THE DEVELOPMENT OF A SLOW-WAVE CHOPPER STRUCTURE FOR NEXT GENERATION HIGH POWER PROTON DRIVERS

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Abstract

A description is given of the development of slow-wave chopper structures for the 3.0 MeV, 60 mA, H^- MEBT on the RAL Front-End Test Stand (FETS) [1]. Two candidate structures, the so called RAL 'Helical' and 'Planar' designs have been previously identified [2], and are being developed to the prototype stage. Three test assemblies have been designed by modelling their high frequency electromagnetic properties in the time domain, using a commercial 3D code [3], and their subsequent manufacture, using standard NC machining practice, has helped to validate the selection of machine-able ceramics and copper alloys. In addition, an electro-polishing technique has been developed that enables the 'fine tuning' of strip-line characteristic impedance, and edge radius. Measurements of the transmission line properties of the 'Helical' and 'Planar' test assemblies are presented.

INTRODUCTION

Proton driver specifications for the next generation of spallation neutron sources, neutrino factories, and waste transmutation plants, call for more than an order of magnitude increase in beam power, typically from ~ 0.16 to ~ 5 MW [4]. During critical accelerator tuning procedures, and crucially for the ring based schemes at injection and extraction, beam loss and the consequent activation of components, can be minimised by a programmed population of longitudinal phase space, produced by 'chopping' the linac beam at low energy. The 'chopper' is required to produce precisely defined gaps in the bunched linac beam, and the chopping field must therefore rise and fall within, and be synchronous with, bunch intervals that are typically just a few nanoseconds in duration.

SLOW-WAVE ELECTRODE DESIGN

Slow-wave (E-field) transmission line structures have demonstrated field transition times in the nanosecond regime [5, 6], and chopping schemes utilising these structures have been described [7, 8]. The structures are designed with the aid of 3D high frequency (HF) field modelling codes, where the complex geometry, extended electrical length, and the effects of inter-electrode coupling set a practical limit on the computational accuracy of the broad-band properties. The basic features and function of the proposed slow-wave electrode structures are shown in Fig. 1, where partial chopping of beam bunches is avoided by ensuring that the deflecting E-field propagates at the beam bunch velocity.

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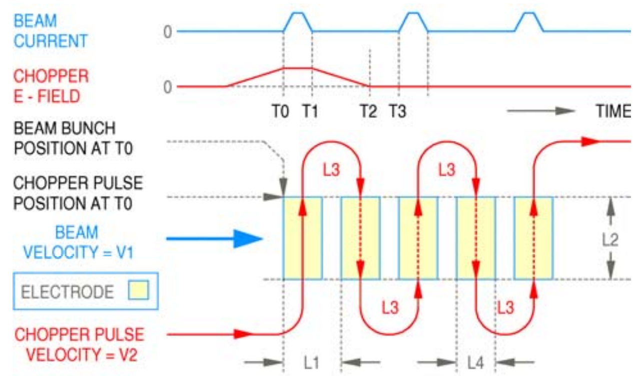

Figure 1: Slow-wave structure design.

In Fig. 1, where:
L1 is the cell length
L2 is the beam width (electrode transmission line length).
L3 is the delay loop transmission line length.
L4 is the electrode width.

Then for the generalised slow wave structure:
The maximum value for L1 = V1 (T3 - T1) / 2 (1)
The minimum Value for L1 = L2 (V1/ V2)

The relationships for field (E), and transverse displacement (x), where q is the electronic charge, ν is the beam velocity, m_0 is the rest mass, z is the effective electrode structure length, θ is the required deflection angle, V is the deflecting potential, and d is the electrode gap, are given by:

$$E = \tan\theta \cdot m_0 \cdot \frac{v^2}{q \cdot z}, \qquad E = \frac{V}{d}, \qquad x = \frac{q \cdot E \cdot z^2}{2 \cdot m_0 \cdot v^2}$$

For given values of m_0, ν, and V, large θ and x are obtained when z is large and d is small. In addition, the inter-electrode gap shown as L1 - L4 in Fig. 1 must be made significant, or alternatively a thin grounded shield must be inserted between adjacent strips, if pulse distortion due to inter-electrode coupling is to be minimised. In either case, for a given overall structure length, the effective electrode length (z) will be maximised, by setting L1 to the value shown in (1) above, and maximising the strip-line width, L4.

