A FAST CHOPPER FOR THE FERMILAB HIGH INTENSITY NEUTRINO SOURCE (HINS)*

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Abstract

A fast chopper capable of kicking single 2.5 MeV H^- bunches spaced at 325 MHz, at rates greater than 50 MHz is needed for the Fermilab High Intensity Neutrino Source (HINS) [1]. Four 1.2 kV fast pulsers, designed and manufactured by Kentech Instruments Ltd., will drive a 0.5 m long meander made from a copper plated ceramic composite. Test results showing pulses from the first 1.2 kV pulser and meander results will be presented.

INTRODUCTION

As a demonstration of the feasibility of a high intensity 8 GeV proton source, Fermilab is constructing a 60 MeV H^- linac (HINS). This would serve as the front end to a superconducting 8 GeV linac, which would deliver beam to the Main Injector. Since the operating frequency of this linac is 325 MHz, not a multiple of the Main Injector's 53 MHz, we are compelled to chop out approximately one out of every six beam bunches. This avoids beam losses due to bunches which would not be captured in a Main Injector RF bucket.

The chopping is to be done in the 2.5 MeV (MEBT) section of the linac. This requires extremely fast (width < 6 ns) high voltage (±2.4 kV) pulses which propagate at the same speed as the beam (β=0.073) along a two plate deflecting “meander” structure. The requirement on the width is such that only one bunch at a time may be removed.

The two meander structures are 50 cm long, each with an impedance of 100 ohms. To obtain the necessary deflection, the beam must be kicked by the electric field (due to the high voltage pulse) for the entire length of the meander.

FAST PULSER

Fermilab has procured from Kentech Instruments, Ltd. [2] a prototype 500V pulser, in June 2006, and a 1.2 kV pulser in November 2007. The average chopping rate imposed by the HINS pulse parameters is close to 1MHz however the switching losses in high voltage (kilovolt) semiconductor switching devices becomes excessive at these pulse rates. In order to obtain fast rise and fall, together with a high pulse repetition rate, the output is generated from an array of custom packaged low voltage (100 volt) semiconductor switches. These relatively low voltage parts have a bandwidth of ~500MHz allowing nanosecond rise and fall times.

The 1.2 kV pulser is based on an array of twenty four 50V pulse cards. The cards are floating, each with an output impedance of ~2 ohms. This output from each card is transported by 12 parallel 25 ohm semi-rigid coax cables and is taken to a summing point. When combined, this yields the 1.2 kV, 50 ohm output.

Figure 1: Kentech 1.2 kV pulser.

Each card has a floating power supply together with PECL trigger logic, burst width and duty cycle limit circuitry and power supply monitoring, all of which are remotely controlled. The TTL burst pattern input trigger signal is regenerated in PECL circuitry on each card before being amplified to a 50V pulse output. Individual cards can be enabled or disabled for testing purposes and the correct operation of the card can be confirmed via the link.

The pulser incorporates load fault detection (open or short circuit) and has an embedded controller for set up and control functions. It may be operated in either a 1 ms or 3 ms mode, triggered by an arbitrary TTL pattern with the option of a 325MHz clocked data input. The maximum total on-time during a 1 ms burst is 0.75 ms. A photograph of the 1.2 kV pulser is shown in Fig. 1. Figure 2 shows the pulser output (attenuated by 60dB). The top scope photo shows several 1.2 kV pulses spaced by ~20 ns. The bottom shows a full 3 ms burst of this pulse pattern.

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MEANDER STRUCTURES

We began our meander R&D with a $Z_0 = 50\Omega$ prototype structure given to us by F. Caspers (CERN) [3]. This is a

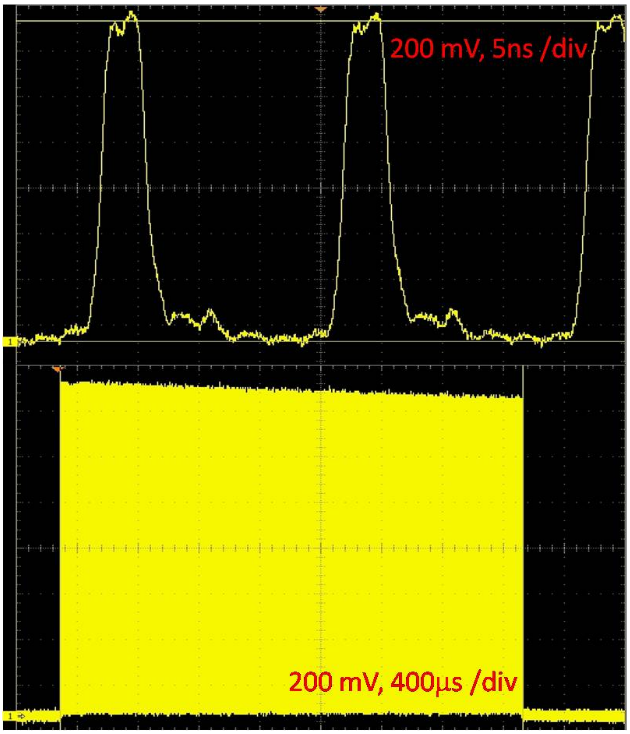

Figure 2: Kentech 1.2 kV pulser output, with 60dB attenuation. The top trace shows several 1.2 kV pulses with ~20 ns spacing. The bottom trace shows this pattern repeated for 3 ms.

