Custom Frequency Response Analysis (FRA) block for Qspice

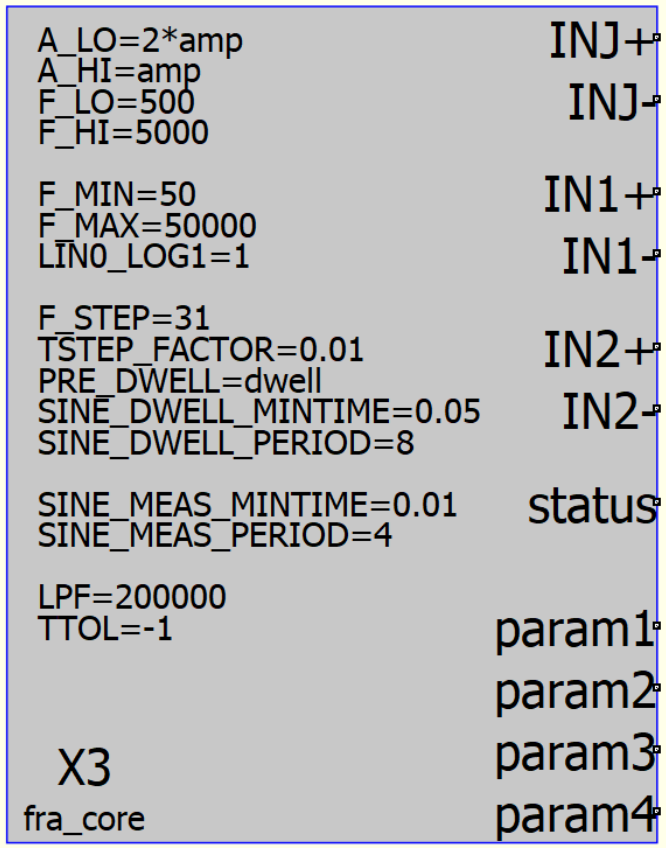
By: Arief Noor Rahman

Background

- In Qspice currently there are two approach for FRA, however they both have their own advantage and disadvantage.
  - To use “.bode” directive
    + Very fast analysis
    - The algorithm is not published
    - Not the best accuracy (from Mike’s word)
    - Performed in post processing
  - To use “.meas fra” directive
    + Utilize standard fourier series algorithm implementation
    + Considered to be the go to reference for standard fra implentation
    - Performed in post processing -> large transient data storage is required and also rather slow

The FRA block - Introduction

- The main motivation to develop this FRA block that runs fast, accurate, and storage efficient (does not require .qraw). Additionally, this FRA block has parameters that is equal to the actual physical FRA analyzer.
- Features:
  - programmable magnitude signal injection
  - programmable linear or logarithmic scale injection frequency stepping
  - programmable startup pre-dwell time
  - programmable injection dwelling time/period
  - programmable measurement dwelling time/period
  - users can easily observe if the time domain data is good enough and made necessary alteration on the FRA block parameters to improve the result
  - Provide param1~4 input to let user save the circuit operation point at the end of pre_dwell period



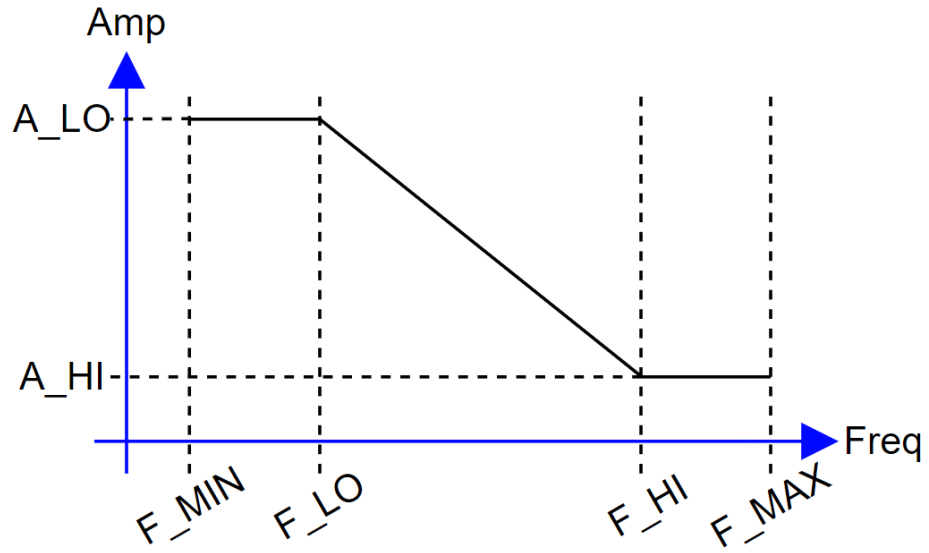
Disadvantage:
The FRA data from this FRA block must be manually imported from the text log data into spreadsheet and plotted.

