

# INJECTOR ELECTRONICS FOR MULTI-TURN OPERATION OF THE UNIVERSITY OF MARYLAND ELECTRON RING\*

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## Abstract

Progress is described toward the development of pulse generators required for injection and extraction of the University of Maryland Electron Ring (UMER). The geometry, described elsewhere, employs a fast ironless dipole at the junction of a Y-shaped section of the ring. The dipole as developed has an inductance of 600nH. The required +21 A long pulse generator for multi-turn operation is installed. The first prototype pulse generator, providing -42 A for deflection of the beam in the opposite sense, has been installed on the beam line and tested. Successful multiple beam laps have been observed.

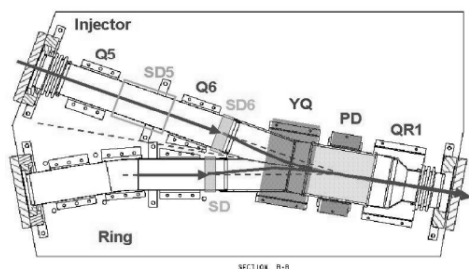


Figure 1: Y-section. "PD" is the pulsed dipole.

## INTRODUCTION

The University of Maryland Electron Ring is a facility for beam physics research. Its motivation and parameters are reviewed in a separate paper [1]. With the closing of the electron ring, achieving multi-turn operation is now the top priority. The key component necessary to achieve multiple turn operation is the successful design of the pulsed electronics for the injection dipole

For injection, a wire-wound pulsed dipole is employed[2]. Figure 1 shows the Y-section of the ring and the position of the pulsed dipole (PD). Figure 2 is a schematic of the wire windings. The dipole replaces one of the ring dipoles for multi-turn operation and thus requires a clockwise  $10^\circ$  deflection with a constant positive current for  $\sim 20 \mu\text{sec}$  for the nominal goal of 100 turns. During injection the dipole must deflect the beam  $10^\circ$  counter-clockwise with a constant negative current for  $\sim 100 \text{ ns}$  for a nominal beam length of 100 ns in view of the circulation time of 200 ns. This method allows the injection line to be placed at an angle of  $20^\circ$  with respect to the adjacent ring segment[3].

## DESIGN REQUIREMENTS

In view of the required fall time, the inductance of the dipole must be minimized. Otherwise, the shape of the

current pulse would be distorted by the release of the inductive energy in the dipole. For this purpose, the upper half and lower half of the dipole are connected in parallel, unlike the ring dipoles, which are connected in series. The unique design of the dipole, based on only six

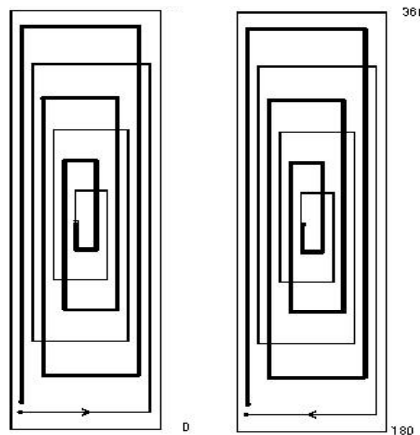


Figure 2: Dipole Schematic.

loops in each half, yields a measured inductance of 0.6  $\mu\text{H}$  with the two halves in parallel. On the other hand, the small number of loops means that the current must be correspondingly higher than the ring dipoles. The nominal required peak current is 20 A in each half, or 40 A for the parallel configuration.

## Design Concept

The method chosen for pulse generation is shown schematically in figure 3. Two pulse generators are employed. A positive 'long' pulse,  $\sim 75 \mu\text{s}$ , provides multi-turn operation, whereas the 'short' pulse for injection must be negative polarity with twice the nominal current, i.e. 80 A in parallel to cancel the current in the long pulse. This method was deemed simpler overall compared with one generator to provide both requirements. Isolation between the two pulsers is provided by a large inductance, which in fact forms part

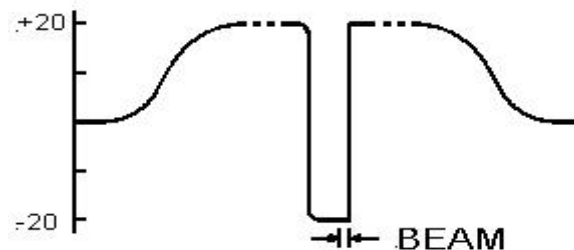


Figure 3: Pulse design concept.

