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Preparation of high power test at the FREIA Laboratory

8 Feb. 2017

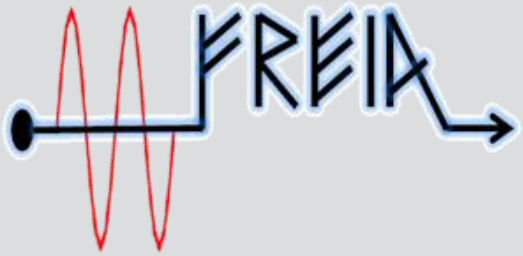
Han Li, Uppsala University

The list of tests in some order of priority

1. Central cavity frequency and spectrum of higher-order modes (HOM) +
2. Loaded Q (basically measurement of the 3 dB bandwidth) +
3. Q0 (calorimetric measurement) +
4. Max gradient +
5. Tuning range of the slow step tuner +
6. Stabilization of the cavity field with LLRF using only RF compensation - +
7. Dynamic Lorentz force detuning (change in the cavity frequency during the RF pulse) - +
8. Compensation for the dynamic Lorentz force detuning with the fast piezo tuner -
9. Stabilization of the cavity field with LLRF using both RF and piezo tuner compensation -
10. Onset and level of field emission +
11. Sensitivity to helium pressure fluctuations +
12. Multipucking +
13. Overall test of electronics. - +

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Test Items



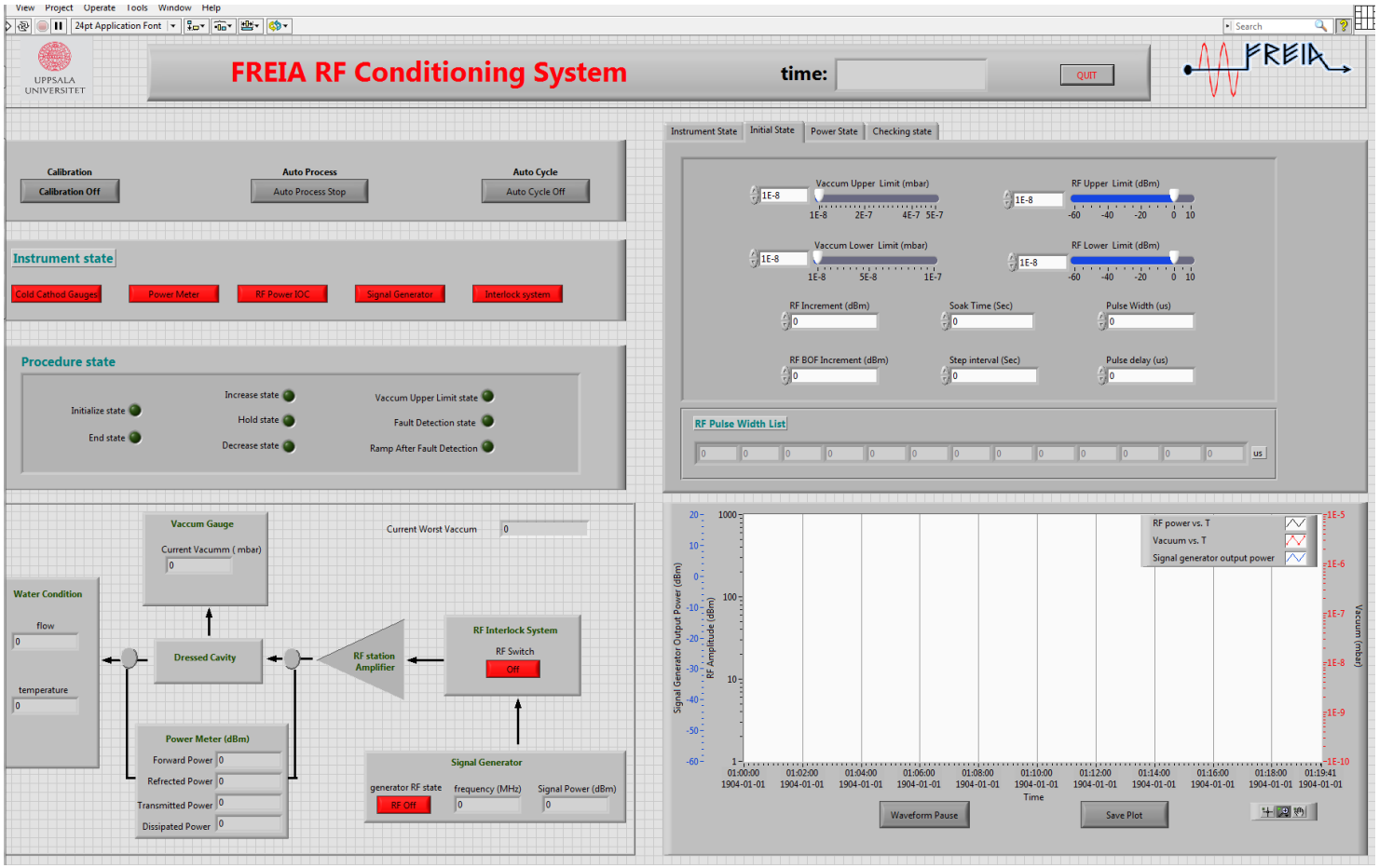
Warm test	Cool down	Cold test	Warm up
✓ Central cavity frequency and spectrum of HOM ✓ Qe	Frequency shift due to cool down	✓ Coupler cold conditioning	Frequency shift vs. T
✓ Coupler warm conditioning		✓ Cavity conditioning	
		✓ Central frequency and HOM ✓ Loaded Q and Qe	
		✓ Q0 ✓ Max gradient ✓ Tuning range of the slow step tuner	
		✓ Stabilization of the cavity field with LLRF using only RF compensation ✓ Dynamic Lorentz force detuning	

