LLRF Control Performance Studies with Different Methods of Cavities Filling

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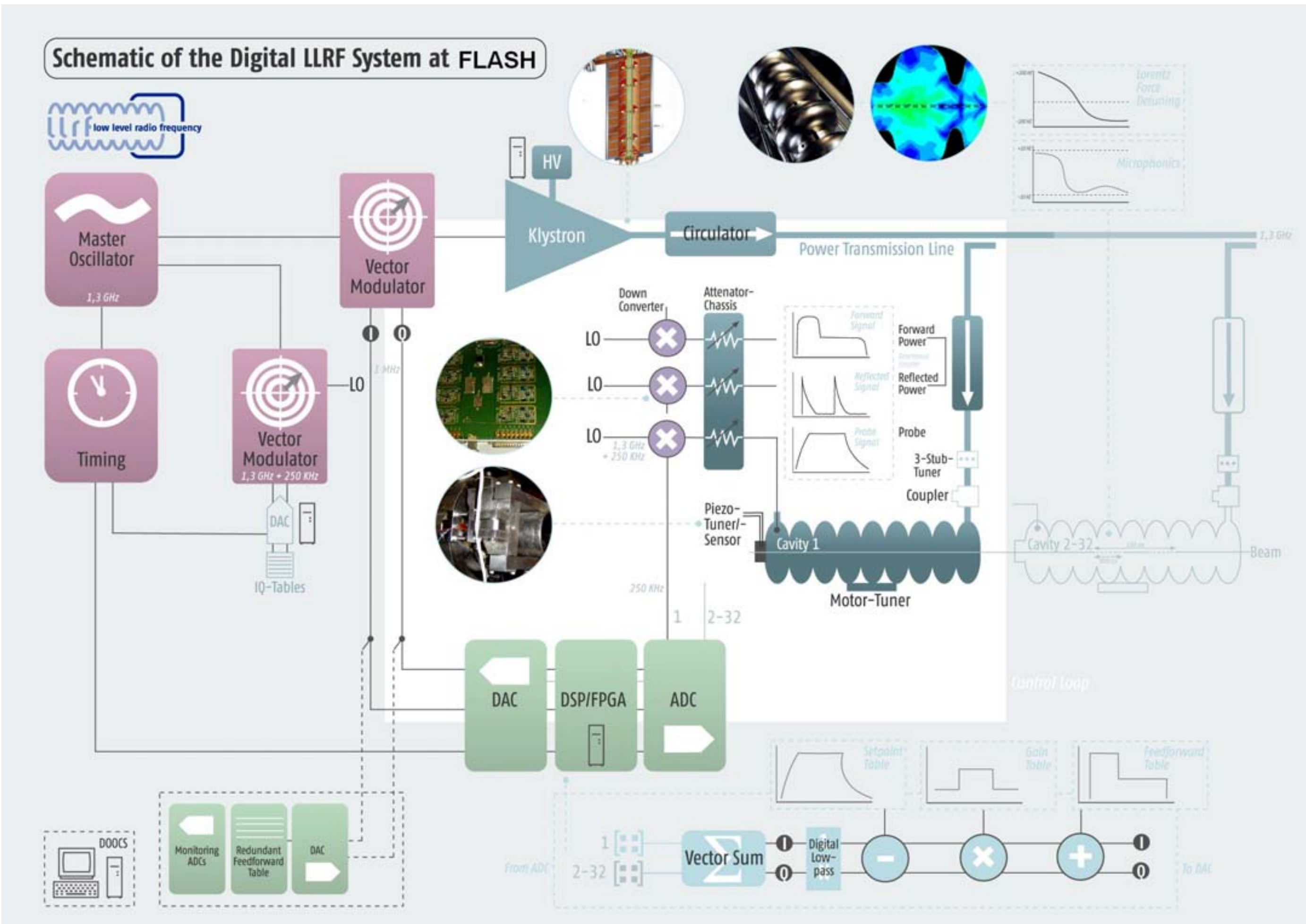
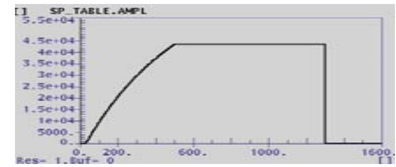
Goals

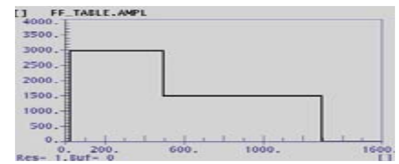
- Minimize the klystron power for RF control
  - avoid unnecessary power overshoot
  - optimize cavities filling procedure by applying amplitude smoothing and phase correction algorithms
  - minimize klystron & coupler trip rates
  - maximize energy gain from RF station (keeping the klystron forward power lower)

