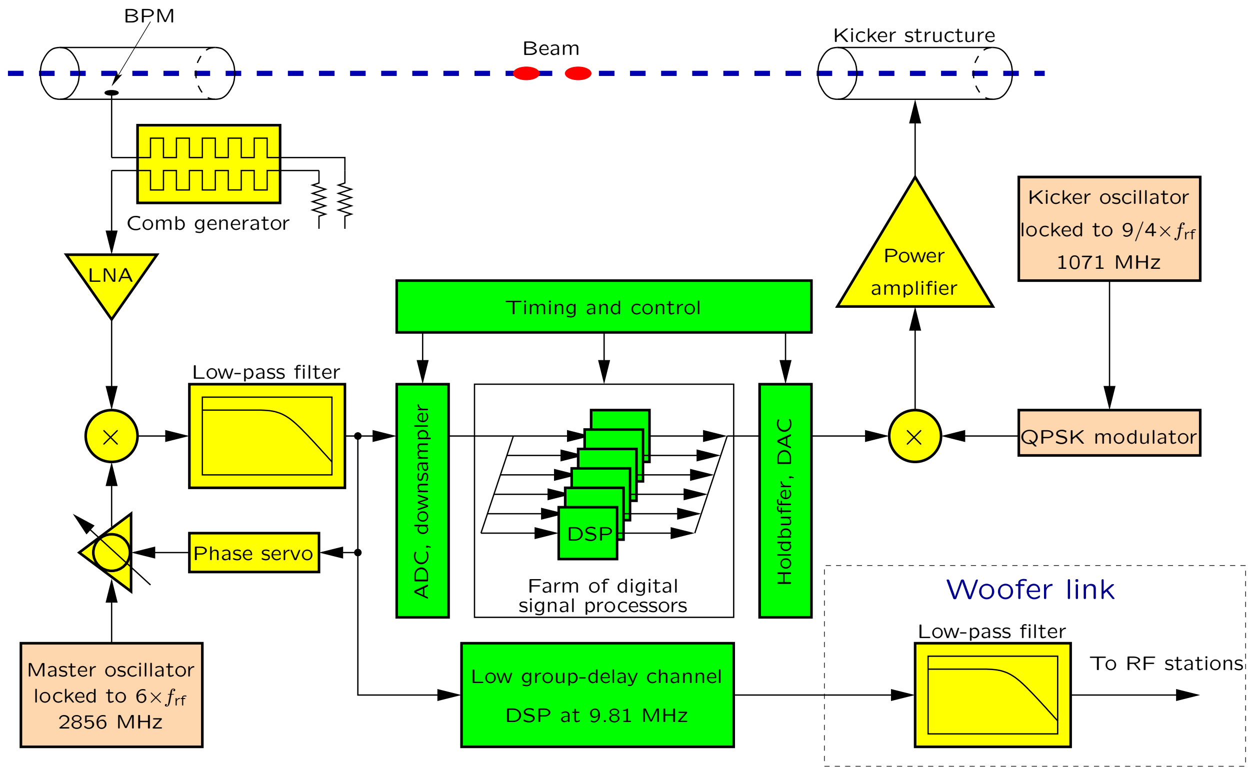
# Advanced Electronics Group, ARDA

J. Fox, T. Mastorides, C. Rivetta, D.Teytelman, D. Van Winkle, Y. Zhou

# Advanced Electronics - Overview

The ARDA Advanced electronics group combines interests in accelerator dynamics and instability control with technology expertise in high-speed signal processing. The group does machine physics development of instability control hardware, develops theoretical models of stability and control techniques, and serves to develop special accelerator instrumentation for experiments.




Efforts in 2005 center on high-current stability in PEP-II via modelling and machine measurements, plus development of next-generation 1.5 GSample.sec. feedback channels in conjunction with LNF and KEK.

The group comprises SLAC staff and Stanford Ph.D. students in EE/Applied Physics. Two APS Dissertation Prizes in Beam Physics have been awarded to group members.

Active collaboration on technology development and measurements with KEK, LNF-INFN,LBL

# Major Activities in 2004/2005

PEP-II High Current Instability studies

- Coupled-bunch studies (HOM driven instabilities), tuning/configurations of LFB systems

PEP-II RF systems

- Fault file analysis
- RF configuration development, station tuning, operations oversight

RF- Beam Dynamics, RF system stability modelling

- predictions for operations, evaluation of future operating conditions

Technology Development

- Gboard - next generation 1.5 GS/sec. reconfigurable processor
- Low Group Delay Woofer
- Klystron Linearizer

