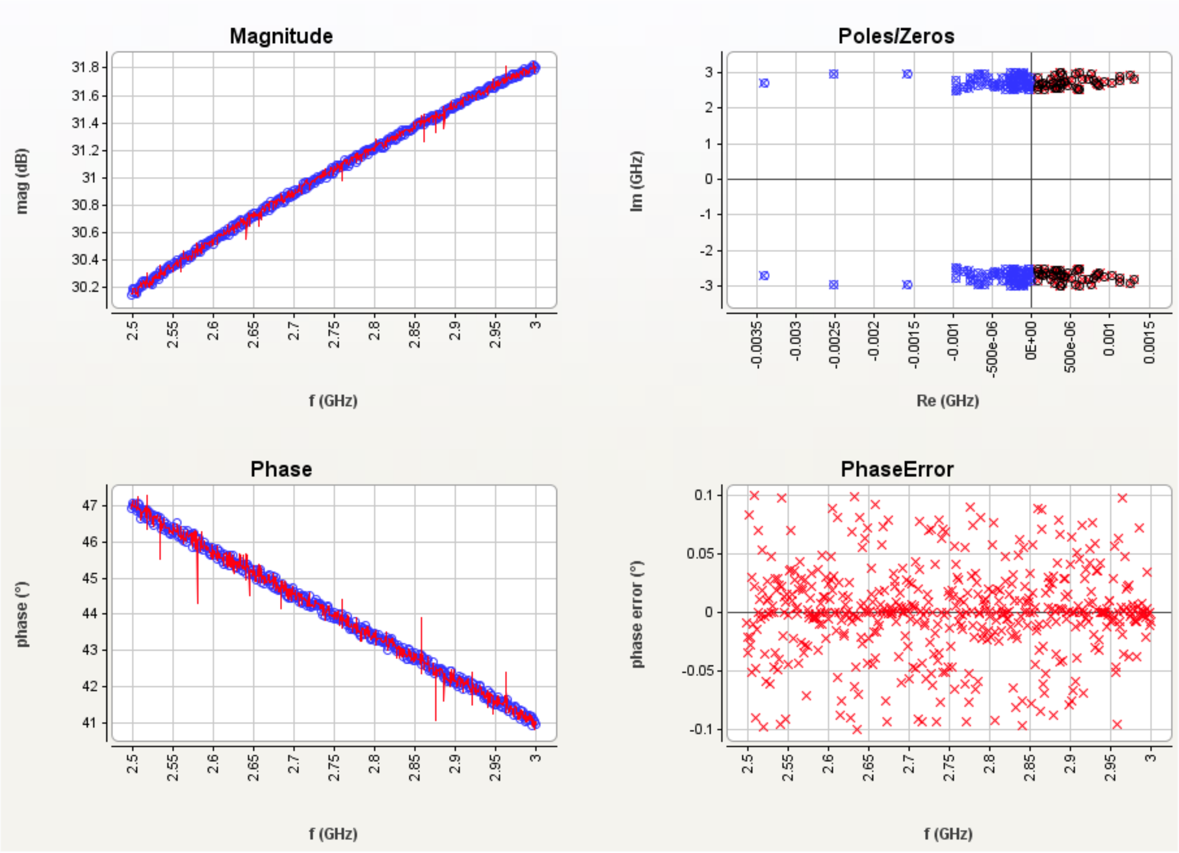


The same holds if you perform an admittance analysis with a voltage source in series at a branch

Document Outline

2.2 Numerical quasi-cancellations

Unfortunately, there is another possible origin for quasi-cancellation → Those coming from the fitting of the numerical noise present in the frequency response



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2.2 Numerical quasi-cancellations

Noise in a simulated frequency response can have different sources and different amplitudes:

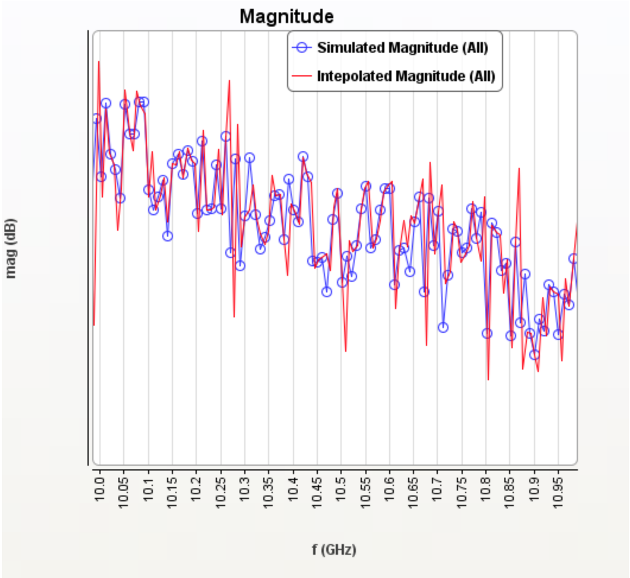
• Numerical noise raises if we need to relax final errors to help convergence in harmonic-balance simulations.

• Generally, amplitude of numerical noise is larger if passive blocks simulated with EM simulators are used in the electrical simulation.

• Inappropriate interpolation between widely spaced frequency points in a S-parameter file can also generate significant amount of numerical error.

• Truncation of the data precision in the frequency response is another source of numerical noise.

• We can even have measurement noise if S-parameter blocks obtained from a experimental characterization are used in the simulation.



