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DESIGN, FABRICATION, AND COMISSIONING OF THE MODE LAUNCHERS FOR HIGH GRADIENT C-BAND CAVITY TESTING AT LANL*

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Abstract

This paper describes the design, fabrication, cold test, and future high gradient test plans for the new C-band TM_{01} mode launchers for the high gradient C-band test stand at Los Alamos National Laboratory (LANL). Modern applications require accelerators with optimized cost of construction and operation, naturally calling for high-gradient acceleration. At LANL we commissioned a test stand powered by a 50 MW, 5.712 GHz Canon klystron. The test stand is capable of conditioning single cell accelerating cavities for operation at surface electric fields up to 300 MV/m. The RF field is coupled into the cavity from a WR187 waveguide through a mode launcher that converts the fundamental mode of the rectangular waveguide into the TM_{01} mode of the cylindrical waveguide. Several designs for mode launchers were considered and the final design was chosen based on a compromise between the field enhancements, bandwidth, and simplicity and cost of fabrication. Four mode launchers were fabricated and cold-tested. The mode launchers will be conditioned to high power in summer of 2021.

INTRODUCTION

Particle accelerators are established tools for National Security (NNSA, DoD), medicine, and basic science missions. Modern day applications such as X-ray sources require accelerator facilities with optimized cost of construction and operation, naturally calling for high-gradient acceleration. Increasing gradients in normal-conducting radio-frequency (NCRF) copper-based accelerator structures requires innovation in two major areas: understanding of the physics mechanisms of radio-frequency (RF) breakdown, and development of novel copper alloys with increased breakdown limits [1]. At Los Alamos National Laboratory (LANL) we initiated a new project with the major goal to use a multi-disciplinary approach that includes accelerator design, molecular dynamics simulations, and advanced manufacturing of metals to develop high-gradient, high-efficiency radio-frequency (RF) structures for both compact and facility-size accelerator systems [2, 3].

As a part of the project we commissioned the high gradient test stand called C-band Engineering Research Facility – New Mexico (CERF-NM). The CERF-NM test stand is built around a 50 MW 5.712 GHz Canon klystron. The klystron system produces 50 MW pulses with the pulse length between 300 ns and 1 microsecond, repetition rate up to 200 Hz, and is tunable within the frequency band of 5.707 GHz to 5.717 GHz. The RF power is being output from the klystron in a WR187 rectangular waveguide. The power is split into two halves by a magic tee that is installed at the klystron's output and protects the klystron from excess reflected power. The WR187 waveguide continues into a 3 foot by 4 foot lead box designed to protect equipment and operators from X-rays generated in cavities under high gradient testing. The lead box is radiologically certified for dark currents with electron energy up to 5 MeV and average current up to 10 μA. For more details on the CERF-NM test stand please see [4].

Most of the cavities that we plan to test at CERF-NM will be coupled on axis to reduce peak surface magnetic fields. Thus, the mode launchers were designed for the test stand to convert the TE_{10} mode of the rectangular WR187 waveguide into the TM_{01} mode of the cylindrical waveguide for the on-axis coupling. The specification on the mode launchers was to have reflection below -20 dB within the bandwidth of the klystron. This paper describes details of the design, procurement, and testing of the mode launchers and the future plans for their high gradient conditioning and use with the cavities.

DESIGN OF LANL MODE LAUNCHER

We considered three different designs for the mode launcher. Each design was modelled with the CST Microwave Studio [5]. An optimization of the transmission/reflection characteristics was conducted to maximize the transmission at the frequency of interest (5.712 GHz), increase the bandwidth, and minimize the peak surface fields. The first design was the original design developed at LANL. The incoming RF field from the WR187 waveguide was split into two halves and then recombined in the TM_{01} mode of the cylindrical waveguide (Fig. 1(a)). The second design was scaled down from the original X-band design developed by a team at the National Institute of Nuclear Physics (INFN). INFN's design split the power from the WR187 waveguide into four parts before recombining it in the cylindrical waveguide (Fig. 1(b)). This design had two times larger bandwidth compared to LANL's design and significantly lower peak surface fields, however at the expense of fabrication complexity and cost. The third design was scaled up from the original S-band design developed at the University of California Los Angeles (UCLA).

