Qspice Project - Frequency Response Analyzer by KSKelvin

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Frequency Response Analyzer (FRA) – Introduction

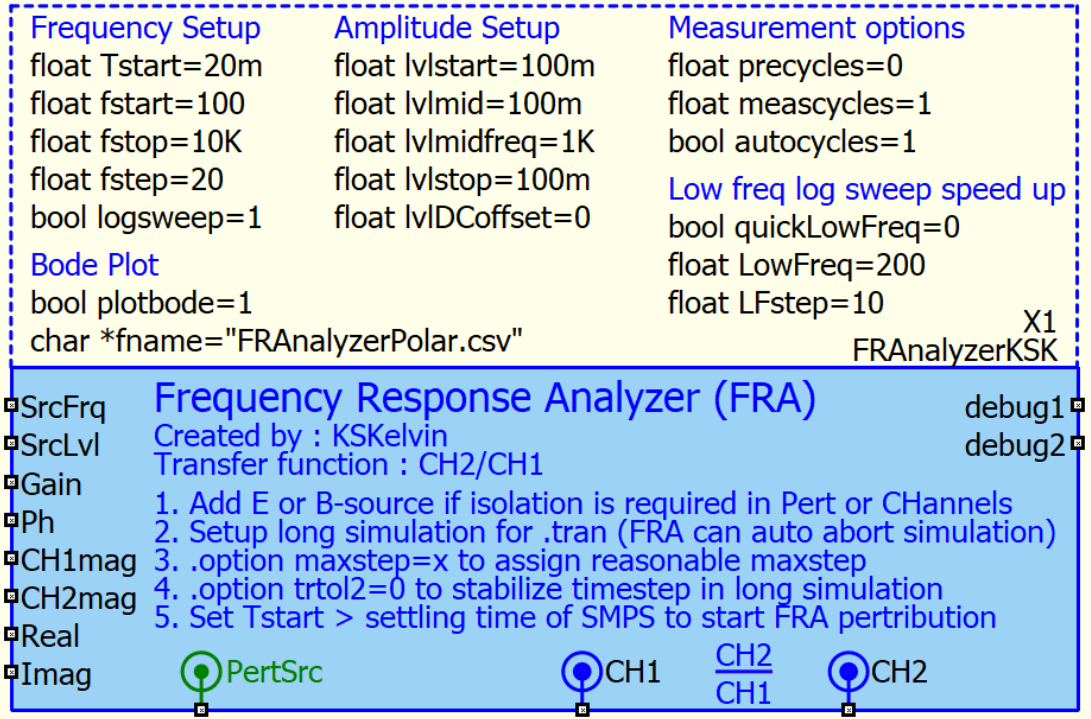
- Introduction
  - The goal of this project is to create a frequency response analyzer (FRA) in Qspice using the Ø-Device (DLL-block). The FRA is a method that analyzes the relationship between signals in a system by injecting a perturbing source.
  - Qspice includes a .bode command to extract frequency responses in the time domain, so why develop an FRA? The FRA project aims to showcase the capabilities of Qspice but not to not to replace .bode. While .bode post-processes time-domain data to extract frequency. responses after .tran simulation, the FRA calculates magnitude/phase during .tran simulation. Due to the various signal processing techniques involved, the FRA serves as an example demonstrating how Qspice can handle both analog and digital simulations seamlessly.
  - In addition, FRA is a real piece of equipment, this project aims to create a device that function and layout similar to this equipment. Therefore, user create a schematic that with same connection method as in real life practice.
  - As far as I know, in Qspice community, Arief Noor Rahman (aka physicboy) is the first who works on FRA project, his work can be found in his Github : https://github.com/physicboy/QSPICE/tree/main/FRA_project

What made this FRA special?