Schematic of LLRF System

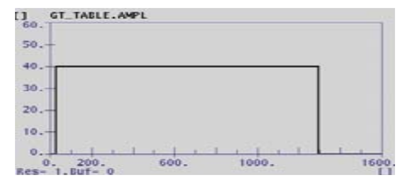




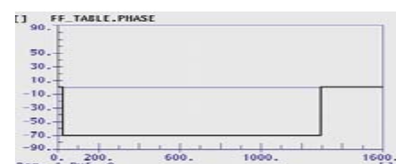
Set point



Feed-forward



Gain



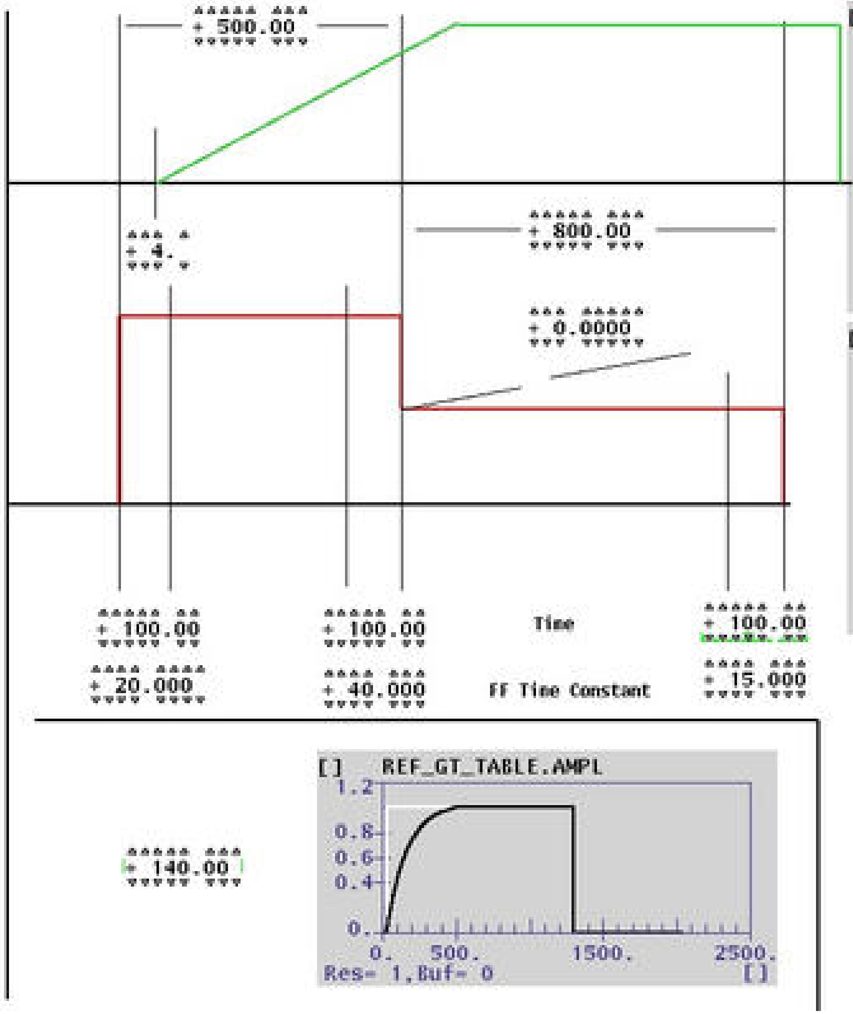
SP/FF phase

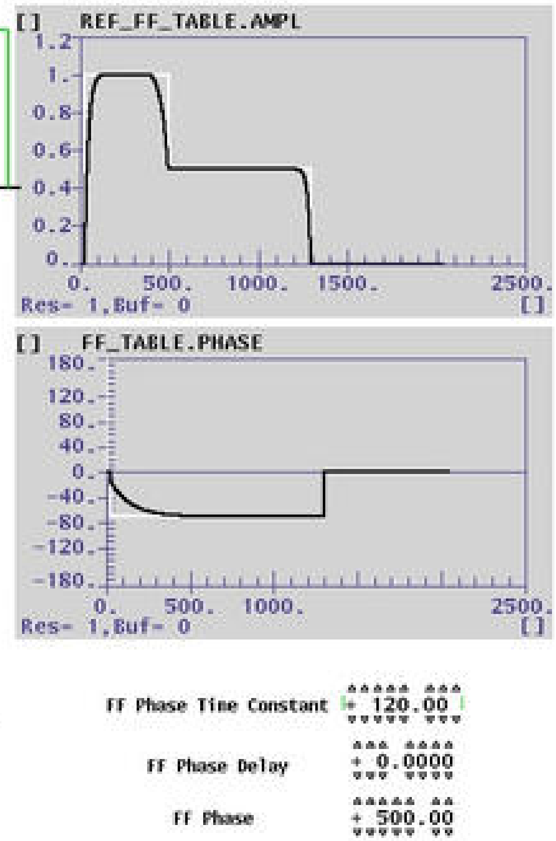
The Method: Feed-forward Optimization

- Smooth the edges of the feed-forward tables to reduce transient RF peak power
- Optimize cavity phase filling procedure with phase modulation to follow cavity resonance frequency
- Time varying gain studies
  – Ramp up gain during filling time
- Feedback gain studies
  – Study gain limits, instabilities, oscillations

Extension of DSP System Functionality

- MATLAB implementation for different kind of table modification
- DOOCS interface

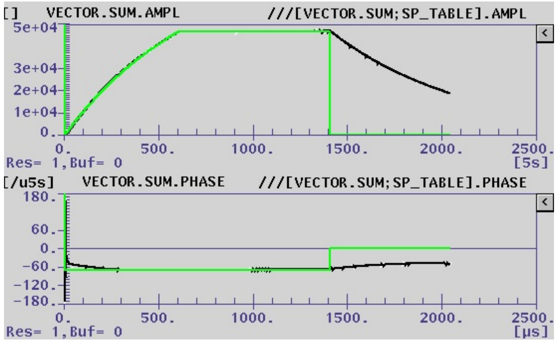


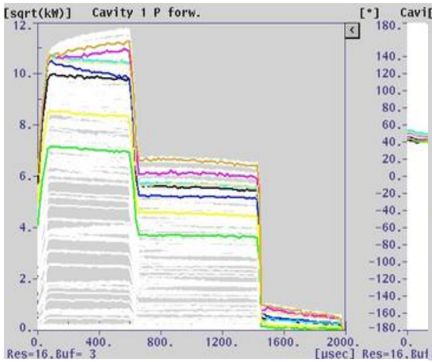


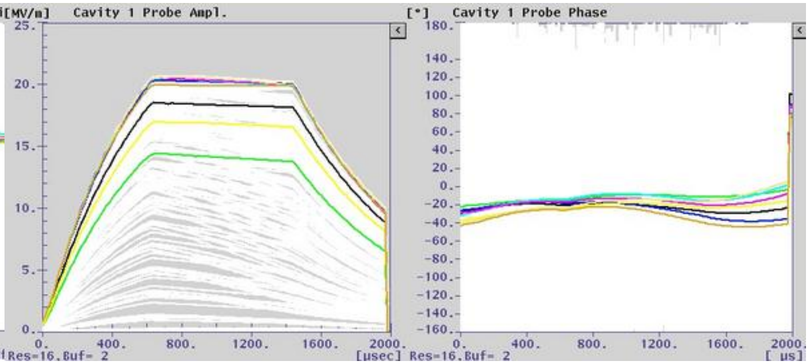
$$\varphi(t) = \varphi_0\left(1 - e^{-\frac{t}{\tau}}\right)$$

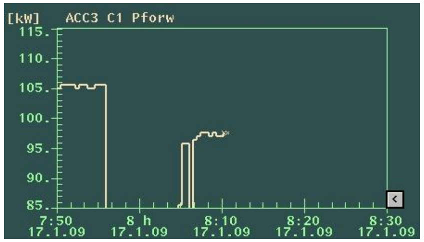
Smoothing of Forward Power Overshoots

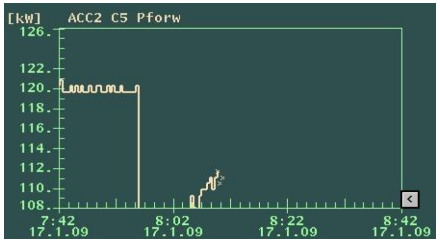
- RF pulse shifted close to the beginning of klystron HV pulse (no change in klystron HV pulse length)
- Increased fill time by 100 us by smoothing shape of feed-forward signal (20/40/20 us)
- ~550 us fill and 800 us flat-top time
- Peak forward power has decreased
- Klystron operates in linear regime of its characteristics