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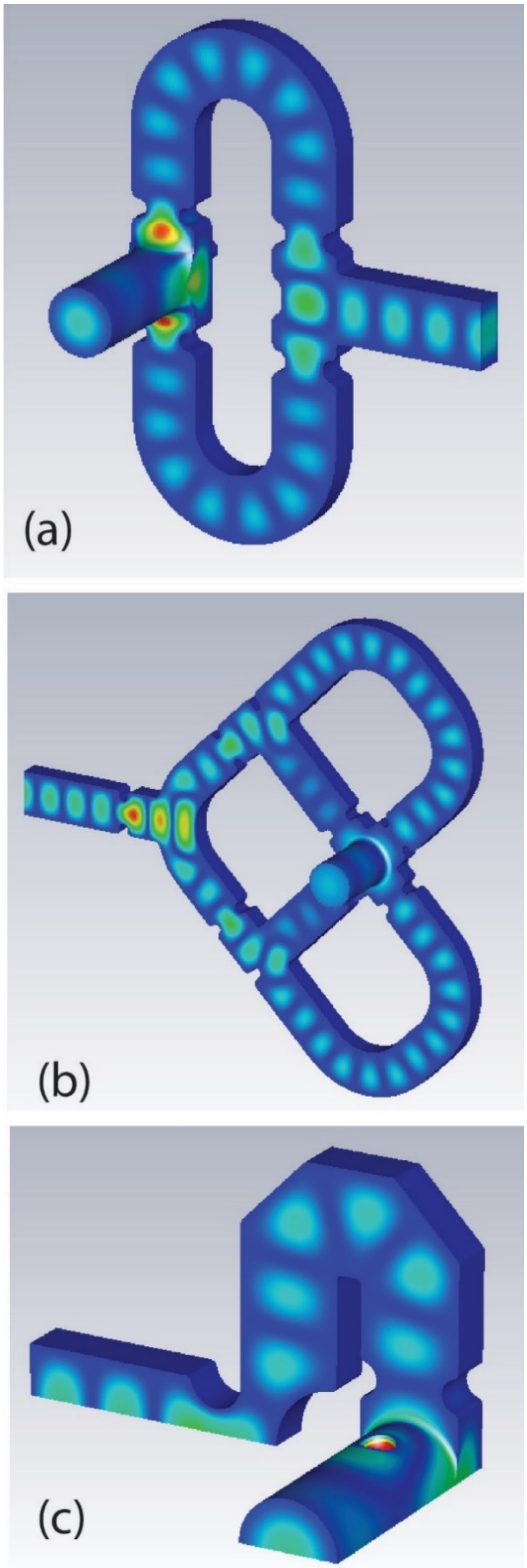

Figure 1: CST Microwave Studio simulations of the electric field magnitude in various designs of the mode launchers: (a) LANL's design; (b) INFN's design scaled to C-band; (c) UCLA's design scaled to C-band. For UCLA's design only a half of the whole mode launcher is shown and the perfect-H boundary condition is used at the bottom plane.

The UCLA's design was very similar to LANL's design with an addition of a spherical knob in the cylindrical waveguide (Fig. 1(c)) that allowed for increase of the bandwidth at the expense of the peak surface fields. The third design had the largest bandwidth among the three designs, but the peak surface fields were also the highest. The comparison of the transmission characteristics in the three mode launcher designs is shown in Fig. 2. A comparison of performances of the three designs is presented in Table 1.