VNA

SGD signal generator driven

SEL

RF conditioning control at FREIA



- ✓ It is important for FREIA to develope its own conditioning system.
- ✓ It is very useful to study an optimal conditioning procedure for ESS turn on procedure.

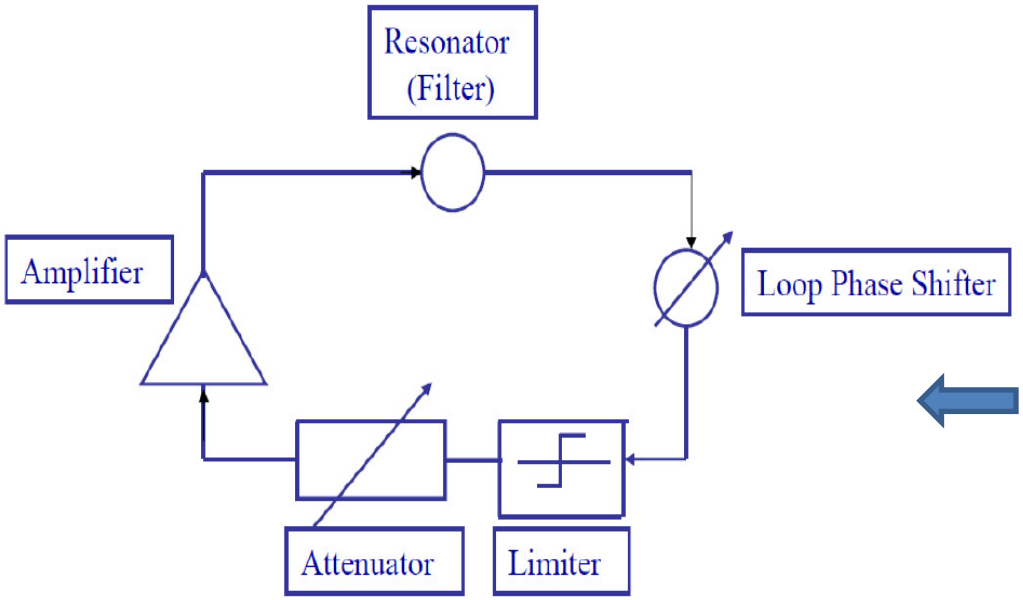
If we want to test our program, the coupler vacuum signal from IPNO system need to introduce into our system.