- What made this FRA special?
  - Only two files required to run simulation
    - Symbol : FRAnalyzerKSK.qsym
    - DLL file : franalyzerksk.dll
    - C++ file (if to review source code) : franalyzerksk.cpp [Not necessary]
  - This FRA fully utilizes the DLL-block for various functions: generating time-varying frequency perturbing signals, combining them with measured signals, and processing signals by averaging and extracting DC components, this remove a hierarchical circuit.
  - It features the ability to set amplitudes at three points (with the flexibility to adjust the midpoint frequency).
  - For each test frequency, the FRA divides the process into pre-cycles and measurement phases, ensuring data collection only after the system stabilizes at a new frequency point. Additionally, it includes auto-cycles for increased measurement cycles at lower gain regions or higher frequency regions, enhancing result stability.
  - During simulations, data of each frequency test point is displayed in the output window. The frequency response data is saved in a user-defined .csv file that is compatible with Qspice. Following simulation completion, a waveform viewer opens this .csv file to plot the bode plot.
  - In extensive frequency range analyses, measuring at low frequencies can be time-intensive. The FRA offers an option to reduce test step when frequencies lower than a threshold frequency.

Frequency Response Analysis from KSKelvin

- FRA workflow
  - PertSrc (OUTPUT) : Output perturbing signal, this needs to inject to control loop
  - CH1/CH2 (INPUT) : measurement input, FRA calculates transfer function of $\frac{CH2}{CH1}$
  - Both input and output are reference to GND. An isolator or differential probes (can model by E-source) can be used to inject or probe signal isolated from GND

