

MEMS Switch HV Gate Driver Design

APN-0001

October 2026

v2.1

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Gate Description for MEMS Switches

Menlo MEMS switches are ohmic MEMS devices that are controlled by a gate as shown in Figure 1 below. The gate voltage determines the switch state; the switch closes or turns ON when the gate is at a high voltage (V_{BB}) and opens or turns OFF when the gate is near zero volts. Gate drivers for MEMS typically require high voltage ($> 60\text{ V}$) but low current ($< 10\text{ nA}$) outputs.

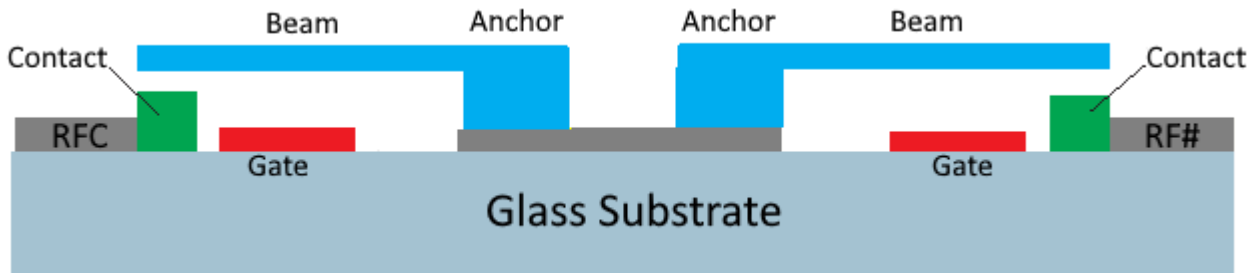


Figure 1: Cross-Section Diagram of MEMS Switch

Gate control signals are typically sourced from a DC-DC boost converter, such as an inductive switching regulator or capacitive charge pump. When controlling a switch from a microcontroller or other low-voltage device, a high-voltage (HV) driver is also required to level translate low-voltage control logic levels to high-voltage gate signals.

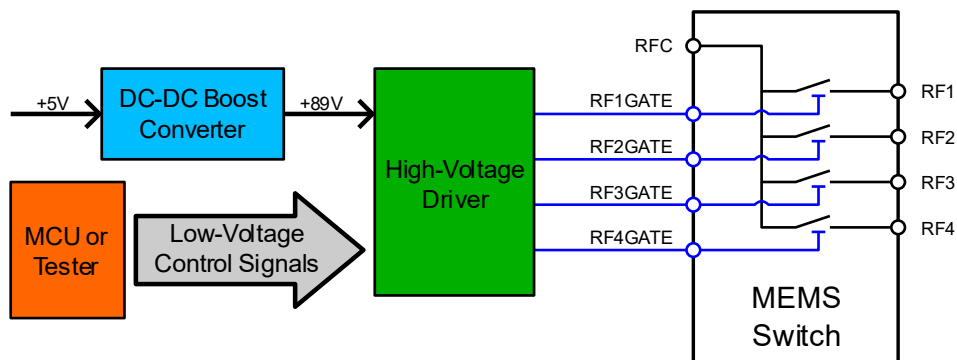


Figure 2: Functional Block Diagram for a MEMS Switch Driver

Safety

Scope of Safety Guidance

Because of the high voltage required to drive a MEMS switch gate, it's critical to design the gate driver such that it is safe for anyone who might contact HV nodes. This document references IEC 62368-1 as an internationally recognized standard for Hazard-Based Safety Engineering (HBSE) to help guide designers in making safe gate driver circuits.

Energy-source classification applies to the accessible parts of a finished product, not to a reference circuit in isolation. The guidance and reference designs in this document are provided to support designers in making gate driver circuits safer for operators and for their own equipment classification. Verifying that a complete product meets IEC 62368-1 or other standards, including under abnormal and single-fault conditions, is the responsibility of the equipment manufacturer.

IEC 62368-1 Guidance

IEC 62368-1 classifies electrical energy sources by the hazard they present to a person. A Class 1 energy source (ES1) is the lowest class: a class 1 source may be contacted by an ordinary person and requires no safeguard.

An electrical source can be classified as ES1 if it is below the steady-state voltage limit **OR** the current limit – it does not have to meet both.¹ The voltage limit is 60 V_{DC}, and the current limits are given below:

- 2.0 mA DC
- 0.5 mA_{RMS} AC, up to 1 kHz

A MEMS gate drive circuit operating at VBB = 89 V exceeds the ES1 voltage limit; therefore, an accessible gate node can only meet ES1 classification standards based on current limiting. Steady-state is defined as 2 seconds or longer.