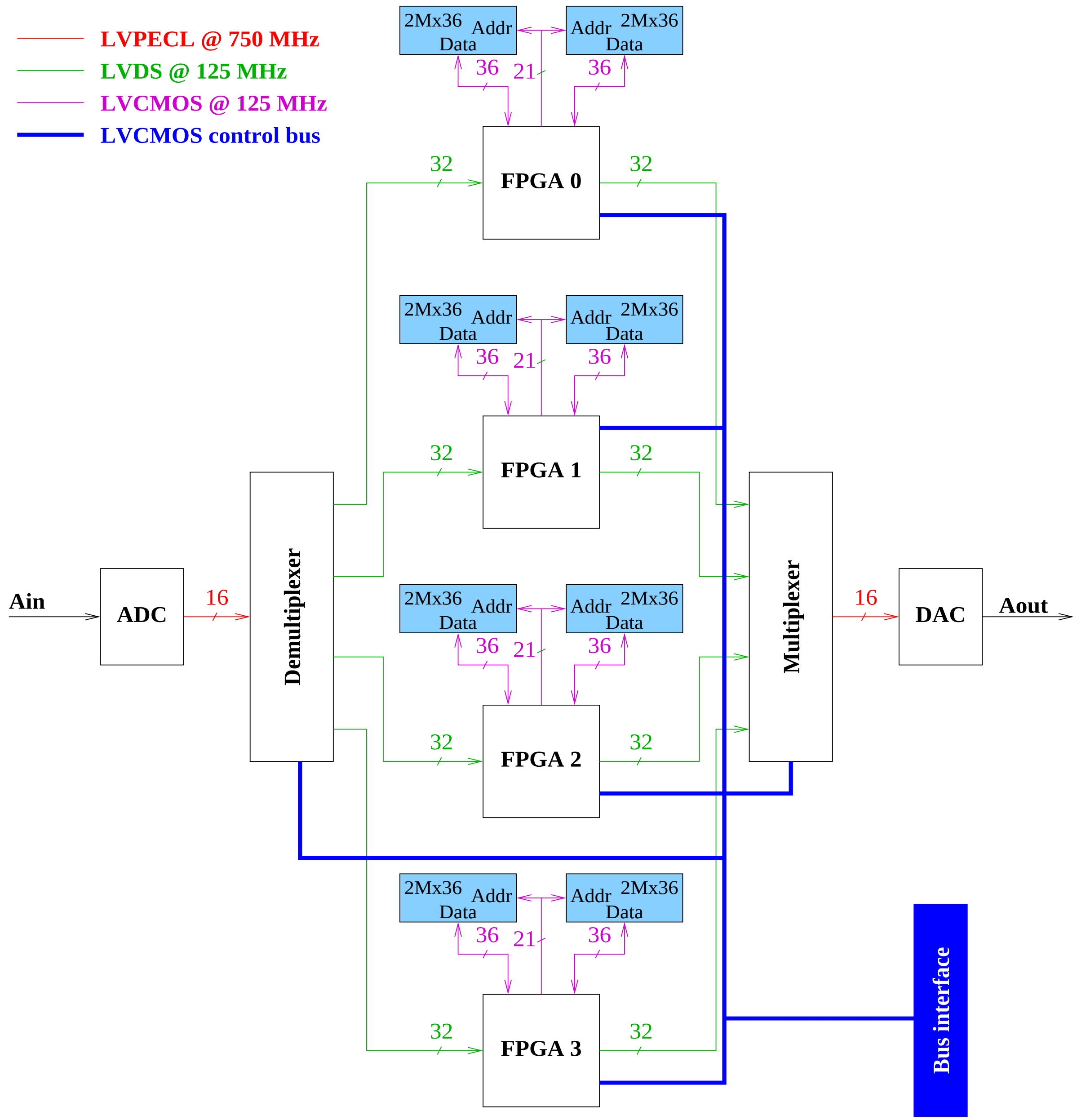
Publications -

- Conference papers (EPAC and PAC), Journal papers, Internal MAC reviews, Internal talks

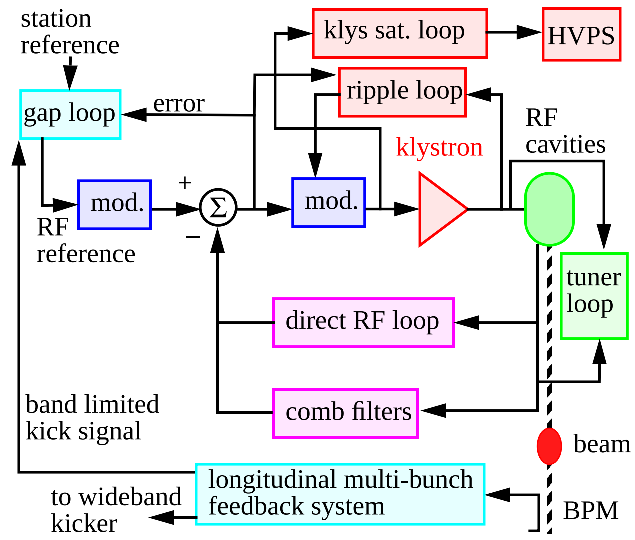
Teaching (Applied Physics, US Particle Accelerator School)

# GBoard 1.5 GS/sec. processing channel

- Next-generation instability control technology
- SLAC, KEK, LNF-INFN collaboration - useful at PEP-II, KEKB, DAFNE and several light sources.
- Transverse instability control
- Longitudinal instability control
- High-speed beam diagnostics (1.5 GS/sec. sampling/ throughput rate)
- Builds on existing program in instability control and beam diagnostics.
- Significant advance in the processing speed and density previously achieved.
- US-Japan Cooperative Project



# PEP-II LLRF Systems




Our group has taken over the analysis, configuration, fault diagnosis, and new technology development for these critical systems

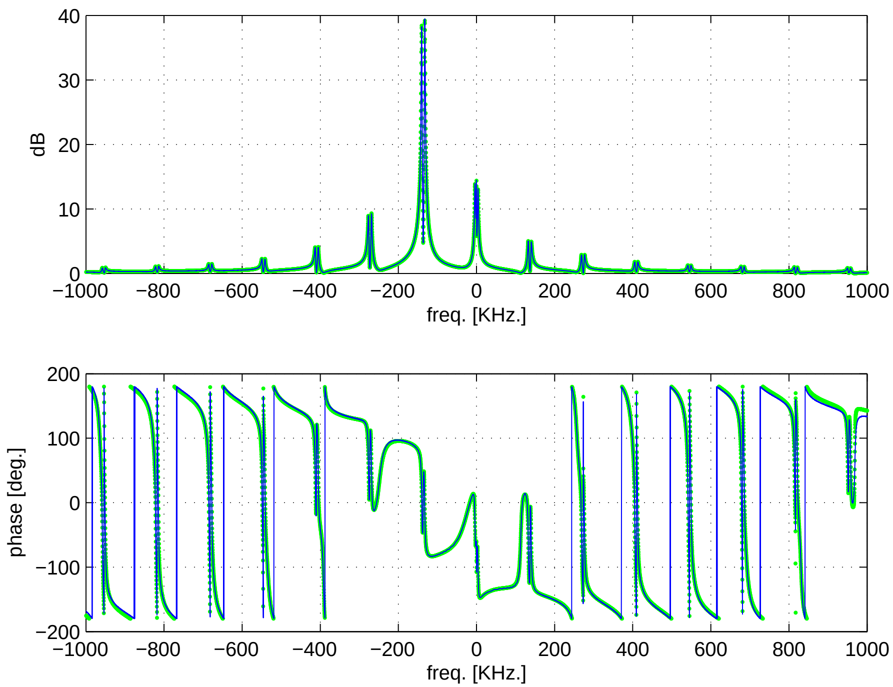
- Heavily Beam loaded
- State of the art in Impedance control via direct and comb feedback
- Multiple complex regulation loops
- Stability issues for RF loops, RF-Beam interactions, and low-mode coupled bunch instabilities.

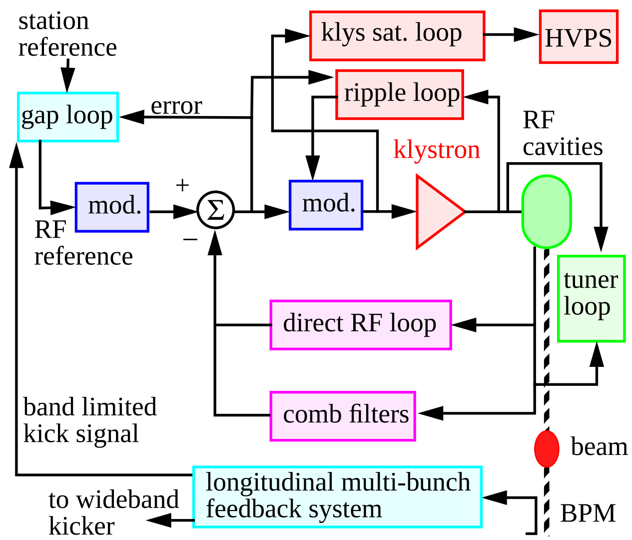
The LLRF in PEP-II includes fast analog, fast digital and slow digital control loops. Impedance control via the direct and comb loops.

