

CST MODELING OF TRAVELING-WAVE CHOPPER STRUCTURES FOR LANSCE AND LAMP*

S. S. Kurennoy[†]

Los Alamos National Laboratory, Los Alamos, NM, USA

Abstract

The Los Alamos Neutron Science Center (LANSCE) accelerator complex delivers both protons and negative hydrogen ions with various beam time patterns simultaneously to multiple users. An upgrade of its front end to a modern, RFQ-based version – a part of the LANSCE Accelerator Modernization Project (LAMP) – is now in the conceptual design stage. The LAMP will need fast beam choppers both in the low-energy transport (LEBT, 100 keV) before RFQ, and in the medium-energy transport (MEBT, 3 MeV) after RFQ. We use CST to model the existing LANSCE plate-coax helix chopper at 750 keV and to develop fast traveling-wave current structures for LAMP MEBT and LEBT beam choppers. A few structure types: plate-coax helix, meander-folded stripline on high-dielectric-constant substrate, and double-helix like at FNAL – are considered and compared. The structures must provide short rise/fall times of the deflecting electric field (1-ns class in MEBT), while still making it possible for the chopper pulse generators to deliver the required voltages at high repetition rates.

INTRODUCTION

Electromagnetic fast beam chopper systems consist of a deflecting structure, where the beam-deflecting fields are created, and a pulse generator (pulser) that feeds the structure with voltage pulses having a needed time pattern. Required fast switching on/off of the chopper deflecting fields can be achieved in traveling slow-wave chopper structures – two plates with voltage pulses of equal amplitude but opposite sign – where the deflecting field pulse propagates along the structure with the same velocity as the beam.

If a beam travels at velocity βc along the z -axis, and its deflection is in the y -direction (transverse to the structure plates), the deflecting Lorentz force per unit charge is $F_y / q = E_y + \beta Z_0 H_x$, where $Z_0 = \sqrt{\mu_0 / \epsilon_0} = 120\pi \Omega$. The maximal deflecting electric field is $E_{\max} = V/h$, where $\pm V$ are potentials applied to two plates and $2h$ is the distance between them. Normalizing the deflection force to E_{\max} , we define the chopper deflection efficiency $\eta = \eta_e - \eta_m$, where $\eta_e = E_y / E_{\max}$ is the electric efficiency and $\eta_m = -\beta Z_0 H_x / E_{\max}$ is the magnetic reduction [1, 2].

The main chopper parameters – length L and aperture $a = 2h$, plus required voltage from pulse generator V – are defined by beam dynamics design. The beam deflection angle α is related to these parameters as follows:

$$\alpha \cong \frac{q}{mc^2 \beta^2 \gamma} \frac{\eta \Delta V L}{a} \cong \frac{q}{2W} \frac{V_{\text{eff}} L}{a}, \quad (1)$$

where q and m are the charge and mass of beam particles (protons or H⁺), $\gamma = (1 - \beta^2)^{-1/2}$, η is the structure efficiency defined above, $\Delta V = 2V$ is the voltage between two plates, and effective voltage is $V_{\text{eff}} = \eta V$.

The chopper system rise and fall times depend on both system elements – structure and voltage pulse generator. If these elements have the rise/fall times t_s and t_p , correspondingly, the chopper rise/fall times can be estimated as $t_c = (t_s^2 + t_p^2)^{1/2}$. One more effect influences the chopper structure rise/fall time. Even if the voltage on chopper plates is turned on instantaneously, in the regions near the plate ends the fields vary from zero to maximal value – the edge effect. If a beam travels at velocity βc through these edge regions in the structure with aperture a , it effectively experiences field change that is equivalent to rise/fall time $t_e \approx a/\beta c$ [2]. This effect can be noticeable in LEBT, where the beam size is large while the velocity is low.

The traveling-wave chopper at LANSCE was designed for the proton beam at the energy of 750 keV and operates since the 1980s [3]. It is based on plate-coax (or strip-coax) helical slow-wave structure described in the next section.