Additionally, IEC 62368-1 lists peak voltage limits for various capacitance values to be classified ES1. Relevant values are 75 V for 0.17 µF, and 100 V for 0.091 µF. Interpolating between these entries for a peak voltage of 91 V (nominal VBB = 89 V plus 2 V tolerance), the maximum capacitance value is 0.119 µF.²

[Table 1](#) summarizes the relevant figures for the circuits recommended in this document.

¹ Refer to IEC 62368-1 Clause 5.2.2.2 and the associated tables for the full limits, including the frequency-dependent values above 1 kHz.

² Refer to IEC 62368-1 Clause 5.2.2.3 and the associated table for the full limits. Capacitance is defined as rated capacitor value plus tolerance. Note that linear interpolation is used as described in the associated table.

Table 1: ES1-Relevant Parameters of Recommended VBB Sources

Circuit	Nominal VBB	Current Limit (Worst-Case Tolerance)	Output Capacitance (Worst-Case Tolerance)
MP3430	89 V	1.97 mA ³	0.11 μ F
MM101	89 V	15 μ A	5.17 nF
MM5120	89 V	15 μ A	5.17 nF

End applications may not require the gate driver nodes to have the lowest classification defined by the standard. IEC 62368-1 gives guidance on safeguards required for Class 2 and higher energy sources when exposed to “ordinary”, “instructed”, and “skilled” persons. Refer to Clause 4.3.2 and the associated figures and safeguard clauses for more details.

Background

IEC 62368-1 replaced IEC 60950-1 (information technology equipment) and IEC 60065 (audio/video equipment), which specified a hard maximum voltage of 60 V irrespective of current for safety classification rather than hazard-based energy classes. The withdrawal dates for the superseded standards are jurisdiction-specific; in the European Union and the United States they were withdrawn in December 2020.

Other Regional Requirements

Some regions may define additional standards that apply to systems with HV circuits. National adoptions of this IEC standard such as UL 62368-1 may apply.

OSHA standards apply to all US workplaces and require electrical equipment operating above 50 V to be guarded against accidental touch by approved enclosures. Refer to provision 29 CFR 1910.303(g)(2)(i) for more details.

³ At APD node.

PCB Requirements

IPC-2221 is an industry standard that defines PCB design guidelines including minimum spacing between conductors based on peak voltage. Table 6-1 in that standard contains minimum conductor spacing based on peak voltage, conductor type, and elevation.

It is recommended to use the following minimum spacing rules for 51-100 V conductors < 10,000 ft:

- Uncovered External Layers: 0.6 mm (24 mils)
- Covered External Layers: 0.13 mm (5.2 mils)
- Internal Layers: 0.1 mm (3.9 mils)

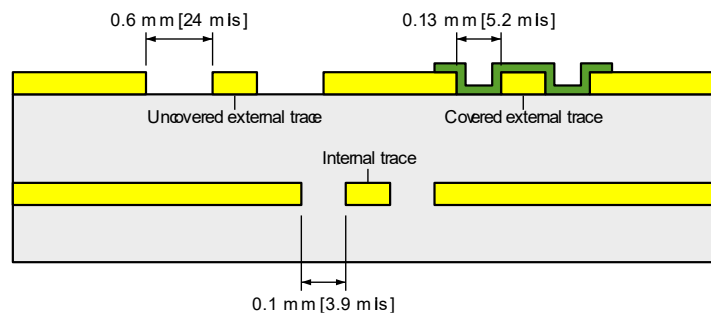


Figure 3: Minimum Spacing for 51-100V PCB Conductors

To reduce parasitic capacitance, it's recommended to use the minimum trace width (0.1 to 0.2 mm [4 to 8 mils]) that is standard for your fabrication process for HV gate lines. Because steady-state current draw of MEMS switch gates is in the low nanoamperes, ohmic voltage drop and self-heating are not a concern, and wide trace widths are not needed.

Board-to-Board Interconnects

It is recommended to **avoid routing HV gate lines across board-to-board or other interconnects**. Long interconnects degrade gate voltage slew rate due to cable inductance and connector parasitic capacitance (see [Slew Rate](#) for more details). They also create additional contact points where ESD discharge can damage the MEMS.

In systems where the gate driver and MEMS switch must be on separate boards, use a driver with high transient output current such as those listed in [High-Voltage Drivers](#). Ensure interconnects are rated for the required gate voltage and avoid hot-plugging/unplugging while the gate lines are high.

Menlo Components with Internal Gate Drivers

An example of a Menlo device that integrates the necessary VBB source and HV driver is the MM5120, as shown in Figure 4. The charge pump uses a +5V supply to generate VBB (+89 V), and the HV driver applies VBB to each MEMS gate when instructed to by the digital core.

