ARBITRARY WAVEFORM GENERATOR FOR ELECTROSTATIC DIPOLES IN A HEAVY ION RECIRCULATOR

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Abstract

The Lawrence Berkeley National Laboratory is working in close collaboration with the Lawrence Livermore National Laboratory in the investigation of using a recirculating induction accelerator as a driver for Heavy Ion Fusion. The deflection dipoles in the recirculator require precise high voltage electrical waveforms. These waveforms are of a parabolic shape and rise to a peak voltage level of 28 kV in 240 µs. A voltage reference is generated internally which is completely adjustable through the computer. The voltage reference is compared to the output voltage and the error signal drives a pulse width modulator carrier frequency of 100 kHz. The high frequency carrier is stepped up with five stages of ferrite transformers, rectifiers and filters to generate a completely adjustable waveform of up to 28 kV which follows the computer generated voltage reference.

1. INTRODUCTION

The small Heavy Ion Fusion Recirculator Ring under construction at the Lawrence Livermore National Laboratory (LLNL) will require precisely tailored waveforms to bend the beam around the circumference (Fig. 1). The bending field will be electrostatic (rather than magnetic) and its strength must increase during acceleration in precise synchronism with the increase in particle energy. This requirement leads to the need for a precisely programmable power supply which can be adjusted through a computer from 7 kV to 28 kV (Fig. 2). As shown in Fig. 1, forty bipolar bending dipoles are spaced around the recirculator. Each dipole is a capacitive load and, with the additional cable capacitance, a total reactive load of 300 pF must be driven by the programmable power supply. Considering the rate of rise in voltage, an average current of 50 mA is required during the 240 µs pulse for each positive and negative power supply. Commercially available programmable power supplies did not meet our requirements and the cost of custom made units would have been prohibitive. It was decided that an in-house effort would be appropriate since the power supplies could be made to satisfy all of the physics requirements with no additional features at a very reasonable cost. Also, for economic reasons, as many dipoles as possible will be driven in parallel from a single power supply. The number of dipoles that can be driven is determined by the output impedance of the high voltage stages. The high voltage stages consist of ferrite transformers wound in such a way as to minimize the leakage inductance.

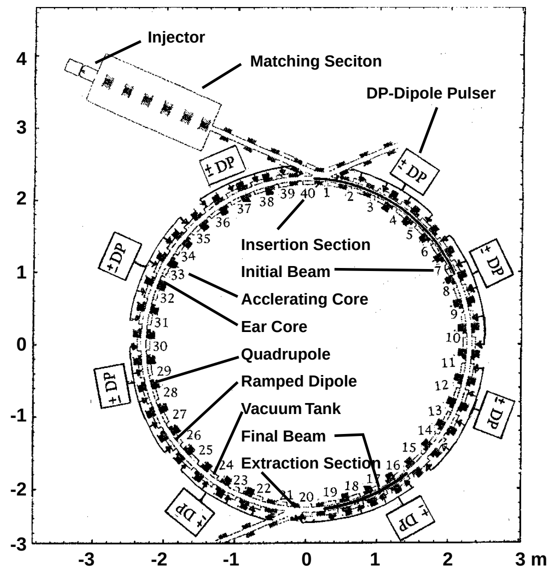

Figure: 1 The Small Heavy Ion Fusion Recirculator Ring.

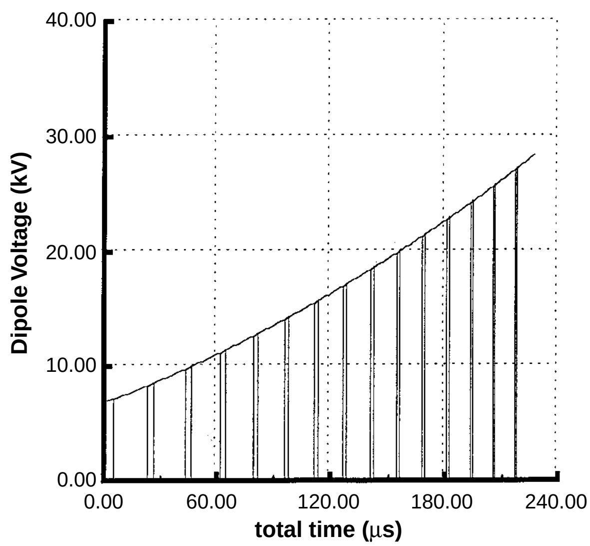

Figure: 2 Required electrostatic bending dipole field.

