Task

- The RF Gun reflects power to the klystron. Large amounts of reflected power to the klystron can cause phase and amplitude instabilities in a klystron. Look at pulse shaping as a way to reduce reflected power to the klystron and eliminate the requirement for a 30MW S-Band circulator between the RF Gun and klystron.
- Calculate the reflected power from the RF Gun as a function of the RF input power pulse.
- Increase the power pulse gradually, so the reflected power stays all the time below 4 MW.

Method

- Calculation of the reflected power is carried out in the frequency domain.
- The frequency domain spectrum of the RF input pulse is obtained by the **FFT** on the user defined shape of the input pulse in the time domain.
- Next the Reflection Coefficient Γ is expressed as a function of the cavity Transfer Function near the resonant frequency.
- Reflected signal is calculated as a product of the Fourier transform of RF input signal and the cavity Reflection Coefficient Γ.
- Reflected signal is transformed back into the time domain applying the inverse Fourier Transform, **IFFT**.
- Filling of the cavity – the increase of the cavity electric field is calculated from the input power pulse and parameters of the RF Gun resonator.
- The reflected power and the cavity voltage vs. time are plotted into the same graph.

Theory

- The general expression for (complex) Reflection Coefficient is:

$$\Gamma = \frac{Z_c - Z_w}{Z_c + Z_w} \qquad (1)$$

$\mathbf{Z_c}$ is the impedance of the "load", i.e. the resonant cavity, and $\mathbf{Z_w}$ is the characteristic impedance of the connecting line.

- The impedance of a resonator near its resonant frequency $\boldsymbol{\omega o}$ is expressed as:

$$Zc = \frac{R_{SH}}{1 + j2\frac{Q_l}{\omega o}\Delta\omega} \qquad (2)$$

$\mathbf{R_{SH}}$ is the resonator shunt resistance, $\mathbf{Q_l}$ is the quality factor (including the loading from the external circuits) and detuning $\boldsymbol{\Delta\omega = \omega - \omega o}$, $\boldsymbol{\Delta\omega \ll \omega o}$. Here $\boldsymbol{\omega}$ is the frequency independent variable and $\boldsymbol{\omega o}$ is the resonant frequency.

- The cavity coupling coefficient $\boldsymbol{\beta}$ is defined as $\boldsymbol{\beta = R_{SH}/Z_w}$.

Substituting for $\mathbf{R_{SH}}$ in (2) and combining (1) and (2), the expression for the Reflection Coefficient in terms of resonator parameters is given

$$\Gamma(\Delta\omega) = \frac{\beta - 1 - j2.\tau.\Delta\omega}{\beta + 1 + j2.\tau.\Delta\omega}. \qquad (3)$$

$\boldsymbol{\tau}$ is cavity filling time constant, $\boldsymbol{\tau = Q_l/\omega o}$.

- The frequency spectrum of the input signal into the cavity is calculated from the shape of the input power pulse as $\mathbf{V(\Delta\omega) = FFT\{\sqrt{p(t)}\}}$.
- The reflected signal in the frequency domain can be directly calculated as

$$\mathbf{V_{refl}(\Delta\omega) = V(\Delta\omega).\Gamma(\Delta\omega)}. \qquad (4)$$

- The Inverse Fast Fourier Transform, (IFFT), transforms this result back into the time domain,

$$\mathbf{v(t) = IFFT\{\ V_{refl}(\Delta\omega)\}}. \qquad (5)$$

- The reflected power is plotted as a function of time using the square of the v(t).

- The exponential increase of cavity electric field is calculated from the input power pulse, cavity shunt impedance $\mathbf{R_{SH}}$ and the cavity time constant τ. It rises as $\mathbf{(1- e^{-t/(2.\tau)})}$.

Program/Calculation

- The MATLAB program is used to calculate reflected power and to plot the results.
- User can define the shape of the input power pulse and the other relevant parameters of the RF gun resonator
  - coupling coefficient β (= 2.1),
  - cavity (unloaded) quality factor **Qo** (=13369),
  - cavity shunt impedance $\mathbf{R_{SH}}$ (=1.65 MΩ).
- The input and reflected power is expressed in MW, the developed cavity voltage signal in MV.
- Program is available and can be tested and used by anyone interested.

Results

- Present MATLAB plots – the results are calculated for the parameters given above.
- The input power pulse has 4 intermediate steps, the height of each step is 25% of the maximum power. The duration, (width), of those steps is 4x, 5x, 5x, 4x of a single interval of the control clock step, 8.4 ns.

