LOW LEVEL RF CONTROL FOR THE LANSCE PROTON STORAGE RING BUNCHER*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) has upgraded the Proton Storage Ring (PSR) for the Short Pulse Spallation Source (SPSS) [1]. 100 microamperes of average beam current is now delivered to the new target assembly. One major task of the improvement project was the design and construction of a power amplifier to increase the drive voltage to the cathode follower final power amplifier used to overcome longitudinal space charge forces in the accumulated beam. With this amplifier and power supply improvements, the buncher voltage from the 2.8 MHz radio frequency system was raised 50% to the present 18 kilovolts (kV) peak [2]. Improvements to the low level RF controls were incorporated, in both the amplitude feedback control and a new phase controller. These systems and the resulting RF performance improvements will be discussed. The upgraded RF buncher has delivered the required performance at LANSCE to ensure that the 100 microampere beam on target was achieved.

1 STORAGE RING

The 90.2 meter circumference PSR ring is a fast cycling accumulator of high current beam over a macropulse from the 800 MeV linac. A pulse (250 ns) of high beam current is extracted in a single turn to drive the new SPSS target, to produce neutrons of the desired characteristics. The PSR has a rotational frequency of 2.79513 MHz (hereafter referred to as 2.8 MHz). With a bunch length of 250 nanoseconds, there is a 107 nanosecond empty longitudinal space to allow for beam extraction. The 2.8 MHz RF voltage keeps this gap free of protons.

2 RF POWER SYSTEM

2.1 Final Power Amplifier

The PSR stores peak beam currents as high as 40 Amperes, so it is imperative to maintain a very low impedance across the gap. Shunting the gap with a low resistance was impractical due to the power required. Active feedback around the final amplifier is a standard approach for circular machines. The PSR buncher uses a cathode-follower (common-anode) final power amplifier (FPA) with extremely low output impedance (11 Ohms). A pair of Philips YD1342/8918 (or EEV BW1643J2) industrial triodes are used in a push pull arrangement in class A mode of amplification, with their cathodes feeding both sides of the beam line gap. The triodes idle with a quiescent current of about 40 Amperes per tube (pulsed) in class A. Fast RF feedback is not required to compensate for beam loading. Capacitance (200 pF) across the gap resonates the assembly at 2.8 MHz, and bypasses higher frequency components of beam. The gap voltage can be ramped up from several hundred volts at the beginning of injection to a flat top value during storage through extraction.

2.2 Intermediate Power Amplifier

A new higher power intermediate power amplifier (IPA) was developed and installed in 1998. It uses a push-pull pair of THALES TH555A tetrodes to provide 19.5 kV peak output voltage. This stage and the driver provide all of the voltage gain (see fig. 1) as the cathode follower has a voltage gain of 0.93. Drive power is provided by a linear solid state amplifier. Further details of the RF power amplifiers may be learned from [2].

3 LOW LEVEL RF CONTROLS

3.1 Overall Control Scheme

With a constant frequency, minimal beam loading concerns, and only one system, we felt that an all-analog design was quick to prototype and put into operation (fig. 1) The flexibility of a programmable DSP approach was unnecessary, although it could certainly be used here. The amplitude must track a programmed ramp, the phase should lock to a reference, and if the errors exceeded a predetermined amount, fast protect signals should shut off the beam before acceleration begins in the linac. Separate amplitude and phase control was implemented from a common feedback signal derived from capacitive voltage dividers at the beam pipe gap. Coupling between paths was minimized through the use of a voltage-controlled amplifier for envelope control and a constant amplitude phase shifter.

3.2 Proportion/Integral Gain Blocks

The core controllers for each loop derive an error term from the incoming demodulated gap voltage sample. The envelope system reference is the ramped DC program from the accelerator control system. Gated integrators are used, and a proportional term is injected at the output summing stage. A steep response multi-pole bandpass filter after the feedback pickup affected the phase margin of the loop. It was replaced with a lower Q filter, and loop stability was enhanced.