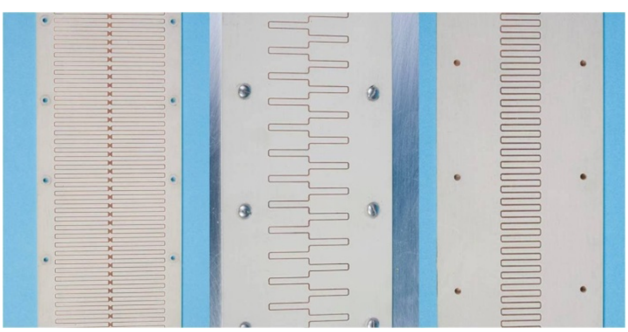

Figure 3: Double meander (left, $Z_0 = 50\Omega$), low dispersion single meander (middle, $Z_0 = 100\Omega$) and high coverage factor single meander (right, $Z_0 = 100\Omega$).

double meander structure printed onto alumina substrate (ε=9.8). We scaled this design (by scaling the width of the trace pattern) to account for the difference in β of ~8%. The new scaled structure is the first shown in Fig. 3.

Rogers TMM10i was chosen instead of alumina for the new meander structure. This material also has ε=9.8, however, the material allows for complete meanders to be made very quickly. Laminates may be procured in 18x24″ sheets with copper cladding on one or both sides. The meander pattern can then be quickly routed out on a small programmable milling machine for PC boards which is available in-house.

To test for suitable behavior of Rogers TMM10i in vacuum, we baked a 24x13 cm sample for 90 hours at 170 C. After the bakeout we obtained a pressure of 8E-08 torr at 55 C (the predicted operating temperature of the meander, given losses) with a relatively low pumping speed of 0.63 L/s. Given that the surface area of the sample is a factor of 3 lower than that of the two meanders which will comprise the final chopper, we expect to be able to attain vacuum levels on the order of 10^{-8} torr. (using a larger vacuum pump) without much difficulty.

We have explored three designs for the meander structure. The first, already mentioned, is a 50 ohm double meander structure. The second and third have a single trace with 100 ohm impedance. These are shown in Fig. 3 and are termed the ‘low dispersion single meander’ (LDSM) and the ‘high coverage factor single meander’ (HCSM). Each structure uses ⅛″ thick Rogers TMM10i High Frequency Laminate Circuit Material with 70 µm Cu cladding. The prototype structures are 18″ (46 cm) long. The transverse extent of the traces is 78 mm for the double meander, 40 mm for the LDSM and 20 mm for the HCSM. In each case the width of the trace is 0.015″.

Pulse Behavior

Figure 4 shows the pulse behavior at the beginning, middle and end of the three meanders. Also shown is the (low voltage) input pulse. Both single meanders show little increase in the pulse width as it progresses down the structure, though the degradation is the least in the LDSM.

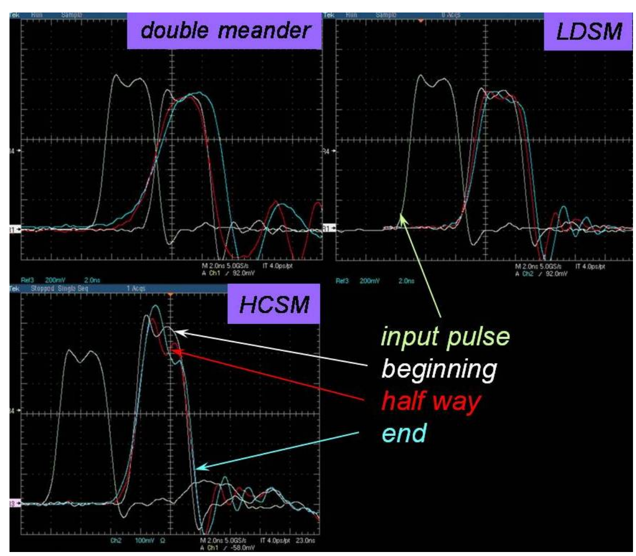

Figure 4: Pulse behavior along the meander structure.

Coverage Factor

Since the metal traces of the meander are not solid conductor (on the scale of the beam size), the effective electric field is less than the voltage difference between two structures divided by their separation. The leads to the definition of the coverage factor, which is $E/(\Delta V/d)$, where E is the actual electric field between the plates, ΔV

is the voltage difference, and d is the separation. We have measured the coverage factor as a function of transverse position for each meander, using the fixture shown in Fig. 5, along with a network analyzer. This is an S_{21} measurement with Port 1 connected to the meander traces and Port 2 connected to a HP85024A high frequency probe which serves as a pickup. The probe tip is the same distance away from the meander surface as the beam (8 mm) and is surrounded by a ground plane. The probe is mounted on micrometer adjustable stages so that it may be moved in the x and z directions.

