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Microwave antennas for short distance communications in cryogenic systems

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INTRODUCTION

At microwave frequencies, cryogenic systems do usually employ coaxial cables, either to feed signals to the cryogenic stage, or to extract the output signal to room-temperature. For applications like imaging systems or multichannel devices for which many parallel channels are necessary, too many cables reduce the hold time of cryostats or require power consumption for cryogenerators that are not acceptable, especially for space applications. These constraints hold true for scientific payloads since future high frequency heterodyne or bolometric imagers for radioastronomy [1] or Earth atmosphere studies [2] do require several parallel data channels in the GHz to THz range. In this case, one solution to this issue is to make use of wireless communication means over short distances between the different cryogenic stages of the cryogenic systems, in order to avoid any thermal loading of the cooled devices. In this work, printed bow-tie antennas have been designed to operate in X-band in near-field configuration in order to transmit signals over very short distances. This frequency range corresponds to a typical intermediate frequency range used for Superconductor-Insulated-Superconductor (SIS) mixers [3] cooled at 4K for radioastronomy applications. Transmission between two bow-tie antennas directly placed across from each other has been simulated and measured for different configurations.

ANTENNA GEOMETRY

The antennas studied for our application are derived from the bow-tie antenna presented in [4] in order to operate in the 8-12 GHz frequency band with a Rogers RT/Duroid RO4003C 0.508 mm-thick substrate with a dielectric constant of 3.38. The conductor loss tangent is 0.0035. Fig. 1 displays the geometry of the front and back views of the bow-tie antennas. Their dimensions are given in Table 1.

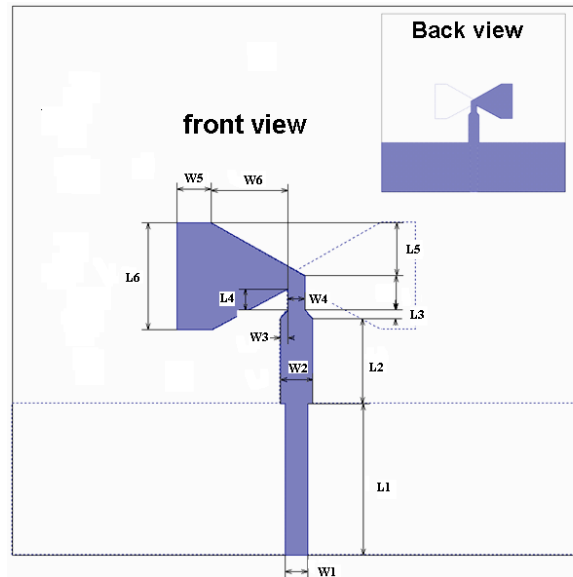


Fig. 1. Geometry of bow-tie antennas studied in this work

Table 1. Dimensions of the antenna

	W1	W2	W3	W4	W5	W6		
d (mm)	1.22	1.67	0.42	0.87	1.84	3.96		
	L1	L2	L3	L4	L5	L6	L7	L8
d (mm)	8	4.5	0.44	1.11	1.78	2.77	5.64	9.68

BOW-TIE ANTENNAS PLACED IN NEAR-FIELD CONFIGURATION

Both antennas of the same geometry have been placed across from each other, as shown in Fig. 2. The distance of the two planes supporting the printed antennas, parallel to each other, has been varied from 2 to 23 mm. This distance range is typical of the space that can be found between different cryogenic stages.

Measurements of the coupling between antennas have been performed in the frequency range of interest, they are presented in Fig. 3 versus the distance between the two antenna planes. One can notice that the coupling is better if the distance is shorter. The best obtained transmission is -3.8 dB at 9.3 GHz for a distance of 2 mm between the antenna planes. The associated bandwidth for a transmission loss lower than -6dB is about 1.85GHz, ranging from 8.5 GHz to 10.4 GHz. Fig. 4 shows the comparison for the S_{12} transmission parameter between measurements and simulations computed with a High-Frequency Structure Simulator (HFSS) for two different distances of 2 mm and 10 mm. The agreement is reasonably good over the whole bandwidth of interest. S_{21} transmission is degraded by about 6 dB when the antenna distance increases from 2 mm to 10 mm.