The FRA block - Under the hood (1)

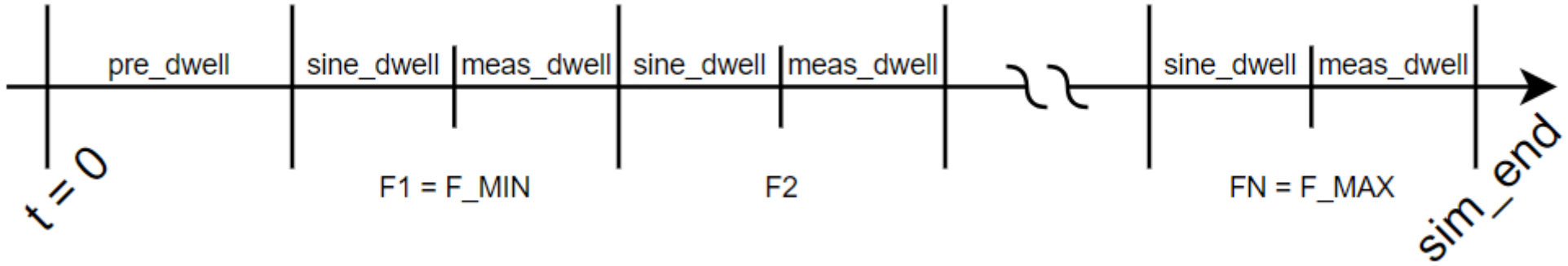
- The core of the FRA block is by simply applying injection signal and analyze the measured input and output signal using fourier series.
- Fourier series is implemented using behavioral source and integral command idt(), as analog integrator implementation will be a lot more accurate compared to the C-block implementation.
- By running the integral command in real time instead of as a post-processing as in the alternative method, our approach is able to run reasonably fast and reliable. *storing transient data into .qraw takes a lot of time
- A C-block is used to control the signal injector (amplitude, frequency, and duration) at different time of the simulation and to sample the integral result to obtain the fourier spectrum.

The FRA block - Under the hood (2)

- Custom user-defined injection amplitude-frequency relationship to maximize the analysis accuracy



- Timing arrangement during the transient simulation from beginning to the end



The FRA block - Under the hood (3)

- To ensure measurement accuracy three dwell times are use in this custom FRA block.
  - pre-dwell time

  This parameter is used to let the FRA block to wait for a certain duration until the circuit can certainly reach steady-state without any disturbance injection. Pre-dwell time only occured one for the whole duration of transient simulation.

