Application Report

Selecting the Right Texas Instruments Signal Switch

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Muxes and Signal Switches

ABSTRACT

Texas Instruments™ offers a wide variety of switches and multiplexers supporting a variety of configuration, voltage, bandwidth, and package needs. This application report summarizes the key features and performance characteristics of our analog signal switches and application considerations for choosing the appropriate TI signal switch.

Table of Contents

List of Figures

List of Tables

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1 Introduction

Analog switches are designed to pass (or isolate) analog signals (both voltage and current) and support analog applications such as audio and video data transmission. Texas Instruments offers a wide variety of switches and multiplexers to improve system design with better accuracy, system reliability and platform scalability.

Selecting the right one can be a formidable task. This application report discusses some of the key characteristics and features of TI's switches and multiplexer families to make the selection process simpler and more efficient.

1.1 Ideal Versus Non-Ideal Switch

When first considering switches, a schematic of the ideal switch (similar to Figure 1-1) might come to mind.

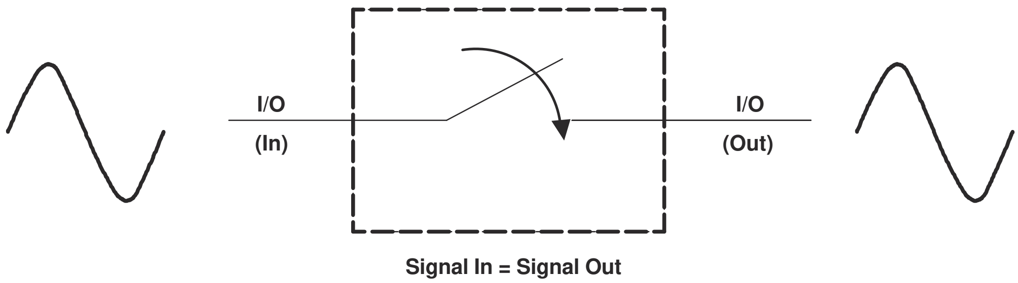


Figure 1-1. Ideal Switch

An input signal applied to the left I/O pin (or port) in Figure 1-1 results in an identical output signal at the right I/O pin, and vice versa. However, in the real world, switches are not ideal and there always is some loss. In the case of clean, properly working mechanical switches, the loss is so minuscule that it hardly bears noting.

Like mechanical switches, solid-state switches are not ideal either. In fact, losses associated with solid-state switches can be significant. Why use a switch like this if it is so far from ideal? The answer is convenience. Solid-state switches are small, fast, easy to use, easy to control, and consume relatively little power compared to traditional electrically controlled switches, such as relays. The switches referred to in this application report are complementary metal-oxide semiconductor (CMOS) field-effect transistor (FET) switches. As mentioned previously, they are not ideal, so we need a way to examine and compare the performance characteristics of the different CMOS families. Figure 1-2 shows a simplified-circuit model of a CMOS switch.

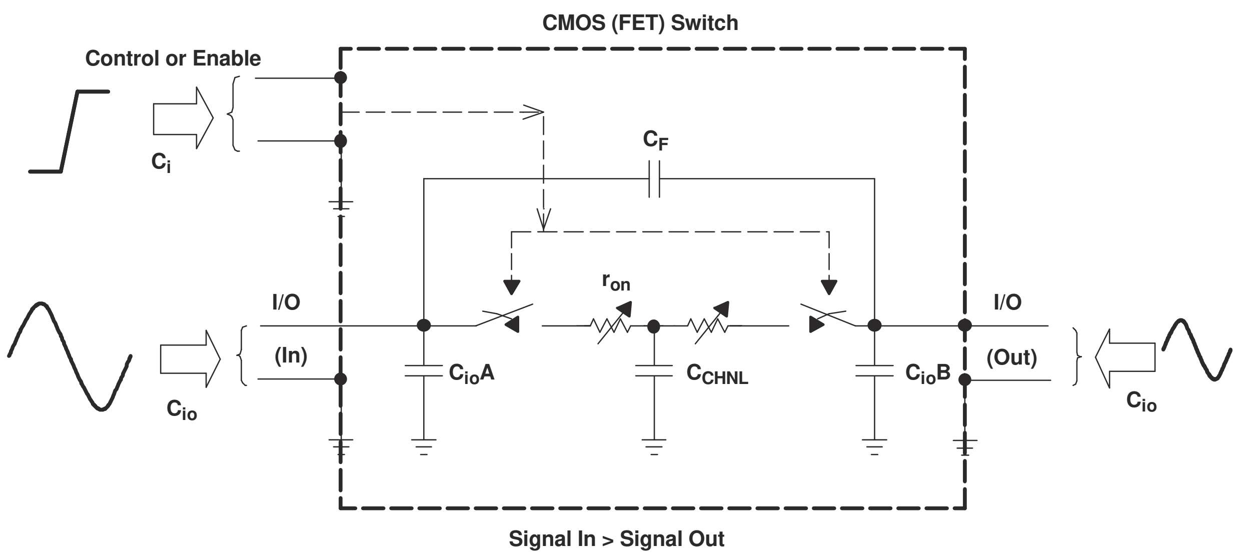


Figure 1-2. Simplified CMOS (FET) Switch

The output signal (right side, Figure 1-2) is altered due to parasitic effects of the switch. Results may include decreased amplitude, signal distortion, phase shift, the introduction of noise, and frequency attenuation.

