AMCAD Engineering
Advanced Modeling for Computer-Aided Design

How to Select the Frequency Range for Analysis ?

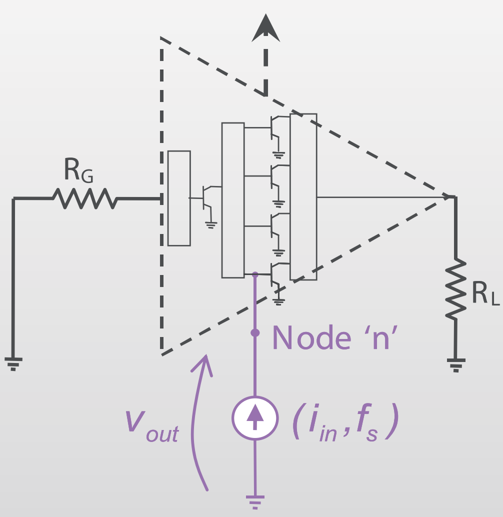
STAN TOOL

Introduction

STAN tool and pole/zero identification technique is based on obtaining a frequency response that contains the stability information. Therefore, the first step of the stability analysis method is to obtain a SISO (Single-Input, Single-Output) frequency response of your circuit.
This application note provides guidelines to select the frequency analysis range to set when running the simulation in your EDA software.

Frequency Response on a DC solution (small-signal)

For the stability analysis of a DC state the small signal source frequency f_s must be swept throughout the whole desired range of frequencies for which the stability of the circuit is to be analyzed. Therefore the frequency response must be calculated for the whole range of frequencies in which the active devices display gain. Frequency sweep is defined from low-frequencies (depending on the validity domain of your models) up to your active devices Ft or Fmax.
It is recommended to do the low-frequency (LF) part separately or use a log sweep to avoid losing information at LF if the sweep covers several decades.



With AC simulation, sweep the f_s frequency from low-frequencies to the max gain of your devices

Do the LF separately or use a log sweep

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freq	mag (Z)	phase (Z)
1.000 MHz	10.332	90.003
11.00 MHz	216.618	91.941
21.00 MHz	270.189	-92.672
31.00 MHz	104.612	-90.829
41.00 MHz	65.997	-90.299
51.00 MHz	47.193	-89.998
61.00 MHz	35.371	-89.798
71.00 MHz	26.831	-89.667
81.00 MHz	20.060	-89.595
91.00 MHz	14.297	-89.585
101.0 MHz	9.095	-89.647
111.0 MHz	4.145	-89.794
121.0 MHz	0.795	89.951
131.0 MHz	5.958	89.554
141.0 MHz	11.599	88.969
151.0 MHz	18.047	88.123
161.0 MHz	25.766	86.902
171.0 MHz	35.480	85.120
181.0 MHz	48.404	82.446
191.0 MHz	66.727	78.252
201.0 MHz	94.580	71.219
211.0 MHz	138.977	58.377
221.0 MHz	199.477	33.980
231.0 MHz	219.444	-1.348
241.0 MHz	176.951	-28.478
251.0 MHz	135.681	-42.995
261.0 MHz	108.466	-50.829
271.0 MHz	90.570	-55.440
281.0 MHz	78.205	-58.363
291.0 MHz	69.241	-60.317
...	...	...

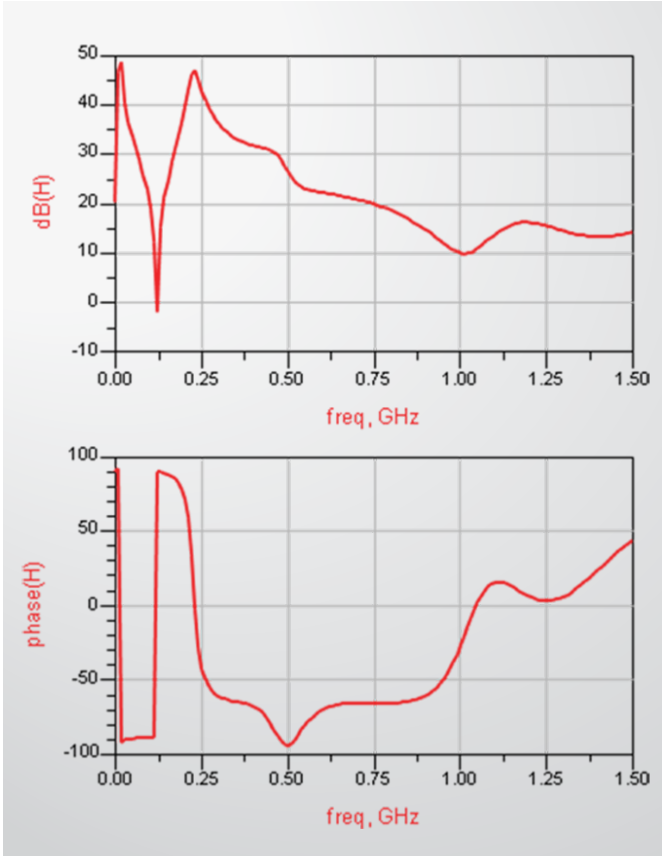
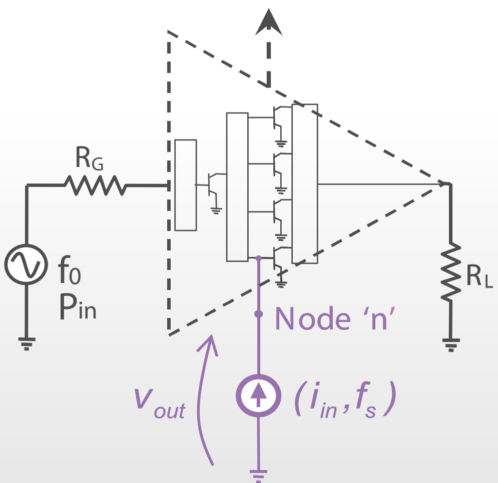