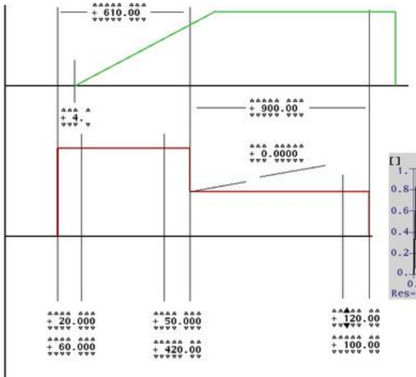


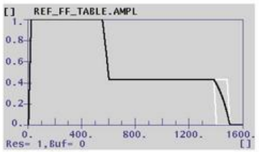


ACC2 forward power

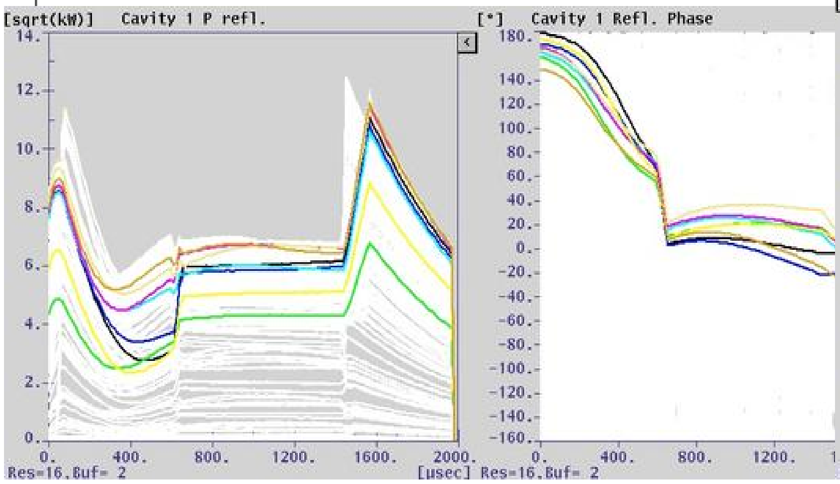
ACC2 probe signals

Minimizing Reflected Peak Power

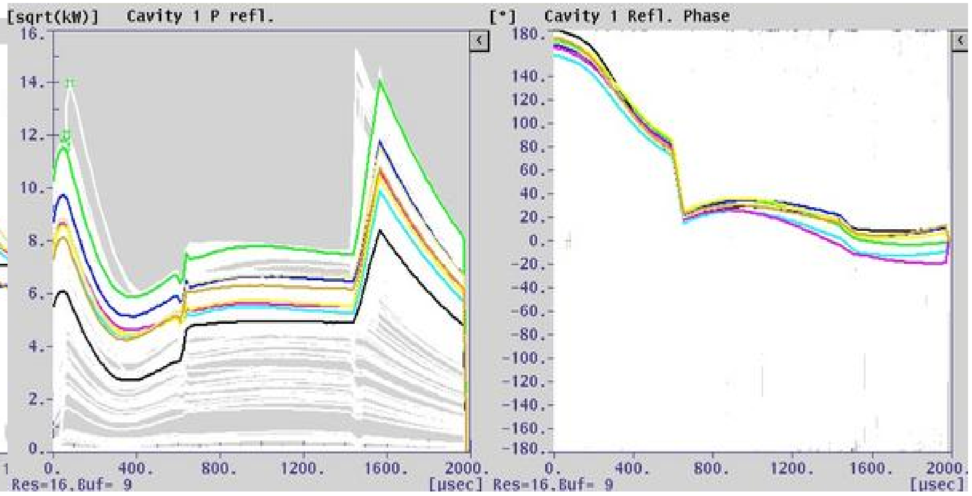




Reflected peak power level at beginning and end of RF pulse is lowered



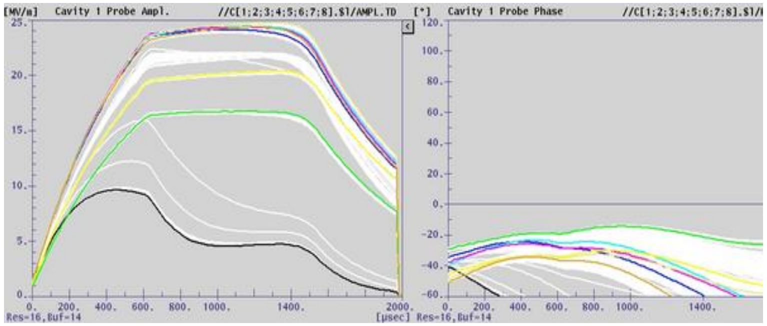
ACC2

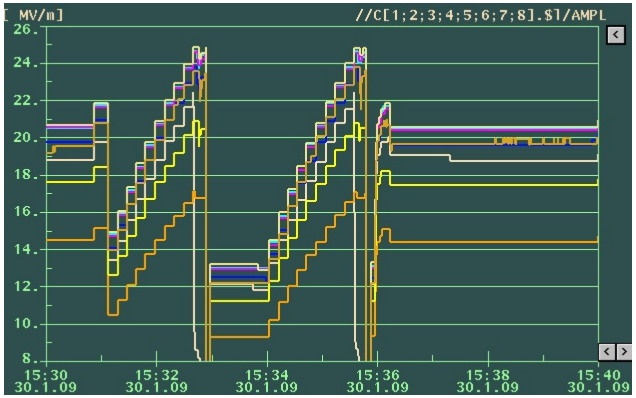


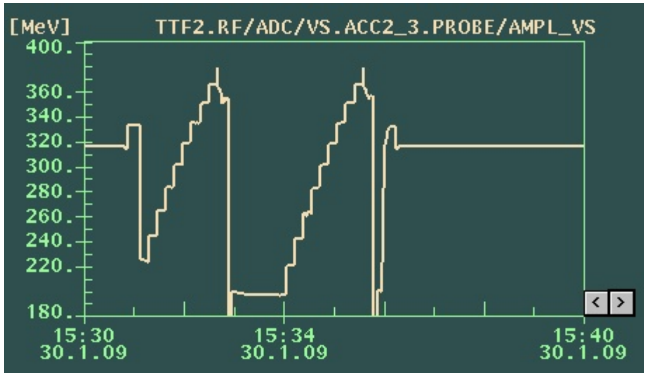
ACC3

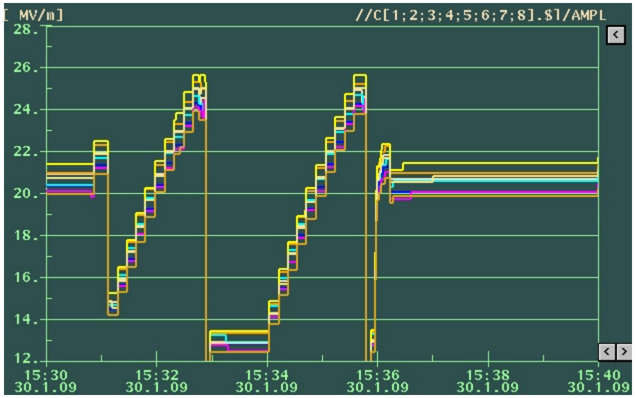
Quench Limitation

- Quench limitations are the same with and without smoothing (max. energy gain from ACC2/3 at 364 MeV)
- No problem for couplers to have long filling time