Approch to get vacuum signal:

1. IPNO program expose this signal to our local network;
2. Connect IPNO's vacuum gauge to our controller.

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Pulsed SEL at FREIA

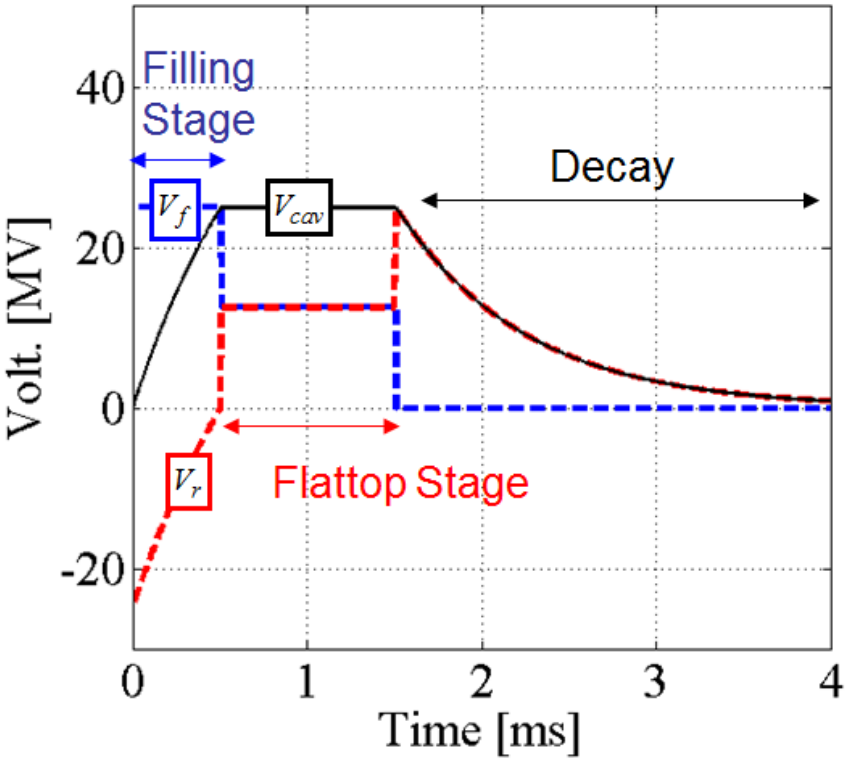


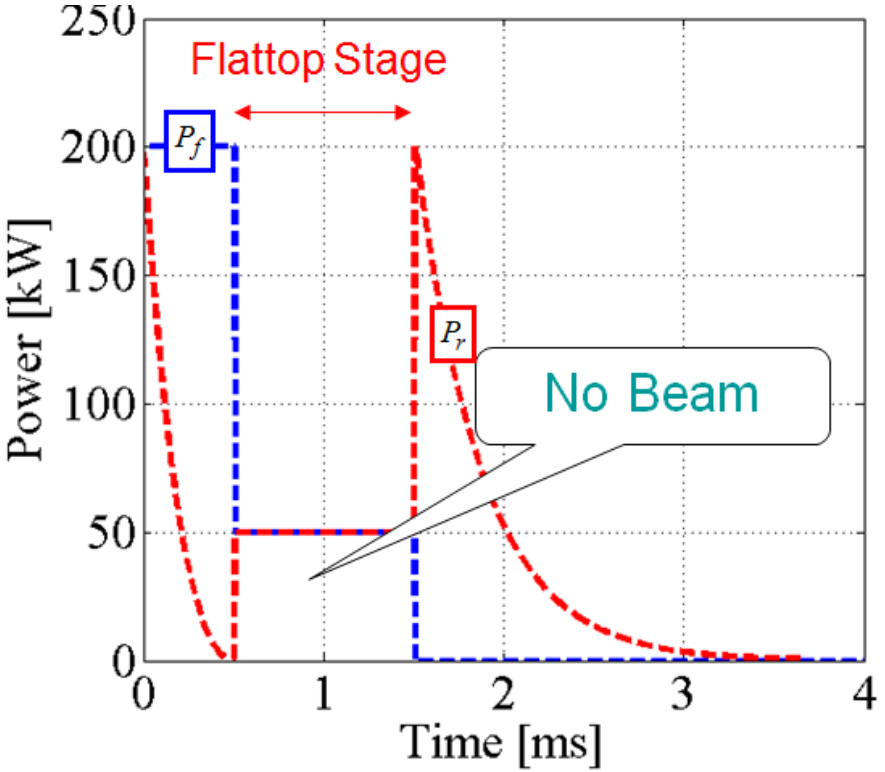
RF switch

Blanking sinal
and
Trigger for RF switch
from lund system

FPGA data acquisition system

