A Novel Technique for Pulsing Magnet Strings with a Single Switch*

R. J. Sachtschale, C. Dickey, P. Morcombe
Duke University, Free Electron Laser Laboratory
Box 90319 Durham, NC 27708-0319

Abstract

A new approach to switching a succession of kicker magnets using a single switch will be described. This technique can be used when different timing delay and power inputs are needed for each kicker. The approach is straight forward and is limited only by the pulse length. Timing jitter between kickers becomes a function of the switch diodes and the transmission lines, rather than the accumulated jitter of individual switches. It is likely that this approach can be used whenever a repeatable pulse train, with arbitrary individual pulse amplitudes, needs to be generated from a single switch and trigger.

1 Introduction

At the Duke University Free Electron Laser Laboratory electron bunches will be injected to a storage ring from a 1.2 GeV linac. In order to achieve the design goal of 1 ampere, *average* e-beam current, the bunches circulating in the storage ring must be augmented by injections from the linac. This is done by making a stored bunch execute a chicane pattern in the injection area as shown schematically in Figure 1.

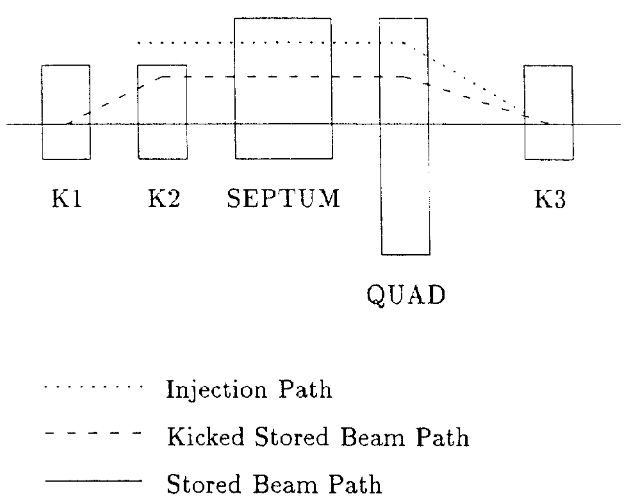

Figure 1: Schematic of Injection Section

There are three beam paths represented in figure 1. They are; the Injection Path, the Kicked Stored Beam Path and the Stored Beam Path. Kickers K1 and K2 kick a stored bunch as shown. This action places the stored bunch closer to the injected bunch. Upon leaving the Septum the kicked stored bunch and the injected bunch are off axis of the Quad. The Quad bends the off axis bunches back toward the stored beam path. Kicker K3 then straightens the bunches into the stored beam path.

For this approach to work, all three kickers must have the same general pulse shape, but with differing amplitudes. Also they must be rigidly phased with each other. In our case it is also important to keep the expense of the system within a very modest budget. To achieve these requirements a circuit using a single switch was developed to switch all three kicker magnets.

2 Switching Circuit

2.1 Overview

The switch circuit is shown in Figure 2. The kicker magnets, K1-K3, are essentially lumped inductances. The kicker Pulse Forming Networks and Delay Lines are made from four lengths of RG-213 in parallel. All of the PFNs are the same length. The delay lengths are varied to provide the appropriate timing skew between the kickers.

Each kicker has three diodes associated with it. They are labeled in figure 2 as; Isolation, Clamp and Termination. The termination diode keeps the PFN voltage from going negative. The magnet and PFN are switched into a shorted load($Z_L \approx 0\Omega$). For the PFN, $Z_o = 12.5\Omega$. Since $Z_o \gg Z_L$, the voltage at the termination end of the PFN will try to reverse polarity. The termination diode and resistor prevent this.

PS 1 through PS 4 are programmable high voltage power supplies with high impedance outputs. The first three charge the PFNs to a level that will supply the required magnet current when switched. The fourth supply is set higher than the others so that the isolation diodes are reverse biased. The isolation diode, when reverse biased, isolates the PFNs from each other so they can be charged to different levels.

When the switch is closed, the delay lines discharge. The voltage on the delay line will try to reverse when it reaches the diodes. This will cause the isolation and clamping diodes to become forward biased. The clamping diode clamps the magnet to ground. This is important because reflections will occur in the delay line and degrade the magnet circuit if the magnet is not clamped to ground.

*Supported by the United States Air Force Office of Scientific Research, contract AFOSR-90-0112.