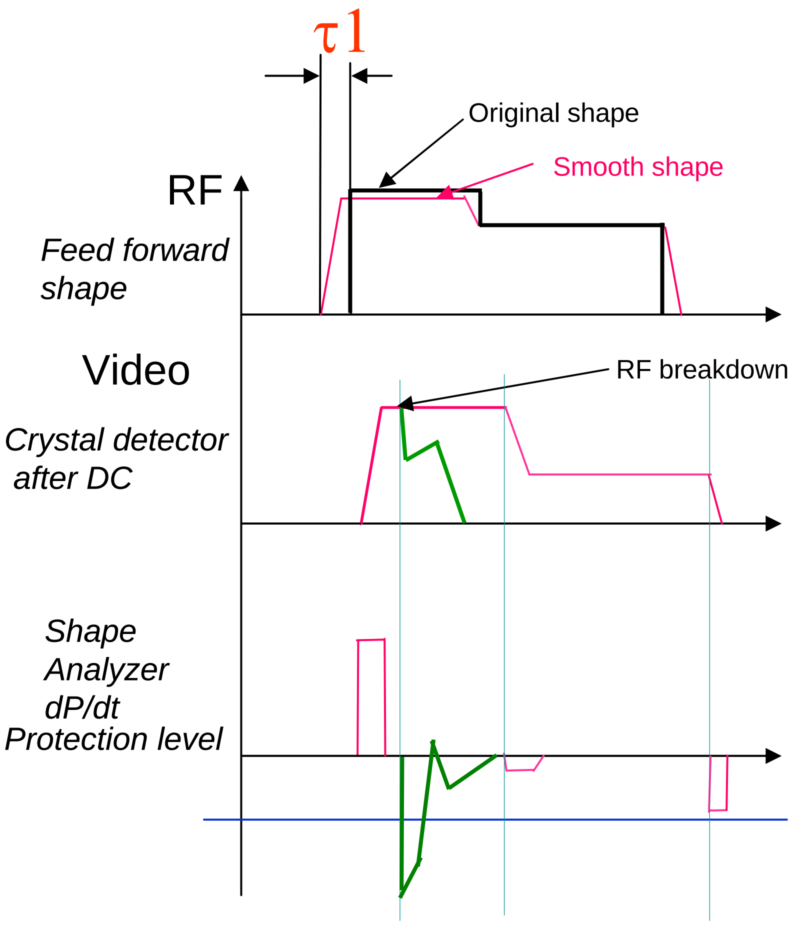




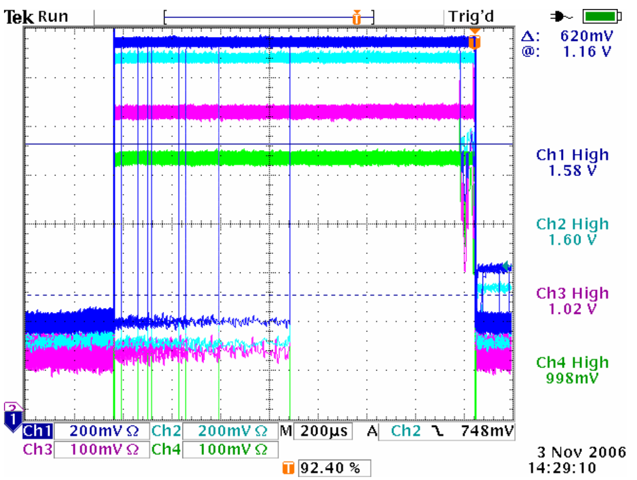


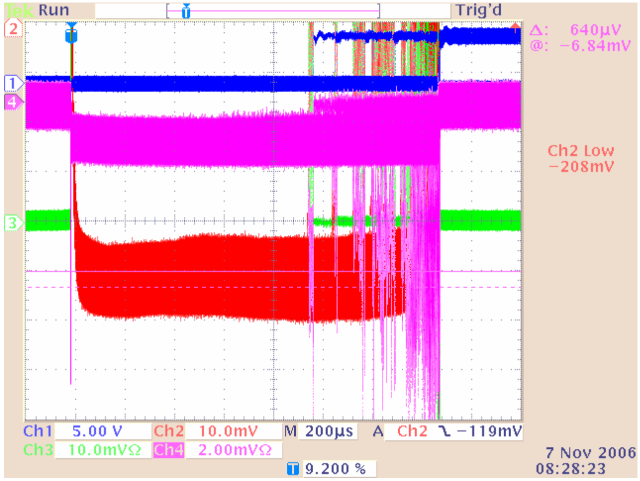
Pulse Shape Analyzer

Smooth shape allows to use simple klystron protection system



November 3, 2006, SN#4

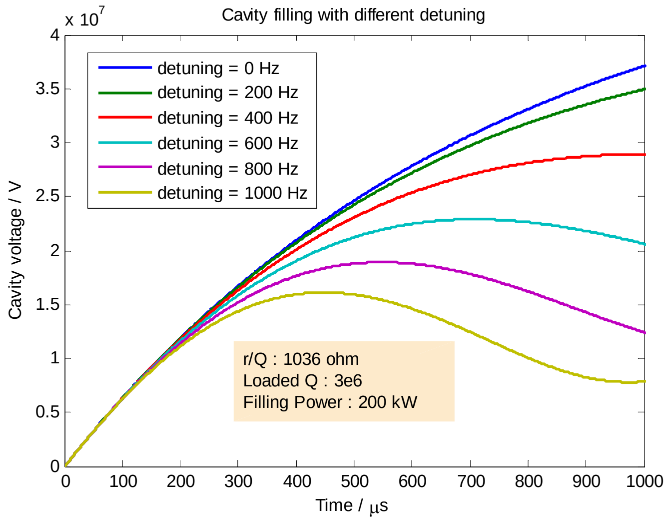


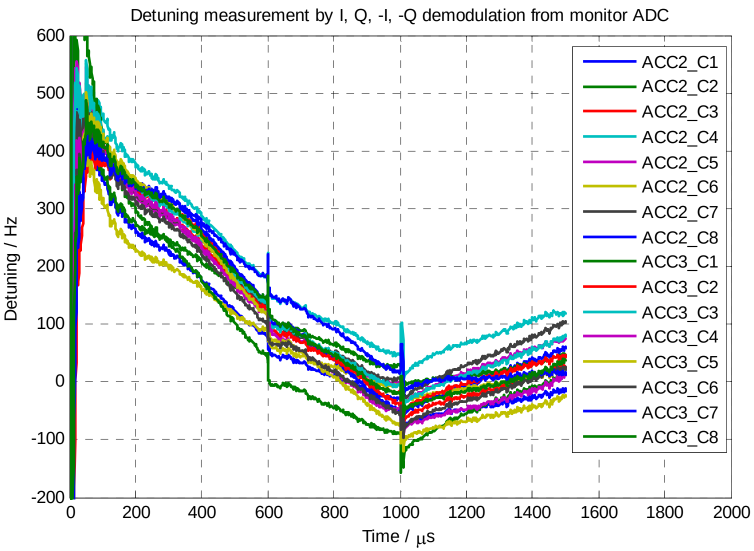


Advantage: Very simple shape analyzer can be implemented if pulse shape is smooth!

