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Comparison of Pulsed Power Supplies for Kicker Magnets

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1. Introduction

This note compares basic circuit configurations for pulsed power supplies, identifying the best option for SLS. Initial investigation showed that semiconductor switches could be used for pulsed power supplies for kicker magnets. The SLS requirements are relatively relaxed: for the booster, two kickers with <100nsec rise time to about 600A are required; and for the storage ring, four matched kickers with about two microsecond risetime/falltime to about 2.5kA are required. The unusual requirement for SLS is very good tracking between the four storage ring kickers; +/-1% is the typical value quoted for existing kicker systems, but +/-0.1% would be preferrable to give minimum disturbance during top-up injection. Radiation levels are expected to be low enough to allow placement of pulsed supplies next to the magnets.

For semiconductors, there are two types of devices: a controllable **switch**, such as an IGBT (Insulated Gate Bipolar Transistor) which can be turned on and off in less than a microsecond; and a **closing switch**, such as a MCT (MOS Controlled Thyristor) which can be turned on in a microsecond but must be turned off by the external circuit.

Three basic configurations are found for pulsed supplies:

1. Series Inductance/Resistance(LR)
   A switch applies a high voltage for long enough that the current rises exponentially to the required value. The voltage is then switched to zero and the current decays exponentially.
2. Transmission Line (TL)
   A closing switch discharges a transmission line through the magnet and into a resistive load. Often, a second closing switch is applied to the other end of the transmission line to damp reflections.
3. Series Inductance/Capacitance (LC)
   A switch completes a high-Q LC circuit. After a half-cycle resonance, the switch is opened.

2. Comparison

Fig.1 shows the PSPICE circuits used to evaluate the three different topologies, while Fig.2 shows the resulting current waveforms.

The SLS kicker magnets all have an inductance around 1µH. For the comparison, a current around 500A was used. Typically, kicker pulsed supplies are run open-loop, relying on the inherent stability of the magnet, etc. to maintain a fixed current amplitude.

Referring to Fig.1-2, the LR configuration uses a relatively large resistance to fix the current flowing through the magnet; the peak current is independent of the inductance. It is not trivial to build a non-inductive, temperature stable resistance for large pulsed currents. The time constant varies inversely with the series resistance, giving a more rectangular pulse but a lower peak current.

The TL configuration is normally viewed in terms of matched transmission lines, with the magnet inductance being periodically loaded with a capacitance to simulate a transmission line. The advantage is that a perfect transmission line has no inductive retardation of the rise of current. Reflections from mismatches are troublesome, and the stray series inductances Lx and Ly were added to illustrate this.

The LC configuration requires the lowest voltage for a given peak current. The performance at the tail of the pulse is critically dependant on the ability of the switch to open.

	Inductive-Resistive Configuration (LR)	**Transmission Line Configuration (TL)**	**Inductive-Capacitive Configuration (LC)**
Peak Current Defined By	$\frac{V}{R}$	$\frac{V}{(Ro+Z)}$	$\frac{V}{\sqrt{\frac{L}{C}}}$
Time Constant	$\frac{L}{R}$	limited by stray reactance	$\sqrt{LC}$
Maximum dI/dt	$\frac{V}{L}$	limited by switch and stray reactance	$\frac{V}{L}$

Table 1. Comparison of the three configurations.

