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Application Note

Cryogenic Operation of Menlo MEMS Switches

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Overview

Menlo Micro MEMS switches have been demonstrated to operate at temperatures as low as 10 mK, making them suitable for use in dilution refrigerators, quantum computing systems, and other cryogenic instrumentation. This application note describes compatible Menlo Micro products, gate control at cryogenic temperatures, the required cooldown procedure, recovery steps in the event of a stuck switch state, and recommended practices for system-level integration.

This document applies to the following Menlo Micro products:

Part Number	Description
MM4250	DC-10GHz - SP6T - RF Switch Module for cryogenic applications
MM5130	DC-26GHz - SP4T 2.5 mm x 2.5 mm 29 pin WL-CSP (100µm Cu pillar)
MM5230	DC-26GHz - SP4T 2.5 mm x 2.5 mm 21 pin WL-FC (200 µm solder ball)

Note: Menlo Micro products that incorporate internal digital circuitry, such as System-in-Package (SiP) products, are not suitable for cryogenic operation. These products contain digital logic components that do not function at cryogenic temperatures. If in doubt, contact Menlo Micro support.

Gate Control at Cryogenic Temperatures

Menlo MEMS switches are ohmic devices controlled by a gate voltage. A high gate voltage (VBB ≈ 90 V) closes the switch channel (ON state), while a gate voltage near zero volts (0 V) opens the switch channel (OFF state). This fundamental gate control behavior is preserved at cryogenic temperatures; however, the switch state during cooldown has a direct impact on reliable operation, as described in the following section.

Gate drivers for cryogenic applications should follow the voltage-level guidance in Menlo Application note APN-0001 (HV Gate Driver Design), specifically the high/low gate voltage level specifications. Slew rate specifications in APN-0001 are not applicable to most cryogenic systems: the wiring and thermal-budget constraints of lines routed into the cryostat typically limit achievable drive current well below what is needed to meet standard slew rate targets, and this does not affect MEMS switch reliability when switching occurs at room temperature prior to cooldown. Because the gate voltage will transition more slowly than the datasheet slew rate under these conditions, the switch will take correspondingly longer to fully actuate; a settling time of approximately **25 ms** after a gate voltage transition is recommended before relying on the switch's RF state. Gate driver circuitry should be located at room temperature, outside the cryogenic system, with gate lines routed through the cryogenic system boundary via appropriate low-thermal-conductance wiring.

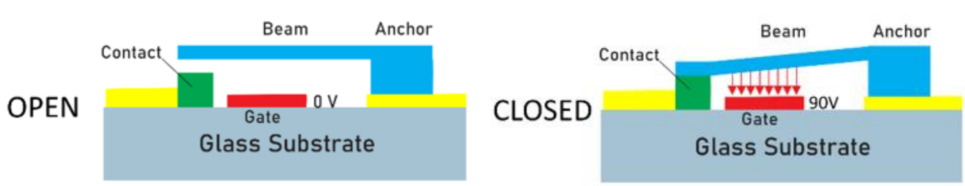

Figure 1: Cross-Section Diagram of MEMS Switch with gate line; 0V = OFF and 90V = ON

Cooldown Procedure

The state of the MEMS switch during system cooldown is critical to ensuring reliable operation at cryogenic temperatures.

All switch channels must be in the open (OFF) state, gate voltage at 0 V, before and throughout the cooldown process.

Cooling a cryogenic system with one or more switch channels in the closed (ON, 90 V) state can result in those channels becoming stuck in the closed state upon reaching cryogenic temperatures. Cooling the system with all switches in the open state allows normal operation to be established at cryogenic temperatures.

The recommended cooldown procedure is:

1. Before initiating cooldown, verify that all gate voltages are set to 0 V and all switch channels are confirmed open.
2. Cool the cryogenic system to the target operating temperature with all switches remaining in the open state.
3. Once the system has reached the target operating temperature and stabilized, apply the desired gate voltages to configure switch states as required by the application.

Recovery from a Stuck Switch State

In the event that a MEMS switch becomes stuck in a closed or open[1] state at cryogenic temperatures, the switch will return to normal functionality upon warming. Menlo MEMS switches are not permanently damaged by a stuck state occurring at cryogenic temperatures.

To minimize system downtime, it is not necessary to warm the system all the way back to room temperature to recover a stuck switch. The mechanical stresses that cause sticking at cryogenic temperatures are typically relieved at temperatures between **30 K and 80 K**. Once this temperature range is reached, the switch will resume normal gate-controlled operation. Full warm-up to room temperature will also recover the switch if necessary.

The recommended recovery procedure is:

1. If a switch is confirmed stuck at cryogenic temperature, begin warming the cryogenic system.
2. Monitor switch functionality as the temperature rises. Apply and remove gate voltage as the system warms to determine at what temperature the switch responds normally.
    - Switches typically resume normal operation in the range of 30 K to 80 K.
3. Once normal switch operation is confirmed, set all switch channels to the open state (0 V on all gate lines).
4. Cool the system back down to the target operating temperature, following the cooldown procedure above (all switches open during cooldown).

[1] In rare instances, a MEMS switch can become stuck in the open state despite proper adherence to the cooldown procedure.

Bias Tee Recommendation for System Integration

A recommended practice for cryogenic systems incorporating Menlo MEMS switches is to install bias tees at the RF input and output ports at the room-temperature boundary of the cryogenic system. A bias tee allows an RF signal and a DC voltage to be applied or monitored on the same coaxial line without interference between the two. This configuration provides a convenient method for checking switch states without a full system warm-up.

Figure 2: Bias tees placed at room temperature side of the RF ports.

This is particularly useful as a troubleshooting tool. If a switch is suspected to be stuck or unresponsive based on the RF performance, the bias tees can be used to send a DC voltage to check for switch continuity against the expected switch state. Note that some multimeters source a small current when measuring resistance or continuity. Avoid continuity/resistance modes on lines going into the cryostat, and instead use a high-impedance voltage measurement, to avoid introducing an unwanted heat load on the cold stage. Additionally, avoid toggling the switch state while a measurement voltage is still applied across it. Switching under load ("hot switching") can degrade the switch over time and shorten its operational lifetime; as a general rule, switching should occur below 0.5 V to avoid this degradation, consistent with manufacturer guidance for these devices.

When implementing bias tees in this configuration, note the following:

- Select bias tees with a frequency range compatible with the MEMS switch being used (DC to 10 GHz for MM4250; DC to 26 GHz for MM5130 and MM5230).
- Locate bias tees at the room-temperature side of the cryogenic system boundary to avoid exposing the bias tee components to cryogenic temperatures.
- Avoid introducing floating DC nodes on the RF lines. Refer to Menlo Application note AN-0002 (Avoiding Floating Nodes in Ohmic MEMS Circuits) for guidance on ensuring all RF nodes have a defined DC potential.

Important Information

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