ELECTRODE STRUCTURES

The development of slow-wave electrode chopper structures at RAL [9] has been motivated by the perception that, with respect to the existing designs [5, 6], a significant improvement in field integral (coverage factor), transverse field uniformity, bandwidth, and mechanical / thermal stability, might be achievable. Two candidate structures, the so-called helical and planar

Table 1: FETS Slow-Wave Structure Parameters

H^- beam energy	3.0 MeV
Beam velocity	2.39032e7 m/s
Beam width / 100%	18 mm
Beam aperture	19 mm
Cell periodicity	19 mm
Stripline width / thickness	14 / 0.5 mm
Cell delay	0.794874 ns
Coverage factor: Centre / Edge	82 / 81 %
Characteristic impedance	~ 50 Ω
Bandwidth	0 – 500 MHz
Breakdown voltage	3 kV

designs have been previously identified [2], and their key parameters are shown in Table 1. Three preliminary test assemblies have been designed, and the manufacture of two of these assemblies has helped to verify the accuracy of the 3D high frequency (HF) field modelling code, investigate the properties of selected machine-able ceramics, the effect of dimensional tolerance on characteristic impedance, and the limitations of NC machining practice. The design and manufacture of the subsequent planar and helical 'short length' prototype structures, will build on the experience gained from the preliminary test assemblies, and should facilitate the choice of a candidate design for the full scale structure, as outlined in the development plan, shown in Fig. 2 .

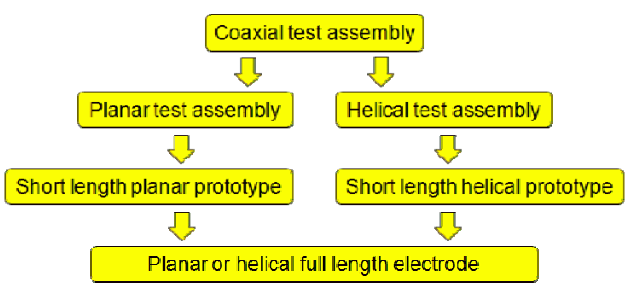

Figure 2: Development plan.

Coaxial Test Assembly

The coaxial to stripline transition is an important common component of the helical and planar structures. The helical structure, in particular, has many of these transitions, and therefore the design must have an excellent wideband transmission characteristic, mechanical and thermal stability, vacuum compatibility and radiation hardness. These requirements have been met

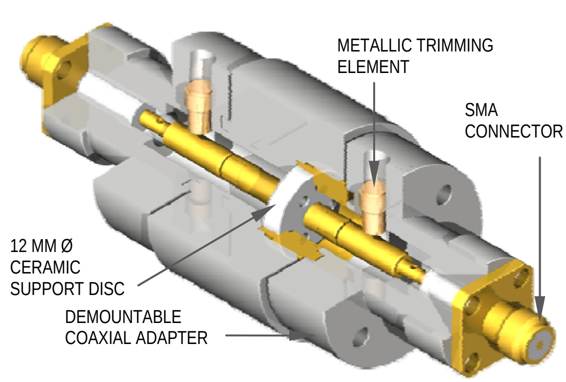

Figure 3: Coaxial Test Assembly / Cut-away view.

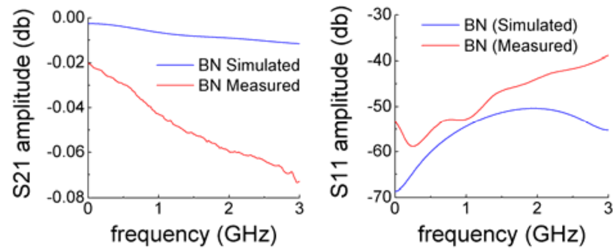

Figure 4: Coaxial Test Assembly / S parameters.

by basing the design around a capacitively compensated machine-able ceramic support disc [10], and a demountable coaxial assembly, as shown in Fig. 3, has been manufactured and tested. Measured transmission and reflection characteristics in the frequency domain, as shown in Fig. 4, are in reasonable agreement with simulated characteristics, and have helped to verify the accuracy of the 3D HF design code.

Helical Test Assembly

The helical test assembly as shown in Fig. 5 is the first step on the path to the realisation of a full scale

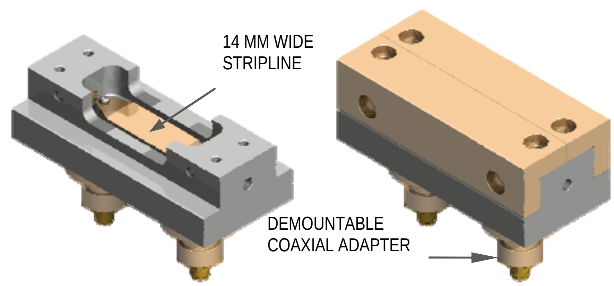

Figure 5: Helical Test Assembly.

helical structure. The design was based on, and utilises parts from, the previously described coaxial assembly. It consists of a demountable input and output coaxial assembly, and a short piece of stripline supported at each end by a captive ceramic disc, in a configuration that models one cell of the proposed short length helical prototype structure as shown in Fig. 6.

