DEVELOPMENT OF MEANDER-LINE CURRENT STRUCTURE FOR SNS FAST 2.5-MEV 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 developed [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 MAFIA to provide rise and fall times around 1 ns. A full-length 50-cm prototype has been manufactured, and its measurements have been performed. Measurements results and their comparison with simulations are presented.

1 INTRODUCTION

The SNS will be a next-generation pulsed spallation neutron source designed to deliver 2 MW of beam power on the target at 60 Hz [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, around 1.04 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. For more detail on the chopper function and requirements, see [1].

The MEBT transports 56 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 design requirement for the MEBT chopper was to provide the rise and fall time below 2.5 ns to avoid partially-chopped bunches. Electromagnetic simulations [3,1] with the MAFIA code package [4] have shown that the suggested meander-line structure can provide the rise 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. That is why it was decided to have a rather long chopper, 0.5 m, and work with a fastest possible FET pulse generator, providing a voltage up to 1.5 kV at the required high repetition rate. This combination would produce the beam deflection of 18 mrad for a 15-mm gap between the two chopper current plates. Since then, beam dynamics simulations have convinced us that partially-chopped bunches will not lead to extra beam loss in the linac or the ring transfer line. In the most recent MEBT version the chopper length has been reduced to 0.35 m, and the inter-plate gap increased to 18 mm. A shorter chopper improves the MEBT beam dynamics. The requirement for the pulser was changed 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 shortly describe the meander-folded notched stripline structure, its parameters and manufacturing. Section 3 contains results of the measurements.

2 MEANDER CURRENT STRUCTURE

The current structure design should provide the proper wave phase velocity (β=0.073) along the beam path 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. The structure should be mechanically stable and reasonably easy to manufacture. These requirements lead us to the design [1] illustrated by Fig. 1.

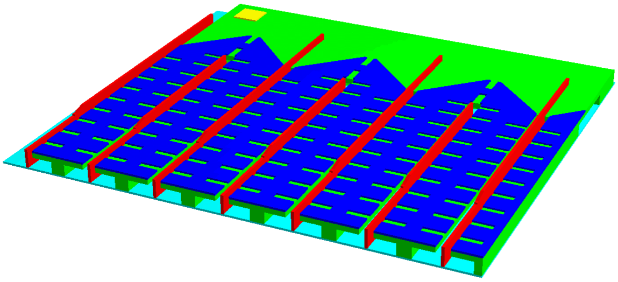

Figure 1: A part of the meander structure model: notched metal meander strip (dark-blue) on dielectric supports (green), metal separators (red) are connected to the ground plate (light-blue, below).

It shows a piece of the full-length 3-D MAFIA model used to calculate and optimize the structure parameters. 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, see in [1]. Before that, 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, 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 0.68c, see [1]. The notches are 3-mm deep and 1-mm wide, and their period is 4 mm. The wave phase velocity along the beam is adjusted to be 0.073c 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. A photograph of the 50-cm prototype current structure is shown in Fig. 2.

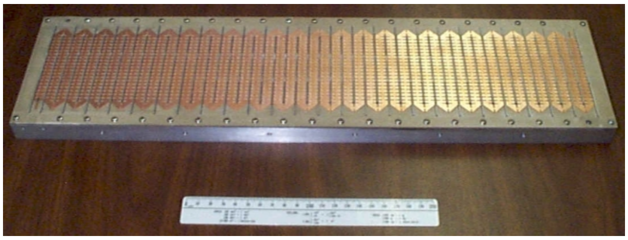

Figure 2: The 50-cm prototype current structure.

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. One can see that for the 2-ns front the overshoot of the output pulse has almost disappeared. MAFIA simulations predict slightly higher overshoots in all cases, as shown in Fig. 4 for the pulses with sin^2-fronts of 0.5, 1, and 2 ns. This should be expected since our simulations do not take into account losses, and high frequencies in measurements are filtered out. 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 [1].