Contributions

- New model based configuration techniques
- Fault analysis methodology, reporting
- Analysis of operating points, estimations of technology limits (PEP-II luminosity increases via increased currents)
- New technology (LGDW, Klystron Linearizer)
- RF Tutorial for SLAC Operations and Accelerator Staff (2 day course,48 attendees)

# Beam-LLRF Simulation and Dynamics Modelling



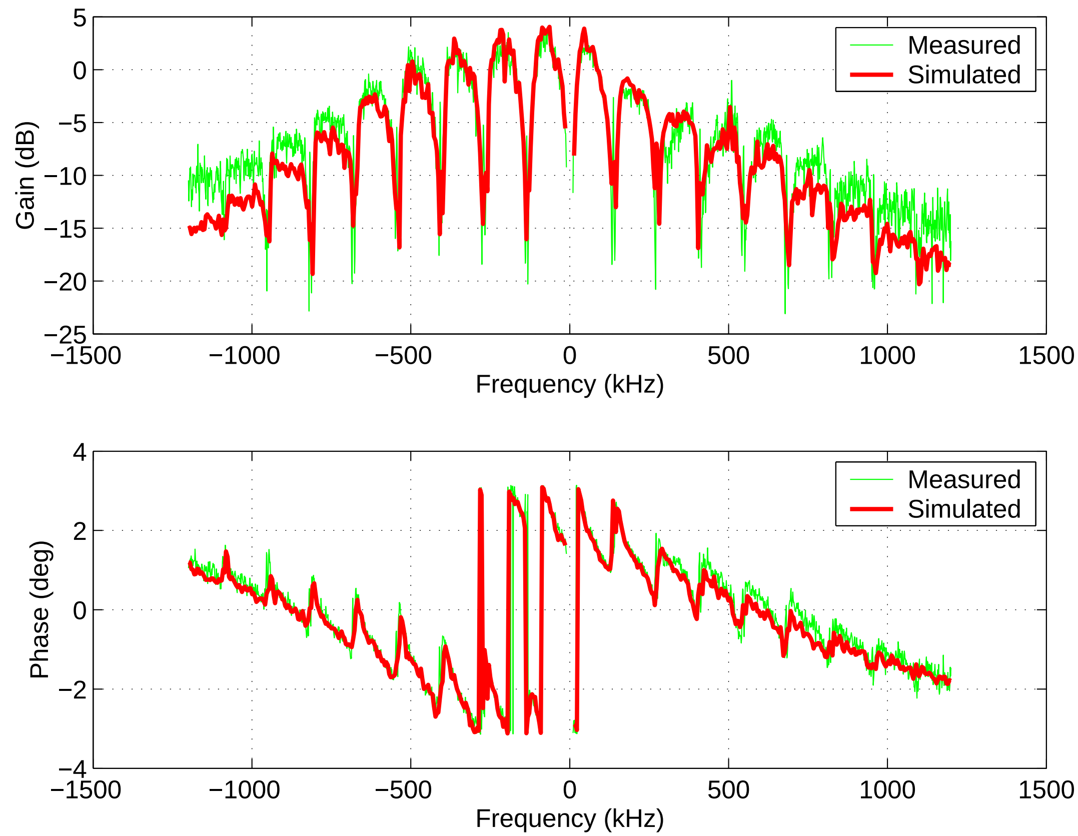

The LLRF in PEP-II includes fast analog, fast digital and slow digital control loops. Impedance control via the direct and comb loops.

To understand the beam-LLRF dynamics in PEP-II, a nonlinear time domain simulation is being expanded. The essential behavior of the LLRF system, plus high power klystron and cavity, is coupled to the longitudinal dynamics of the beam. The simulation results can model existing conditions (confirming margins and limits), and the analysis tools are based on those used for machine physics measurements. Issues - 2/4 cavity stations (Hybrid macromodel), multiple stations with unique operating points, non-linear klystrons, wide dynamic system time scale variations.

# Development of time-domain RF system model

Main limitation in predicting longitudinal stability at higher beam currents is the uncertainty in estimating the growth rates of the fundamental-driven eigenmodes

Impedance reduction via the LLRF feedback loops is critical, however the effectiveness of these loops is difficult to predict due to klystron saturation.

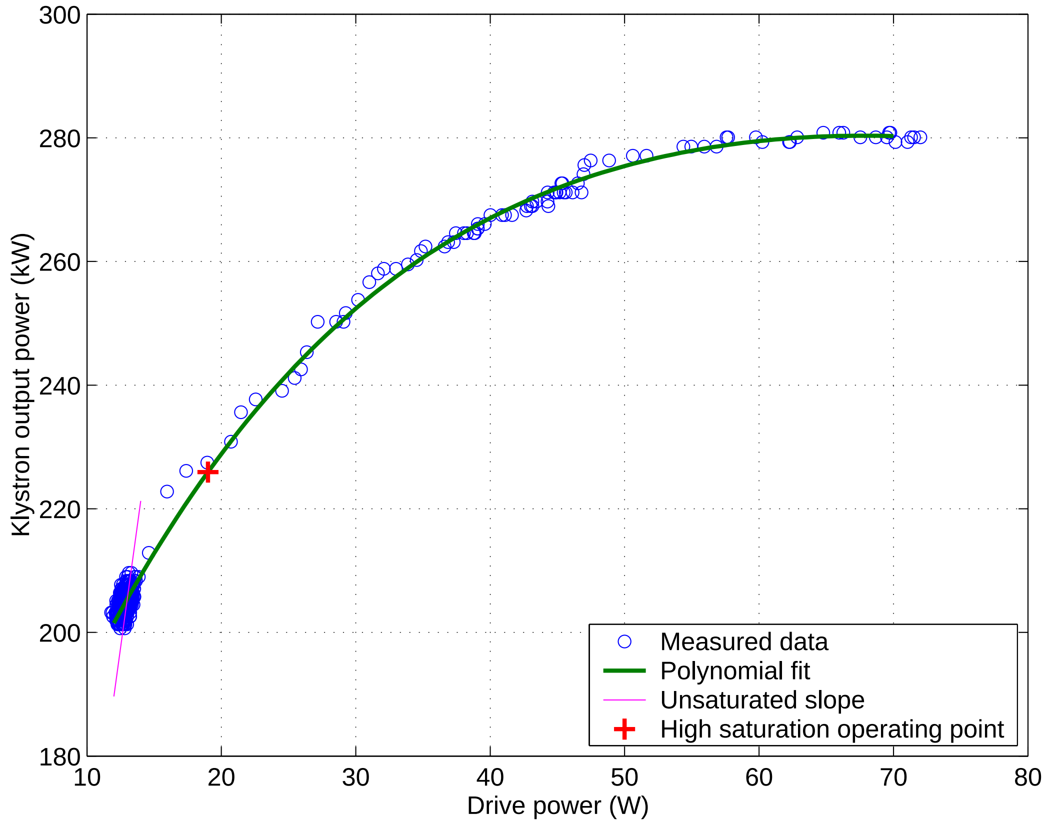



## Recent efforts

- **time-domain model consistent with the current RF system topology.**
- **As a test run the time-domain model using parameters extracted from an RF station transfer function measurement**
- **Transfer function extracted from the time-domain simulation data agrees very well with the transfer function of the physical station.**

# PEP-II fast impedance control loops -Limitations of cavity impedance control due to klystron saturation

A major effort by the group involves understanding the high-current instability limits in PEP-II. Our machine physics measurements have led to a better understanding of the limitations of impedance control in the PEP-II RF systems. Due to klystron saturation a linear impedance control model is not applicable.




