A Cryoelectronics Sample Holder Design with Perpendicular Coaxial to Microstrip Transitions

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We present a cryoelectronics sample holder design which provides a compact perpendicular coaxial to microstrip transition with a return loss better than 14dB and insertion loss less than 2dB from DC-20GHz, and port isolation better than 60dB up to 8GHz and 40dB up to 10GHz. The design fully encloses the sample, provides good electrical and thermal contact to the sample, and is straightforward to construct.

PACS numbers:

I. INTRODUCTION

Many mesoscopic experiments employ microwaves to excite and probe planar structures at low temperatures. In practice, a sample holder which supplies a transition from coaxial to planar geometry is required, and must be compatible with cryogenic experiments. The holder needs to have good impedance matching and port isolation, shield the chip from electromagnetic noise, avoid cavity resonances, and provide good thermal contact with the chip, all while being compact. These requirements are often in conflict with one another, so making a suitable compromise in designing a sample holder is a delicate task. Edge launch coaxial to microstrip transitions are commonly used, and achieve good performance [1, 2], but the geometry is not always favorable for sample holders. An example of a cryoelectronics sample holder with edge launch transitions can be found in [3]. End launch geometry becomes impractical as the number of connectors increase. Alignment of the printed circuit board (PCB) with the connector is critical, and the board must terminate along the edge of all connectors. A problem particular to cryoelectronics then arises: Contraction of the PCB when cooling results in cracks in the joints between the PCB and edge launch connectors.

With the above goals in mind, we developed a sample holder that utilizes perpendicular coaxial to microstrip transitions. Fig. 1 displays one of our sample holders, and Fig. 2 shows an internal view with a chip mounted. This transition is naturally compact, and lends itself to a holder that fully encloses the sample. Our transition is illustrated in Fig. 3. The ground conductor of the microstrip is formed by the base of the holder, and the microstrip trace is soldered to the center conductor of the coaxial cable. The guiding principle of our transition is that the coaxial line is shrunk appropriately before launching it onto the microstrip. With the size of the cable narrowed, the difference in path lengths that current must travel through the ground shield of the coaxial line to the ground plane of the microstrip becomes negligible. Other perpendicular coaxial to microstrip transitions exist [4–6], but for high frequency performance they require intricate lithographically-defined or multi-layer compensating adaptors. Perpendicular coaxial to CPW transitions which are cryogenic compatible have been demonstrated by [7], but the enclosure machining has very tight tolerances, and the transitions utilize complex PCB's that must be supplied by a PCB manufacturer. Our transition achieves high frequency performance using a single sided PCB that may be manufactured in-house.

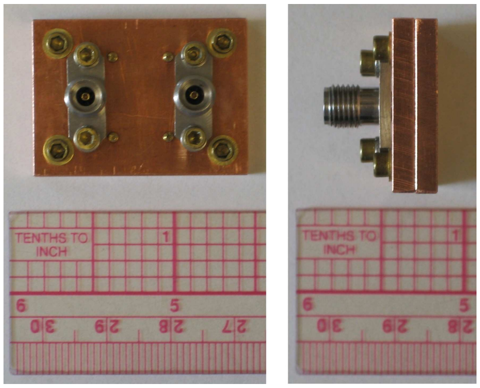

FIG. 1: Overall view of the sample holder described in this article.

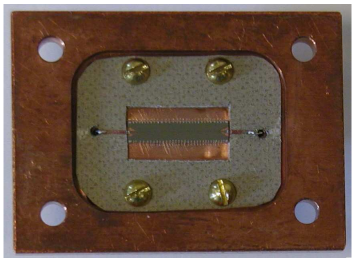

FIG. 2: A chip mounted in the sample holder.

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II. CONSTRUCTION

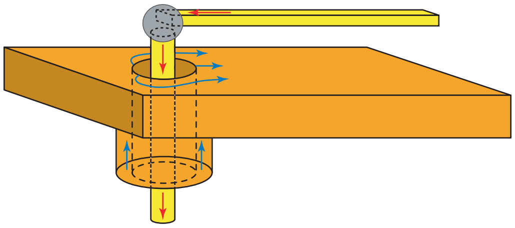

FIG. 3: An example of a coaxial to microstrip transition. Blue arrows show how the currents in the grounding conductor are routed from the coaxial shell to the ground plane of the microstrip, while red arrows show the current in the center conductor and microstrip.