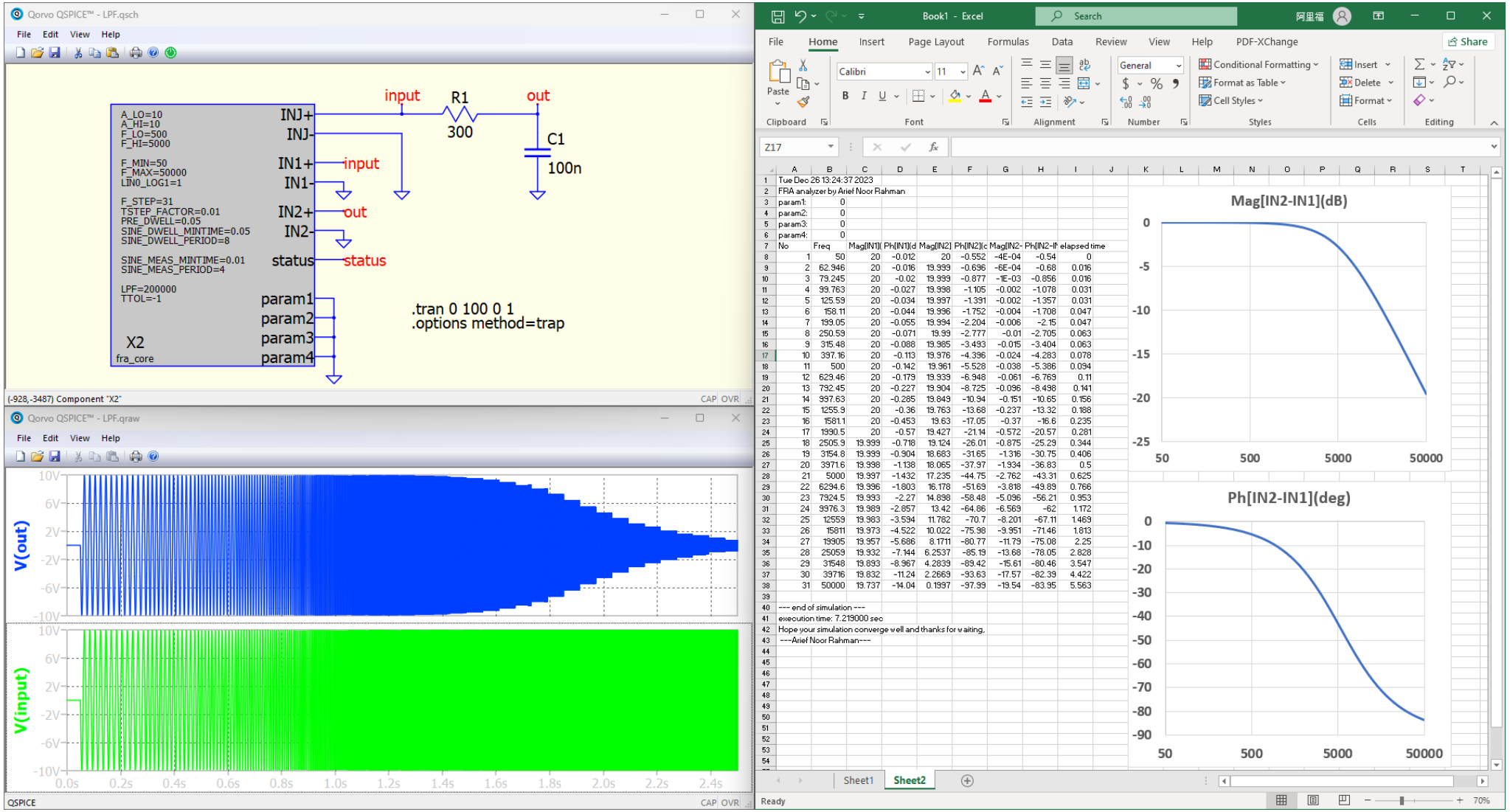
  - sine_dwell_mintime and sine_dwell_period

  These parameter is used to let the circuit reach the next bounded AC steady-state with various AC disturbance injection. The C-block will choose the one with the longest duration for any given frequency.