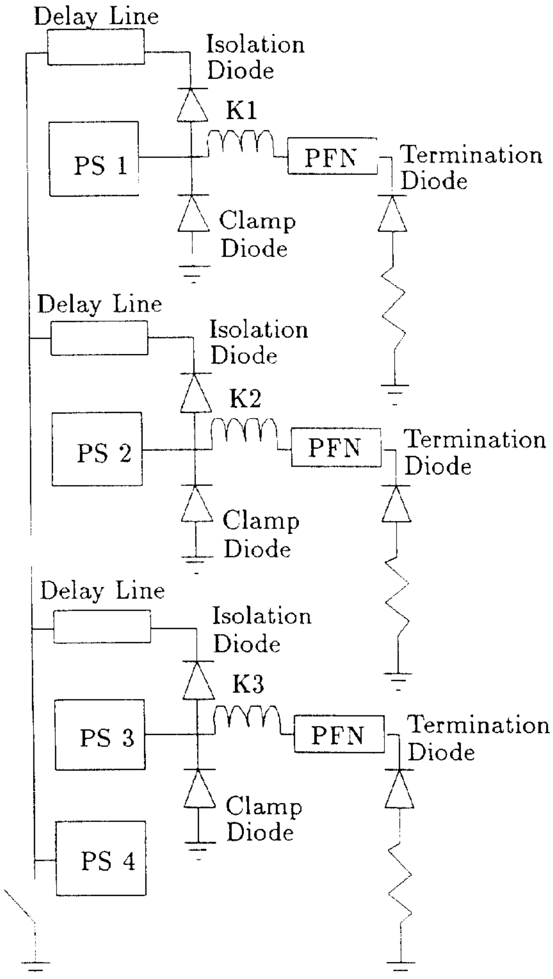

Figure 2: Schematic of Switch Circuit

2.2 Initial Development

The circuit was modeled with PSPICE. The modeled magnet current is shown in Figure 3. It was tested at low level using an avalanche transistor as a switch and 1N4004 diodes. The circuit performed as the PSPICE model predicted. The circuit then had to be scaled up to operational levels.

The diodes used must withstand 2.5 kiloamps surge and 30 kilovolts. At the suggestion of W.M. Portnoy at Sandia Labs, uncased diodes were selected. These are raw diodes from standard stud mounted cases. Diodes can be found that are rated for 1800 volts and 2850 amperes surge. When stacked, a compact package can be designed for a wide range of standoff voltages.

A holder was designed to stack the diodes. Between each diode is a 25 mil aluminum disc. The holder compresses the stack for proper contact between each element. The holder fits into a copper microwave guide. The wave guide is filled with transformer oil to improve voltage standoff and heat dissipation from the large surge currents.

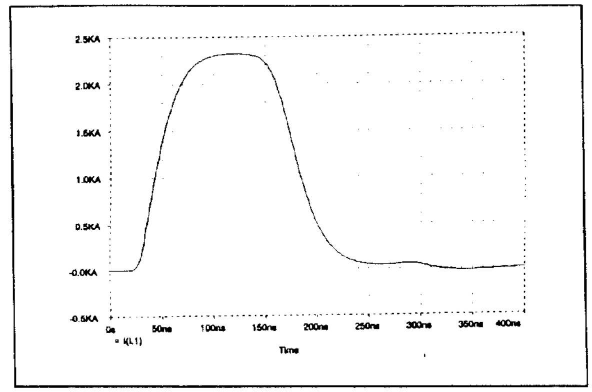

Figure 3: PSPICE Modeled Magnet Current

During the initial phase the kicker circuit consisted of only the magnet and PFN with a diode/resistor terminator. The magnet and PFN were charged to 30 kilovolts and discharged through a hydrogen thyratron switch, once a second. (The pulse repetition rate for injection from the linac to the storage ring is 1 pps). The circuit was life tested for 1.25 million pulses. The only degradation observed in the diodes was an increase in leakage current.

The outer insulation was removed from the PFN cables and they were wound around a 12 inch diameter by 18 inch long copper tube. This was done to keep the outer conductor resistance as low as possible. The assembly is placed in transformer oil. The cable has been in service for over a year, with more than 2 million shots at 30 kilovolts, without a failure.

2.3 Present Development

To improve switch performance the hydrogen thyratron was replaced by a Maxwell Labs 40184 spark gap. This spark gap is rated for 15-35 kilovolts with less than 1 nanosecond of jitter when used with a Maxwell Labs 40168 Trigger Generator.

We are testing a single branch of the circuit shown in figure 2 (i.e. just one kicker magnet). The overall pulse shape in the magnet is good put contains small oscillations from reflections in the delay line of the trigger circuit. If the clamping diode turns on properly and clamps the magnet to ground, the oscillations from the trigger leg should not be present.

