

Fig. 3. Block diagram of a HER RF station showing down-conversion to baseband, signal processing and up-conversion to RF.

The signals pass through a final baseband I/Q modulator which is used to implement a digital feedback loop around the up-converter, pre-amplifier and klystron. This loop will be described in detail later in this paper. The final baseband drive signals are next up-converted to 476 MHz using a RF I/Q modulator. High level mixers are used in this device to minimize errors and to allow driving the solid-state klystron pre-amplifier directly. This topology removes the need for a RF limiter to protect the input stage of the solid-state amplifier.

### 3. ADDITIONAL CONTROL LOOPS

A multi-channel I/Q detector is being developed to create a modular RF measurement and control system [5]. Each channel will be capable of digitally measuring the I/Q components of the RF carrier over a programmable bandwidth producing non-aliased measurements for output rates ranging from 25 Hz to above 50 kHz. Errors will be  $<0.05^\circ$  in phase and  $<0.1\%$  in amplitude at a 5 kHz data rate. Proposed measurement locations are labeled as "to I&Q" in figure 3. Using this approach it becomes natural to implement digital control for cavity tuners, gap voltage, station phase, and klystron ripple reduction.

Klystron high voltage power supply (HVPS) ripple causes mainly phase modulation, although some amplitude modulation may also be present. The modulation appears at multiples of 60 Hz with the largest component at 720 Hz due to the power supply transformer configuration. This situation lends

itself well to a digital control technique known as disturbance estimation. Since the modulation (disturbance) is composed of several superimposed sinusoids at known frequencies, a state-space error estimator can be designed to track and cancel them [6]. Using digital I/Q information, the output phase and amplitude is calculated, compared to desired values and delivered to two separate state-space disturbance estimators. The estimators converge on the errors which are then subtracted from the system baseband reference. Analysis shows that disturbance reductions of 40 dB are possible.

A simulation of the klystron feedback loop was made using the Simulink control system analysis software package. The superposition of a 720 Hz sinusoid and a step function forms the disturbance for both phase and amplitude. The phase disturbance estimator was augmented with an integration function to track dc errors, this feature is not useful in the amplitude loop. White noise was also injected into each I/Q measurement. The sample rate was 5 kHz. Results of the simulation are shown in figure 4. Note that the 720 Hz phase error is effectively cancelled in 50 ms and the step disturbance is also removed. The amplitude error plot shows cancellation of the 720 Hz while ignoring the step. In each case the convergence rate of the estimators is completely programmable. Slower convergence yields greater noise immunity. In the actual PEP-II implementation the estimators will be designed to track all the necessary power line harmonics.

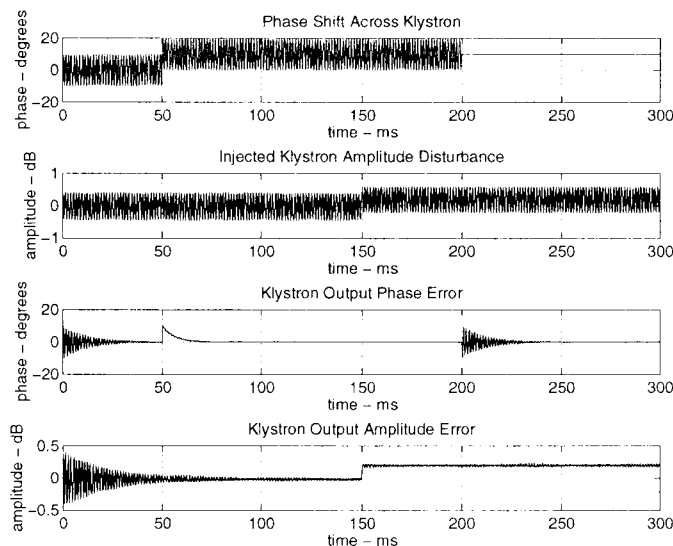


Fig. 4. Simulation of klystron ripple cancellation.

There are several other feedback loops, all of which will be implemented digitally. The baseband station I/Q reference must track the cavity transients caused by the ion clearing gap to prevent the klystron from reaching saturation. An adaptive feed-forward algorithm for minimizing klystron output power variation on a 1-turn basis has been developed and simulated [4]. The algorithm produces a station RF reference which minimizes the variation of the average klystron drive power. The adaption rate is designed to be slow compared to all the feedback loops in the system. In simulation this procedure reduces the klystron output power variations down to a few kW with a 5% beam gap.