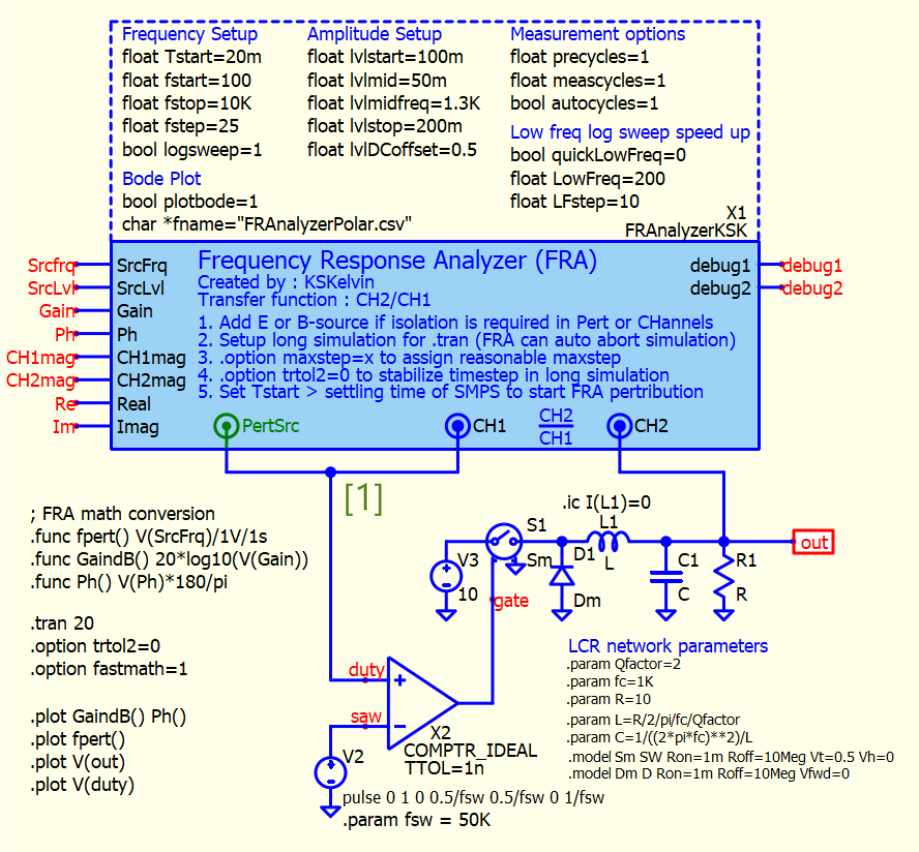


FRA Setting

- Frequency Setup
  - Tstart : Time to start output perturbating signal, set Tstart > settling time of SMPS
  - fstart, fstop and fstep : Set start and stop frequency, and number of frequency step
    - In log sweep, fstep is step per decade; In linear sweep, fstep is total step
  - logsweep : 0 is linear sweep and 1 is log sweep
- Amplitude Setup
  - lvlstart, lvlstop : amplitude of perturbating signal at fstart and fstop
  - lvlmid, lvlmidfreq : lvlmid is amplitude of perturbating signal at frequency = lvlmidfreq
  - lvlDCoffset : DC offset from pertubating signal
- Measurement options
  - precycles : number of AC cycles not to take measurement at each frequency test points
  - measycles : number of AC cycles to average for measurement results after precycles
  - autocycles : if enable (1), auto adjust measycles according to gain (lower gain, more cycles)
- Low freq log sweep speed up (only available at log sweep)
  - quickLowFreq : enable (1) to reduce number of step when test frequency less than LowFreq
  - LowFreq : frequency threshold
  - Lfstep : reduce number of step to Lfstep per decade when test frequency less than LowFreq

Example #1 : FRA open loop measurement example – Schematic

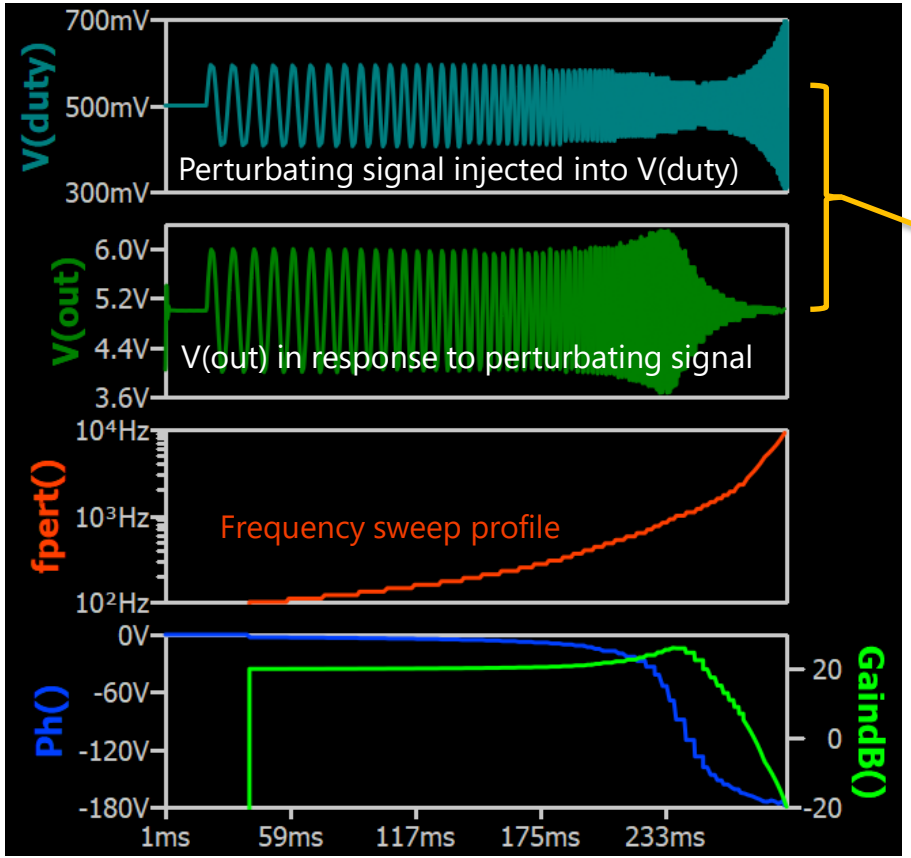
Schematic : example1.Buck-FRAnalyzerKSK.qsch