To test this, the clamping diode was removed from the circuit. The circuit performed identically with or without the clamping diode. The waveform is shown in Figure 4. Various techniques are being discussed and tested to make the diode turn on and clamp the magnet to ground.

To turn the clamping diode on, the delay line must be able to sink more current than the magnet can initially source. Since the magnet is a lumped inductance, it cannot source current instantaneously. The magnet inductance is estimated to be 400 nH. Recalling that the delay line is

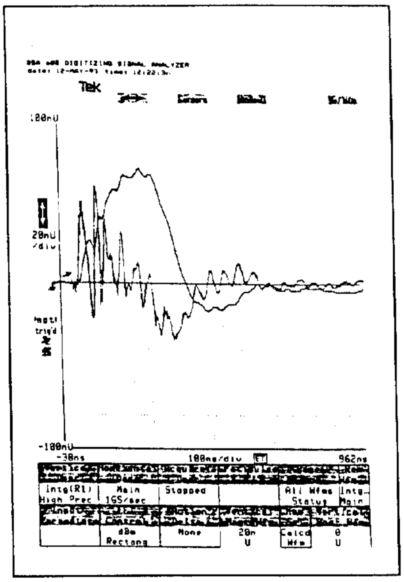

Figure 4: Normally Triggered $\dot{B}$ and $\int \dot{B}$

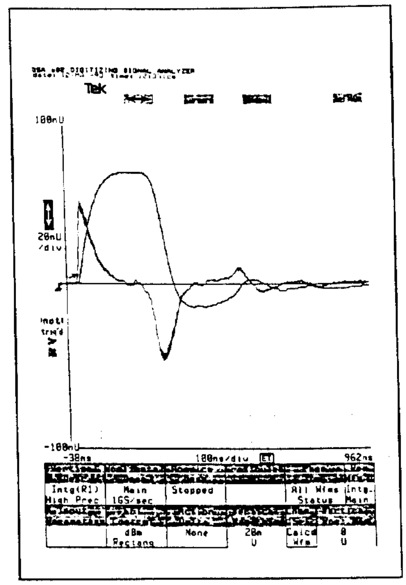

Figure 5: Self Triggered $\dot{B}$ and $\int \dot{B}$

made of four lengths of 50Ω cable, the inductance is less than 20 nH/ft. The cable used for these tests is only three feet long.

We have realized that four cables in parallel aren't necessary for the delay line. That choice was made to keep symmetry with the PFN. The PFN uses four cables to keep Z_o low. Also, lower Z_o requires less PFN voltage for a given magnet current. If there is only a single 50Ω delay cable, the inductance will be 75 nH/ft but a larger voltage will be required to flow the same current. The same current flowing through a larger inductance will sink more current from the kicker circuit. Using a single length of RG-220 will raise the delay line inductance and the voltage can be increased to maintain current levels through the higher impedance. The salient point being, delay line current flowing in a larger inductance will sink more current from the circuit and turn on the clamping diode before the magnet can begin to source current.

3 Unexpected Observations

While working with the diode disks some unexpected, but explainable observations were made. Each disk was tested for leakage at rated reverse voltage. The leakage current rose and fell regularly at approximately three second intervals. Our high voltage lab has a red rotating warning beacon. It was determined that the light from the beacon increased leakage in the diode due to the photo-electric effect.

During testing the circuit self triggered. The $\dot{B}$ and $\int \dot{B}$ waveforms were nearly ideal. Figure 5 shows the waveforms and the magnet's potential as a kicker. We have not acquired such clean waveforms via normal triggering.

While switching the magnet with and without the clamping diode in place, air bubbles or some other foreign debris may have gotten inside the clamping diode assembly. There may have been an arc to ground or possibly the clamping diode avalanched. Recalling our observations during leakage testing, photons from an arc may have triggered an avalanche of the diode. If this is possible and reproducible, a very fast, high power, optically triggered switch could be made. A common feature of some diodes is controlled avalanche breakdown and we are investigating the availability of such diodes.

4 Results

Although a simple circuit at low levels, making it operate at the high levels required has been difficult. During development, much has been learned about all the components in the circuit. The biggest difficulty has been in turning on the clamping diode. Future experiments will involve using a single length of RG-220 for the delay line part of the circuit. Another area we look forward to investigating is the possibility of developing a high power, optically triggered avalanche switch.

5 Acknowledgements

We are grateful for the advice provided by W.M. Portnoy of Sandia Laboratories in making compact pulse power diodes from stacked diode disks. Also the mechanical designs by Chris Ware and the technical efforts of Richard Taylor and Rob Cataldo were indispensable.