Choosing the Right RF Switch for High-Power Applications

July 2024

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POWERED BY ideal switch™

RFMW®

Available from Stock

Worldwide Distribution

Technical Design

RFMW has been the premier RF & Microwave and specialty distributor for over 20 years, now with Power Management products.

From introduction to production, our team of experts support your component selection, technical design and fulfillment needs.

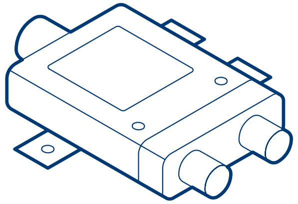
Strategically Aligned Distribution for RF, Microwave, and Power

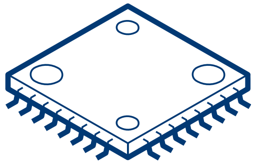
Agenda

- Switch Technology for RF High-Power
- What Makes an RF Switch “High-Power”?
- The Key Specs
  - Insertion Loss and Frequency Range
  - Thermal Performance
  - SWaP-C
  - Peak Power Handling
  - Linearity
  - Switching Time
  - IL Variation
- High-Power Application Examples
  - Switched Filter Banks
  - RF Blocking

Switch Options for High-Power

The common switch technologies for high-power and high-frequency applications.





- Mechanical
  - Coaxial
  - Waveguide
  - Microelectromechanical System (MEMS)
- Semiconductor
  - Field Effect Transistor (FET)
  - PIN Diode
    - Silicon-on-Insulator (SOI)
    - Gallium Arsenide (GaAs)
    - Gallium Nitride (GaN)

Power Limits for Switch Technologies

What are the general limits for switch technologies?

Waveguide

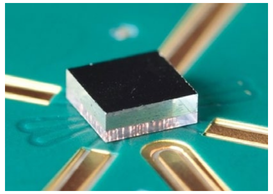
Kilowatts

40 GHz+, Narrow Band

Coaxial

100+ Watts

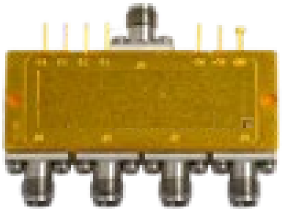
40 GHz+, Broadband



MEMS

100+ Watts Peak, 10+ Watts CW

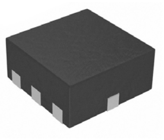
20 GHz, Broadband



PIN Diode

100+ Watts

6 GHz, Narrow Band



FET

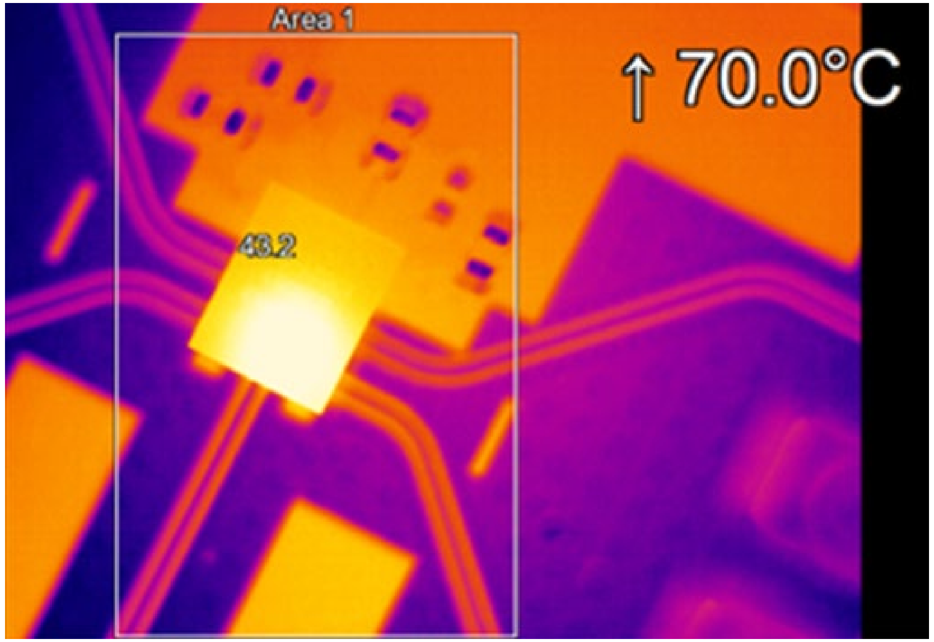
<10 Watts

40 GHz, Broadband

Is a "High-Power" Switch Always High-Power?

One spec line does not tell the whole story!

- Parts that appear to fit design requirements often come with trade-offs.
- Power handling is derated at high frequency and high temperature.
- Choosing the wrong part forces last-minute design changes, schedule delays, or reliability problems.



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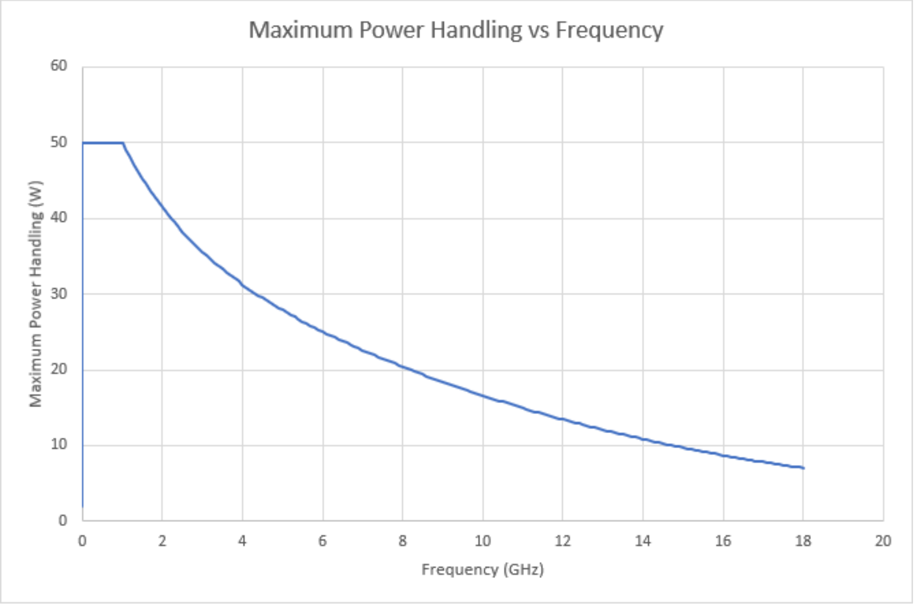
Insertion Loss and Frequency Range

- Insertion loss increases with frequency. High insertion loss means lower power handling.
- Semiconductor switches are higher loss than mechanical or MEMS switches.
- Semiconductor and waveguide switches are designed for narrow bands. New frequency band, new design!
- Switches can be cascaded for more throws and higher isolation, but losses add up.