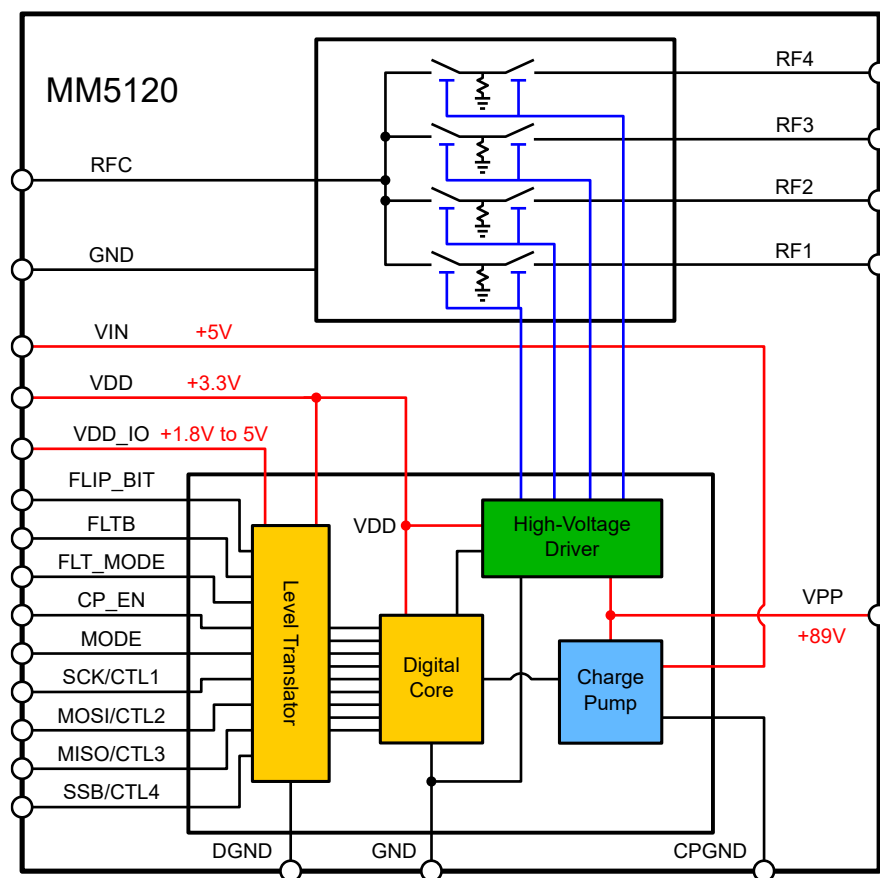


Figure 4: MM5120 with Integrated Charge Pump and HV Driver

MEMS switches with integrated drivers reduce footprint size for applications using a small number of MEMS switches. The integrated driver has familiar GPIO (parallel) and SPI control options and requires no specific power supply sequencing, simplifying schematic design.

In applications using dozens or hundreds of switches per system, it may be more efficient to use a single boost converter combined with a separate HV driver circuit to drive all switch gates.

Noise Considerations

MEMS switches with integrated charge pumps like the MM5120 and MM5140 will have elevated noise figure due to proximity between the RF pins and the charge pump. The RF channel closest to the charge pump, CH4 in the case of MM5120 and MM5140, is the worst-case channel.

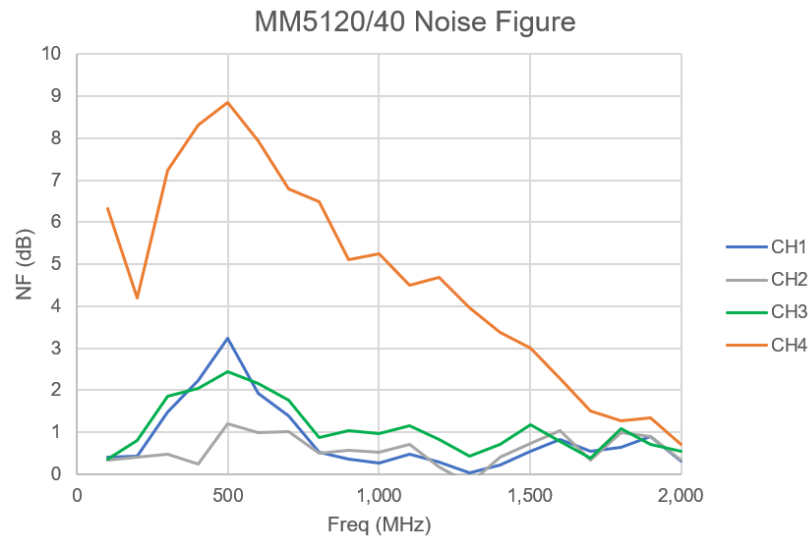


Figure 5: MM5120 and MM5140 Noise Figure Over Channels

For any application that has a maximum noise figure requirement, disable the internal charge pump and supply the VBB voltage from one of the recommended DC-DC Boost Converters (see MM5120 Datasheet or other relevant datasheet for implementation details). Alternatively, use MEMS switches without internal driver circuits like the MM5230 combined with one of the external driver circuits listed later in this document. In both cases, measured noise figure is equal to the insertion loss.