Fig. *Frequency response obtained from Agilent ADS*

Frequency Response around a periodic state (large-signal)



Let's consider initially the circuit operating in the periodic state forced by a large signal input generator at the fundamental frequency f_0. Under these large signal operating conditions a small signal RF current source i_{in} is introduced in parallel to the frequency f_s in a node of the circuit.

This current source represents input of the LTV (Linear Time-Varying) system and has a single frequency component at f_s. The output voltage v_{out} in this node is the output of the LTV system and has frequency components (corresponding to the mixing terms)

$$n f_0 \pm f_s \qquad n = -NH,...0,...,NH$$

NH being the number of significant harmonics of the fundamental frequency f_0 (k = 2NH+1 at total).
Thus k frequency responses can be obtained, each relating one of the frequency components of the output signal $v_{out}(j\omega)$ with the small signal input signal $i_{in}(j\omega_s)$.

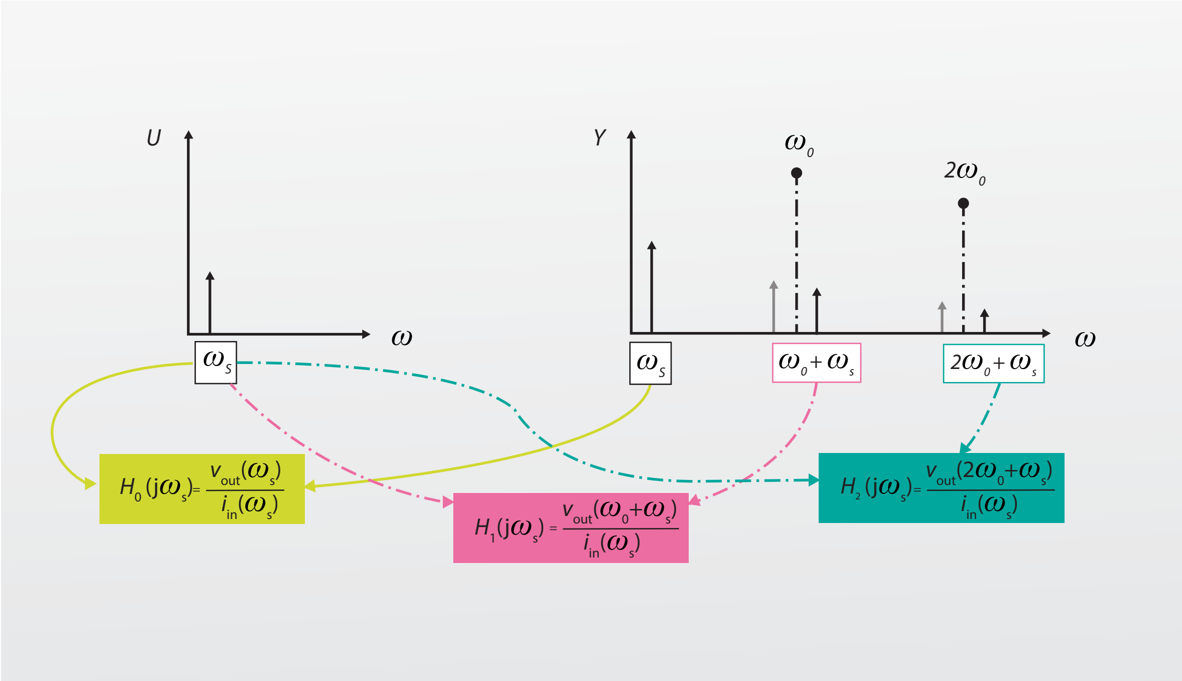


Fig. *Transfert functions $H_k(jw_s)$ with $k \geq 0$*

From a single harmonic balance analysis in mixer mode in which the frequency ω_s of a current probe is swept, any of the $H_k(j\omega_s)$ can be obtained. In the mixer mode analysis, the large signal input signal f_0 plays the role of the local oscillator signal while the small signal input to f_s acts as the radio frequency signal.