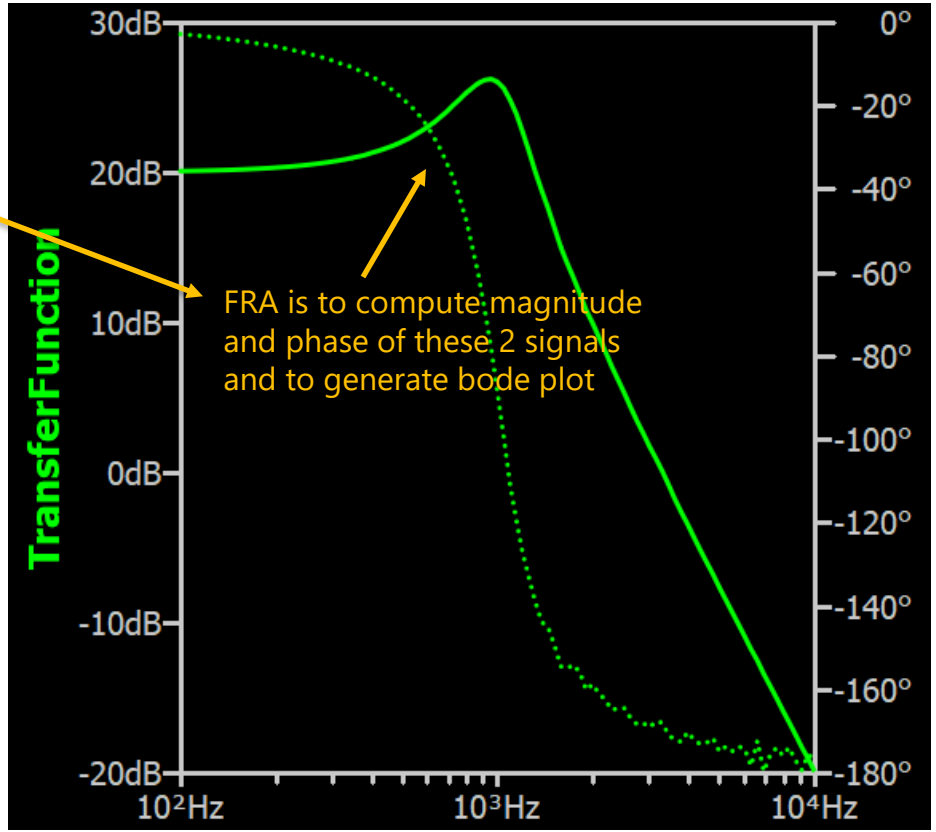


- Example #1
  - To demonstrate basic workflow and setup for open loop measurement
- Open Loop of Buck Converter
  - [1] PertSrc is injected to compare with sawtooth and generate PWM. lvlDCoffset set to 0.5 for 50% duty in this example. A small signal AC perturbing signal started to inject from time>Tstart and sweep from fstart to fstop
  - CH2 probe V(out) and CH1 probe V(duty). DC level is ignored, and FRA computes magnitude ratio and phase between CH2 and CH1, defines transfer function = $\frac{\mathrm{CH2}}{\mathrm{CH1}} = \frac{\tilde{v}(out)}{\tilde{v}\,(duty)}$

