menlomicro

The Ideal Switch®

Enabling the electrification of everything:

Milliwatts-to-kilowatts, DC-to-light.

May 2026

Menlo Micro Company Overview

The Ideal Switch® is the most revolutionary electronics component invention since the transistor

- **Company:**
  - Founded in Dec, 2016
  - Irvine, CA (Headquarters);
  - Albany, NY (SUNY) (Advanced R&D)
  - Employees – 70+ in the US
- **Capitalization:**
  - $228M raised through series C
  - Closed series C $151M Feb 2022

Our investors

standard investments · PALADIN · FUTURESHAPE · VERTICAL VENTURE PARTNERS · PIVA · DBL PARTNERS DOUBLE BOTTOM LINE VENTURE CAPITAL · Fidelity · Adage

- **The Ideal Switch® Technology:**
  - World's smallest, most reliable, most efficient micro-electro-mechanical switch (MEMS) for RF and Power
  - Developed over 12+ years at GE Research and 7+ years of commercialization by Menlo Micro
  - Ideal Switch 8" wafer manufacturing line in production since Q4 2020
- **Intellectual Property:**
  - Fundamental material science-based IP licensed exclusively from GE, 65 patent families
- **Markets:**
  - Semiconductor Test, Test & Measurement
  - Aerospace and Defense
  - Wireless Infrastructure
  - Energy Distribution

What's new at Menlo Micro:

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- 5 years of production on Ideal Switch® 8" manufacturing line. 1M total units shipped through Q2-2025
- 2023 to 2024 YOY $ growth: **3x increase**, 2024 to 2025 forecast YOY $ growth: **2x increase**

ideal switch® Gaining Traction!

(10) products now released to production!

- MM5130 (Nov-2020), MM5600 (Nov-2021)
- MM5120, MM5140 (Aug-2022), MM101 (Dec-2022)
- MM5620 (April-2023), MM5622 (Sep-2024)
- MM5230 (Mar-2025), MM5625 (Jun-2025)
- MM5130-NLX (Sep-2025)

Next products to be introduced in 2025:

- RF Products: MM5130-EDC, MM4250
- First Power Products: MM9200 (300V/10A)

Key Product Initiatives for 2026:

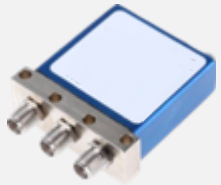
- Launch next high frequency product developments
  40GHz, 70GHz & 128Gbps loopback relays
- Power Products: MM9200 (300V/10A)

Two types of switches power today's world.

But they're full of compromises.

ELECTROMECHANICAL

RF



High Power RF Coax
High Isolation
Low Insertion Loss

RF Surface Mount
High Isolation
Low Insertion Loss

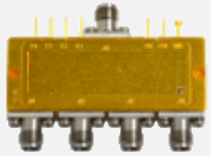
POWER

AC/DC Power Relay

Surface Mount Signal Relay

SOLID STATE

RF



PIN diode
High Power
Fast Switching
Long Life

CMOS
Low Power
Fast Switching
Long Life

POWER

AC/DC SSR w/heatsink
High Voltage
High Current

DC SSR w/heatsink
High Current

The Good: Can handle lots of power

- Metal contacts: low loss and great linearity for RF signals.
- Can handle high power, eg circuit breakers or RF relays.
- "On" - doesn't generate heat under high currents.
- "Off" - air-gap open, fully isolated.

The Bad: Big, slow, clunky and expensive

- Moving parts limit switch rate, speed and reliability.
- Manufacturing inconsistencies (some are still assembled by hand).
- Sensitive to mechanical shock, vibration and humidity.

The Good: Small, fast

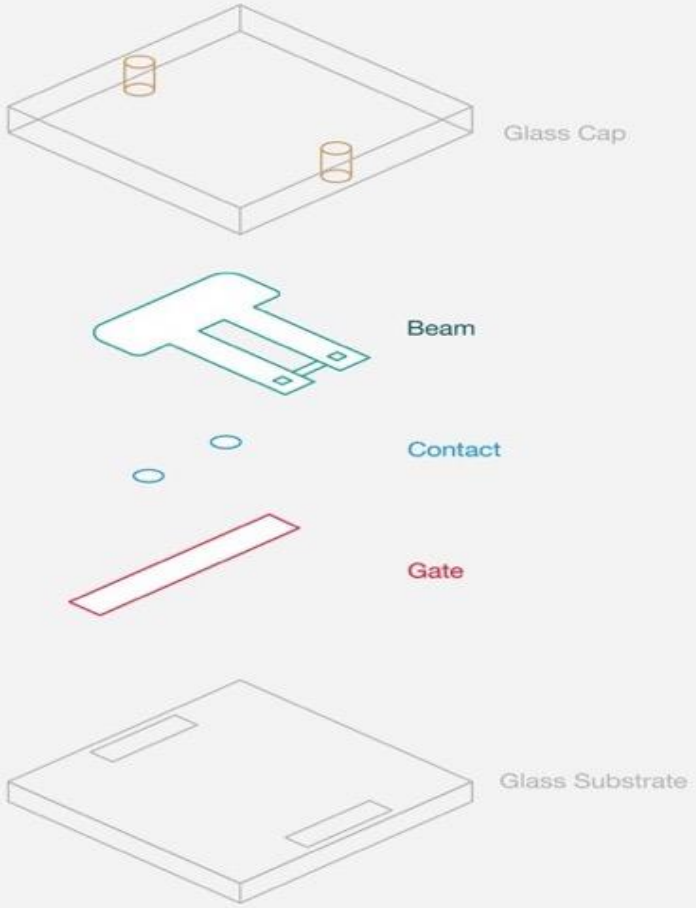
- Small size allows for lightweight, tighter packing.
- Inexpensive to manufacture at scale.
- Fast, silent switching.
- Immune to mechanical shock, vibration, humidity.

The Bad: It's a semiconductor, not a conductor

- "On" - non-zero losses, generates heat requiring large heatsinks.
- "Off" - always on, leakage currents, waste power.
- Non-linear effects of transistor distorts RF signal integrity.

Introducing the Ideal Switch™

Technology platform with breakthrough innovations in materials and processing



Unique Glass Packaging

Improved RF & thermal performances
High RF power handling

Through-Glass-Via

Low parasitics and resistance
Small-size package

High Reliability

>3B switching cycles
Hermetic-sealed package

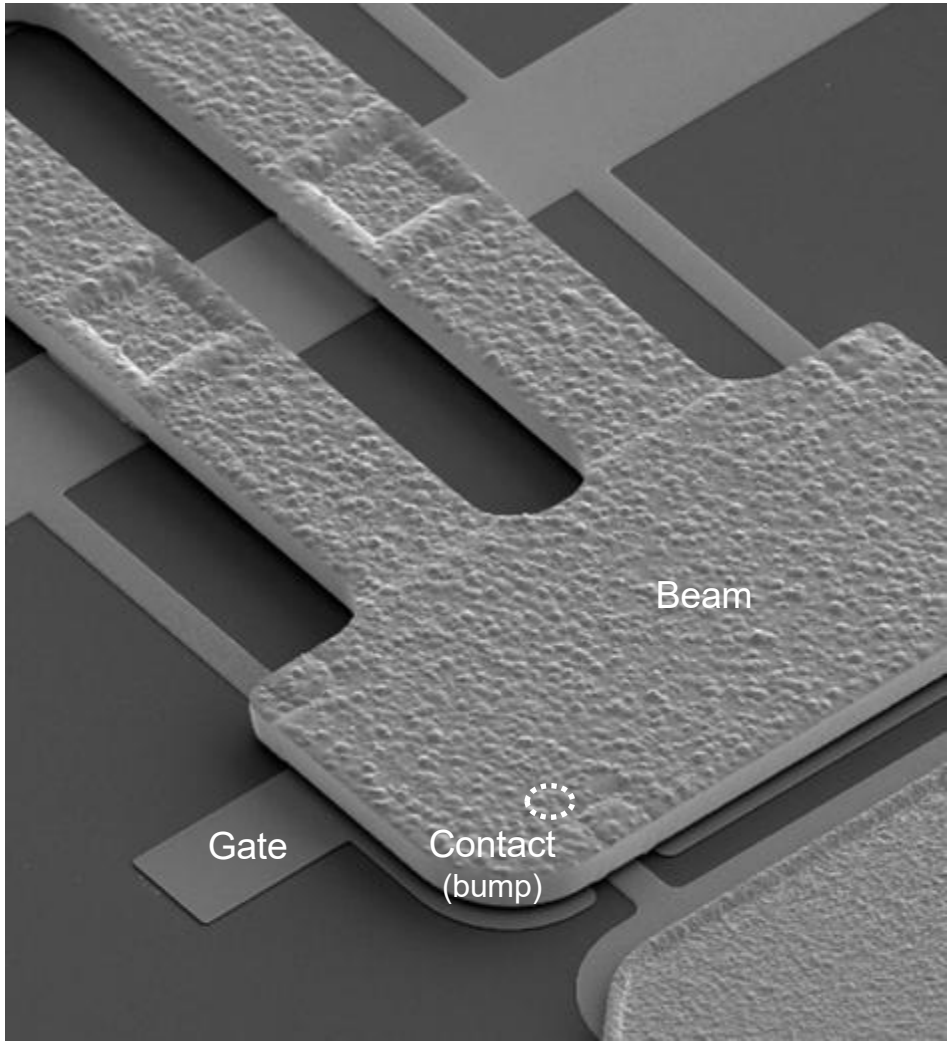
Scalability

100µm x 100µm (unit cell)

Scalable switch arrays for high voltage, high current, high power

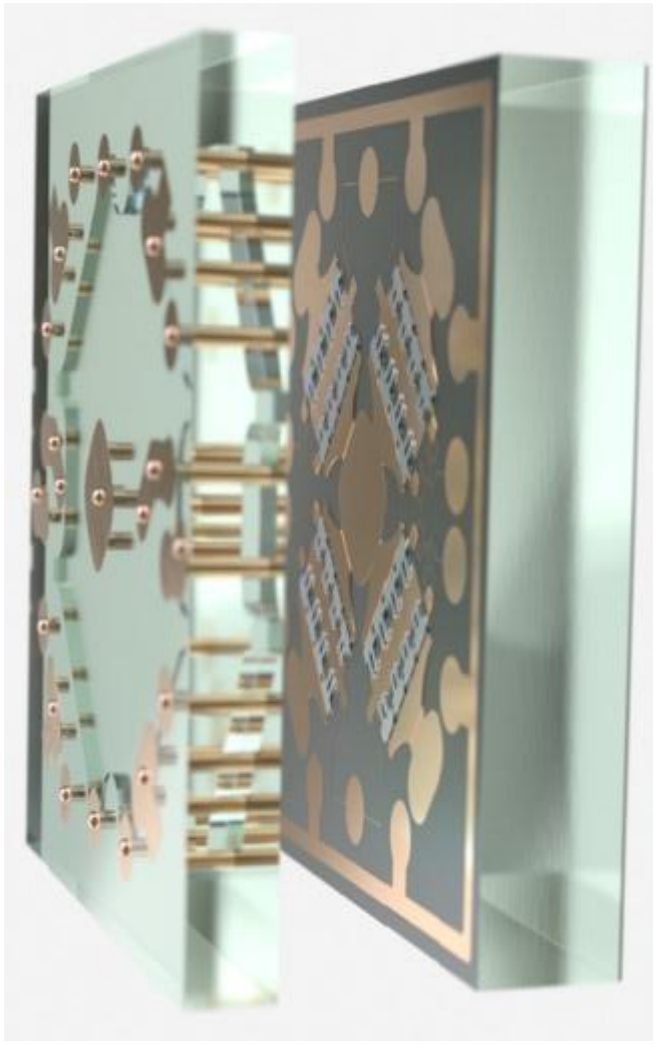
The Beam

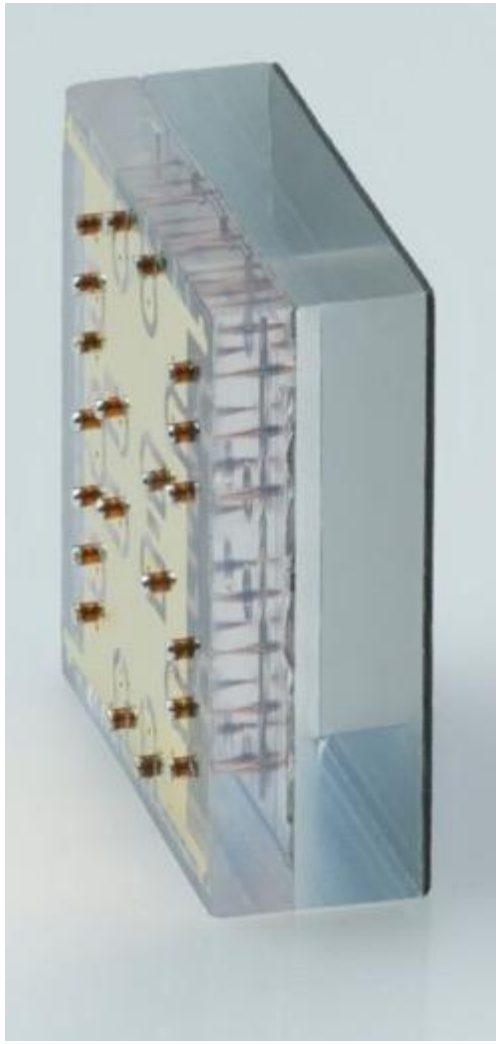
Smaller than a human hair, can handle >400 V



System-In-Glass Packaging

Close-up view of Through-Glass-Vias and hermetically sealed package





Ideal Switch® Products

Product Portfolio – RF & Microwave Products

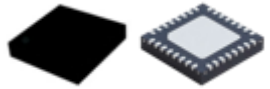


	RF & Microwave			
	MM5230	**MM5130-NLX**	**MM5120**	**MM5140**
Markets	Telecommunication, Wireless Systems, Aerospace & Defense, Test & Measurement			
Applications	Tunable & Programmable Filters, High-Power Low-Loss RF Switch Matrices, Programmable RF Beam Steering			
Switch Type	SP4T			
Frequency Range	DC – 26 GHz		DC – 18 GHz	DC – 8 GHz
RF Power	25 W (CW), 150 W (pulsed)	25 W (CW), 150 W (pulsed) **OFF: 480 W (pulsed)**	25 W (CW), 150 W (pulsed)	25 W (CW), 150 W (pulsed)
Insertion Loss	0.3 dB @ 6 GHz		0.4 dB @ 6 GHz	0.3 dB @ 3 GHz
Linearity (IP3)	>90 dBm			
Control	Direct HV		SPI/GPIO	SPI/GPIO
DC Supply	89 V (gate)		**3.3 V (ctrl), 5 V (V_{CP})**	**3.3 V (ctrl), 5 V (V_{CP})**
Lifetime	>3B cycles			
Package	2.5 mm x 2.5 mm **21-pin WLCSP**	2.5 mm x 2.5 mm 29-pin WLCSP	5.2 mm x 4.2 mm LGA	
Operating Temp	-40C to 85C	-40C to 85C	-40C to 85C	
Availability	**In production**	**In production**	**In production**	

