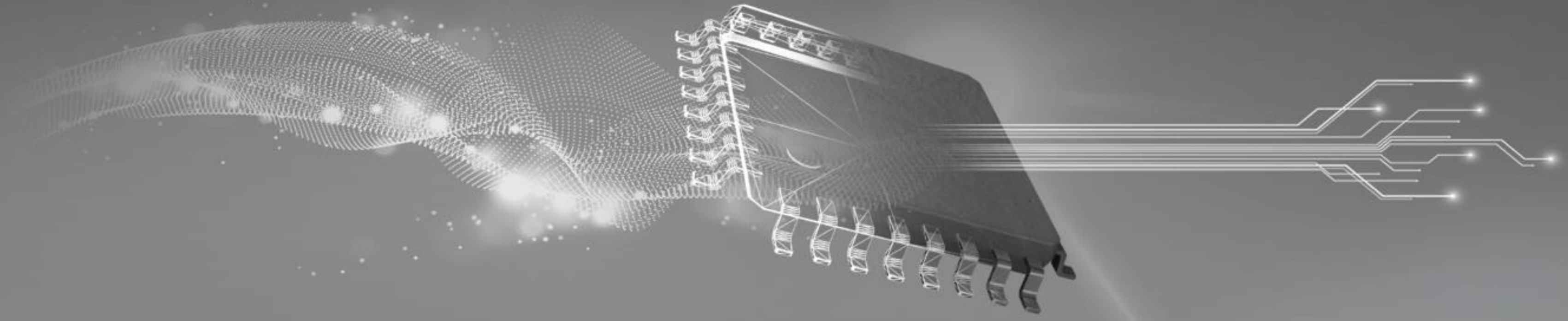
TI TECH DAYS



How to select the right multiplexer or signal switch to maximize system performance

Saminah Chaudhry, System Engineer

Multiplexers and Protection Devices

Agenda

- **Critical parameters for multiplexers and signal switches**
  - Critical parameters for precision multiplexers
    - On-resistance
    - On-capacitance
    - Leakage current
    - Charge injection
  - Protection multiplexer features and common use cases
    - Powered-off protection
    - Fail-safe logic
    - Latch-up immunity
    - Common use cases
- **TI package technology**
- **Portfolio overview and Q&A**

Critical parameters for multiplexers and signal switches

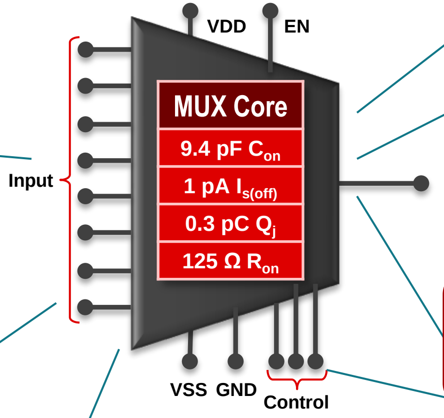
Critical parameters | Multiplexers & signal switches

Supply range
- Single supply: 24 V, 15 V, 5 V, 3.3 V
- Dual supply: ±15 V, ±10 V, ±5 V

Supply current
- 10 nA – 100 µA max

On-resistance
- R_{ON}: 3 Ω, 60 Ω, 125 Ω
- Flatness: flat, 1 Ω, 20 Ω
- Drift: 0.5%/°C - 2%/°C

Input signal range
- Low level: 10 mV – 100 mV
- High level:
  - Current input: 4…20 mA, 0…24 mA, 0…20 mA
  - Voltage input: ±10 V, ±5 V, 0 to 10 V, 0 to 5 V
- Rail-to-rail, above-rail



On-capacitance
- Con: 3 pF, 60 pF, 125 pF

Charge injection
- Low: 0.1 pC
- High: 50 pC

HBM ESD level
None, 2 kV

Leakage @ 125°C
- Low: 2 nA max
- High: 1 µA max

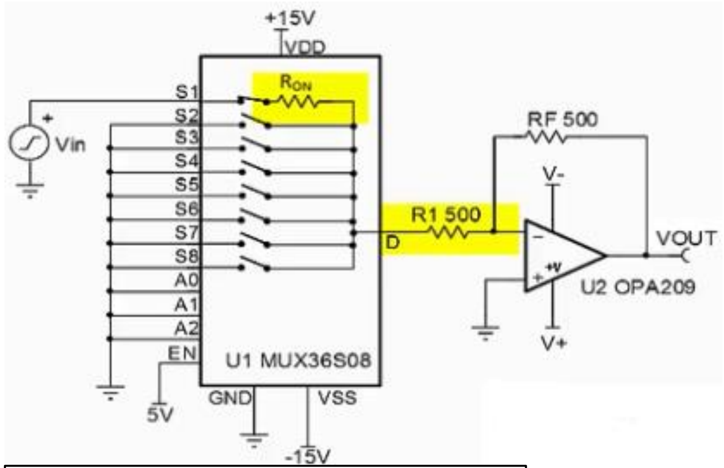
Powered-off protection, Fail-safe logic, Latch-up immunity
Simplify power sequencing design complexity

Transition time
- Fast switching: 50 ns- 100 ns
- Slow switching: 1 µs- 10 µs

Control logic
- Logic level (V_{DD}): 3.3 V, 5 V, 10 V
- Protocol: GPIO, SPI

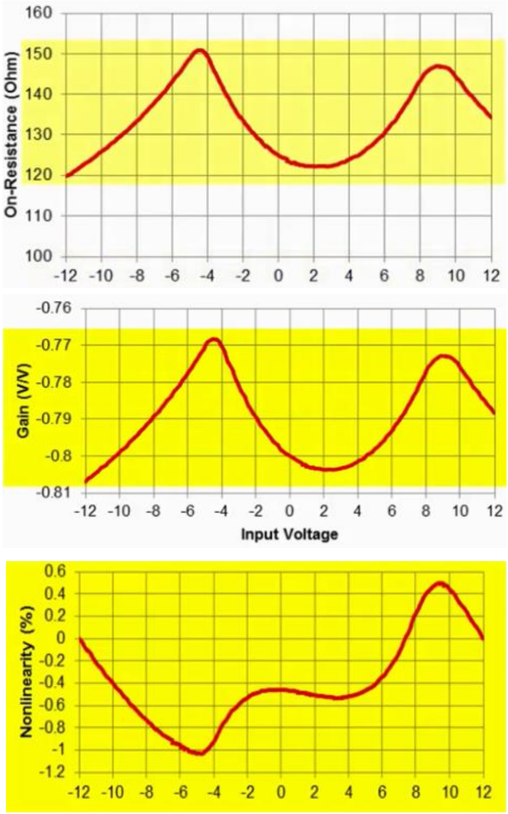
Why is R_{ON} important for your system?