Example #1 : FRA open loop measurement example – Results

Schematic : example1.FRAnalyzerKSK-Buck.qsch

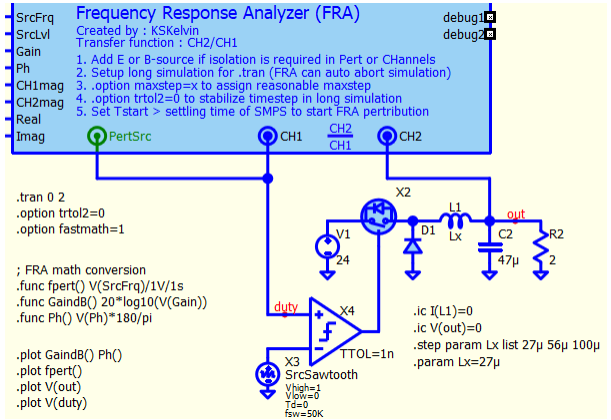


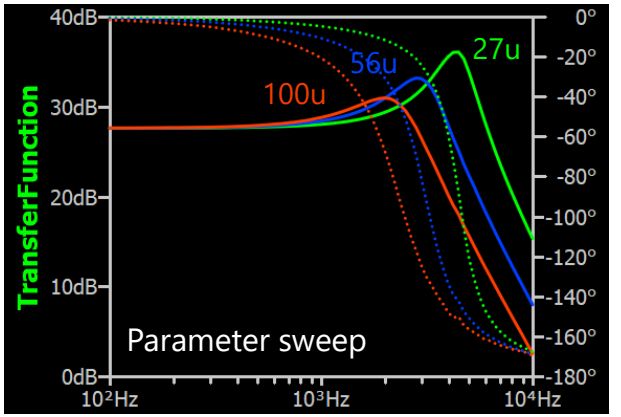


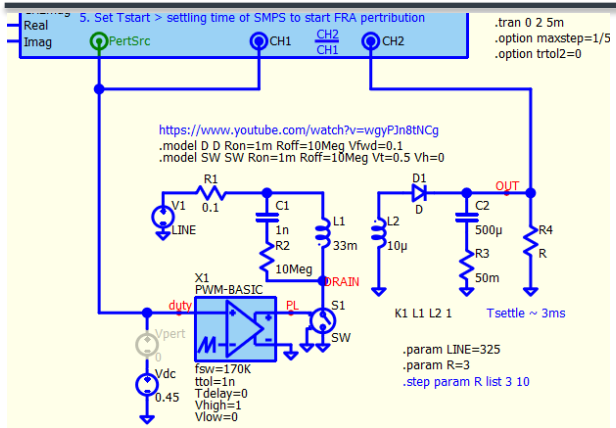
Example #2 and #4 : FRA with .step and a flyback example

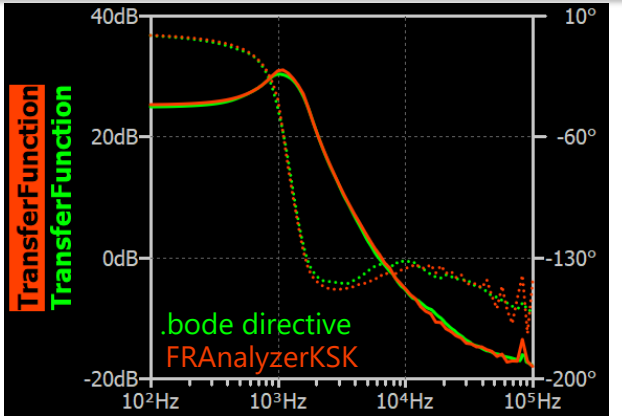
Sch : example2.Buck-FRAnalyzerKSK-(.step).qsch | example4.FlybackSamBen-Yaakov.qsch

- Example 2 (Buck)
  - Buck converter with inductance sweep, to demonstrate FRA can generate overlay plot for comparison
- Example 4 (Flyback)
  - This circuit is captured from Prof. Sam Ben-Yaakov youtube (https://www.youtube.com/watch?v=wgyPJn8tNCg)
  - Result is compared with FRA and .bode method









Example #5 : Compare FRA and .bode

Sch : example5.QspiceDemo.BodePlot-FRAnalyzerKSK.qsch | example5.QspiceDemo.BodePlot-(.bode).qsch

- Example 5
  - Get open loop transfer function from a close loop system
- FRA and .bode
  - Qspice with a demo schematic BodePlot.qsch to demonstrate the use of .bode
  - This example rework Qspice schematic to run bode plot with FRA method
  - This is a close-loop feedback SMPS and perturbating source is injected through an isolator when FRA is used