MEANDER-LINE CURRENT STRUCTURE FOR SNS FAST BEAM CHOPPER*

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Abstract

A new current structure for the fast traveling-wave 2.5-MeV beam chopper for the Spallation Neutron Source (SNS) project has been proposed recently [1]. It is based on the meander-folded straight or notched stripline with separators. Detailed electromagnetic modeling with MAFIA has been used to optimize the structure design and parameters. The time-domain 3-D MAFIA simulations predict the structure rise and fall times around 1 ns. A notched meander line with a dielectric substrate has been developed to accommodate both electromagnetic and mechanical requirements.

1 INTRODUCTION

The SNS is a next-generation pulsed spallation neutron source designed to deliver 1 MW of beam power on the target at 60 Hz in its initial stage [2]. The SNS design stipulates a 1-GeV linear H^- accelerator and an accumulator ring. The SNS storage ring accumulates the linac beam during a few hundred turns (a macropulse, about 1 ms) using H^- injection through a carbon foil. The beam injected into the ring is stacked into a single long bunch, and the linac macropulse must be chopped at near the ring revolution frequency, 1.188 MHz, to provide a gap required for the kicker rise time during a single-turn ring extraction. The final clean beam chopping in the linac is to be done by a fast chopper in the Medium Energy Beam Transport (MEBT) line. For more detail on the chopper function and requirements, see [3].

The MEBT transports 28 mA of peak beam current from a 2.5-MeV 402.5-MHz RFQ to a drift-tube linac. A 0.5-m space is allocated for the chopper that deflects the beam into a beam stop during the 35% beam-off time. The updated chopper parameters are listed in Table 1.

Table 1: MEBT Chopper Specifications

Parameter	Value	Comment
Beam energy	2.5 MeV	β=0.073
Length	≤ 0.5 m	shorter is better
Gap	≥ 15 mm	adjustable
Pulser voltage	±1500 V	2 FETs in series
Deflection angle	18 mrad	90 % effective field
Chopping period	841 ns	
Duty factor	35 %	65 % beam on
Rise / fall time	< 2.4 ns	4.8 ns as initial goal

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Based on the results of MAFIA simulations [1] and [4], the chopper current structure consisting of a meander-folded notched stripline with separators was chosen as the one providing the best rise and fall times, in the 1-ns range. However, a mechanical design and manufacturing of a thin (0.25 mm) metal notched strip with some kind of supporting dielectric pins are rather complicated. To find a compromise satisfying both electromagnetic and mechanical requirements, we have studied a few variants of the notched meander line with a dielectric support. Fortunately, materials with a low dielectric constant and low losses in a wide frequency range, up to 10 GHz, and good mechanical properties are available from industry (see Sect. 2). After a series of MAFIA simulations, we have arrived to a new current-structure design which provides about the same electromagnetic performance as the previous one [1],[4], but is much better mechanically.

2 MATERIAL CHOICE

To keep the structure design close to the original one, which guarantees good electrical properties, we needed materials with a low dielectric constant and low losses. Materials for high-frequency applications like printed-circuit boards are available from industry, e.g., from the Rogers Corp. They usually also come with deposited copper layers that fit quite well our goal: the required meander pattern can be chemically etched with a high precision. The properties of some Rogers' glass microfiber reinforced PTFE composites are listed in Table 2.

Table 2: Some Properties of RT/duroids®

Property	RT/5880	RT/6002	RO3003
Diel. constant	2.20±0.02	2.94±0.04	3.0
Loss tangent @10 GHz	0.0009	0.0012	0.0013
Resistivity, 10^{10} Ωm	20.0	1.0	10.0
Density, g/cm^3	2.2	2.1	2.1
Thermal exp., 10^{-6}/K X/Y/Z	31/48/237	16/16/24	24/17/17

Our first choice was RT/5880 as having the lowest dielectric constant. However, due to its thermal expansion anisotropy the samples we received had a significant bow, which makes difficult its processing within the required tolerances. The two other materials in Table 2 are more isotropic, but RO3003 was unavailable with a desired copper layer thickness. It left us with RT/6002.

3 NEW CURRENT STRUCTURE

The current structure design should provide the proper wave phase velocity along the beam path (β=0.073) while keeping the characteristic impedance of the line equal to 50 Ω. The rise and fall times of the deflecting field (due to the current structure itself) has to be in the 1-ns range. In addition, the structure should be mechanically stable and reasonably easy to manufacture. These requirements lead us to the design illustrated by Figs. 1-3. Figure 1 shows a piece of the full-length 3-D MAFIA model used to calculate and optimize the structure parameters. The notched meander line (see Fig. 2) is supported by a T-shaped dielectric support that goes all along the stripline length (Fig. 3). The T-support will be carved from a continuos dielectric plate, as well as wide side supports, see Fig. 3. The structure will be clamped by bolts near its sides to the metal ground plate. The grounded metal separators protrude through the narrow cuts in the dielectric plate.