For the HER at 1 A the growth rates rise from linear prediction of 0.12 $ms^{-1}$ to actual 1-1.8 $ms^{-1}$.

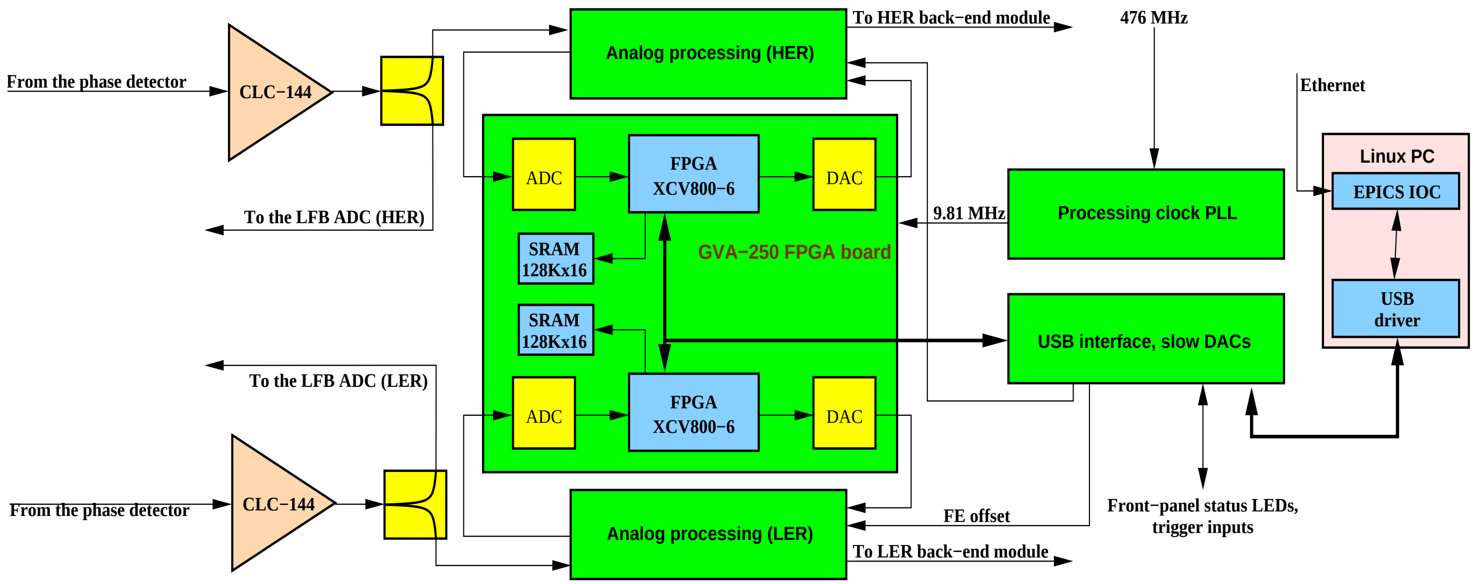
These high growth rates were limiting HER currents above 1380 mA.

We are attacking this limitation through a new RF woofer channel in the longitudinal feedback paths, and a novel klystron linearizer within the low level RF processing.

Our group is the technical resource which advises PEP-II on RF configurations, and has developed the model-based RF tuning techniques required to achieve record luminosities in PEP-II. We continue to improve dynamic simulation models to predict limits of control and evaluate new control methods.

# Low group-delay woofer

The woofer is based on a reconfigurable FPGA DSP board. It uses the existing LFB front-end monitor signal and the woofer output is passed to the LLRF via the existing back-end LFB module.




The LGDW implements a 32 tap FIR filter, with a 9.81 MS/s processing rate. Decoupled low-mode and HOM channels allow independent optimization of loop gains and dynamic ranges. EPICS user interface panels via IOC and software.

Prior to HER LGDW commissioning we were limited to 1380 mA with very tight margins - running with 1 -3 longitudinal aborts per day. With the LGDW currents immediately increased to 1550 mA, with much better margins.

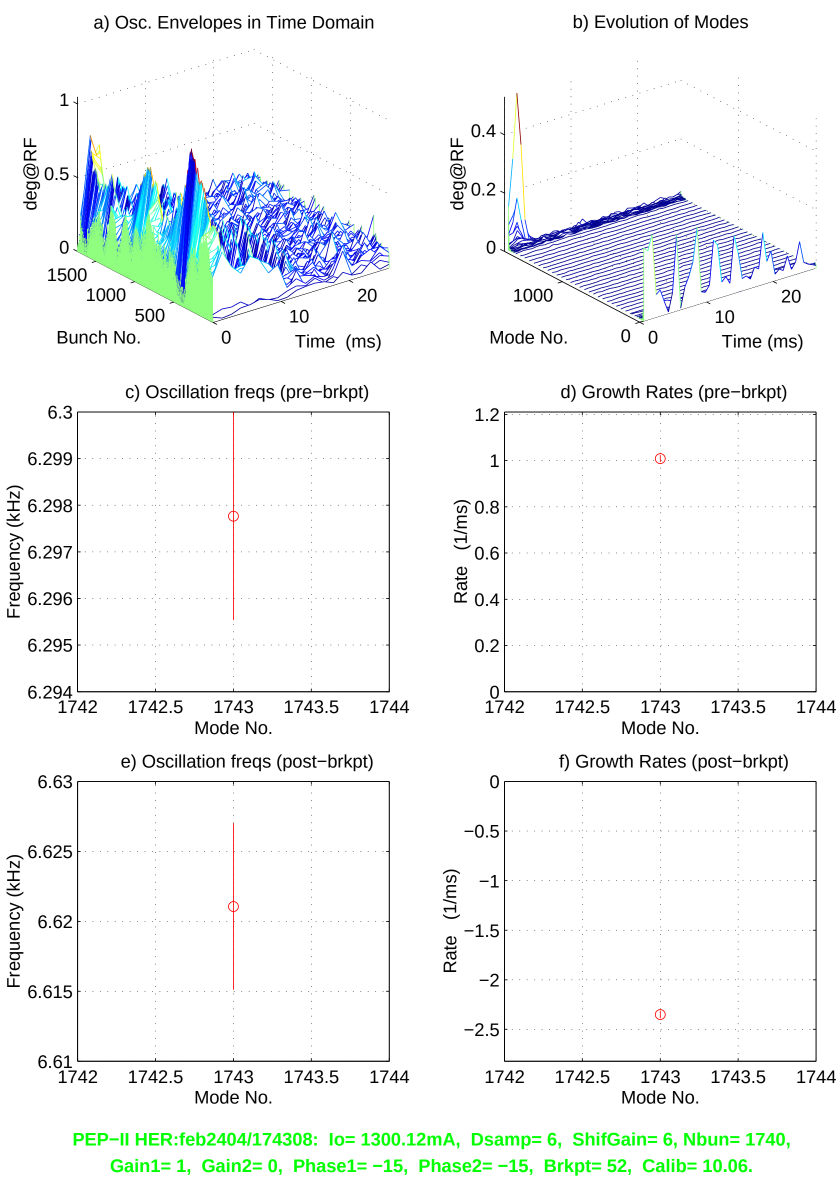
# Grow/damp measurements for the low modes

During these measurements we turn off both wideband (LFB) and narrowband (LGDW) channels. Measures open-loop growth and closed-loop damping for the fundamental driven modes

Due to optimized gain partitioning the system can recapture beam motion at larger amplitudes. For the grow/damp measurements this allows longer growth intervals and better SNR.