3.3 Envelope Feedback

A simple envelope feedback AGC system is adequate to maintain gap RF voltage in compliance with the

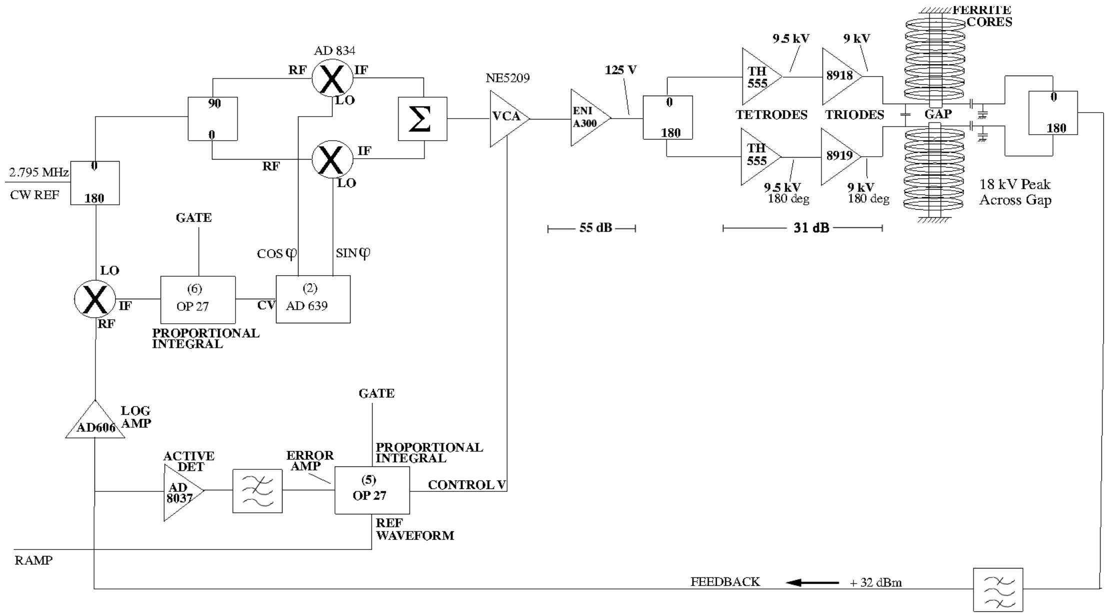
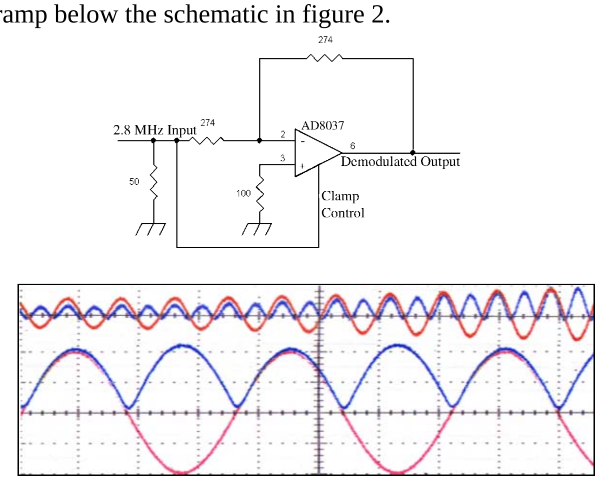


Figure 1: Diagram of RF Amplifiers and Low Level RF Controls

programmed ramp. FPA anode power supply droop is one of the primary sources of amplitude shift. The regulation in the power supplies is only able to hold the voltage constant on an average basis, not across a millisecond pulse.