TI Precision Labs video - On-Resistance



Effective
Gain (AG) = - RF / (R1 + R_{ON})

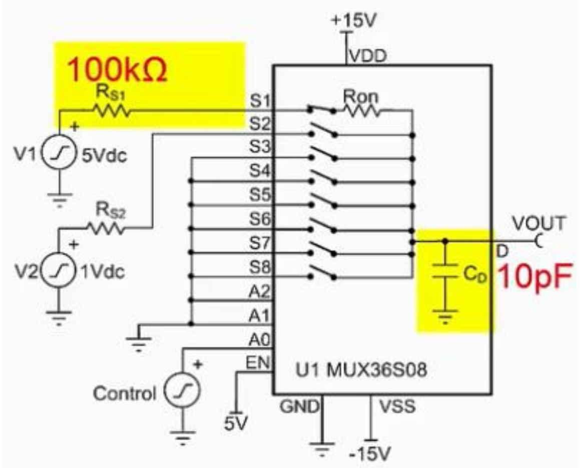
However, if R1 is very high compared to R_{ON} then any gain error non-linearity introduced due to the MUX R_{ON} is negligible

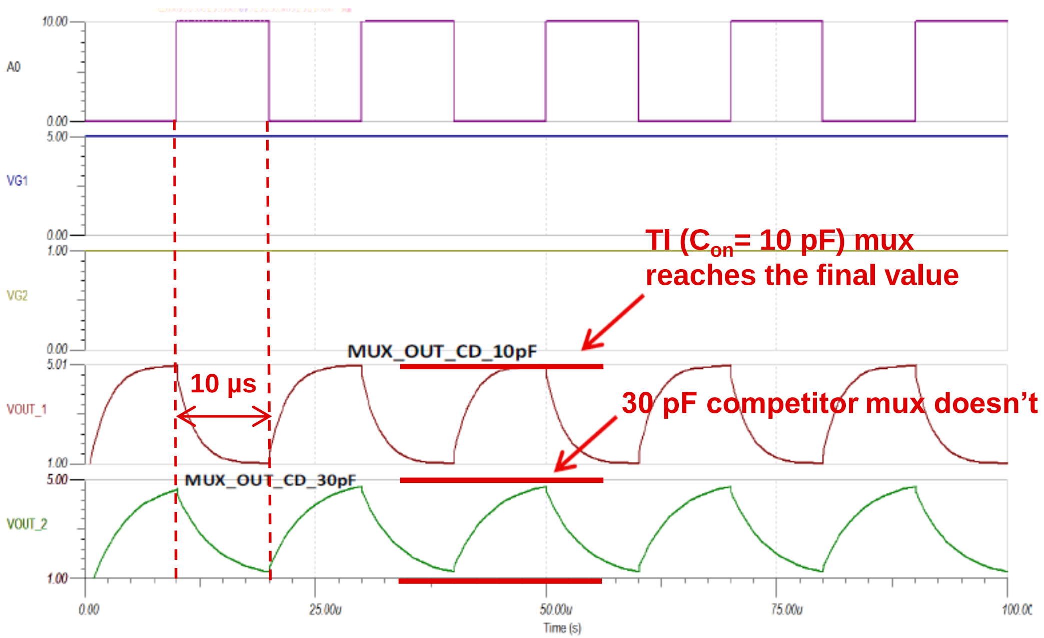


- The on-resistance of a switch can introduce **variations** and **gain error**, which produce signal dependent distortion
- R_{ON} drifts over temperature that **limits accuracy and degrades linearity of V_{OUT} related to V_{IN}**
- To counter gain error introduced due to R_{ON}, it is recommended to interface the MUX output to a high impedance stage R1 (buffer amplifier)

TI Precision Labs video - On-Capacitance

Why is C_{ON} important?



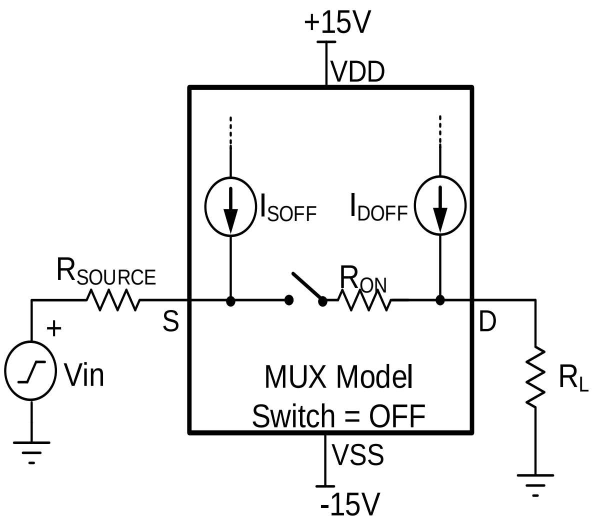


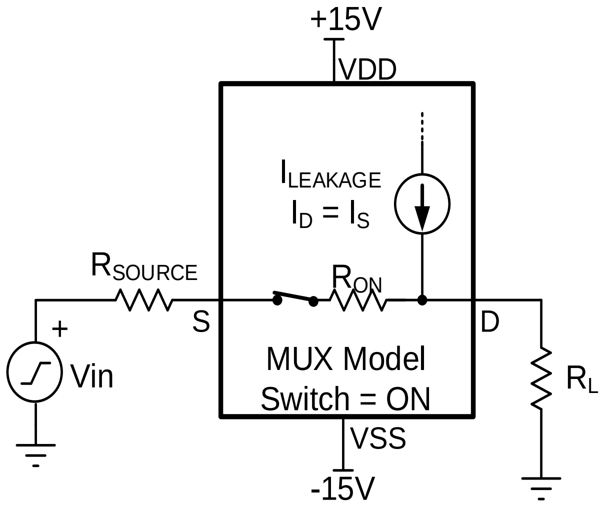
Multiplexer examples	Input source impedance	Switching between channels	Outcome
MUX36S08 (C_{on} = 10 pF)	100 kΩ	10 µs	TI mux settles to the input source's final value
Competitor mux (C_{on} = 30 pF)	100 kΩ	10 µs	The other mux doesn't settle to the final value due to long RC time constant formed by mux on-capacitance (30 pF) and 100 kΩ input impedance of source

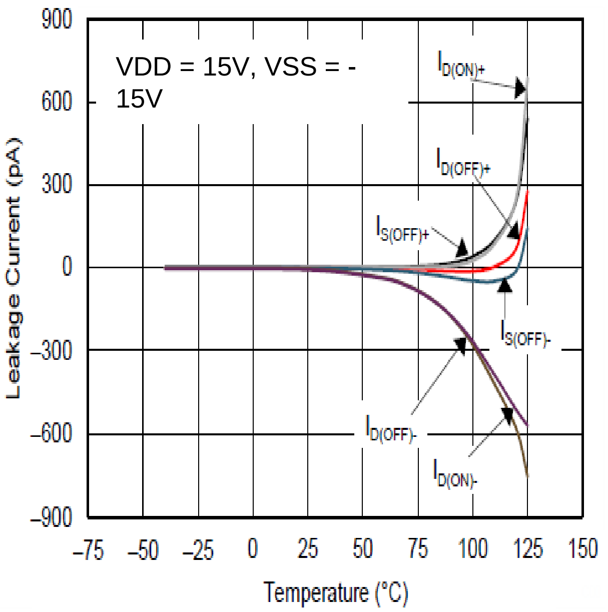
- ❑ On-capacitance **affects settling behavior of multiplexers**, which impacts transient performance of the system
- ❑ Higher C_{on} **can introduce distortion** in systems where input channels are switched at a very fast rate
- ❑ **For high input impedance data acquisition systems and fast switching data acquisition systems, a low C_{on} multiplexer is recommended**

Why is $I_{LEAKAGE}$ important for your system?