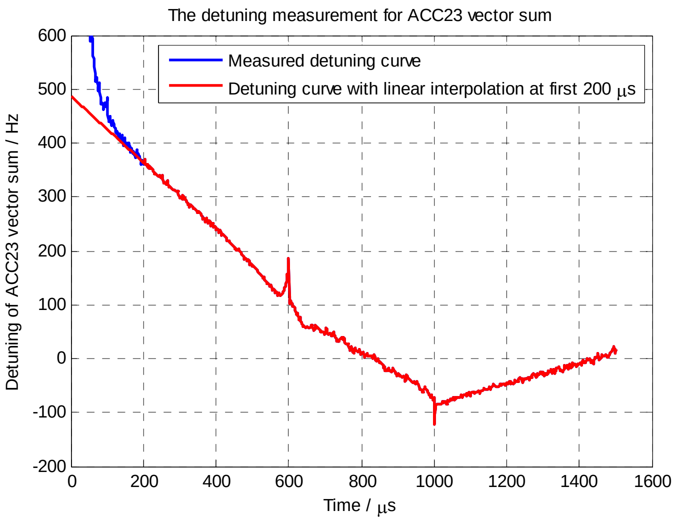
example

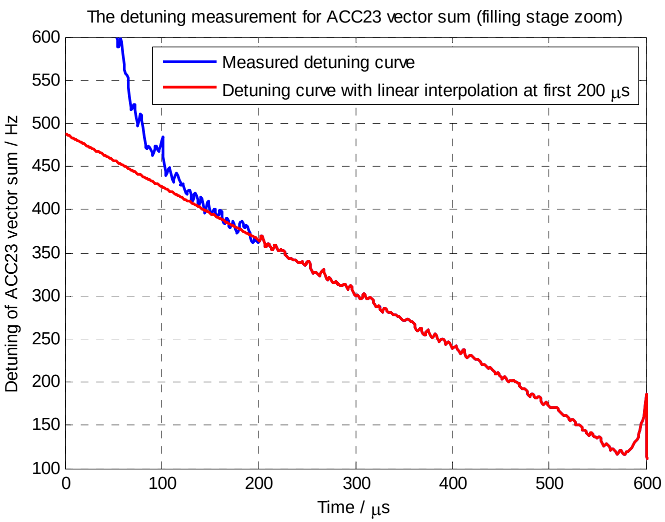
Cavity Filling with Different Detuning



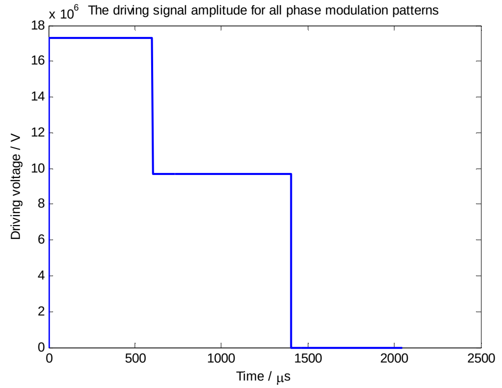


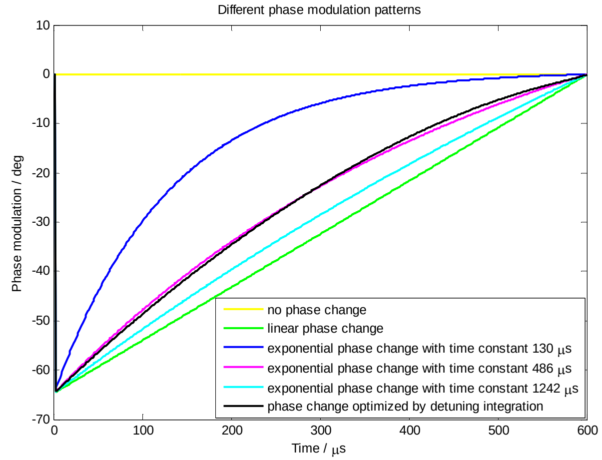
Expected energy gain ~5%

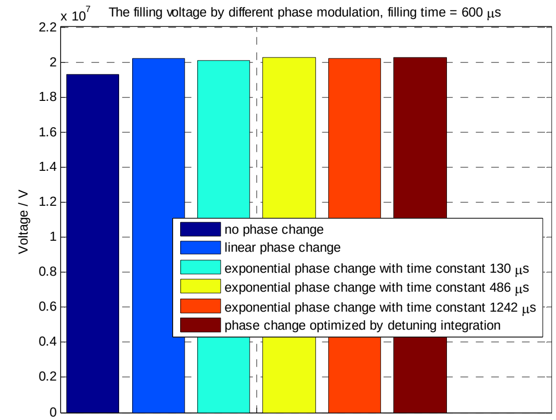


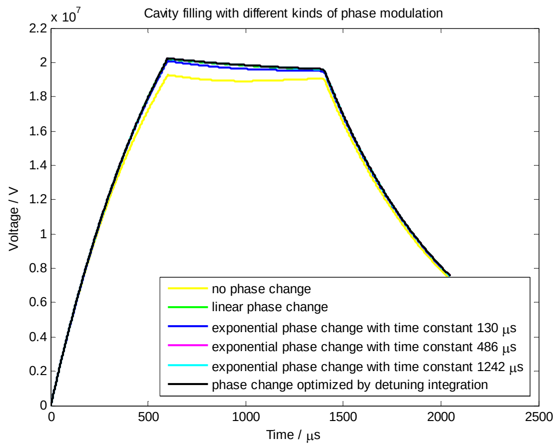


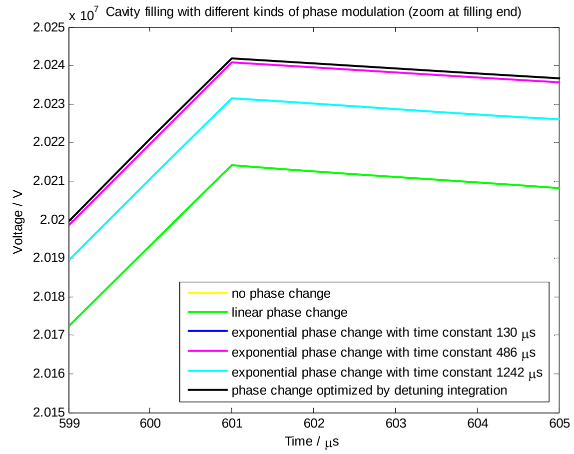
Simulation: Cavity Filling with Phase Modulation