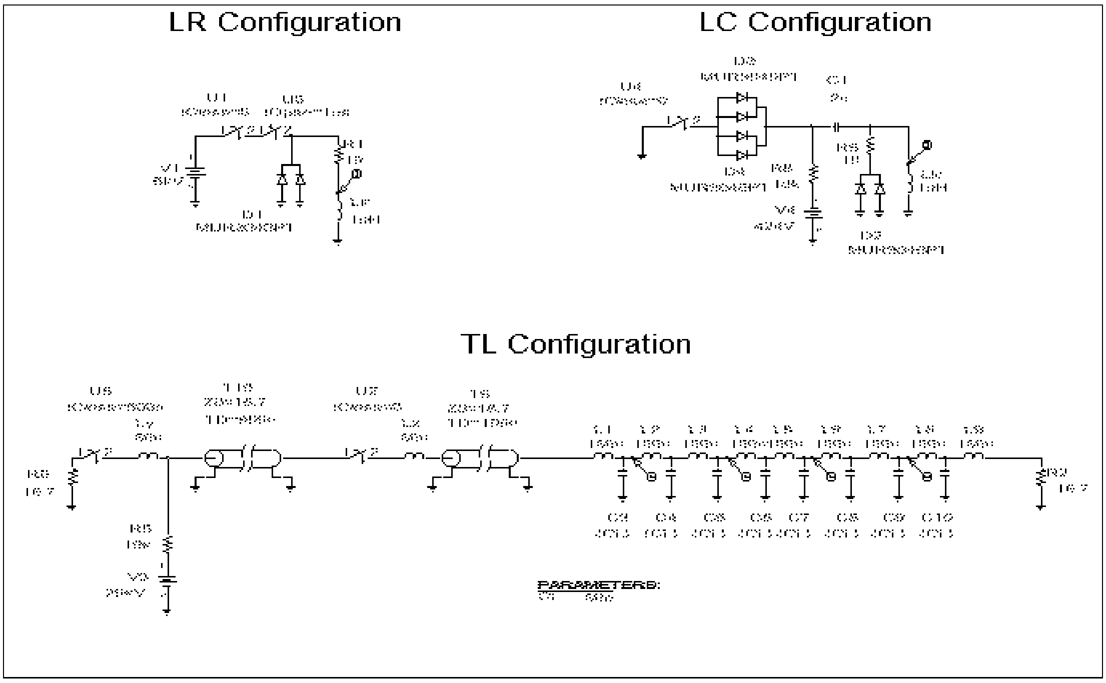

Fig.1 PSPICE circuits for comparison

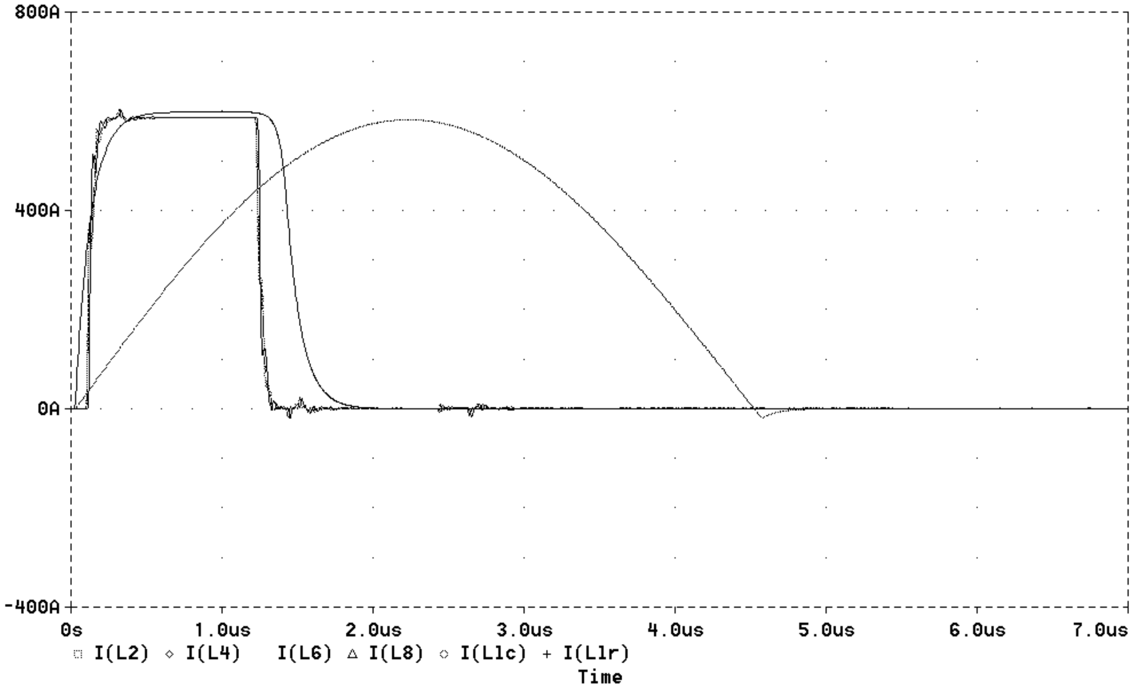

Fig.2 Current waveforms for the three types of pulsed supplies.

3.. Additional Comment on Transmission Line Configuration

The simulation was repeated with various values of loading capacitance, and the results are shown in Fig.3 In detail, the current into the load resistor R2 shows considerable improvement in rise time with loading capacitance. However, the magnetic field experienced by the electron beam would be proportional to the average current within the magnet structure. Fig.3 shows the loading capacitors do not change the overall shape of the magnetic field pulse. With zero capacitance, the TL configuration becomes like the LR configuration, with the series resistance replaced by the characteristic impedance of the cable. In Fig.2, the rise time for a Transmission Line is faster than for the LR, but this is normal because the charging voltage and resistance values chosen were much higher.

