MEANDER-LINE CURRENT STRUCTURE DEVELOPMENT FOR SNS FAST CHOPPER

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Abstract

A new current structure for the fast traveling-wave 2.5-MeV beam chopper in the front end of the Spallation Neutron Source (SNS) has been suggested in [1]. The structure is based on the meander-folded notched stripline with dielectric supports and separators. Its design has been optimized using electromagnetic 3-D modeling with the MAFIA code package to provide rise and fall times in the range of 1 to 2 ns. A full-length (50 cm) prototype has been manufactured, and its preliminary measurements showed a good agreement with the calculations. Detailed measurements results and their comparison with simulations are presented. The latest front-end design requires a shorter, 35-cm chopper with a higher pulse voltage. Its meander-line current structure, based on the same principles, has also been optimized with MAFIA.

1 INTRODUCTION

The SNS is a next-generation pulsed spallation neutron source designed to deliver 2 MW of beam power on the target at 60 Hz [2]. Its 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, 1 ms) using H^- injection through a carbon foil. The beam injected into the ring is stacked into a single long bunch. The linac macropulse must be chopped at the ring revolution frequency, around 1 MHz, to provide a gap required for the ring 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.

The MEBT transports 52 mA of peak beam current from a 2.5-MeV 402.5-MHz RFQ to a drift-tube linac. The traveling-wave MEBT chopper has to fill the space between its two mirror-symmetric current structures, one carrying a positive and one negative voltage pulse, with a wave of the deflecting electric field propagating along the beam path at the same speed as the beam does, v=0.073c. This is achieved by sending the wave along the meander-folded transmission line. The initial requirement for the MEBT 50-cm long chopper was to provide the rise and fall time below 2.5 ns to avoid partially-chopped bunches. Simulations [3,1] with MAFIA [4] have shown that the suggested meander-line structure can provide the rise and fall time in the 1-ns range. The main difficulty to achieve a short chopper rise time is not with the structure itself, but rather with the pulse generator.

Since then, beam dynamics simulations have shown that partially-chopped bunches will not lead to extra beam loss in the linac or the ring transfer line. In the most recent MEBT design the chopper length has been reduced to 35 cm, and the inter-plate gap increased from 15 to 18 mm. A shorter chopper improves the MEBT beam dynamics. The requirement for the pulser voltage was changed from 1.5 to 2.35 kV with a slower rise and fall time, below 10 ns, thus allowing up to 3 partially-chopped bunches in the beginning and the end of each chopper pulse, which lasts around 300 ns.

Nevertheless, a 50-cm prototype of the structure has already been manufactured, and we had it available for the measurements. Obviously, the performance of a 35-cm current structure can only be better than that of the longer prototype, and its manufacturing is easier. In Sect. 2 we describe the meander-folded notched stripline structure. Section 3 contains results of the measurements.

2 MEANDER CURRENT STRUCTURE

A general and close-up view photographs of the 50-cm prototype meander-line current structure are presented in Fig. 1. Details of the structure can be better seen in Fig. 2.