Product Portfolio – High-Speed Products

	High-Speed Digital			
	MM5600	**MM5620**	**MM5622**	**MM5625**
Markets	Semiconductor Test & Measurement, Automated Test Equipment, Aerospace & Defense Equipment			
Applications	High-Speed Digital SoC Loopback Testing, PCIe Gen6, DDR5, MIPI, USB-C, High-Speed Ethernet, etc			
Switch Type	DPDT	2x DP3T Diff **AC** Coupled	2x DP3T Diff **DC** Coupled	2x DP3T Diff **AC** Coupled
Max Data Rate PAM4	40 Gbps	64 Gbps	80 Gbps	80 Gbps+
Insertion Loss	1.3 dB @ 10 GHz	1.5 dB @ 16 GHz		1.1 dB @ 16 GHz
Control	Serial to Parallel	SPI/GPIO		
DC Supply	5 V (control), 89 V (gate)	3.3 V (control), 5 V (V_{CP})		
Lifetime	> 3B cycles			
Package	8 mm x 8 mm LGA	8.2 mm x 8.2 mm LGA		
Operating Temp	-40C to 85C			
Availability	**In production**			

Product Portfolio – Drivers & Power



	Drivers	Power Chip	Power Module
	MM101	**MM92xx**	**DC Module xx**
Markets	All	Hi-Rel, Data Center, Industrial Automation	Hi-Rel, Data Center, Industrial Automation
Applications	All	Replacement for Electro-Mechanical relays, contactors and circuit breakers	Replacement for Electro-Mechanical relays, contactors and circuit breakers
Switch Type	High voltage CP + 8-channel driver	SPST	SPST
DC Current		15 A (AC or DC), 10 mΩ*	30A, 15 mΩ*
DC Carry/Standoff Voltage	---	400 V (AC or DC)*	800 VDC
Control	SPI/GPIO	Direct	Direct
DC Supply	3.3 V (control), 5 V (V_{CP})	90 V (gate)	90V
Lifetime	---	>100M cycles	>10M cycles
Package	5 mm x 5 mm QFN 1.6 mm x 2.4 mm WLCSP	5 mm x 5 mm WLCSP	14 pin 40 x 30 mm*
Operating Temp	-40C to 85C		
Availability	**In production**	**Engr. Samples: Q2, 2027** **Production: Q4 2027**	**Engr. Samples: Q1, 2027**

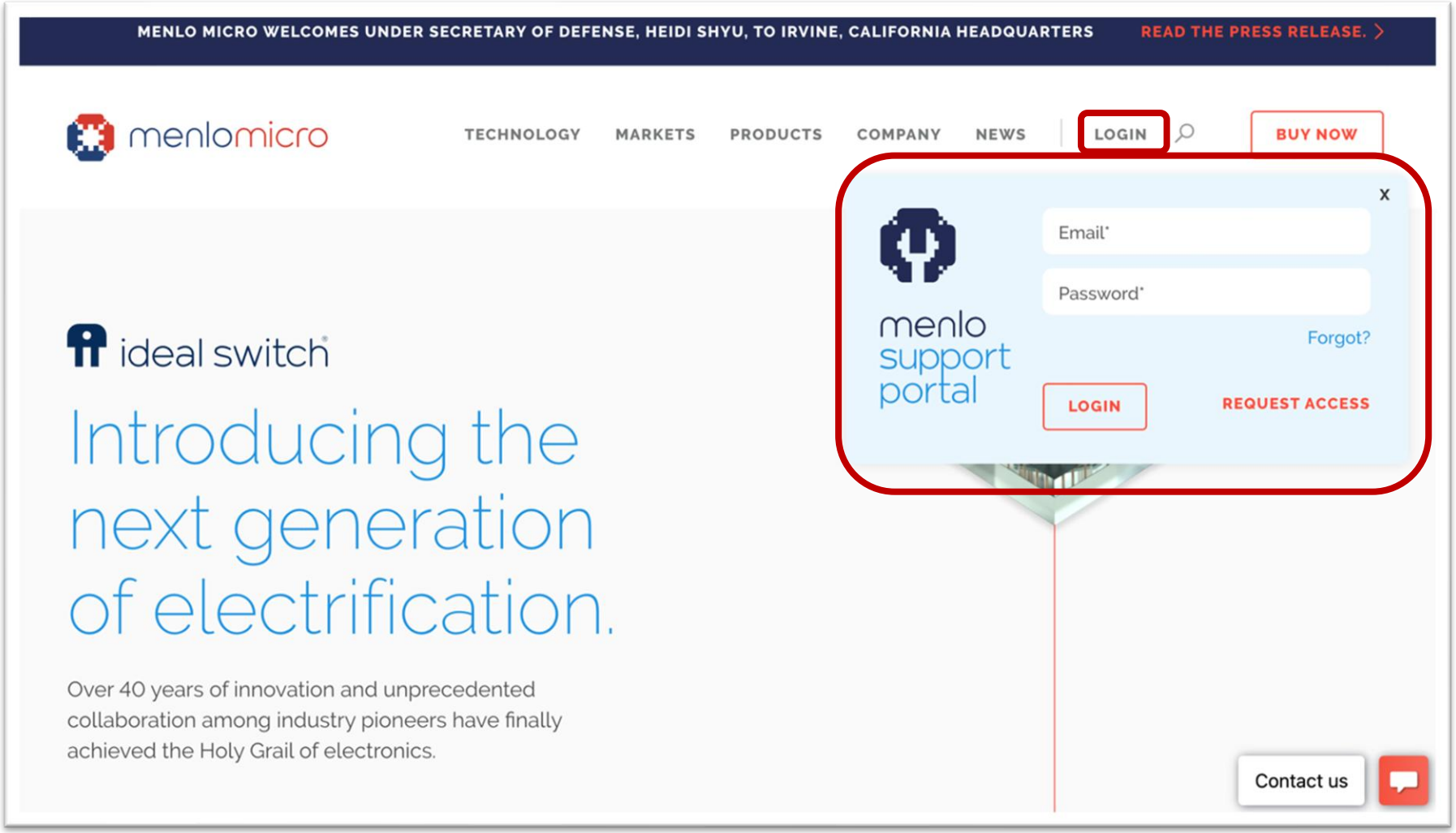
Product Portfolio – Cryogenic Products

	RF & Cryo	
	MM5230	**MM4250**
Markets	Quantum Computing	
Applications	Cryogenic Device Characterization, Cryogenic multiplexing	
Switch Type	SP4T	SP6T
Frequency Range	DC – 26 GHz	DC – 10 GHz
RF Power	25 W (CW), 150 W (pulsed)	
Insertion Loss	0.3 dB @ 6 GHz	2 dB @ 6 GHz
Linearity (IP3)	>90 dBm	
Control	Direct HV	
DC Supply	89 V (gate)	
Lifetime	>3B cycles	
Package	2.5 mm x 2.5 mm 21-pin WLCSP	4.5 cm x 4.5 cm x 3.6 cm SMA
Availability	**In production**	**Engineering Devices Available**

Website Resources – The Menlo Support Portal

Additional product support/documentation can be found by logging in through Menlo's website http://www.menlomicro.com/

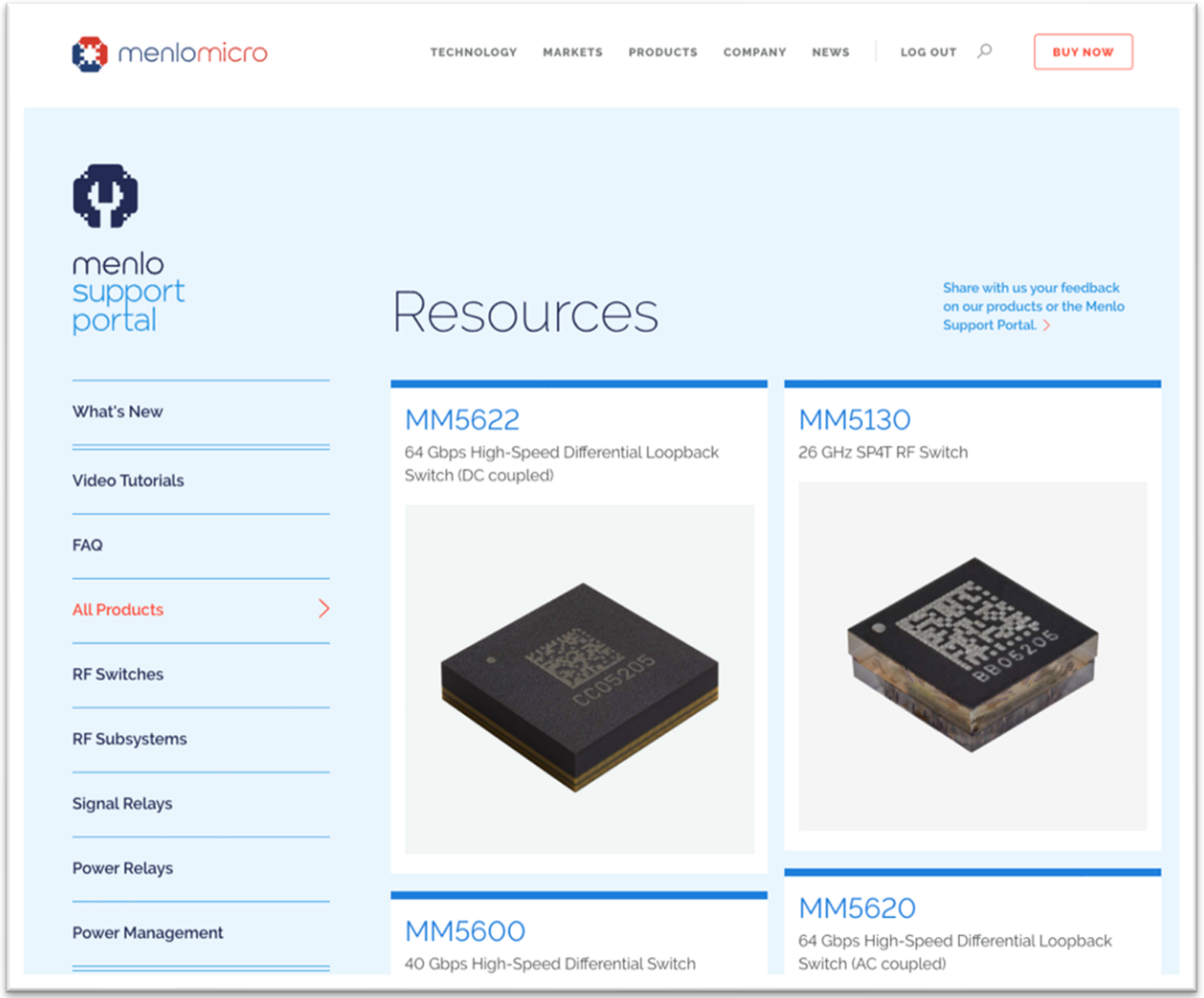
- Users can sign up by clicking on "Login" and then "Request Access"
- Access is typically granted within 24hrs



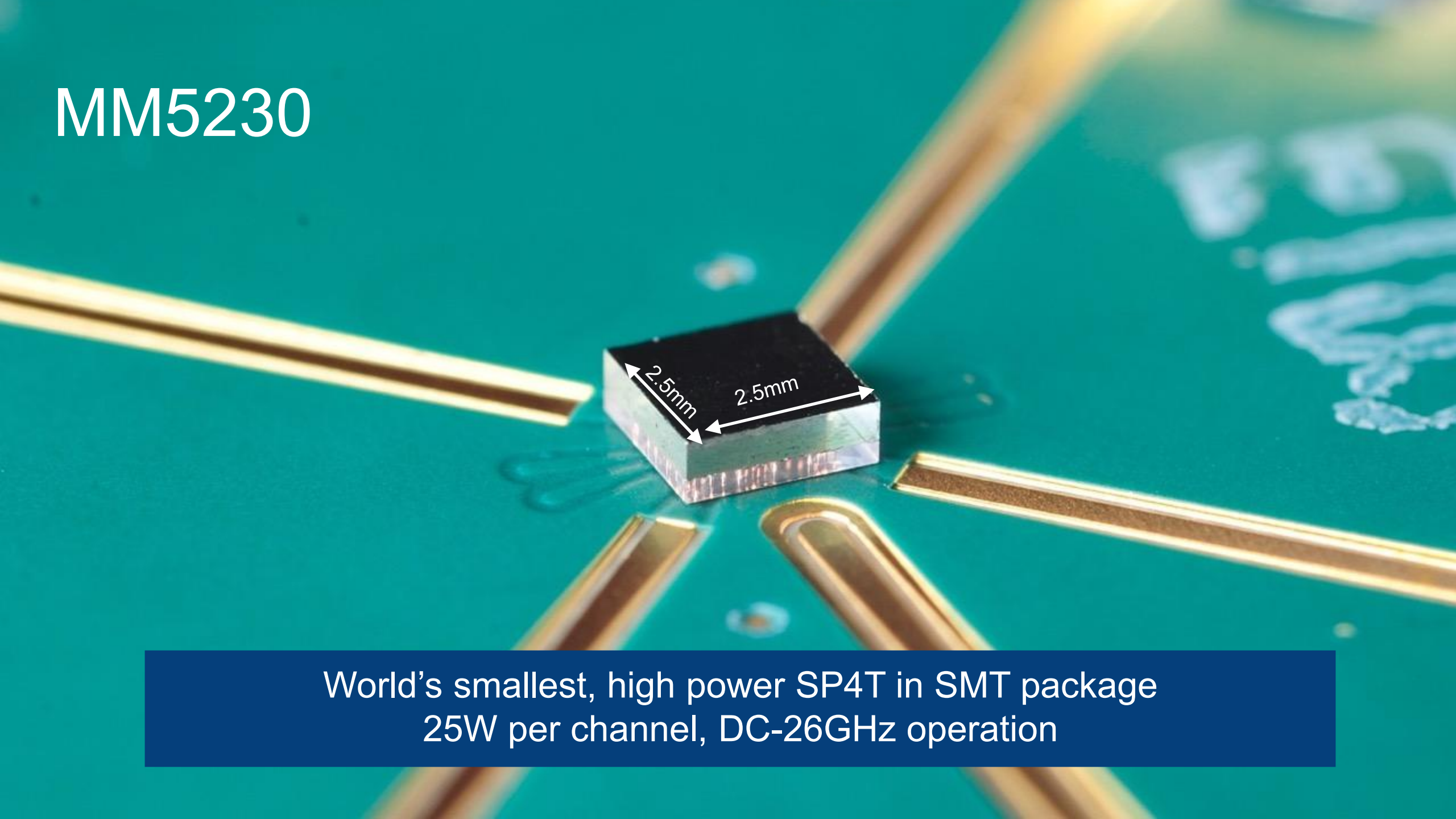
Website Resources – The Menlo Support Portal

Each Series consists of the following where you can find:

- Product Briefs
- Application Notes
- Qualification Reports
- S-Parameters
- Transmission Line Models
- CAD Drawings
- Assembly Instructions
- RoHS/REACH Certificates
- Eval Board GUI
- Eval Board Instructions
- Video Tutorials
- FAQs
- Product Images



