SELF EXCITED OPERATION FOR A 1.3 GHZ 5-CELL SUPERCONDUCTING CAVITY

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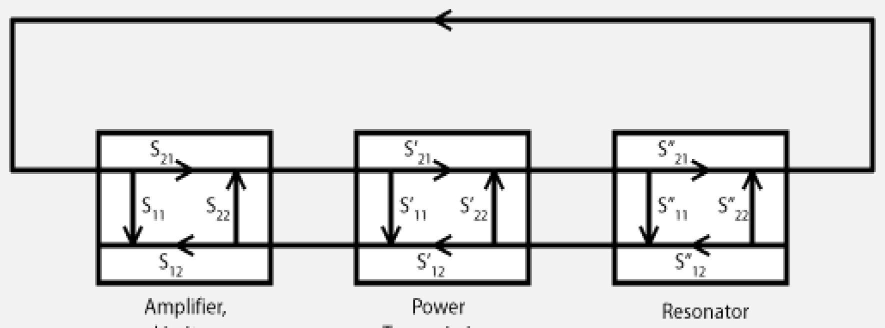
Abstract

Self-excited operation of a resonant system does not require external frequency tracking, as the frequency is determined by the phase shift of the self-excited loop. This makes it very useful for testing high-Q RF cavities that do not have an automatic tuning mechanism. Self-excited operation has long been shown to work with single-cell cavities. We have recently demonstrated that it is also practical for multi-cell cavities, where multiple resonant modes are present. The Cornell 1.3 GHz 5-cell superconducting cavities were operated using self-excited operation and we were able to lock onto the accelerating mode, despite the presence of neighboring modes that were less than 10 MHz away. By controlling the loop phase shift, we were able to determine which mode was excited.

Open loop cascade method with s-parameters



$$S' = e^{-\gamma l}\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix}$$

$$\gamma = \alpha + i\beta$$

Condition for self-excited oscillation:

$$\left(S_{21}S''_{21} + S_{22}S''_{11}\, e^{-\gamma l}\right)e^{-\gamma l} = 1$$

if $S_{22} = 0$ (for circulator) $\left|S_{21}\right|\left|S''_{21}\right|e^{-\alpha} \geq 1$

$$\angle S_{21} + \angle S''_{21} - \frac{\omega}{c}l = 2n\pi$$

$$S''_{21}(s) = \prod_{i=1}^{N}\frac{a_i}{\left(s^2 + p_i^2\right)} \approx \prod_{i=1}^{N}\frac{b_i}{\left(s - p_i\right)}$$

$$\angle S_{21} + \sum_i \tan\left(\omega - \omega_i\right)\frac{2Q_i}{\omega_i} - \frac{\omega}{c}l = 2n\pi$$

- Initial linear gain margin > 1.
- Oscillation does not occur at the gain peak, it occurs at the phase zero-crossing
- Phase slope should also be negative at the zero-crossing.
- The phase characteristics are more important than the amplitude characteristics.

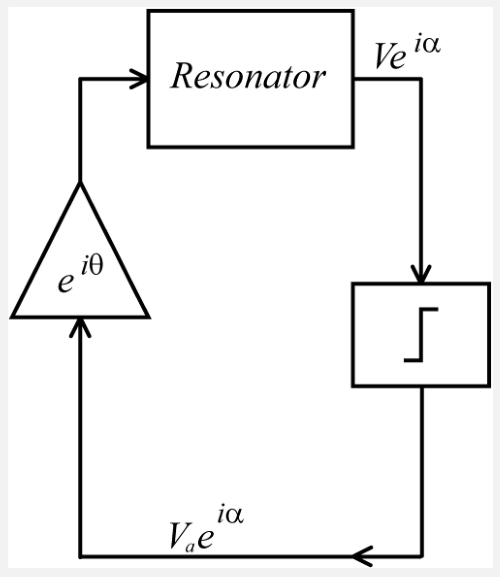
Capture Effect

- A non-linear effect where the amplitude limiter will only extract Zero Axis Crossings of the strongest of competing signals.
- If several signals have different amplitudes, the amplitude limiter amplifies the strongest signal while attenuates other weaker signals.