Larger dynamic range of the new woofer allows significantly larger beam transients due to injection, RF, etc.

This transient- instability measurement technique uses common codes and formalism for both longitudinal and transverse measurements

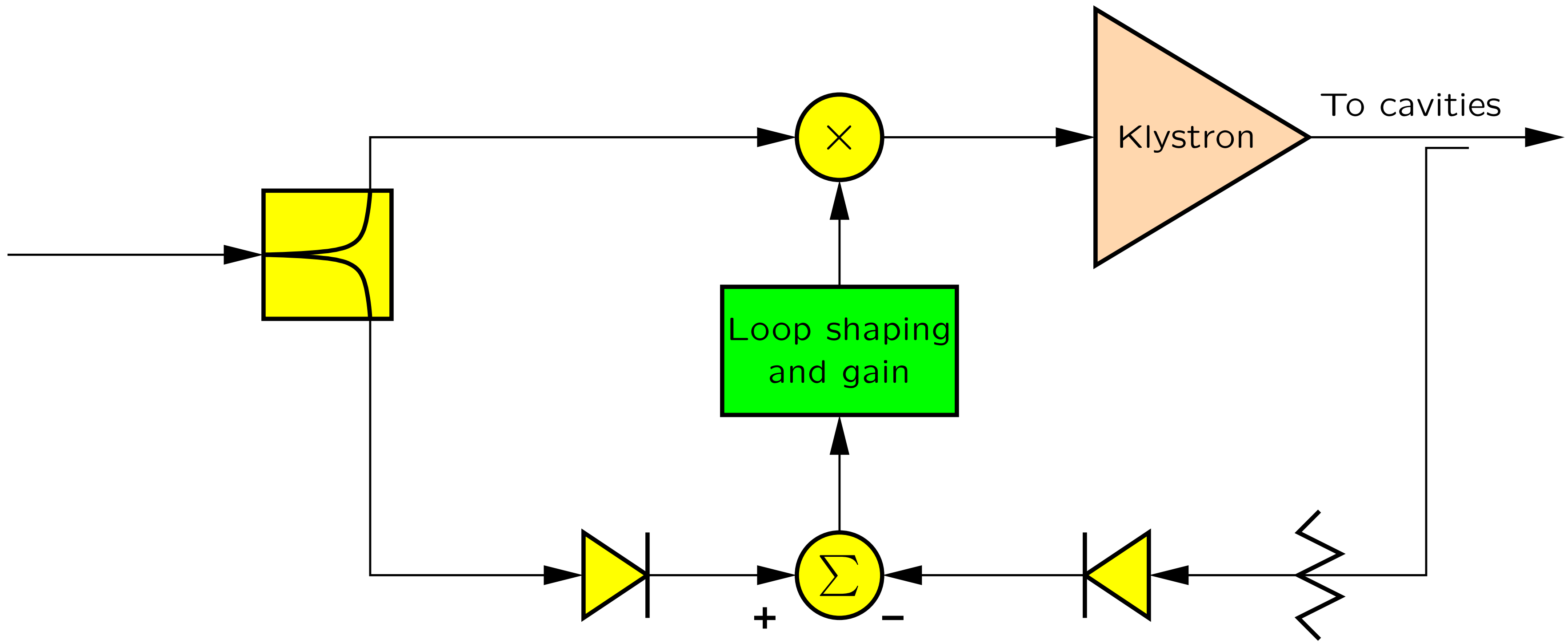


# Klystron linearizer: block diagram

In the past year we have developed a new technique to improve the impedance control of the RF direct loops by linearizing the high power klystron

Compare the input of the klystron and the output, use amplitude modulator to make the two match. Linearizes the klystron so that large- and small-signal gains are identical. Feedback does increase the effective klystron delay.

Full-power test stand data, 5 prototype processors in place in LER for beam tests



# Linearizer Prototype

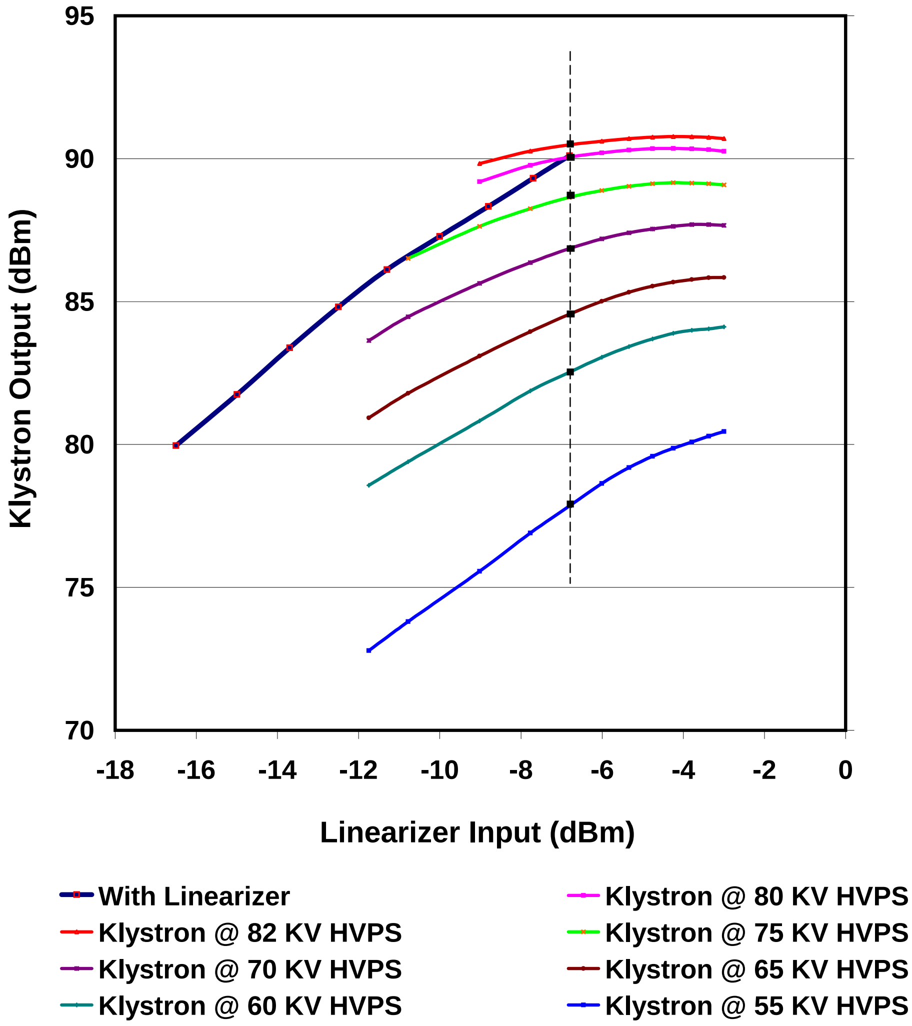
5 linearizer prototypes have been fabricated - 4 linearizers installed in LER, ready for beam testing

- High Power Test Stand Tests, lab test results

Features - 476 MHz center frequency, 1 MHz closed-loop bandwidth

- 15 dB amplitude non-linearity correction range
- Dynamic gain compensation via software in microcontroller (10 Hz bandwidth)

# High Power Test Stand Results - Linear Sweep




The LLRF systems operate the klystron at a regulated input power, adjusting the klystron high voltage.