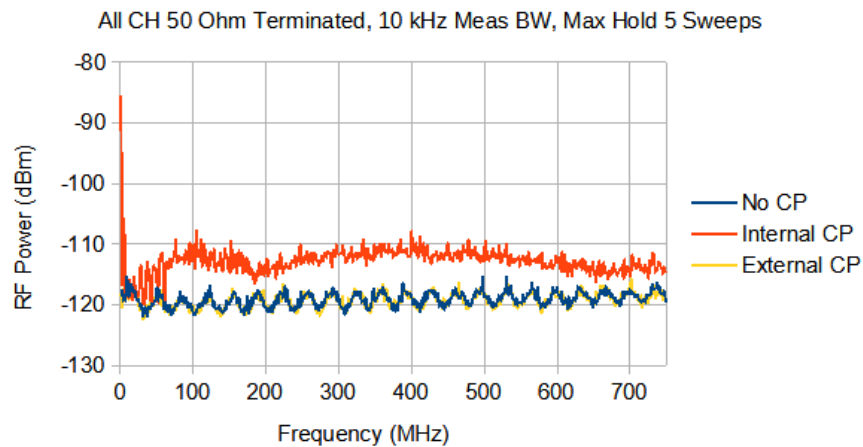


Figure 6: MM5120/40 CH4 Baseband Noise

Design Considerations for External Gate Drivers

Gate driver control should satisfy all datasheet specifications for the connected MEMS devices. Several MEMS gate specifications are listed below.

Absolute Maximum and Minimum Gate Voltage

Gate driver circuits must never exceed the absolute maximum or minimum gate voltage specifications of the connected MEMS device, including during power-up, power-down, fault, and non-operational conditions. Absolute maximum ratings are stress limits, not operating limits: exceeding them even briefly may cause permanent damage or latent degradation that does not appear as an immediate failure. Maximum gate voltage for MM5230 is given in [Table 2](#) below for reference.

Table 2: MM5230-03NDB Maximum Gate Voltage Specification (Rev 2.2)

Parameter	Minimum	Maximum	Unit
Closed State Voltage RFGATE Pins to RF1-RF4, RFC, GND	-100	100	V

Gate Voltage Levels

Driver circuits should be designed to always comply with the recommended high and low operating gate voltages. Ensure the tolerance of the boost converter output does not exceed the MEMS gate voltage tolerance.

The gate voltage range for MM5230-03NDB is given in [Table 3](#) below for reference.

Table 3: MM5230-03NDB Gate Bias Specification (Rev 2.2)

Parameter	Symbol	Minimum	Typical	Maximum	Unit
Gate Bias Voltage	V_{BB}	87	89	91	V

To design a V_{BB} source for a MEMS switch, it's common to use a DC-DC boost converter with a feedback topology like the one shown in [Figure 7](#).

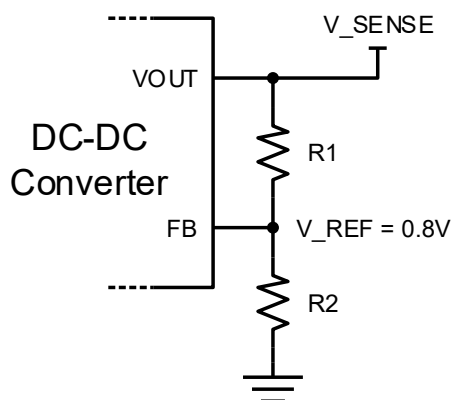


Figure 7: Common DC-DC Boost Converter Feedback Circuit

The divider sets the regulated node V_{SENSE} to a steady-state value calculated using the formula below:

$$V_{SENSE} = V_{REF} + R1 \cdot \left(I_{REF} + \frac{V_{REF}}{R2} \right)$$

Tight-tolerance resistors are required for R1 and R2. Because R1 is much larger than R2, almost the full ratio error of the divider appears at the output. With 5% tolerance resistors $V_{SENSE} = 89$ V, the worst-case output error results in +9.4 / -8.5 V variation in V_{SENSE} , which far exceeds the Gate Bias Voltage window. With 1% resistors the error is ± 1.81 V, consuming 90% of the error window alone and leaves no room for other error sources such as the regulator's reference. **Choose 0.1% tolerance** for feedback circuit resistors, which limits the contribution to ± 0.18 V.

Supply Current/Load Resistance

Boost converters should be capable of supplying the maximum current draw of the HV driver without voltage droop or thermal failure. This current draw is dependent on the HV driver design and parasitic resistive loads on the HV driver output. Current draw from MEMS gates is typically negligible (<10 nA per device).