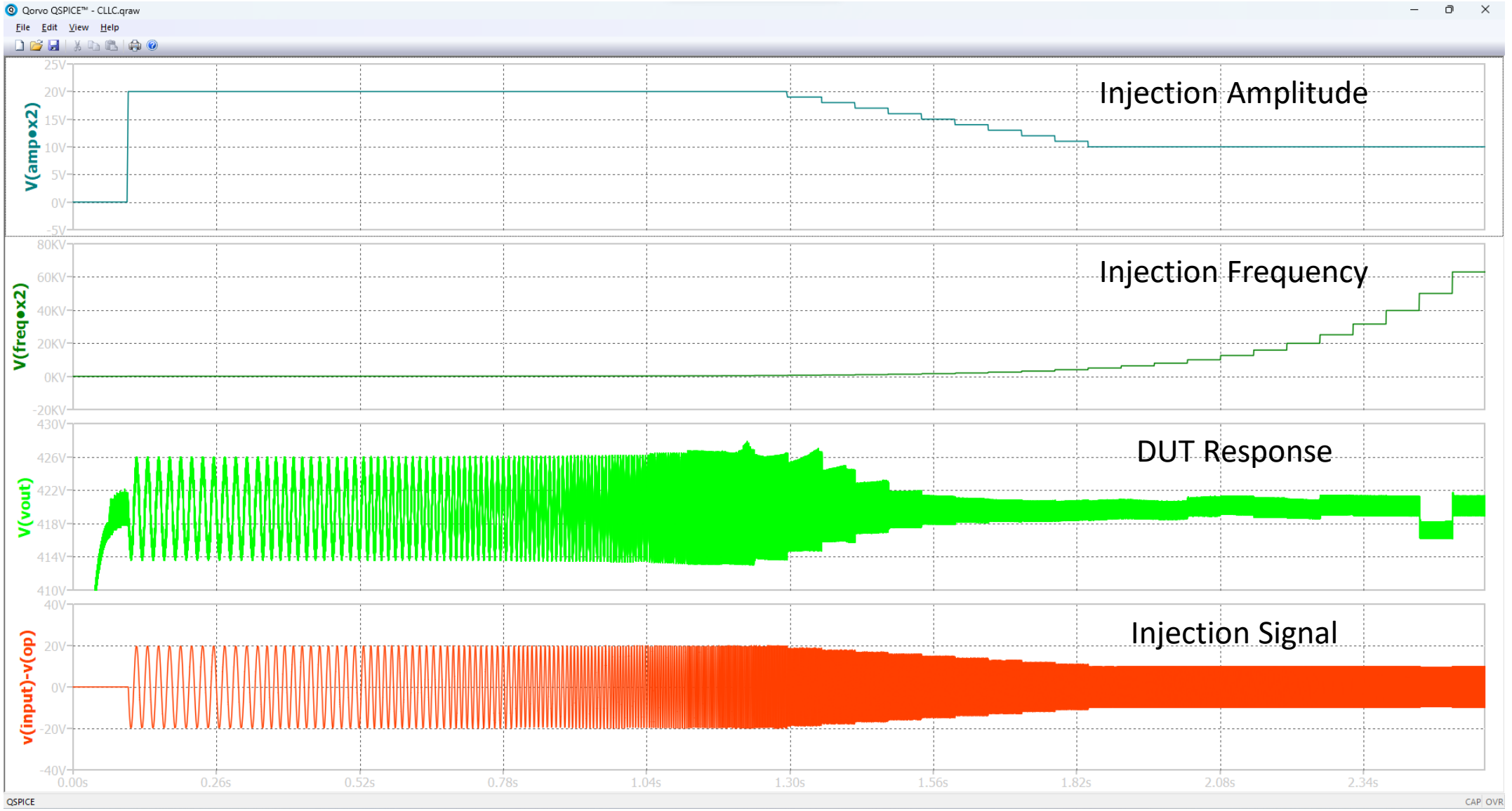
  - sine_meas_mintime and sine_meas_period

  These parameter is used by the c-block to determine the sampling duration of the fourier series spectrum. The C-block will choose the one with the longest duration for any given frequency.

Basic Example



DUT Converter Example Waveform Output



DUT Converter Example Data Output

```
Tue Dec 26 12:32:14 2023
FRA analyzer by Arief Noor Rahman
param1: 53.454545
param2: 420.000000
param3: 1010.237615
param4: 0.000000
```