References

1)Zenghai Li: Reflection Isolator using a Hybrid and a Dummy Cavity for the LCLS RF Gun., SLAC/LCLC, (2005)
2) Jens Knobloch: Basic Concepts of Measurements Made on Superconducting RF Cavities., SRF note, #910927-07, (1991)
3) Tom Hays: Cavity Analysis By Reflection, SRF note # 940525-04, (1994)

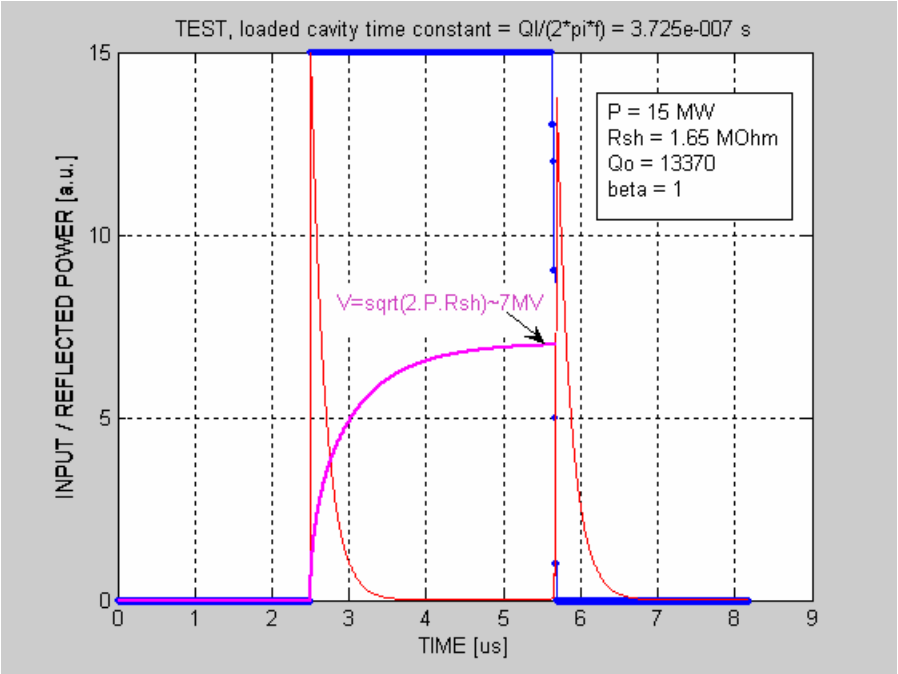

Fig. 1 Test of the program, for given cavity parameters and β = 1.

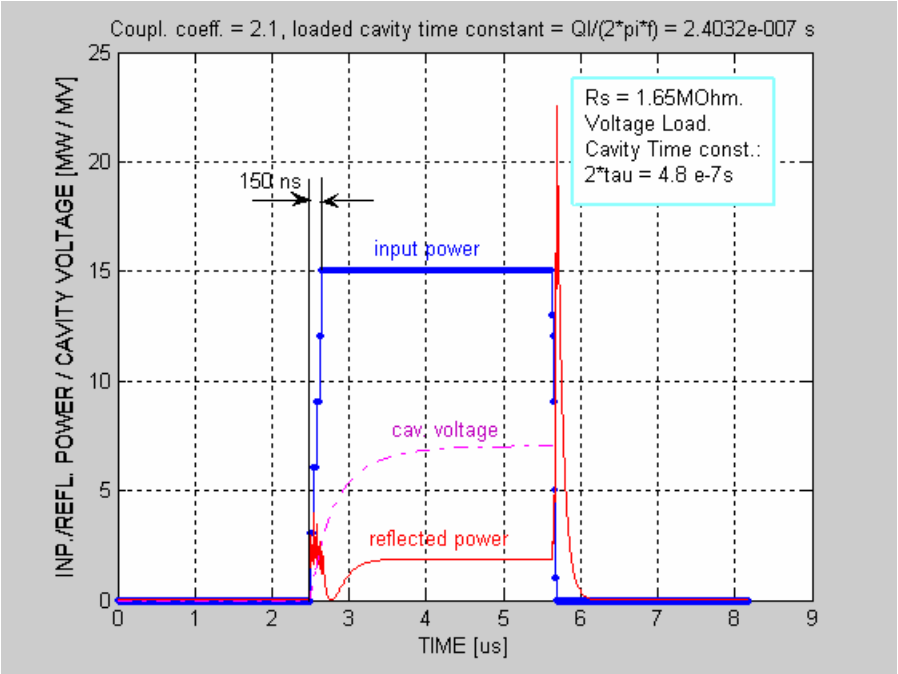

Fig. 2 Five-step shape of the input power pulse keeps reflected power below 4 MW.