TI Precision Labs video - Leakage Current

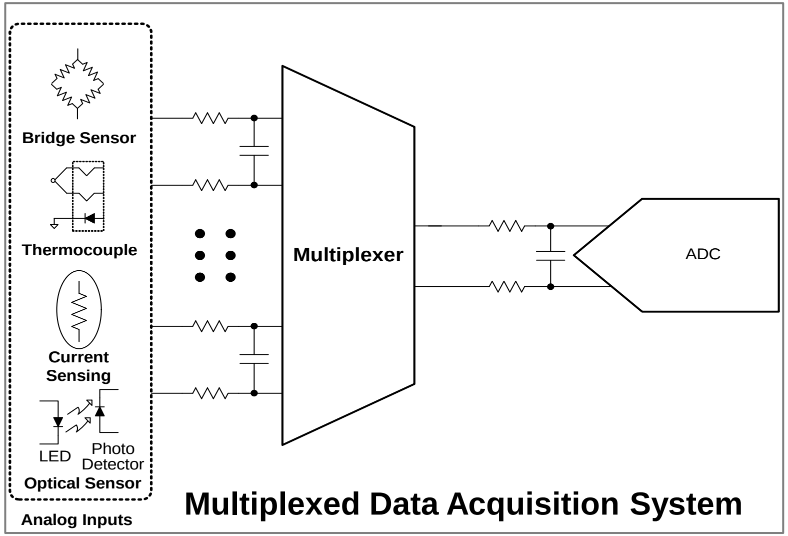




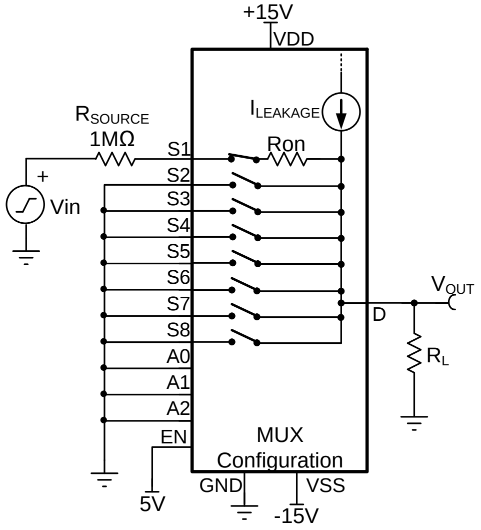


- **Switch = OFF:** $I_{S(OFF)}$ flows through R_{SOURCE} and $I_{D(OFF)}$ flows through R_L
- **Switch = ON:** Error introduced by leakage current: $V_{ERROR} = (R_{ON} + R_{SOURCE}) \times I_{D(ON)}$

Industrial applications | Factory automation - PLC



Multiplexed Data Acquisition System



Multiplexer examples	Multiplexer leakage current (25°C/85°C)	Offset error (25°C/85°C) ($I_{LEAKAGE}$ x R_{Source})	Offset error 18-bit system (in bits)
MUX 1 (Low leakage)	10 pA / 50 pA	10 µV / 50 µV	0.52 / 2.62
MUX 2 (High leakage)	100 pA / 500 pA	100 µV / 500 µV	5.24 / 26.22

18-bit system example calculation:

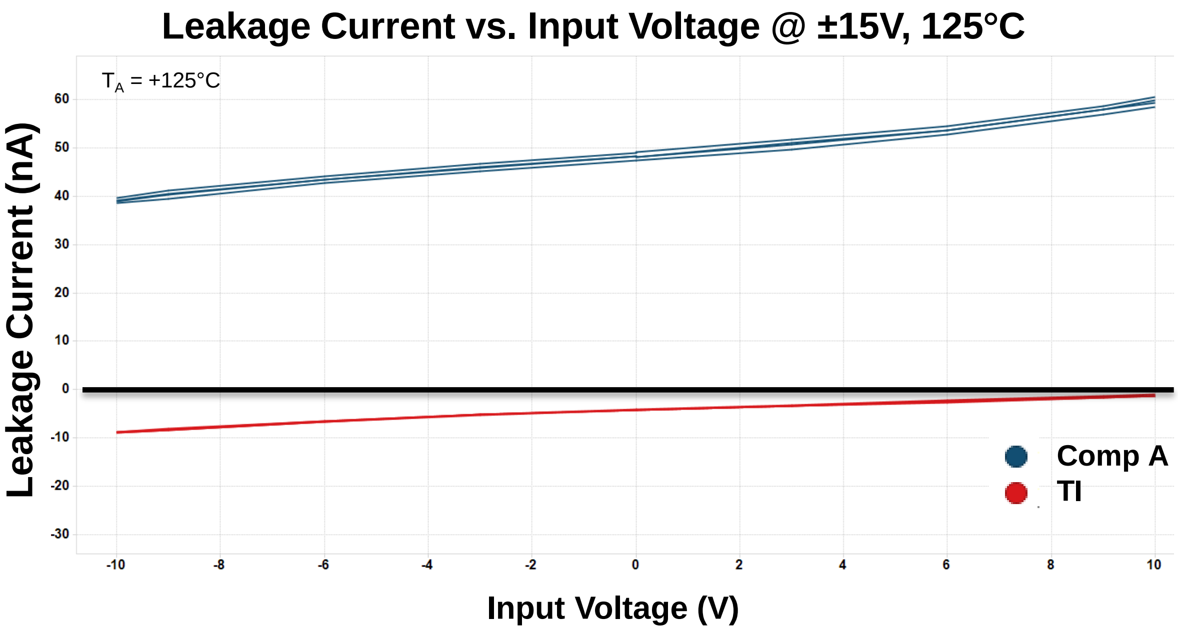
$$V_{ref} = 5V$$

$$V_{LSB} = \frac{5V}{2^{18}} = 19.073\mu V$$

$$OffsetError(V) = I_{LEAKAGE} \cdot R_{SOURCE} = (100pA)(1M\Omega) = 100\mu V$$

$$OffsetError(Bits) = \frac{OffsetError(V)}{V_{LSB}} = \frac{100\mu V}{19.073\mu V} = 5.24\ codes$$