No	Freq	Mag[IN1](dB)	Ph[IN1](deg)	Mag[IN2](dB)	Ph[IN2](deg)	Mag[IN2-IN1](dB)	Ph[IN2-IN1](deg)	elapsed time
1	50.00000	26.02060	-0.01432	14.39503	-4.95882	-11.62557	-4.94449	12.906
2	62.94627	26.02060	-0.01803	14.41661	-7.03241	-11.60399	-7.01437	20.047
3	79.24466	26.02060	-0.02271	14.45445	-8.98246	-11.56615	-8.95975	25.813
4	99.76312	26.02060	-0.02859	14.50291	-11.25047	-11.51769	-11.22187	30.313
5	125.59432	26.02059	-0.03601	14.57973	-14.13339	-11.44086	-14.09738	33.922
6	158.11388	26.02059	-0.04534	14.66534	-17.61435	-11.35524	-17.56901	36.813
7	199.05359	26.02059	-0.05706	14.78722	-22.20267	-11.23337	-22.14561	39.547
8	250.59362	26.02058	-0.07185	15.03932	-28.50717	-10.98125	-28.43531	42.125
9	315.47867	26.02056	-0.09018	15.25736	-37.56457	-10.76320	-37.47438	44.610
10	397.16412	26.02057	-0.11357	15.46962	-51.16427	-10.55095	-51.05070	46.797
11	500.00000	26.02055	-0.14317	14.43489	-72.40184	-11.58565	-72.25868	48.906
12	629.46271	25.57498	-0.18019	13.82648	-97.51963	-11.74851	-97.33943	51.094
13	792.44660	25.10528	-0.22728	10.36205	-120.25989	-14.74323	-120.03261	53.250
14	997.63116	24.60877	-0.28674	6.04991	-140.19888	-18.55886	-139.91214	55.375
15	1255.94322	24.08217	-0.36249	0.79567	-151.53431	-23.28649	-151.17182	57.516
16	1581.13883	23.52126	-0.45789	-4.16141	-160.58492	-27.68267	-160.12703	59.672
17	1990.53585	22.92143	-0.57208	-8.95003	-167.63955	-31.87146	-167.06748	61.813
18	2505.93617	22.27739	-0.71783	-13.63949	-173.94794	-35.91688	-173.23011	64.031