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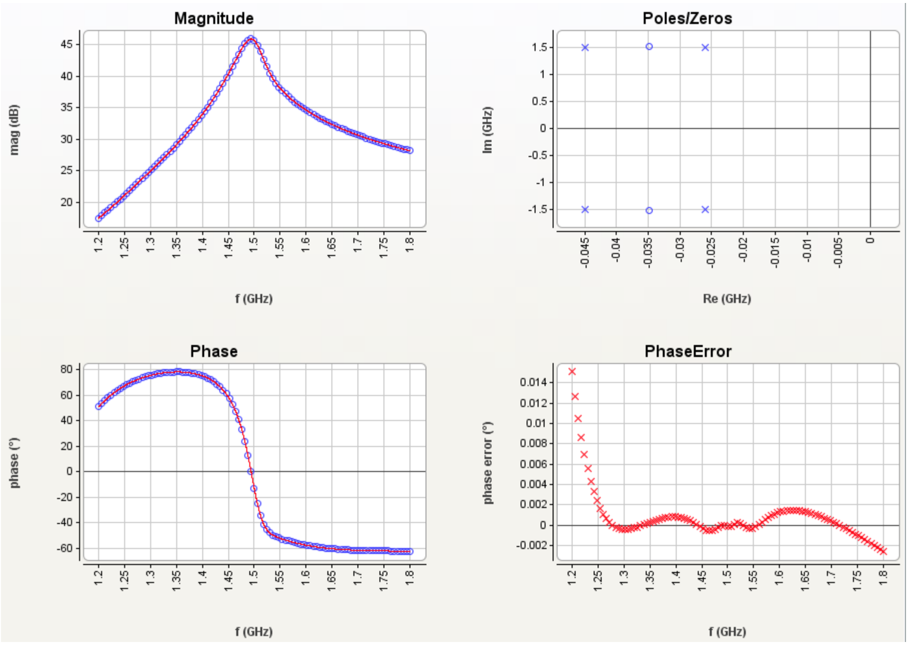
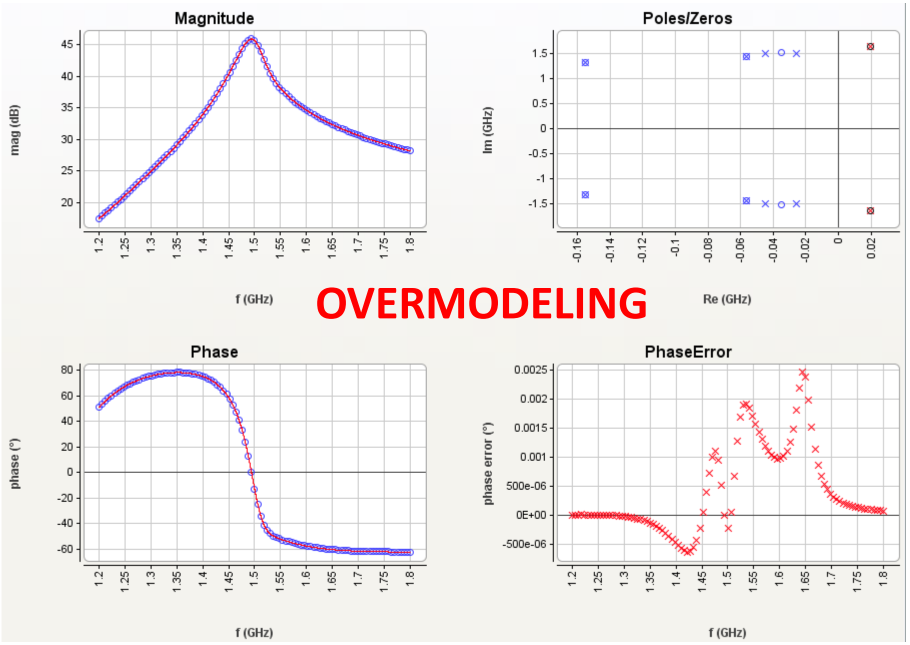
2.2 Numerical quasi-cancellations

Even when numerical noise is very low, quasi-cancellations can happen if we manually select an order for the transfer function that is far too high for the system dynamics: this is called **over-modeling**.

See for instance this simple frequency response, that is obtained with an accurate electrical simulation ensuring very small level of numerical noise.



With order n=6 the dynamics is perfectly modeled

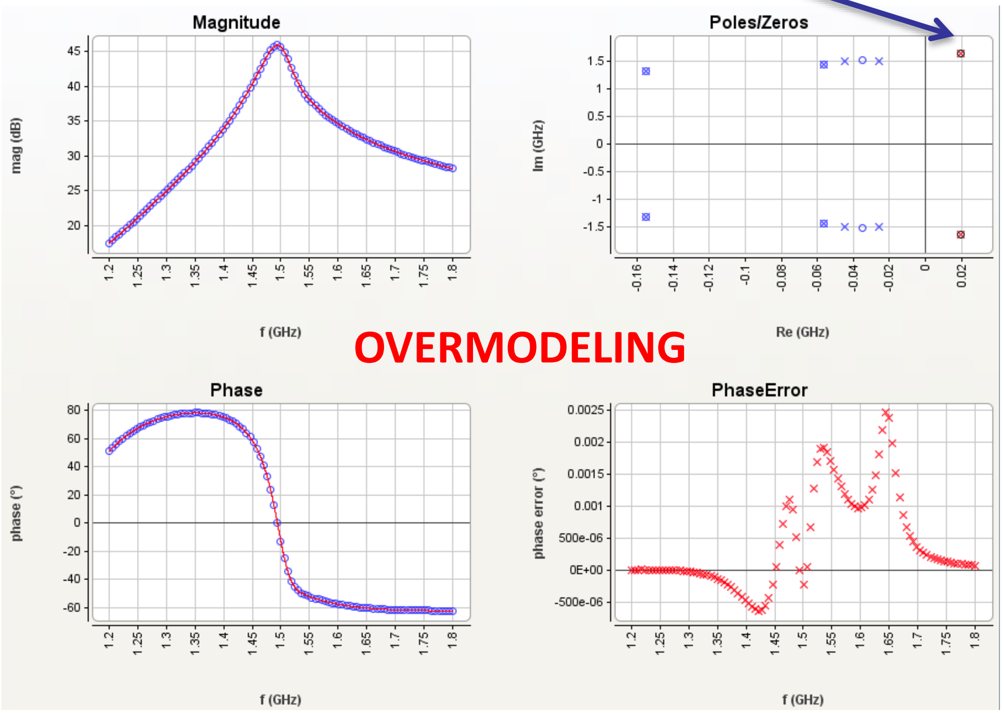


With order n=20 the dynamics is modeled, but numerical quasi-cancellations appear

2.2 Numerical quasi-cancellations

This is problematic when the numerical quasi-cancellation appears on the RHP because it does not represent an actual oscillation!!!!