TMUX7219 benchmarks | Leakage current

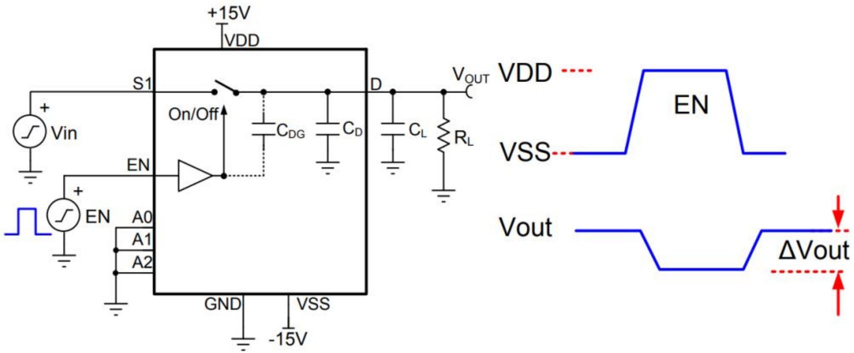


- **TMUX7219 is designed to be the lowest leakage low R_{ON} mux in the industry**
- Lower leakage with linear scaling means
  - Less error in measurement
  - Less drift
  - Easier to calibrate in high precision systems

Why is $Q_{INJECTION}$ important for your system?

TI Precision Labs video - Charge injection

- What is charge injection error?
  - Charge injection is a voltage change introduced at the output of the switch when logic is turned ON or OFF.
  - This can introduce output voltage error when the control logic is switched.



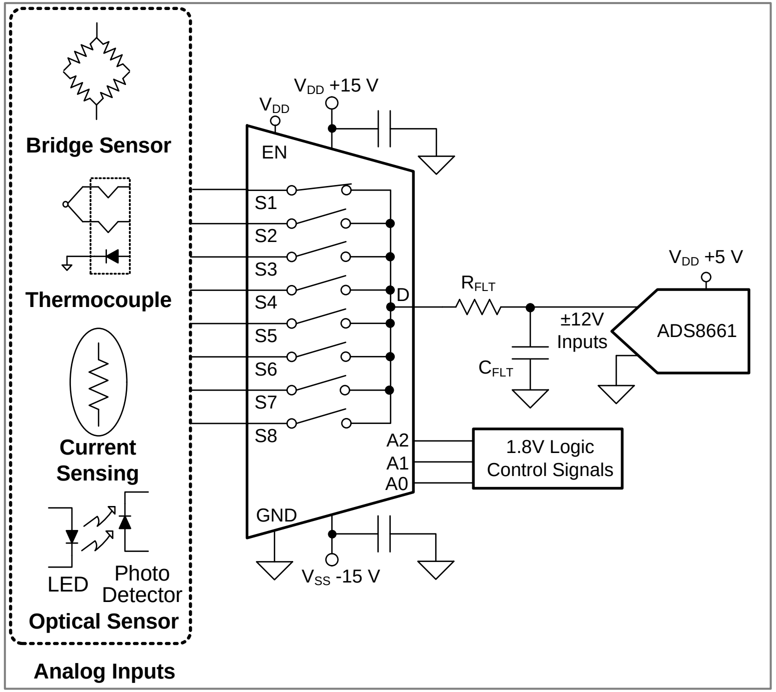
- Voltage change introduced at the output of switch when switch is turned ON or OFF:

$$Q_{INJ} = (C_D + C_L) \times \Delta V_{OUT}$$

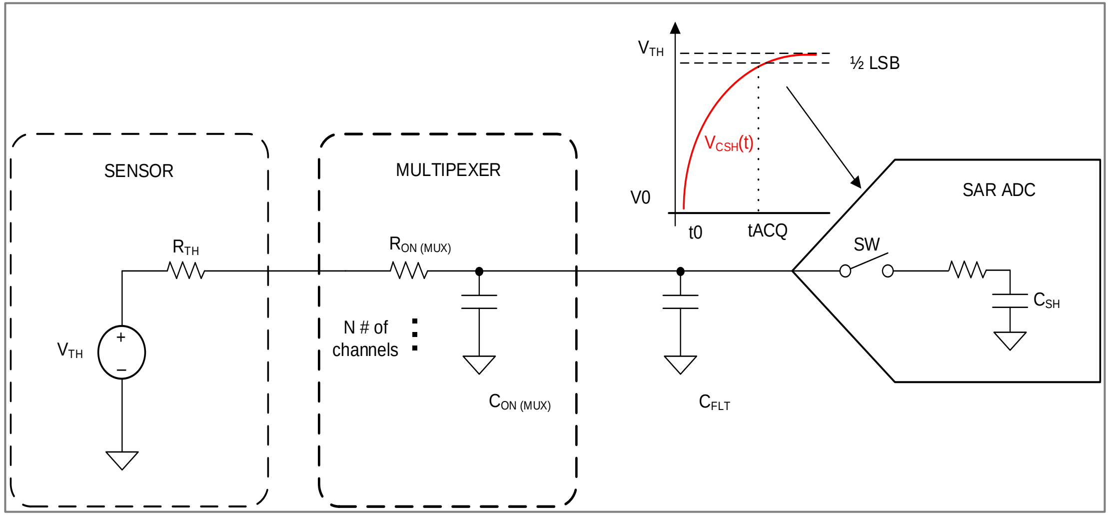
- With large load capacitance, effect of C_D can be ignored:

$$V_{ERROR} = \Delta V_{OUT} \approx \frac{Q_{INJ}}{C_L}$$

Industrial applications | Analog input modules



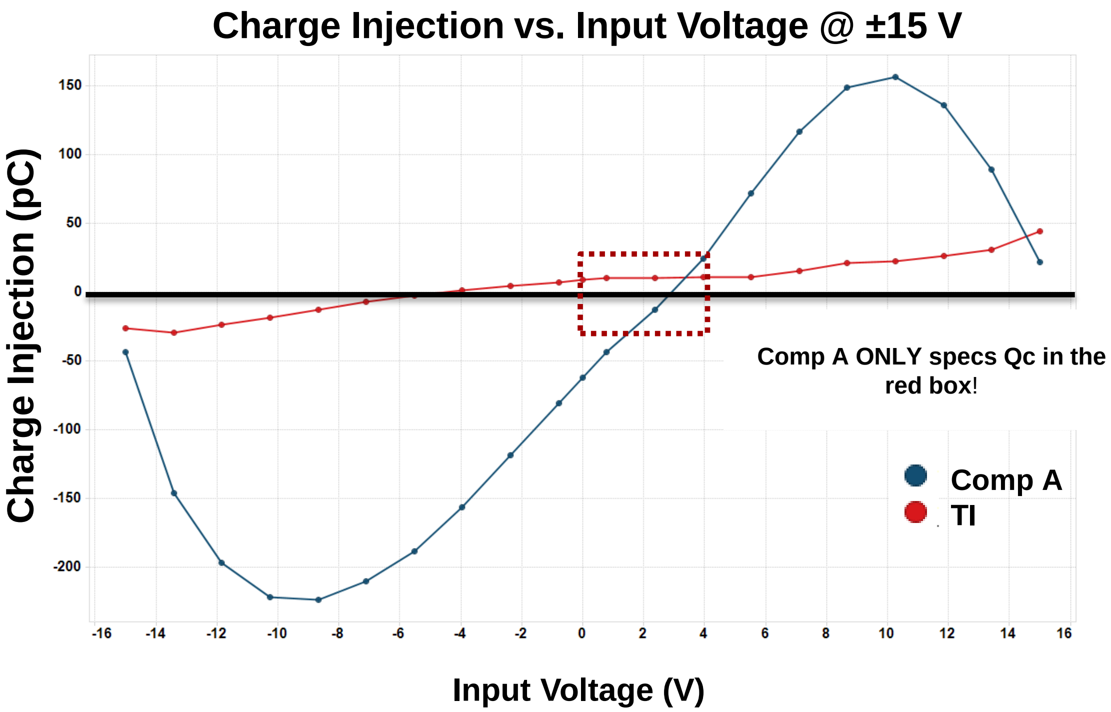
Multiplexed Data Acquisition Front End



$t_{ACQ} > k \times \tau_{FLT}$

- $\tau_{FLT} = (R_{TH} + R_{ON\ (MUX)})\ X\ (C_{FLT} + C_{ON\ (MUX)})$
- k is single pole time constant for N bit ADC

TMUX7219 benchmarks | Charge injection



- **TMUX7219 delivers class-leading charge injection performance across the entire signal range**
- Lower charge injection means
  - Less error in the signal chain
  - Faster sampling
  - Less overshoot & ringing on switching channels

Critical parameters | Multiplexers & signal switches

Supply range
- Single supply: 24 V, 15 V, 5 V, 3.3 V
- Dual supply: ±15 V, ±10 V, ±5 V

Supply current
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On-resistance
- R_{ON}: 3 Ω, 60 Ω, 125 Ω
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Input signal range
- Low level: 10 mV – 100 mV
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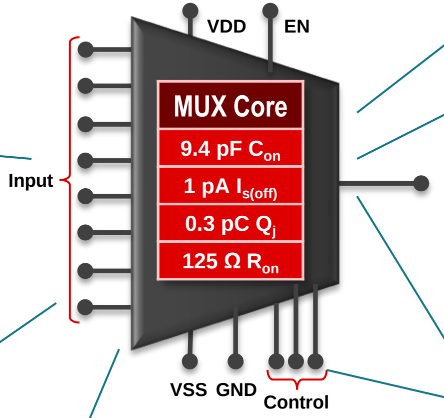

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None, 2 kV

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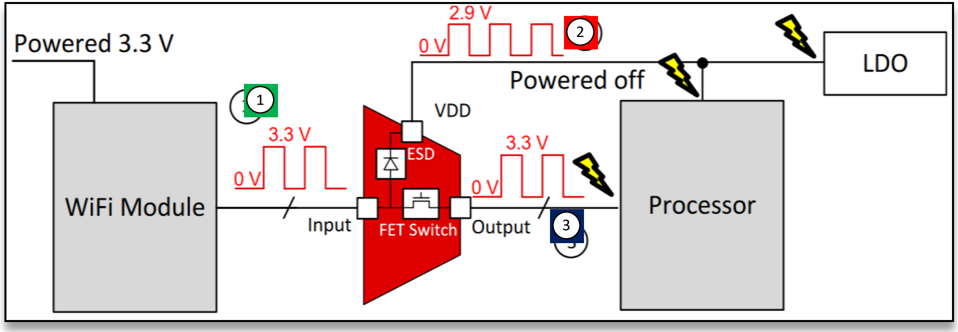
Powered-off protection, Fail-safe logic, Latch-up immunity
Simplify power sequencing design complexity

Transition time
- Fast switching: 50 ns- 100 ns
- Slow switching: 1 µs- 10 µs

Control logic
- Logic level (V_{DD}): 3.3 V, 5 V, 10 V
- Protocol: GPIO, SPI

TMUX features | Powered-off Protection

1. Subsystem A transmits a 3.3 V signal to the switch input when the switch is **OFF**
2. The 3.3 V signal back-powers the unpowered switch through the ESD diode, unintentionally turning the switch **ON**
3. The 3.3 V unwanted signal is transmitted through the switch, damaging the system.



Feature Description

TI switches with powered-off protection will protect downstream components when input signals are present in the I/O pins while the switch is **unpowered**. The switch maintains a high-impedance state on the I/O pins which **prevents back-powering V_{DD} and the select (SEL) pin.**

Benefits

Provides electrical isolation between subsystems

Prevents data from being transmitted unintentionally

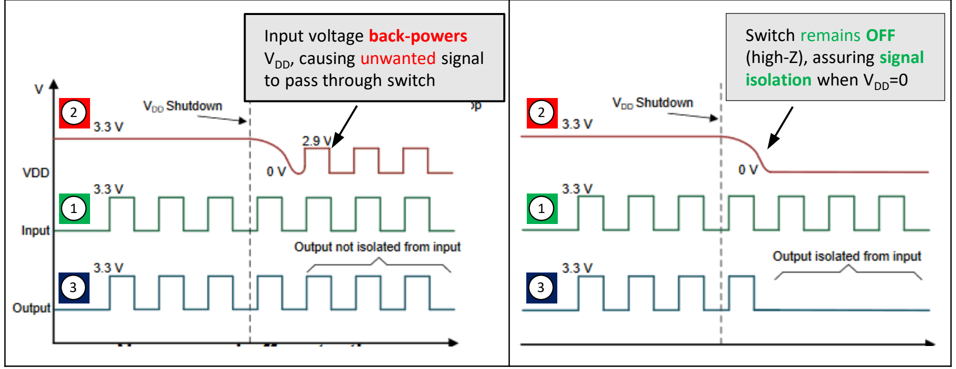
Eliminates need for power sequencing solutions

- Reduces BOM count and cost
- Simplifies system design
- Improves system reliability

Learn more about how to eliminate power sequencing issues here!

