Introduction:

The Linac beam structure is based at the RFQ frequency of 162.5 MHz and the following Fast Beam Chopper in the MEBT, which is able to remove, predetermined bunches in any arbitrary pattern ranging from 0% to 100% duty factor. The kicking electric field is produced in a delay line structure with a phase velocity matching the beam beta. The required waveform voltage in the chopper gap is 450 V.

These requirements place many demands on the chopper power supply: wide bandwidth, high slew rate, fast switching, high voltage, large power dissipation from internal switching losses and a desired matched source impedance to absorb reflected signals from the chopper structure. R&D for both 50 Ω and 200 Ω systems has been underway for some years and has shown the level of these difficulties. The combination of high voltage and switching losses has been the most challenging for the solid-state devices under evaluation.

RF Rail Chopper:

The switching losses in the transistors are dominated by the internal dissipation of the stored energy of the drain to source capacitance on every turn on. To only way to reduce this loss is to lower the voltage across the device during switching. The chopper power supply does not need to be a time invariant linear device as we have knowledge of the required symbols and rates. In this application we know the output is must be in one of two states, (pass or kick) and it has a symbol rate equal to 162.5 MHz or the beam arrival from the RFQ. We can take advantage of this information and create a circuit that allows zero-volt switching of the transistors. This is done by replacing the power supply plus, minus DC rails, with 162.5 MHz RF sources with source impedances that match the load, that are offset with plus minus DC voltage equal to the peak RF voltage. A differential H-bridge topology, shown in figure 1, is chosen to reduce circuit complexity. The two rail voltages are easily generated with a standard narrowband RF amplifier driving a 4:1 balum going from unbalanced 50 Ω to balanced 200 Ω. These two signals are then AC coupled with a DC block to a AC blocked DC supply which offsets the AC component such that the minimal voltage on the positive rail is zero volts and the maximum voltage on the negative rail is also zero volts. These rails then both provide the required voltage and matched source impedance to the load.

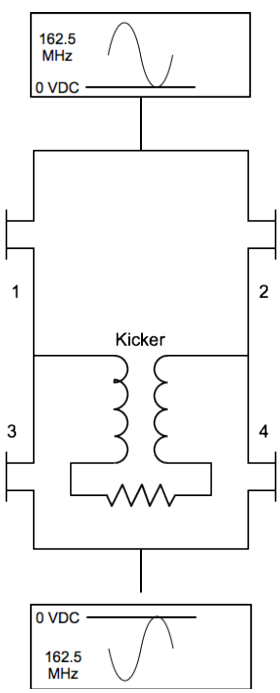

Figure 1 Chopper Schematic

The circuit operates as follows. For a positive kick waveform, switches 1 and 4 are turned on when both rail voltages are approaching 0 volts while switches 2 and 4 are turned off. The left side of the chopper structure is driven positive and the right side is driven negative. For a negative kick, as the rails approach 0 volts, switches 1 and 4 are turned off and switches 2 and 3 are turned on. The benefit is that all switching is done with near zero voltage across the devices and therefore they incur minimal switching loss. The individual switches may be built up as a cascode of a GaN RF device on the low side with a high voltage device on top to handle the standoff on minimum and maximum rail voltage.

Figure 2 is shows a Matlab simulation of the RF power supply rails and the differential output waveform. Shown are positive kicks with three negative kicks interspersed.

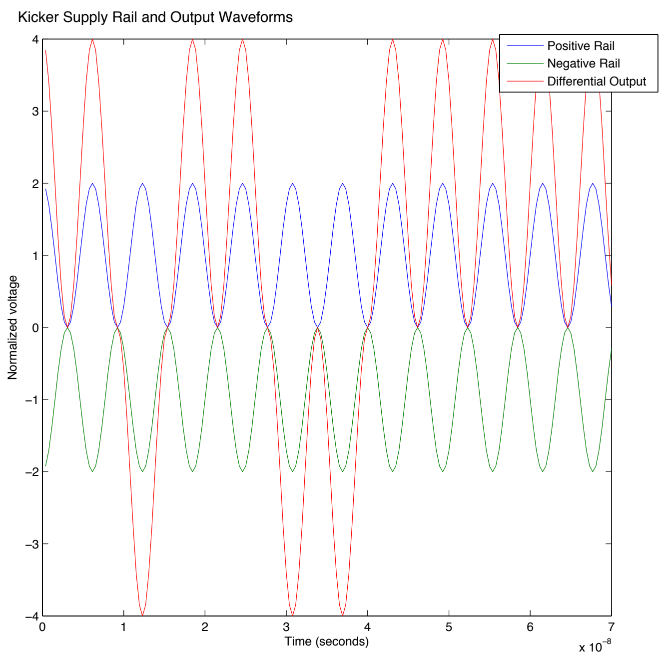

Figure 2 Chopper power supply rails and differential output

There are a few variants on this scheme that would improve the signal flatness for passed beam, however, the basic concept of modulating the power supplies to switch at zero volts across the devices is central and the proper place to begin an investigation.

Matlab code to produce simulation:

```
%% MEBT Chopper Simulation
%B. Chase 12/11/2012

%simulate mosfet switch with sinwave rails
% make plus and minus sin rails with V DC offset
clear all;
sampleRate=2.6e9;
injPeriod=7e-8;
m=floor(injPeriod*sampleRate);
a=zeros(4,m);
F=162.5e6; % frequency of rail voltage
beamPeriod=1/F;
```

```
n=floor(beamPeriod*sampleRate);% compute the number of samples in a
162.5 MHz period

deltaT=1/2.6e9; %half period
A=1;        %RF peak voltage

% calculate waveforms 1- time, 2- positive rail, 3- negative rail,
% 4- output
for x=1:m
    a(1,x)=x*deltaT;
    a(2,x)=A*cos(F*2*pi*a(1,x))+A;
    a(3,x)=-a(2,x);
    a(4,x)=a(2,x)-a(3,x);
end
%generate negative pulses
hn=n/2;
for x=n+8:2*n+8
    a(4,x)=a(3,x)-a(2,x);
end
for x=4*n+8:6*n+8
    a(4,x)=a(3,x)-a(2,x);
end


plot(a(1,1:m),a(2,1:m),a(1,1:m),a(3,1:m),a(1,1:m),a(4,1:m));
```