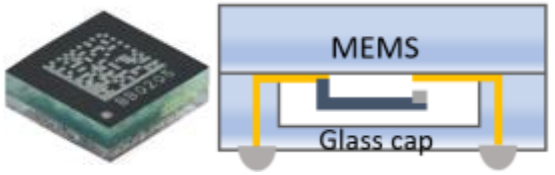
MM5230

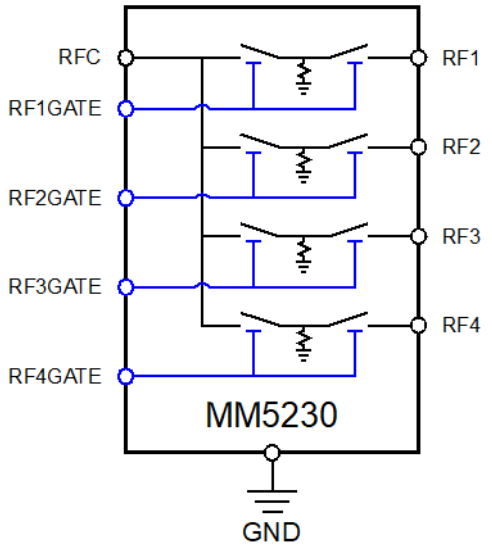


World’s smallest, high power SP4T in SMT package
25W per channel, DC-26GHz operation

MM5230 – Product Highlights

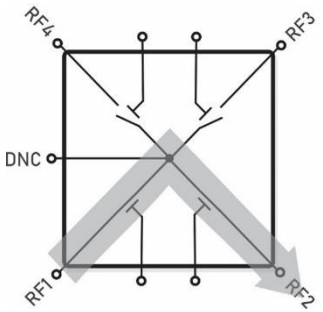
- **Switch Type**: SP3T (Super-Port), SP4T (Standard)
- **Frequency**: DC to 26 GHz (Super-Port)
- **Insertion Loss**: 0.8 dB @ 18 GHz (Super-Port)
- **Isolation**: 28 dB @ 18 GHz (Super-Port)
- **RF Power**: 25 W (CW) @ 6 GHz, 150 W (pulse)
- **IP3**: 95 dBm
- **Actuation Voltage**: 89 V
- **Reliability**: 3B switching cycles guarantee
- **Package**: 2.5 mm x 2.5 mm x 0.9mm WLCSP (BGA)



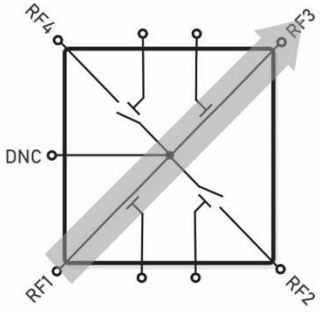


MM5230 Super-Port Mode

- Bypass the RFC connection, connect any of the remaining 4 channels to any other channel
- SP3T with improved broadband performance out to 26 GHz