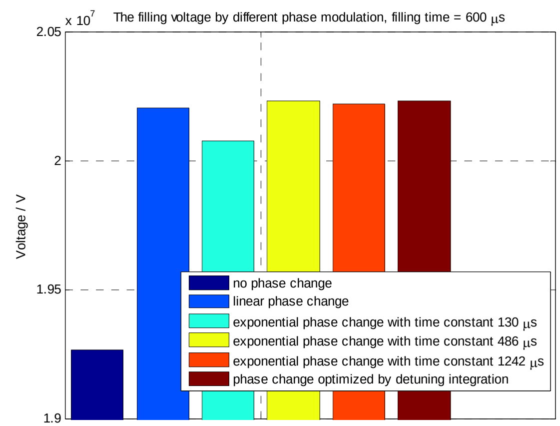










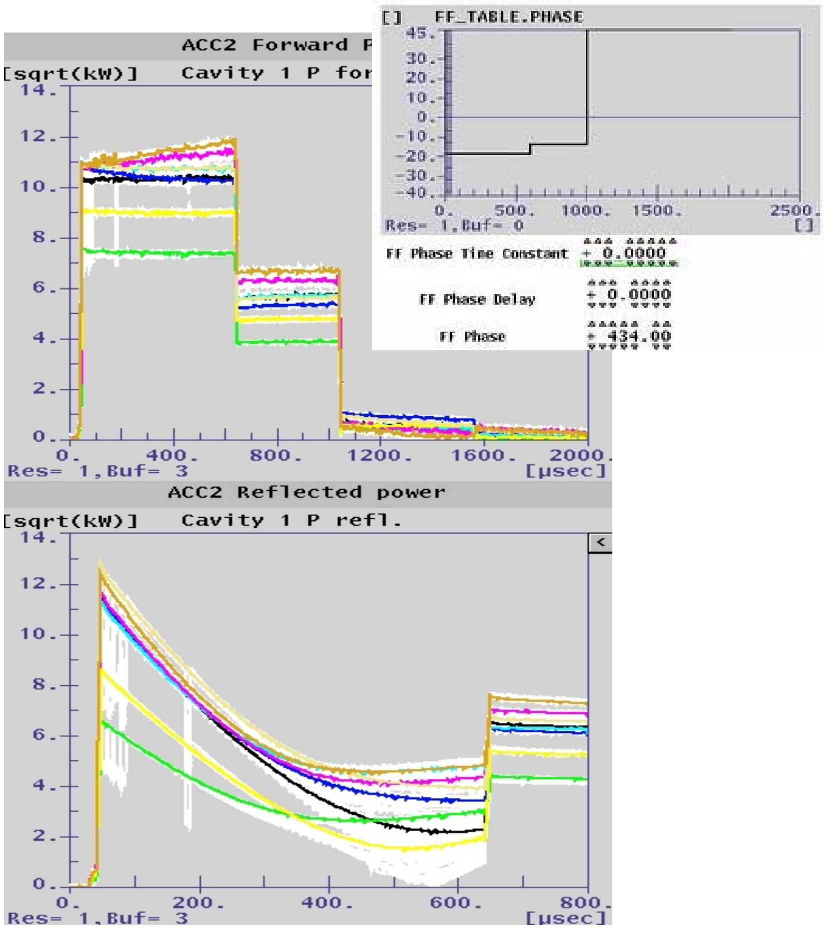


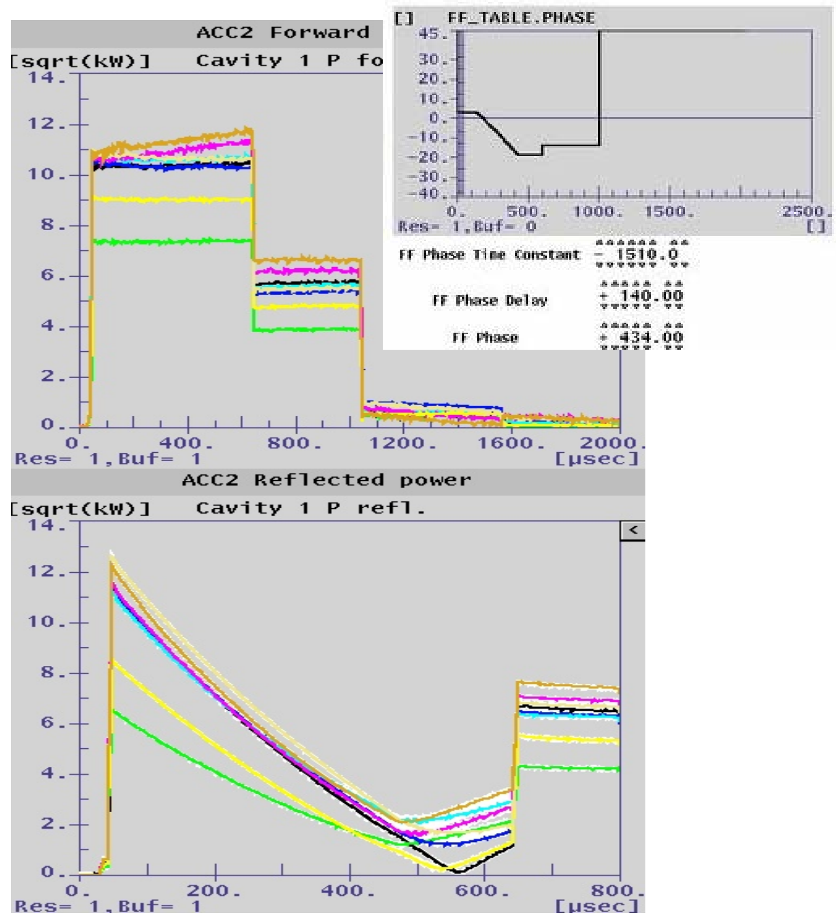
Gradient/Energy gain ~5%

Phase Optimization

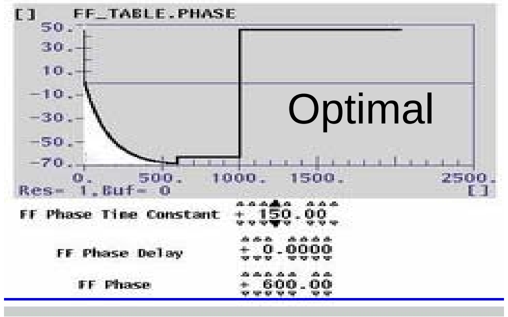
Phase modulation during filling: linear

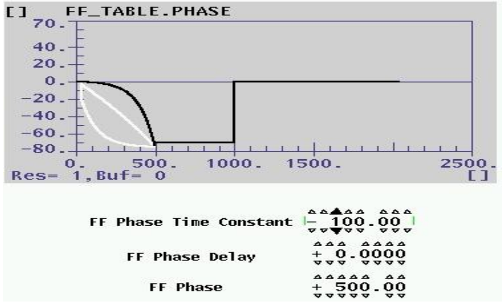
Minimum reflection at the end of filling time has been reached

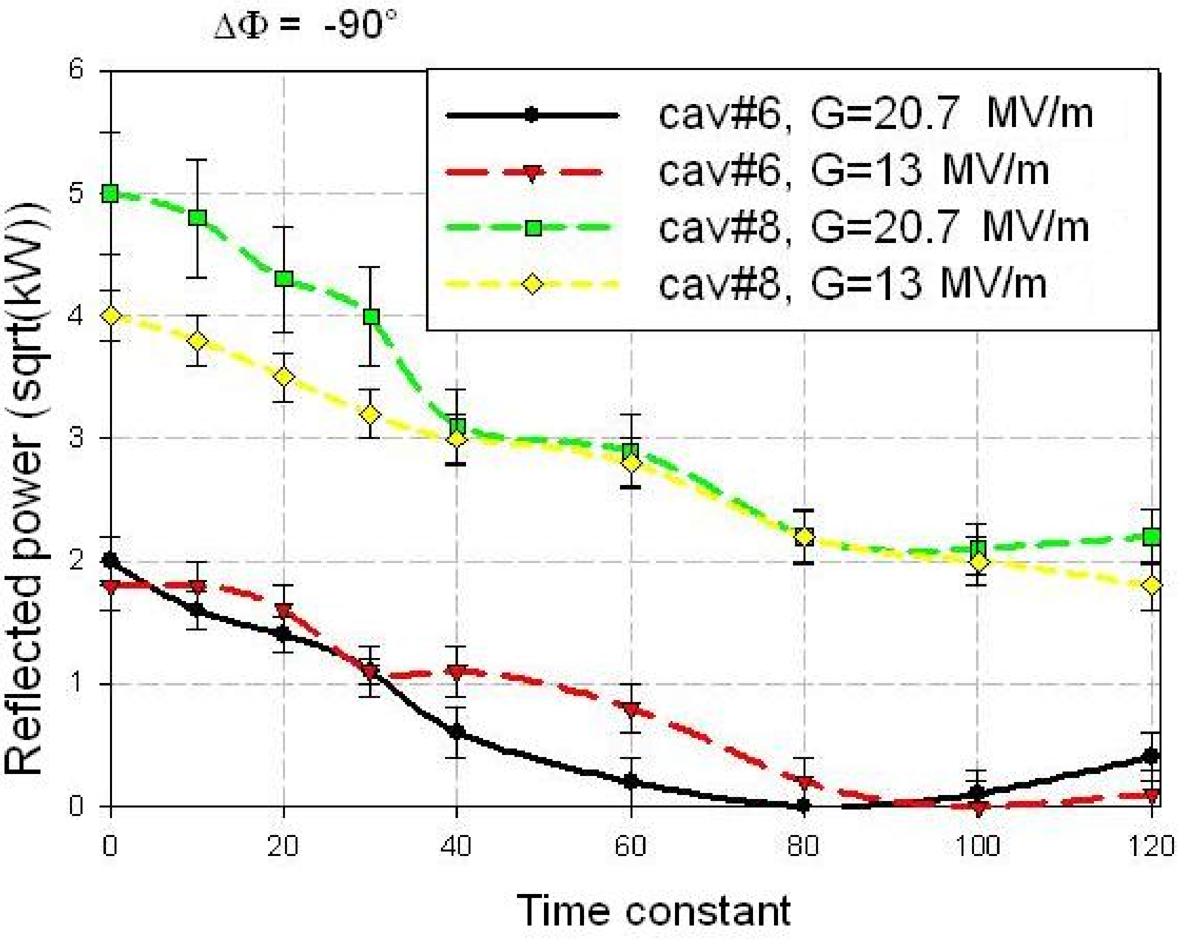




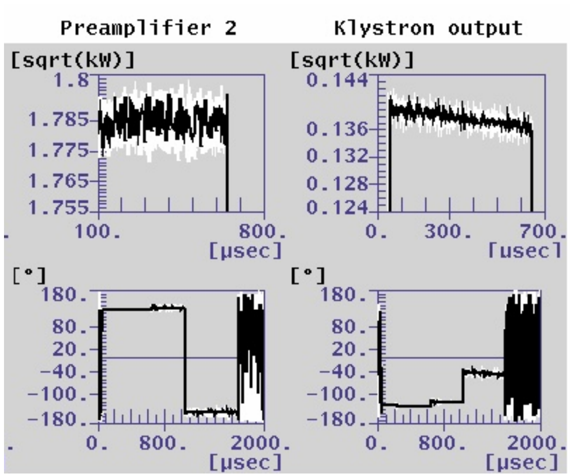
Minimization of Reflected Power: Results