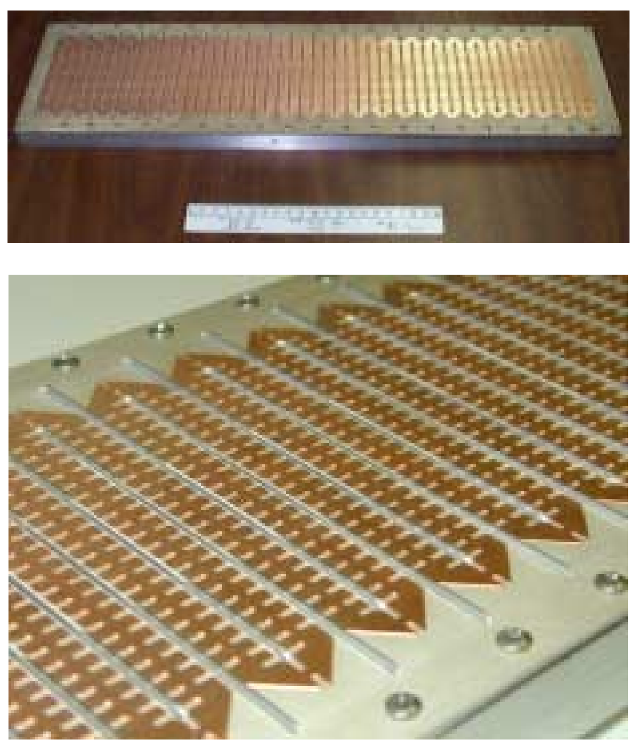

Figure 1: The 50-cm prototype current structure.

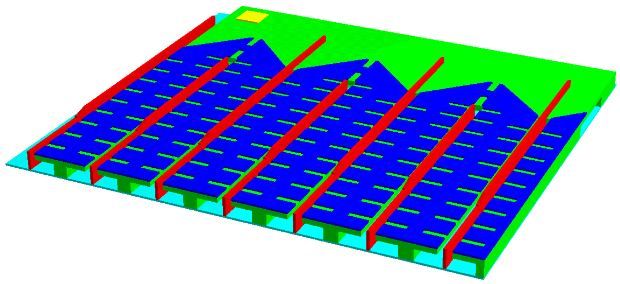

Figure 2: A part of the MAFIA model: notched metal meander strip (dark-blue) on dielectric supports (green), metal separators (red) are connected to the ground plate (light-blue, below). Compare Fig. 1.

Figure 2 shows a piece of the full-length 3-D MAFIA model [1] used to calculate and optimize the structure. The notched meander line is supported by a T-shaped dielectric support that goes all along the stripline length. The T-support and the wide side supports are carved from a continuous dielectric plate of Rogers' duroid RT/6002. The notched meander line pattern is chemically etched on the copper coating of the dielectric plate. The copper thickness in the transmission line is 0.25 mm, and the dielectric thickness is 2.5 mm. The metal width in the line is 8 mm, and the meander period is 1 cm; it leaves 2-mm gaps between the straight strips. The grounded metal separators protrude into these gaps through the narrow cuts in the dielectric to reduce the coupling between adjacent pieces of the meander line. The notches on the line serve to slow down the TEM wave along the line straight sections to 0.68*c*. The notches are 3-mm deep and 1-mm wide, and their period is 4 mm. The wave phase velocity along the beam can be adjusted to 0.073*c* by choosing the meander width in the direction transverse to the beam. This width is 98 mm in our case.

The whole structure is clamped by bolts near its sides to the metal ground plate. In the process of manufacturing it was decided to glue the dielectric supports to the ground plate with a special epoxy to provide the required flatness of the meander line. Mechanical measurements show that the meander line is flat within ±1.25 μm along the beam line. The structure is mechanically stable and reasonably easy to manufacture.

The rise and fall times of the deflecting field (due to the current structure itself) has to be in the 1-ns range, according to the MAFIA simulations [1,3,5]. The current structure should provide the wave phase velocity 0.073*c* along the beam path and the characteristic impedance of the line equal to 50 Ω.

3 MEASUREMENT RESULTS

Measurements of the prototype current structure have been performed using the time-domain reflectometer (TDR) HP54120A and, in the frequency domain, with the network analyzer HP8753D. The snapshots of the TDR screen in Fig. 3 show the response (output signals) of the structure to the input pulses with the fronts 0.5, 1, and 2 ns in transmission measurements. For the 2-ns front the overshoot of the output pulse has almost disappeared.