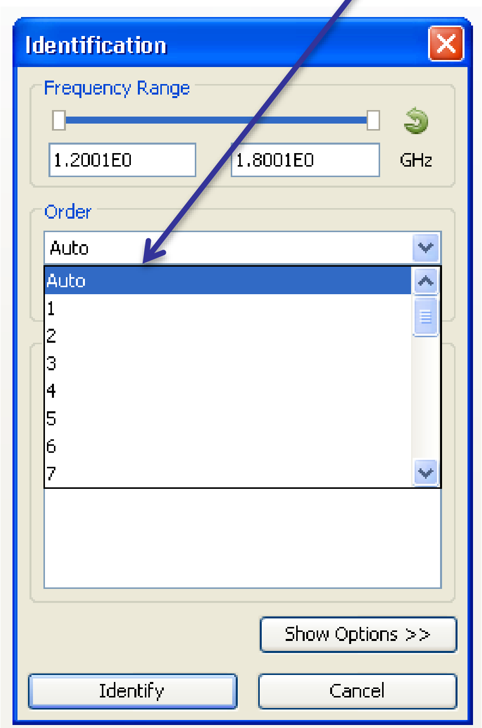
order n=20



Note that, a priori, we do not know the order of the transfer function

2.2 Numerical quasi-cancellations

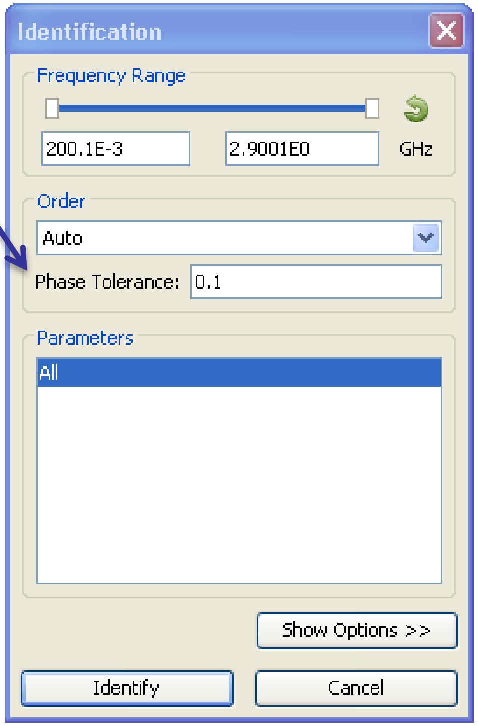
STAN Tool has an automatic algorithm for the selection of the order of the transfer function that minimizes the numerical quasi-cancellations on the RHP due to overmodeling



This automatic algorithm is controlled by a phase tolerance parameter

✓ This is the maximum allowed phase error between the frequency response and the identified transfer function.

✓ The automatic algorithm fits the frequency response until this phase error is lower than the selected phase tolerance in all the analyzed frequency band.



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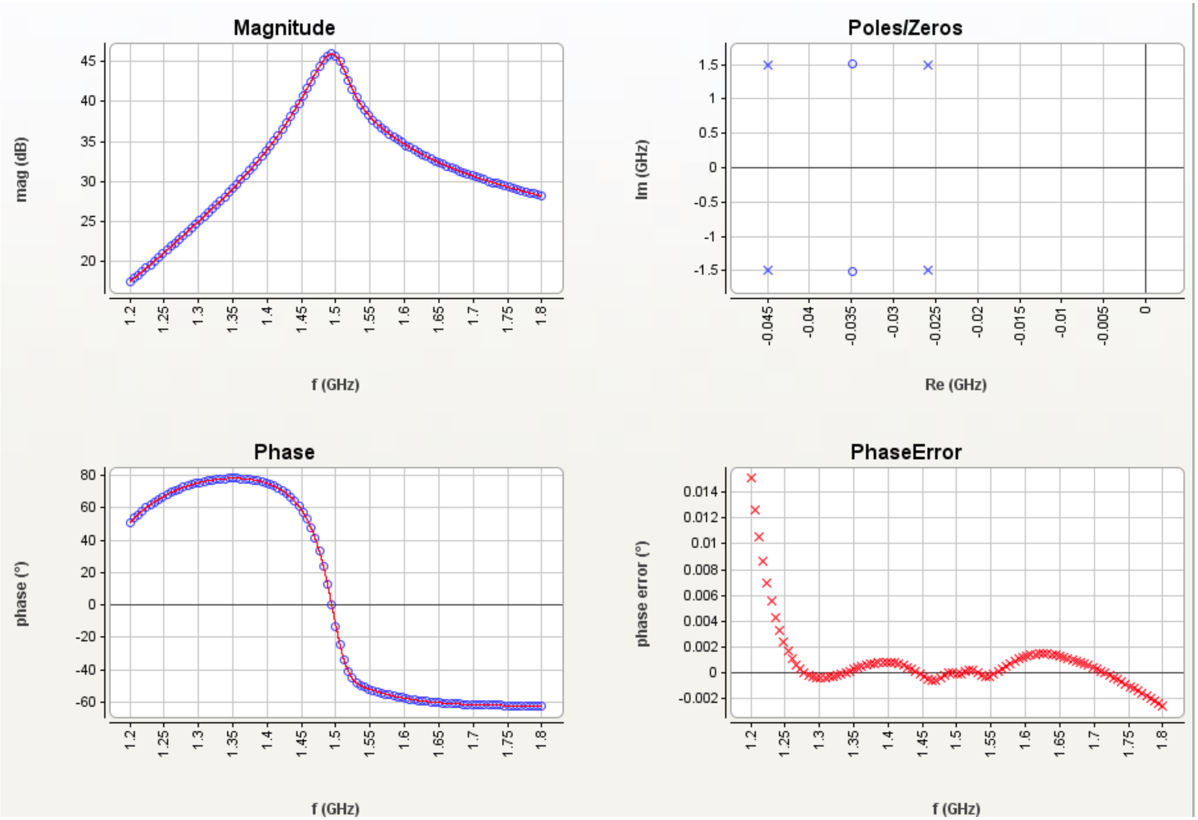
2.2 Numerical quasi-cancellations

See the application of the automatic algorithm to the previous frequency response **with a phase tolerance of 0.1º** (and compare with results on slide 19):

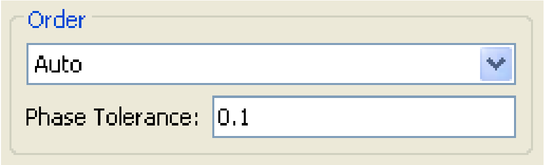


- ✓Phase error remains lower than 0.1º in all the analyzed frequency band.
- ✓No RHP numerical quasi-cancellations take place

2.2 Numerical quasi-cancellations

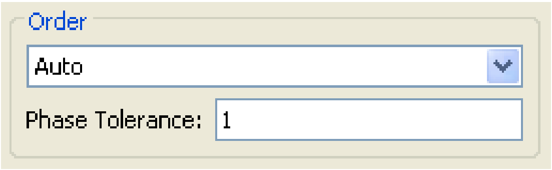
The phase tolerance parameter can be relaxed in the presence of noise