Refer to [IEC 62368-1 Guidance](#) for information on designing for maximum safe current output of the VBB source.

Slew Rate

HV drivers must comply with slew rate specifications in the low-to-high and high-to-low transitions of the gate voltage. Failure to meet slew rate specifications can result in reduced cycle lifetime and switching time that degrades from cycle-to-cycle. Slew rate is typically measured in Volts per microsecond, and can be calculated using the formula below:

$$SR = \frac{\Delta V}{\Delta T}$$

- SR = Slew Rate in $V/\mu s$
- ΔV = Voltage difference between 10% and 90% of gate voltage in V
- ΔT = rise or fall time between 10% to 90% of gate voltage in μs

When using a current-controlled HV driver, such as the MM101, the slew rate can be calculated using the formula below:

$$SR = \frac{I_{HV}}{C_L}$$

- SR = Slew Rate in $V/\mu s$
- I_{HV} = HV driver sink/source current in μA
- C_L = Load Capacitance in pF

The operating slew rate specification for MM5230-03NDB is given in [Table 4](#) below for reference.

Table 4: MM5230-03NDB Operating Slew Rate Specification (Rev 2.2)

Parameter	Minimum	Typical	Maximum	Unit
Gate Voltage Slew Rate	20	—	200	$V/\mu s$

The primary contributor to load capacitance is PCB conductor parasitics. This capacitance can be either simulated from the layout or approximated as 2 pF per centimeter.⁴ Menlo Micro's MEMS switches have gate capacitance to GND that is typically 2 pF.

When using the MM101, tie at least two outputs together to double the sink and source current to 120 μA , therefore doubling the slew rate. See [Figure 9](#) for an example circuit diagram.

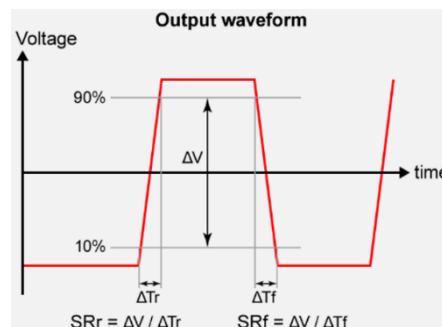


Figure 8: Calculation of Slew Rate

⁴ This is a conservative estimate calculated for a 0.2 mm wide stripline routed on an inner layer. Routing on external layers and increasing spacing to adjacent ground planes can reduce parasitics to approximately 1 pF per centimeter.

MM101 External Gate Driver

The MM101 is an ideal solution for applications using **less than 20 MEMS devices per system**. The MM101 is a complete DC-DC boost converter and HV driver solution capable of driving one SP4T MEMS switch. The internal DC-DC boost converter is a charge pump that operates with a 5V source and can generate an 80V or 89V source. The internal HV driver can operate with either serial (SPI) or low-voltage parallel (GPIO) inputs to generate 8 HV outputs.

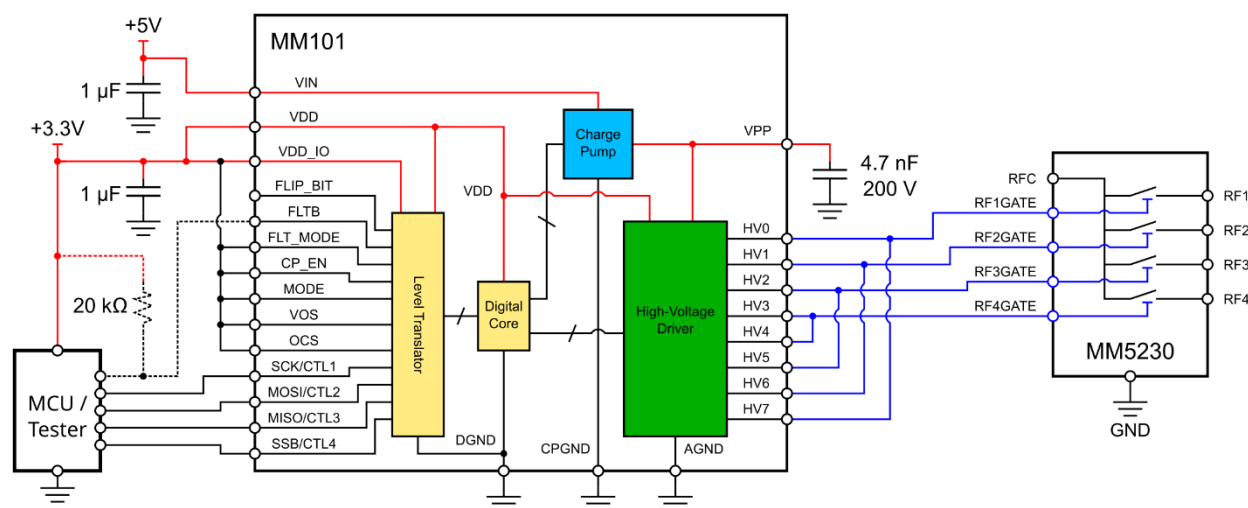


Figure 9: MM101 Circuit Diagram to Drive MM5230 from 4 GPIO

When designing with the MM101, tie at least two outputs together to increase the output current to 120 μ A. Place the MM101 as close as possible to the MEMS switch and route HV gate lines on external layers if possible to minimize the parasitic capacitance.