TI Precision Labs video – Powered-off protection

Switch without powered-off protection | **Switch with powered-off protection**



TMUX features | Fail-safe logic

(1) The MCU transmits a 3.3 V logic signal to the switch select (SEL) when the switch is **OFF**

(2) The 3.3 V logic signal back-powers V_{DD}, back-powering Subsystem B and turning the switch **ON**

Feature Description

TI switches with fail-safe logic will protect downstream components when a logic signal is present in the select (SEL) pins while the switch is unpowered. The switch maintains in a high-impedance state on the SEL logic pins **preventing power from going through V_{DD} during power sequencing**.

Benefits

Protects mux and downstream ICs from damage

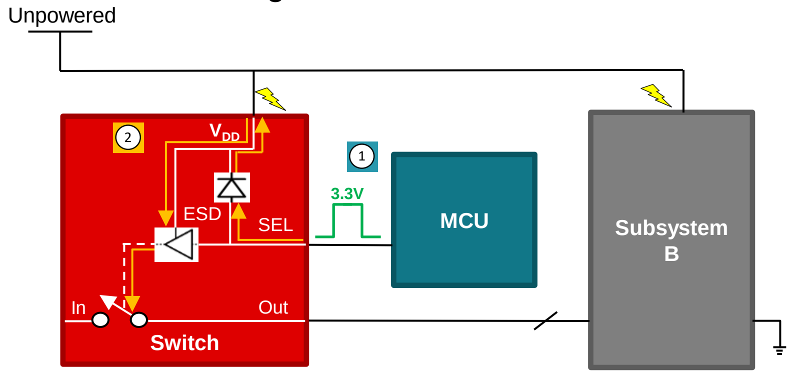
Eliminates need for power sequencing solutions

- Reduces BOM count and cost
- Simplifies system design
- Improves system reliability

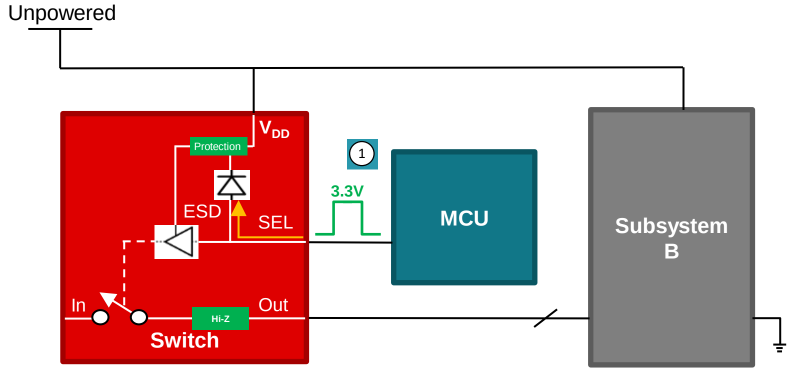
Standard low-voltage TMUX feature

TI Precision Labs video - Fail-safe Logic

Switch without fail-safe logic:



Switch with fail-safe logic:



TMUX features | Latch-up immunity

Feature Description

TI switches with latch-up immunity prevent undesirable high current events between parasitic structures within the device typically caused by overvoltage events. The TMUX62xx/TMUX72xx family of devices are built in a Silicon On Insulator (SOI) process and will not latch-up when exposed to current injection or overvoltage events.

Benefits

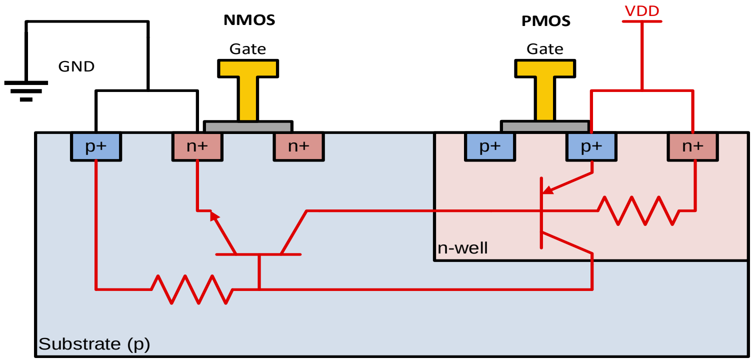
Prevents undesirable high current events between parasitic structures within the device typically caused by overvoltage events.

Provides a simpler, more compact protection solution

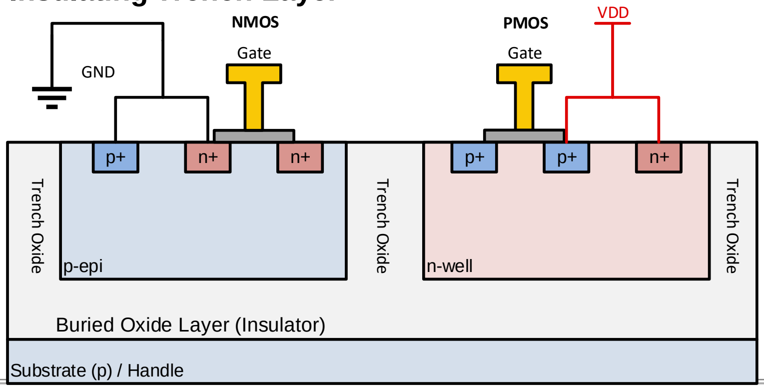
- Reduces BOM count and cost
- Simplifies system design
- Improves system reliability