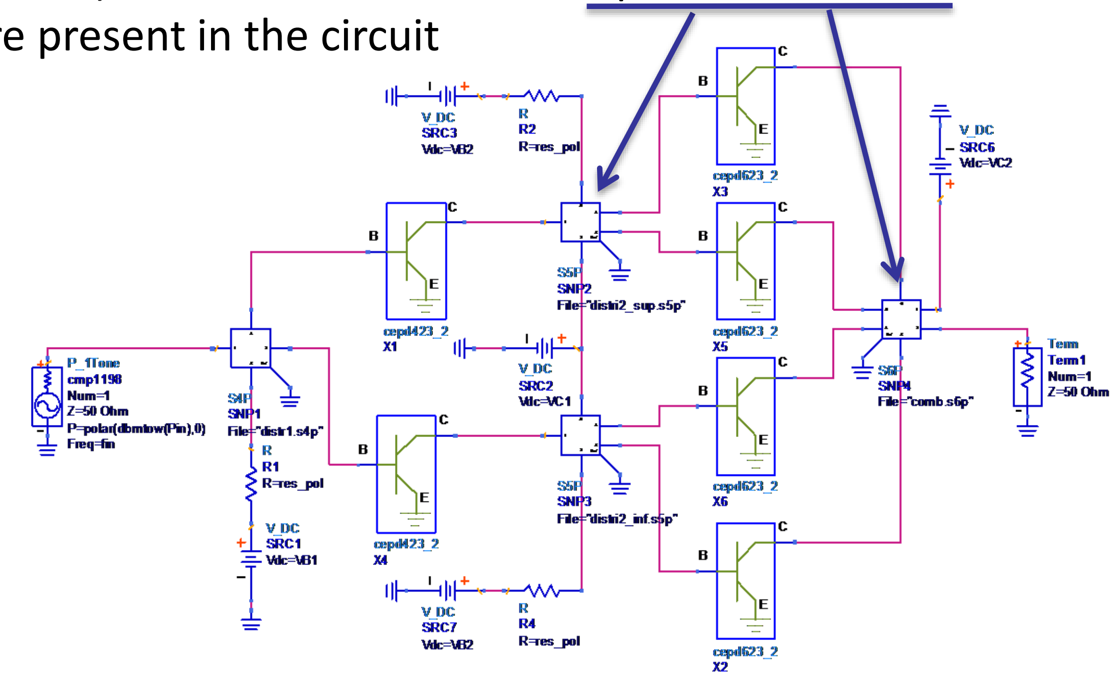
The default value is 0.1º



This is recommended for electrical simulations performed with standard precision and no S-parameter blocks from EM simulations or measurements, no truncation, no simulation defaults, etc.

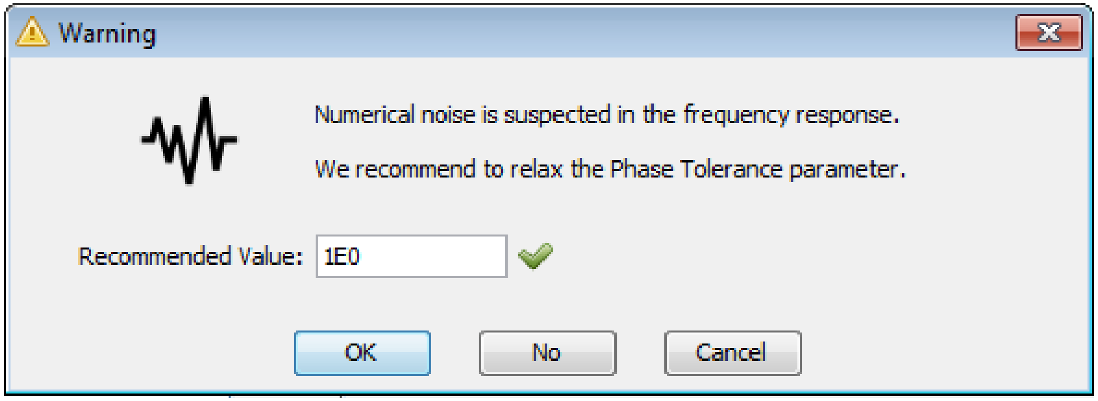
Relaxing this value (to 1º for instance) is recommended when S-parameter blocks from EM simulations or measurements are present in the circuit





2.2 Numerical quasi-cancellations

To guide the user, the automatic algorithm of STAN detects the presence of noise in the frequency response and provides a warning. A recommendation is given to relax the Phase Tolerance parameter to avoid over-modeling.



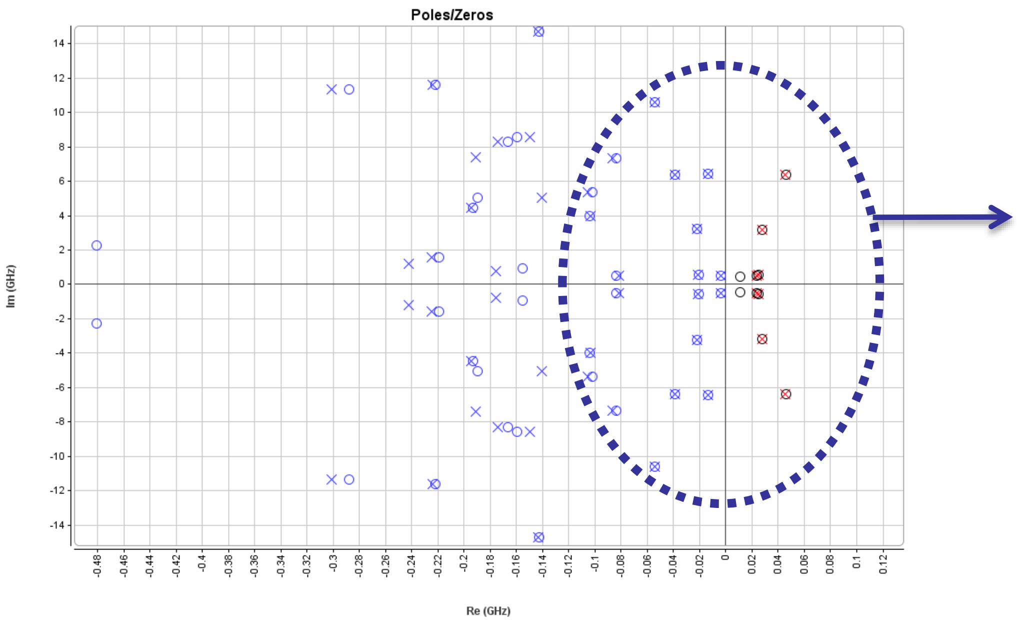
Note: new algorithm is implemented in IVCAD v3.5, more robust to noise.

Document Outline

3. How to distinguish physical/ numerical

The automatic algorithm of STAN tool is very useful to minimize the presence of numerical quasi-cancellations on the RHP originated by over-modeling, but still, its effectiveness depends upon the selection of the Phase Tolerance that is controlled by the user.

Example, if you find a pole-zero plot with a bunch of RHP quasi-cancellations , most likely you are facing an over-modeling problem. **You should relax the Phase Tolerance**.