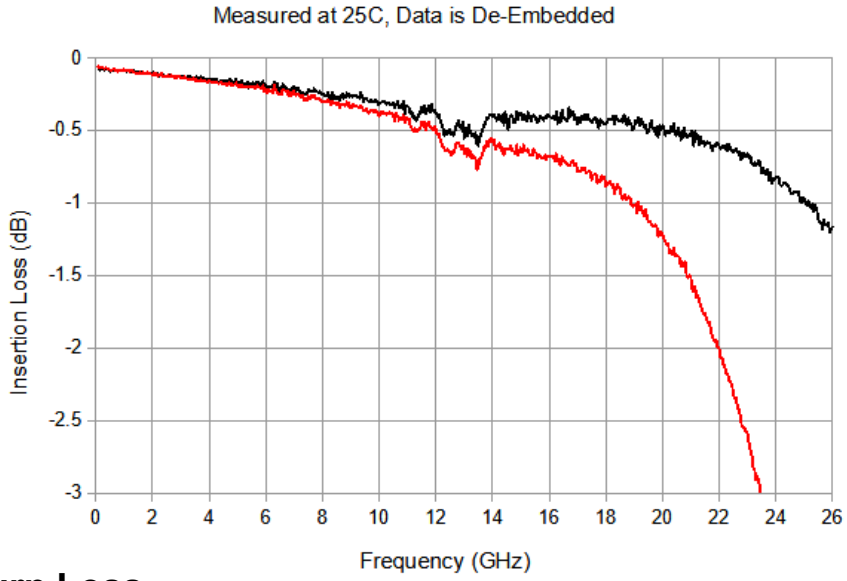


Adjacent
RF1-RF2
RF2-RF3
RF3-RF4
RF4-RF1



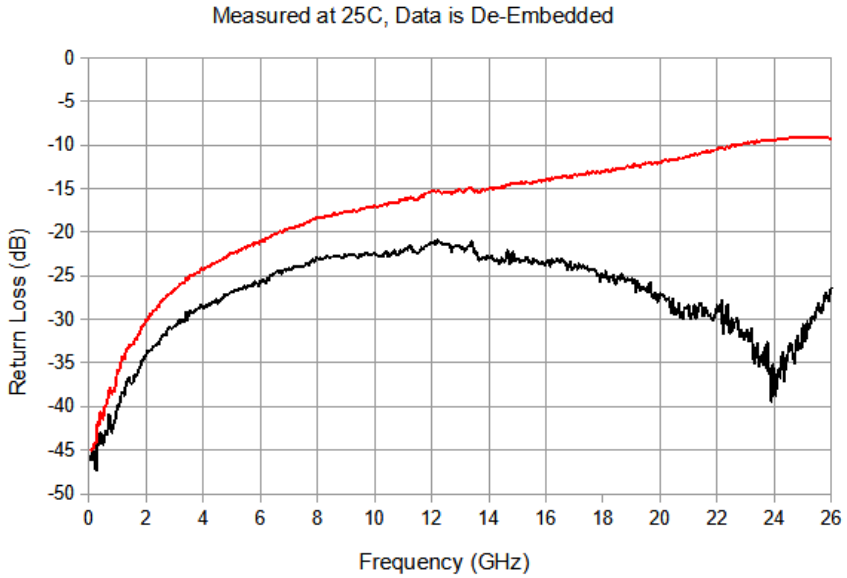
Non-Adjacent
RF1-RF3
RF2-RF4

Insertion Loss

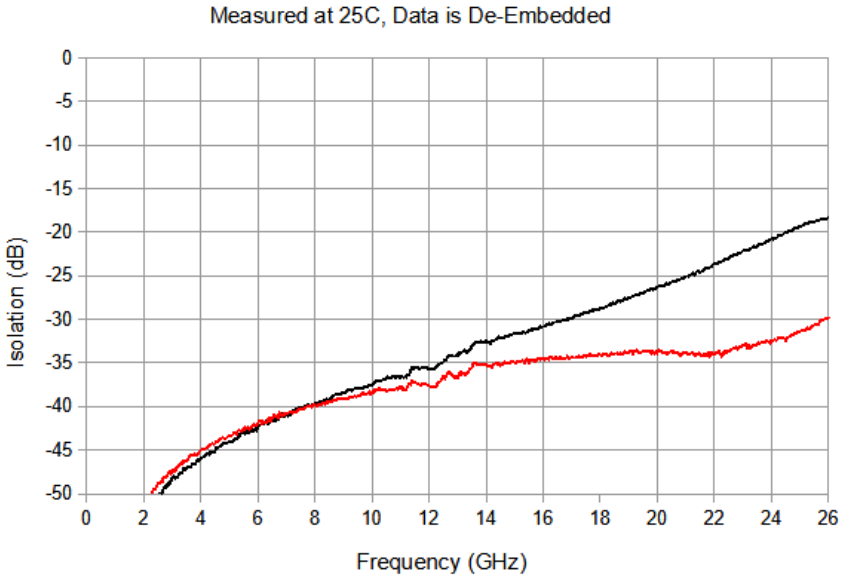


Adjacent
Non-Adjacent

Return Loss



Isolation



MM5230 – CH. To CH. Variation

MM5230

25W SP4T
DC to 18GHz+
2.5mm x 2.5mm
WL-Flip-Chip
package

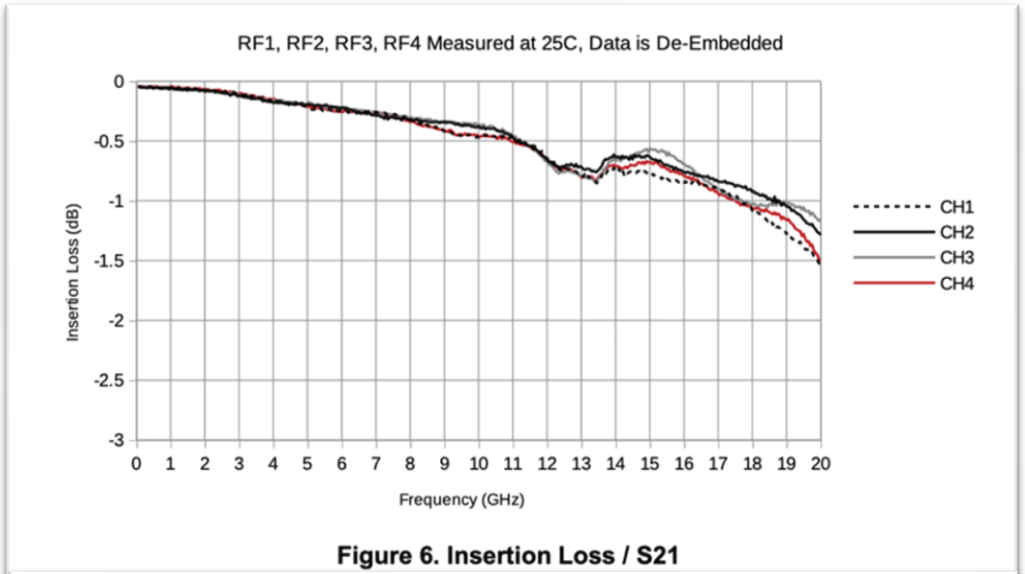


Figure 6. Insertion Loss / S21

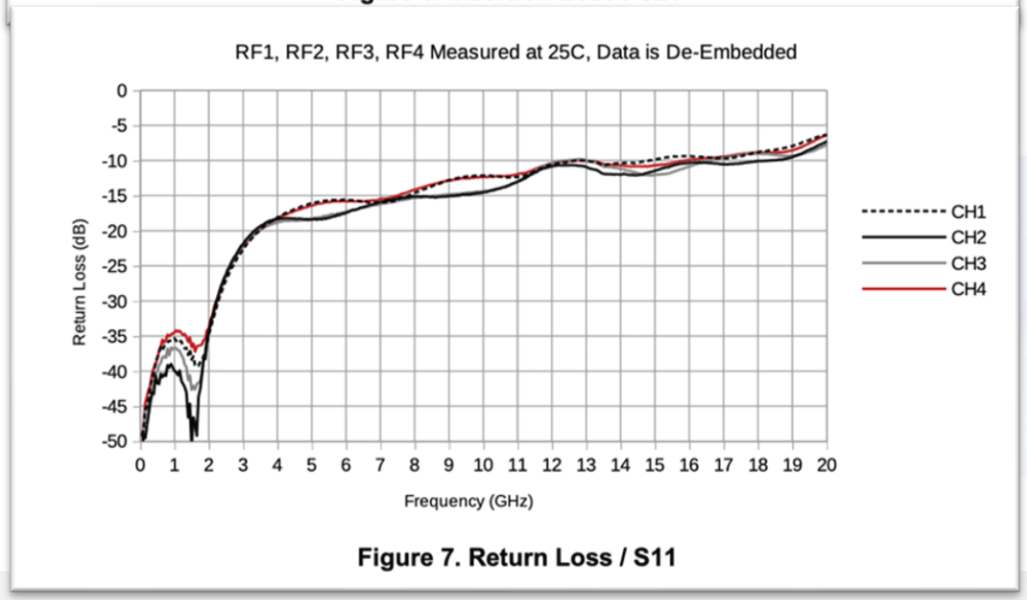


Figure 7. Return Loss / S11

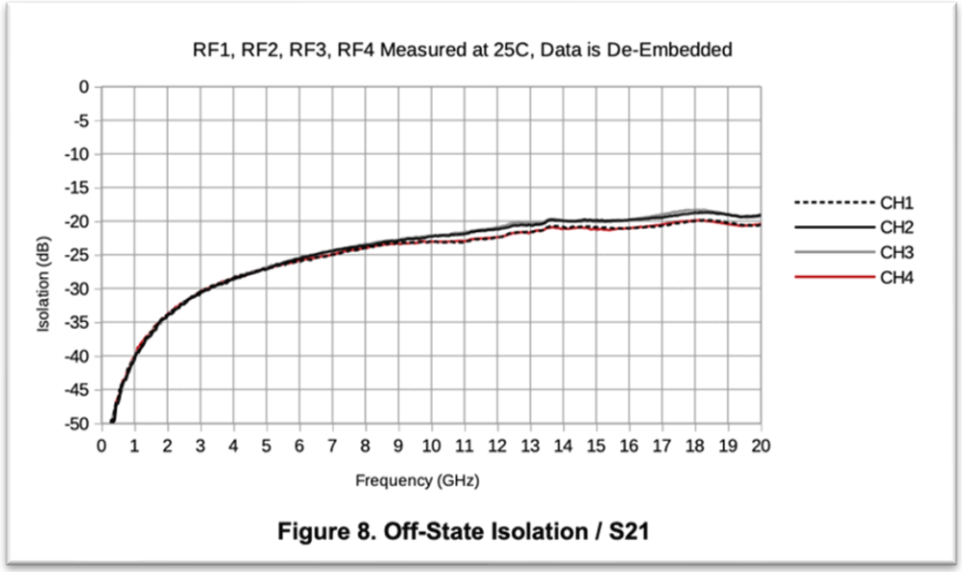


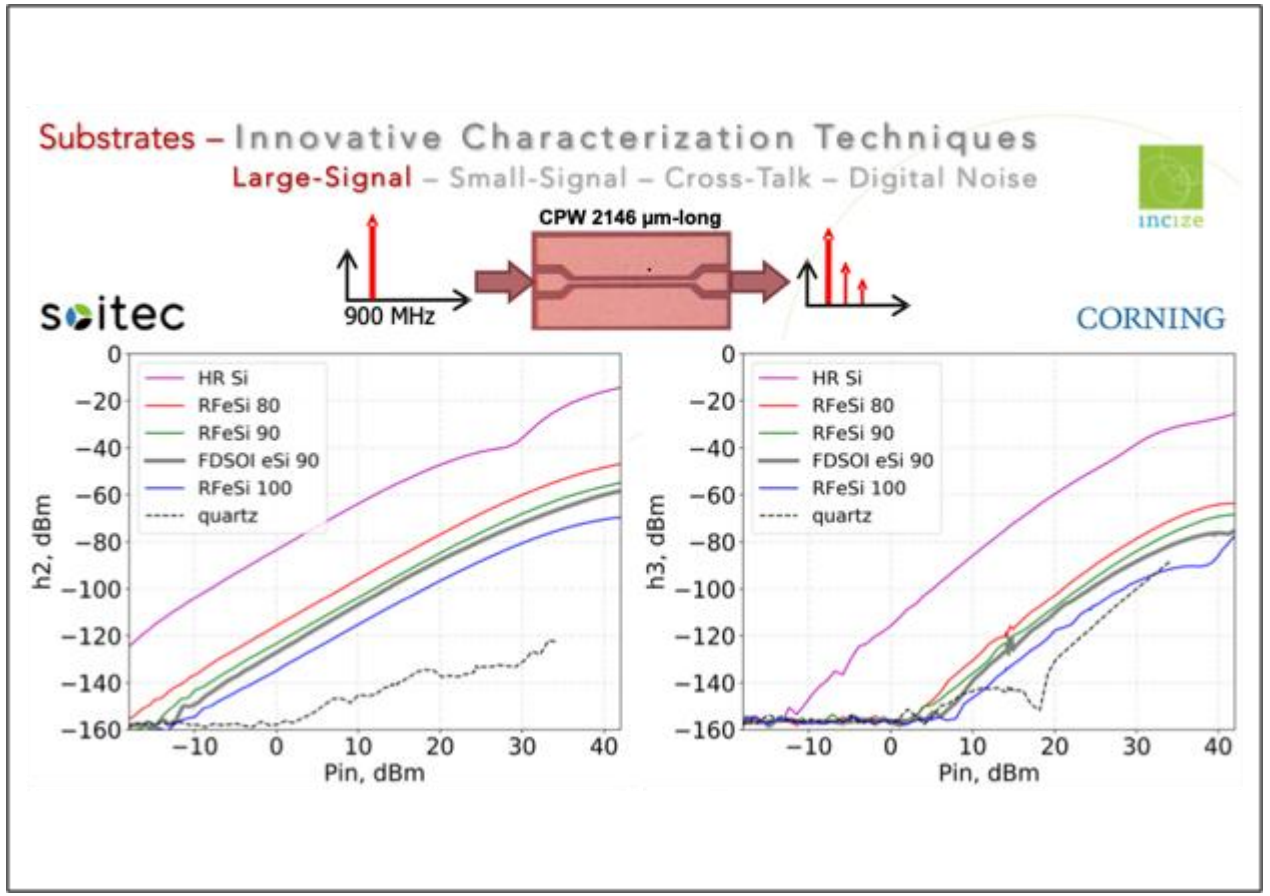
Figure 8. Off-State Isolation / S21

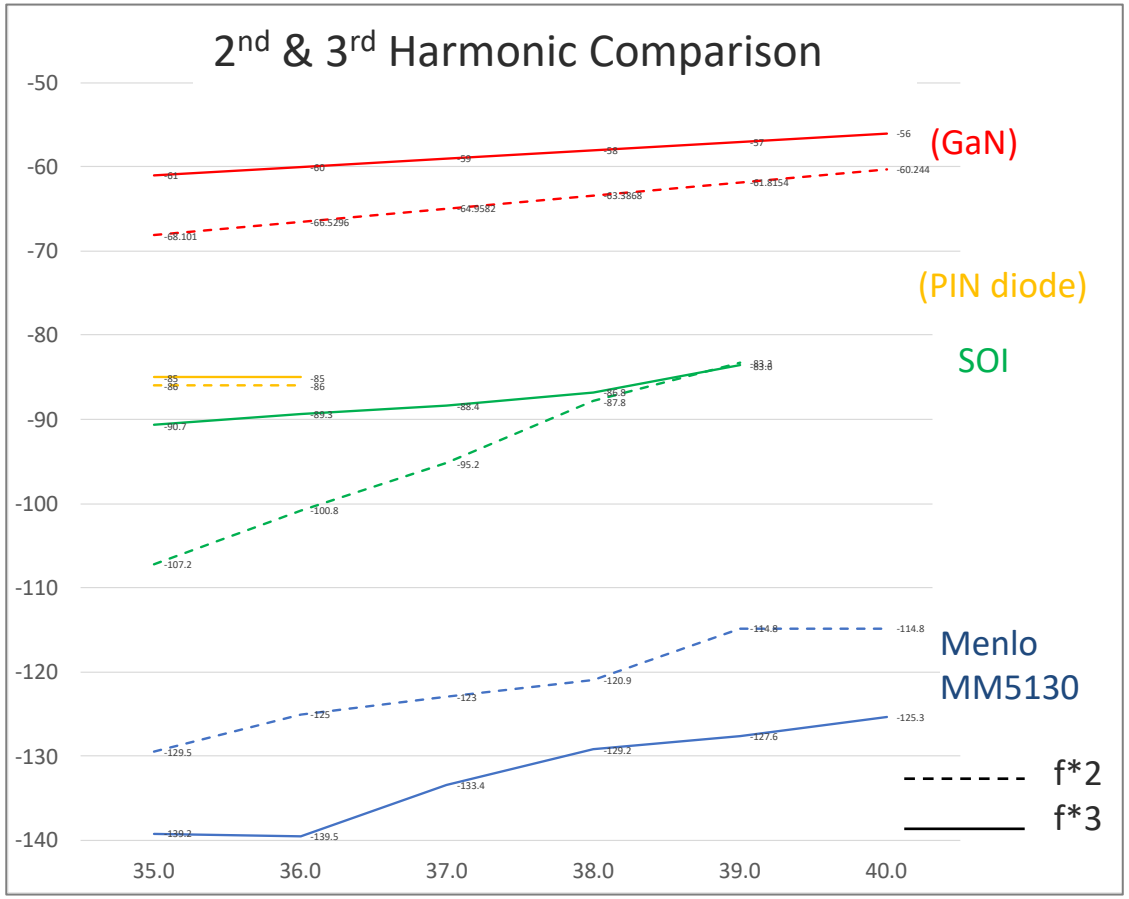
MM5230 EVK

- Measurements taken on Keysight M9375A VNA
- PCB and connectors deembedded using Keysight AFR method:

http://literature.cdn.keysight.com/litweb/pdf/5992-0656EN.pdf

Metal-on-Glass for Highest Linearity



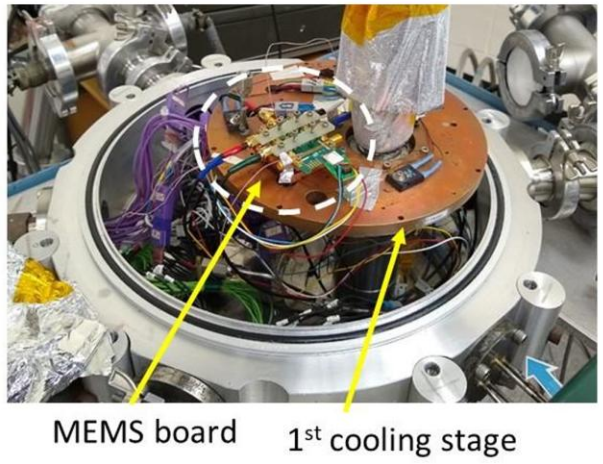


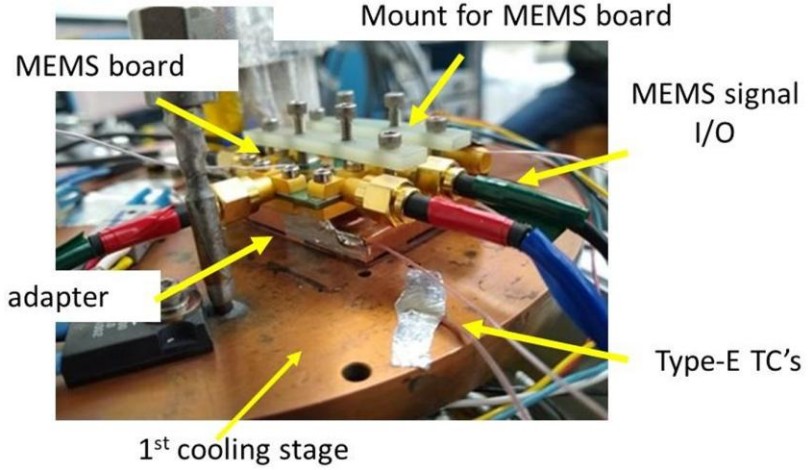
Moving from silicon to glass and removing the transistor from the RF signal chain helps reduce many sources of non-linearity.

MEMS Testing at Cryogenic Temperatures

- NIST - Small Scale Mechanical Testing Group
- Testing of MM5130EVK at 15K and 60K

- Publications:
  - Characterizing MEMS Switch Reliability for Cryogenic Applications such as Quantum Computing | NIST (2023)
  - Evaluating MEMS switch lifetime at cryogenic temperatures (Currently under review)





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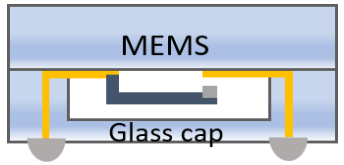
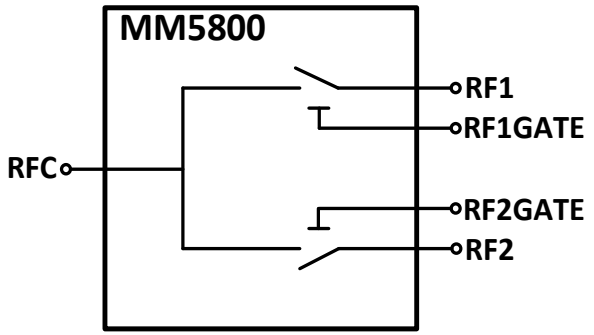
MM5800
DC – 70 GHz
SPDT Switch

Product Roadmap – MM5800 DC to 70 GHz SPDT Switch

New Die for mmWave Applications

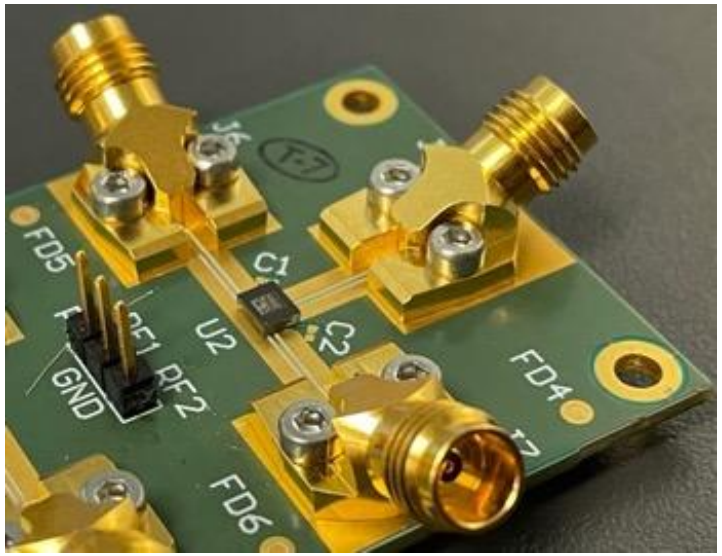
- Single SPDT
- Low Loss: 0.4 dB @ 40 GHz
- High Power: 2 W (CW), 20 W (pulsed)
- High Linearity: 95 dBm (IP3)
- High Isolation: 30 dB @ 40 GHz
- Fast Switching Speed: 8 µs
- High Reliability: >3 B switch cycles
- WL-CSP easy to assemble package





3.4mm x 2.7mm WL-CSP

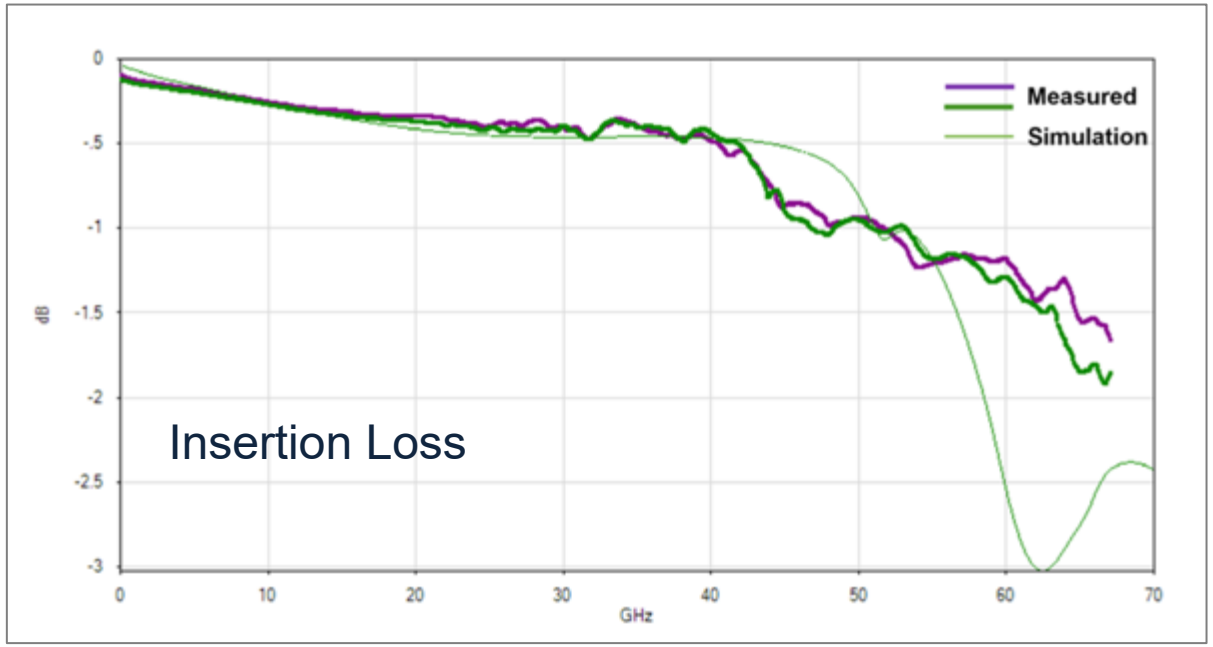
MM5800 EVK

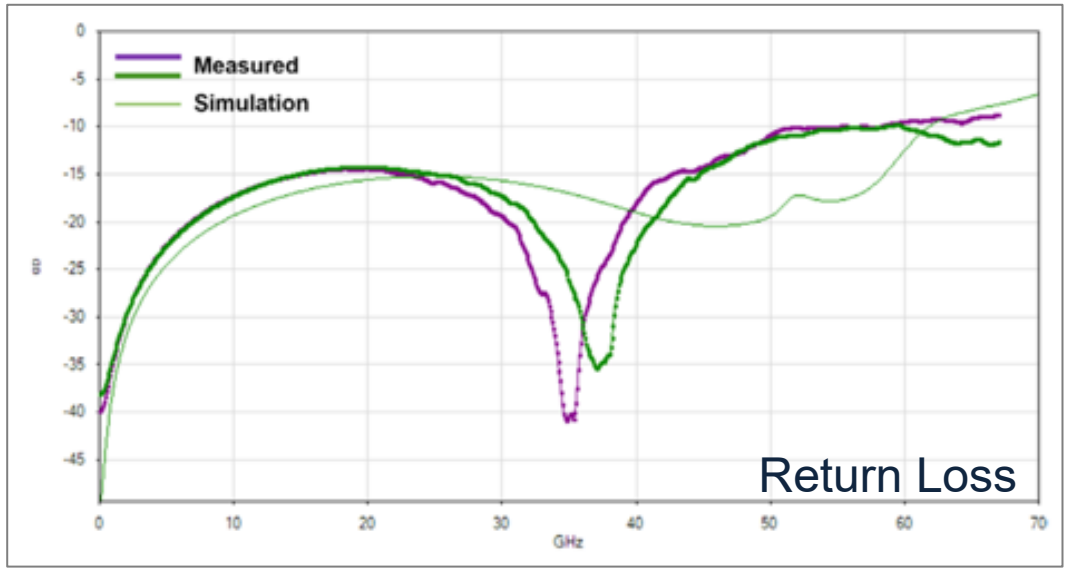


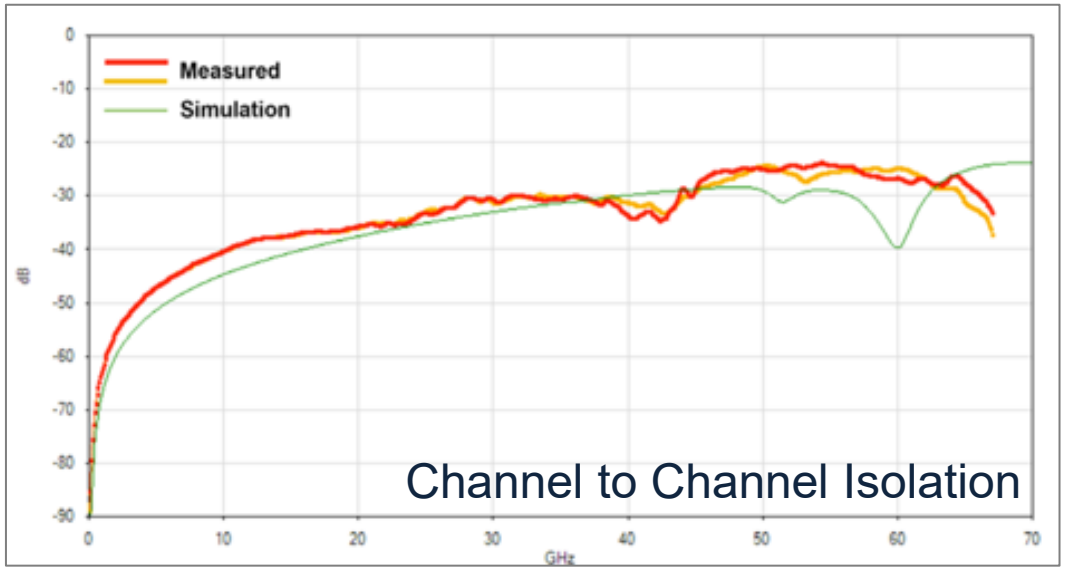
- Engineering devices currently available for sale.