The LAMP conceptual design continues to evolve. Unlike the description in the abstract, the LEBT chopper in the present version [4] was replaced by an electrostatic device, and the beam energy in the MEBT became 2.1 MeV ($\beta = 0.067$). CST models of the MEBT traveling-wave current structure were adjusted correspondingly.

LANSCE CHOPPER

The slow-wave structure – a helical delay line formed by parallel short sections of a metal stripline connected in series by semi-rigid 50- Ω coaxial cables (UT250A) under the ground plate – was developed at LANSCE in the 1980s [3] to chop a continuous 750-keV beam ($\beta = 0.04$); see Fig. 1.

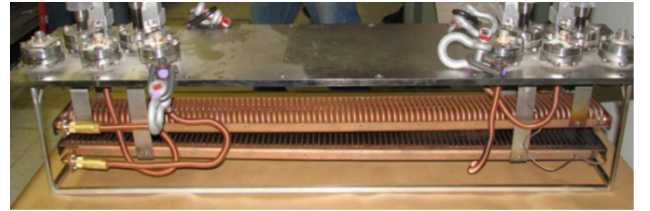


Figure 1: LANSCE chopper: two plates are tapered out downstream. Coaxial cables are visible on the top plate; the strips can be seen at the bottom one.

There are 97 periods of length 1.016 cm along the beam-line; the strip length is 8.407 cm, width 0.7925 cm. The beam aperture is large, with half-gap $h = 18$ mm, but the deflecting efficiency is high, $\eta = 0.96$. The rise/fall times of the structure itself are about 2 ns; the existing pulser at 700 V is much slower, with voltage rise and fall ~ 7 -10 ns.

* Work supported by the US Department of Energy.

[†] kurennoy@lanl.gov

We built a CST model of this strip-coax current structure using chopper drawings. The model is shown in Fig. 2 (top). Figure 2 (bottom) shows a snapshot of electric field produced by a short voltage pulse with 2-ns \sin^2 rise and fall and a 5-ns flattop at the time $t = 50$ ns from the start of pulse propagation.

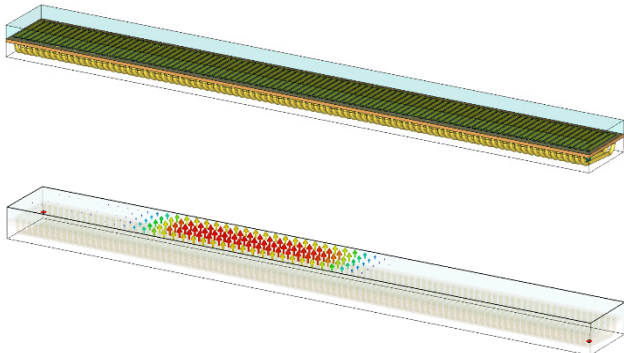


Figure 2: CST model of LANSCE strip-coax chopper current structure: (top) the lower chopper plate, light-blue box indicates a half of chopper aperture; (bottom) snapshot of deflecting electric field of pulse 2-5-2 ns at time $t = 50$ ns.

Figure 3 compares calculated and measured values of transmission parameter S21 for the chopper plate. Both show a well-resolved stopband around 600 MHz. However, S21 results calculated with values of the coax dielectric loss from CST material library and ideal copper conductivity $5.8e7$ Sm/m are noticeably higher than the measured ones. One possible reason is increased losses in coaxes, which served in radiation environments for many years. Increasing the dielectric loss and copper resistivity in simulations indeed reduces the difference.

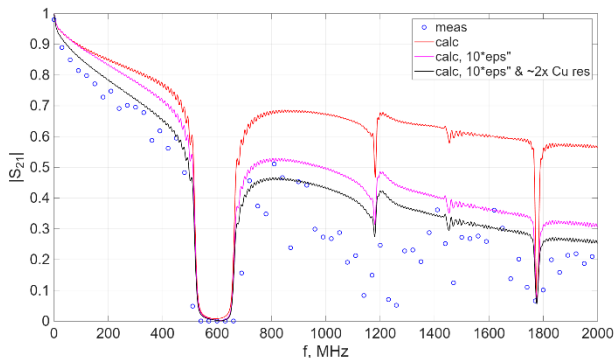


Figure 3: Calculated and measured values of S21 for the LANSCE chopper structure; see legend in the plot.