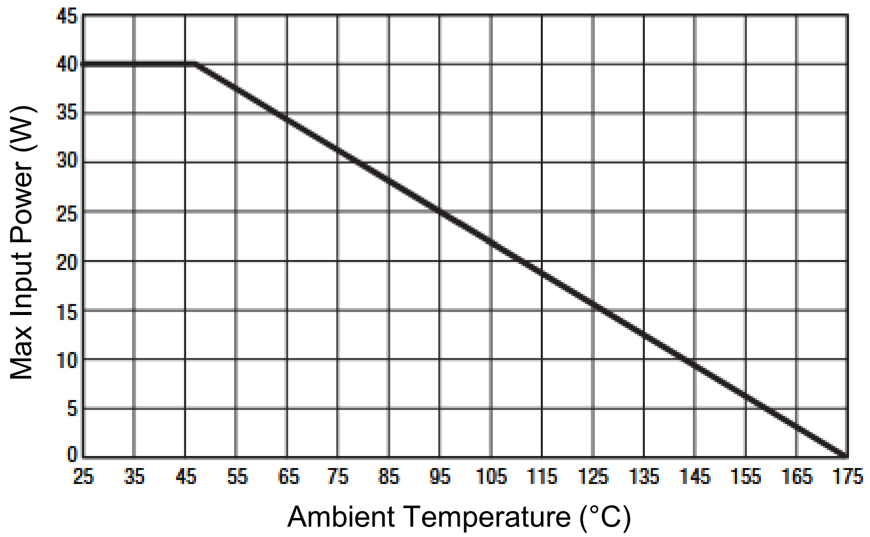
A power handling derating curve for a broadband MEMS switch. T_A = 85 °C.

Thermal Performance

- High input power into high insertion loss creates heat at the junction. This heat is added on to the ambient temperature.
- Exceeding max case (T_C) or junction (T_J) temperature can damage the switch.
- Simulations are used to translate between input power, dissipated power, and temperature rise.
- If max T_J = 85 °C, and T_A = 85 °C, maximum input power is 0 W!

Dissipated power (P_{Dis}) is derived from insertion loss (IL) and input power (P_{IN}):

$$P_{Dis} = P_{IN} \times \left(1 - 10^{IL/10}\right)$$

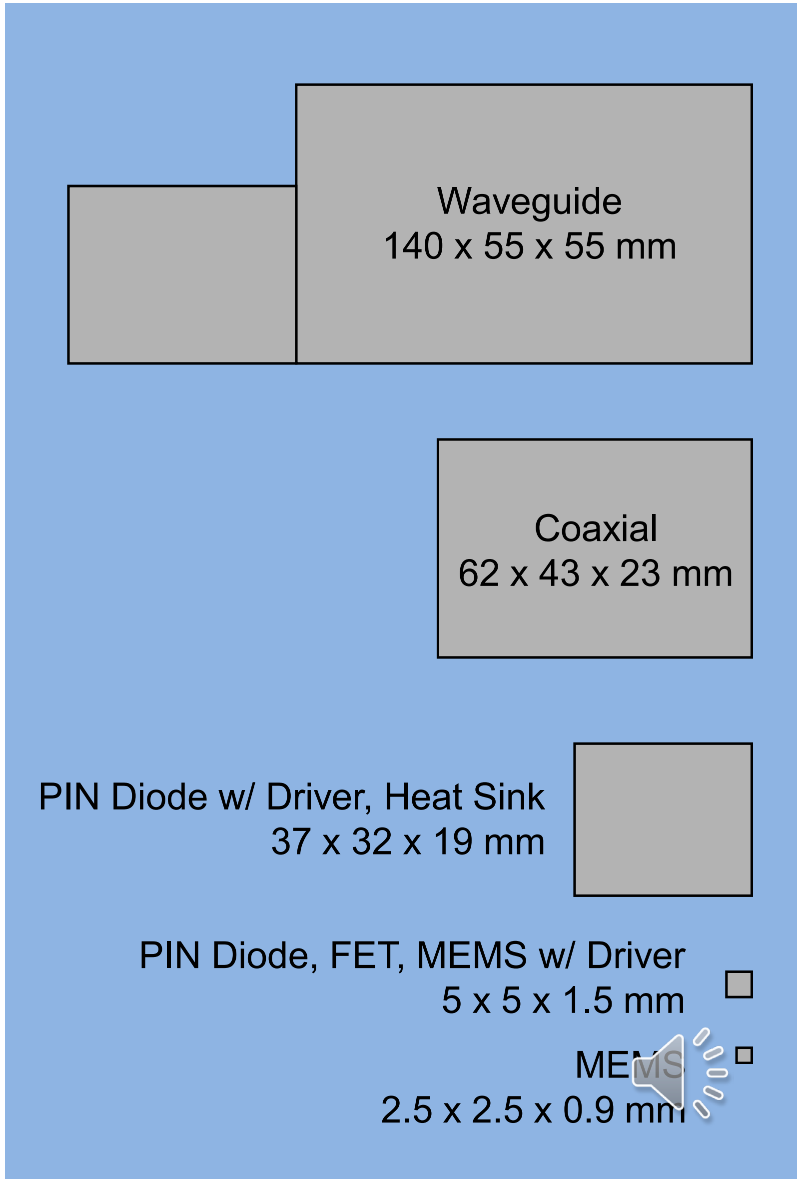


A power handling derating curve for a PIN diode switch.

SWaP-C – Size

System-level performance is measured in Size, Weight, Power, and Cost

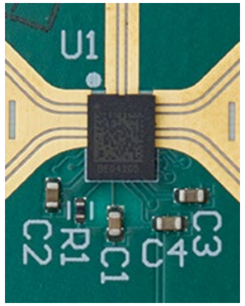
- Waveguide and coax switches are much larger than semiconductor or MEMS.
- Lossy semiconductor switches require heat sinks.
- Small semiconductor and MEMS switches may require external drivers, adding to total solution size.