Quasi-cancellations most probably originated by over-modeling

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3. How to distinguish physical/ numerical

If we have doubts to determine whether a RHP quasi-cancellation is physical or numerical, we suggest to follow these three tips that are explained in the next slides:

3.1 – Perform narrow band identification about the frequency of the critical poles

3.2 – Perform a parametric identification varying a circuit parameter

3.3 – Perform the analysis at multiple observation ports

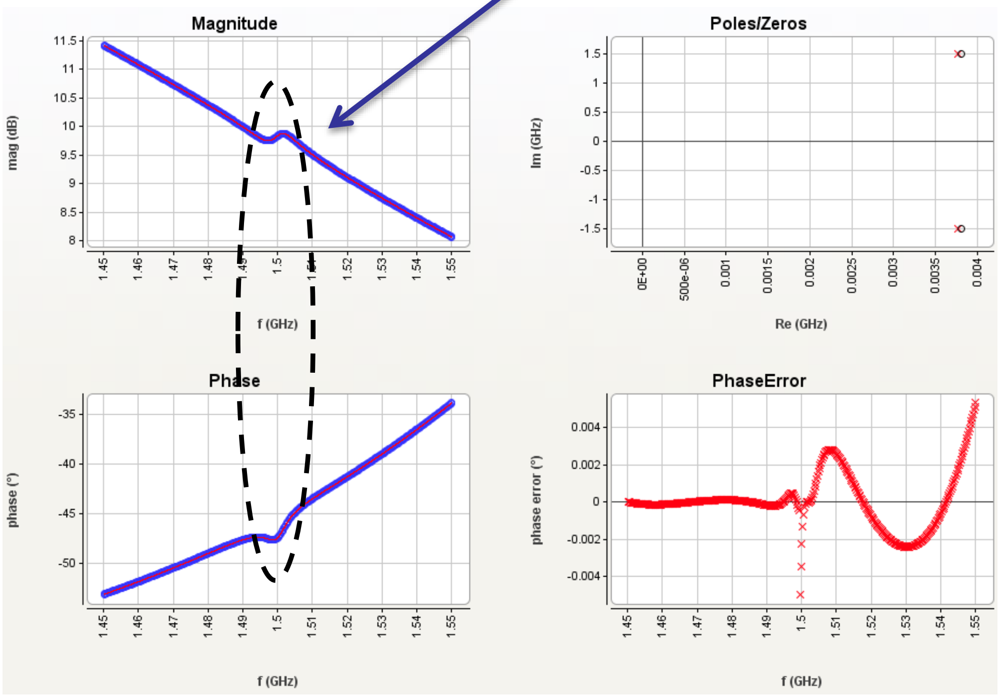
Document Outline

3.1 Narrow bandwidth identification

Perform narrow band identification about the frequency of the critical poles

Center the analysis on a sub-band about the frequency of the RHP poles and re-identify, ensuring a fine frequency step (if needed simulate again)

Then, verify graphically that the quasi-cancellation persists and correlates with a tiny, although appreciable, resonance in the frequency response



Now we are sure that the RHP quasi-cancellation is actually modeling a physical instability observable in the frequency response

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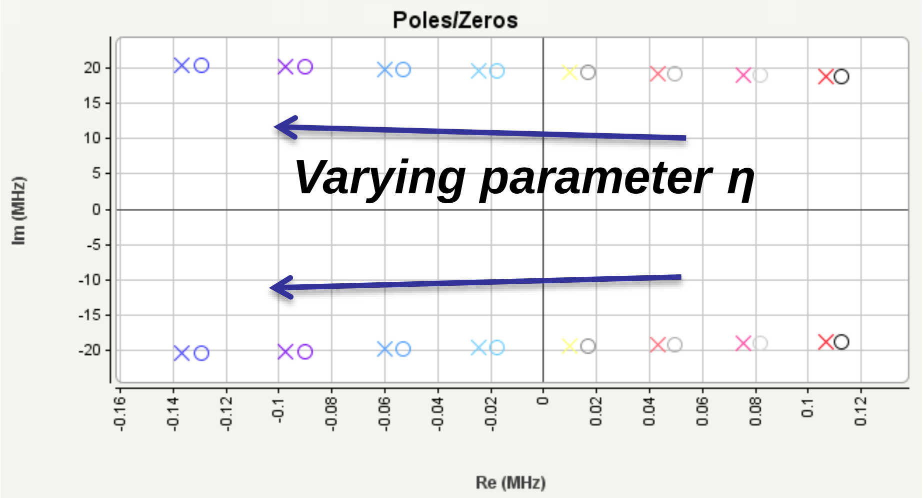
3.2 Parametric analysis

Perform a parametric identification varying a circuit parameter
Poles from numerical quasi-cancellations do not follow a deterministic path versus a relevant circuit parameter like bias voltage or input power, etc.

Therefore it is always recommended to perform a parametric analysis to observe the evolution of the poles. The best is to see them crossing from the RHP to the LHP as a parameter associated to the gain of the active is varied. For the poles to be physical (not numerical), the unstable poles have to cross to the LHP plane as the transistor tends to pinch-off. This can be done varying Vgs bias voltage from active to pinch-off in the case of a FET amplifier, for instance. Other parameter variations are possible as well, obviously.

Physical quasi-cancellation that has a deterministic path crossing the imaginary axis versus the parameter η



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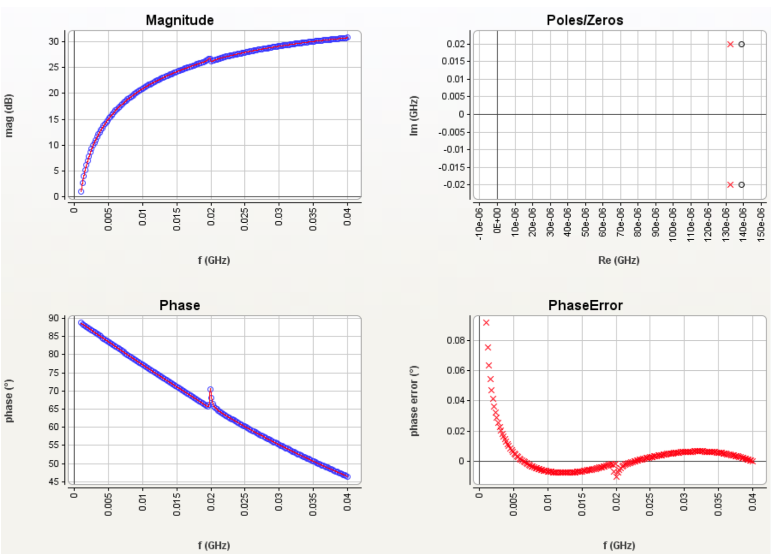
3.3 Analyses at multiples nodes

Perform the analysis at multiple observation ports

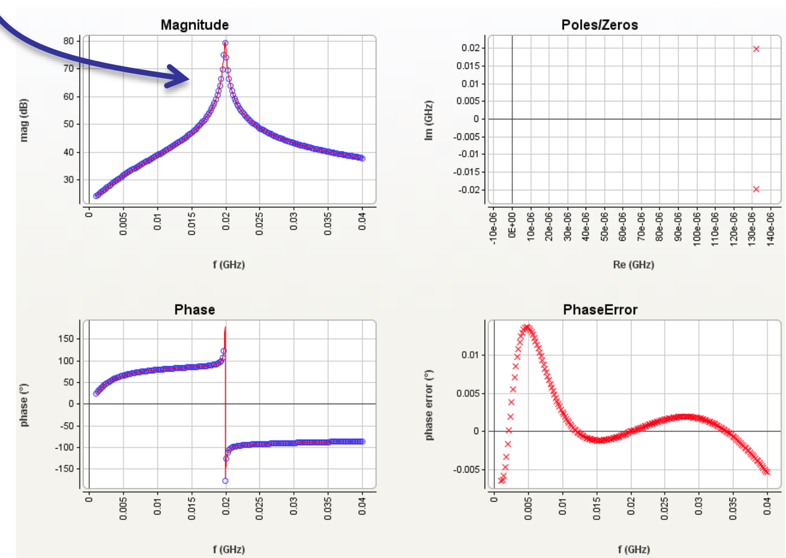
As seen in section 2.1, physical quasi-cancellations are associated to a low sensitivity of the dynamics from the observation port (node or branch at which we are performing the analysis)