LAMP MEBT CHOPPER

The current LAMP design [4] defines the main parameters of the MEBT chopper: $\beta = 0.067$, length $L = 55$ cm, aperture $a = 2.2$ cm, and the pulser voltage $V = 1.5$ kV with the rise/fall times of 3 ns. One simple solution – meander-folded 50- Ω stripline on solid high-purity alumina substrate on top of a grounded metal plate – was considered in Ref. [5]. Such a structure provides 2.5-ns rise/fall times, but its efficiency (in 3-MeV version) was low, $\eta = 0.82$, which would require an increased pulser voltage.

Strip-Coax 50- Ω Structure

A strip-coax structure similar to the LANSCE chopper can serve as a LAMP MEBT chopper if the strips and coaxes are shortened to increase the pulse phase velocity along the beam path. Figure 4 shows a CST model of the strip-coax chopper structure adjusted for LAMP MEBT parameters. It has 55 periods and the strip length is reduced to 4.7 cm to match the beam velocity $\beta = 0.067$.

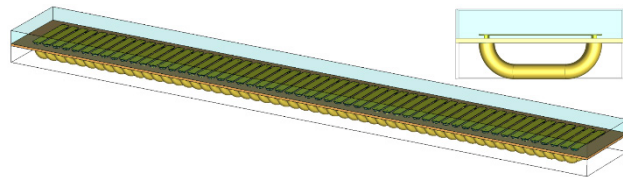


Figure 4: CST model of LAMP MEBT strip-coax chopper structure. The inset shows the end view.

The calculated transmission and reflection signals are plotted in Fig. 5 for the input signal that consists of two pulses with 3-ns \sin^2 rise and fall and a 20-ns flattop (3-20-3 ns) separated by 2 ns. Such a double-pulse voltage will be applied to remove satellite bunches before and after the main high-charge bunch coming out of the LAMP RFQ. One can see reflections and ripples in the output pulse at the level of 1-2% after the voltage rise and after the pulse. By coincidence, the output signal of the first pulse in Fig. 5 almost overlaps with the second input pulse, so the pulse shape comparison is easy.

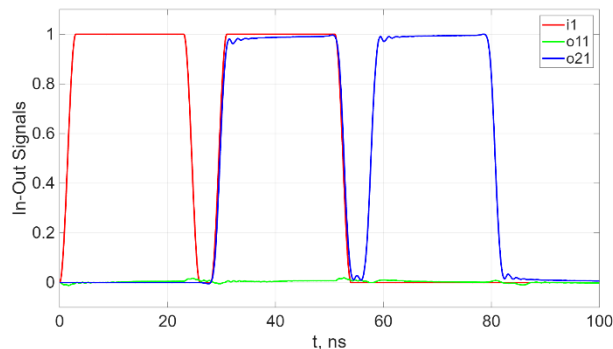


Figure 5: Calculated signals in the LAMP MEBT strip-coax chopper structure with double-pulse input (red).

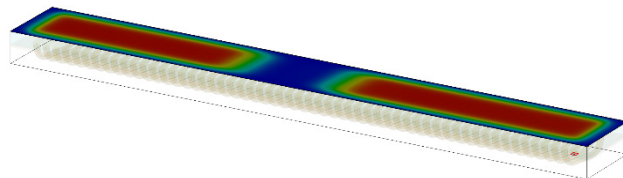


Figure 6: Contours of deflecting electric field in the beam plane of the LAMP MEBT strip-coax chopper at $t = 40$ ns.