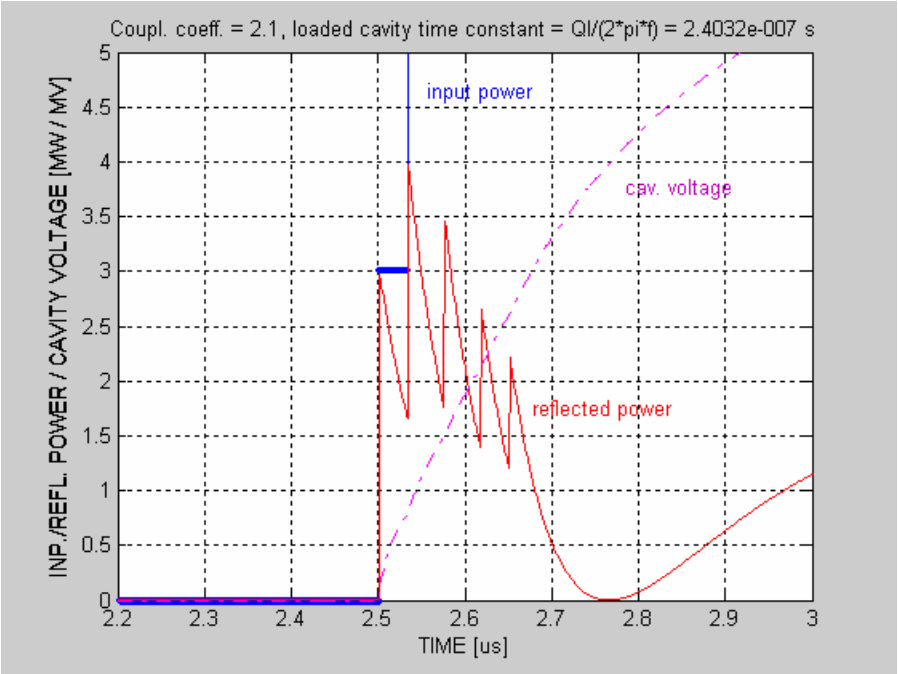

Fig. 3. Detail of reflected power.

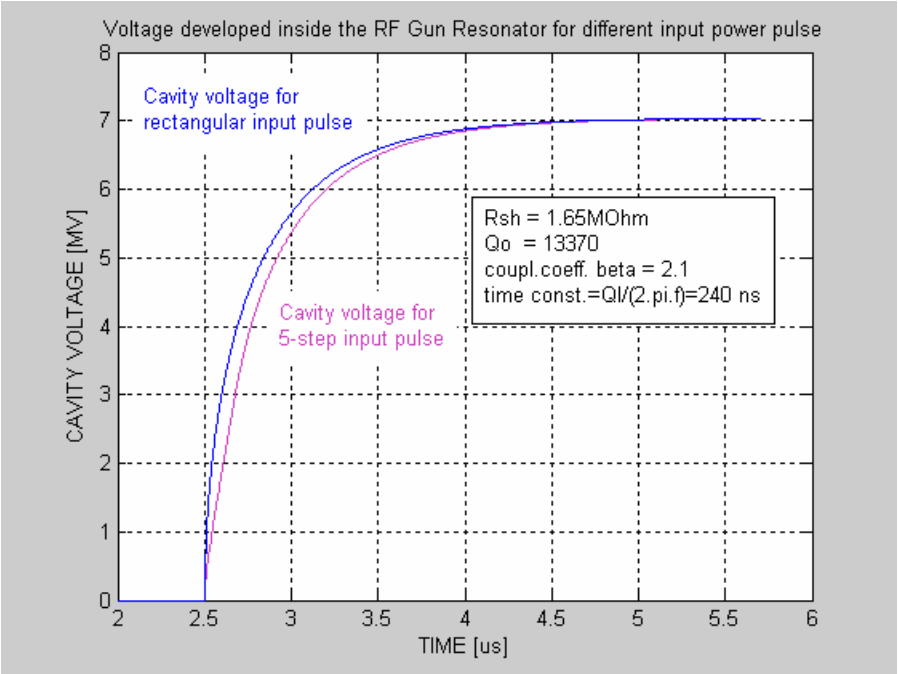

Fig. 4. Rise of the cavity electric field, (voltage), for the input step function and 5-step pulse.

Input power pulse with a linear ramp increase