To meet a 20 V/ μ s lower limit, maximum load capacitance per output pair including the MEMS gate should be kept below 6 pF total. Assuming 2 pF gate capacitance, this leaves 4 pF, or ~2 cm of trace, for PCB parasitics.

See the [MM101 datasheet](#) and contact Menlo Microsystems for further details and design support.

External Gate Drivers

For applications using more than 20 MEMS devices per system, Menlo recommends a two-chip solution that uses one DC-DC boost converter circuit combined with one or more HV driver circuit(s). These solutions can drive hundreds of MEMS devices with a smaller total footprint compared to solutions using many switches with internal drivers, or many MM101.

DC-DC Boost Converters

MP3430

For an external DC-DC boost converter, Menlo recommends the MP3430 from Monolithic Power.

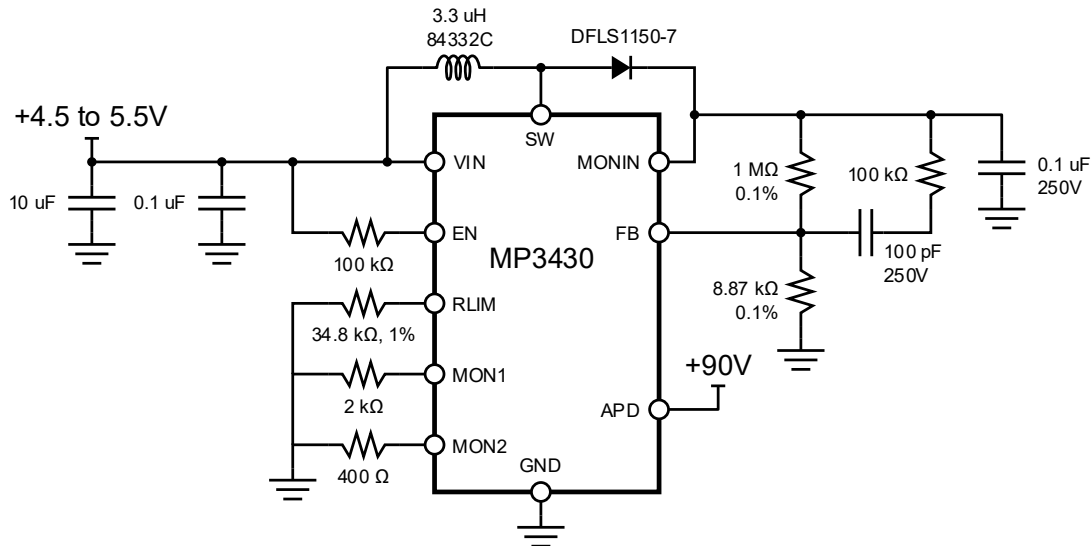


Figure 10: MP3430 Boost Converter Recommended Circuit

Table 5: Boost Converter BOM of Critical Components

Description	Manufacturer	Part Number
Step-Up Converter, 90V, 3 x 3 mm	Monolithic Power Systems	MP3430HQ-LF-Z
Inductor, 3.3 μ H, 4.5 x 3.3 mm	Murata Electronics	84332C
Schottky Diode, 3.9 x 1.9 mm	Diodes Inc.	DFLS1150-7
Capacitor, 0.1 μ F, 250 V, 1206	Murata Electronics	GRM31CR72E104KW03L
Capacitor, 100 pF, 250 V, 0805	Murata Electronics	GRM21A5C2E101JW01D
Resistor, 34.8 k Ω , 1%, 0402	Panasonic Industry	ERJ-2RKF3482X
Resistor, 1 M Ω , 0.1%, 0805	Panasonic Industry	ERA-6AEB105V
Resistor, 8.87 k Ω , 0.1%, 0402	Panasonic Industry	ERA-2AEB8871X

Note that the current-monitored “APD” output is used to limit output current and reduce noise on the +89 V output. The feedback resistors are chosen to account for a 1.0 to 2.0 V drop between the MONIN and APD pins. Nominal APD output voltage is ~1 V higher than the typical gate bias voltage (see [Table 3](#)) to allow more margin to the lower limit, as error sources in the positive voltage direction are mitigated by maximum output voltage of the MP3430.

Note the 250 V rating on capacitors at the high-voltage output, and the larger 0805 size on the 1 M Ω feedback resistor. See [Series Resistor Working Voltage](#) for more details.