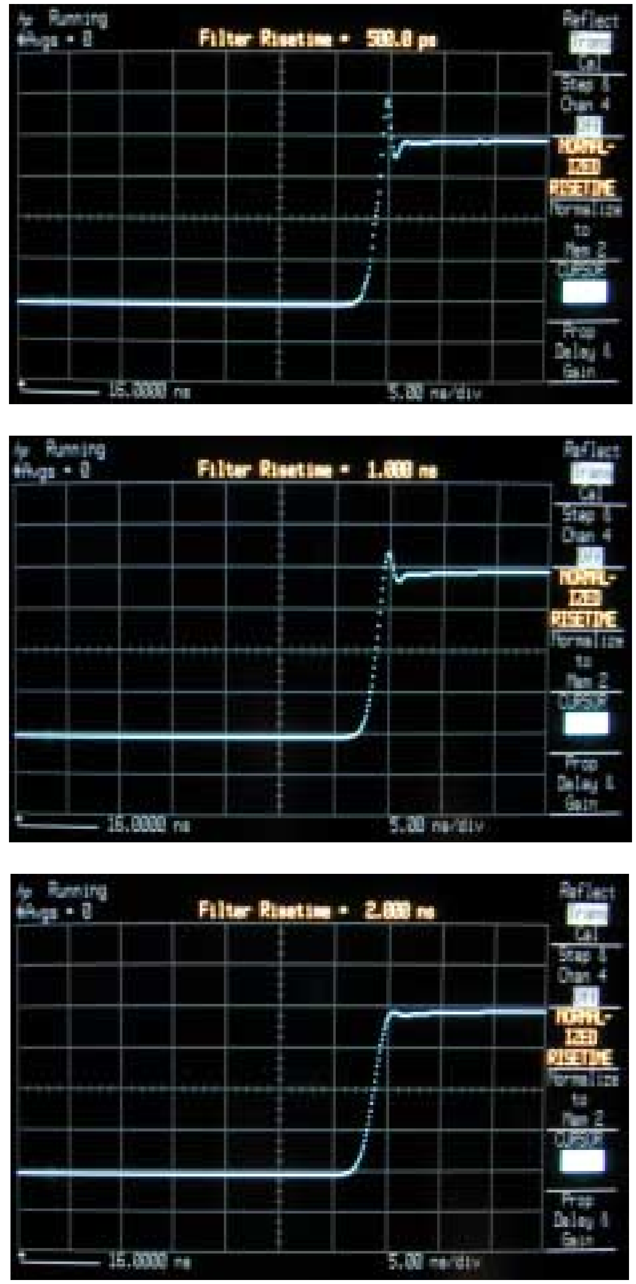

Figure 3: TDR transmission measurements using voltage pulses with fronts 0.5, 1, and 2 ns.

Overall, the measurements confirm that the rise and fall times of the deflecting pulse, due to the current structure itself, are close to 1 ns, and certainly below 2 ns, as was predicted by MAFIA calculations, see [5] for more details. The pulse propagation time through the structure was found to be 22.65 ns, which gives us the phase velocity along the beam line about 2% below the design value 0.073*c*. It will be adjusted in the final design by decreasing the meander width from 98 to 96 mm.

Figure 4 shows the reflection measurements with the TDR. The normalized trace (the lower one, blue) is very flat and shows the measured characteristic impedance 50.0 Ω with periodic variations along the structure no more than ±0.4 Ω, in a very good agreement with the calculations. The notch on the left side corresponds to the beginning of the structure, and the rise on the right shows its open end.

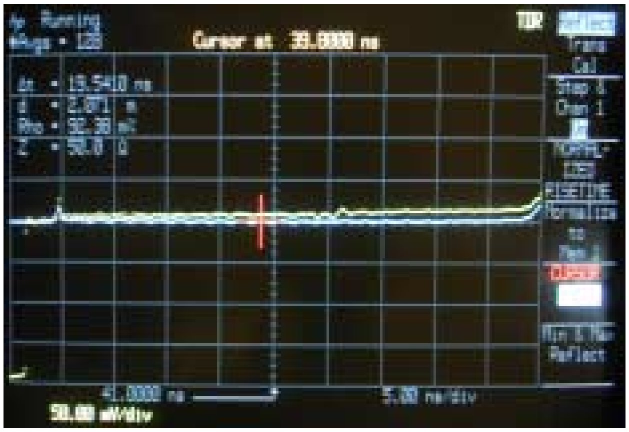

Figure 4: TDR reflection measurements.