MM5800 – SPDT Target Specifications

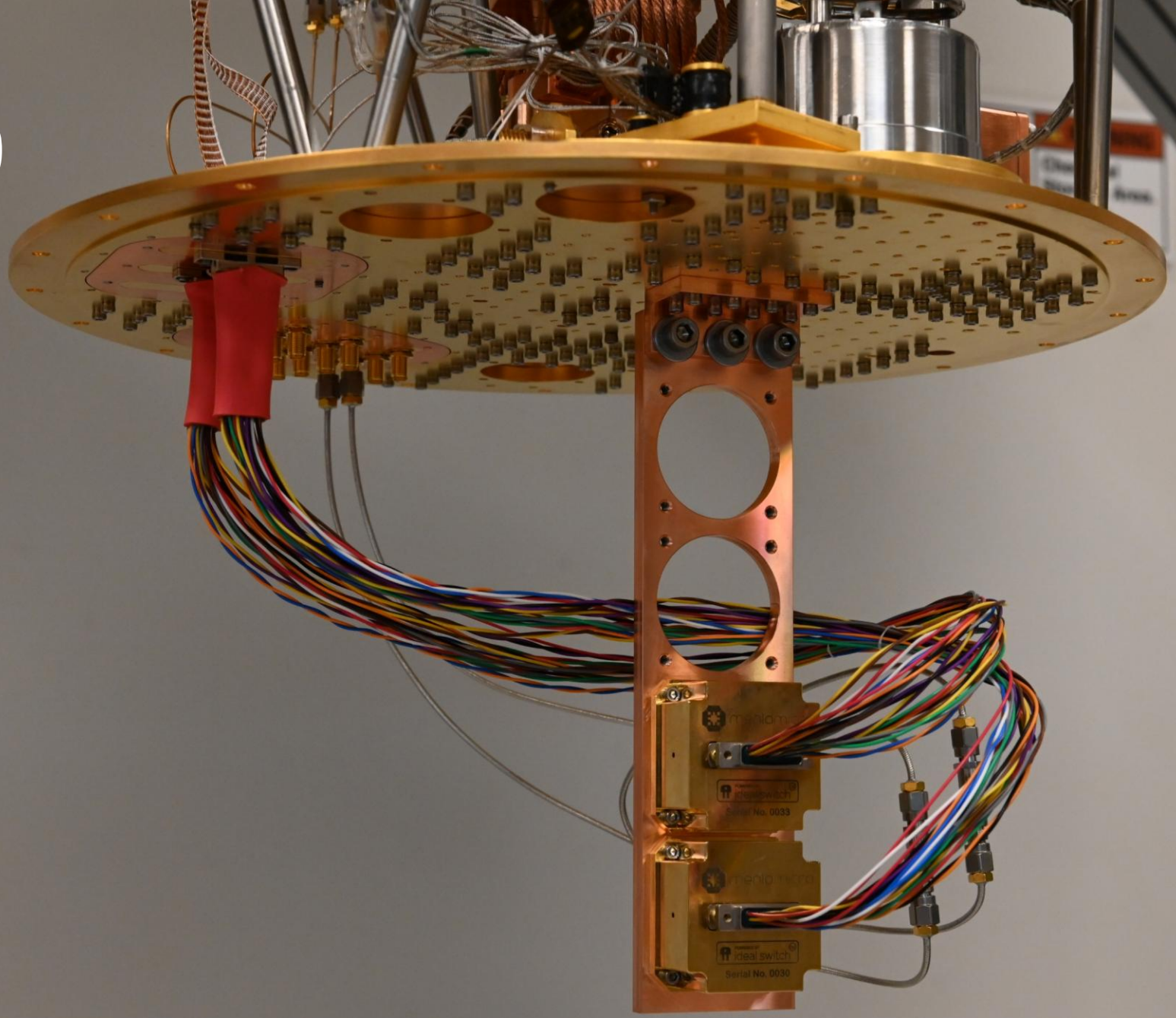
- Initial wafer probe test results show SPDT passband performance to 70GHz (< 2dB IL)







MM4250



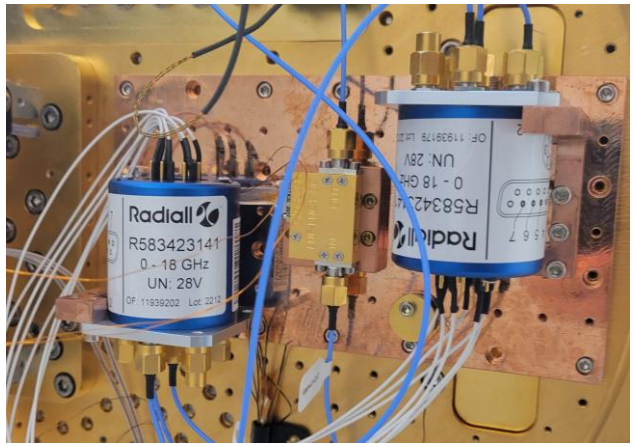
Ideal Switch for Cryo – MM4250

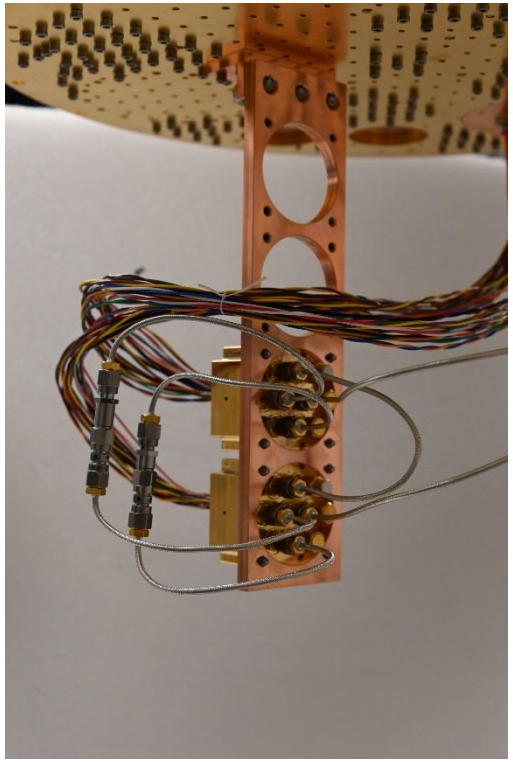
Ultra-Low Power SP6T Switch Module for Quantum Computing

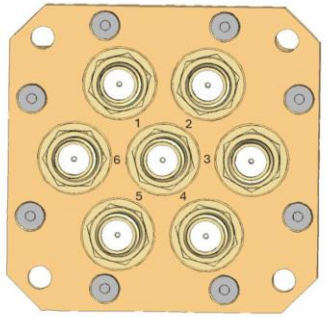
- ***RF switching to 10mK***, compatible with existing dilution fridge connectivity
- Extremely low activation power to eliminate heating. ***Speeds measurements*** and ***avoids damaging sensitive electronics***
- Built-in internal RF calibration standards.
- Engineering devices currently available for sale.

MM4250

Ease of adoption/integration into existing fridge RF measurements



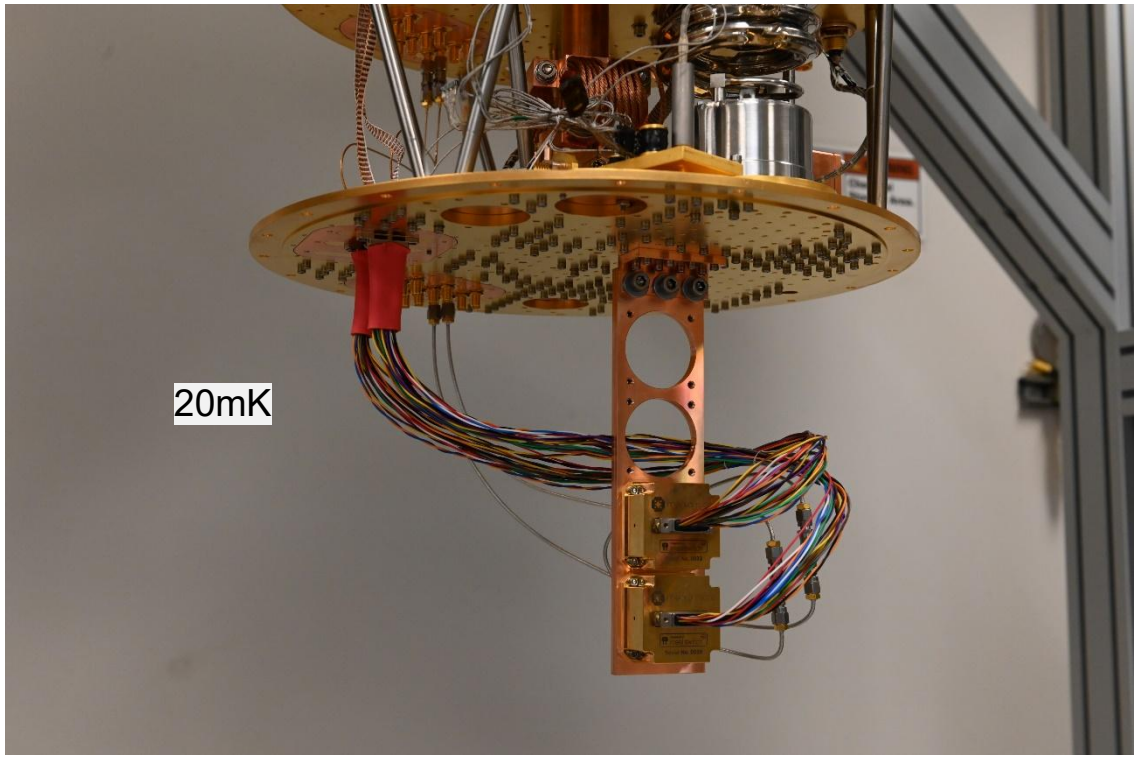


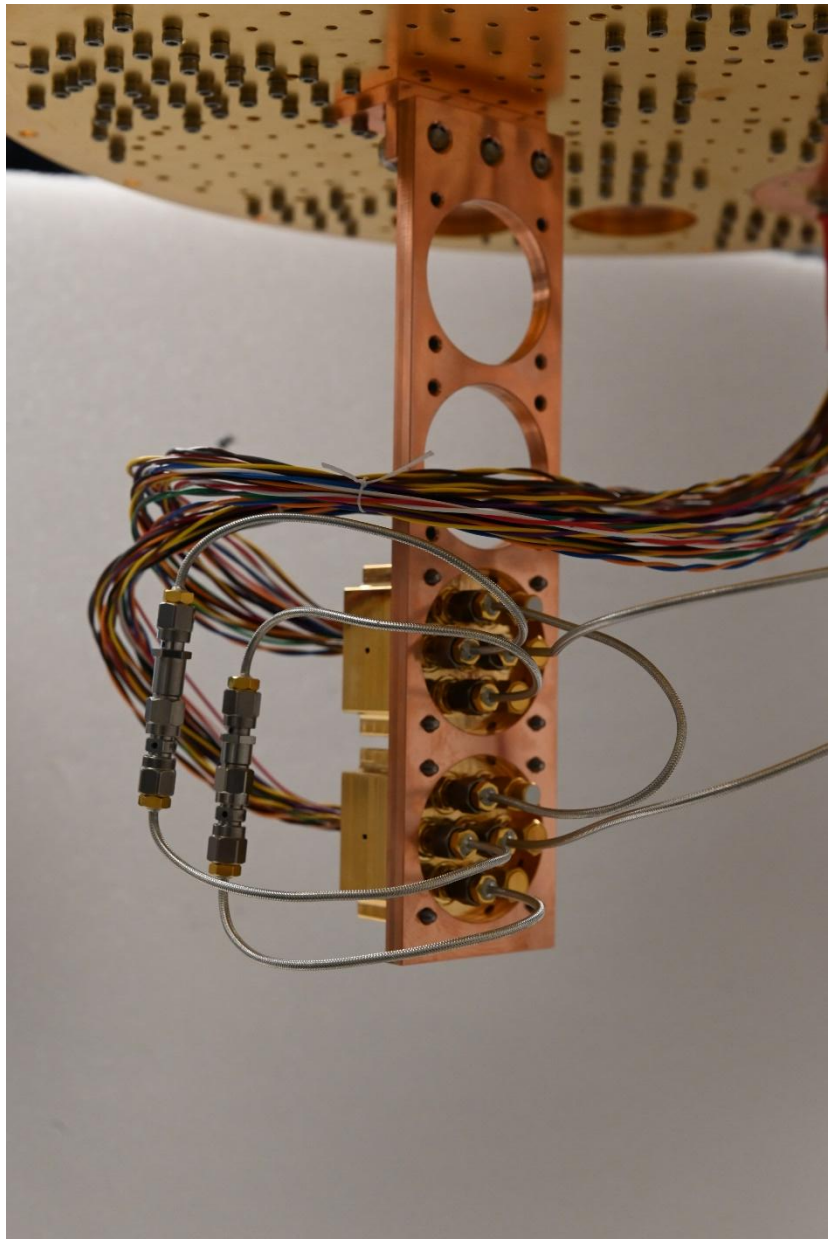


MM4250 intended to be “mounting plate compatible”

Superior Environmental Performance Temperature **COLD**

Ideal Switch can also operate at extreme cold temperatures!





