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FAST CHOPPER STRUCTURE FOR THE CERN SUPERCONDUCTING PROTON LINAC

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Abstract

The SPL chopper is a travelling wave device, which deflects a slow beam (β = v/c = 0.08) by its transverse electric field. We discuss the chopper deflecting structure based on a meander line printed on an alumina substrate. This concept profits from the radiation resistance of alumina, its excellent out-gassing properties and its good thermal conductivity. The use of well established MIC (microwave integrated circuit) thick film technology allows easy implementation of prototypes; the thickness of the printed layer should be increased by means of an electrochemical deposition method. The topology of the structure has been chosen from standard MIC layouts and was subsequently optimized using numerical simulations. Several prototypes have been manufactured and measurements have shown encouraging results.

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The SPL chopper is a travelling wave device, which deflects a slow beam (β = v/c = 0.08) by its transverse electric field. We discuss the chopper deflecting structure based on a meander line printed on an alumina substrate. This concept profits from the radiation resistance of alumina, its excellent out-gassing properties and its good thermal conductivity. The use of well established MIC (microwave integrated circuit) thick film technology allows easy implementation of prototypes; the thickness of the printed layer should be increased by means of an electrochemical deposition method. The topology of the structure has been chosen from standard MIC layouts and was subsequently optimized using numerical simulations. Several prototypes have been manufactured and measurements have shown encouraging results.

1 Introduction

Meander type deflecting structures have been proposed and used in fast kickers for beams with low β values [1]. Such structures are forward coupling devices in contrast to the well-known quarter wavelength strip-lines, which are frequently applied for beams with β-values close to 1, and then act as backward couplers. Previously discussed meander structures used low dielectric constant substrates and separating ridges to reduce the coupling between adjacent lines. Considerable lateral dimensions of such a design prevent the chopper being inside focusing magnets, which would be a big advantage for beam dynamics.

2 Motivation

A new type of chopper deflector should meet as many as possible of the following requirements:
- below 2 ns rise-time (10-90%) with 50 cm length, acceptable loss and dispersion;
- very good impedance match to avoid kicking bunches by a reflected wave;
- reasonable field homogeneity over the beam volume (not too critical as we need just a minimum kick and not a precision kick);
- insensitivity of characteristic impedance with respect to variation of the chopper aperture;
- mechanical stability, radiation hardness, low out-gassing, easy production, and good heat transfer to water-cooled ground plane;
- possibility of high characteristic impedance (reduces requirements on the driver power);
- small lateral dimensions and no separating ridges

Obviously some of these requirements do not apply to all machines where the use of choppers is envisaged, but here we discuss a version that would be suitable for the CERN SPL (Superconducting Proton Linac, which is in reality an H^- accelerating structure).

3 Implementation

3.1 Topology

The proposed topology is shown in Fig 1. For a 50 Ω system the parameters of this double meander structure have been calculated in a first approach using a semi-analytical technique. The width of the (thin) 100 Ω lines is 0.45 mm and the length of the elementary cell amounts to 6 mm; the lateral extension is 42.5 mm. The beam direction here: $\Downarrow$ or $\Uparrow$, above the wide metal strips, horizontally in the centre of the double meander shown below

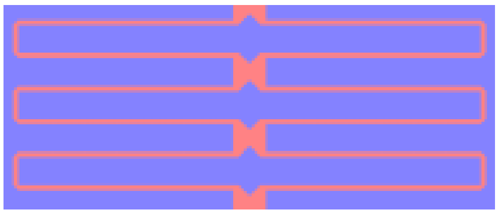

Figure 1: Basic layout of a double 100 Ω meander type deflector. Metal pattern is shown in red.

The free parameters for this kind of design are:
- length of the elementary cell (period) in beam direction. Short lengths increase the coupling between adjacent cells and the nonlinear phase-shift vs frequency (dispersion).
- the lateral width of the structure. For a given β value a certain delay per unit cell must be provided in order to maintain synchronism with the beam, while the spacing between adjacent micro-strip lines cannot be made too small to keep the dispersion within reasonable limits.
- the field coverage factor defined as the ratio of the deflecting electric field on the beam path to that for the case when a continuous metal plate replaces the meander pattern; see in Sect. 5.