Table 1: A Comparison of RF Characteristics for the Three Mode Launcher Designs

	LANL	INFN	UCLA
Bandwidth at -20 dB	17 MHz	35 MHz	44 MHz
E_{max} for 25 MW power	15.3 MV/m	11.4 MV/m	29.4 MV/m
H_{max} for 25 MW power	46.9 kA/m	41.7 kA/m	57.39 kA/m
Pulse heating for 25 MW power and 1 µs long pulse	0.67 °C	0.53 °C	1.00 °C

Upon reviewing the three designs, LANL's design was chosen for fabrication due to its relative simplicity, low peak surface fields, and sufficient bandwidth that satisfied the requirement of being larger than the bandwidth of the klystron at the CERF-NM test stand (10 MHz).

FABRICATION AND COLD TESTING OF LANL MODE LAUNCHER

Fabrication of the mode launchers was performed commercially by Dymenso, LLC in San Francisco, CA. We fabricated the total of four mode launchers. A photograph of the two mode launchers is shown in Fig. 3. The cold test was conducted with the two pairs of the mode launchers connected to each other at the ends of cylindrical waveguides first directly and then through a quarter wavelength long extension. The transmission and reflection characteristics for each mode launcher were calculated from there measurements and are shown in Fig. 4. All four fabricated mode launchers satisfied the requirements of having the reflection below -20 dB in the frequency band of 5.707 GHz to 5.717 GHz.

The mode launchers were delivered to Los Alamos and are currently awaiting the high power test at the CERF-NM high gradient test stand.

CONCLUSIONS AND FUTURE PLANS

In summary, this paper described the design, fabrication, and cold testing for the high gradient C-band mode launchers. At LANL we commissioned a new C-band high gradient test facility called CERF-NM, and high gradient testing of accelerator cavities has commenced. We have plans to

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test multiple C-band accelerator cavities for high gradient performance. In many cases these cavities will be coupled through an on-axis coupler that delivers the TM_{01} mode in a cylindrical waveguide. The power from the klystron is output into a WR187 rectangular waveguide that brings the power to the cavity installed inside of the lead box for radiation protection. The job of the mode launcher is to convert the TE_{10} mode of the rectangular waveguide into the TM_{01} mode of the cylindrical waveguide with the least possible reflection. Three different designs of the mode launchers were considered, and the final design was chosen based on the compromise between the simplicity and cost of fabrication, sufficient bandwidth, and the lower peak surface fields and pulse heating. Four mode launchers were fabricated based on this design. The mode launchers were cold-tested, and all four of them were able to meet specifications.

