# DESIGN OF A HIGH-POWER RF BREAKDOWN TEST FOR A CRYOCOOLED C-BAND COPPER STRUCTURE

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## *Abstract*

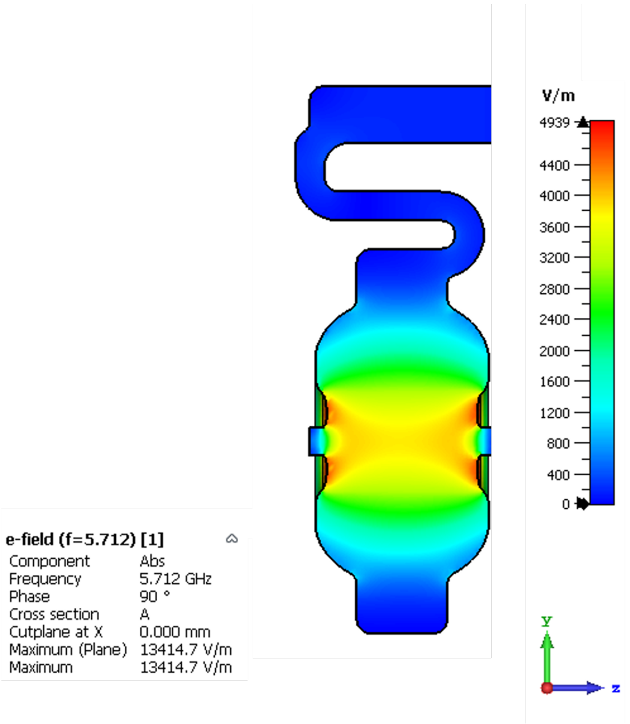
High-gradient RF structures capable of maintaining gradients in excess of 250 MV/m are critical in several concepts for future electron accelerators. Concepts such as the ultra-compact free electron laser (UC-XFEL) and the Cool Copper Collider (C3) plan to obtain these gradients through the cryogenic operation (< 77 K) of normal conducting copper cavities. Breakdown rates, the most significant gradient limitation, are significantly reduced at these low temperatures, but the precise physics is complex and involves many interacting effects. High-power RF breakdown measurements at cryogenic temperatures are needed at the less explored C-band frequency (5.712 GHz), which is of great interest for the aforementioned concepts. On behalf of a large collaboration of UCLA, SLAC, LANL, and INFN, the first C-band cryogenic breakdown measurements will be made using a LANL RF test infrastructure. The 2-cell geometry designed for testing will be modifications of the distributed coupled reentrant design used to efficiently power the cells while staying below the limiting values of peak surface electric and magnetic fields.

## INTRODUCTION

A major thrust of electron linear accelerator development is to increase the accelerating gradients accessible for different applications. Ultra high gradients have been heavily explored from a number of different perspectives [1]. Cryogenic operation of normal conducting cavities has been shown to significantly reduce breakdown rates (BDR) and in doing so increase the maximum accelerating gradient in cavities that we can consider from 120 MV/m to numbers in excess of 240 MV/m [2, 3]. Several concepts including the Cool Copper Collider (C3) and Ultra compact xray free electron laser (UCXFEL) intend to use high shunt impedance reentrant cavities with distributed coupling [4, 5]. Test of breakdown of these type of cavities then becomes a necessity at the relatively less explored Cband frequencies at which both machines intend to operate [6]. In addition, material additional material properties tests are required such as additional alloys, especially copper-silver of different concentrations [7].

## CAVITY DESIGN

The cavities we intend to test are two cell reentrant cavities using the distributed coupling optimization used at SLAC [8]. It is a 2-cell cavity structure. Shown in Fig. 1 is an eigenmode solution showing electric field magnitude with arbitary scaling used to illustrate certain relevant features. The resonant mode of 5.712 GHz is intended for 40 K operation. Multiple values for coupling $\beta$ were considered with order µs pulse length. The relevant numbers for this discussion are intended peak surface fields around 250 MV/m with and on access peak accelerating gradient of 200 MV/m. As part of our collaboration with LANL, these cavity measurements will be made at the newly commissioning high power Cband cryogenic test bed [9].



**e-field (f=5.712) [1]**
Component Abs
Frequency 5.712 GHz
Phase 90 °
Cross section A
Cutplane at X 0.000 mm
Maximum (Plane) 13414.7 V/m
Maximum 13414.7 V/m

Figure 1: 1 cell of 2-cell cavity structure with electric field eigenmode solution of arbitrary scaling showing the distributed coupling waveguide structures.

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## CAVITY FABRICATION

The fabrication of this 2-cell structure for use in a functioning cryostat is a nontrivial consideration. The needs are multifaceted. The cavities themselves must be machine with sufficient precision with easy access on the outside for cryogenic conduction cooling connections and tuning where necessary. Previous reentrant cavity tests were performed in nitrogen baths with many cells [10]. We opt here a design as simple as possible. Braze connections are necessary for our initial structure we may be changed for future variants.