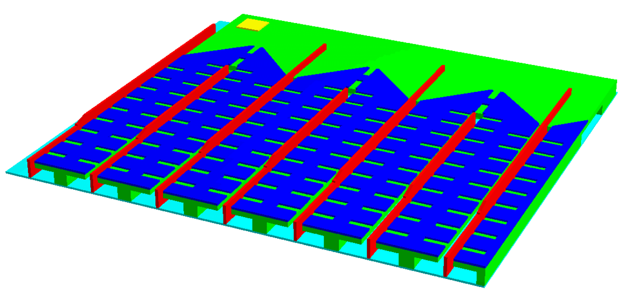

Figure 1: A small part of the 3-D model of the meander structure with dielectric supports: notched metal meander strip (dark-blue) with dielectric supports (green), metal separators (red) are connected to the ground plate (light-blue). Yellow pin in the corner is a clamping bolt.

Table 3 lists some relevant dimensions of the meander-line structure. The metal thickness in the strip is 0.25 mm. The separators are flush with the meander line near the beam path and rise 0.75 mm higher to the sides.

Table 3: Structure Dimensions

Parameter	Value
Length along the beam path	50 cm
Meander width, *b*	98 mm
Notched-strip width, *w*	8 mm
Strip-to-strip gap width, *g*	2 mm
Width of dielectric plate	130 mm
Thickness of dielectric, *h*	2.5 mm
T-support top	8 x 0.75 mm
T-support leg	2 x 1.75 mm
Notch spacing period	4 mm
Notch depth / width	3 mm / 1 mm

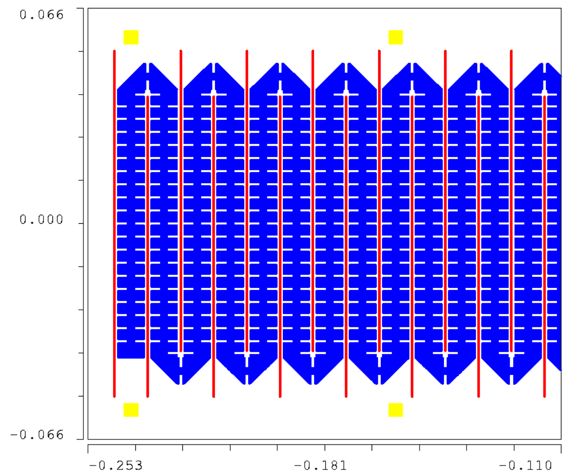

Figure 2: A part of the meander structure (about ¼ of the total length) in the plane of the notched stripline, at *z*=*h*. Dimensions are in meters.

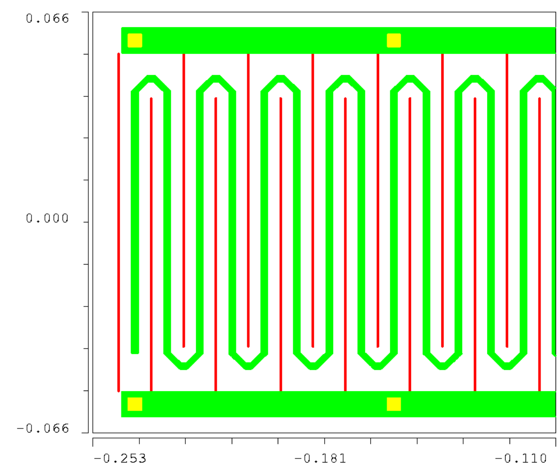

Figure 3: Same as Fig. 2, cut in the middle plane between the stripline and the ground, at *z*=*h*/2.

The notches provide some additional inductance, see [4], and the dielectric presence increases the capacitance *C*' per unit length of the line. From 3-D time domain MAFIA simulations the phase velocity $v_{ph}= 1/(L'C')^{1/2}$ of the TEM wave along the stripline was found to be 0.68*c*. The line characteristic impedance $Z_c=(L'/C')^{1/2}$ was adjusted to be 50 Ω by a proper choice of the dielectric thickness and the T-support shape. For Z_c calculation we first apply 2-D and 3-D electrostatic solvers to obtain an average *C*', then derive Z_c as $1/(v_{ph}C')$. Finally, the pulse phase velocity along the beam path was adjusted to match the beam velocity 0.073*c* by changing the meander width. To avoid pulse reflections from the meander bends, we adjust depth of the additional notches on the bends. All MAFIA simulations have been performed on a Sun Ultra 60 360-MHz workstation. For a detailed full-length 3-D model (about 3.5 million mesh points) a typical time-domain run with T3 takes about 30 hours of CPU time.

4 SIMULATION RESULTS

To model the chopper field pulse, we assume that a generator produces an idealized voltage pulse with smooth 2-ns rise and fall and a flat top of 5 ns at 1500 V. This voltage is fed into the meander stripline, and the produced fields are calculated with the MAFIA T3 module, see [4] for details. In Fig. 4 the deflecting electric field near the beam path is shown as a function of time t for three different locations x along the structure. Three snapshots of the field profile are presented in Fig. 5.