TI Precision Labs video – Latch-up Immunity

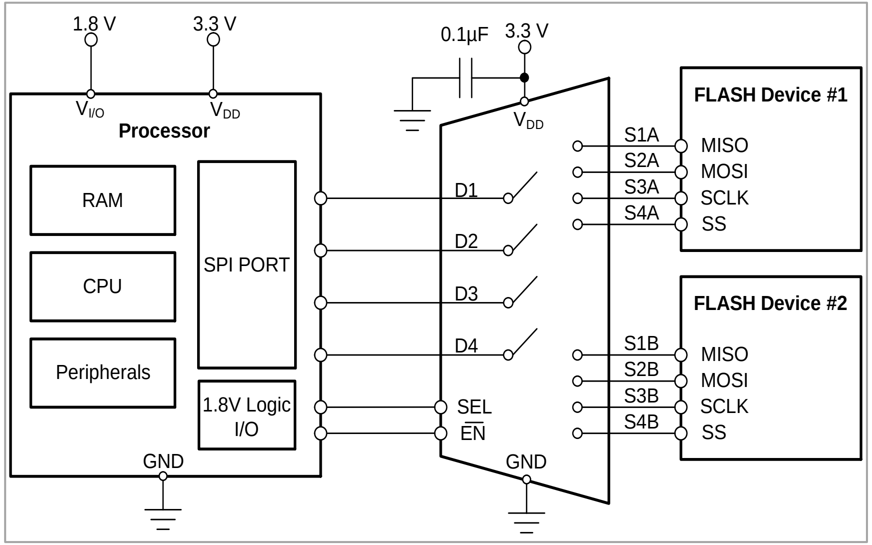
Cross section of CMOS Inverter with SCR



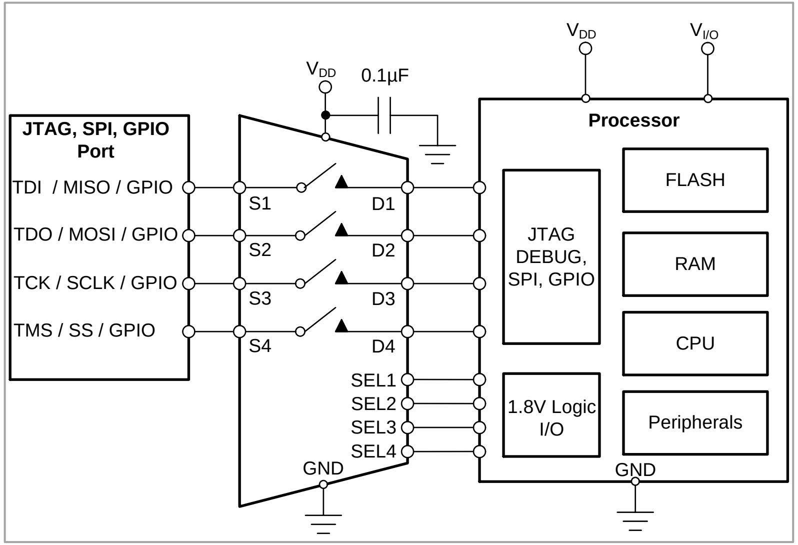
Oxide Insulating Trench Layer



Industrial applications | Protection multiplexers



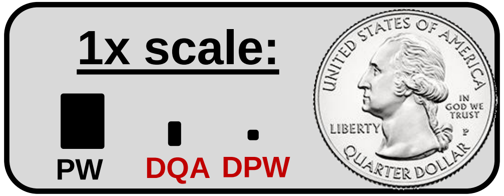
Multiplexing Flash Memory

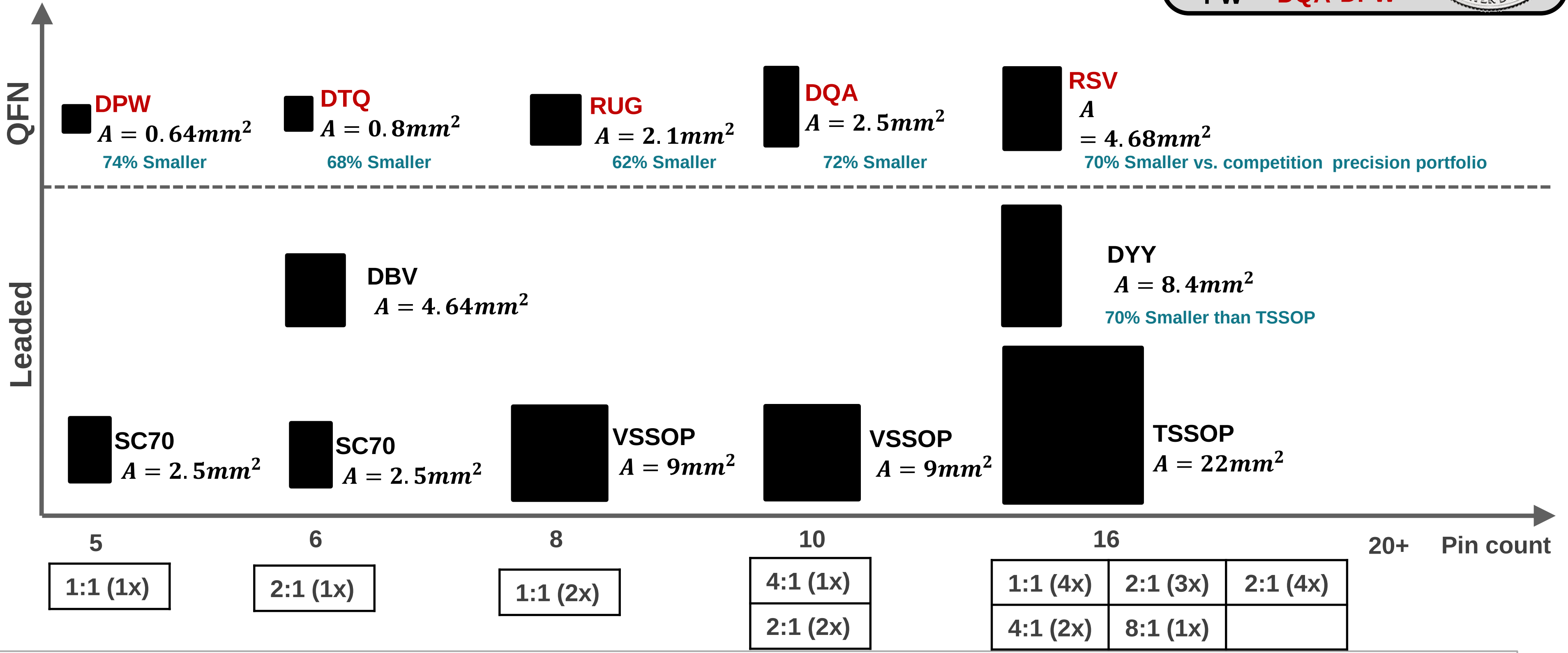


Protocol / Signal Isolation

TI packaging & technology

TI multiplexer | Package differentiation

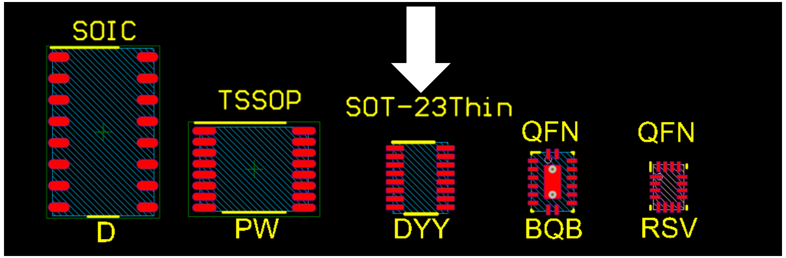




TI package technology | SOT-23-THIN (DYY)

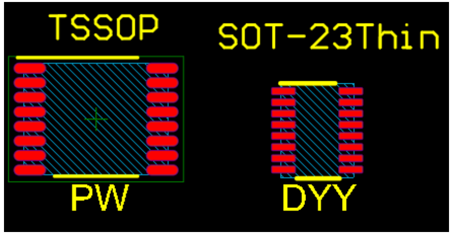
Industry's smallest 16-pin leaded packages