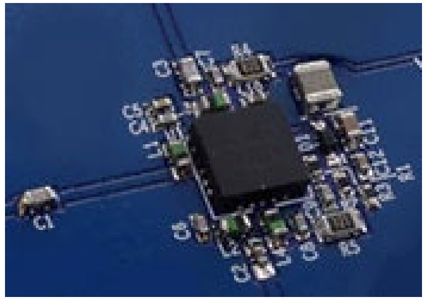
SWaP-C – Drivers and Power Consumption

Check solution size, not just component size.

- Coaxial and waveguide switches require Watts of power to toggle.
- PIN diodes require negative voltage drivers and complex biasing circuits.
  - 100s of mW per throw.
- MEMS switches require high voltage (>70V) drivers but very low current (10nA).
  - ~5mW per throw.
- Internal drivers save space but can create noise issues.



5 x 4 mm MEMS Switch w/ Internal Driver and Supporting Components



5 x 5 mm PIN Diode Switch w/ Internal Driver and Supporting Components

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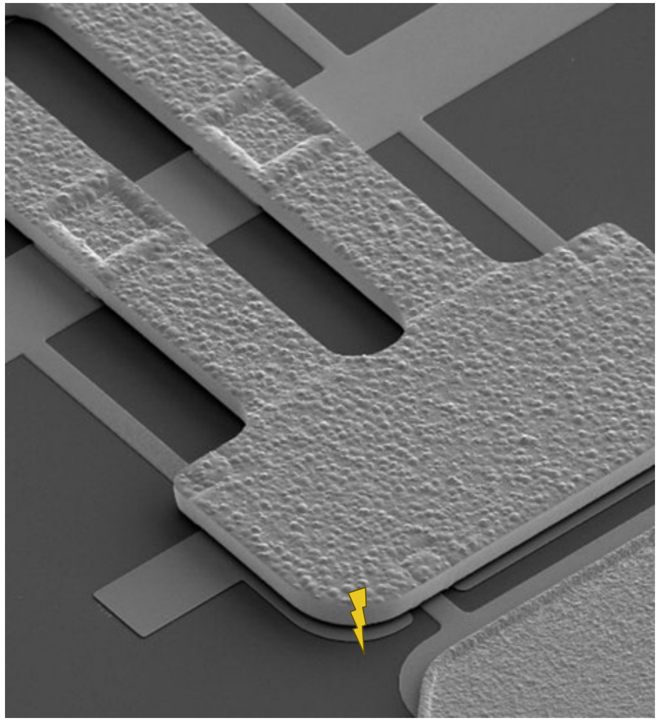
Peak Power Handling

Heat is not the only failure mode in high-power applications.

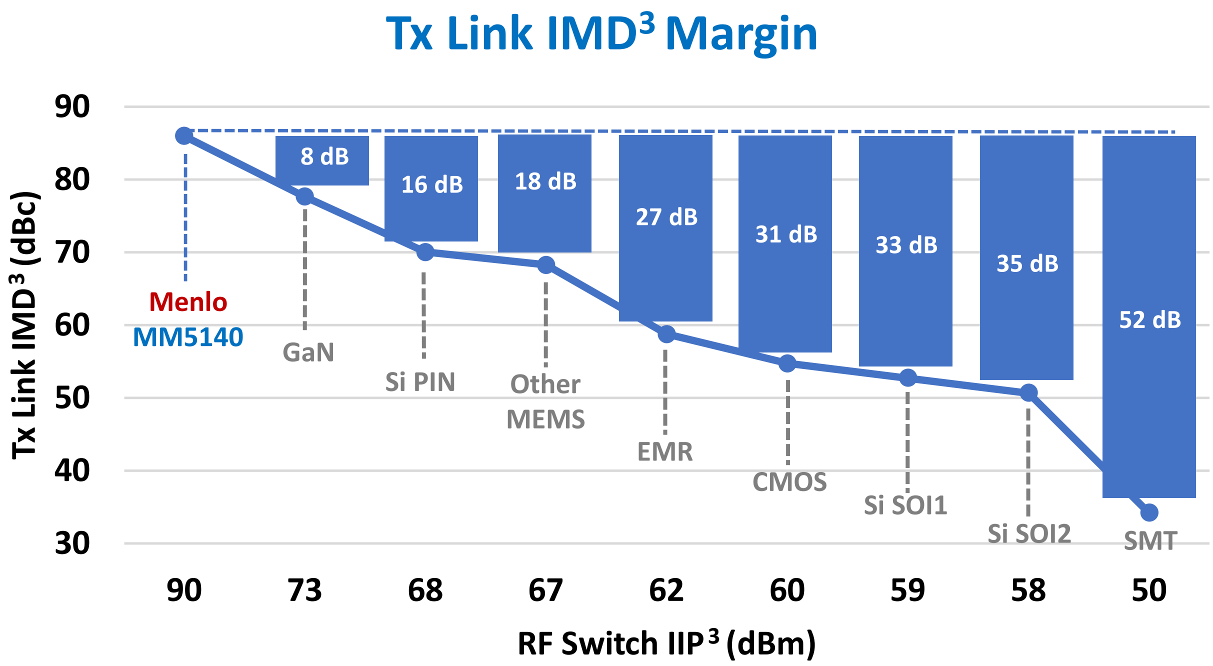
- For low duty cycles, voltage breakdown happens before thermal failure.
- Waveguide switches reach kW peak power handling.
- MEMS switches reach up to 400W peak power handling at 6 GHz.
- PIN diodes reach 500W below 4 GHz.
- High-frequency switches have worse peak power handling due to smaller geometry.
- Use underfill and increase line spacing for high peak-power applications at high-altitude.