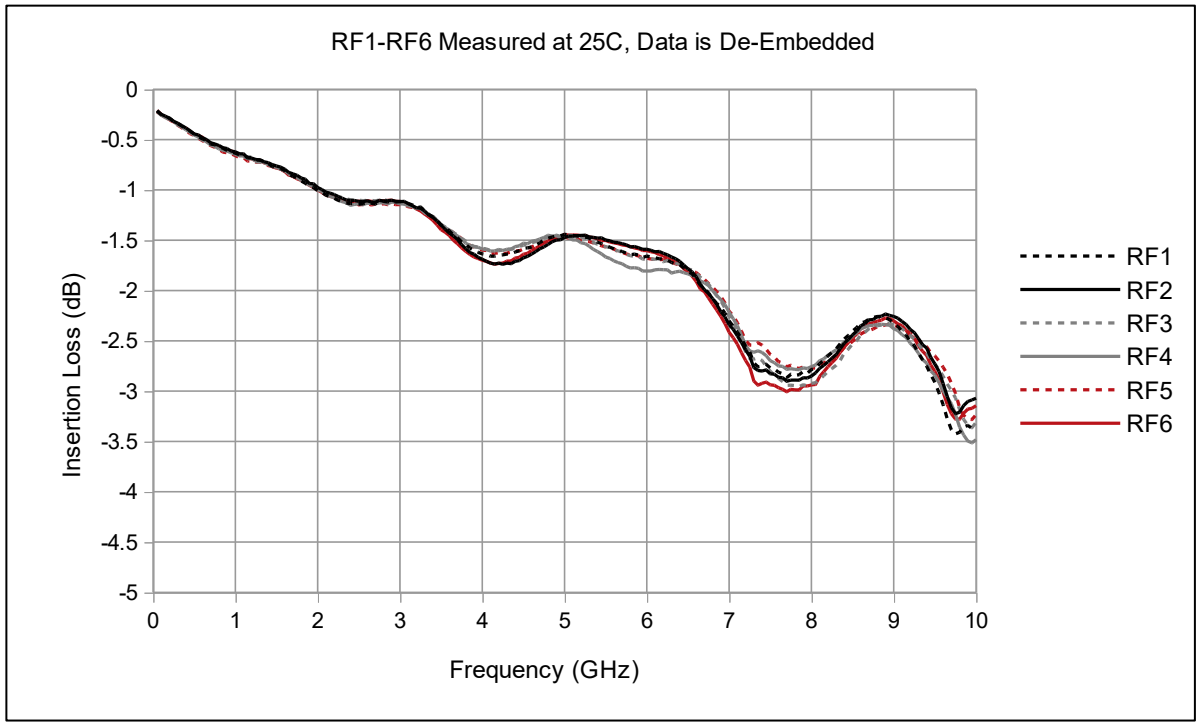
Testing performed at

FormFactor™

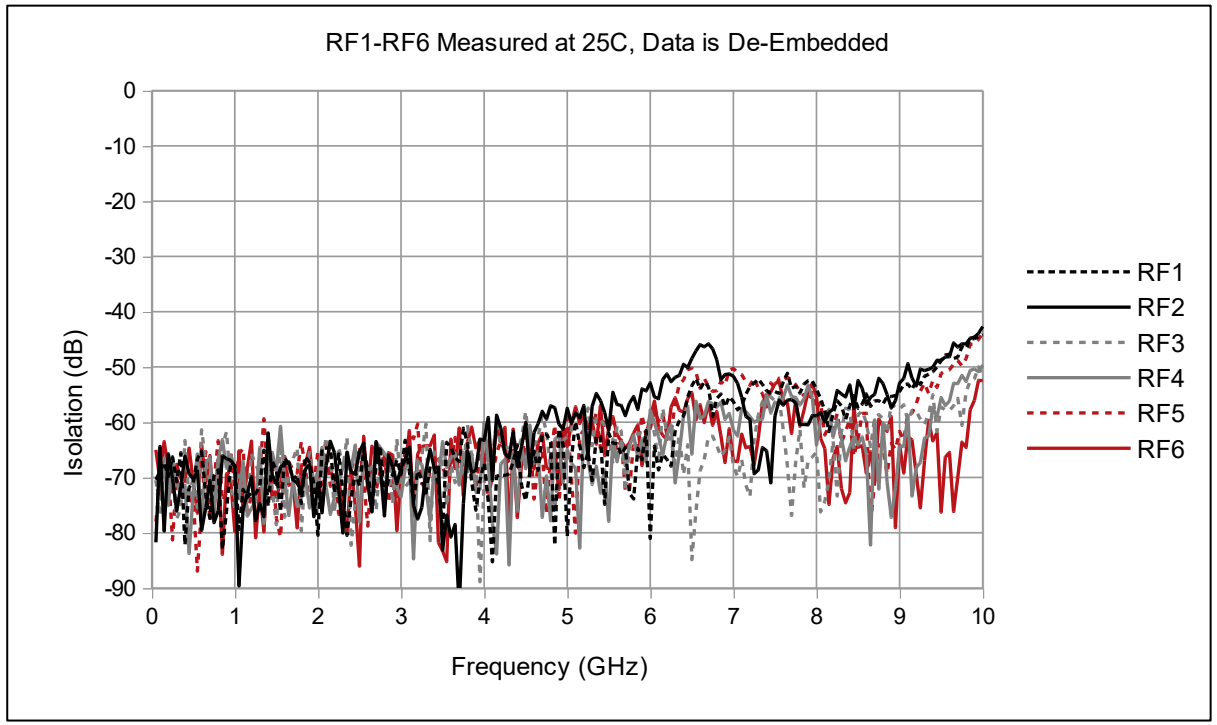
MM4250 Performance

Ambient Temp; Common to RF Channel Measurements

Insertion Loss



Isolation

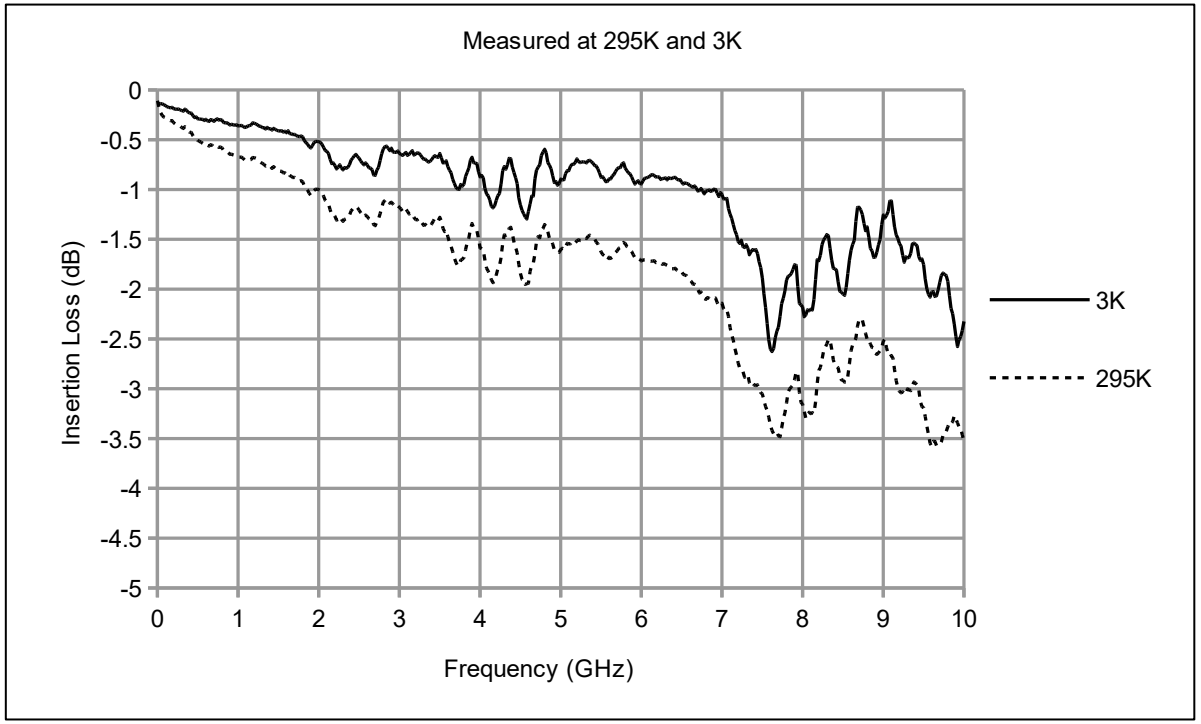


Preliminary Measurements

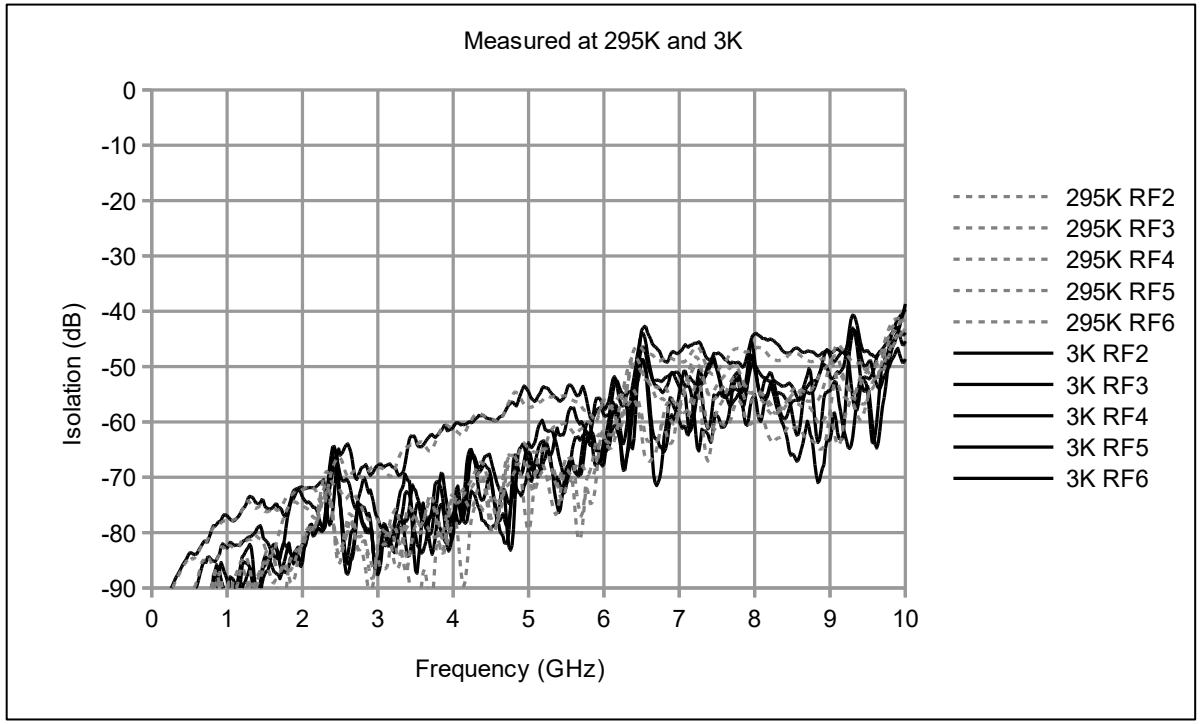
MM4250 Performance

Room vs **Cold** Temperature Measurements

Insertion Loss



Isolation



National Institute of Standards and Technology

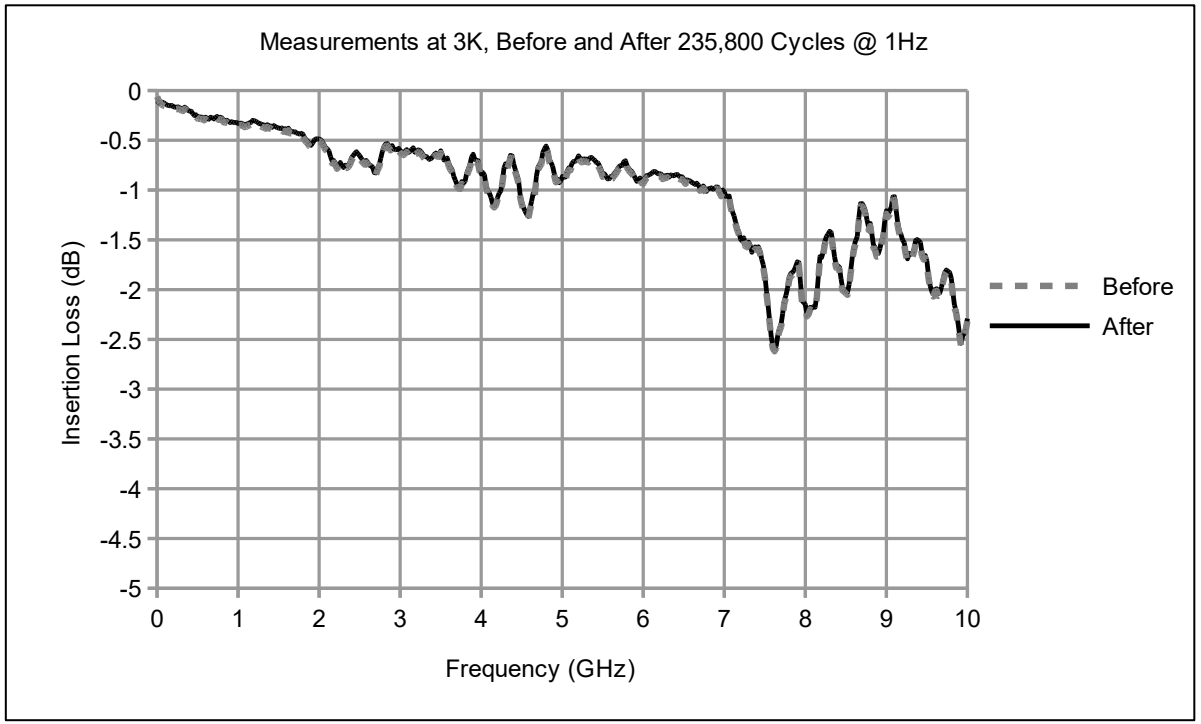
L. F. Spietz, C. Giovanniello, B. Takaki, W. Ye, B. Boiko, C. Long, N. E. Flowers-Jacobs, A. J. Sirois, P. F. Hopkins, S. P. Benz, and D. Williams, *"Cryogenic RF MEMS Switch with Electronic Calibration Capability,"* in preparation for submission to IEEE Journal of Microwaves, 2025.