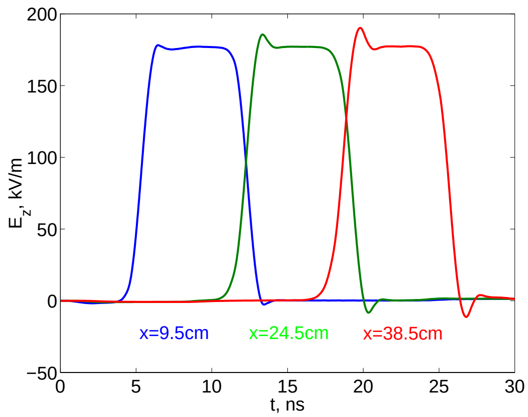

Figure 4: Deflecting field versus time in 3 different points on the beam path in the chopper.

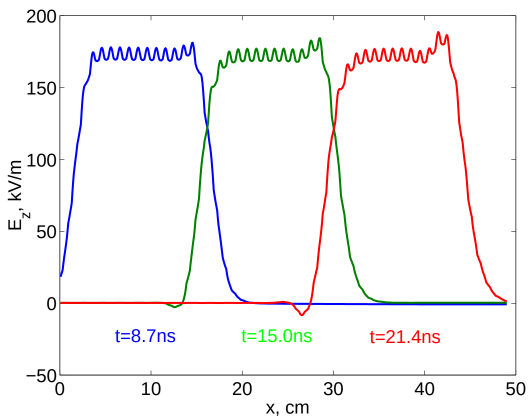

Figure 5: Snapshots of the deflecting field in the chopper.

As the pulse propagates along the chopper, its shape is slightly distorted by developing some overshoots. However, both the pulse front and end do not exceed 2.5 ns – the bunch-to-bunch temporal separation, – so that the meander structure contributes only a little to the initial 2-ns voltage fronts. Similar calculations with sharp voltage fronts show the structure rise and fall times around 1 ns. Obviously, for 4-ns voltage fronts the pulse distortion by the current structure will be smaller than in Figs. 4-5.

Figure 6 shows the deflecting field in the beam plane: a horizontal cut in the middle plane between two current structures with opposite voltages, at 7.5 mm from both of them. The same part of the structure as in Figs. 2-3 is shown. Small variations of the field along the beam path (center line of Fig. 6, at y=0) are due to field differences above the strip middles and above the grounded separators, compare the wiggles on the pulse tops in Fig. 5.

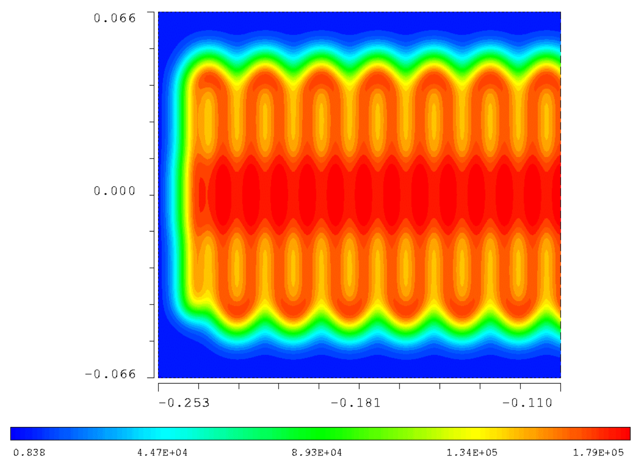

Figure 6: Contour plot of the chopper deflecting field.

An ideal flat capacitor with 3-kV voltage across 15-mm gap would have the electric field 200 kV/m. As one can see from Figs. 4-6, the calculated field at the pulse top is near 180 kV/m, which means the structure efficiency is close to 90%. One should mention that our simulations include all details of the mechanical design. In particular, we have not seen any influence on the deflecting field when dielectric clamping bolts were replaced by metal ones, or when a finite metal conductivity and/or dielectric resistivity were introduced.

5 SUMMARY

A new design of the current structure for the SNS fast chopper has been developed. Being based on the notched meander stripline that was developed earlier [1,3-4], it includes now a special dielectric substrate, which makes the structure mechanically stronger and easier to manufacture. The structure rise and fall times remain in the 1-ns range. A full-length prototype manufacturing is in progress, and its electrical measurements are expected soon.

6 REFERENCES

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[2] NSNS Collaboration, “NSNS Conceptual Design Report”, NSNS-CDR-2/V1, Oak Ridge, TN (1997); also available at URL: http://www.ornl.gov/~nsns/nsns.html

[3] S.S. Kurennoy, “Beam Chopper System for SNS”, Report LA-CP-98-156, Los Alamos (1998).

[4] S.S. Kurennoy, In Proceed. ICAP98, Monterey, CA, 1998; Report LA-UR-98-5344, Los Alamos (1998).