In the original buncher there was difficulty setting the gap voltage below 2 kV. In 1998 an active rectifier with a fast op amp and diodes was installed to control at a lower gap voltage, about 500 volts minimum. This is being replaced with a new detector, using a very fast clamp amplifier shown in figure 2. For the negative half cycle of RF it behaves as a unity gain inverter, providing a positive half cycle output. For the positive half cycle of RF the clamp input is activated, and the resultant voltage is again a positive half cycle. A carefully designed low pass filter follows this for minimum phase. Low distortion full wave rectification is the result [3]. The RF and demodulated voltages are plotted at the beginning and end of a linear ramp below the schematic in figure 2.



[Top : Start of Ramp, Vert.= 50 mV/div, Horiz.= 0.4 mS.
Bottom : 18 kV Flat Top, Vert.= 1V/div, Horiz.=0.1 mS.]

Figure 2: Improved Active Detector

Amplitude control is accomplished with a voltage-controlled amplifier designed for wireless applications. It has differential input/output with transconductance multipliers. DC shift is eliminated with blocking capacitors. The plot (fig. 3) shows the RF log gain versus control voltage from 0 to 1 VDC. The improved lower threshold of this AGC is now several hundred volts. A small amount of leakage is not a problem.

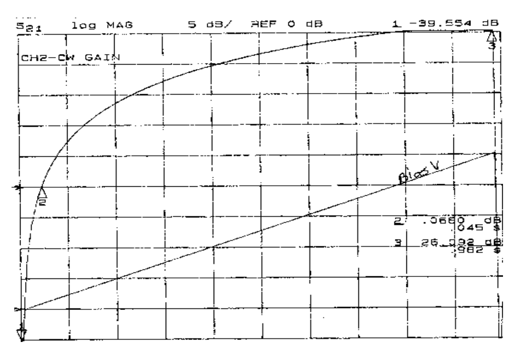
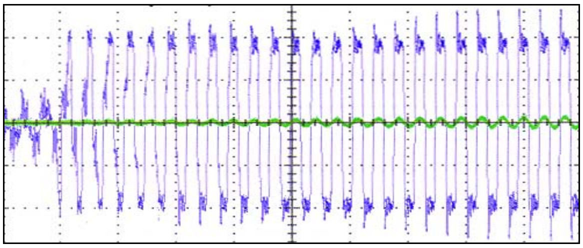


Figure 3: NE 5209 VCA - Range of Gain Control

3.4 Phase Feedback

After the 1998 voltage upgrade, phase "skew" was measured across the full range of output. Approximately 18 degrees of phase change was measured, from injection through storage. This was decreased with the design of a new feedback loop locked to the phase to the CW reference programmed for the machine. Key to the design was a wide dynamic range phase detector. A monolythic 50 MHz log amplifier was utilized as a hard limiter for the ramped feedback voltage, which then drives a double-balanced mixer for phase detection. Figure 4 shows the limiting action before the mixer, with the low voltage ramp just beginning. The phase is now stabilized at this low level to 18 kV at the gap.



[Vert.= 0.1 V/div, Horiz.= 1 uS/div]

Figure 4: Log Amp Input and Output, Start of Ramp

After the phase error is processed with direct and integral gain, the controller drives an active phase shifter. The design is very linear, and has almost no amplitude ripple over +/-180 degrees after trimming DC offsets. The linear phase control voltage must be converted to a quadrature pair of voltages to drive the two multipliers. It is similar to the design of Ciardullo [4], including the use of novel (but already obsolete) sine and cosine generator integrated circuits. Other approaches are discussed in the literature including look-up tables or sine/cosine function approximation with linear devices [5][6].

3.5 Operating Results

Bode plots of the overall system were obtained using a low frequency network analyzer. Two sets of sweeps demonstrate the closed loop response of the AGC during bench testing, while driving a solid state amplifier. A low Q 2.8 MHz bandpass filter is before the demodulator. Figure 5 shows the response with integral gain applied.

