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FAST KICKER SYSTEMS FOR ALS-U*

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Abstract

Fast kicker systems are required for the proposed upgrade of ALS to a diffraction-limited light source (ALS-U). The main approach is to have multiple stripline kicker magnets driven by inductive adders. The design details of the kicker structures and the inductive adder options will be discussed.

SYSTEM REQUIREMENTS

ALS-U [1] is a proposed upgrade to the Advanced Light Source at LBNL to achieve a diffraction limited storage ring. The project will require replacing the existing storage ring with one that uses more dipole magnets of less strength to reduce dispersion. It also requires the addition of an accumulator ring at the same energy as the storage ring, and on-axis swapping of bunches between the two rings. A schematic of this swap-out injection is shown in Figure 1. Two sets of thick and thin septa are placed symmetrically around the kicker to separate the injected and stored beams.

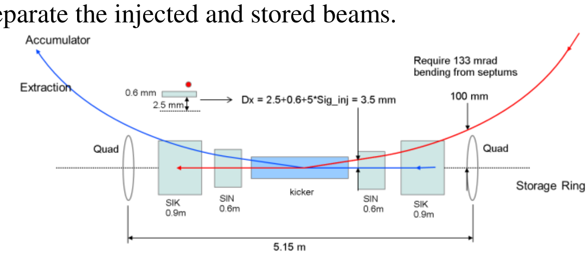

Figure 1 Schematic of swap-out injection.

Tracking studies on the ALS-U lattice showed that the requirements for the injection kicker pulse to pulse reproducibility and pulse flatness are > 10%, which relax the required performance specifications of the kicker pulser. Figure 2 shows the evolution of the injected beam for the first six turns and after the first four horizontal damping times in phase space. The beam has an emittance of 2 nm-rad, coupling of 1% and a horizontal offset of 1 mm when injected into the ALS-U lattice and achieves 100% injection efficiency. The lattice has a set of random errors in all bending and quadrupole magnets of $\Delta g/g=1\times10^{-3}$ (normal) and 1×10^{-4} (skew).

The requirements for the kicker system are to kick a 2 GeV electron beam by 3.5 mrad over a 2 meter magnet length. The full requirements are shown in Table 1.

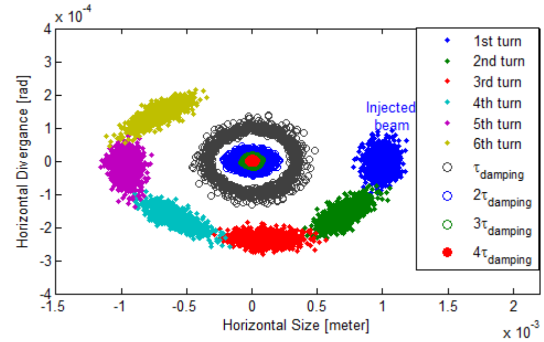

Figure 2: Evolution of the injected beam with an offset in phase space of ALS-U lattice at injection point.

The baseline design for the magnet is a tapered stripline, whose cross section with flux lines along with the **B** field across the center of the magnet, normalized to ±1 A, are shown in Figure 3. The magnet will actually be composed of four (or possibly more) shorter magnets, each driven by its own power supply. This will be done because of the fill time of the magnet, but more importantly because of the mechanical difficulty of fabrication and supporting very long, thin structures. There are two solid state adder topologies being considered for the modulator, a conventional inductive adder, and a transmission line adder. Both are shown in simplified form in Figure 4. The specifications for the modulator are given in Table 2.

Table 1: System Requirements

Parameter	Value
Beam Energy	2 GeV
Bend Angle	3.5 mrad
Magnetic Length	2 m
Aperture	10×6 mm (HxV)
Rise/Fall Time	<10 ns
Pulse Width	50 ns
PRF	<1 Hz
Inter/Intra Pulse Ripple	<10/1 % FS
B Field	5.83 mT
E Field	1.75 MV/m

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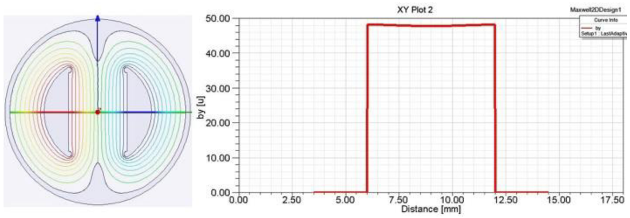

Figure 3. Cross section and flux of the magnet on the left and B field on the right.