R_{LIM} is chosen such that worst-case tolerance current limiting is still below 2 mA, using the formula provided in the MP3430 datasheet below:

$$R_{LIM}[k\Omega] = \frac{68}{I_{APD,MAX}[mA]}$$

For a worst-case R_{LIM} of 34.452 k Ω , this results in $I_{APD,MAX}$ of 1.97 mA.

To avoid voltage droop on the high-voltage output, total load resistance should be greater than 50 k Ω .

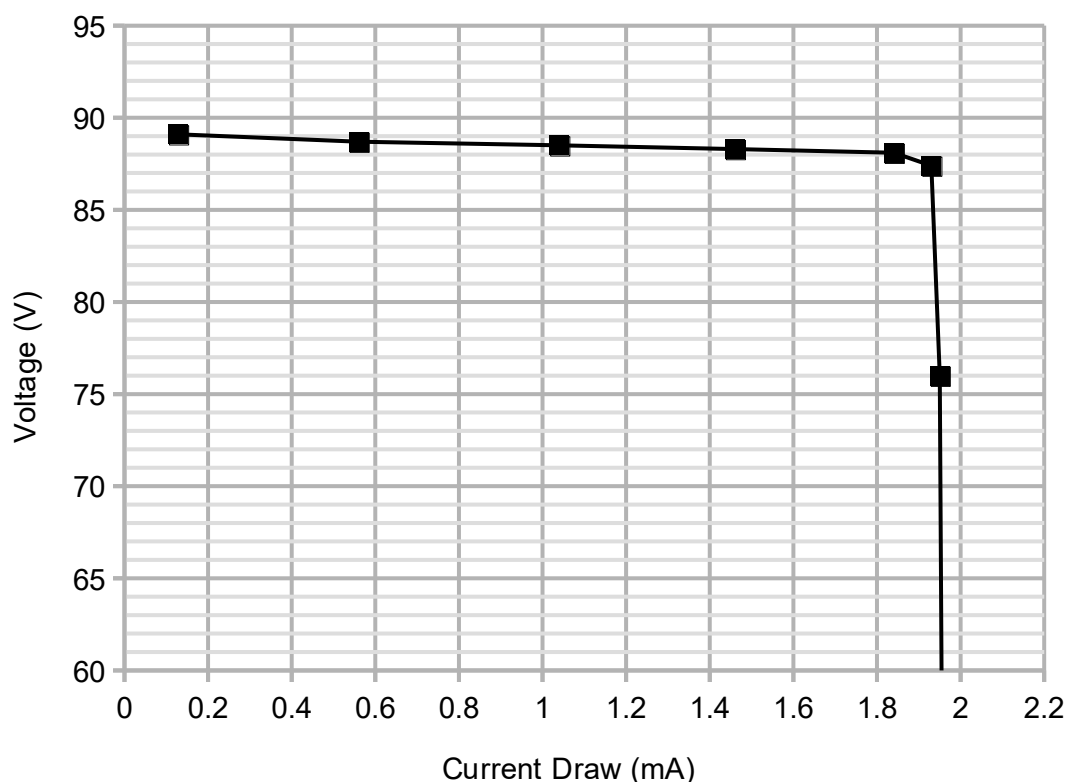


Figure 11: MP3430 APD Output Voltage Over Current

High-Voltage Drivers

Menlo recommends the following HV driver chips from Microchip:

- HV513: 8-Channel, Serial to Parallel Converter, Push-Pull Outputs, 250 V
- HV509: 16-Channel Serial to Parallel Converter, Push-Pull Outputs, 250 V
- HV7620: 32-Channel, Serial to Parallel Converter, Push-Pull Outputs, 200 V
- HV507: 64-Channel, Serial to Parallel Converter, Push-Pull Outputs, 300 V

An example circuit for the HV513 is shown in [Figure 12](#) which can be scaled to drivers with higher channel counts.