Therefore, performing the analysis at other observation ports we should be able to find a node (or branch) at which the unstable resonance is clearly appreciable in the frequency response

Quasi-cancellation



Positive jump in the phase

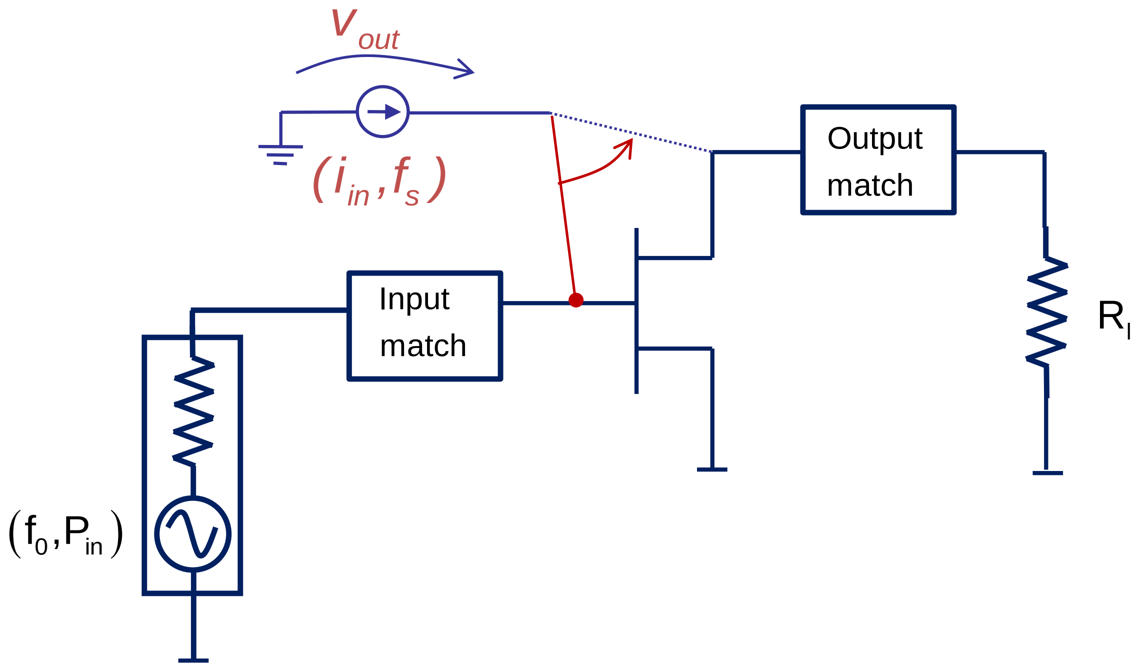


The idea is to always try to find/ select a node with high sensitivity in which the critical pole is not quasi-cancelled and cannot be confused with a numerical pole-zero quasi-cancellation

Document Outline

4. Selecting appropriate nodes for the analysis

In circuits with only one transistor, it is enough to perform the analysis at the gate or drain (base or collector for bipolar transistors)

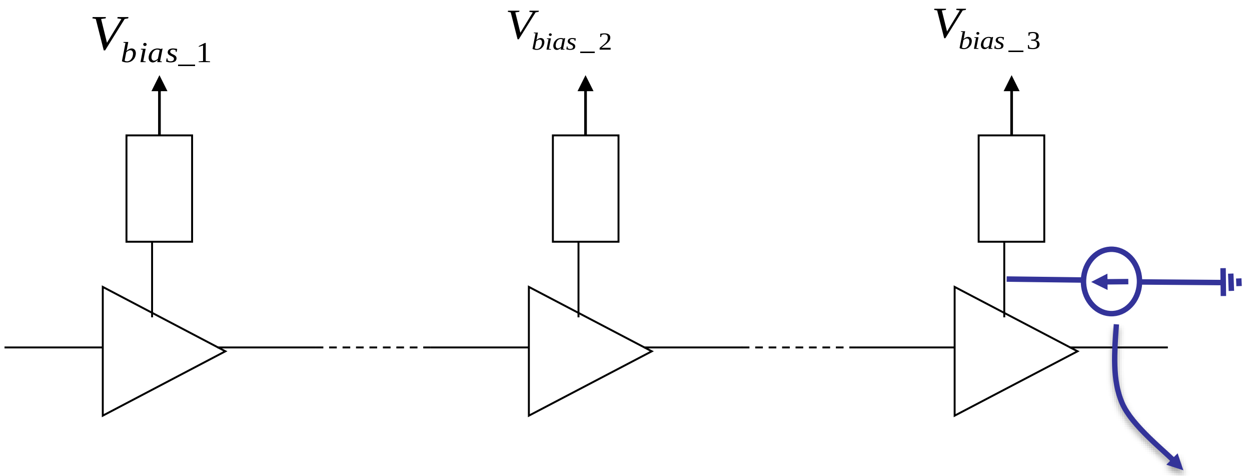


As suggested in section 2.1, the closest to the intrinsic terminals of the transistor, the better

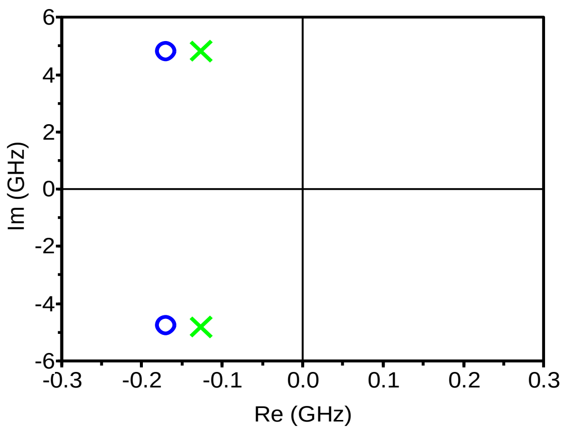
4. Selecting appropriate nodes for the analysis