Pulse distortions in the deflecting electric fields recorded by CST field probes placed along the beam path are even smaller. Figure 6 shows a snapshot of the deflecting electric field in the beam plane at the time $t = 40$ ns when the gap between two pulses reaches the middle of the structure length. The maximum deflecting electric field (red) in Fig. 6 is 132.7 kV/m for the 1.5 kV pulser voltage.

The structure rise/fall times are estimated to be around 2.5 ns. Even with the large aperture of 2.2 cm, the structure deflecting efficiency remains high, $\eta = 0.96$. However, to provide high switching rates, up to 1.12 MHz in bursts, a 200- Ω chopper structure is preferable.

Double-Helix 200- Ω Structure

A 200- Ω dual-helix chopper structure was developed at FNAL [6] for 2.1-MeV beam ($\beta = 0.067$). The structure had risetime ~ 2.5 ns, small aperture of 1.6 cm, and high efficiency. The 200- Ω line impedance makes it easier for the voltage pulser to provide high repetition rates of pulses. We built a CST model of the structure to adjust its parameters for the LAMP MEBT. The model is shown in Fig. 7. Flat copper wire of cross section 2.667×1.067 mm² is wound with pitch 10.465 mm around a grounded copper cylinder (tube) of diameter 28.346 mm. The helix wire is supported by four ceramic spacers shown in grey. The helix has 54 periods. Rectangular electrode plates 7.62×20 mm² are connected to 52 of them. For two end periods without electrodes the ground tube diameter is reduced to minimize line impedance mismatch.

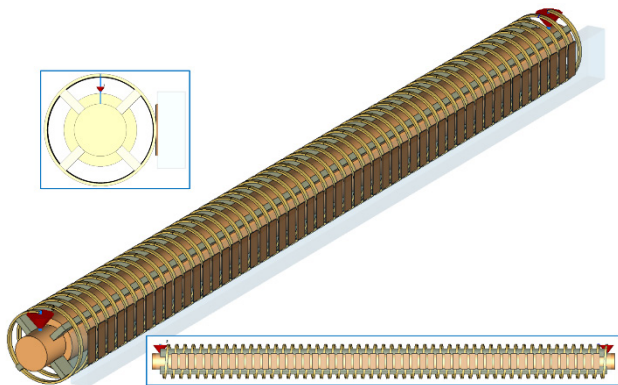


Figure 7: CST model of LAMP MEBT helix chopper structure. The right half is shown, with light-blue box indicating a half of chopper aperture. Insets show end and side view.

The calculated transmission and reflection signals are plotted in Fig. 8. One can notice that output pulse distortions in this structure are larger compared to those in Fig. 5, reaching up to 5%.

Figure 9 shows a snapshot of the deflecting electric field in the beam plane of the helix chopper at the time $t = 40$ ns when the gap between two pulses reaches the middle of the structure length. It should be compared with Fig. 6 for the strip-coax version of the chopper. The maximum deflecting electric field (red) in Fig. 9 is 135.2 kV/m for the 1.5 kV pulser voltage, slightly higher than in Fig. 6 for the strip-coax chopper, due to larger pulse overshoots.

We estimate the rise/fall times of the helix chopper structure to be around 3 ns. The calculated structure deflecting efficiency is high, $\eta = 0.945$. The magnetic reduction in this case is larger, $\eta_m = 3e-3$, compared to the strip-coax structure, where it is very small, $\eta_m = 1e-4$.

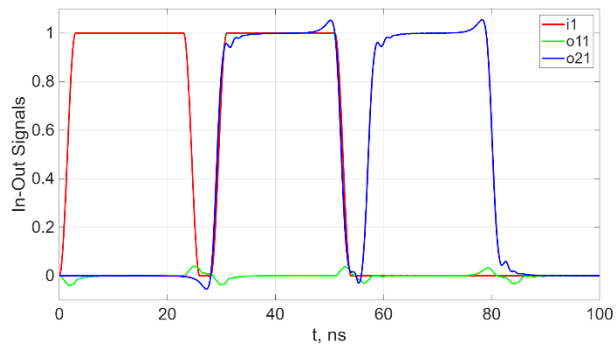


Figure 8: Calculated signals in the LAMP MEBT helix chopper structure with double-pulse input (red).