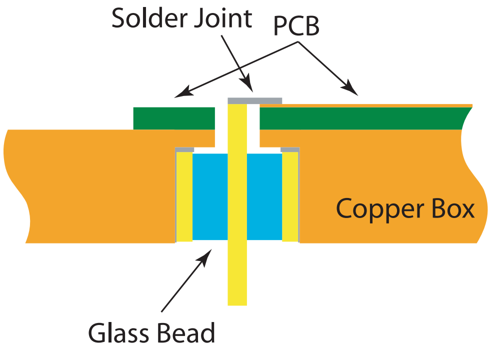

FIG. 4: A cross section of our physical implementation of the coaxial to microstrip transition. We have not represented the Anritsu K connector flange launcher which sits on the bottom of the coaxial bead.

The coaxial to microstrip transition is made with a K flange launcher (Anritsu K103F for female, or K103M for male), which sits on top of a small coaxial glass bead (Anritsu K100B) that is soldered into the copper holder (see Fig. 4). A useful feature of the flange launchers is that male and female connectors are interchangeable. On the sample side of the holder, the center pin from the glass bead protrudes from the copper plate, with the tip of the pin lying flush with the microstrip on a 0.015" thick printed circuit board (PCB). The center pin and microstrip are soldered together to form a connection, while the base of the sample holder forms the ground plane. It is essential that the base of the sample holder where the PCB lies is flat, and free from any burrs after machining. If the board does not lie flat, the microstrip impedance will stray from 50Ω, decreasing the performance of the coaxial to microstrip transition.

The solder joints between the center pin of the coaxial glass bead and microstrip are made with a low temperature bismuth alloy with a melting point of 158 °F. The reason for using this alloy as opposed to conventional tin/lead solder is that the surface tension of the bismuth alloy is much lower than electronics solder, making it easier to bridge any gap between the coaxial pin and microstrip, without using an excessive amount of solder. It is important to use as little solder as possible, while still making good contact, as excessive solder will result in lower return losses. After multiple thermal cycles between cryogenic and room temperatures, we have noticed the low temperature solder joints do hold up well, and should not need to be resoldered.

The sample holder is machined from oxygen free high conductivity (OFHC) copper. A pocket is milled out to form the inside of the box, and a matching cap is made with tapped holes. Brass screws may be used throughout to avoid collecting magnetic flux, which would pose a problem in some experiments. Brass also has the advantage over steel in that its expansion coefficient is greater than copper, so as the sample holder is cooled the brass screws will pull the parts tighter together.

III. MICROWAVE CHARACTERIZATION

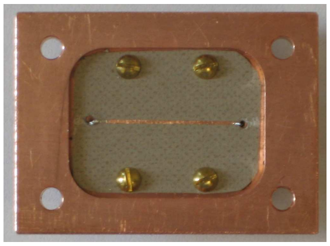

FIG. 5: Sample holder with a through microstrip for characterization of return losses.

To check the quality of the transitions, a straight microstrip between the two ports is used, as in Fig. 5. The resulting S parameters for three different trials are shown in Fig. 6, where between trials the solder joints to the microstrip are redone. It can be seen that changing something as simple as the solder joint changes the finer structure of the S parameters, but the more general lowpass trend is stable. When connections are made with an excessive amount of solder, the return losses may decrease by more than 10dB.

In most practical applications, the sample holder will need to be capped to prevent electromagnetic noise from reaching to the sample. This results in cavity resonances which can pose problems if these resonances are near frequencies of interest. Fig. 7 demonstrates what happens when the sample holder containing a straight microstrip is capped. Cavity resonances can clearly be seen near 11GHz and 22GHz. When two small patches of Eccosorb (type GDS SS-6M 6-35GHz) about 3mm square are placed on either side of the cap, these resonances are eliminated.

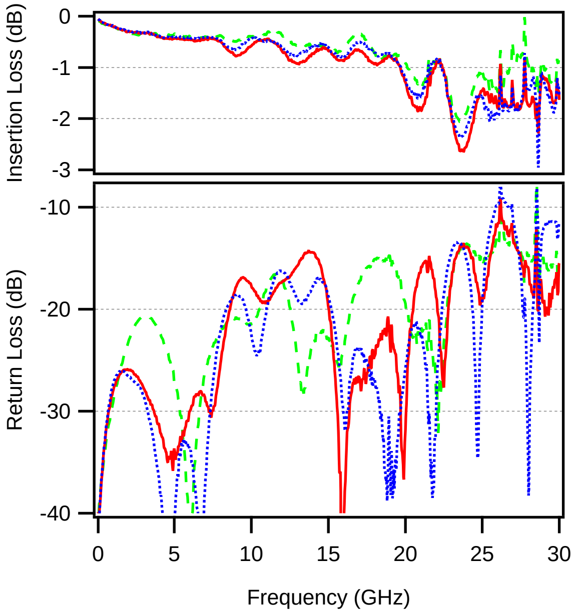

FIG. 6: Insertion and return loss with a microstrip between ports for three different trials, each trial corresponding to redoing solder joints to the microstrip. The top plot is insertion loss, while the lower is return loss. Similar line styles in the two plots correspond to the same trial.