All the transfer functions $H_k(s)$ share the same denominator; any of the $H_k(j\omega_s)$ have all the Floquet exponents that allow the extraction of information relative to the stability. In particular, one sets out to obtain $H_0(j\omega_s)$ which is the ratio between the output signal v_{out} at the input signal frequency and the small signal input i_{in}. The poles of $H_0(s)$ are the Floquet exponents that determine the stability of the periodic solution.

For the stability analysis of periodic solution, it is sufficient to obtain the frequency response sweeping the frequency f_s of the small signal current source in a band $\Delta f_s = f_0 + \delta$. This is because the Floquet exponents repeat in a periodic manner in the frequency response.

Note: That is true, although in power amplifiers we normally loose sensitivity as we increase in frequency which makes that only a few (two or three) repetitions can be detected in practical circuits. We don't try to find a pole at $\omega_p + 5\omega_0$ for instance.

Thus, analyzing the frequency response of the circuit obtained between $f_{s1} = f_1$ and $f_{s2} = f_1 + f_0 + \delta$ the presence of any instability can be detected. Note that the term δ is introduced with the purpose of obtaining the frequency response in the vicinity of f_0 in order to be able to also detect a possible instability at f_0

In the sweep, **avoid the precise case where the frequency f_s** of the frequency generator **coincides exactly with a harmonic** (not sub-harmonic) of the large signal operating frequency f_0 of the circuit, since in that case the conversion matrix of the mixer mode is singular.

It is important to emphasize that the simulation to obtain the frequency response can be limited to any desired frequency range. Detailed analyses around the frequencies of interest can be carried out with a much lower computation cost. It is interesting, for example, to carry out more meticulous analyses with reference to $f_0/2$ where instabilities frequently appear.

Conclusion

Recommended procedure to select the frequency analysis range:

1- Always do first a small signal stability analysis from low frequencies (LF) to the max gain of the devices. Do the LF part separately or use a log sweep to avoid losing information at LF if the sweep covers several decades.

2- In large-signal stab analysis use [f1, f1 + f0 + δ] but keep in mind at least two things:

- Survey the evolution of the critical poles found in the AC analysis as input drive is increased. Focus the analysis on those bands.
- Focus the analysis also in instabilities that are very common as f0/2

Annex: Mixer-mode vs. 2-tone HB

The mixer mode analysis is based on the conversion matrix methodology, which is the reason why it is adapted to obtain the transfer functions $H_k\ (j\omega_s)$. The conversion matrix provides a precise linear relation between the amplitudes of the sidebands. In the mixer mode analysis, we first obtain the large signal response by carrying out a harmonic balance analysis in the sole presence of the large signal stimulus. Linearizing the circuit around the periodic solution obtained by harmonic balance, we obtain a periodic LTV system to which a small signal excitation is applied in order to finally obtain the complete response of the circuit. The second analysis is linear, hence it is guaranteed that the small signal excitation will not perturb the large-signal steady state. The analysis in mixer mode is very efficient since the required computing time to obtain the conversion matrix is reduced and the harmonic balance analysis is carried out with a single tone. Note: conversion matrix requires that model derivatives are correctly introduced in the non-linear models.

The transfer functions $H_k\ (j\omega_s)$ can also be obtained from a two-tone harmonic balance analysis. Nonetheless, in circuits that involve small and large signal excitations, the mixer mode analysis typically provides more precise results than a multi-tone harmonic balance simulation.

In addition to the reduction of the computation cost and the increase in precision, the main advantage of carrying out a mixer mode analysis instead of a conventional two-tone harmonic balance analysis resides, in the first case, that the preservation of the large signal steady state is assured for any value of amplitude i_{in}. In this manner, it is guaranteed that the system is linear with respect to i_{in}.
Indeed when performing a two-tone harmonic balance analysis the small signal test tone current needs to be selected with care ... too small and we risk the danger of HB noise and too large and the test tone drives the system under test too hard and modify the steady state of the circuit.
Harmonic balance analysis in mixer mode is available in both Agilent ADS and AWR Microwave Office.

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