For normalization, a wide (25 mm) stripline is used. In this case, the probe tip is located at one of the stripline groundplanes. Each groundplane is 8mm from the stripline center conductor. Measurements for 100 ohm meanders are corrected for reflection due to the impedance mismatch between the network analyzer and the meander. For the double, LDSM and HCSM we measure coverage factors of 71%, 48%, and 74%. We also measure the coverage factor for the double meander in a slightly different configuration: with 0.062″ spacers between the double meander and groundplane. Here the double meander has 100 ohm impedance; we measure a coverage factor of 87%. Simulations of the CERN SPL double meander chopper structure [3], which has the same trace density as the double meander discussed here predict a coverage factor of 80%. Microwave Studio (MWS) simulations at FNAL predict a slightly lower coverage factor of 75%. Figure 6 shows measurements of the coverage factor versus transverse position on the meander.

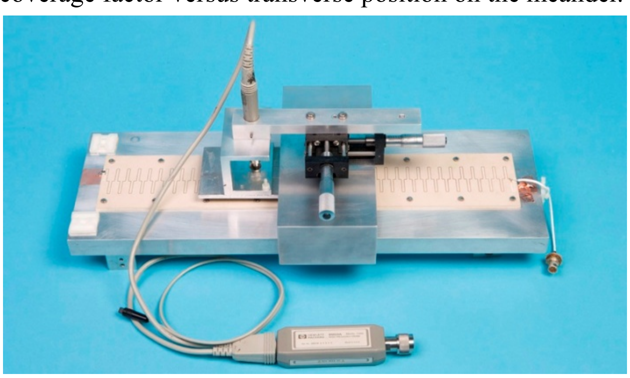

Figure 5: Coverage factor measurement fixture.

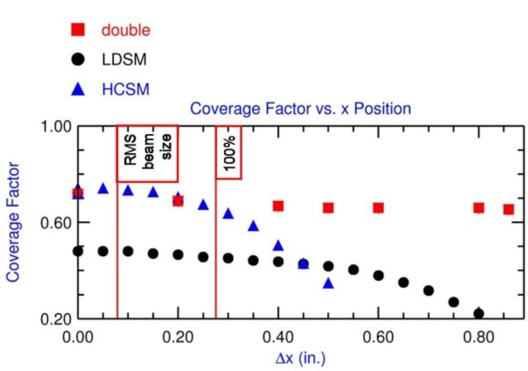

Figure 6: Coverage factor vs. transverse position.

FINAL DESIGN

The final chopper will consist of two 50 cm long meander structures with a spacing of 16 mm. Obtaining the necessary beam deflection angle of 24 mRad imposes the requirement ΔV(plates) = 4.8 kV (accounting for a coverage factor of 80%).

Figure 2 shows that a high quality 53 MHz 1.2 kV pulser is possible. Thus, we plan to combine the output of two 1.2 kV/50 ohm pulsers into one 2.4 kV/100 ohm pulser. This can be done for both polarities (for ± 2.4 kV) and will yield the desired 4.8 kV, when used with a 100 ohm meander structure. It is this reasoning which initially led us to explore the 100 ohm meander design as opposed to the more common 50 ohm version. Of the 100 ohm single meanders, the LDSM exhibits the best pulse behavior along the length; however, the coverage factor is much too low. Thus we have chosen for our final design the HCSM, which has good pulse behavior along the length of meander as well as a high coverage factor.

We have built a combiner, or coaxial cable impedance transformer, using 46 turns of Andrew FSJ2-50, ⅜″ heliax superflexible foam coaxial cable, wrapped around five 1″ thick cores. These are MN60 cores with an OD and ID of 11″ and 4.5″. We have tested the combiner using the Kentech 0.5 and 1.2 kV pulsers. We obtain good quality output pulses of approximately 1.6 kV, shown in Fig. 7.

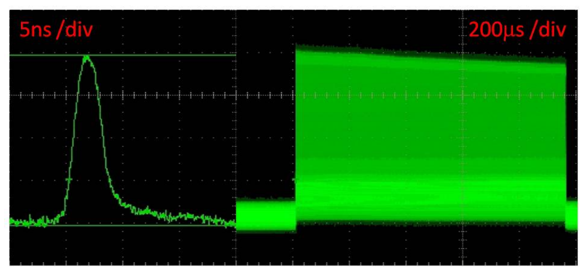

Figure 7: Combiner output.

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We also wish to thank Gennady Romanov (FNAL) for the MWS simulation predicting the coverage factor for the meander structure, and Terry Anderson (FNAL) for performing the TMM10i vacuum test.

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