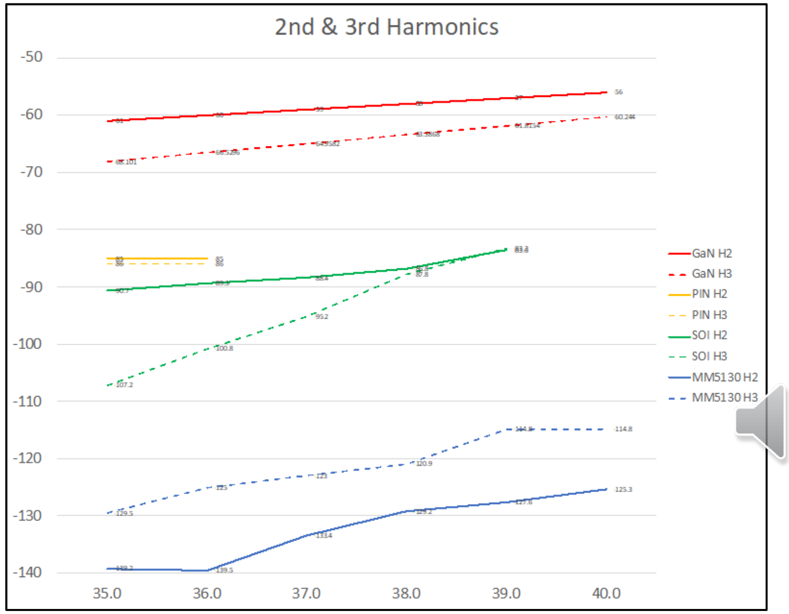


Peak voltage can cause arcing inside semiconductor and MEMS

Linearity

- Linearity includes harmonic distortions (H2, H3, …) and intermodulation. 3rd order intermodulation (IP^3) is most relevant for narrow-band.
- Mechanical switches and MEMS have best linearity.
- Poor switch linearity impacts system performance, even when the switch is 10-20 dB better than the amplifier.
- Requires more filtering or lower output power to meet out-of-band spur requirements.



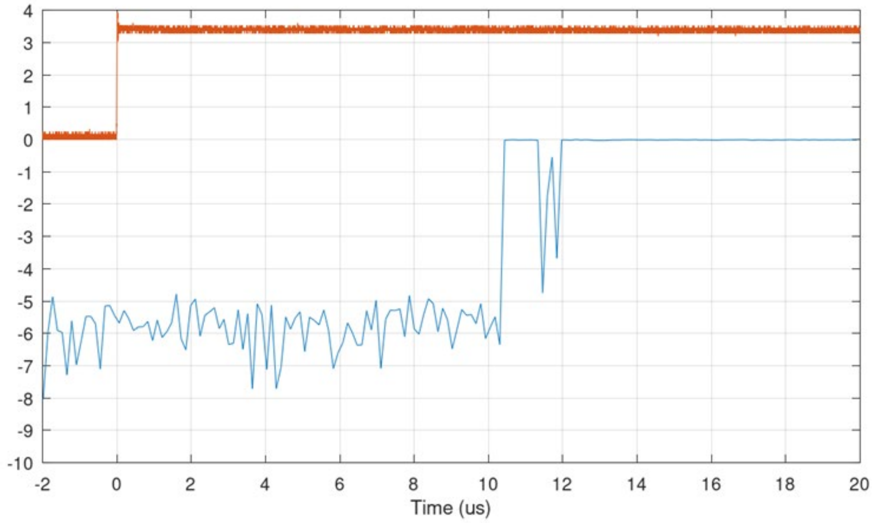


Switching Time

- Semiconductor switches are required for nanosecond switching times, but have longer settling times if hot-switching high-power.
- MEMS switches have 10 – 30 µs switching times. Some MEMS can hot switch up to 1 Watt with derated lifetime.
- Mechanical switches have millisecond switching times. Maximum hot-switch power is higher than MEMS but may reduce cycle lifetimes.

Control

RF Output Power



MEMS Switching Time

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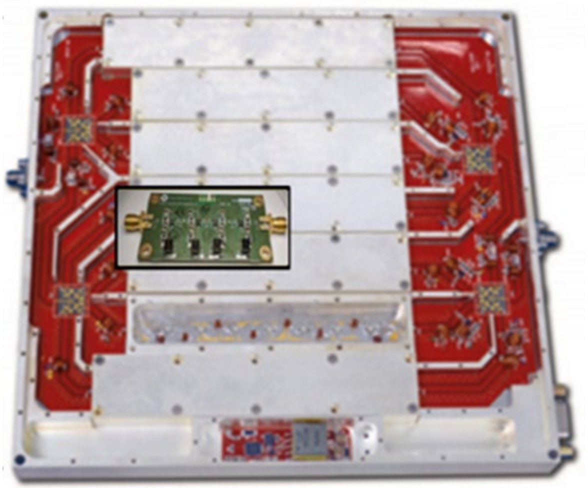
Insertion Loss Variation

Switch performance can vary in certain conditions.

- Insertion loss of coaxial switches increases after cycling.
- Insertion loss of semiconductor switches increases at high temperature. At 85 °C, insertion loss could increase by 0.4 dB.
- Variation causes thermal issues, and in test & measurement applications can degrade calibrations. A sudden drop in yield might trace back to small ambient temp changes, or aging switches.
- Compensating for variation requires complex feedback loops. Thermal sensors must be calibrated, and feedback loops require simulations.

High Power Switch Application Example – Filter Bank

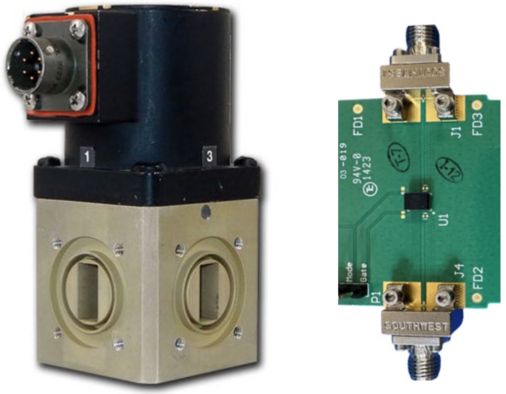
- PIN diodes can offer higher power handling but significantly larger size to dissipate heat.
- GaN offers faster switching times but high loss and requires heat sinking.
- MEMS offers best thermal performance and size.



Specification (at 3 GHz)	PIN diode (4 cascaded SPDT)	GaN (4 cascaded SPDT)	MEMS (2 cascaded SP4T)
Input power, CW (W)	100	20	25
Insertion loss (dB)	4 x 0.5 = 2.0	4 x 0.7 = 2.8	2 x 0.15 = 0.30
Switching speed	1.5 μs	0.05 μs	8 μs
Switching cycles	Unlimited	Unlimited	3 billion
IP3 (dBm)	75	60	90
Solution Size (cm^2)	426	121	32
Dissipated Power (W) (P_{IN}=20 W)	7.4	9.5	1.4

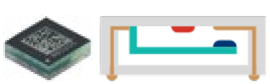
High Power Switch Application Example – RF Blocking Switch

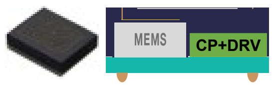
- Semiconductor switches are not yet capable of 100+ Watt power handling at high frequencies.
- MEMS offers 500x better size, power, and switching time for any application without kW power requirements.