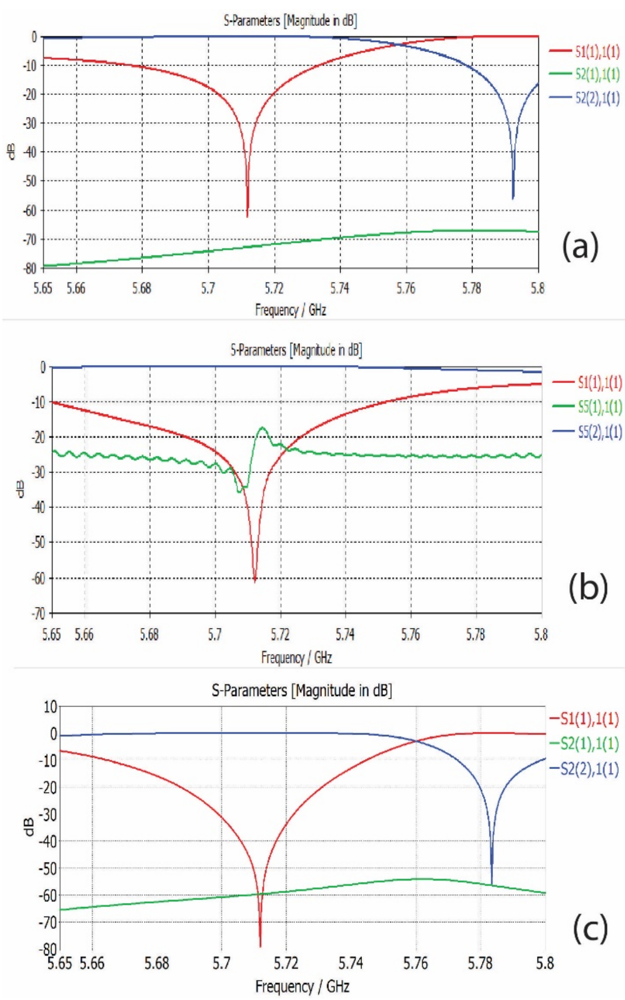

Figure 2: CST Microwave Studio simulations of S-parameters in various designs of the mode launchers: (a) LANL's design; (b) INFN's design scaled to C-band; (c) UCLA's design scaled to C-band.

In July of 2021 the mode launchers will be tested with high power on the CERF-NM high gradient test stand. The mode launchers will be tested in pairs. We plan to couple up to 10 MW of power into each pair of the mode launchers and measure the transmission and reflection. We will operate with pulse lengths of 400 ns, 700 ns, and 1 microsecond and repetition rate of 100 Hz. Diagnostics will include two directional couplers (before and after the mode launchers) and two Faraday cups installed on two beam pipe ports of the mode launchers.

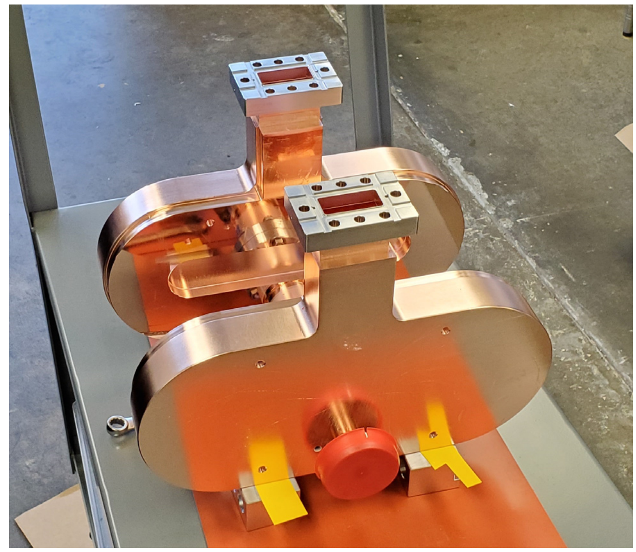

Figure 3: A photograph of two mode launchers fabricated by Dymenso, LLC.

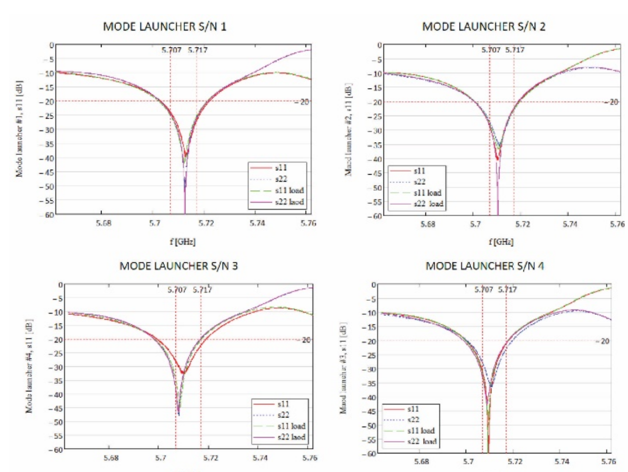

Figure 4: Reflection characteristics measured for the four fabricated mode launchers.

We expect the mode launchers to be fully conditioned by the end of summer, 2021. At that point, high gradient testing of the cavities with on-axis coupling will commence. We expect that the test stand will be open to multiple collaborators starting in fall of 2021.

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[5] CST Microwave Studio 3D EM simulation and analysis software, `www.3ds.com`