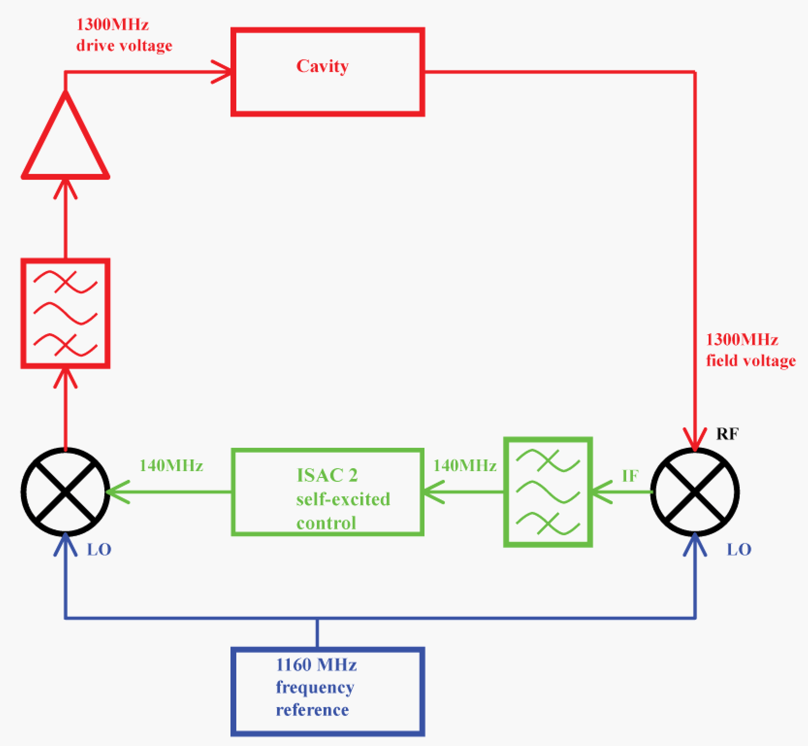
Oscillator Start-up Time

- Thermal noise in the system
- Band-limited by the resonator, no longer white, but "fuzzy" sine wave
- Component of this "fuzzy" sine wave that is at the correct phase builds to reach steady-state oscillation.
- Other frequencies are attenuated due to capture effect