19	3154.78672	21.58147	-0.89692	-17.84126	178.52110	-39.42274	179.41802	66.250
20	3971.64117	20.82473	-1.12074	-21.28006	168.75852	-42.10480	169.87925	68.547
21	5000.00000	19.99554	-1.38763	-23.86339	155.19098	-43.85893	156.57861	70.797
22	6294.62706	19.99461	-1.75657	-26.42243	145.15237	-46.41704	146.90894	72.985
23	7924.46596	19.99379	-2.21643	-29.24401	123.80958	-49.23780	126.02602	75.156
24	9976.31157	19.98622	-2.82946	-31.83600	106.60677	-51.82223	109.43624	77.344
25	12559.43216	19.98494	-3.59705	-37.17001	72.09195	-57.15496	75.68900	79.656
26	15811.38830	19.97375	-4.52774	-38.32697	28.22522	-58.30073	32.75296	81.985
27	19905.35853	19.95640	-5.68369	-40.03008	-24.02761	-59.98647	-18.34392	84.594
28	25059.36168	19.93597	-7.13770	-40.61084	-70.50414	-60.54680	-63.36644	87.266
29	31547.86722	19.89253	-8.97678	-41.83879	-163.46037	-61.73132	-154.48359	90.360
30	39716.41174	19.83257	-11.24093	-46.90954	80.58077	-66.74211	91.82170	93.906
31	50000.00000	19.73660	-14.03896	-76.35364	-171.41486	-96.09023	-157.37590	97.985

```
--- end of simulation ---
execution time: 103.281000 sec
Hope your simulation converge well and thanks for waiting,
 ---Arief Noor Rahman---
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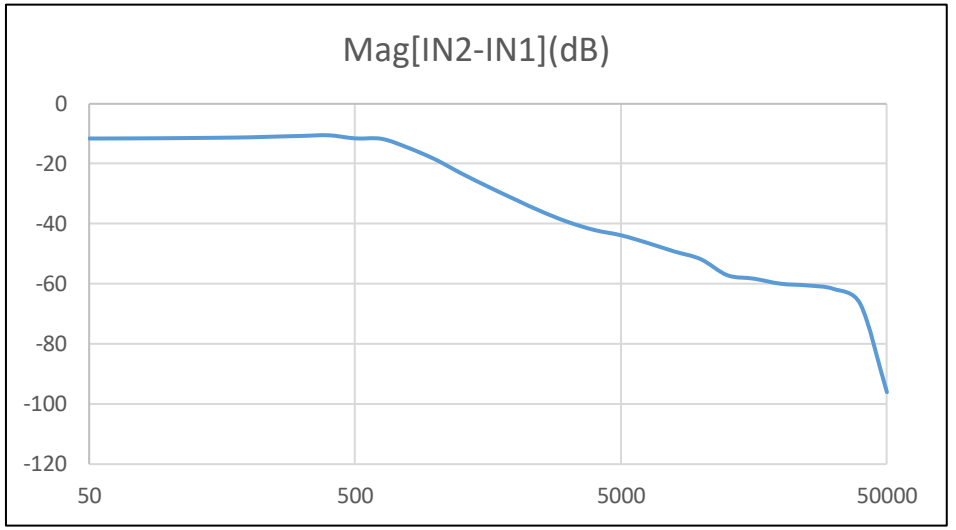
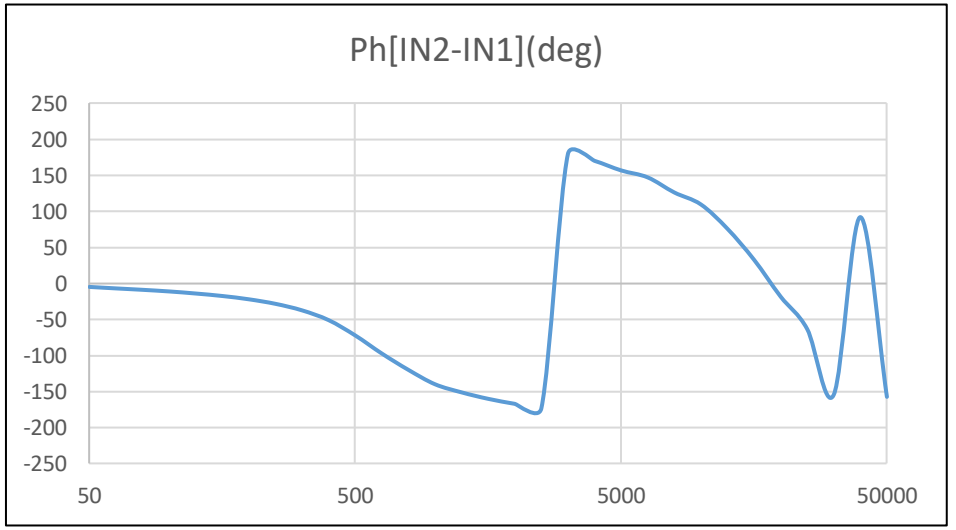
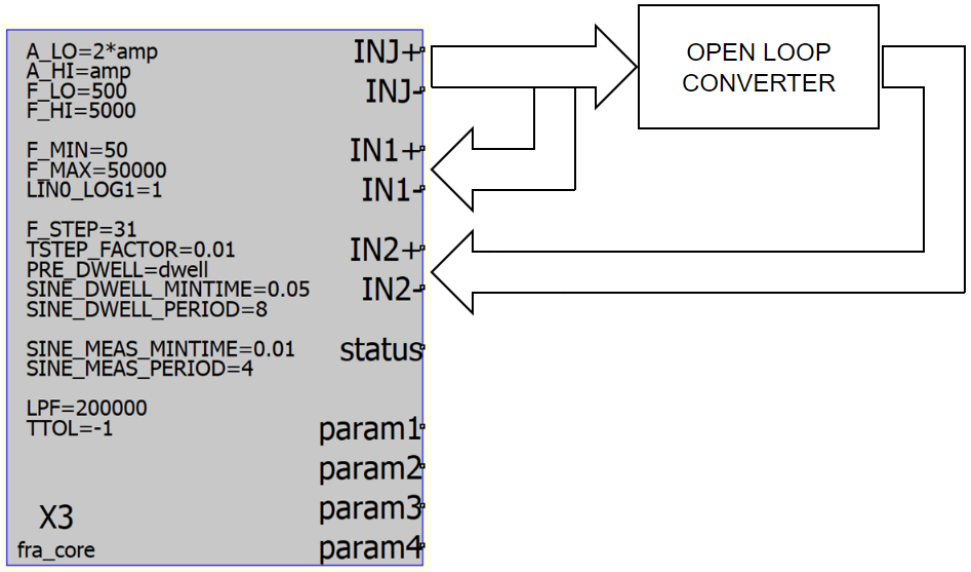




Possible Connection for Converter Analysis

Open Loop Gain Analysis



Close Loop Gain Analysis