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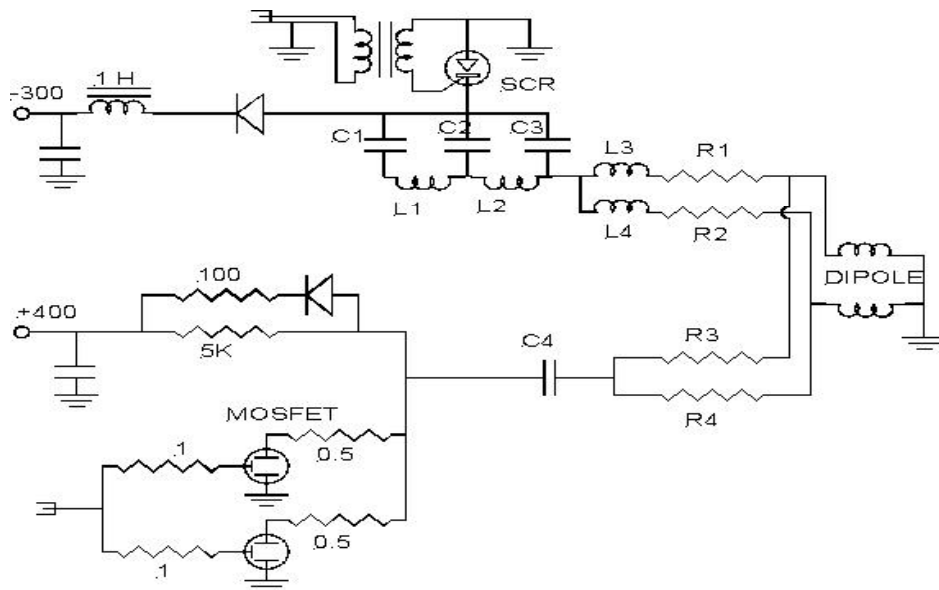


Figure 4: Pulsed dipole circuit. Long pulse generator is above, short pulse below.  $C1=C2=1.5\ \mu\text{F}$ ,  $C3=1.65\ \mu\text{F}$ ,  $C4=10\ \mu\text{F}$ .  $L1=L2=100\ \mu\text{H}$ ,  $L3=L4=330\ \mu\text{H}$ ,  $R1=R2=10\ \Omega$ ,  $R3=R4=12\ \Omega$ .

of the network for generating the long pulse.

The circuit schematic is shown in figure 4. A small pulse-forming network generates the long pulse. Inductive/diode charging is used for the capacitors in the long-pulse network to reduce the average power. A 3-section network is adequate since the rise and fall times are not critical. The charging time constant, 2 ms, is adequate for 60 Hz operation. Since the primary purpose of the long pulse is duty factor reduction, the rise time and fall time of the pulse-forming network is not important.

A capacitive discharge modulated by fast switching power MOSFET's generates the short pulse. Using this method only the fall time of the generated pulse needs to be less than 100 ns since the injection only needs the last 100ns of the pulse. The fall time is almost completely determined by the ability to quickly turn off the MOSFET switches. Inductive/resistive time constant is only a major factor in the rise time, which in this case is unimportant. This allows the lowering of the load resistance to keep the power and voltage requirements within the range of current solid-state technology. However, two MOSFET's operating in parallel are necessary to achieve the require current. Solid-state switches are ideal because of their speed and precision control.

The fast switching at high currents creates a very large "back EMF". This large voltage spike can destroy the MOSFET switch. A 100 ohm resistor and diode are used to reduce the large voltage spike and prevent breakdown of the MOSFET.

An SCR is used for the long pulse. Since the long pulse provides positive polarity, the power supply must be negative and the SCR must be inverted, i.e., the anode grounded. Since the gate is normally at cathode potential (-300 V), a small pulse transformer is used to couple the

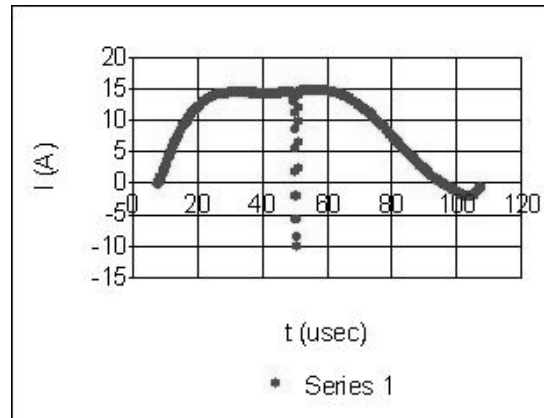


Figure 5: Oscilloscope trace of Long Pulse.