2. SYSTEM ARCHITECTURE

The basic requirement boiled down to building a DC to pulse converter with the appropriate bandwidth to precisely reproduce the required reference waveform. Several options were investigated but the one which appeared most efficient was one which used pulse width modulation in the feedback loop. The block diagram for the arbitrary waveform generator is shown on Fig. 3. The reference waveform required to bend the beam in the

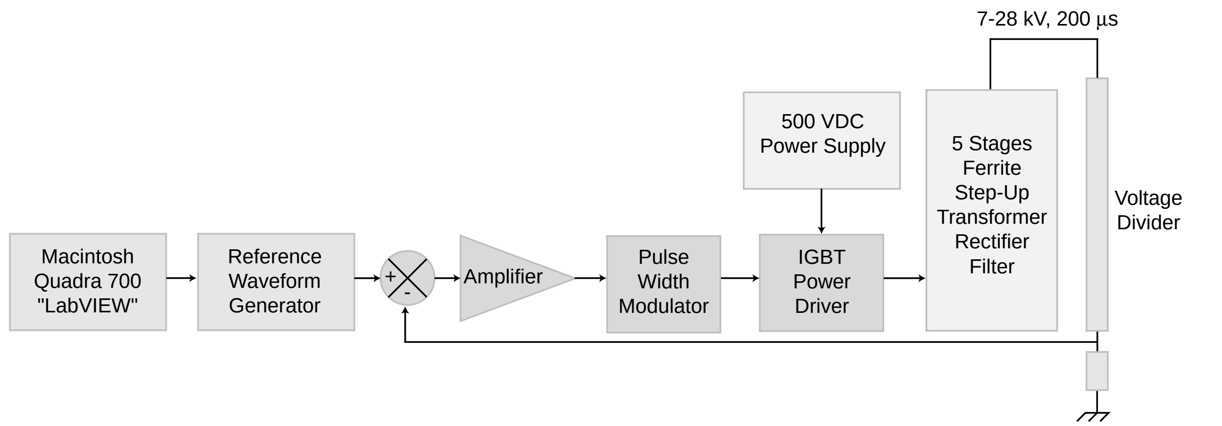

Figure: 3 Block diagram of the arbitrary waveform generator.

recirculator is shown on Fig. 2. This waveform can easily be adjusted by the accelerator tuner through the Macintosh computer using the software LabVIEW. The reference is compared to the output voltage and the error signal adjusts the pulse width modulator to insure that the high voltage output is a precise reproduction of the reference. The feedback loop gain and response are adjusted at the amplifier stage. The insulated gate bipolar transistors (IGBT) provide the switching power that drives the input ferrite 12:1 step-up transformer which is coupled to the other four stages of one-to-one transformers. The secondaries of all five transformers are connected in series to provide a 60:1 step up ratio (Fig. 6). The carrier frequency of 100 kHz was chosen since it provided sufficient slewing rate to accurately generate the high voltage waveform in a full wave rectifier system. A low pass filter consisting of an inductor in series with the distributed dipole and cable capacitance provided the smoothing function. Five stages of ferrite transformers were chosen rather than a single high voltage step-up transformer because it resulted in lower overall leakage inductance, a better distribution of the high voltage, and a higher safety factor.

It is estimated that the capacitance of the dipole and ten feet of 100 ohm high voltage cable will have a capacitance of 300 pF. The high voltage system was developed and tested by loading it with 2500 pF, hence, up to eight dipoles can be driven by one waveform generator.

3. REFERENCE GENERATOR AND INTERFACE

The reference generator must be capable of accurately duplicating the waveform dictated by the heavy ion beam transport dynamics (Fig. 2) and be capable of easily being adjusted during the beam tuning process. The commercially available waveform generators had many features which were not necessary and as such cost considerably more than the budget allowed. It was decided that a simple waveform generator which met all of the performance and cost requirements could be developed in-house and that LabVIEW, which was already in use on other experiments, could provide a simple user interface. Fig. 4 is a simplified block diagram of the reference generator and interface. The software LabVIEW on a Macintosh Quadra 700 programs the reference board through a GPIB parallel port. The data for the pulse can be stored on a spreadsheet, can be derived from an equation, or can be derived graphically from within the LabVIEW driver.

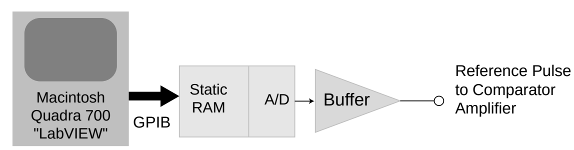

Figure: 4 Simplified block diagram of the reference generator and interface.