Figure 5 presents S-parameter measurements with the network analyzer. It plots the amplitude of the transmission coefficient S_{21} versus the frequency. As one can see, the 3-dB range is close to 1 GHz, and even at 1.5 GHz the transmission losses are still less than 4 dB. Simple estimates show that in this frequency range the losses are dominated by the ohmic losses in copper, not in the dielectric substrate.

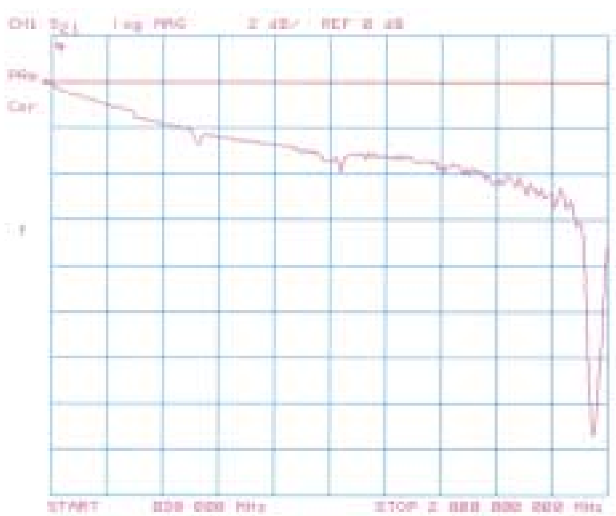

Figure 5: Amplitude of S_{21} parameter versus frequency.

The prototype structure was tested with a higher voltage, 1 kV, using a proof-of-principle pulser with the fall time near 8 ns. The output voltage of the pulser connected directly to HV attenuators and an oscilloscope, and that in the case when the current structure has been inserted between the pulser and the attenuators, are almost identical. The only noticeable effect was a slight change in the ringing following the pulse.

The final 35-cm current structure for the MEBT chopper is being manufactured now. The meander width was reduced to 96 mm. Figure 6 shows a 3-D CAD drawing of the current plate assembly: the meander line on the dielectric substrate, the ground plate with separators, and scrapers on its both ends.

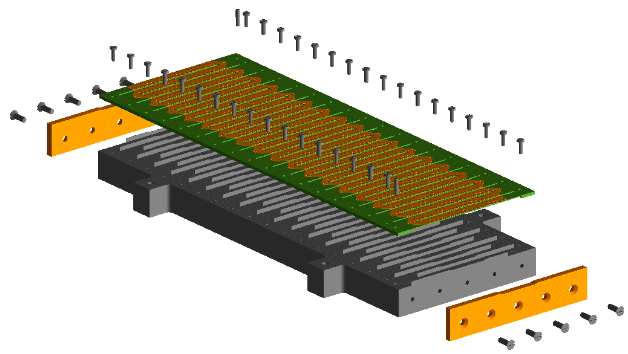

Figure 6: Exploded view of the 35-cm current structure assembly (courtesy of R.J. Roybal, LANSCE-1)

4 SUMMARY

Measurements of the electromagnetic properties of the 50-cm prototype meander-line current structure for the SNS MEBT fast chopper give the results in a good agreement with predictions from electromagnetic MAFIA modeling of the structure. The only change made in the final design of the shorter current structure was a small reduction of the meander width. Some additional tests of the prototype structure, like vacuum and radiation ones, are planned in the nearest future. Overall, we are quite satisfied with the results, and believe that this kind of the traveling-wave chopper structure can be useful for other projects where very fast rise and fall times are important.

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