MM4250 Cycling Performance

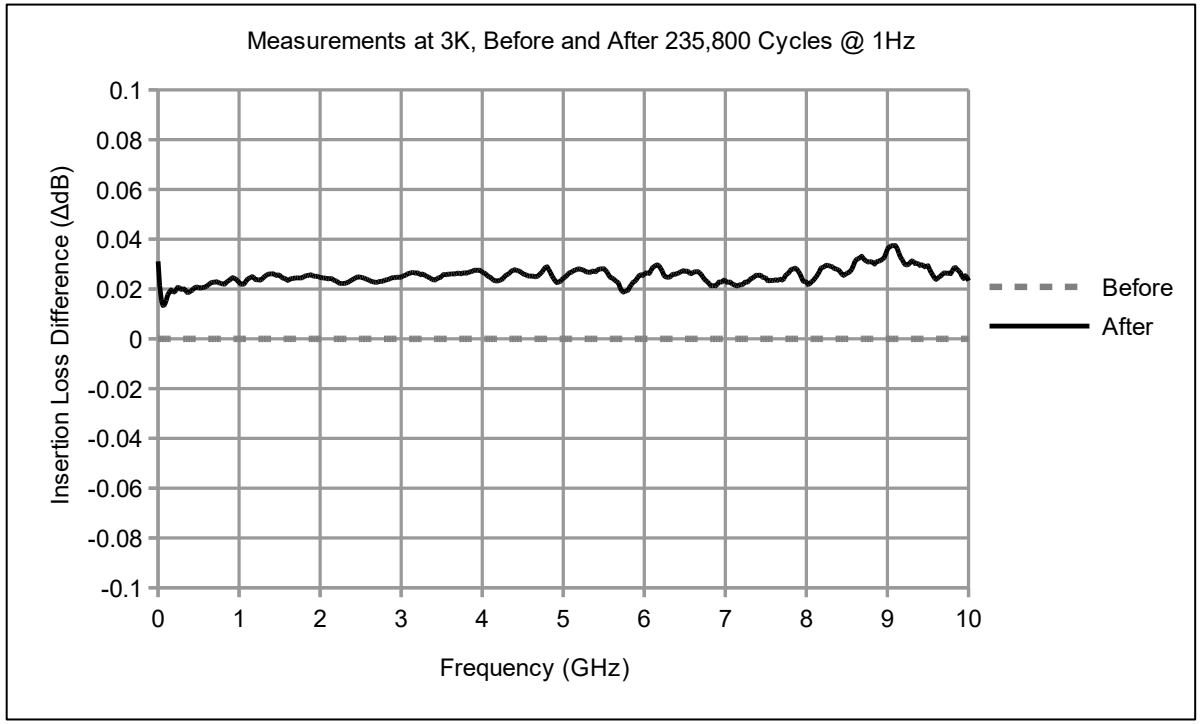
Cold Temperature Cycling Measurements

Before and After 235,800 Cycles @ 1 Hz

Insertion Loss



Insertion Loss Difference



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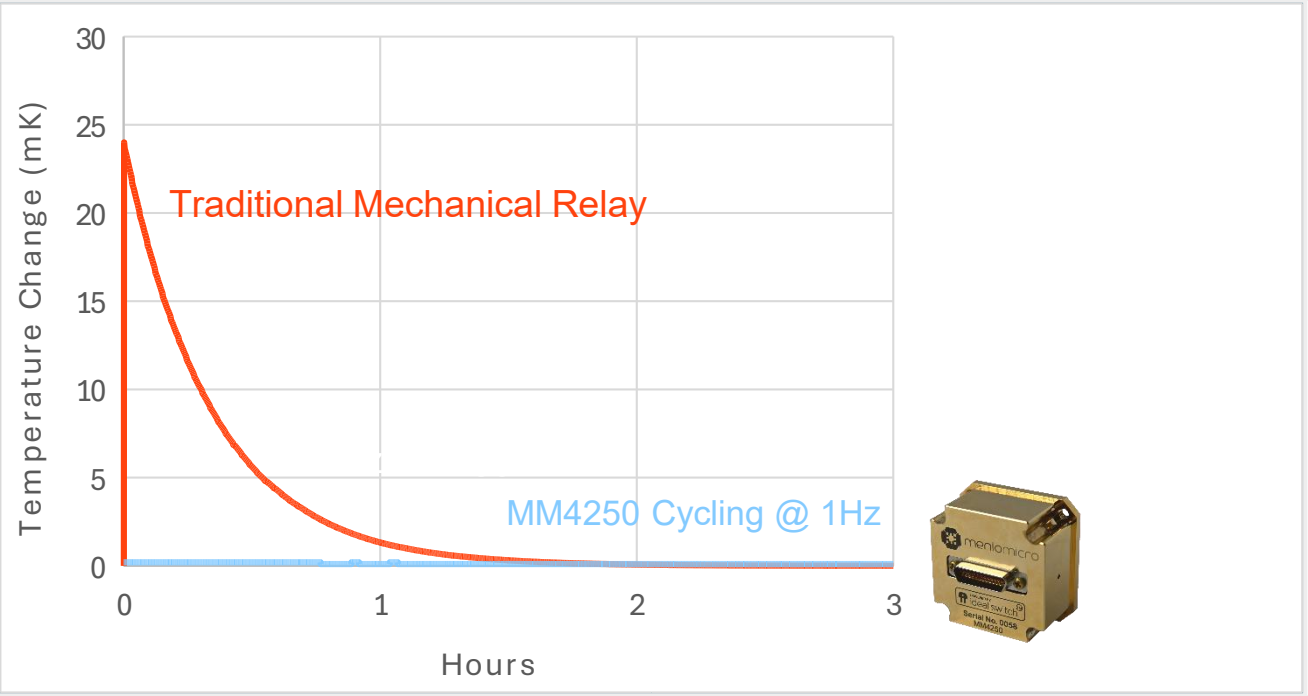
MM4250 offers dramatic throughput improvements

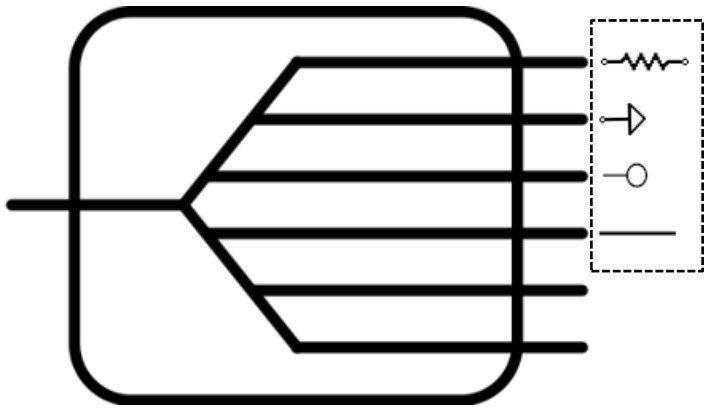
NO HEATING from Ideal Switch means **NO WAITING** for the dilution fridge to cool back to base.



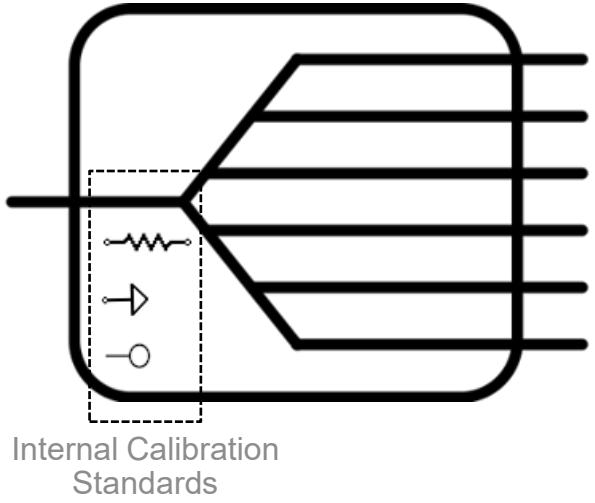
- *Traditional mechanical relays* increase the temperature in the fridge by *20 mK or more*, leading to hours of delays to test multiple channels.
- Menlo's Ideal Switch actuation is electrostatic requiring **less than 1 microwatt of power** to actuate the switches, compared to standard cryo switch generating a few Watts.
- Opening and closing the switch at any cycle rate causes **no measurable temperature increase** when operating at mK temperatures.
- This substantially increases throughput for device test and calibration!
- **SAVES HOURS IN DEVICE TEST/CALIBRATION**

Built-in Internal RF Calibration Standards

- The MM4250 is designed with built in RF Calibration standards (OSL) to allow users to transfer RF calibration plane to connector outputs *without consuming RF Channels for calibration*.



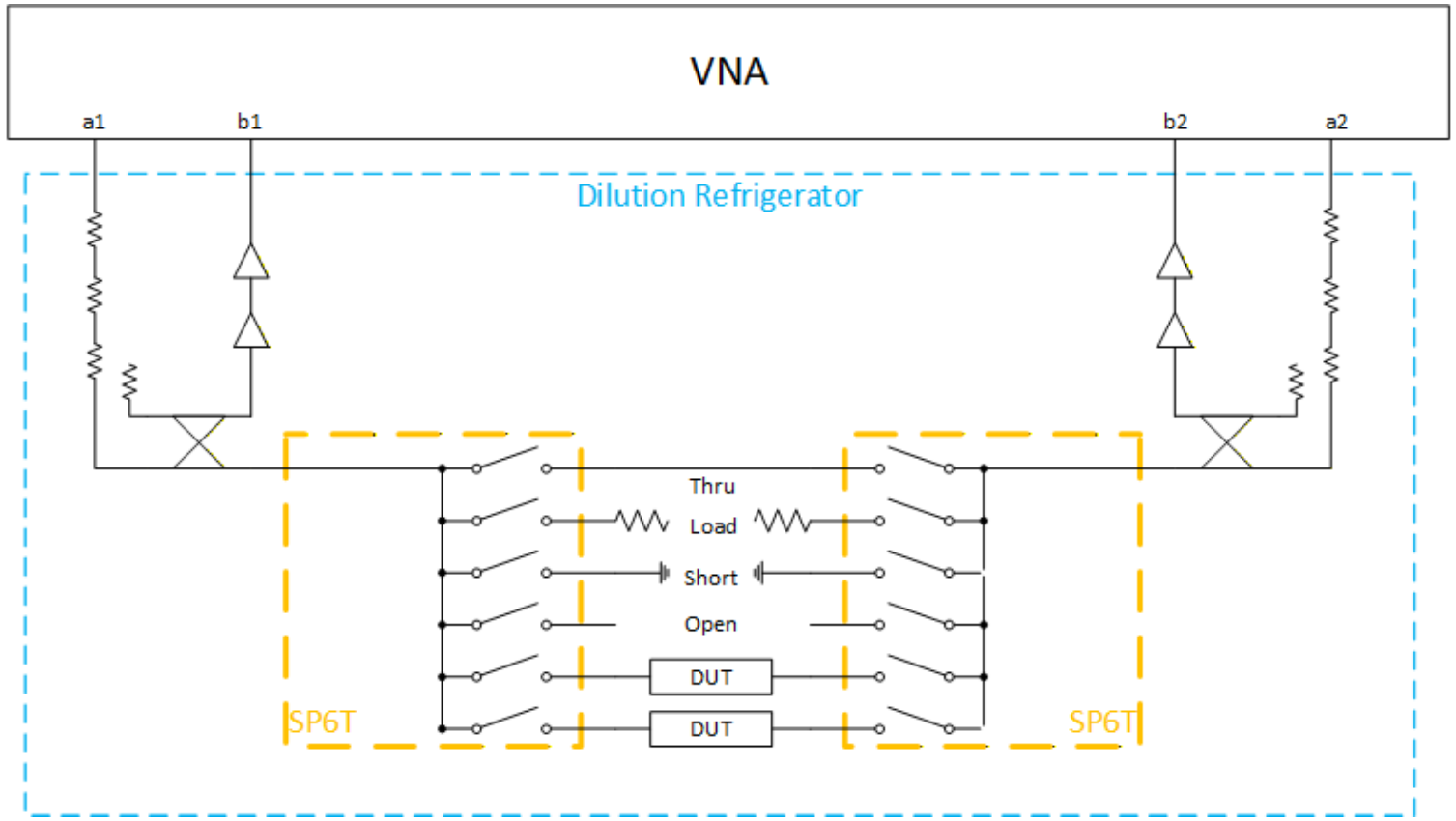
- This provides **more available channels for DUTs** measurements.



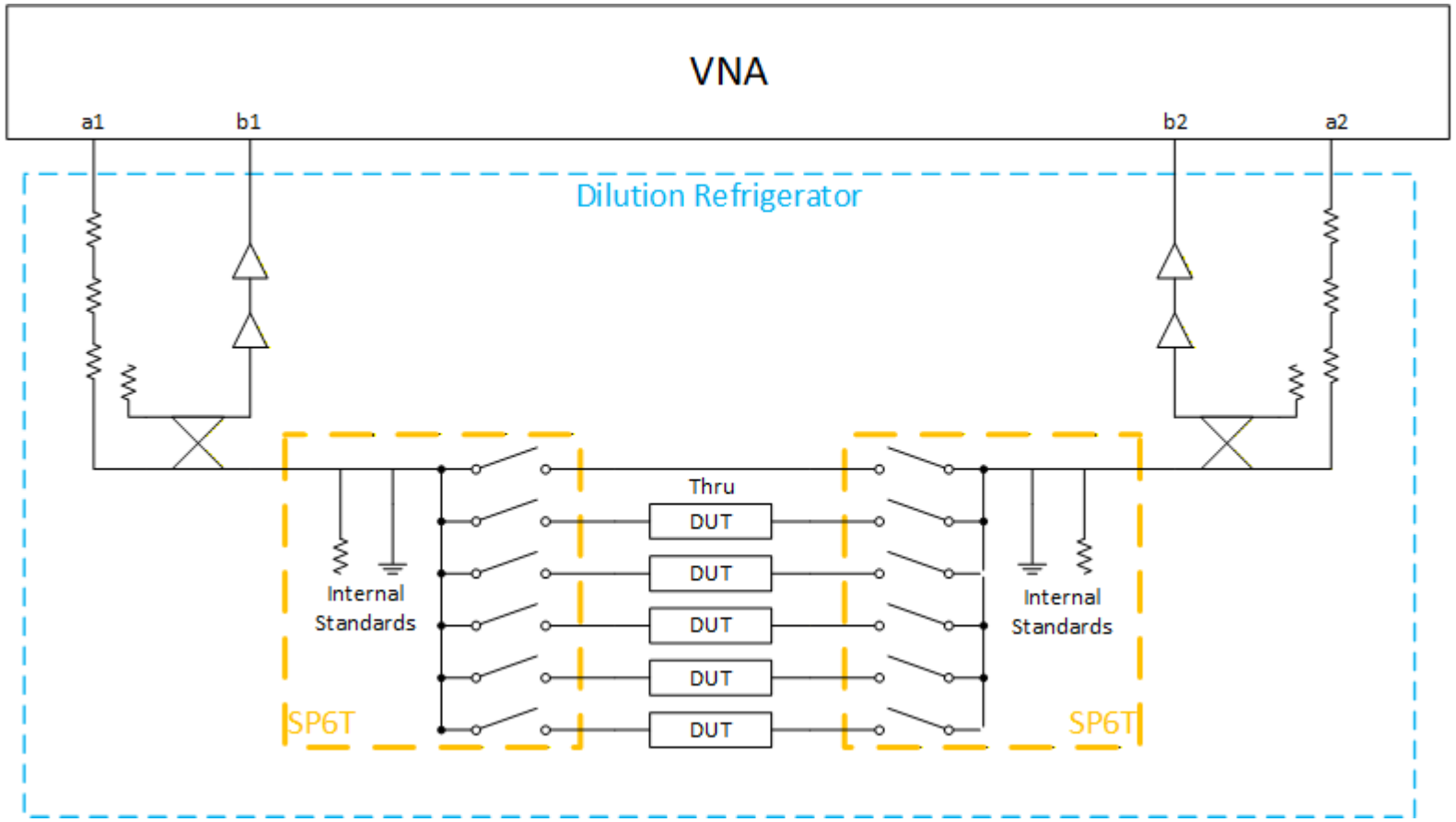
Traditional Dilution Refrigerator Test System

- Mechanical Switches limited to 6 channels.
- Using calibration components, limits 2 DUTs per test
  - Each test takes ~36hr for cool down/up

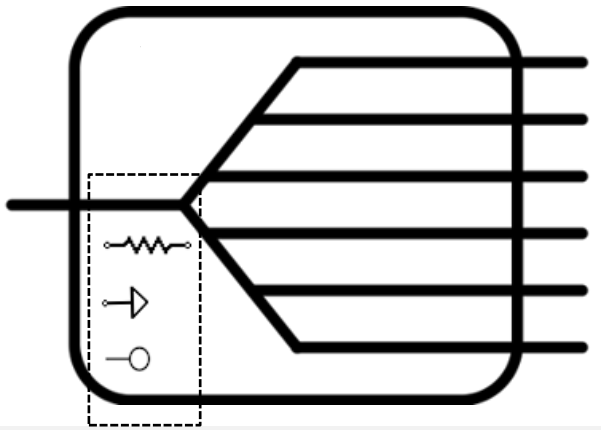
- What was previously an advantage for calibration, is now a disadvantage for test throughput.