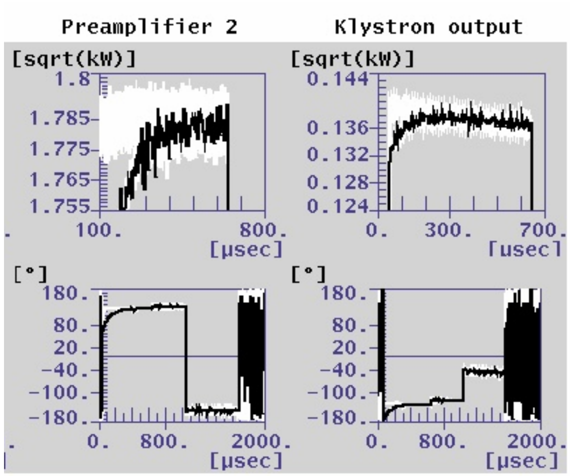




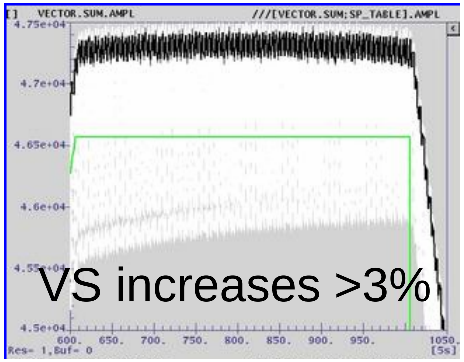


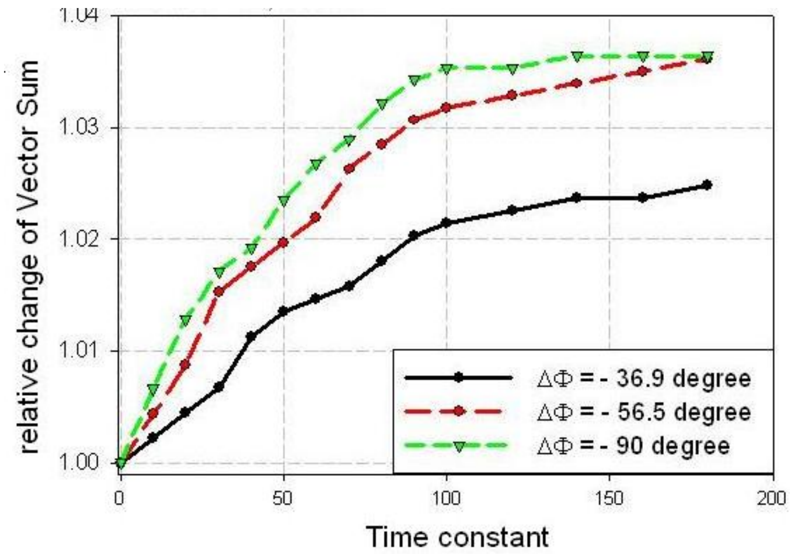
Energy Optimization

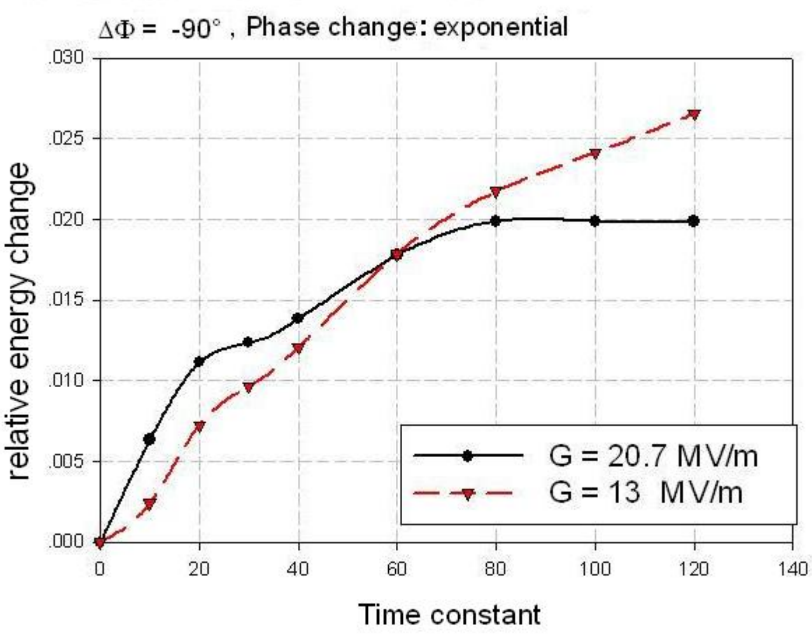




Vector sum by DSP

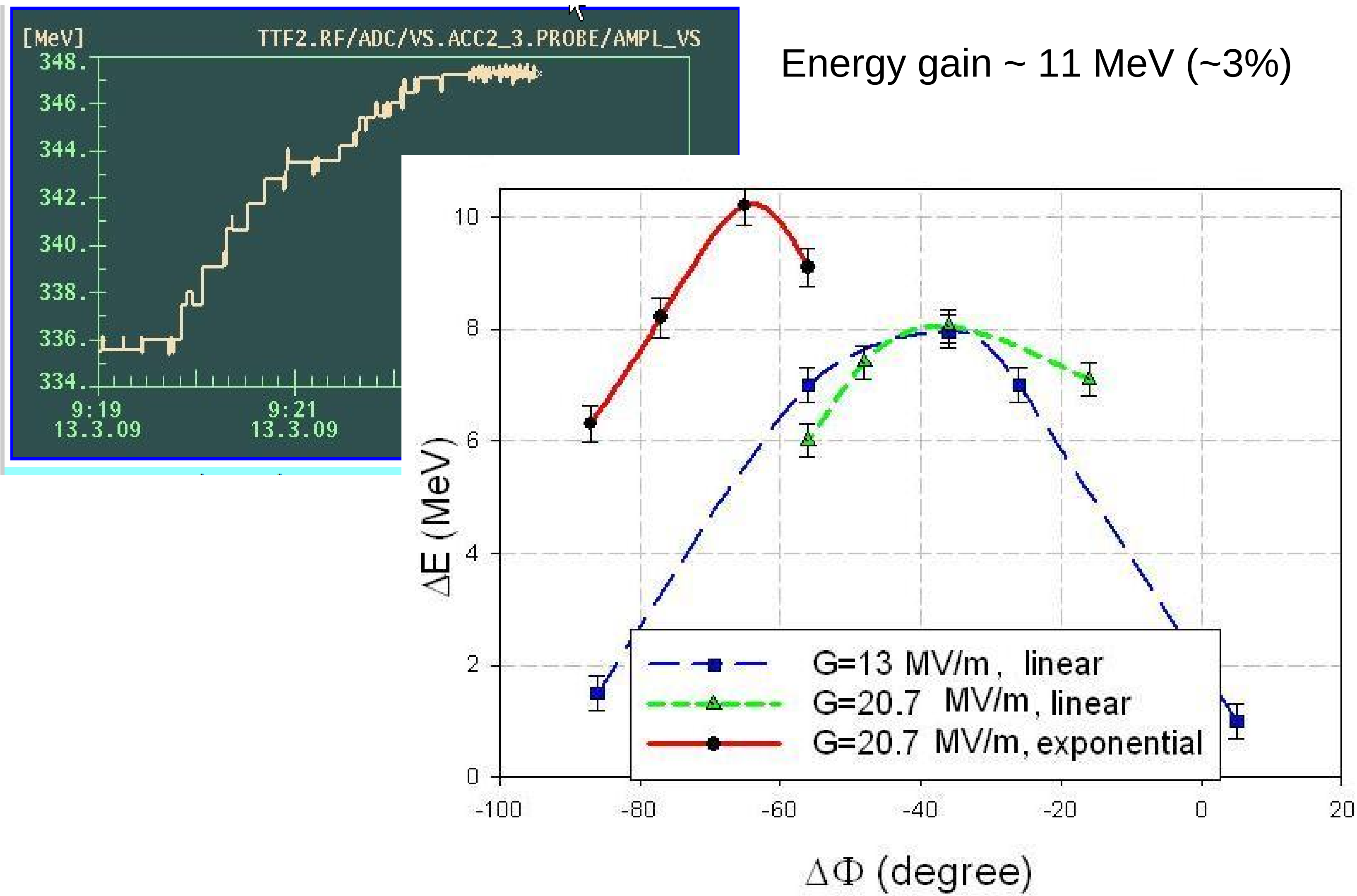






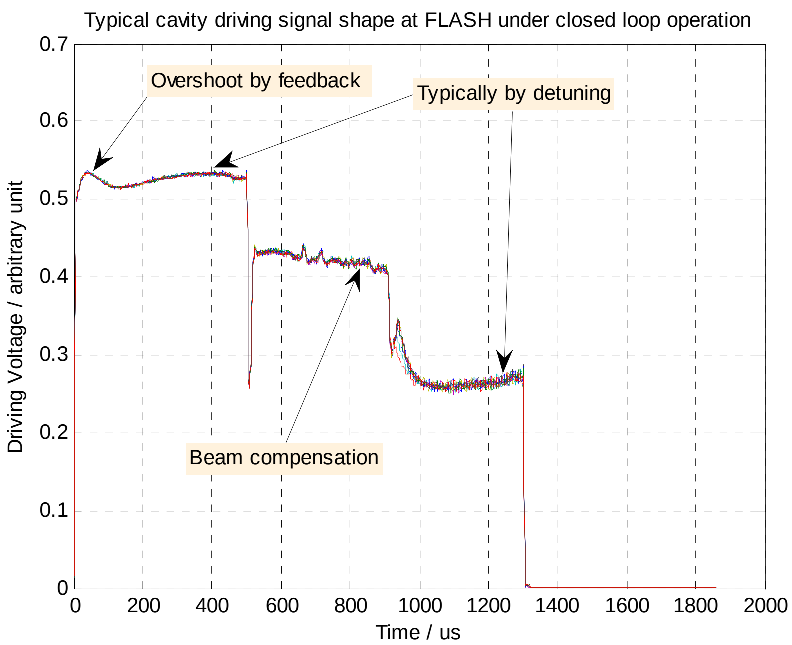
Optimal Timing Settings

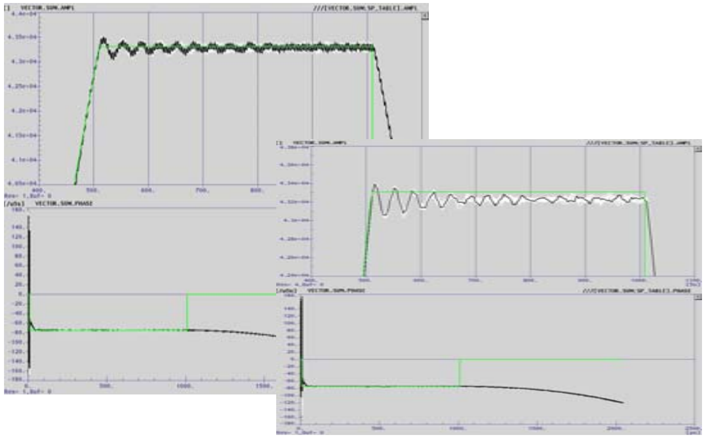
Energy gain ~ 11 MeV (~3%)



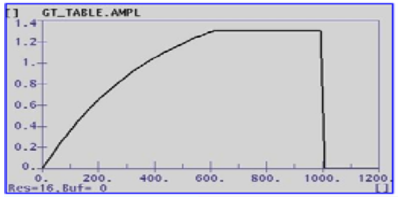
Variable Gain Studies

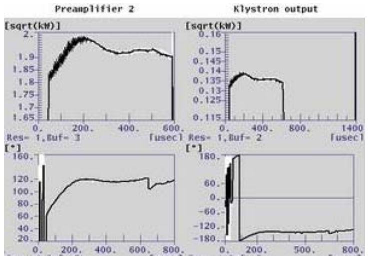
Forward power is smoothed adjusting gain values in several portions of the table

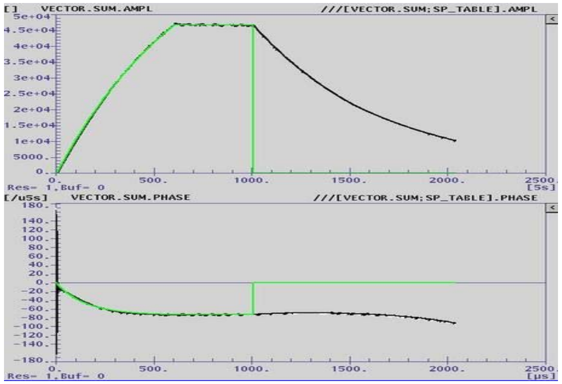




Oscillation at gain of 100 (08/01/2009)

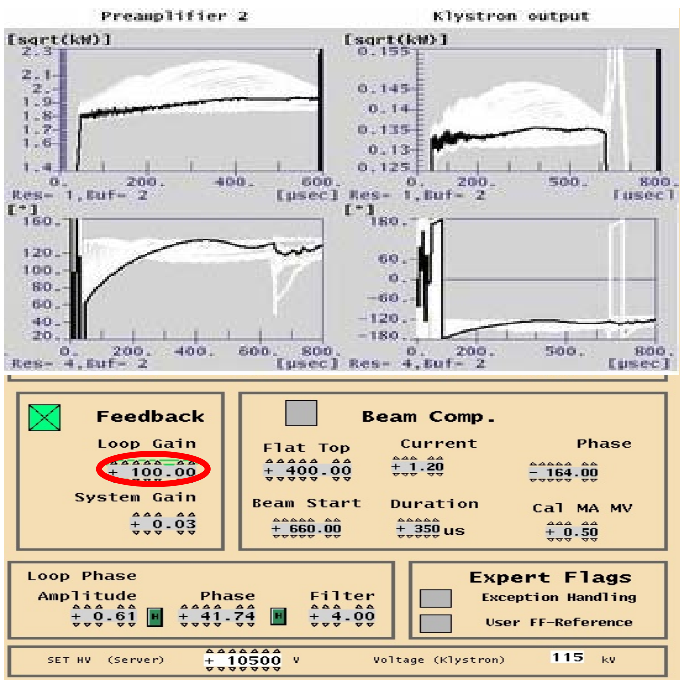


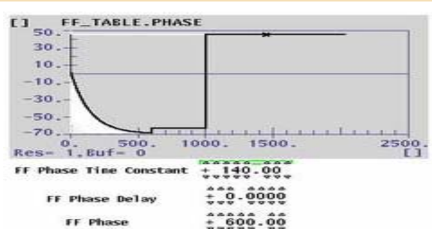


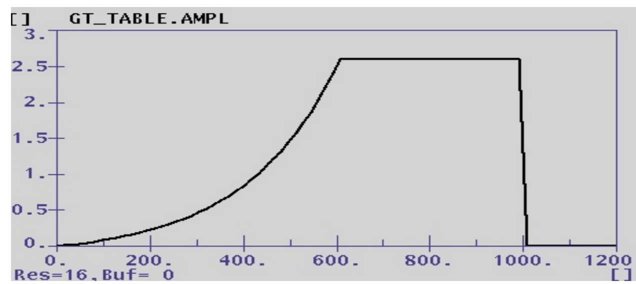


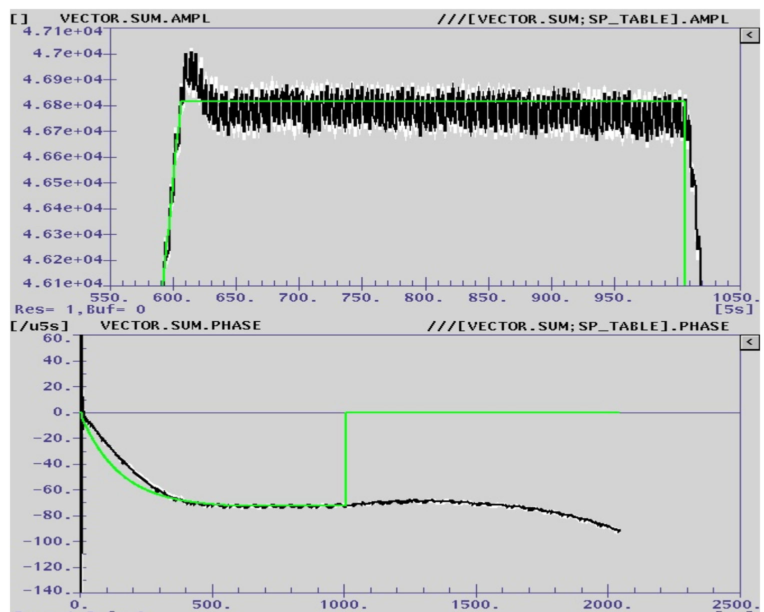
Variable Gain Studies: Optimal Gain Shape

- Running feedback loop with gain of 100 without significant oscillations
- Reduction of ~15% peak forward power required for feedback regulation during filling time









Summary

- Optimization of cavities' filling procedure
- Significant reduction of the reflected power level
- Reduction of ~15% peak forward power required for feedback regulation during filling time
- Increased gradients/energy ~ 3% within the same forward power level
- Running feedback loop with relatively high gain (100) without significant oscillations
- More stable operation of the klystron has been reached

Future Plans

- Study effects on beam and SASE stability
- Study in different gradient levels with optimum pre-detuning
- Implement and apply for all modules

  - It is more important for MBK since high voltage rise time is about two times longer (~200μs)
- Continue improvements for 9mA experiment