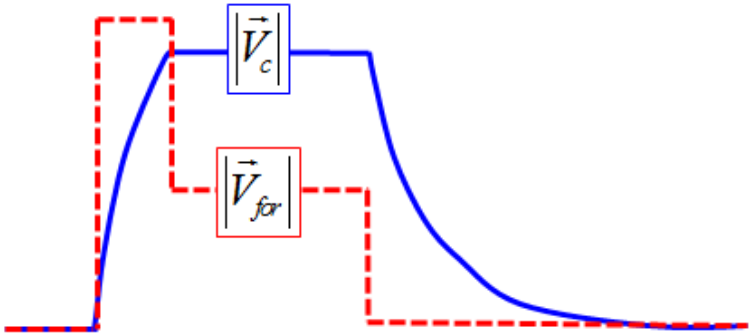
RF Power Profile for Cavity Operation





$$\omega_{1/2} = \frac{\omega_0}{2Q_L} = \frac{1}{\tau},$$

τ is the time constant of the cavity

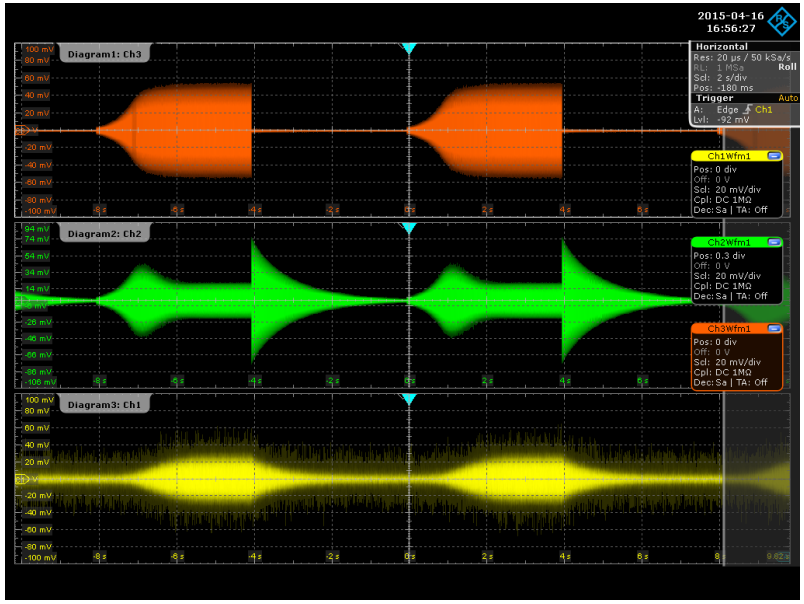


$$\frac{1}{Q_L} = \frac{1}{Q_e} + \frac{1}{Q_0} + \frac{1}{Q_t},$$

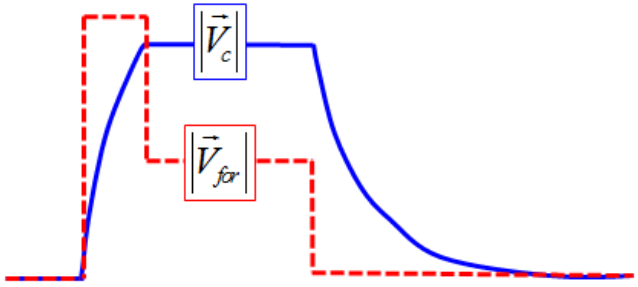
Q_e is much smaller than Q_0 and Q_t, so Q_L is roughly equal to Q_e