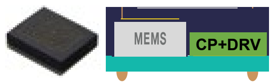


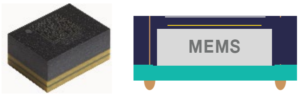
Specification (at 6 GHz, 85 °C)	Waveguide	MEMS
Pk Power (10% Duty Cycle)	320 kW	400 W
Insertion Loss	0.02 dB	0.3 dB
Switching Speed	100 ms	14 µs
CW Power	12 kW	25 W
Isolation	70 dB	45 dB
Max Power Consumption	6 W	15 mW
Solution Size	430 cm^3	0.5 cm^3

Menlo Micro High-Power Switch Portfolio









	RF & Microwave			
Model	**MM5130**	**MM5120**	**MM5140**	**MM5815**
Markets	Telecommunication, Wireless Aerospace & Defense, Test & Measurements			Aerospace & Defense
Applications	Tunable & Programmable Filters, High-Power Low-Loss RF Switch Matrices, Programmable RF Beam Steering			RF Blocking Switch
Switch Type	SP4T			SPST
Frequency Range	DC – 26 GHz	DC – 18 GHz	DC – 8 GHz	DC – 20 GHz
RF Power	**25 W (CW), 150 W (pulsed)**			**400 W (pulsed)**
Insertion Loss	0.4 dB @ 6 GHz	0.4 dB @ 6 GHz	0.3 dB @ 3 GHz	0.4 dB @ 6 GHz
Linearity (IP3)	>90 dBm			
Control	Direct	SPI/GPIO	SPI/GPIO	Direct
DC Supply	89 V (gate)	3.3 V (control), 5 V (V_{CP})	3.3 V (control), 5 V (V_{CP})	89 V (gate)
Lifetime	>3B cycles			
Package	2.5 mm x 2.5 mm WLCSP	5.2 mm x 4.2 mm LGA		4.3 x 3.2 mm BGA
Availability	**In production**			**Samples: Q4 2024** **Production: 2025**

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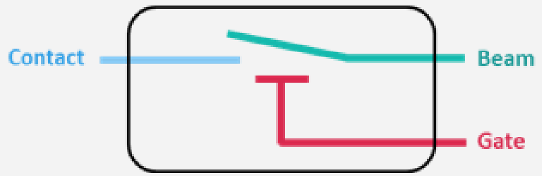
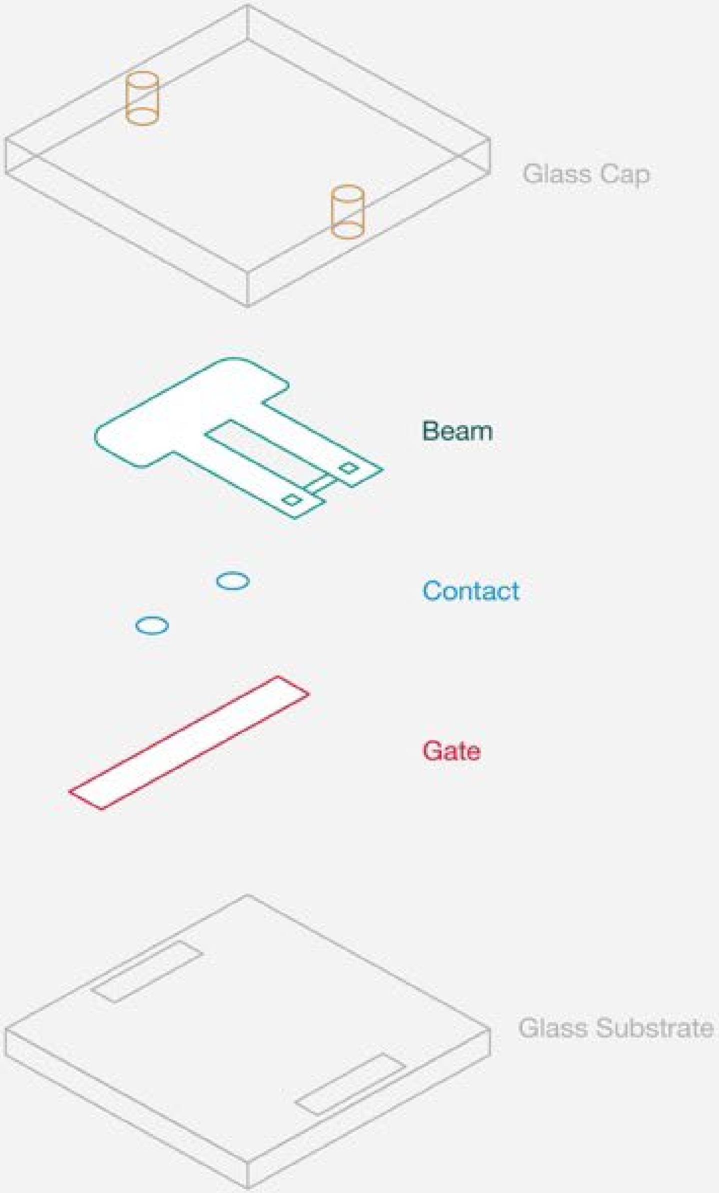
Backup Slides

Technology Overview

Ideal Switch™ unit cell is the core technology in our MEMS devices.