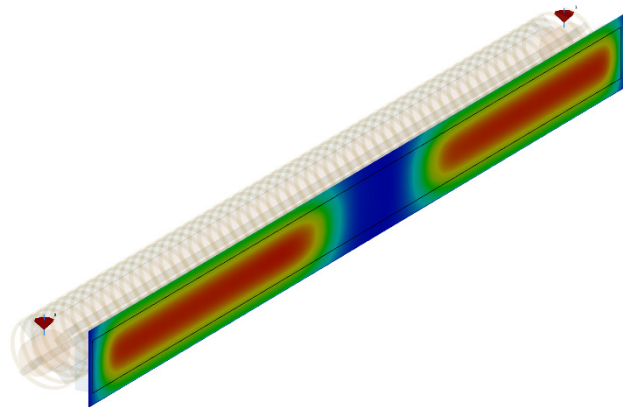


Figure 9: Contours of deflecting electric field in the beam plane of the LAMP MEBT helix chopper at time $t = 40$ ns.

CONCLUSION

We modeled traveling-wave current structures for fast beam choppers considering strip-coax and helix designs. A simple alternative version – meander-folded stripline on high-dielectric-constant substrate – was considered [5]; it is not included here because of lower deflecting efficiency.

The strip-coax helix structure of the existing LANSCE chopper [3] is modeled in CST. The calculated S-parameters agree with the measurements when idealized material losses are increased to reflect realistic material conditions.

Strip-coax structures pioneered in the LANSCE chopper can be used for the LAMP MEBT choppers with adjusted parameters. CST modeling confirms the high efficiency, with $\eta = 0.96$, and rise/fall times of about 2.5 ns.

The dual-helix structure developed at FNAL [6] is adjusted for the LAMP MEBT chopper. Its main advantage is 200- Ω line impedance that makes it easier for the pulser to achieve high pulse repetition rates. CST calculations indicate good deflecting efficiency $\eta = 0.945$ and acceptable rise/fall times around 3 ns.

The MEBT pulser design remains challenging. This is caused not only by the required short rise/fall times, but also by the high voltage needed, and especially by the high pulse repetition rate.

The author is grateful to the AOT-AE pulsed power team for S-parameter measurements of the LANSCE chopper.

REFERENCES

- [1] S. S. Kurennoy, “Ceramic-supported traveling-wave structures for SNS fast beam chopper”, in *Proc. PAC07*, Albuquerque, NM, USA, 2007, MOPAS049, pp. 545-547.
- [2] A. V. Aleksandrov, “Overview and future demands of fast choppers”, in *Proc. LINAC2010*, Tsukuba, Japan, 2010, WE104, pp. 689-693.
- [3] J. S. Lundsford and R. A. Hardekopf, “Pulsed beam chopper for the PSR at LANSCE”, *IEEE Trans. NS-30*, 2830 (1983).
- [4] S. Sosa Guitron *et al.*, “Error and sensitivity studies for LANSCE Accelerator Modernization Project”, presented at IPAC’26, Deauville, France, May 2026, paper WEP4331, this conference.
- [5] S. S. Kurennoy, “Traveling-wave chopper structures for LANSCE Modernization Project”, in *Proc. NAPAC25*, Sacramento, CA, USA, 2025, pp. 1136-1139.
[doi:10.18429/jacow-napac2025-thp089](https://doi.org/10.18429/jacow-napac2025-thp089)
- [6] G. Saewert *et al.*, “First performance results of the PIP2IT 200 Ohm kicker prototype”, in *Proc. IPAC’2018*, Vancouver, BC, Canada, May 2018, pp. 2724-2726.
[doi:10.18429/JACoW-IPAC2018-WEPML021](https://doi.org/10.18429/JACoW-IPAC2018-WEPML021)