Cryogenic Electrically Small HF Transmit System

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***Abstract*—An antenna and tuning system is designed to be installed within a cryogenic chamber to increase its efficiency via chilling. Electrical, material, and mechanical design constraints imposed by using a cryocooler are discussed.**

I. Introduction

Losses scale unfavorably in electrically small antennas with decreasing electrical size, greatly limiting system performance [1]. In this work we aim to install a transmit antenna and tuner within a cryogenic system to explore potential efficiency gains that may be obtained by cooling conventional materials (e.g., copper) to cryogenic temperatures (<60 K). In particular, we target the high losses present in a simple tuning inductor. If successful, this cryogenic transmitter system will be capable of transmitting narrowband, high power, HF signals through an electrically small front-end.

II. Cryogenic System Design

The cryogenic system shown in Figure 1 was designed using primarily off-the-shelf components. A CryoTel GT cryocooler was chosen as the chilling element. This cryocooler is designed to be mounted to a vacuum system via a 2.75″ CF flange. This cryocooler operates by chilling a cylinder called a “cold finger” extending into the vacuum chamber when the cryocooler is mounted to the outside of the chamber via a CF2.75 flange. The GT cryocooler is capable of reaching a temperature of 40 K at the tip of its cold finger [2]. To avoid potential mechanical issues, a separate vacuum chamber for the tuner and the antenna was created.

The antenna tuner chamber was constructed using three off-the-shelf, stainless steel components: a 10″ CF-flanged plate with six 2.75″ CF flange ports on its face, an 8″ diameter by 16″ tall cylinder with a 10″ CF flange on either end, and a 10″ CF-flanged plate with a single 2.75″ CF flange. The GT cryocooler is mounted to the central CF2.75 port on the plate with six CF2.75 ports.

A custom, double-sided CF2.75 feedthrough is mounted to the single CF2.75 flange on the top plate. The feedthrough is a single copper rod insulated by an alumina insulator from the stainless steel flange.

The antenna chamber consists of a CF2.75 to KF16 adapter, a 3 meter long PEEK tube with KF16 flanges milled from its ends, and a KF16 vacuum port. The CF2.75 to KF16 adapter connects one side of the custom double-sided CF2.75 feedthrough to one end of the PEEK tube. The other end of the PEEK tube is capped with a vacuum port to enable the tube to be placed under vacuum.

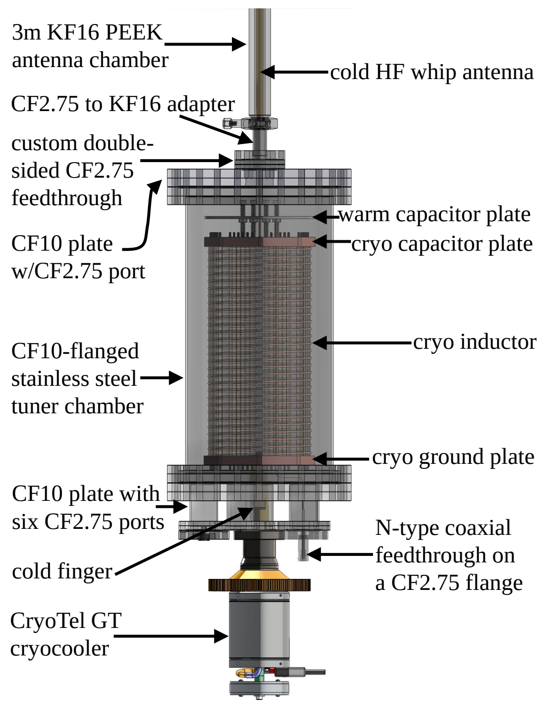

Fig. 1. Cryogenic system model with the chamber walls made translucent

III. Cryogenic Circuit Design Constraints

The antenna and tuner system was designed within the constraints of the cryogenic system. These constraints impact the geometry, materials, and thermal design of the cryogenic system. Geometrically, the antenna tuner must fit without touching its 16″ tall by 8″ diameter chamber. The antenna must similarly fit within its 9.5′ tall by 15 mm inner diameter antenna chamber.

Placing the cryogenic system under vacuum and at cryogenic temperatures places unique material requirements. A major concern for vacuum systems is outgassing, where a material slowly releases its molecules as a gas, which degrades the vacuum. The following are materials with low outgassing that are recommended for cryogenic temperatures [3]:

- copper 101, aluminum, or gold for conductive components.
- aluminum nitride (AlN) for thermally conductive, electrically insulating components.
- PEEK plastic for insulating components.

Thermal concerns place several constraints on the antenna and tuner design. All cryogenic components must be in good thermal contact with the cold finger of the cryocooler. Also, anything in direct electrical contact with the cold finger must be considered ground, as the cold finger is electrically connected to the cryocooler chassis. Additionally, the warm input to the tuner must be thermally isolated from the cryogenic environment. Finally, the antenna must not absorb a significant amount of the radiative heat impinging on it. This is not a concern for the tuner, as the stainless steel chamber shields its contents from thermal radiation.

Fig. 2. The left photo shows the cryogenic system, and the right photo shows the antenna and tuner designed to be installed within this cryogenic system.

IV. Cryogenic antenna and tuner design

The L-network [4] tuner topology shown in Figure 3 was chosen because it conforms to the constraints of the cryogenic system. This design employs a parallel plate capacitor C_t in series at the source input of the tuner followed by a shunt inductor L_t. The capacitor acts as a thermal barrier between the warm input ant the cryogenic environment. The inductor provides a thermal link between the cold finger of the cryocooler and the antenna via its copper windings.

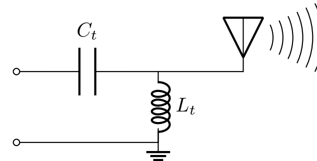

Fig. 3. Electrical schematic of the antenna and tuner.

The inductor is wound around a 12″ tall, 5.5″ diameter spool of AlN and PEEK rods that is capped on either end by 6″ diameter copper plates labeled "cryo ground plate" and "cryo capacitor plate" in Figure 1. This configuration allows for the construction of a wide range of tuning inductances. The cold finger of the cryocooler is fastened to the cryo ground plate. The antenna is connected to the cryo capacitor plate via the feedthrough between the two chambers. The aluminum capacitor plate labeled "warm capacitor plate" is electrically (and thermally) connected to the input feedthrough of the system. The warm capacitor plate and the wire attached to it are isolated from the cryogenic components of the system via PEEK spacers. The antenna is a 9.5' tall, 1 cm diameter whip antenna that is plated with gold to ensure excellent electrical conductivity and high thermal reflectivity.

The antenna and tuner system was constructed and tested at ambient temperature as shown on the right side of Figure 2. The system was verified to have an efficient, narrowband ($\sim 1\%$ VSWR ≤ 2) match at 2.33 MHz.

V. Conclusions

An antenna and tuner system was designed to be placed into a cryogenic environment. The system was verified to perform as designed at ambient temperature. During the conference presentation, details on the electromagnetic and thermal design of the system will be discussed along with plans for experimentally assessing cryogenic cooling impacts on the system's overall efficiency.

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References

[1] C. A. Balanis, *Antenna theory: analysis and design*. John Wiley & Sons, 2016.
[2] *GT Datasheet*, CryoTel Inc, Athens, OH, 12 2020.
[3] J. Tuttle, E. Canavan, and A. Jahromi, "Cryogenic thermal conductivity measurements on candidate materials for space missions," *Cryogenics*, vol. 88, pp. 36–43, 2017.
[4] D. M. Pozar, *Microwave engineering*. John Wiley & Sons, 2011.