From the design of IPNO, Qe =2.1 E 5
Cavity resonat frequency is 352,42 MHz
Therefore, the fillinf time of ESS spoke cavity is 1.2 ms
Filling time means when the cavity power become (1-1/e)*Pc=0.63Pc

So it takes even longer time to get the flat top of the cavity voltage!!



On the other hand, with a SEL, we never produce forward power with a pure pulse shap.
SEL is a positive feedback loop that starts to oscillate by itself from the noise.
This also increas the time to get the cavity voltage flat top
In our case, it is roughly ~ms.



Then, the consequense of all above reasons is:

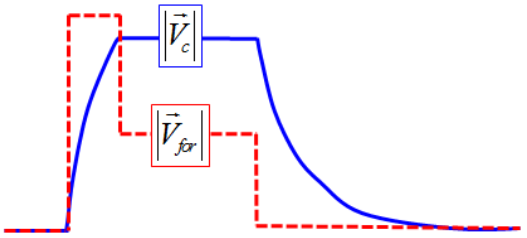
A. We only get a short duration of flat top of Vc;
B. We even have no flat top!
C. How to control Vc?
D. How to calculate the Pc from helium throwmeter?

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Potential Solutions

Approch to get flat top:

1. Get maximum gain in the loop, to make forward power increase as fast as possible. On the other hand, be careful with the hardware protection.
   - ✓ put in some small amplifier into the loop;
     The total gain we can have?
     Note that the cavity has -60dB gain loss.
     Some gain loss from FPGA.
     Some gain also loss from cables.
     What is the order of the time for SEL to reach its design vaulue?
   - ✓ the max input power for the RF station is 16 dBm, set some limiter or attenuator before input point



Data from of IPNO,
Qe =2.1 E 5
Qt=9.3 E 10
Q0~ E9

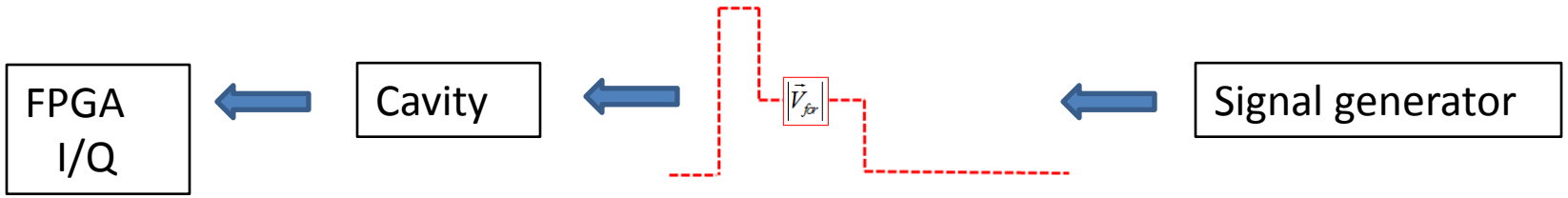
2. Calculate the P_{fill} and set an attenuation after Tfill in each pulse.
   - ✓ This need to be done by FPGA
   - ✓ Another trigger signal synchronized with other two trigger

$$P_{fill} = \frac{V_0^2\left(\omega_0^2 + 4Q_L^2\Delta\omega^2\right)}{4\left(\frac{r}{Q}\right)Q_L\omega_0^2 \cdot \left[1 + e^{-\frac{\omega_0 T_{fill}}{Q_L}} - 2e^{-\frac{\omega_0 T_{fill}}{2Q_L}}\cos\left(\Delta\omega T_{fill}\right)\right]}$$

$$P_{forward} = \frac{V_0^2}{4\left(\frac{r}{Q}\right)Q_L}\left[\left(1 + \frac{Q_e}{Q_0} + \frac{r}{Q_0}\frac{Q_e I}{V_0}\cos\theta\right)^2 + \left(2Q_e\frac{df}{f}\right)^2\right]$$