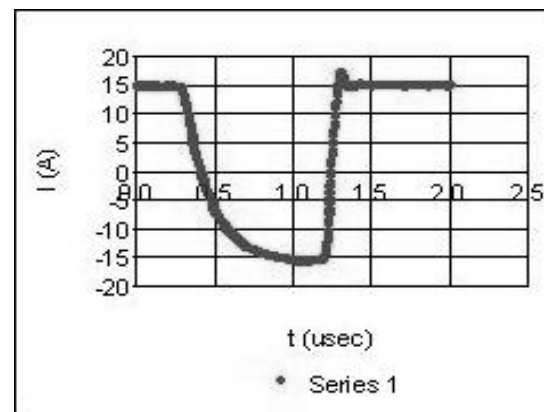


Figure 6: Oscilloscope trace of Short Pulse.

input trigger, at ground potential, to the gate. A standard TTL trigger pulse is adequate. The MOSFET gates are driven directly, but require a larger trigger, ~14 V at 50 ohm impedance. The fall time of the trigger must be less than the fall time required by the dipole. The delay between the long-pulse trigger and the short-pulse (and injection) trigger is ~40  $\mu$ sec.

Isolation between the two pulsers is provided by a 330  $\mu$ H inductor in series with each 10-ohm load resistor. As a result the change in voltage (and current) of the long pulse induced by the presence of the opposite-polarity short pulse is very small. Also, all that matters is that following the short pulse the long pulse must be flat for 15  $\mu$ sec to allow for the possibility of 100 turns in the future.

### TESTING RESULTS

Figures 5 and 6 show oscilloscope traces of the two pulse generators working together. Figure 4 is on a large timescale and shows the full length of the long pulse. The dotted line spiking down is the short pulse. Figure 5 is on a smaller time scale and shows a close up of the short pulse action.

The isolation between the circuits is excellent. There is no difference in the performance of the short pulse from when it is operated independently and in the presence of the long pulse. The fall time (or rise time considering the polarity) is 100ns with some fluctuations occurring after the current reaches 0.

Figure 7 shows an oscilloscope trace of a beam position monitor (BPM) located on the ring after the Y section. The trace is from the first test of both pulse generators on the beam line. This was the very first attempt of multi-turn operation on UMER done May 5, 2005. Only a rough steering solution was used, which accounts for the beam loss as the beam makes successive laps. The signal was recorded while running a 24 mA beam. Each pulse on the trace represents a complete lap made by the beam minus the initial pulse (3 laps in this case). The results show the first successful multi-turn operation of UMER due to the implementation of the injection electronics.

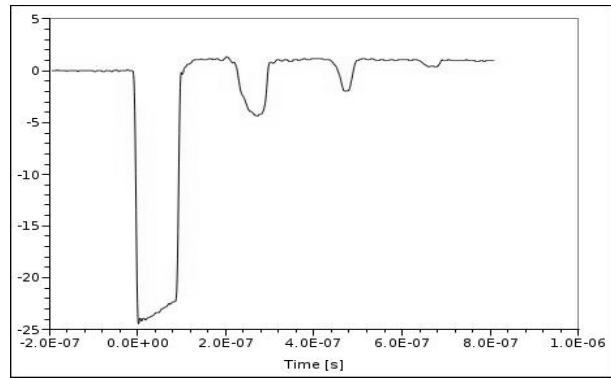


Figure 7: BPM traces of the first attempt of multi-turn operation taken May 5, 2005.

### CONCLUSION

The first successful test of multi-turn operation in UMER is complete and the design concept for the injection electronics has so far been successful. The small current fluctuations that occur after the fast switch present a problem to beam deflection at the head of the beam. For the time being the beam length may have to be reduced to ~60ns. Further work will be done to decrease the fall time of the short pulse to less than 100ns and reduce the fluctuations.

### REFERENCES

- [1] S. Bernal et. al., "Commissioning of the University of Maryland Electron Ring", these proceedings.
- [2] T. Godlove, UMER Technical note "Pulse Dipole with Six Loops" UMER 030317-TF, March 17,2003. (unpublished)
- [3] H. Li et. al., "Beam Optics Design on a New Injection Scheme for UMER", PAC 2003, p.1676.