A further observation is that, if the final value has a small tolerance band such as +/-1%, the capacitive loading is counter-productive since the final settling is slightly oscillatory. (The number of sections is limited to 10-20 for practical reasons. The problem of modelling a transmission line with lumped elements has been thoroughly studied e.g. “Selection of Lumped Element Models for Coupled Lossy Transmission Lines”, Dhaene T and De Zutter D, IEEE Trans Computer Aided Design Vol 11, No 7, Jul 92, pp805-815.)

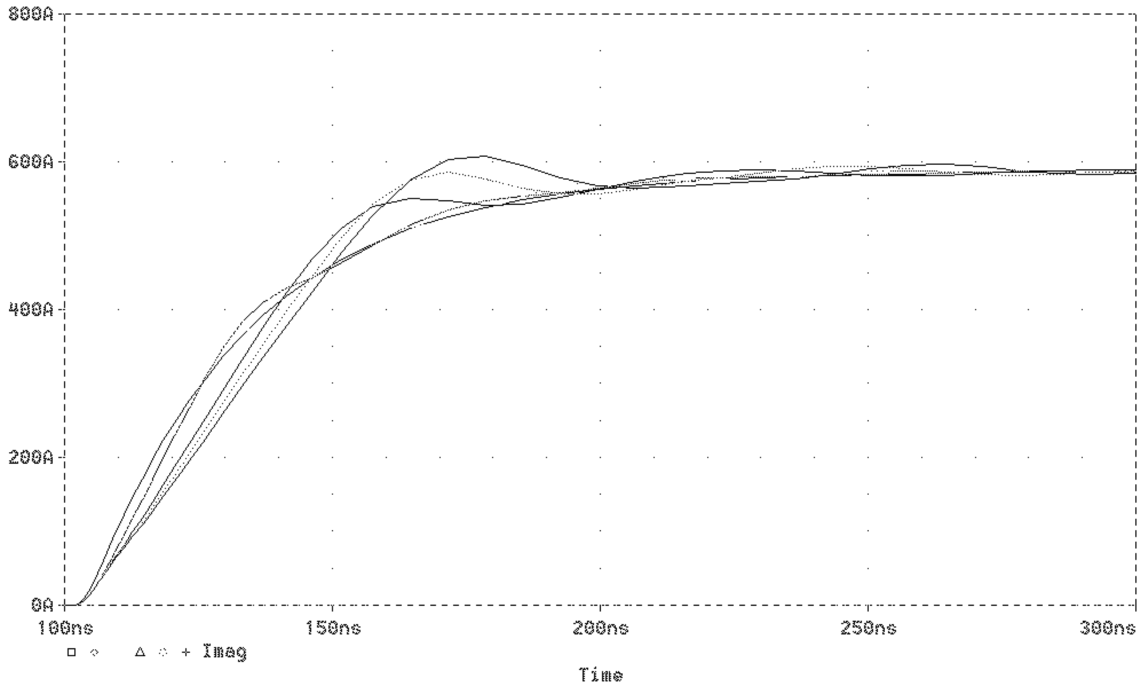

Fig.3 Effect of loading capacitance in magnet, for 0 - 500pF, switch risetime 50nsec

4. Conclusions

A simple re-assessment of pulsed power supplies for application to SLS has given considerable insight. The use of PFNs and transmission line magnets has been found to be an extension of a series inductive-resistive circuit. If the pulsed power supplies are placed directly next to the magnet (which is the intention for the SLS), transmission line magnets have no particular benefit; the magnet impedance no longer needs to be matched to that of the transmission cable.

The major factor affecting the choice of configuration is the amplitude stability and waveshape stability with temperature change. It is necessary to quantify the temperature stability possible from magnets, capacitances and resistances so as to select which type of supply offer better performance. A separate cooling system to keep the magnet or resistance or capacitance within +/-0.1^{o}C is one possibility.

A secondary factor is the long-term stability of the magnet or resistance or capacitance with aging and irradiation.

The risetime performance of commercial semiconductor switches is typically <250nsec, but the switches could be replaced in a few years when faster devices come on to the market. The risetime can be reduced by the use of saturating inductances.