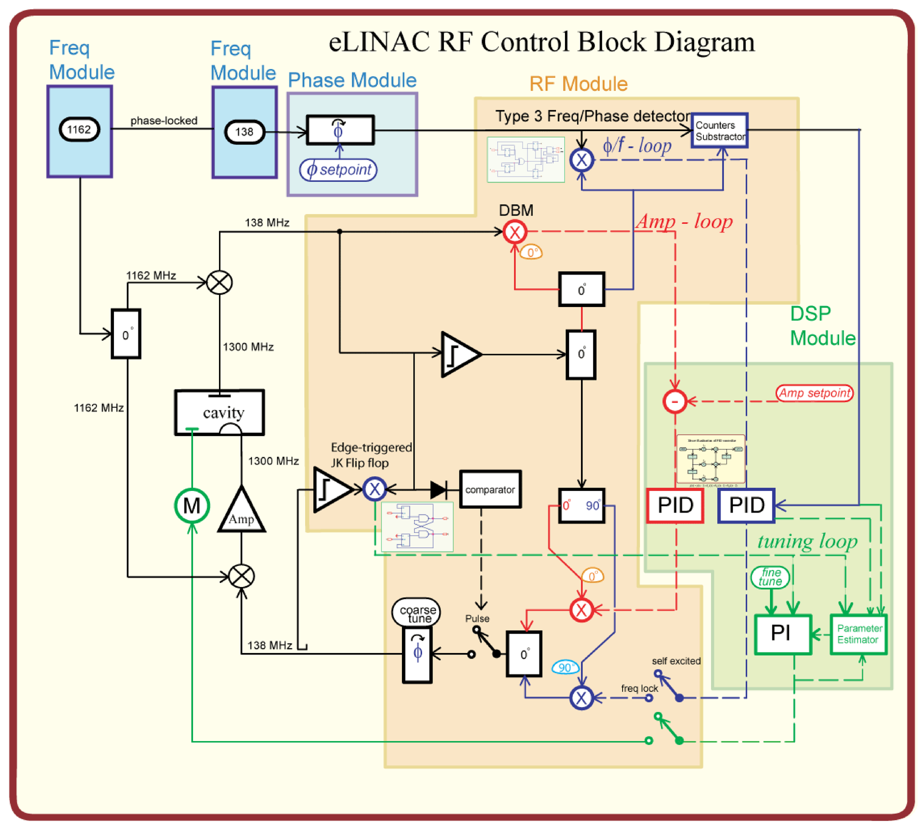
Basic self-excited loop



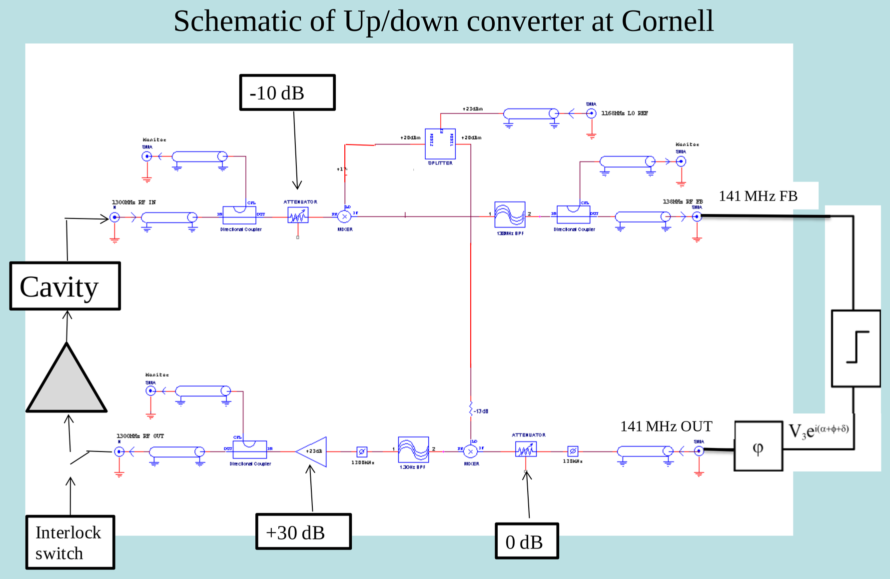
Basic self-excited loop for 1.3GHz



eLINAC RF Control Block Diagram

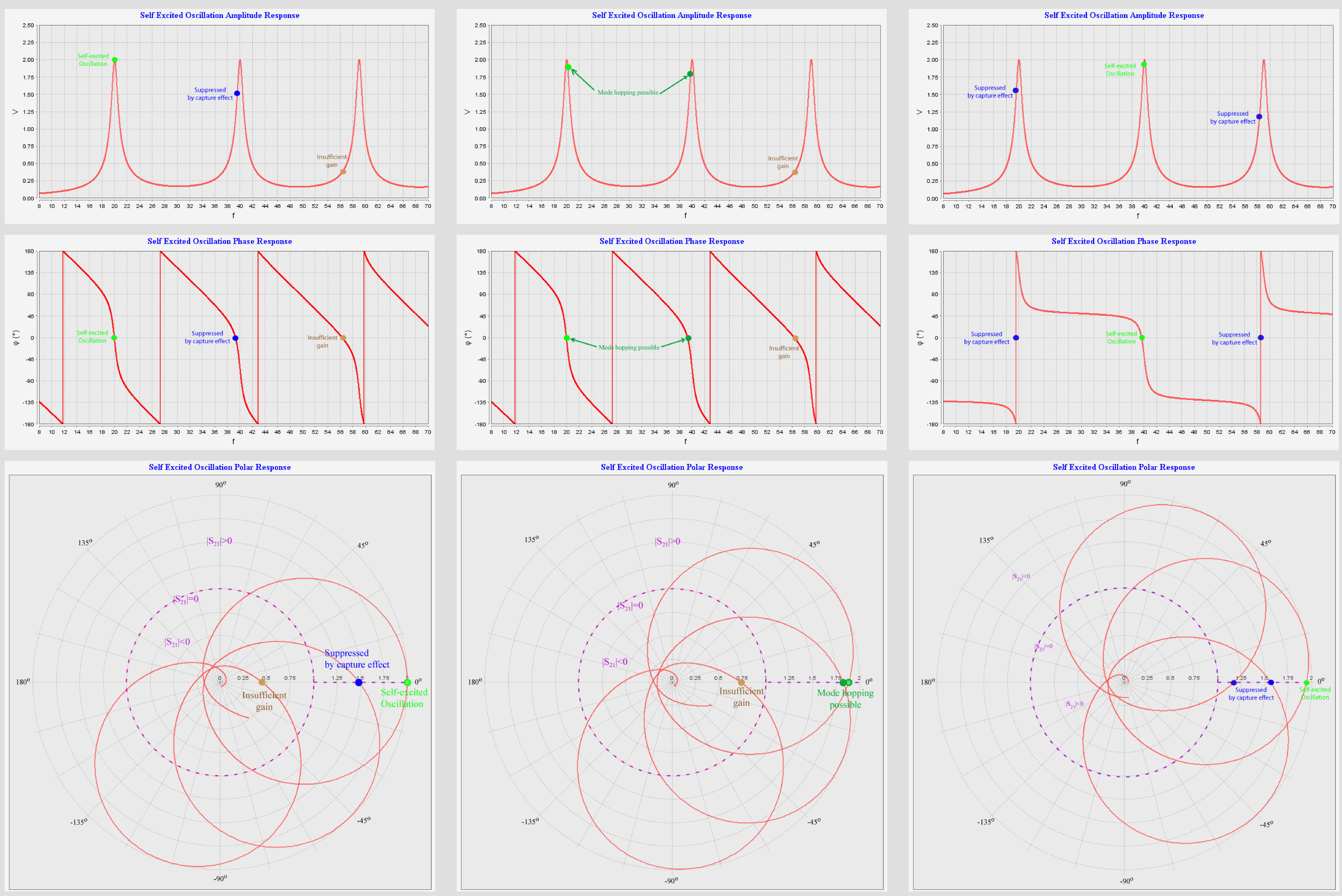


Schematic of Up/down converter at Cornell



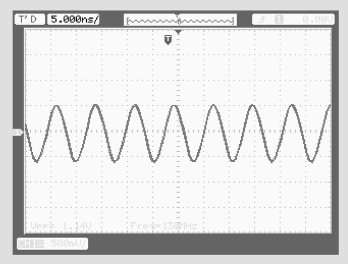
Loop Responses for different Phase delays

First mode locked | Mode hopping between first and second mode | ~Second mode locked

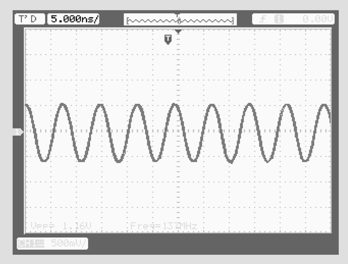


Using a fixed LO frequency of 1160MHz and varying the loop phase alone, we have been able to lock to 3 different cavity modes.

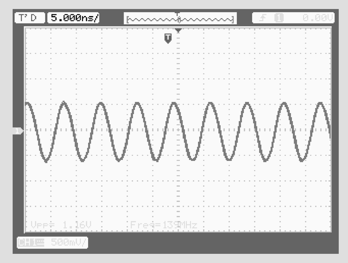
IF Feedback loop ~ 130 MHz
Cavity = 1289 MHz



IF Feedback loop ~ 137 MHz
Cavity = 1296.5 MHz



IF Feedback loop ~ 139 MHz
Cavity = 1299.1 MHz



CONCLUSION

We have demonstrated that it is possible for 5-cell cavity to be operated in the self-excited mode. By adjusting the loop phase and the LO frequency, it is possible to lock to any resonant mode of a multi-cell cavity. In the middle of the phase range, stable operation is possible with no mode hopping. Even better performance of the self-excited loop should be possible with a narrow band-pass image-rejection filter, and with better matching of the voltage levels between the TRIUMF-built control system and the Cornell-built up/down converter.