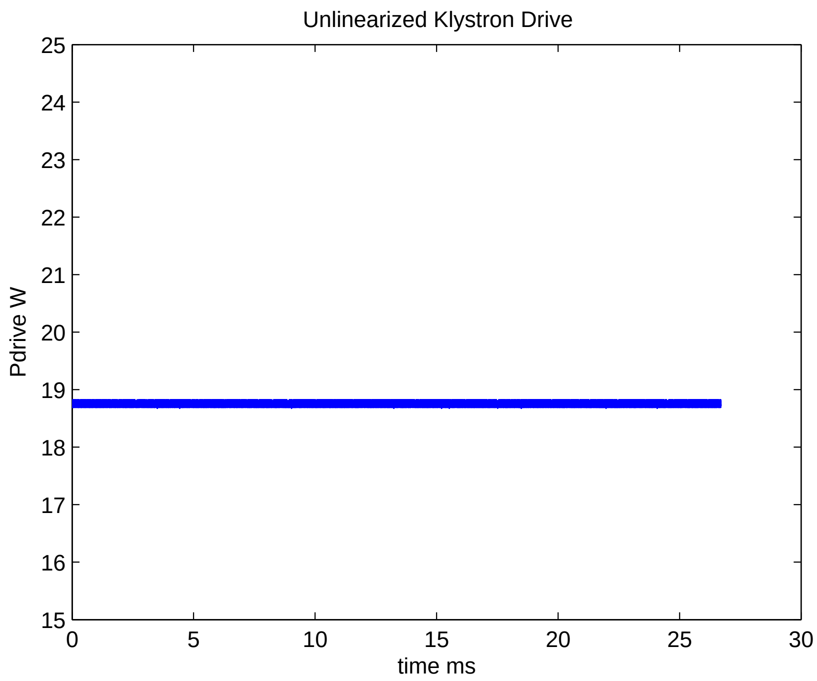
The figure shows a linearity sweep on the test stand for 100kW to 1 MW output power

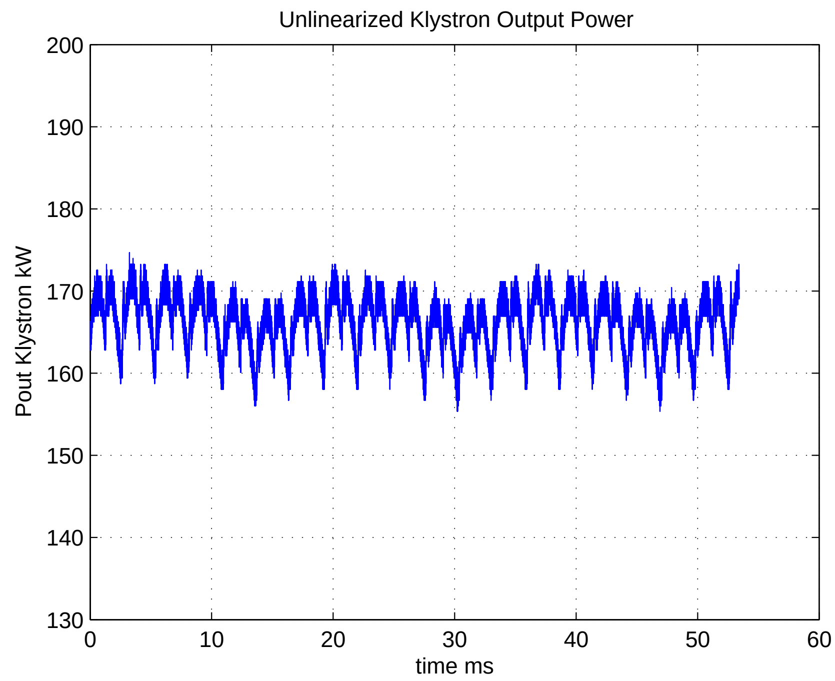
At each operating point the non-linear klystron characteristic is also shown.

Dynamic tests, with AM modulated carriers, also show the action of the linearizer via constant carrier/ sideband ratio.

Next step is beam testing (instability growth rate measurements) in the LER. An important issue to quantify is the necessary dynamic range of modulated signals in operation due to injection, transients, ripple, noise.....

