Nan\-o CNC Milling of Two Different Designs of 0.22 THz TWT Circuits


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Abstract: To satisfy the growing interest in high power (~1-200 W) THz sources, our research group has been working on various technologies to miniaturize vacuum electronic devices while keeping the power levels high and offering wide instantaneous bandwidth operation. We have manufactured two different designs of full 0.22 THz circuit structures including input/output couplers to WR4 waveguide. We have used nano CNC milling as our primary approach and we were able to achieve excellent surface finish and meet the high tolerance requirements of the high frequency wide bandwidth travelling wave tube circuit.

Keywords: nano machining, 0.22 THz circuit, TWT, sheet beam, fabrication

Introduction

Background: In our previous work we have shown that nano CNC milling is a great technology for manufacturing advanced high vacuum electronics structures in a small production environment [1]. The Mori Seiki NN1000 machine developed by Digital Technology Laboratory in Davis, CA allowed us to produce advanced high precision parts for the development of the 0.22 THz wide bandwidth and high power circuit for a travelling wave tube (TWT). We have shown that the challenges that this milling technology introduces can be overcome by thorough analysis using simulation software like CST, HFSS, and MAGIC, methodical design, and attentive machining practices. For example, structures built using nano CNC milling will have a radius at the corners of the walls due to the radius of the tool that is used for cutting. If the structure is designed considering this manufacturing artifact (see paper by A. Baig for these proceedings), the fabricated product will have much higher rate of success not only by meeting the tolerances and surface quality requirements, but also by producing high power and wide bandwidth output it was primarily designed for.

Key contribution: Digital Technology Laboratory Inc. (DTL) and Mori Seiki have developed a nano CNC mill that is capable of holding micron and even sub-micron tolerances.

Fabrication Approach

We have attempted to manufacture two different 0.22 THz circuit designs developed by UC Davis and CPI. Each of the circuit designs were created to achieve the same goal (wide bandwidth and high power output), but one was designed considering ease of fabrication so that the results can be achieved quickly (referred to as Fabrication Oriented Design in remainder of paper), while the other was designed to be easily integrated into a travelling wave tube (referred to as Integration Oriented Design in remainder of paper).

Fabrication Oriented Design

The key features that were considered in this design were: splitting the circuit in the high current plane to keep the aspect ratio of the tool below three and coupling the standard WR4 waveguide in such a way that the circuit could be manufactured in two halves [1]. Other aspects were considered also: corner radii, surface finish, and compact design [3]. We started by building a 40 mm long circuit first, then we built a back to back coupler, and finally we combined both of the structures together (Figure 1). We tested each structure individually and adjusted our design appropriately until optimal results were achieved (Figure 2).

Figure 1. Fabrication Oriented Design: circuit with input/output couplers to WR4 waveguide

Figure 2. S21 and S11 parameters of the fabrication oriented circuit design

Integration Oriented Design

The high frequency wide bandwidth and high power travelling wave tube that is being developed under the HiFIVE program is small, it requires high magnetic compression in a small amount of space, and it also needs to be cooled to run in CW operation mode. The amount of available space set a requirement such that this circuit would have to be fabricated in three layers to keep the aspect ratio of the tool manageable (lower half of the circuit, upper half of the circuit, and the waveguides). Testing of this design approach is still continuing.
Preliminary results show that we can at least achieve $\sim 7$ dB loss over 30 GHz of bandwidth.

**Figure 2.** (a) Three Layer Manufacturing Approach for Integration Oriented Circuit Design, (b) Scanning Electron Microscope Image of the Bottom Half of the Manufactured TWT Circuit

**Summary**

We have successfully built two different designs of high bandwidth and high power travelling wave tube circuits. We were able to show that the test results of the fabrication oriented design are in excellent agreement with simulation results. Also, we are continuing to collect test results on integration oriented design, preliminary results look promising. We use nano CNC milling technology as our primary approach for manufacturing parts with challenging tolerance and surface roughness requirements. It allows us to produce high quality parts with a short amount of development and manufacturing time.

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**References**