Glass Packaging

- Better thermals & power handling, improved RF performance

Reliability

- >3B min cycles spec
- High-power capability

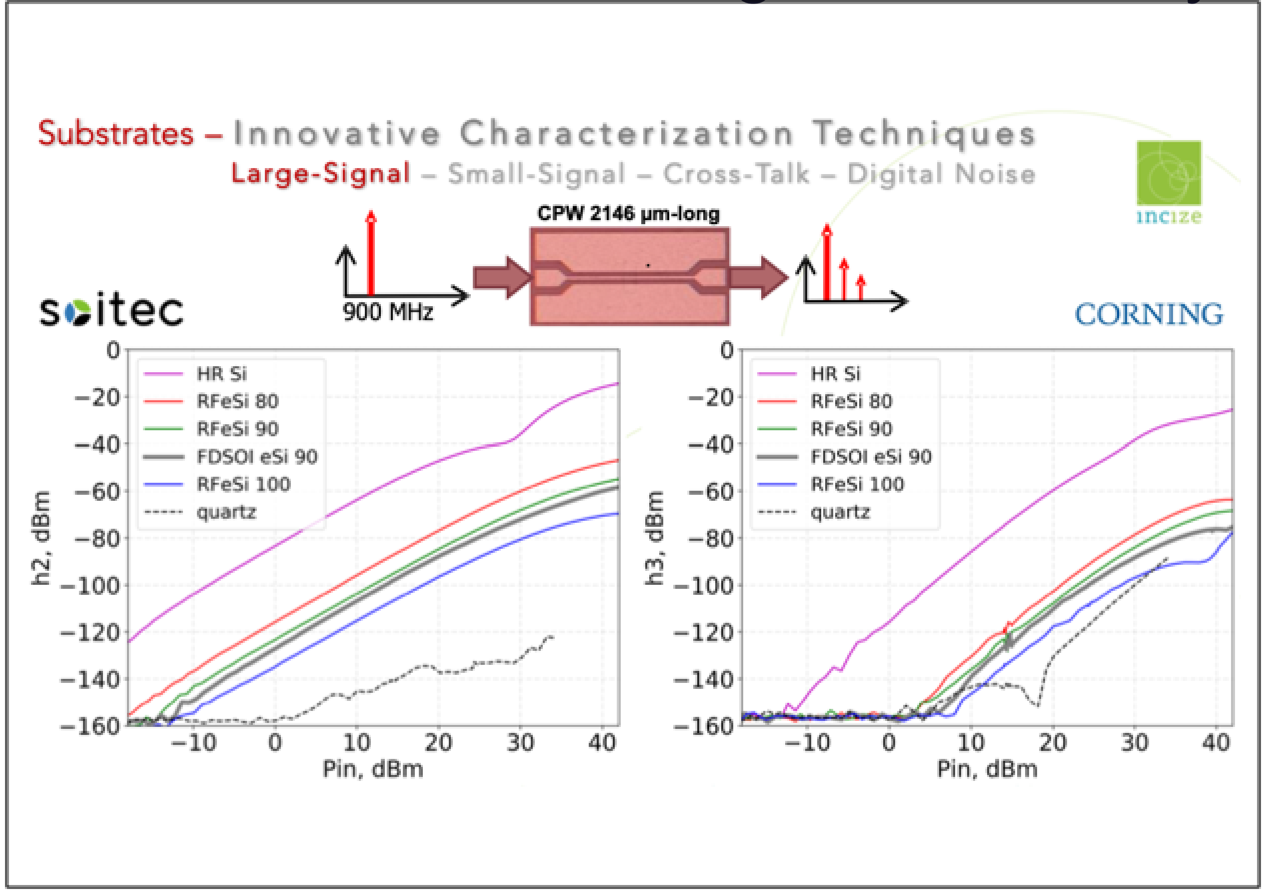
Through-Glass-Via

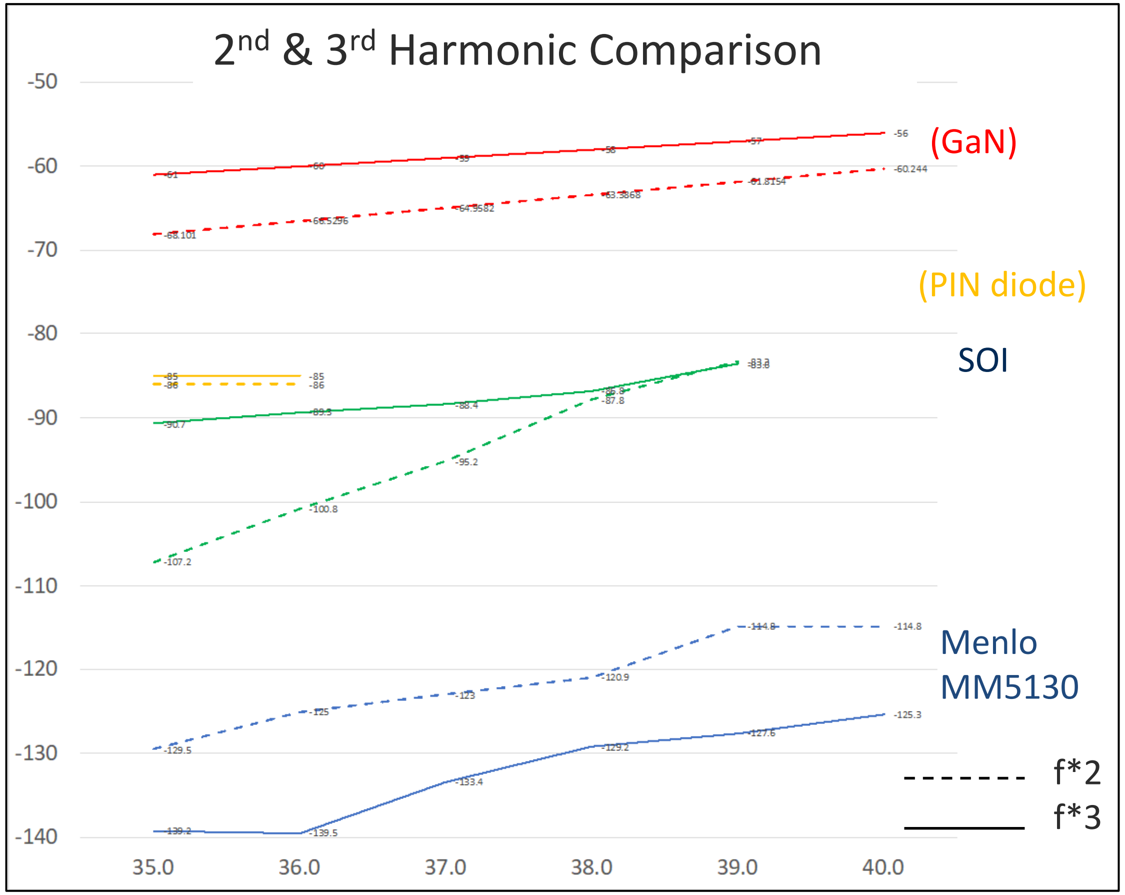
- Lower parasitics, lower resistance, small-size package, lowest cost

Scalability

- 50 x 50µm unit cell
- Allows scaling for high power through massive switch arrays