The idea of the new layout was to bring as much as possible distributed inductance into a meander structure without using separating ridges. Such ridges would be very hard to implement for a ceramic substrate. Typical values for the effective dielectric constant ε of a 50 Ω

micro-strip line on alumina are about 6.5 and close to 6.0 for a 100 Ω line [2]. Alumina itself has an ε value of 9.8. We are basically interested to lower the group velocity in this deflector by a reasonable compromise between inductive and capacitive loading. This has led to the concept of putting two 100 Ω meanders in parallel in order to form a 50 Ω line. Using graphs and formulae available in [2], and based on previous experience with large size MICs used for the stochastic cooling system combiner boards in the CERN antiproton collector (AC), an alumina substrate thickness of 3 mm was chosen. Thinner substrates would lead to a significant increase in conductor losses, and thicker ones are more prone to radiation (waveguide mode coupling) and stronger mutual coupling for the same elementary cell length. A picture of one of the prototypes, including the coaxial/strip-line transition with SMA connectors, is shown in Fig 2.

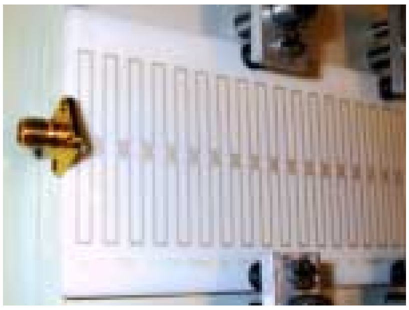

Figure 2: Double meander pattern on the alumina substrate with transition to a coaxial line.

3.2 Technology

There are two basic techniques for the implementation of MICs, namely thick film and thin film technology. In our case we have decided to use thick film, as it allows easier enhancement of conductor thickness by electrochemical deposition of silver. Despite the name "thick film" the layer is not really very thick (around 10-15 micron after firing) and requires additional metal added to reach up to about 50 μm. However there are a few technological precautions and rules to observe. Due to the large substrate size (up to 50 cm long) the usual firing procedure of about 30 minutes including warm-up to 800°C and cool-down cannot be permitted. A practical value is a heating/cooling rate of 100 °C per hour to keep thermal stress in the alumina within reasonable limits. This requires the selection of thick film paints, which can stand the largely extended exposure time to high temperatures in air (firing in air is mandatory to allow the formation of metal oxides). A second condition to be met is the subsequent exposure of the fired substrate to aggressive acids in the chemical bath. Certain conductor paints, which are good for extended heat exposure are dissolved by these acids and thus cannot be used. The necessity of electrochemical deposition has been shown in a first 19.2 cm long prototype (double meander, 50Ω), which had a DC resistance of slightly more than 4 Ω over this length. This is to be compared with 1.3 Ω for a 50 cm long double meander with additional 20-30 microns of silver. Note that the 10-15 microns of the fired silver paint do not at all reach the bulk conductivity of pure silver, but rather one order of magnitude lower. Another aspect is the admissible DC current density in the narrow 100 Ω strips. For certain driver or amplifier designs it may be interesting to let the complete anode DC current pass though the chopper structure and it may reach a value of about 10 A.

The rear side of the alumina substrate is NOT metallized in order to avoid undefined contacts with the massive metallic (aluminum) ground plane. This ground-plane will be water-cooled to remove heat from ohmic losses as well as from particle losses in the structure. Such particle losses were estimated to reach values of several 10 Watts. The average ohmic losses should be below 50 Watt for SPL operating parameters. The alumina substrate as well as the ground plane will have very tightly machined surfaces with less than 10 micron unevenness leading to a maximum gap of 20 micron. A worst case 20 micron "air" gap together with a 3 mm alumina thickness leads to a change in effective ε well below 1%. The ceramic substrate is pressed against the ground plane with strong springs, which assures a good thermal contact (similar to a domestic cooking vessel on a glass–ceramic plate). Depending on the construction concept used for the driver [3] the ground-plane may be kept wrt DC in order to simplify the combination of high and low frequency spectral components for the beam. Assuming a maximum voltage of 500 V between the conductors and ground, the maximum field-strength in the air-gap should not exceed roughly 1.7 kV/mm, which should not lead to problems. As for the coaxial/micro-strip transition, obviously one would not take a simple SMA connector as shown in Fig 2, but instead a (not easy to find) version without any organic material.

4 Measurements

Apart from the DC resistance of the meander mentioned above, the really significant information is in frequency-dependent transmission and reflection properties of the structure. Critical parameters are the characteristic impedance, transmission losses and dispersion, as well as homogeneity of the structure over the length. Fig. 3 shows the attenuation ($=|S_{21}|$) for the 20 and 50 cm long structures, and Fig. 4 gives the nonlinear phase-shift (dispersion). It turned out that this nonlinear phase-shift is the main source of pulse distortion and may require further optimisation.