TI 16-pin packages



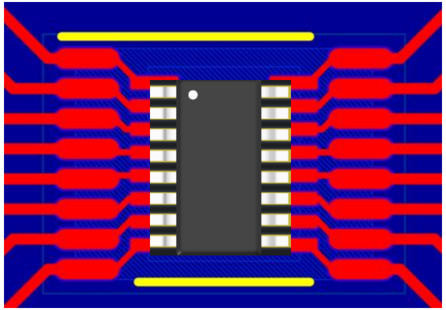
SOT-23-THIN vs. TSSOP – 57% space savings

	SOT-23 THIN (DYY)	TSSOP (PW)
D (length)	4.2 mm	5.0 mm
E (width)	3.2 mm	6.4 mm
Pitch	0.5 mm	0.65 mm
Area	13.7 mm^2	32.0 mm^2



57% smaller

SOT-23-THIN fits inside TSSOP footprint



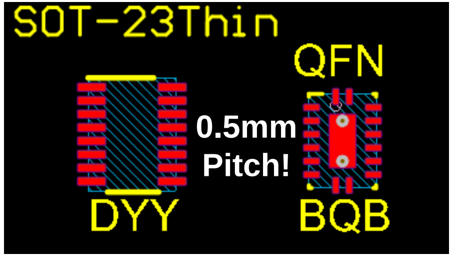
Dual footprint option

SOT-23-THIN will fit inside TSSOP footprint and can be dual routed using conventional PCB design rules.

SOT-23-THIN vs. QFN – QFN size with leaded reliability

QFN size with leaded reliability

- SOT-23-THIN package achieves small QFN size and maintains 0.5 mm pitch
- SOT-23-THIN is a QFN alternative for space constrained designs with the added benefits of optical inspection, easier debug, and mechanical reliability of a leaded package

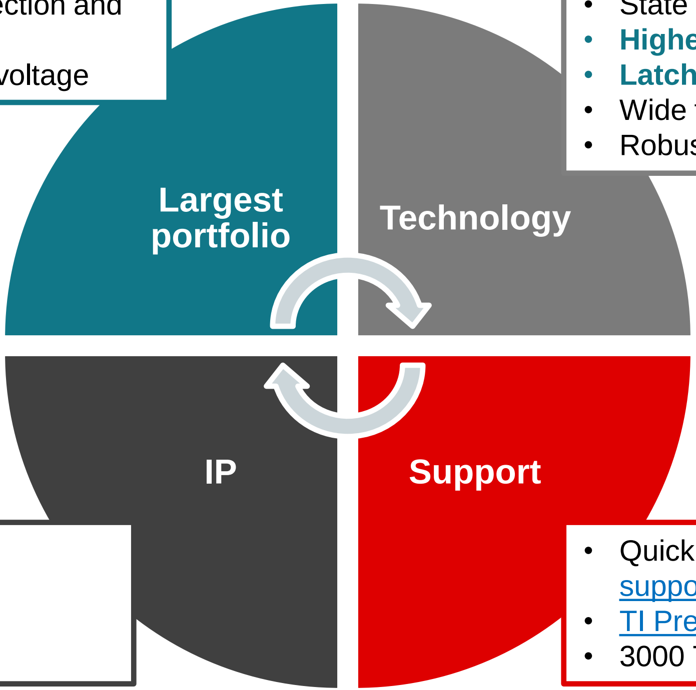


TI multiplexer & signal switch portfolio

TI multiplexer & signal switch portfolio

- **Broad portfolio** of precision, protection and general-purpose multiplexers
- Broad selection from low and mid-voltage

- State of the art silicon and packaging technology
- **Higher voltage** support without sacrificing R_{ON}
- **Latch-up immunity**
- Wide temperature support -40ºC to 125ºC
- Robust ESD



- **Lowest & flattest charge injection**
- Integrated 1.8V logic
- Powered-off protection
- Fail-safe logic

- Quick technical support through TI E2E™ support forums
- TI Precision Labs training video series
- 3000 TI reference designs

Backup

Selection guide | Low-voltage $V_{SIGNAL} < 24$ V

- Precision
- Protection
- General Purpose
- *CD : up to 20 V Supply

Configuration	1	2	3	4
8:1	TMUX1108 TMUX1208 TMUX1308 SN74LV4051 *CD4051 SN74LV4051			
4:1	TMUX1104 TMUX1204	TMUX1109 TMUX1209 TMUX1309 SN74LV4052 SN74CBT3253 TS5A5017 *CD4052		
2:1	TMUX1119 TMUX1219 TMUX1247 SN74LVC3157 TS5A3159	TMUX1136 TMUX136 TMUX154E TMUX1072 TS5A23157/59 TS5A22364	TMUX1133 SN74LV4053A CD74HC4053 *CD4053	TMUX1134 TMUX1574 TS3A44159 SN74CBTLV3257
1:1	TMUX1101 TMUX1102 SN74LVC1G66 TS5A3166	TMUX1121 TMUX1122 TMUX1123 SN74LVC2G66 TS5A2066 TS5A21366		TMUX1111 TMUX1511 TMUX1311 SN74CBTLV3125 SN74HC4066 *CD4066

Number of Channels

TMUX Key Differences

	Precision	*Protection*	*General Purpose*
Ultra-Low Leakage (pA)	✓	–	–
Powered-off Protection	–	✓	–
Overvoltage Protection	–	✓	–
1.8 V Logic Control	✓	✓	✓
Fail-safe Logic	✓	✓	✓
Smallest QFN packages	✓	✓	✓
TI Device Families:	TMUX11xx	TMUX15xx	TMUX12xx, TMUX13xx

TMUXxxxxX Nomenclature

1st Digit	2nd Digit	3rd & 4th Digit	Final Letter
Supply Range	Product Family Generation	Channel Count & Configuration	Key Differentiation

Selection guide | Mid-voltage (24 V > V_{SIGNAL} > 100 V)

Precision

Protection

General Purpose

Configuration	1	2	4
16:1	MUX36S16 MUX506		
8:1	MUX36S08 MUX508	MUX36D08 MUX507	
4:1	TMUX6104	MUX36D04 MUX509	
2:1	TMUX6136	TMUX6119	
1:1		TMUX6121/22/23	TMUX6111/12/13

Number of Channels

TMUX Key Differences

	Precision	*Protection*	*General Purpose*
Ultra-Low Leakage (pA)	✓	–	–
Powered-off Protection	–	✓	–
Overvoltage Protection (up to ±60 V)	–	✓	–
Fail-safe Logic	✓	✓	✓
Smallest QFN packages	✓	✓	✓
TI Device Families:	TMUX61xx TMUX72xx	TMUX73xxF TMUX74xxF	MUX50x

TMUXxxxxX Nomenclature

1st Digit	2nd Digit	3rd & 4th Digit	Final Letter
Supply Range	Product Family Generation	Channel Count & Configuration	Key Differentiation

SLYP717

TEXAS INSTRUMENTS