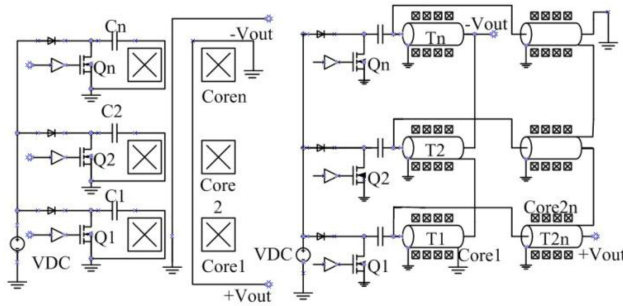

Figure 4. Simplified schematics of an inductive adder on the left, and a transmission line adder on the right.

Table 2: Modulator Requirements

Parameter	Value
System Impedance	43.1 Ω
Magnet Current	± 122 A
Magnet Voltage	± 5.24 kV
No. of Adder Cells	8
No. of Parallel MOSFETS/Cell	8-10

MAGNET DESIGN

Both stripline and short, ferrite loaded window frame magnets were initially considered. However, stripline magnets were chosen as the baseline because the number of ferrite magnets needed to meet the fill time requirement as well as limiting the operating voltage required to that of a MOSFET, is large. In addition, the coated chamber required for a ferrite magnet that would allow a 10 ns rise time would be approximately 1 Ω/sq and would dissipate several hundred Watt per meter, requiring an elaborate cooling system.

The stripline magnet was originally designed for 50 Ω, however the impedance changed as attempts were made to improve the matching of the even and odd modes, to improve the field uniformity, and the efficiency in terms of field strength per Watt from the pulser. Once these issues are fully analyzed [2], the final system impedance will be restored to 50 Ω because of the availability of feedthroughs.

The operating mode for the ALS-U is to simultaneously extract and inject an entire bunch train. The baseline design (500 MHz main RF) involves 11 trains of 25 bunches each, with a bunch separation of 2 ns and a gap between trains of τ_G = 10 ns. As a consequence, the maximum length for the stripline electrodes in each module is given by

$$L_{mod} \le \frac{\tau_G - \tau_R}{2} c \qquad (1)$$

where τ_R is the pulser rise/fall time and c the speed of light. Equation (1) underscores the importance of achieving the shortest possible rise time from the pulser. Longer rise times could conceivably be accommodated by reducing the bunch train length, at the price of reducing the total current, or increasing the current per bunch. Shorter striplines also have the disadvantage of requiring a higher number of pulsers and occupy an overall longer portion of the beampipe due to the space needed to separate modules.

The pulser voltage required by each module can be derived from the total integrated deflecting voltage $V_\perp$ necessary:

$$V_\perp = \int_0^L \left(E_\perp + cB_\perp\right)dz = \Theta \cdot E_{beam} \qquad (2)$$

where $E_\perp$ and $B_\perp$ are the transverse electric and magnetic fields, Θ the total bending angle and E_{beam} the beam energy.

Using N_{mod} kicker modules, the bipolar voltage required for each module is

$$\pm V_0 = \frac{V_\perp}{2N_{mod}} \left(\frac{h/2}{g_\perp L_{mod}}\right) \frac{\theta}{\sin\theta} \qquad (3)$$

where h is the vertical gap between striplines and

$$g_\perp \approx \tanh\left(\frac{\pi w}{2h}\right) \approx 1 \qquad (4)$$

is the stripline coverage factor, which is close to 1 for 10 mm wide striplines.

The $\theta / \sin\theta$ term ($\theta = \omega_{max} L_{mod} / c$) takes into account the kicker's required bandwidth. If the pulser rise time can be kept as short as 6.5 ns then (Eq. 1) it is possible to use four 0.5 meter long magnets. The bandwidth is in the range 50-100 MHz, according to

$$\omega_{-3dB} \approx 0.35 / \tau_R \qquad (5)$$

so that the required pulser voltage would fall between ±5.25 kV (Eq. 3).