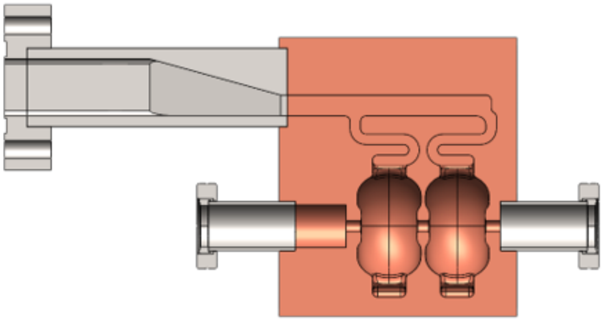

Figure 2: CAD model of one half of the planned 2-cell high gradient test structure. Note the necessary waveguide taper from WR187 dimensions to the smaller dimension of the cavity coupler section.

Significant features to note (which can be seen in the CAD model in Fig. 2) are the two CF half nipples on either side of the 2-cell structure where Faraday cups are necessary. More notable however is the waveguide taper necessary to convert from the Cband WR187 waveguide to the smaller section where the distributed couplers are located.

In addition to the simplified longitudinal braze manufacturing, we are also pursuing the possibility of additive manufacturing and coating with collaborators at Sapienza University of Rome.

## CRYOGENICS

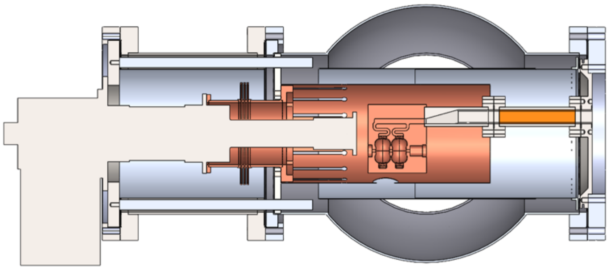

Figure 3: Cross section of planned cryostat addition to LANL test facility to house 2-cell structure for breakdown tests at 40 K.

Our primary inspiration for conduction cooled breakdown tests comes from SLAC collaborative work performed at X and S band [6]. We scale down the previous S-band cryostat design to C band relevant dimensions which is furthermore necessary to fit within the LANL test bunker. The cryostat shown in Fig. 3 is also designed with the LANL Sumitomo pulse tube cryocooler in mind in terms of geometry and cooling capacity.

The design contains in addition to the test structure shown in Fig. 2 two layers of thermal shielding, a copper coated stright steel waveguide section, and vibration reducing thermal braids to couple to the test structure (these are omitted for simplicity from the schematic shown). One layer of the thermal insulation is at room temperature and the other is cryogenic to be cooled by the cryocooler's first stage. The most challenging aspect of this design is the thermal insulation necessary in the waveguide feed through. Ideally, a significantly longer steel waveguide section would be used to achieve the 40 K temperatures for which we are aiming.

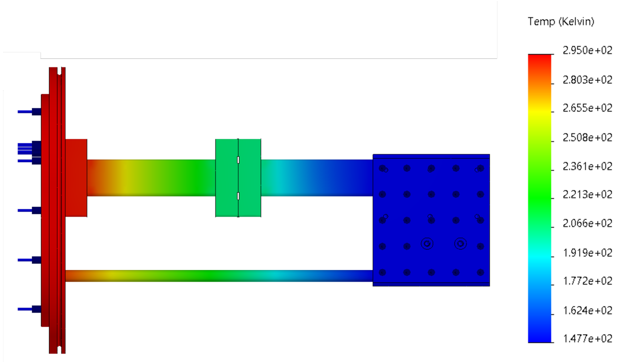

Figure 4: Temperature gradient given approximate numbers from the main heat leaks (including waveguide) and cooling capacity. Additional insulation is necessary to reach 40 K goal. Progress to this end is ongoing.

We can perform a steady state thermal simulation using approximate numbers for the main heat leaks including most significantly the waveguide and the cooling capacity of the LANL cryocooler. These results are shown in Fig. 4. We can see that the large leak from the waveguide does not allow us to easily reach 40 K. Alternative designed for lengthened waveguide to serve as additional insulation are underway. Figure. 5 shows mechanical simulations used to show the degree to which asymmetric contraction of the cavities leads to undesired detuning. The effect does not appear significant in our initial analysis.

## CONCLUSION & FUTURE DIRECTIONS

A 2-cell Cband reentrant structure has been designed and fabrication preparation has begun as part of a large collaboration exploring the effects of cryogenic temperatures on RF breakdown. The structure will eventually be used to study RF performance at very high gradients in this less explored frequency regime with implications towards several future linacs. Near term low level RF measurements will be performed at UCLA before moving to LANL for high power RF

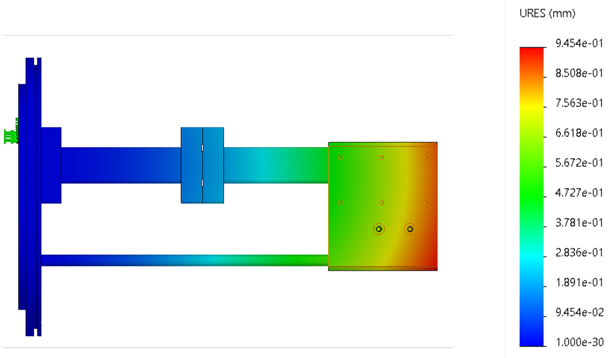

Figure 5: Example mechanical analysis given the temperature gradient from Fig. 4. Done for completeness to establish degree of temperature detuning from asymmetric contraction.

tests. Additional alloys and fabrication methods are being considered in parallel.

## ACKNOWLEDGEMENTS

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