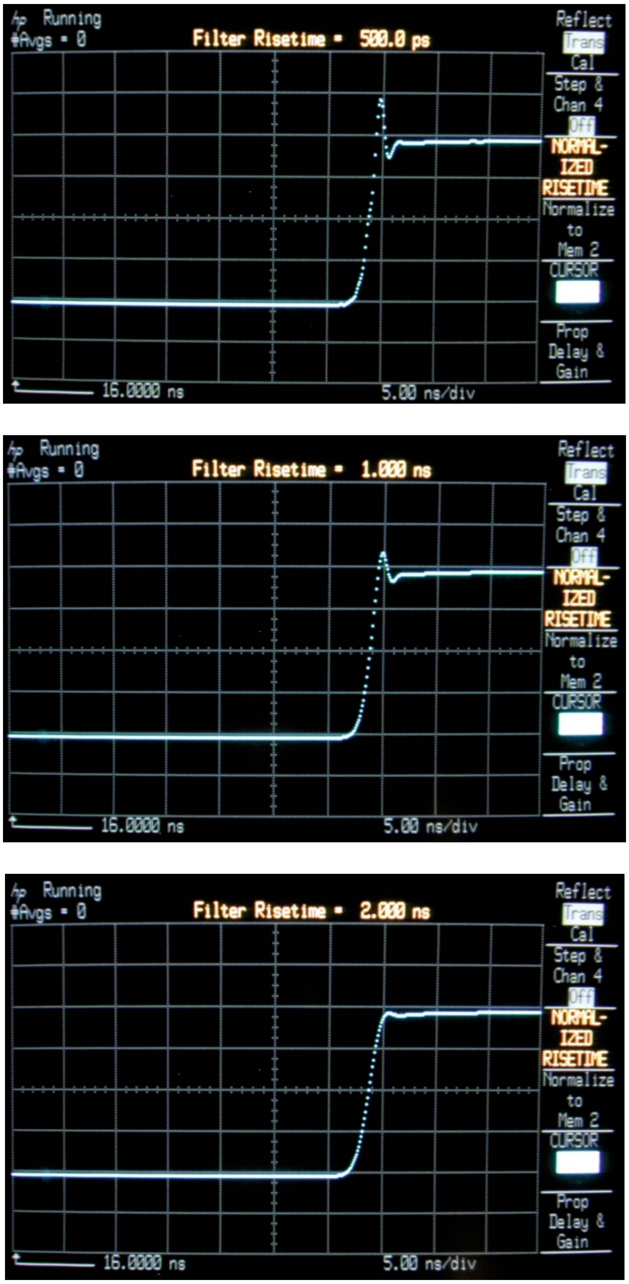

Figure 3: TDR transmission measurements using voltage pulses with fronts 0.5, 1, and 2 ns.

The pulse propagation time through the structure was found to be slightly below 23 ns. It gives us the phase velocity along the beam line within a couple of percent of the design value of 0.073c.

Figure 5 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.

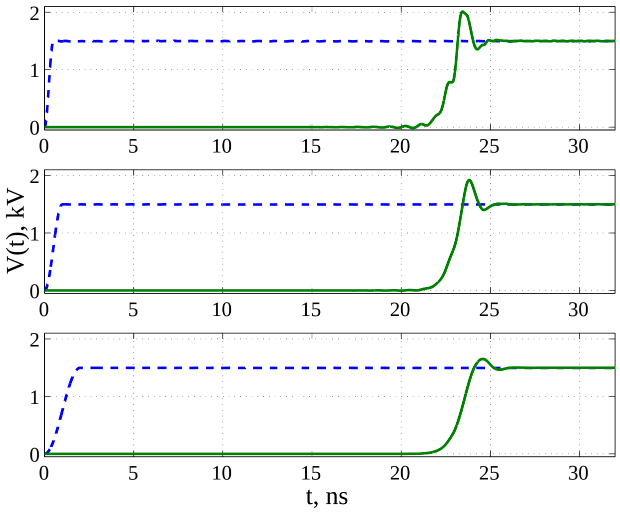

Figure 4: MAFIA results: input (dashed) and output voltages for the pulses with fronts 0.5, 1, and 2 ns.

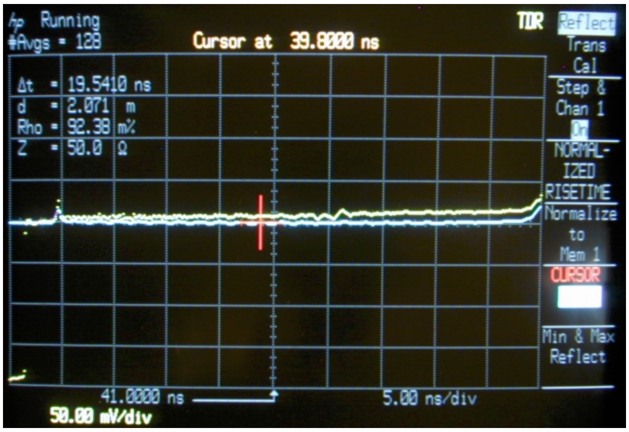

Figure 5: TDR reflection measurements.

Figure 6 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 by the dielectric losses.

The 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.

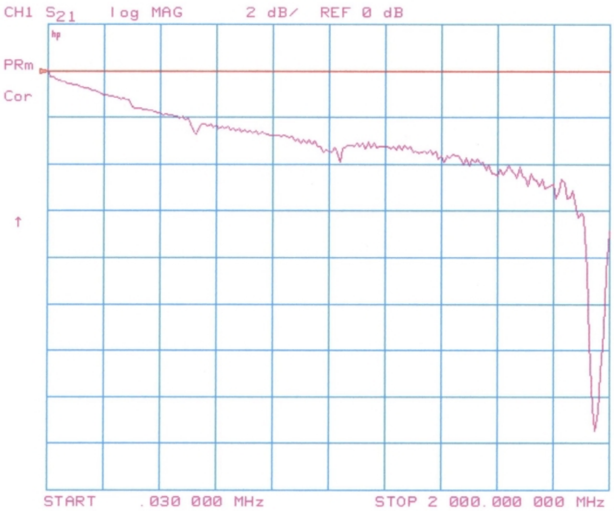

Figure 6: Amplitude of S_{21} parameter versus frequency.

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. Essentially, we can just use a shorter version of this prototype as our final chopper current structure. There are still some tests left that we would like to complete with the prototype, like vacuum and radiation ones, to check against any possible degradation of its performance. Nevertheless, 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.

The authors would like to thank D.L. Shrage, R.J. Roybal, and J.C. Mitchell for their efforts and contributions in mechanical engineering, design, and manufacturing of the prototype structure.

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