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MODULATOR DESIGN

Both modulator topologies being considered are based on a MOSFET switch and driver circuit developed for the kickers for the Next Generation Light Source and shown in Figure 5 [3]. The switch is an IXYS DE275-102N06A capable of producing pulses up to approximately 800 V and 50 A peak, with rise and fall times under 5 ns. The gate driver is a discontinued IXYS IXDD-415SI, so another driver will need to be found for production.

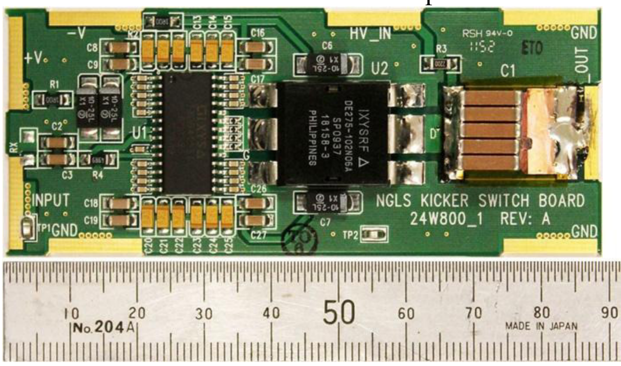

Figure 5. Photo of MOSFET switch circuit.

For the R&D effort, both a conventional inductive adder topology and a transmission line adder circuit are being investigated, as there are advantages and disadvantages to both approaches. The inductive adder is more expensive and complicated mechanically. Since it is difficult to match the impedance throughout the propagation time through the adder structure, pulses with rise times of less than 10 ns may be difficult to achieve. Because the adder structure of the transmission line adder can be as simple, and short, as stacking striplines together, both the mechanical complexity and the problem of propagation times can be reduced. However, the transmission line adder will either require a large number of coaxial cables, or custom built striplines, and the matching of cable and load impedances and cable lengths is critical.

The design of the conventional inductive adder uses CMD5005 NiZn ferrite cores. The core geometry has been determined by the minimum inner diameter to accommodate the stalk using RG-213 coaxial cables to bring out the positive and negative voltage and having an acceptably high inductance to minimize voltage pulse droop from the characteristic L/R time constant for the system. For this cross-section core, the losses are insignificant and the volt-second product is many factors more than required. Each of the 8 stages has 8 parallel MOSFET boards. A single adder cell is shown in Figure 6. Secondary stalk geometries with different impedances will be tested for the optimum risetime [4].

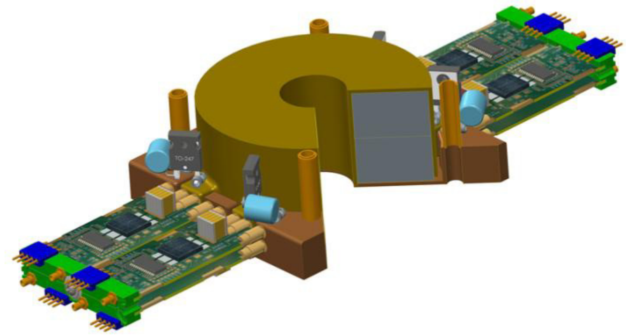

Figure 6. CAD model of single stage of the conventional inductive adder showing the cross-section of the ferrite core.

A design for a prototype transmission line adder is still in the conceptual stage, however a five cell adder was built with existing parts and is shown along with the output pulse into a 50 Ω load in Figure 7. The ringing seen is partly due to grounding issues, and partly from impedance mismatches in the circuit. It does however demonstrate that with careful control of the impedances, grounding, cable lengths and strays, achieving the required ripple should be possible.

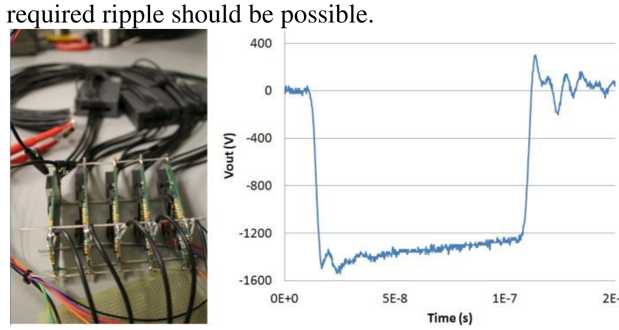

Figure 7. Five cell transmission line adder and output pulse into 50 Ω.

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