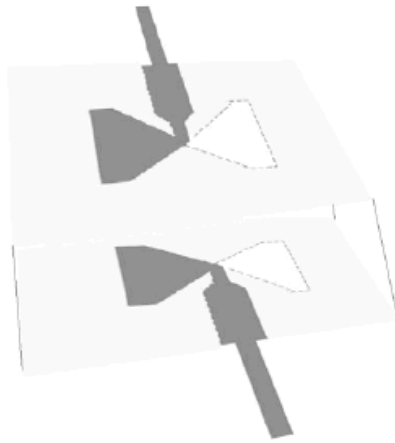


Fig. 2. Respective placement of the two bow-tie antennas placed in near-field configuration. The distance between the planes of the antennas has been varied from 2 to 23 mm.

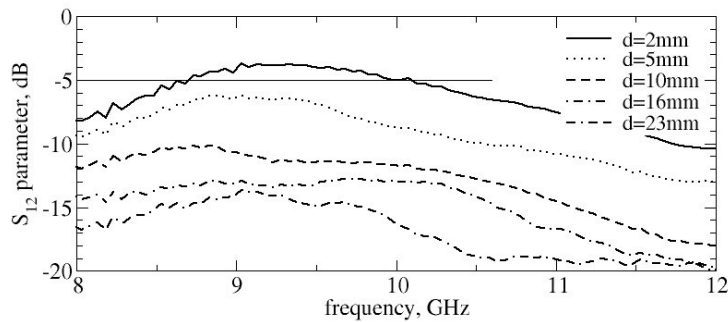


Fig. 3. Coupling measured between the two bow-tie antennas for different distances d between antenna planes

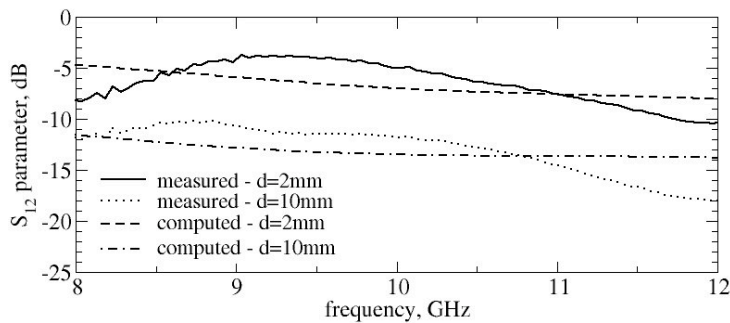


Fig. 4 Coupling, measured and computed with HFSS software, of near-field coupled antennas, separated by $d = 2$ mm and 10 mm.

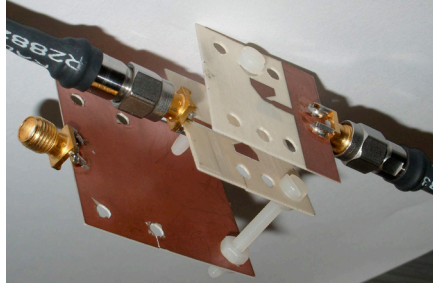


Fig. 5. Photograph of the two bow-tie antennas in near-field coupling configuration with their respective conducting reflecting planes (the second plane is not shown for clarity).

Though this performance can be acceptable for some cryogenically-cooled detectors, it is preferable to obtain a better coupling to compete with existing solutions based on coaxial cables. To this regard the antennas will be placed close to the metallic radiation shields into the cryogenic system and located with their back side parallel to these shields. In order to simulate this fact, a conducting reflecting plane has been placed behind the back side of each antenna (see Figure 5).

BOW-TIE ANTENNAS WITH BACKSIDE REFLECTING PLANES

In order to estimate the influence of the conducting planes on the coupling between the antennas, we have measured the transmission by varying the distance between each reflecting plane and its antenna. For all measurements, we kept a 2 mm distance between the two antennas. Fig. 6 shows measurements of the coupling between the antennas in presence of the reflecting plane behind each antenna for different distances h . A best coupling has been found for a distance $h=9$ mm, corresponding to a transmission of -1.48 dB around 8.43 GHz. It stays better than -3 dB over a bandwidth of 1.7 GHz. One can notice that the 8.5-10.4 GHz bandwidth associated to a coupling better than -6 dB without reflecting plane is slightly translated to the 8-9.7 GHz range with a reflecting plane located at 9 mm. But this is associated to a significant improvement of the coupling that stays better than -3 dB. A shift is observed between simulation and measurement results that may occur because of the effect of the SMA connector and the approximation of the antennas dimensions for the simulations.