In multistage circuits: at least one analysis per stage is recommended

Example of a three-stage PA exhibiting an oscillation



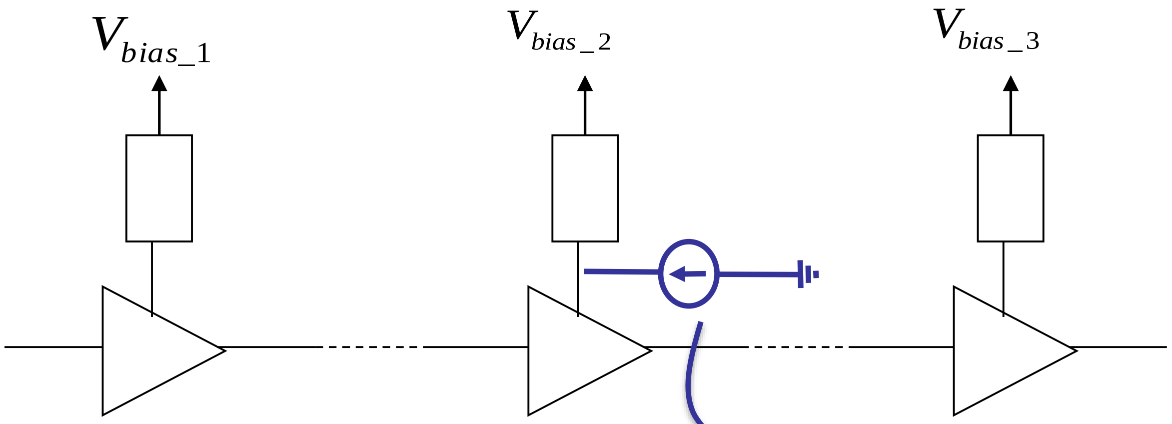
Connecting the probe to a node of the 3rd stage, no instability is detected (we are electrically isolated from where the actual oscillation takes place)



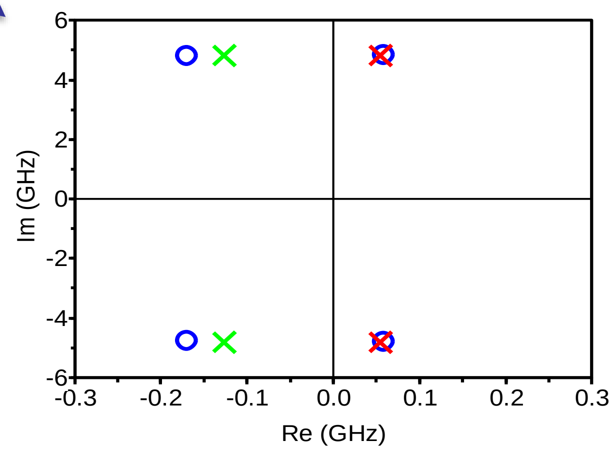
4. Selecting appropriate nodes for the analysis

In multistage circuits: at least one analysis per stage is recommended

Example of a three-stage PA exhibiting an oscillation



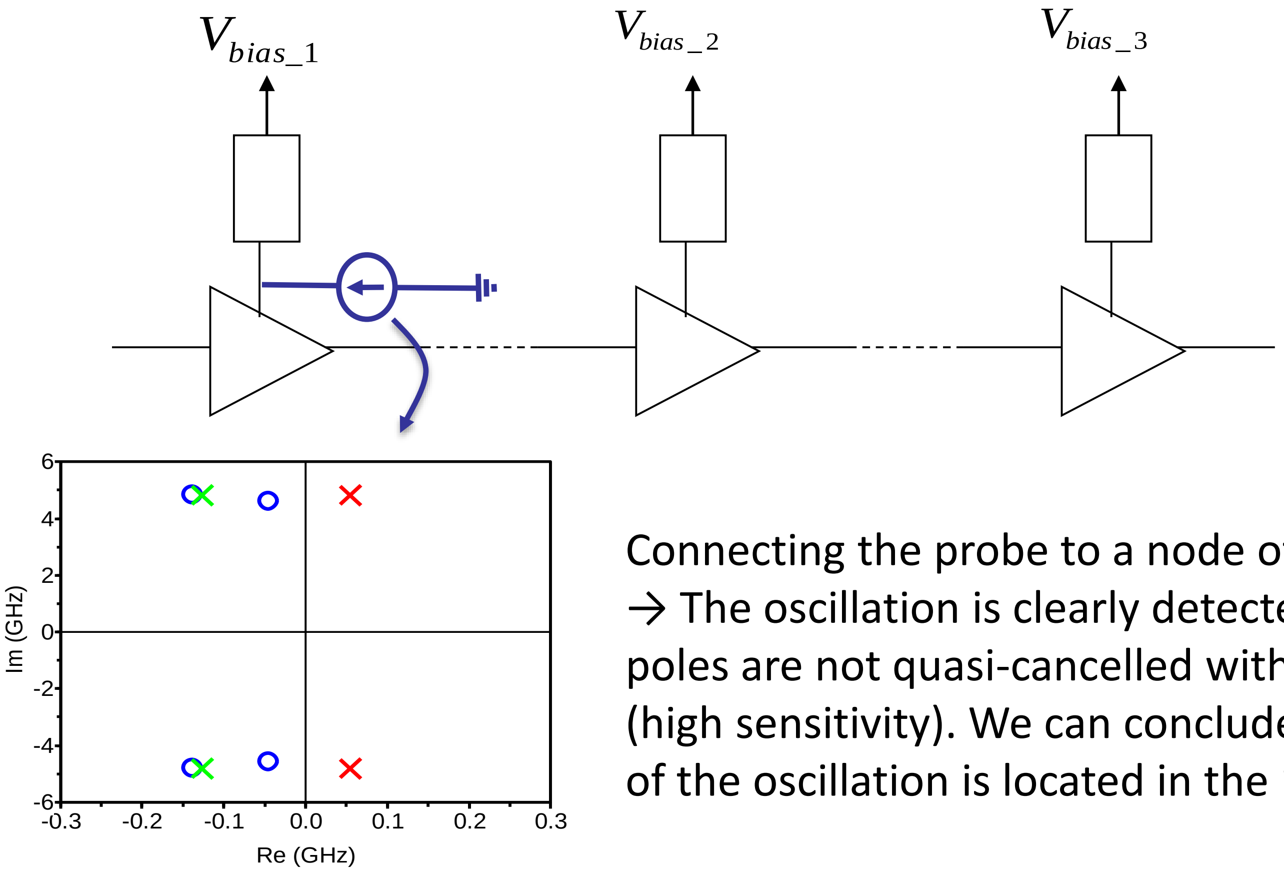
Connecting the probe to a node of the 2nd stage → physical quasi-cancellation (we still have low sensitivity from the observation port)