# Testing the Linearizer

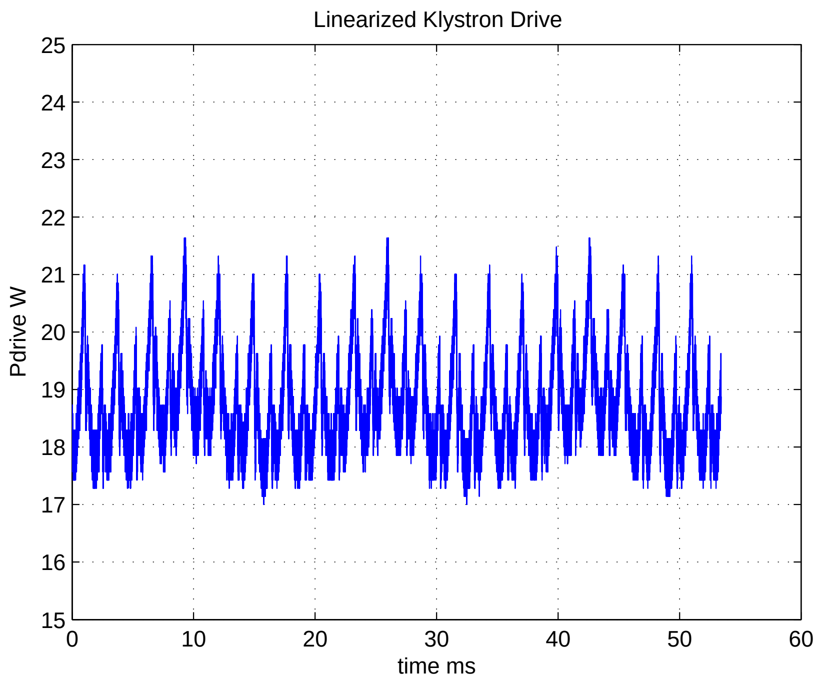


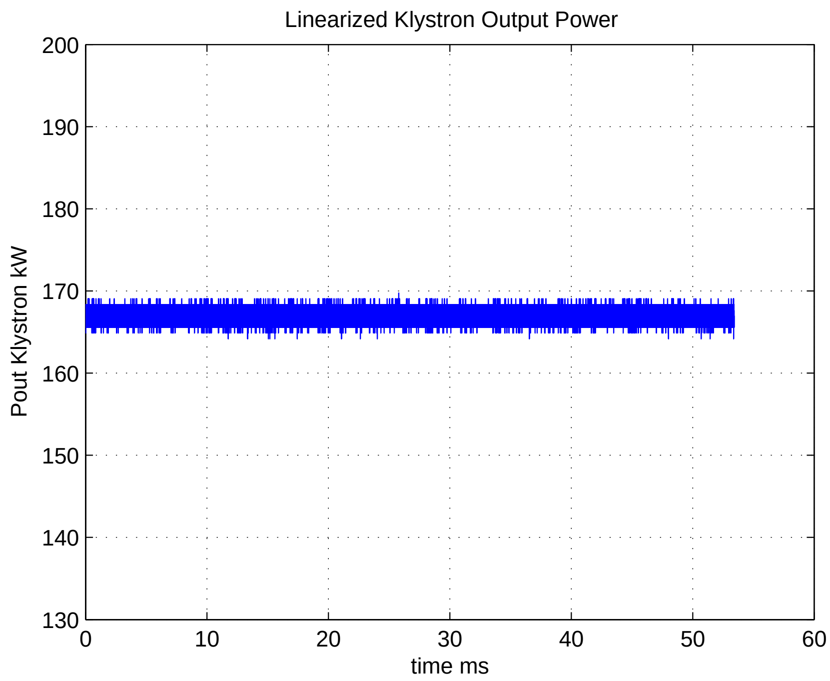




The unlinearized klystron input and output show:

- Constant input power level
- Modulated output power level (the klystron gain is modulated by power supply voltage ripple)

# Testing the Linearizer, continued




The linearized klystron input and output show:

- Modulated input power level - the input is modulated to compensate for the gain variation)
- Constant output power level (the product of the linearizer and klystron gains is constant)

# Advanced Electronics Progress in 2004/2005 - Goals for 2005/2006

Significant accomplishments related to PEP-II high-current commissioning -

- Development and installation of the production low group delay woofers. Tests show the prototype channel increased the stable stored current in the HER from 1380 to 1550 (plus) mA.
- Machine development related to measurement and control of coupled-bunch instabilities - studies of transverse and longitudinal stability margins, identification of more optimal configurations for LLRF loop stability and margin.
- Continued analysis of the low-level RF systems and feedback stability, understanding of RF saturation effects on impedance control. Evaluation of klystron linearizer idea from lab prototypes through initial installation for beam measurements
- Development of fault file analysis tools, techniques to better configure RF systems. Selection and recruitment of new SLAC staff with RF engineering expertise to strengthen expertise in this area.Transfer of system level knowledge of PEP-II RF to accelerator physicists and operations group via formal 2 day RF tutorial (over 48 participants).

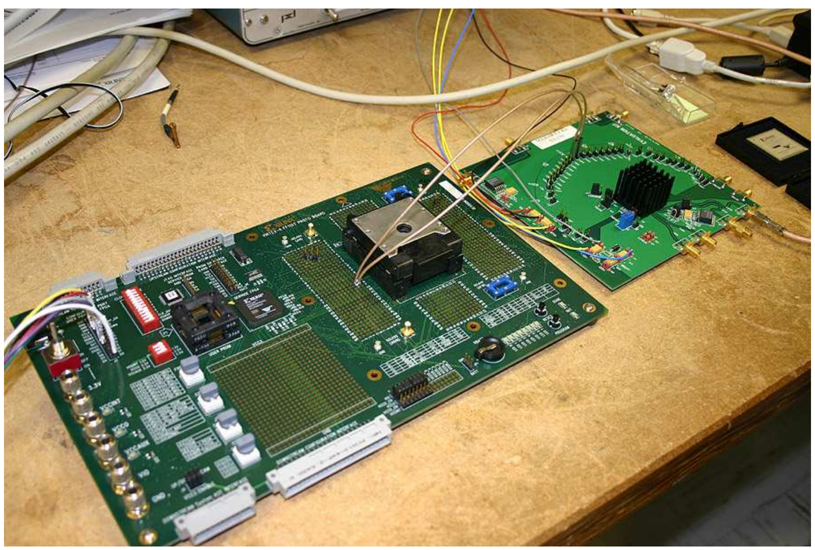
## GBoard Processing Channel

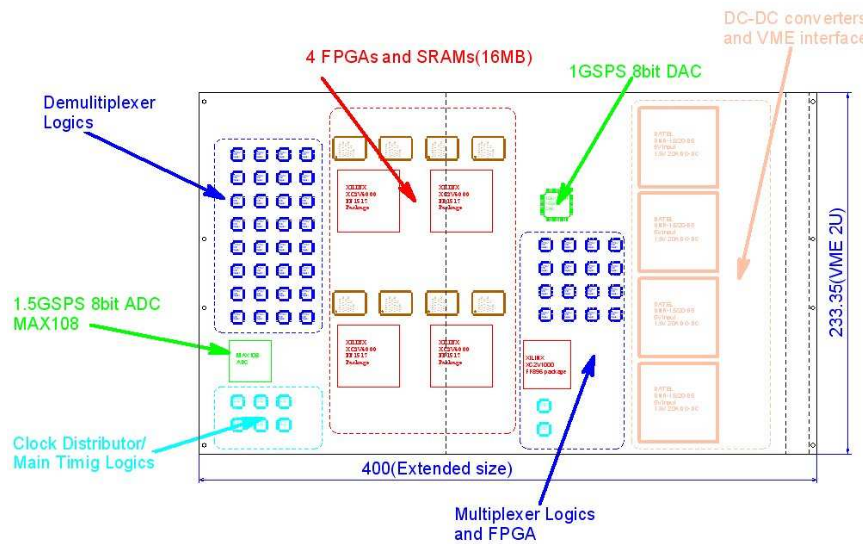
- Continued design and development of the 1.5 gigasample (GBoard) processing channel (joint development project with KEK and LNF-INFN). Simplification of ECL high speed mux-demux functions into FPGA based reconfigurable logic, initial lab tests of high speed links between ADC and FPGA components in this scheme. Ready to fabricate prototype channel

# Advanced Electronics Progress in 2004/2005 - Goals for 2005/2006

Goals for 2005/2006

- commissioning of Gboard 1.5GS/sec. baseband channel, initial tests at PEP-II and other facilities
- Lab and Accelerator tests of the prototype klystron linearizer, evaluation of technique
- High-Current PEP-II stability analysis and technology R&D for increased currents and luminosity. Coupling of simulation model results with future operating configurations, evaluation of new control schemes.
- evaluation of ultrafast instrumentation needs, R&D proposal