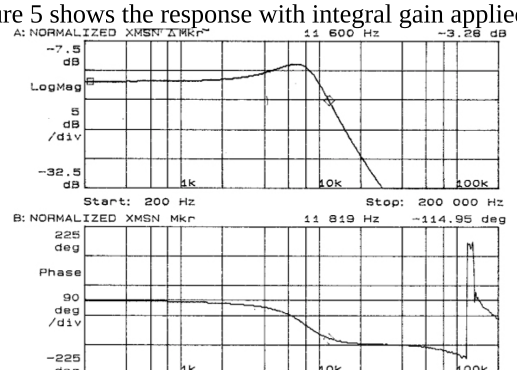


Figure 5: Minimum ∫ Gain at AGC Lock.

Figure 6 shows the response when proportional gain is added to integral. The response peaks above 100 KHz but the system is stable.

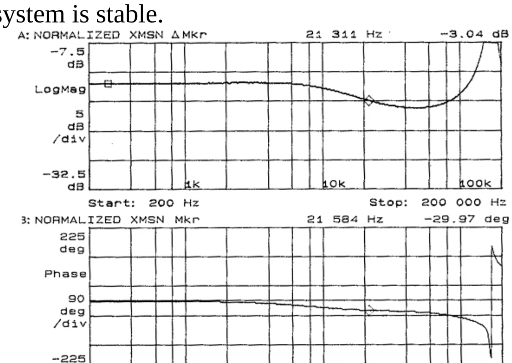


Figure 6: ∫ and Proportional Gains Increased

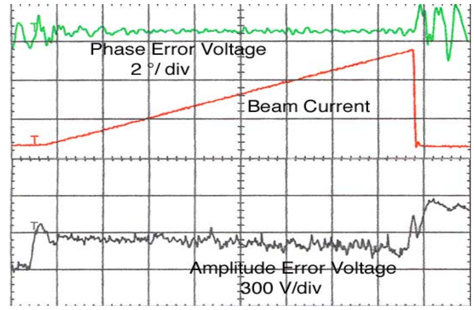


Figure 7: Amplitude and Phase Errors

The error signals shown in figure 7 were observed while 2.5 microcoulombs (μC) of charge was stored in the ring. The amplitude controller has a correction of about 300 V p-p before extraction, including for droop from the power supplies. The phase controller has less than one degree of error across the ramp.

5 CONCLUSION

The new low level controller works well and requires no adjustment for various storage operations. As a dedicated system it serves the need for AGC and phase correction for the buncher RF system. The low output impedance of the cathode follower stage is sufficient to compensate for beam induced voltage. Further information on the effects of beam current with the buncher can be found in [7]. Most recently, PSR has accumulated beam intensity up to 9.7 uC (6 x 10^{13} protons) per macropulse [8].

4 REFERENCES

[1] R. Macek, et al. “Overview of Progress on the Improvement Projects for the LANSCE Accelerator and Target Facilities," Proc. of Particle Accelerator Conference, Vancouver, BC, 1997, pp. 1159-1161.

[2] J. Lyles, J. Davis, “Improvements to the Cathode-Follower RF Amplifier System for the LANSCE Proton Storage Ring Buncher,” Proc. of 1999 Particle Accelerator Conference, New York, 1999, pp. 1001-1003.

[3] Analog Devices Inc. AD8037 datasheet, figure 79.

[4] D. Ciardullo, “A High Accuracy Phase Shifter Based on a Vector Modulator,” RF Design, Oct., 1993, pp. 106-114.

[5] R. Garoby, “Low Level RF Building Blocks,” Proc. CERN Accelerator School, CERN 92-03, V. II, June 1992, p. 447.

[6] D. Sabolic, “Large-Shift Constant-Amplitude Phase Modulators,” IEEE Trans. Broadcasting, V. 45, N. 2, June, 1999, pp. 253-258.

[7] J. Lyles, A. Browman, R. Kustom, “Commissioning the Upgraded RF Buncher at the LANSCE Proton Storage Ring,” Proc. of 1999 Particle Accelerator Conference, New York, 1999, pp. 998-1000.

[8] R. Macek, “Electron-Proton Two Stream Instability at the PSR,” Invited Presentation, 2001 PAC.