4. Selecting appropriate nodes for the analysis

In multistage circuits: at least one analysis per stage is recommended

Example of a three-stage PA exhibiting an oscillation

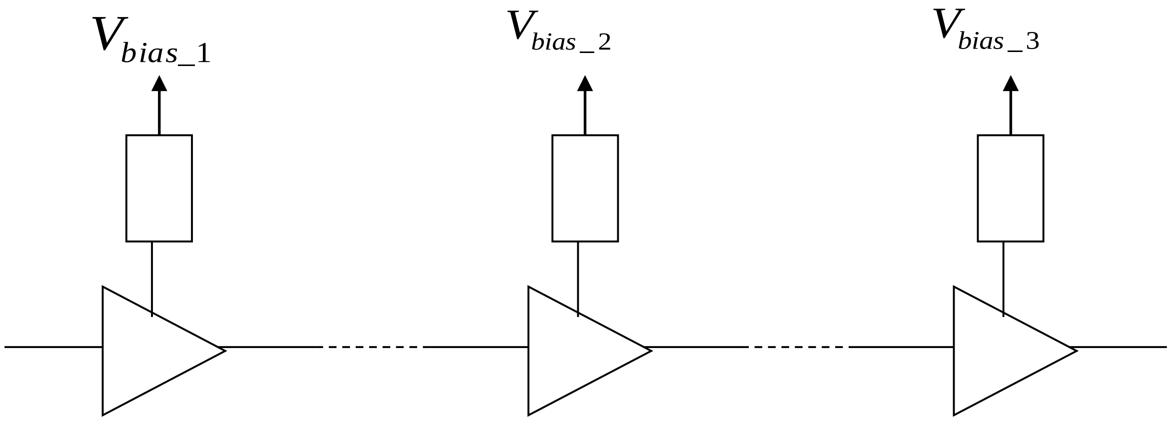


Connecting the probe to a node of the 1st stage → The oscillation is clearly detected, unstable poles are not quasi-cancelled with nearby zeros (high sensitivity). We can conclude that the origin of the oscillation is located in the 1st stage

4. Selecting appropriate nodes for the analysis

In multistage circuits: at least one analysis per stage is recommended

Example of a three-stage PA exhibiting an oscillation

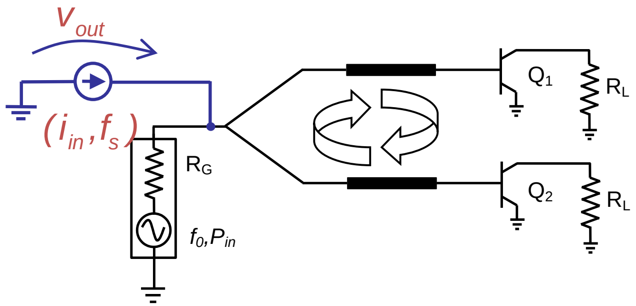


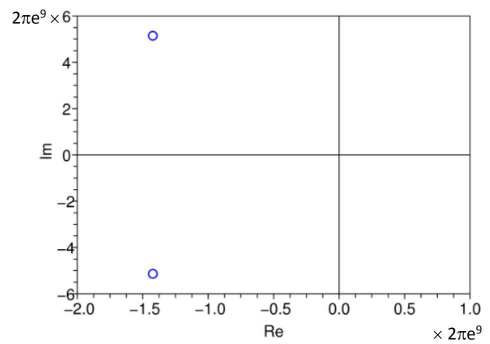
From the analysis at multiple nodes, relevant information about the nature of the oscillation and the place in which it is being generated can be extracted
→ Very useful for circuit stabilization

4. Selecting appropriate nodes for the analysis

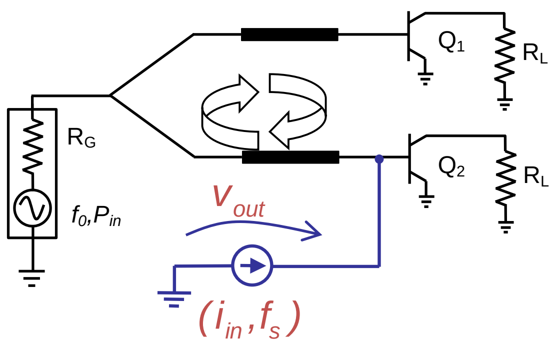
Amplifiers with power combining structures

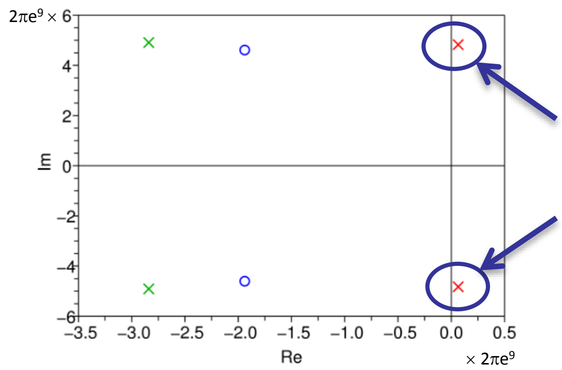
Oscillation at the fundamental frequency divided by two ($f_0/2$) is very common in amplifiers with parallel power combining structures. This kind of oscillation is generally odd mode (one part of the circuit oscillating 180º out of phase with other part) due to the circuit symmetry. As a result, combination nodes represent virtual ground for the odd mode oscillation, which translates into an exact pole-zero cancellation if the analysis is performed at that node.





Odd mode oscillation is not detected at the combining node. Exact pole-zero cancellation





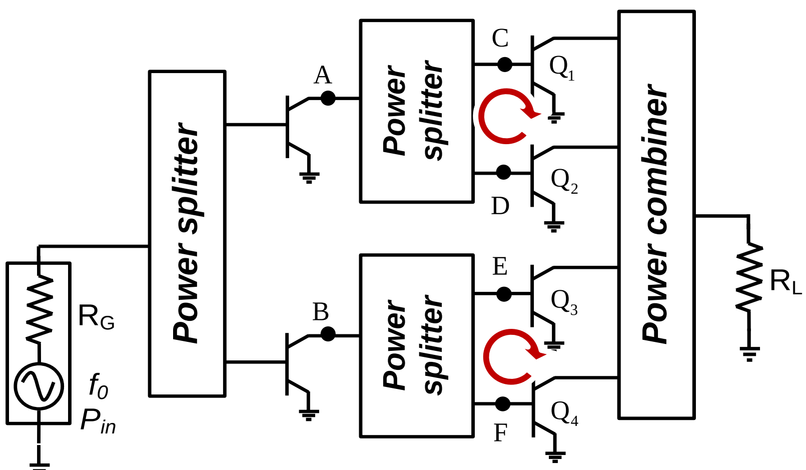
Odd mode oscillation is clearly detected at the gate of the transistors

4. Selecting appropriate nodes for the analysis

Amplifiers with power combining structures

Repeating the analysis at different nodes (gate/drain or base/collector) and analyzing where the oscillation is observable and where is not, one can conclude on the nature of the oscillation

Example: Detection of parametric frequency division in a X-band power amplifier



Instability detected at nodes C, D, E and F and non-detected at nodes A and B

Conclusion: Odd mode oscillation [+ - - +] → Q_1 oscillates out of phase with Q_2, same for Q_3 and Q_4 → with this information, stabilization resistances can be connected at optimum places