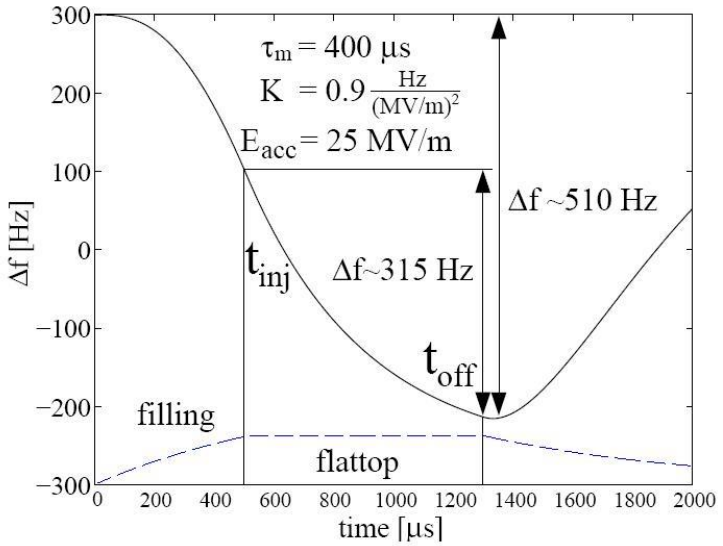
How to calculate the Pc from helium throwmeter?