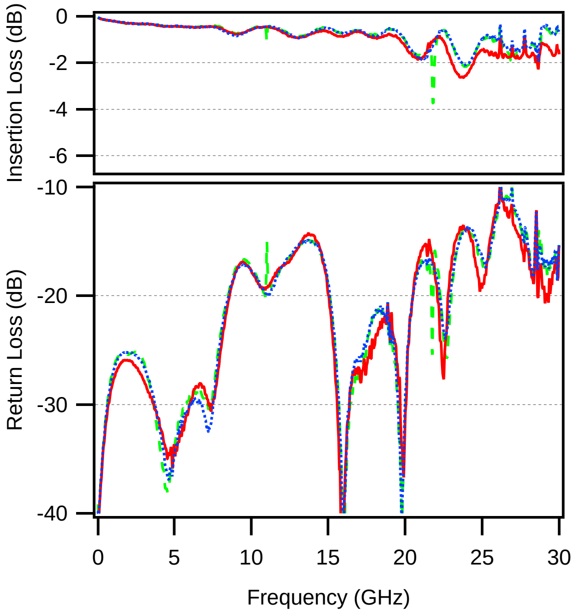

FIG. 7: Insertion and return losses with no cap (red solid, same as solid data in Fig. 6), S parameters with a cap (green dashed, cavity resonances can be seen), S parameters with cap and Eccosorb (blue dotted, cavity resonances are reduced).

Port isolation also becomes a concern when the sample holder is capped. Fig. 8 displays the port isolation when there is a 10mm break in the microstrip with and without a cap, as well as the effectiveness of adding Eccosorb to the cap. While capping the sample holder decreases the isolation between the ports, the ports are still isolated by 40dB up to 10GHz, and better than 60dB up to 8GHz even without Eccosorb. If the holder and cap were machined even tighter to shrink down the cavity size, the cavity resonances could be pushed even higher, improving high frequency port isolation.

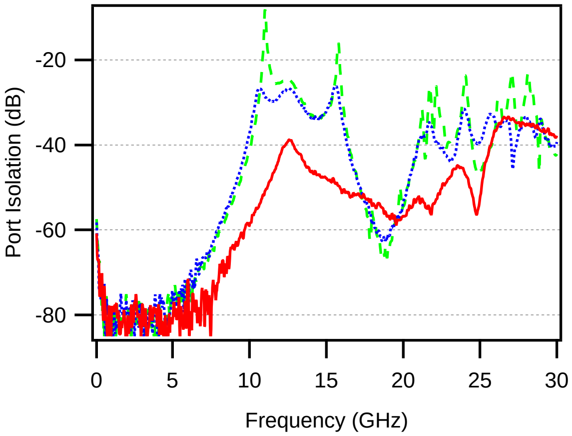

FIG. 8: Port isolation with no cap (red solid), capped (green dashed), and capped with Eccosorb (blue dotted). The cap provides a cavity for microwaves to propagate, but Eccosorb reduces the transmission of microwaves.

IV. SAMPLE MOUNTING

With the above tests performed to ensure proper performance, a hole may be cut in the PCB for placement of the chip. The chip is mounted directly to the copper plate, held in place with a small amount of GE varnish. Wirebonds between the microstrip on the PCB and center conductor of a coplanar waveguide on the sample launch the microwaves, while the ground planes are connected by wirebonds along the edge of the sample to the base of the sample holder. An example of a mounted chip is shown in Fig. 2. Because the chip is in direct contact with the copper plate, it is well thermalized with the sample holder. Samples may be easily removed from the holder without damage, and after cleaning the base of the holder, a new sample may be mounted with the same PCB.

V. CONCLUSION

The sample holder for cryoelectronics measurements described in this article provides a compact enclosure which satisfies several conflicting requirements: It shields the sample from electromagnetic noise with controllable cavity resonances, while offering good thermal and electrical contact to the sample, and high port isolation. We achieved return losses better than 14dB from DC-20GHz, and port isolation better than 60dB up to 8GHz and 40dB up to 10GHz. By shrinking down the cavity size, these port isolations may be extended to even greater frequencies.

Acknowledgments

Discussions with I. Siddiqi and R. Schoelkopf have largely contributed to this work.

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