MM4250 Dilution Refrigerator Test System



Built-in internal RF Calibration Standards provides **more available channels for DUTs** measurements.



Internal Cal Standards

Built-in Internal RF Calibration Standards

IEEE Journal of Microwaves

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Cryogenic RF MEMS Switch with Electronic Calibration Capability

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ABSTRACT We characterize a cryogenic radio-frequency micro-electro-mechanical-systems single-pole-six-throw switch to 10 GHz. We test the switch from room temperature to milliKelvin temperatures. The switch contains an internal electronic calibration capability suitable for performing vector network analysis at room temperature and cryogenic temperatures. We demonstrate two calibration types, the first designed for measuring the scattering parameters of microwave devices connectorized with 3.5 mm coaxial connectors and the second for measuring the scattering parameters of microwave devices connectorized with Sub-Miniature version A (SMA) connectors.

INDEX TERMS Cryogenic measurement, electronic calibration, micro-electro-mechanical-systems, radio frequency, vector network analysis.

I. INTRODUCTION

We describe the calibration and characterization of a cryogenic coaxial radio-frequency (RF) micro-electro-mechanical-systems (MEMS) single-pole-six-throw (SP6T) switch from to 10 GHz and from room temperature to milliKelvin temperatures.[1] We also calibrate and test an internal electronic calibration capability integrated into the switch that greatly simplifies calibrating vector network analyzers (VNAs) at the switch's output ports, especially at cryogenic temperatures. Finally, we develop two calibration types for the switch, the first designed for measuring the scattering parameters of devices under test (DUTs) connectorized with 3.5 mm coaxial connectors and the second for measuring the scattering parameters of DUTs connectorized with Sub-Miniature version A (SMA) connectors.

The first system for performing calibrated two-port vector scattering parameters at milliKelvin temperatures was reported by Ranzani, *et al.*, in [1]. Ranzani, *et al.* described a thru-reflect-line (TRL) calibration approach in coaxial transmission lines based on electromechanical coaxial switches. The switches allowed for routing signals from the VNA to coaxial calibration standards and to a coaxial DUT. Ranzani, *et al.* applied their approach to the development and characterization of connectorized circuits in [2, 3], Similar approaches have been used since by Yeh, *et al.* [4], Oates, *et al.* [5] and others [6, 7]. More recently, Stanley, *et al.* [8, 9] and Celep, *et al.* [10] have introduced traceable coaxial calibrations at milliKelvin temperatures.

However, these approaches to performing calibrated scattering-parameter measurements in coaxial media suffer from several deficiencies at cryogenic temperatures. They are based on electro-mechanical switches that are slow compared to many other technologies, sometimes generate electrical pulses at their outputs that can destroy sensitive amplifiers used in performing network analysis at milliKelvin temperatures and can generate enough heat to be significant at milliKelvin temperatures (although some significant progress has been made to improve the switching efficiency of electro-mechanical switches at cryogenic temperatures [11]). They also often use difficult-to-characterize flexible cables to connect calibration standards and DUTs to the switch and rely on symmetry in the switches and flexible cables to obtain accurate calibrations.

In this work, we calibrate and characterize a novel Menlo Microsystems[2] MM4250 SP6T RF coaxial switch based on their Ideal Switch® technology, which is a MEMS process technology. The MM4250 is designed to be a direct replacement for RF electro-mechanical switches currently in use at cryogenic temperatures.

The internal electronic calibration capability of the MM4250 switch greatly simplifies calibrations for the user. Unlike a standard electronic calibration unit [12, 13], which would calibrate a VNA to the switch's input port, we set the calibration reference planes in our experiments to the output ports of the switch. This allows use of the MM4250's internal electronic calibration standards to calibrate a VNA connected to the input port of the switch to any of the switch's six output ports over a wide range of temperatures with a calibration adapted to characterizing either 3.5 mm-connectorized DUTs or SMA-connectorized DUTs.

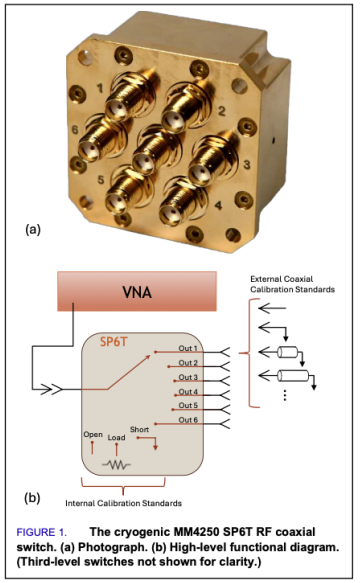


FIGURE 1. **The cryogenic MM4250 SP6T RF coaxial switch. (a) Photograph. (b) High-level functional diagram. (Third-level switches not shown for clarity.)**

II. CRYOGENIC SP6T RF SWITCH

Figure 1 shows a photograph and high-level functional block diagram of the MM4250 RF switch that we characterized. The switch's SMA input port can be seen in the center of the switch face surrounded by its six SMA output ports near the periphery of the switch.

The switch was designed to have an RF 3 dB bandwidth of approximately 8 GHz and is built using a series of Menlo Micro SP4T RF MEMS switches arranged in three levels. The first level consists of a single switch, which is used to select between either a) a set of internally selectable open, short and load calibration standards or b) allowing the signal to pass through to the second switching level, which selects between the main RF measurement paths.

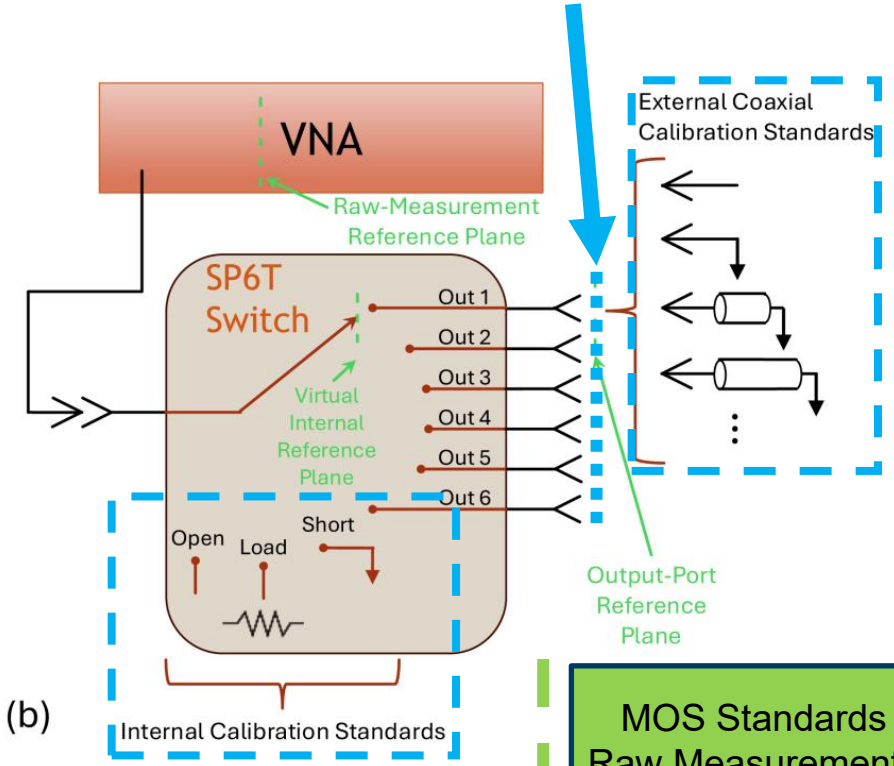
The second-level SP4T switches fan out to the six output paths. The design employs a special mode on the Menlo Micro RF switches called "super-port mode", which greatly improves return loss and insertion loss for applications requiring many

[1] We use this term to mean less than 50 mK.

[2] We use brand names only to clarify the experimental configuration. The National Institute of Standards and Technology does not endorse commercial products. Other products may work as well or better.

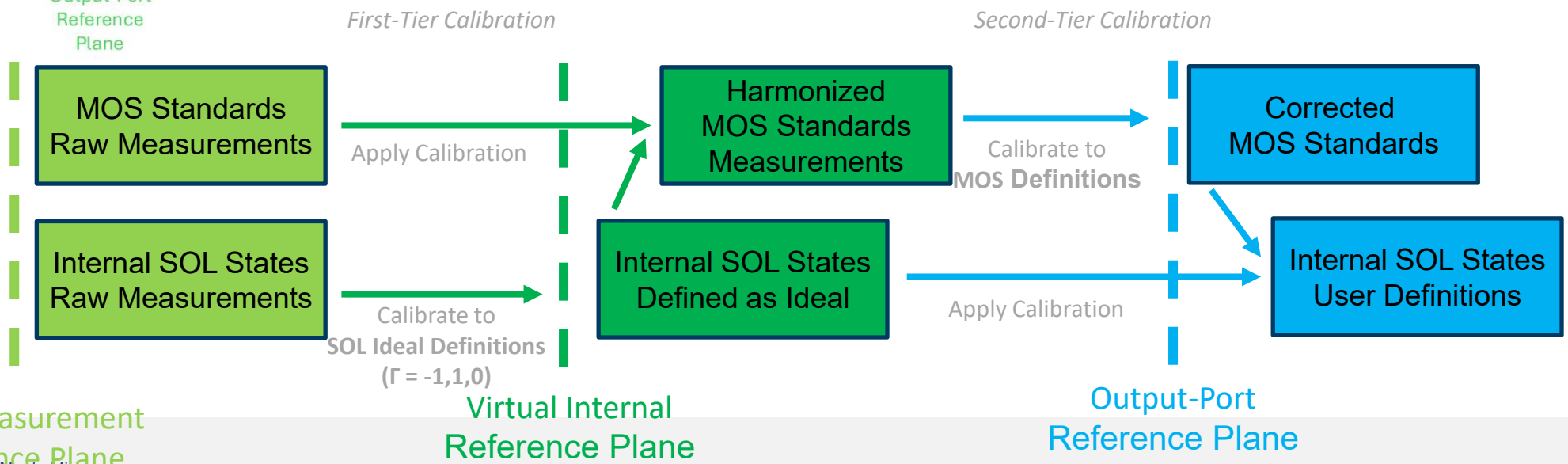
- Paper summarizes the characterization of the MM4250 internal standards and associated measurement uncertainty
- Can be viewed/downloaded here:
- https://menlomicro.com/newsroom/cryogenic-rf-mems-switch-with-electronic-calibration-capability

Webinar for Internal Calibration Standards



Check out this webinar that describes MM4250's new calibration methodology described in the NIST paper.

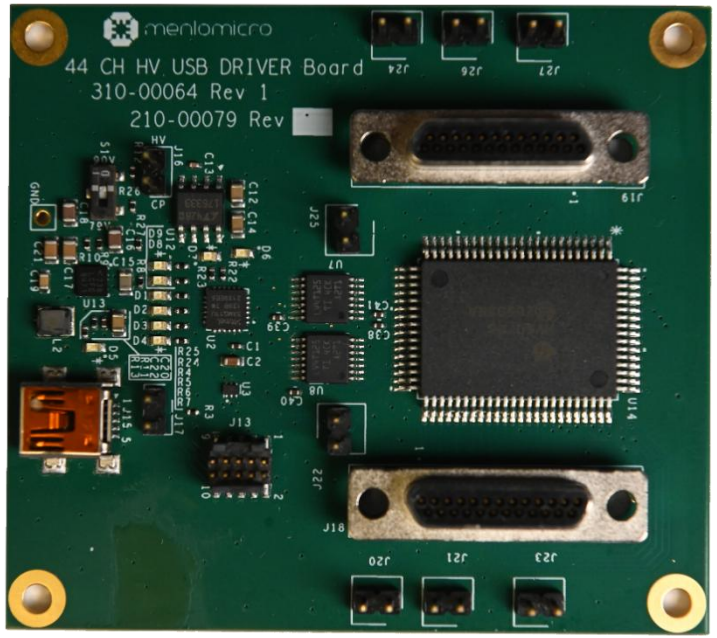
[RF Calibration at Cryogenic Temperatures: A New Measurement Paradigm for Quantum Technologies | FormFactor, Inc.]



USB HiV Driver Board

Controlling MM4250

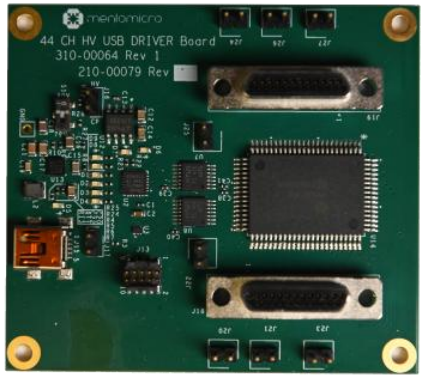
- The MM4250 requires 90V to be supplied to the Micro-D connector pins to actuate the channels of the device.
- The USB HiV driver board is for controlling one or multiple MM4250 devices.
- By connecting the driver board to a computer via USB, the user can control one or both Micro-D Male 25p connectors to be able to synchronously control one or two MM4250s at once.
- The board can be control manually with an installable PC application or programed via API.



Micro-D Connector Configurations

- The MM4250 and Driver Board use Micro-D 25p connectors for device control.
- If the inside of your system has a:
  - Micro-D **Plug**: Connect to the MM4250 with a **plug-to-socket** cable assembly.
  - Micro-D **Socket**: Connect to the MM4250 with a **plug-to-plug** cable assembly

USB Driver Board
Male/Plug

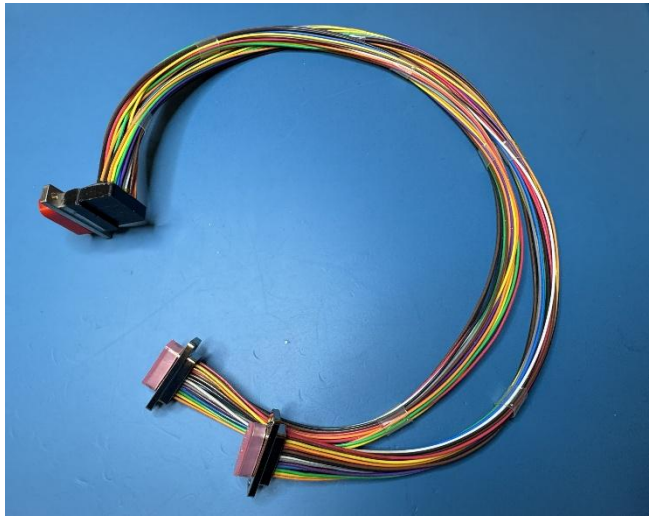


MM4250
Female/Socket

MM4250-KIT1-ENG

Full “turnkey solution” to enable engineers to get up and running ASAP

- (2) SP6T RF Switch Module for cryogenic applications
- (1) USB HiV Driver Board
- (1) Micro-D 25P, Split Male to Female Cable Assembly
  - We offer a split Male to single Female cable assembly for connecting two MM4250s to the same DC control source.



- Please contact sales@menlomicro.com for inquiries.

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Thank you.