SGD loop at FREIA

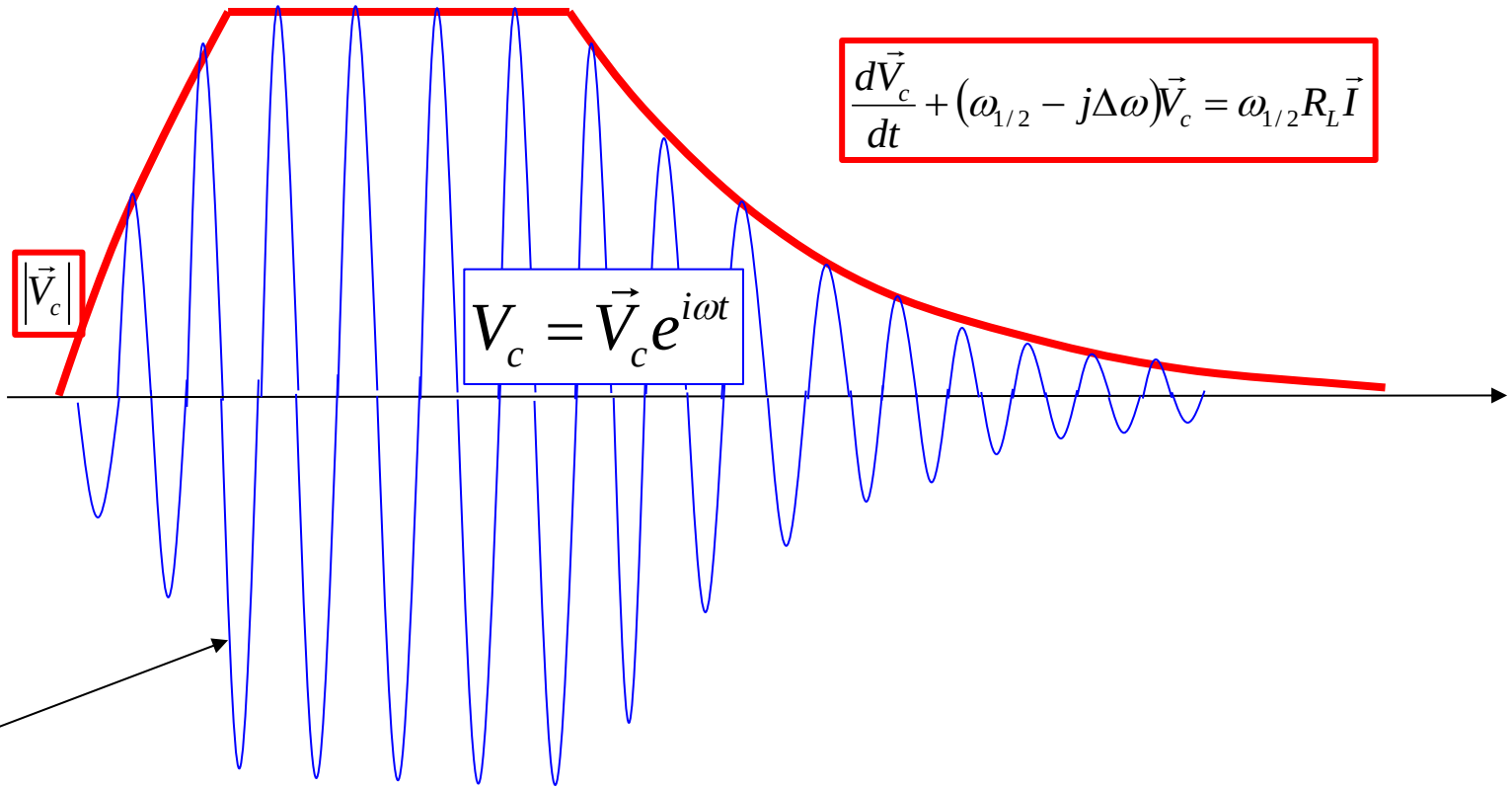


Signals in Polar Coordinate

$$\frac{d\vec{V}_c}{dt} + (\omega_{1/2} - j\Delta\omega)\vec{V}_c = \omega_{1/2} R_L \vec{I}$$



RF vs. Baseband



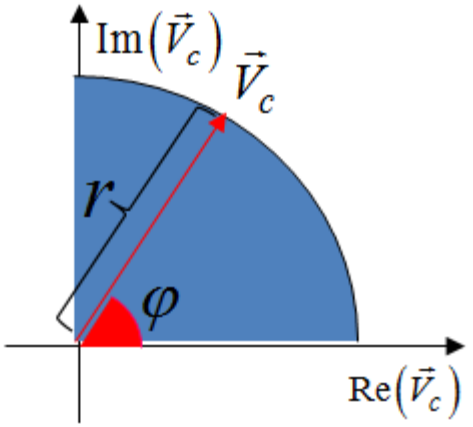
$$\frac{d^2V_c}{dt^2} + 2\omega_{1/2}\frac{dV_c}{dt} + \omega_0^2 V_c = 2\omega_{1/2} R_L \frac{dI}{dt}$$

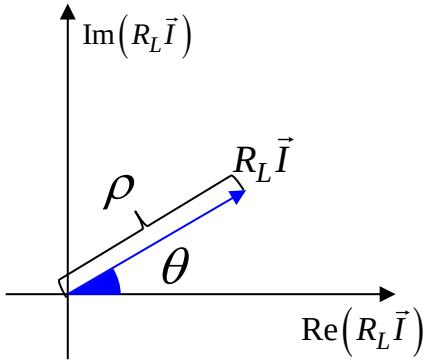
State Space Equation of the Cavity

- Cavity equation in Polar Coordinate

$$\frac{d\vec{V}_c}{dt} + (\omega_{1/2} - j\Delta\omega)\vec{V}_c = \omega_{1/2} R_L \vec{I}$$

$$\begin{cases} r\varphi' - r\Delta\omega = \omega_{1/2}\rho\sin(\theta-\varphi) \\ r' + r\omega_{1/2} = \omega_{1/2}\rho\cos(\theta-\varphi) \end{cases}$$





$$u = R_L\vec{I} \xrightarrow{(\rho,\theta)} \xrightarrow{(r,\varphi)} \vec{V}_c$$

Approch>

- ✓ To get all signals in Polar Coordinate, we acquisition all signals along the pulse by FPGA and complete the I/Q in the program.
- ✓ With the help of lund system to produce a design forward pulse.