Metal-on-Glass for Highest Linearity



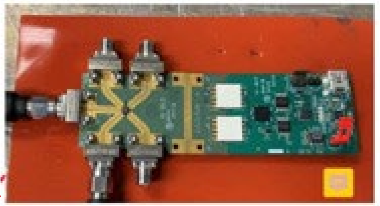


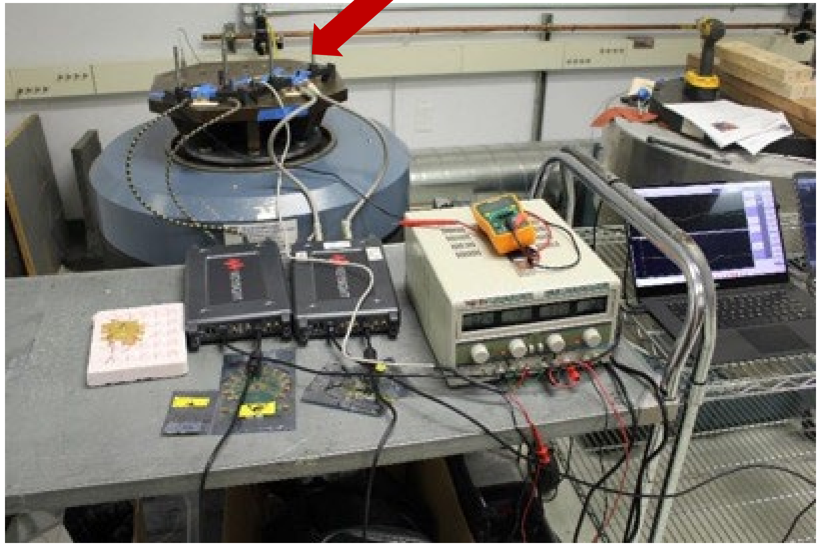
Moving from silicon to glass and removing the transistor from the RF signal chain helps reduce many sources of non-linearity.

Superior environmental performance – Shock & Vibration

MM5130 exceeds the IEC 60601/60068 standard, and also passes MIL-STD 810G/H stresses, and beyond…

MM5130
EVK Assembly





Shock/Vibration test system:
Westpak Labs, San Jose, CA &
NTS Labs, Fullerton, CA

Test Setup:

- Monitor switch *during* stress, analyze the data for any unexpected open or close.
- Test #1: IEC 60601/60068 standard – X,Y,Z-Axis 30 mins
- Test #2: MIL-STD-810G random vibration – X,Y,Z-Axis 30 mins
- Test #3: MIL-STD-810H random vibration – Z-Axis
- Test #4: Supplemental vibration testing in 6 dB increments above 810H to the maximum level of the vibration table (62 Grms)

Results:

- MM5130: under IEC 60601/60068 *and* Mil-Std-810G tests
- MM5130: under Mil-Std-810H up to 62 G_{RMS} tests
- Multiple devices showed no performance degradation during stress or at post-stress verification