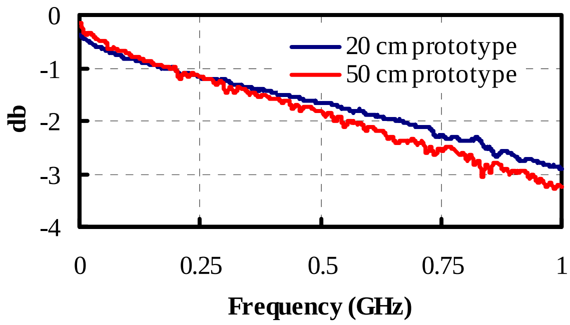

Figure 3: Measured attenuation vs frequency for a 50 cm long meander silver-coated on alumina in comparison with an uncoated 20 cm (19.2 cm exactly) prototype.

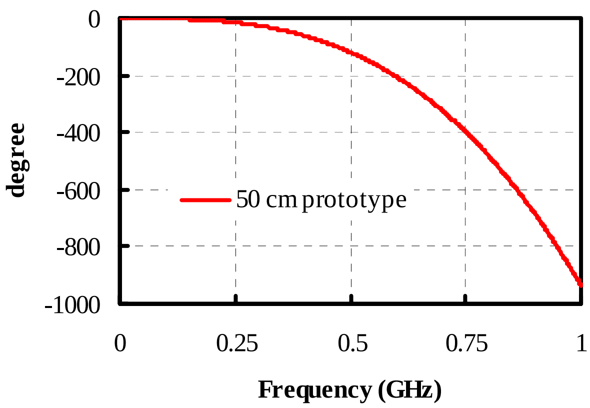

Figure 4: Measured nonlinear phase shift vs frequency for a 50 cm long meander on alumina; unwrapped phase, electrical delay = 21 ns.

The measured characteristic impedance is slightly too low (about 46 Ω). This is believed to be related to an increase in effective strip width by the electrochemical deposition process and can be compensated in a next iteration.

5 Simulations

Numerical simulations have been done using Microwave Studio (MWS) and MAFIA [4]. The time-domain simulations give results in agreement with measurements: the S-parameters, the pulse delay of about 21 ns for a 50-cm meander, and about 46 Ω for the input port impedance. Calculated S-parameters also indicate the first noticeable resonance of the structure at 1.65 GHz. As an example, Fig. 5 shows the evolution of a pulse with 2-ns rise and fall as it travels along the dispersive structure, computed with MWS. The plotted deflecting electric field on the beam path (10 mm above the structure) is normalized to the maximum field achievable in the same structure with a continuous metal surface (a flat capacitor), so that this ratio gives the field coverage factor directly. One can clearly see a growing overshoot vs distance, related to the different group delays.

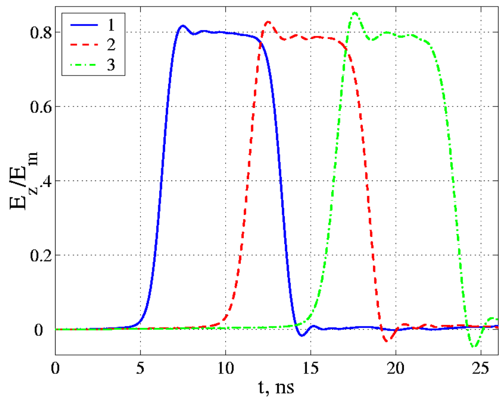

Figure 5: Pulse distortion for the 50-cm alumina meander at points ¼, ½, and ¾ of the length along the structure.

The field coverage factor has also been calculated independently with an electrostatic approach in MAFIA. For the 50 Ω meander, we obtain a peak value of 0.79 (cf. pulse flattop in Fig. 5) in the centre (compared to 0.89 for the spallation neutron source (SNS) [1] structure), and 0.74 for the 100 Ω meander on alumina.

6 Outlook and conclusion

The use of an alumina substrate and the new topology described here appears to be a competitive alternative to design concepts used so far. Since a kicker can also be used as a pick-up, the structure may serve for non destructive low β beam diagnostics with high time resolution.

The feasibility of the new type of meander as a chopper kicker has been demonstrated. It should be able to stand rather high thermal loads (electrical and radiation losses), has a low out-gassing rate and good radiation resistance, and also a reduced lateral width, in particular for the 100 Ω (single meander) version. Numerical simulations give us a good tool for the structure optimisation.

7 References

[1] S.S. Kurennoy, J.F. Power, “Development of meander line current structure for SNS 2.5-MeV beam chopper,” Proceed. EPAC, Vienna, 2000, p. 336.

[2] R.K. Hoffmann, “Integrierte Mikrowellen-Schaltungen,” Springer, 1983.

[3] M. Paoluzzi, “Design and Performance of a 500 V Pulse Amplifier for the Chopper on the CERN SPL,” this conference.

[4] CST GmbH, Darmstadt, Germany. http://www.cst.de