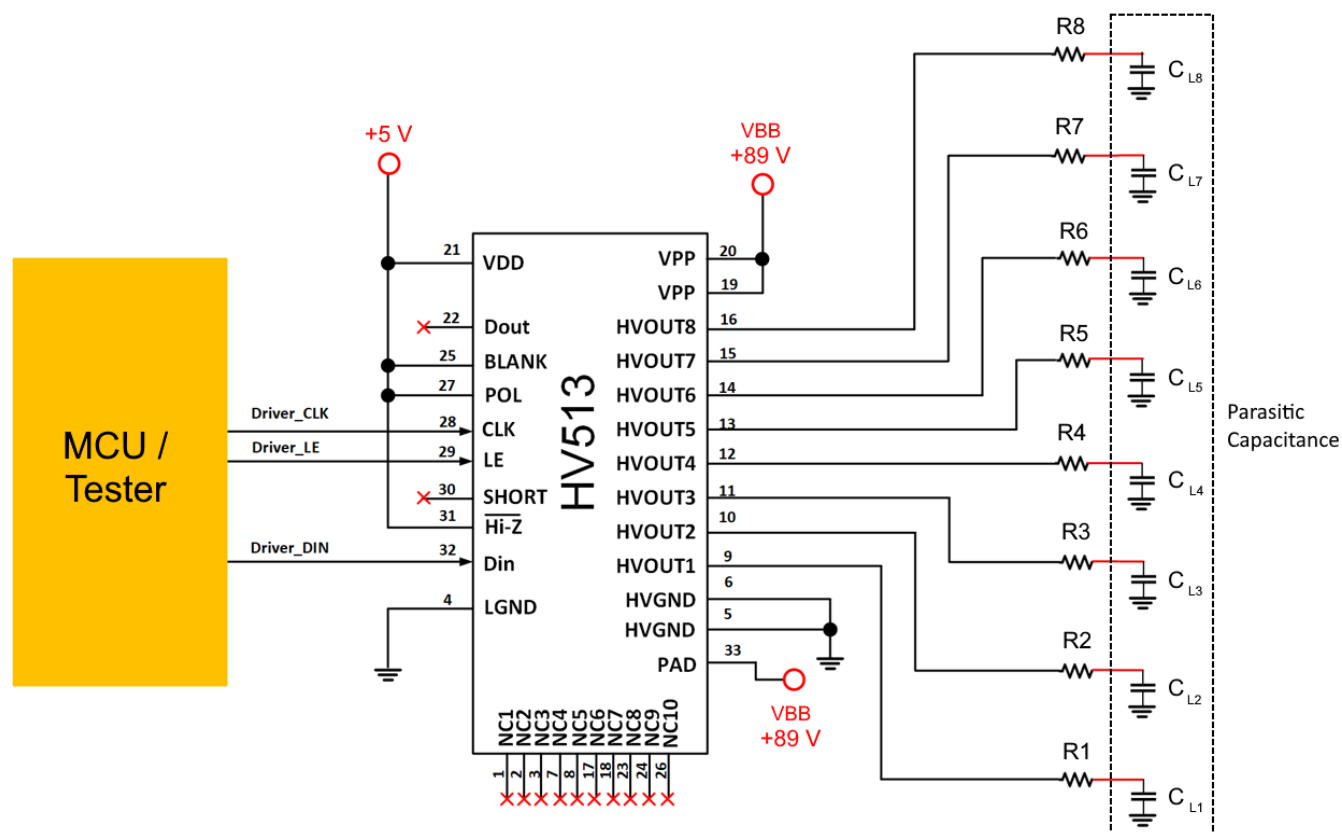


Figure 12: HV513 MEMS Gate Driver Recommended Circuit

Note the intentional lack of decoupling capacitors and the center PAD connected to VBB. Refer to HV513 Datasheet Rev B for more details.

$C_{L\#}$ refers to parasitic capacitance at each node, which includes the MEMS gate and any PCB trace capacitance.

Serial-to-parallel HV drivers such as the HV513 have push-pull outputs with high transient current capability. Driven directly into the low capacitance of a MEMS gate, these outputs will slew far faster than the MEMS switch slew-rate specification allows. A series resistor R_S on each HV output is therefore required to set the slew rate.

Series Resistor Value

Treating the output as a voltage step through the series resistance R_S into the total load capacitance C_L , the 10–90% transition time ΔT is:

$$\Delta T = 2.2 \cdot R_S \cdot C_L$$

The target series resistance can therefore be calculated from the formula below:

$$R_S = \frac{\Delta V}{2.2 \cdot SR \cdot C_L}$$

For a VBB voltage of 89 V and calculating slew rate from 10% to 90%, $\Delta V = 71.2$ V. Then assuming a target slew rate of 100 V/ μ s, this simplifies to:

$$R_S[k\Omega] = \frac{324}{C_L[pF]}$$

As an alternative, [Table 6](#) gives standard resistor values that hold the slew rate within a 20 to 200 V/ μ s range. See [Slew Rate](#) for more details and relevant MEMS switch slew rate specifications.

Table 6: Recommended Series Resistance by Load Capacitance

Load Capacitance	Recommended Series Resistance
2 to 10 pF	100 k Ω
10 to 50 pF	22 k Ω
50 to 250 pF	4.7 k Ω
250 to 1,000 pF	1.0 k Ω
1,000 to 2,000 pF	470 Ω

Series Resistor Working Voltage

The full VBB voltage appears across R_S at the start of each transition. Thick-film 0402 and 0603 resistors are commonly rated for only 50 V working voltage and are not suitable. Use 0805 size resistors which are typically rated for 150 V.

Important Information

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