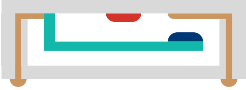
Pass

- Other mechanical relays subjected to same stress profile

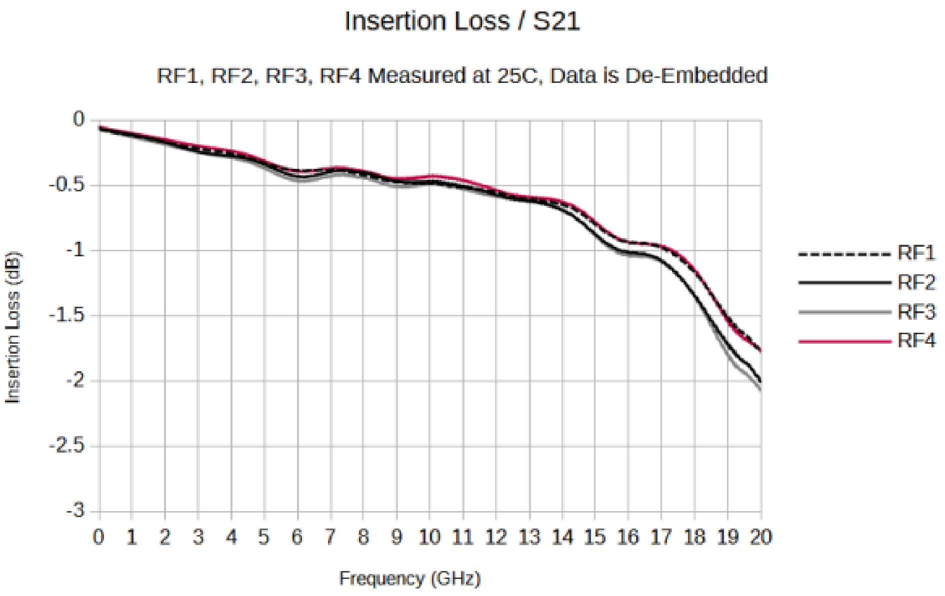
Fail

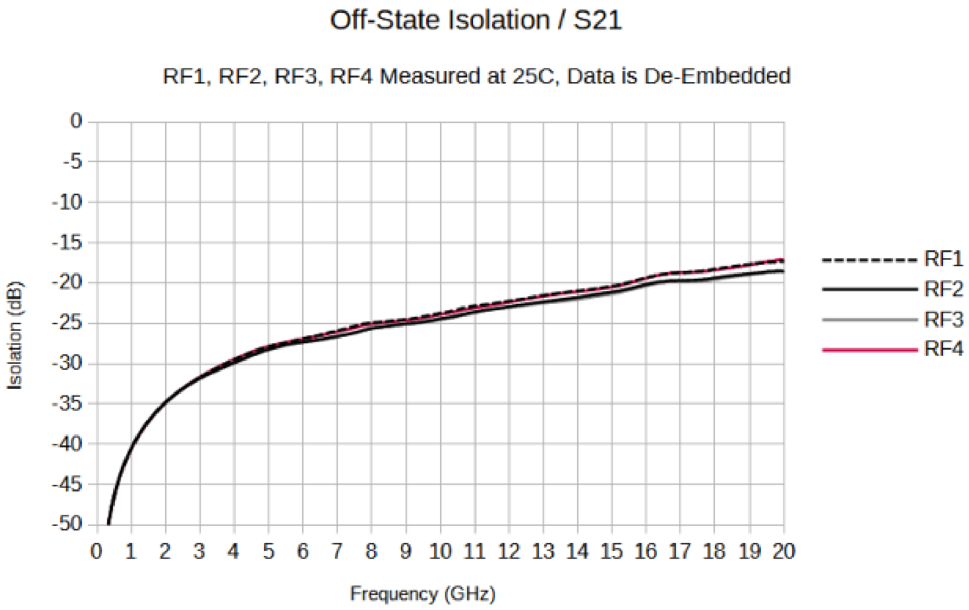
MM5120 EVK – CH. To CH. Variation

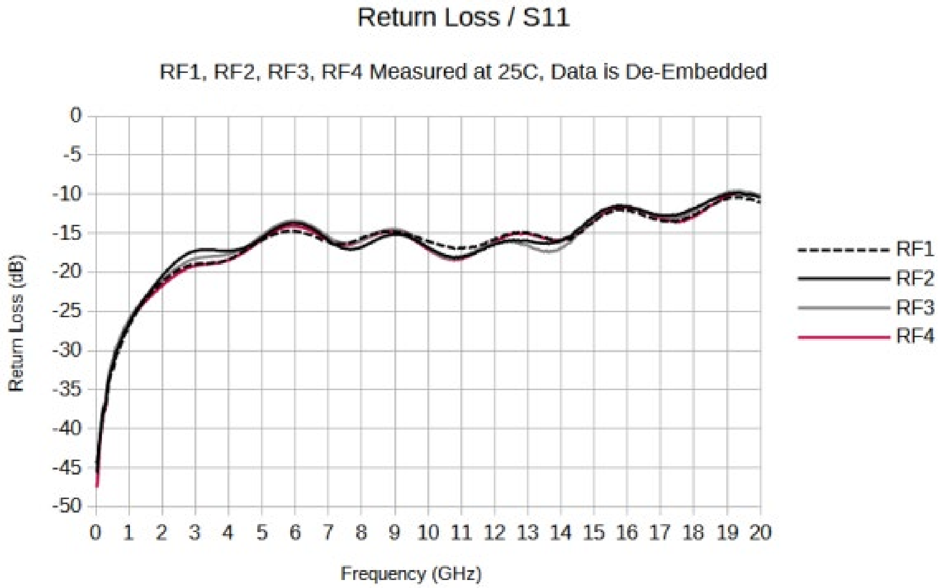
MM5120



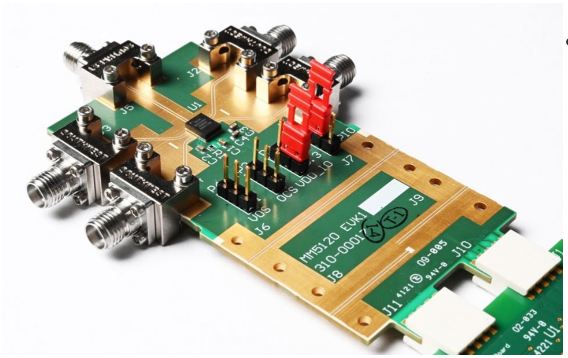
25W SP4T
DC to 18GHz+
5.2mm x 4.2mm
LGA package







MM5120 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

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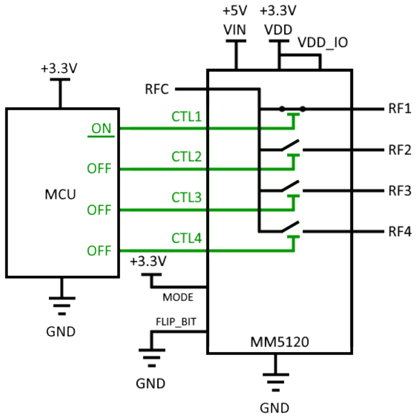
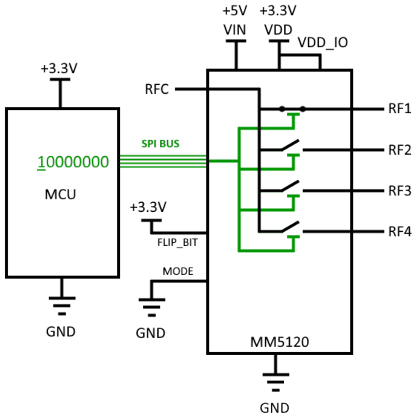
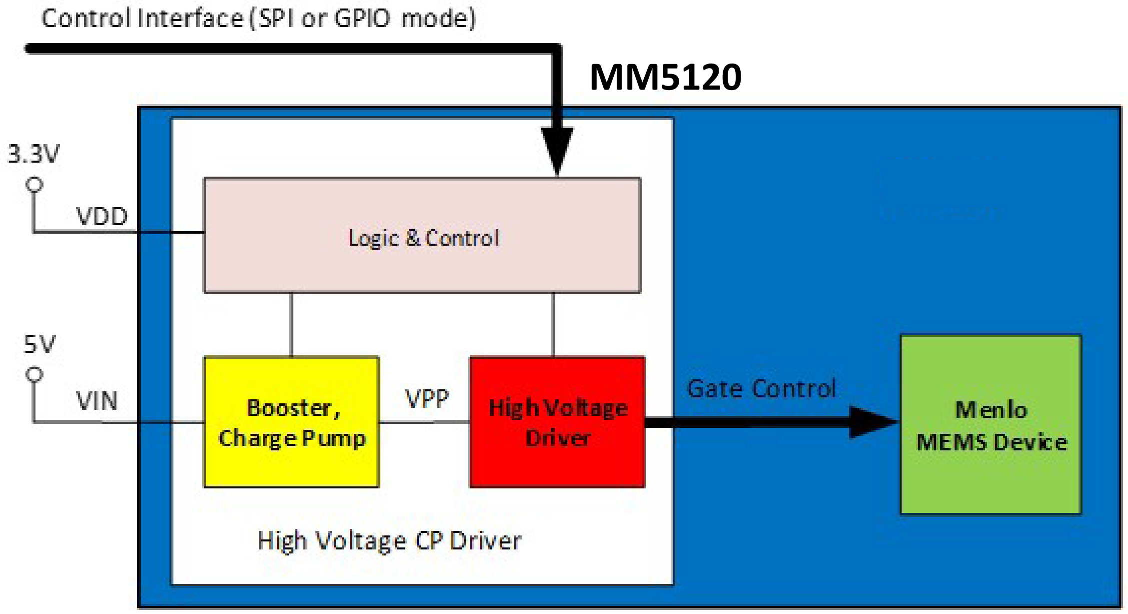
MM5120 – CSP ASIC Charge Pump and Driver (MM100)

Fully integrated ASIC provides high voltage charge pump and driver/mux for the MM5130 die

- V_{IN}: 5 Volt nominal for the charge pump bias
- V_{DD}: 3.3 Volt nominal for DC supply bias
- Serial (SPI) and parallel (GPIO) interface modes.







MM5120 Application Circuit

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