# Publications and Talks

## Recent Publications and Talks from the Electronics Research Group, SLAC (2005)

"Beam-Loading Compensation for Super B-factories", D. Teytelman, Invited paper at the 2005 Particle Accelerator Conference (PAC 2005) Knoxville, Tn, May 2005

"Klystron Linearizer for use with 1.2 MW 476 MHz Klystrons in PEP-II RF Systems", J. Fox, S. Gallo, T. Mastorides, D. Teytelman, D. Van Winkle and Y. B. Zhou, Presented at the 2005 Particle Accelerator Conference (PAC 2005) Knoxville, Tn, May 2005

"In Depth Diagnostics for RF System Operation in the PEP-II B Factory", Daniel Van Winkle, John Fox, Dmitry Teytelman, Presented at the 2005 Particle Accelerator Conference (PAC 2005) Knoxville, Tn, May 2005

"A Non-invasive Technique for Configuring Low Level RF Feedback Loops in PEP-II"", D. Teytelman, Presented at the 2005 Particle Accelerator Conference (PAC 2005) Knoxville, Tn, May 2005

"Operating performance of the low group delay woofer channel in PEP-II", D. Teytelman, Presented at the 2005 Particle Accelerator Conference (PAC 2005) Knoxville, Tn, May 2005

" PROPOSAL OF A BUNCH LENGTH MODULATION EXPERIMENT IN DAFNE", D. Alesini et al., SLAC-PUB-11077, LNF-05-04-IR, Feb. 2005

"Study of the Beam-Ion Instability at BESSY-II", S. Heifets, D. Teytelman, SLAC-PUB-10892, Dec. 2004. (Submitted to PRST-AB)

"Longitudinal Beam Dynamics and Feedback", D. Teytelman, Talk for the PEP-II MAC, December 2004

"2007 Goals and Feedback Systems", D. Teytelman, Talk for the PEP-II MAC, December 2004

"PEP-II Longitudinal Feedback and the Low Group Delay Woofer", D. Teytelman, Talk for the PEP-II Accelerator Physicists and Operations Group

"PEP-II RF SYSTEM OPERATION AND PERFORMANCE", J. Browne, J.E. Dusatko, J.D. Fox, P.A. McIntosh, W.C. Ross, D. Teytelman, D. Van Winkle, Presented at the 2004 European Particle Accelerator Conference (EPAC 2004) Lucerne, Switzerland, July 2004

"Measurements of Transverse Coupled-Bunch Instabilities in PEP-II", D. Teytelman, R. Akre, J. Fox, S. Heifets, A. Krasnykh, D. Van Winkle, and U. Wienands, Presented at the 2004 European Particle Accelerator Conference (EPAC 2004) Lucerne, Switzerland, July 2004

"Development and Testing of a Low Group-delay Woofer Channel for PEP-II", D. Teytelman, L. Beckman, D. Van Winkle, J. Fox, and A. Young, Presented at the 2004 European Particle Accelerator Conference (EPAC 2004) Lucerne, Switzerland, July 2004

"PEP-II RF aborts and coupled-bunch stability", D. Teytelman, talk presented at PEP-II machine Advisory Committee, April 2004

# ARDA Advanced Electronics Major Activities in 2003/2005

PEP-II High Current Instability studies, RF- Beam Dynamics, RF system stability modelling

- Coupled-bunch studies (HOM driven instabilities), tuning/configurations of LFB systems
- Fault file analysis tools and RF diagnostics
- LLRF model-based configuration tools, station tuning, operations oversight
- Predictions for operations, evaluation of future operating conditions
- Tutorial course on PEP-II LLRF systems taught to 48 SLAC Accelerator and Operations Staff

Technology Development

- Gboard -1.5 GS/sec. reconfigurable processor - critical technology prototyped - in test
- Low Group Delay Woofer - Augments PEP-II instability feedback-developed, commissioned
- Klystron Linearizer - Increased Impedance reduction- prototypes ready for beam tests in LER

Publications

- Conference papers (EPAC and PAC), Journal papers, Internal MAC reviews, Internal talks

Teaching (Stanford Applied Physics, US Particle Accelerator School)

Staffing - Recruitment and hire of 2 new SLAC staff with RF and Control engineering expertise

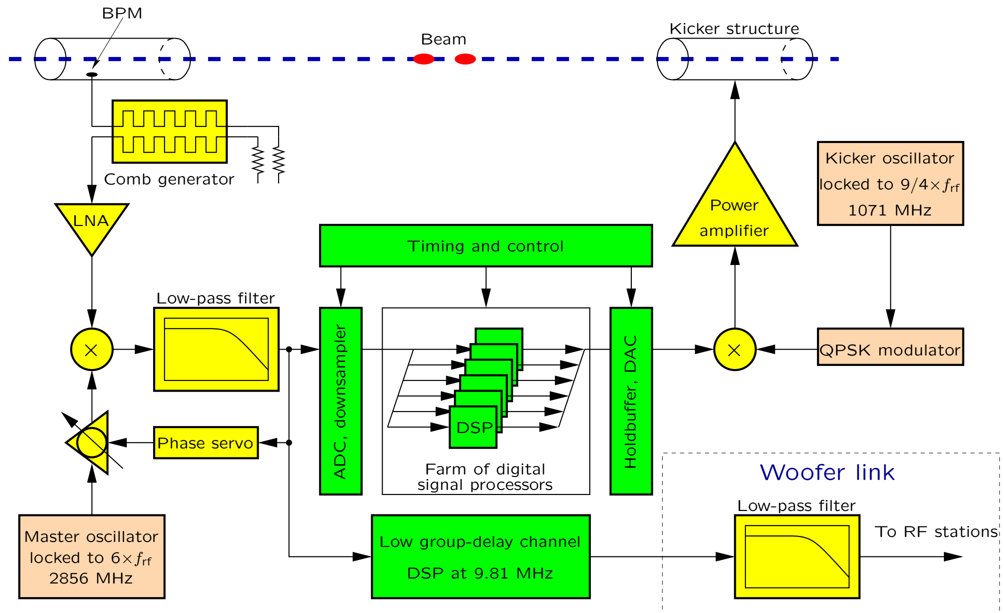
# ARDA Advanced Electronics - Overview

Group - 4 SLAC Staff, 2 Ph.D. Students

14 publications 2004-2005 (invited talk at PAC 2005). Taught 3 Stanford Applied Physics and 2 USPAS courses.

D. Teytelman won the 2003 APS Dissertation Prize in Beam Physics (our second Ph.D. APS Dissertation Prize)

Active international collaboration on technology development and measurements




## Recent Achievements

PEP-II RF- Beam Dynamics, RF system stability modelling, high current instability control.

## Technology Development

- Gboard - next generation 1.5 GS/sec. reconfigurable processor - critical technology prototyped
- Low Group Delay Woofer - developed, commissioned - increases PEP-II currents and luminosity via low-mode stability
- Klystron Linearizer - developed, prototypes ready for beam tests in LER. Improves direct feedback impedance control

Long Range Vision - development of reconfigurable high-speed signal processing systems for accelerators and light sources. Leadership role in beam instability dynamics and control. Development of wideband electronic and optoelectronic technology for ultrafast applications.