The PEP-II klystrons will not contain collectors capable of absorbing the full 2 MW maximum available klystron beam power. A feedback loop measuring the klystron high voltage power supply output and the delivered RF power will be used to program the operating voltage. The goal will be to keep the klystron operating a fixed amount below saturation to insure sufficient AM gain for the RF feedback loops. Electrical efficiency also benefits from this strategy. Since the phase shift across the klystron varies by  $\sim 14^\circ/\text{kV}$ , the klystron phase loop discussed earlier must be capable of providing a large range of continuous phase shift. With the I/Q topology, phase may be rotated infinitely without discontinuities by simply applying the proper analog weights to the baseband I/Q modulator.

The PEP-II RF control system will also contain the "standard" feedback loops to control gap voltage, station phase and cavity tuners for each station. In addition to minimizing reflected power, the tuner loop must also balance the power delivered to each cavity. Each of these will also be implemented digitally. A major advantage of this approach is that configuring loops or adding new ones becomes a software task - provided that the measurement and control ports are already hardware supported. A programmable I/Q source will be included in the RF module to allow measuring loop responses by injecting white noise or a swept sinusoid. This feature will allow the possibility of automated calibration and remote operation

## 4. SYSTEM HARDWARE TOPOLOGY

A PEP-II low-level RF station will be composed mainly of modules in a VXI crate. Like CAMAC, VXI has an addressable data bus and standard power supply voltages. VXI goes further to provide more power supply voltages, larger module size, better shielding and standards for neighboring modules to pass analog and digital information. With the planned baseband signal processing, many system connections can take advantage of the local bus connections effectively eliminating many external connections. Fast interlock functions for window arc detection and excessive klystron reflected power use VXI shared trigger lines to remove RF drive and fire the HVPS crowbar. The VXI module layout planned for PEP-II is shown below in figure 5.

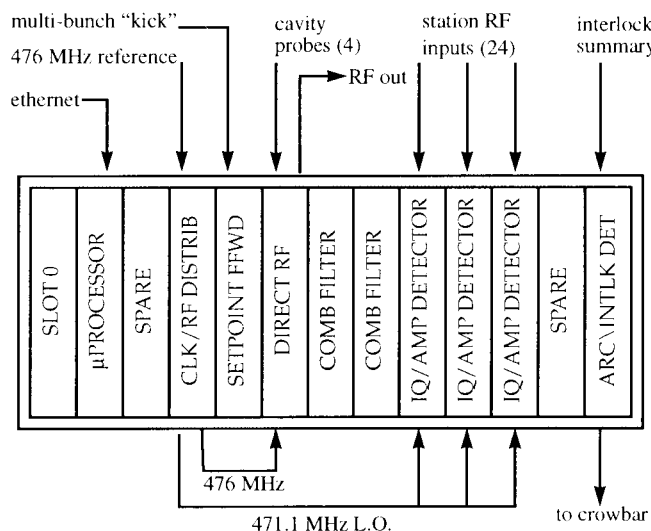


Fig. 5. Planned PEP-II HER VXI Crate Layout.

## 5. SUMMARY

The PEP-II low-level RF system design described is modern, cost effective and extremely flexible. The system is easily transportable and could be considered for use in other storage rings. Future papers will describe test results as the system is constructed.

## 6. REFERENCES

- [1] P. Corredoura, L. Sapozhnikov, R. Tighe, "RF Feedback Development for the PEP-II B Factory" Proceedings of the 1994 European Particle Accelerator Conference.
- [2] F. Pedersen, "RF Cavity Feedback", B Factories - The State of the Art in Accelerators, Detectors, and Physics", SLAC-400, November 1992, pp. 192-207.
- [3] J. Fox et al, "Feedback Control of Coupled-Bunch Instabilities", Proceedings of the 1993 IEEE Particle Accelerator Conference.
- [4] R. Tighe, P. Corredoura "RF Feedback Simulation Results for PEP-II", this conference (PAC 95).
- [5] C. Ziomek, P. Corredoura "Digital I/Q Demodulator", this conference (PAC 95).
- [6] P. Corredoura "Development of Digital Control for the PEP-II Klystrons" SLAC PEP-II Tech Note #60, 1994.