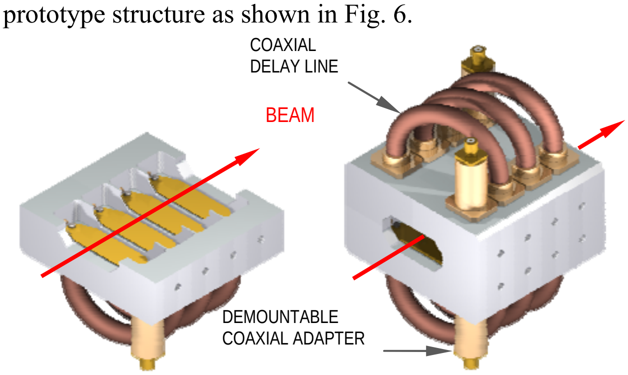

Figure 6: Short length helical prototype.

HF simulations have shown that stripline width and edge radius must be carefully controlled to achieve the required tolerance in characteristic impedance (Z_0), and to minimise edge field enhancement. An electro-polishing

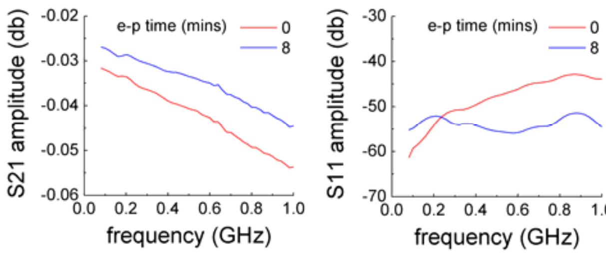

Figure 7: Helical Test Assembly / S parameters.

(e-p) technique has been developed to address this requirement, and a helical test assembly has been manufactured and tested. Measurements of the HF characteristics in the frequency domain as shown in Fig. 7, indicate, that the amplitude of the reflected wave (S11) was minimised after an e-p processing time of eight minutes. No measurable change in the amplitude of the transmitted wave (S21) was to be expected, and so the rather small change, as shown, was thought to be due to instrumental error.

Planar Test Assembly

The planar test assembly as shown in Fig. 9 will be the first step on the path to the realisation of a full scale planar structure. The design is based on, and utilises parts from, the previously described coaxial assembly, and is conceptually similar to the helical test assembly described above. However, the assembly has two additional features that are peculiar to the structure, and these are the capacitively compensated machine-able ceramic [10] pillars that provide stripline support at regular intervals, and a spring loaded sliding joint that permits stripline thermal expansion due to beam heating. The assembly models a section of the proposed short length planar prototype structure, as shown in Fig. 10.

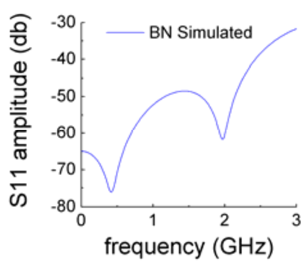

Figure 8: Planar test assembly (half) / S11.

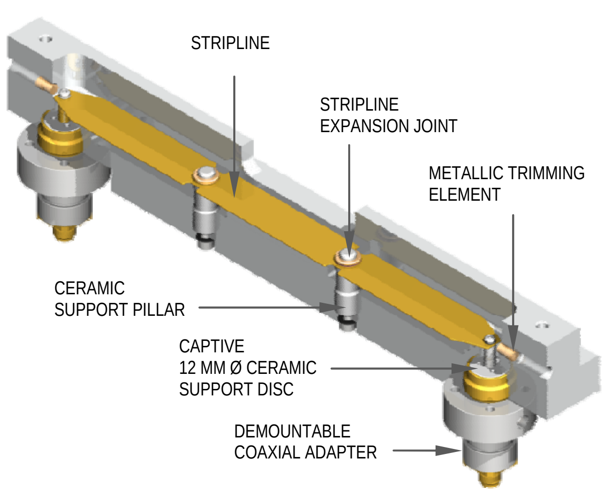

Figure 9: Planar test assembly / Cut-away view.

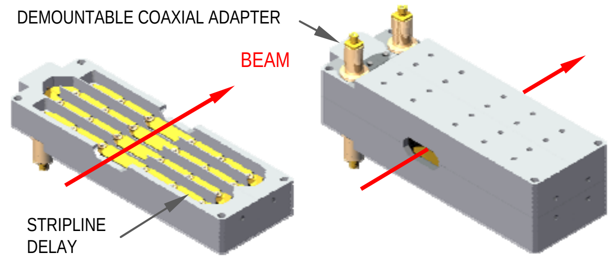

Figure 10: Short length planar prototype.

SUMMARY

Three preliminary assemblies have been designed and two have been tested. Measurements of their HF characteristics have helped to verify the predictive accuracy of the 3D HF design code [3]. The design and manufacture of the subsequent planar and helical 'short length' prototype structures, will build on the experience gained from the test assemblies, and should facilitate the choice of a candidate design for the full scale structure.

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