The pulse is produced digitally at a sample rate of 1 MHz with 12 bit precision for the data. Static RAM is used to hold the data which is sent to an analog to digital converter (A/D) in sequence. The pulse shape is defined by 512 integers between zero and 4095 which corresponds to an output voltage of zero to 5 volts with a maximum duration of 512 µs. This reference pulse is exactly proportional to the high voltage required on the electrostatic dipoles. The reference voltage is compared to the output voltage and the pulse width modulator (PWM) automatically sets the pulse duration to generate the desired voltage. Due to switch inpedances the time constant for charging the cable and dipole capacitance is considerably shorter than the discharge time constant. Components in the power stage were chosen such that the rise time would be sufficient to track the (monotonically increasing) desired pulse. To achieve the highest possible bandwidth, a small phase margin was chosen in the control loop. Because of this, a step function at the input results in an overshoot by the system. The slow discharge time constant results in unacceptable recovery time from an overshoot. To eliminate the problem a

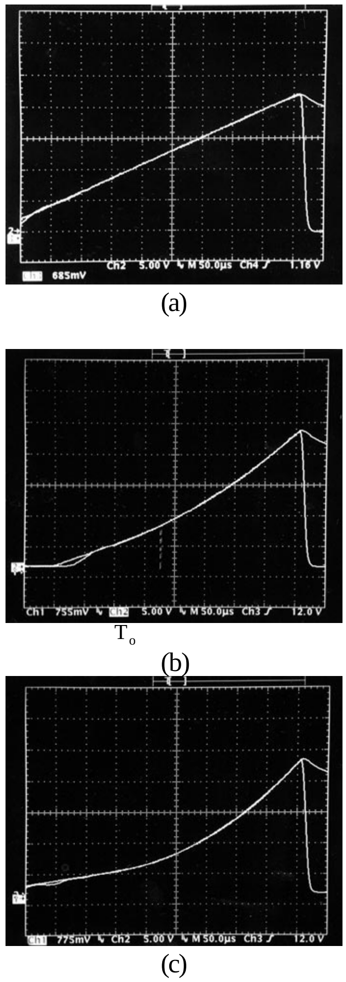

Figure: 5 Superimposed waveforms of the reference and the high voltage outputs.

smooth ramp is introduced before the pulse to prevent a discontinuity at the beginning of the useable pulse.

4. TEST RESULTS

The waveforms of the reference and the high voltage output shown on Fig. 5, were taken driving the equivalent capacitance of eight dipoles. Although there is a slight discrepancy between the two waveforms at the beginning of the pulse, the active region, which consists of the 240 µs at the end of the pulse, tracks the reference to better than 1%. The waveforms include a linear ramp and two parabolas of different curvature. Each waveform can be adjusted to a precision of 0.1% in amplitude and timing. The most representative of the required shape (Fig. 2) is the waveform 5(b). The bending field provided by this waveform would be synchronized to the acceleration cycle so that the heavy ions enter the ring at point T_0 or where the voltage is about 7 kV and would recirculate and gain energy over the next 240 µs where the voltage has ramped to 28 kV.

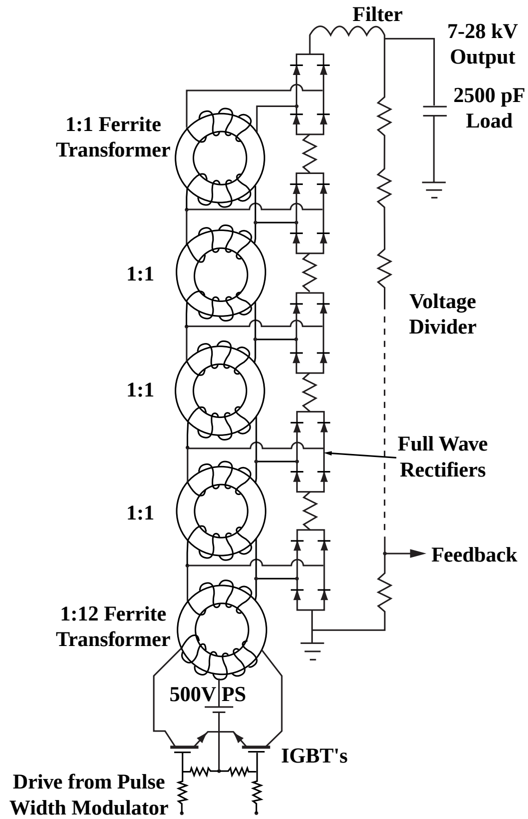

Figure: 6 High Voltage Drive

.5. CONCLUSION

Limited funding directed our efforts in the development of a fully programmable high voltage waveform generator for steering a heavy ion beam around a recirculator. The design was based on inexpensive components and was optimized to fully satisfy the physics requirements. Projecting the cost of this prototype toward the complete system for the recirculator, it appears that it should be well within the allowed budget .

6. ACKNOWLEDGMENTS

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