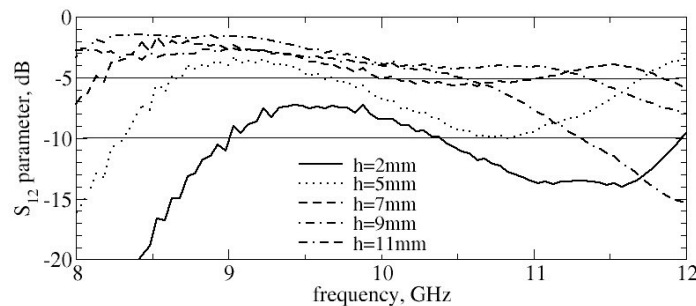


Fig. 6. Coupling between the two bow-tie antennas for different distances h between the antenna plane and its associated back reflecting plane.

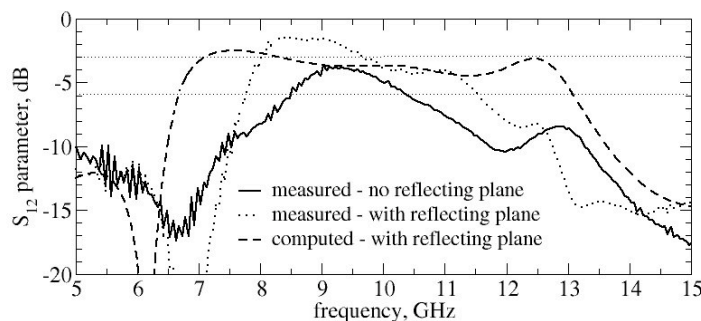


Fig. 7. Measured S₂₁ between the two bow-tie antennas separated by 2 mm without and with their reflecting plane located at 9mm.

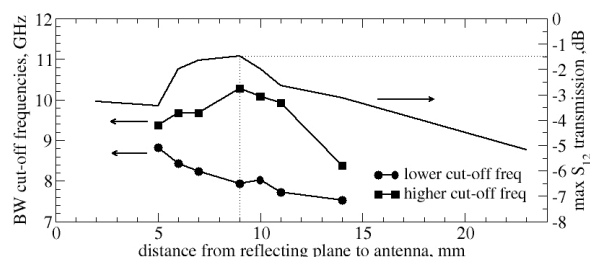


Fig. 8 Variations of cut-off frequencies at -4 dB and value of optimum coupling versus the distance between the conducting reflecting plane and the antenna. The distance between antennas was kept constant at 2mm.

Fig. 8 shows the variation of the bandwidth and the value of the optimum coupling versus the distance between the conducting reflecting plane and the antenna. A maximum transmission of -1.48 dB has been found at about 9 GHz for $h=9$ mm. It corresponds to a maximum bandwidth, taken at -4 dB for the transmission, of 2.4 GHz, which corresponds roughly to a 27 % bandwidth. This value is quite encouraging for the wireless transmission of analog signals. Nevertheless, it still needs to be increased for transmission of digital signals in order to keep a good bit-error-rate.

CONCLUSION

A set of two bow-tie antennas designed for X-band has been optimized and measured in near-field configuration to transmit microwave signals into cryogenic systems. It has been shown that the combination of the near-field configuration of the antennas, associated to a back reflecting plane carefully located behind each antenna, enables the transmission of a microwave signal in the 8 to 9.7 GHz range with a loss lower than 3 dB. The transmission loss stays below 2 dB over a 1 GHz bandwidth and can be as low as 1.5 dB over a narrower bandwidth centered at 8.45 GHz. These measurements are very encouraging for designing microwave cryogenic systems with improved performance regarding thermal loads and microwave losses. More work is on-going to further increase the bandwidth of such wireless system, in order to allow the transmission of digital signals.

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