Parameters contributing to the nonideal characteristics include:

- C_i - Control (enable) pin input capacitance
- O_{ISO} - Off Isolation: Measurement OFF-state switch impedance
- C_{io} - Capacitance measured from either the input or output of the switch
- C_{CHNL} - NMOS (PMOS) channel capacitance
- R_{ON} - The resistance inserted into the signal path as a result of the switch path being turned on

2 Basic Signal Switch Structure

Texas Instruments signal switches share the common switch architectures NFET switch, Transmission gate switch and NFET with charge pump.

2.1 NFET Switch

Figure 2-1 shows a simplified FET switch, which consists of an N-channel transistor and gate bias and enable circuitry. The switch is bidirectional; the source and drain are interchangeable (while operating, the side with the lowest $V_{I/O}$ is the source). TI CBT bus switches are this type.

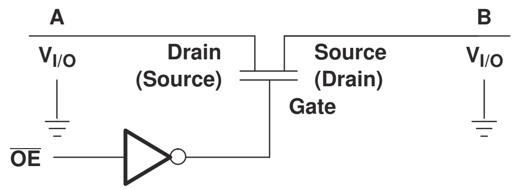


Figure 2-1. N-channel FET Switch

For an N-channel FET to operate properly, the gate should be biased more positive than the magnitude of the signals to be passed. This is because the on-state resistance, R_{ON} (or $R_{DS(ON)}$ as it also is called), increases as the gate, minus source voltage, V_{GS}, decreases. If the lowest $V_{I/O}$ signal approaches the magnitude of V_{CC}, V_{GS} decreases and R_{ON} increases (see Figure 2-2). The ability to maintain a low R_{ON} in a FET switch depends on maintaining V_{GS} as large as possible. In many applications, this characteristic is not a problem, but the designer should be aware of the nonlinearity of this type of device.

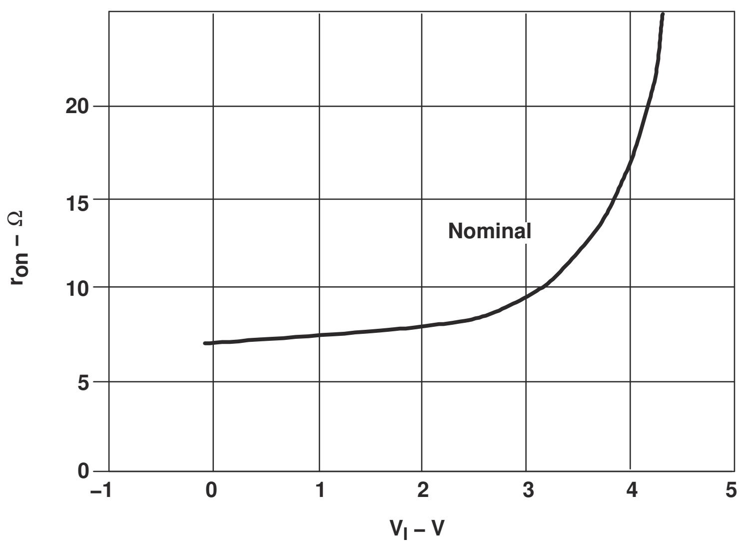


Figure 2-2. On-State Resistance vs Lowest I/O Voltage for an N-channel FET Switch With V_{CC} = 5 V

An N-channel FET can be used to implement a level translator. This switch can pass a signal from 0 V to V_{CC} – V_T, where V_T is the threshold voltage of the NMOS. This characteristic can be used for down translation. For voltage-translation applications, the switch is required to translate efficiently over a wide frequency range and is required to maintain the proper signal level. For example, when translating from a 5-V TTL to a 3.3-V LVTTL signal, the switch is required to maintain the required V_{OH} (output high voltage) and V_{OL} (output low voltage) of 3.3-V LVTTL signal. One important consideration is that the switch can be used only for down translation, for example, high to low level. For low- to high-level translation, additional components (for example, pullup resistors) are required.

2.2 Transmission Gate Switch

Analog (or bilateral, as they also are called) switches consist of a single N-channel transistor in parallel with a single P-channel transistor (see Figure 2-3). These are also known as the Transmission gate switch.

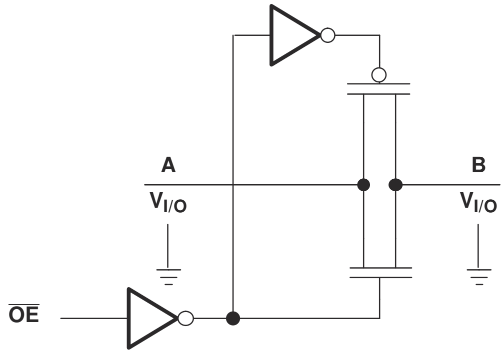


Figure 2-3. Parallel N-/P-Channel FET (Transmission Gate) Switch

As before, when $V_{I/O}$ approaches V_{CC}, the N-channel conductance decreases (R_{ON} increases) while the P-channel gate-source voltage is maximum and its R_{ON} is minimal. The resulting parallel resistance combination is much flatter than individual channel resistances (see Figure 2-4). Examples of switches and multiplexers with parallel n and p channel include TMUX11xx, TMUX61xx, TMUX12xx, TMUX13xx, HCT, HC, CD4000, LV-A, LVC, and CBTLV families.

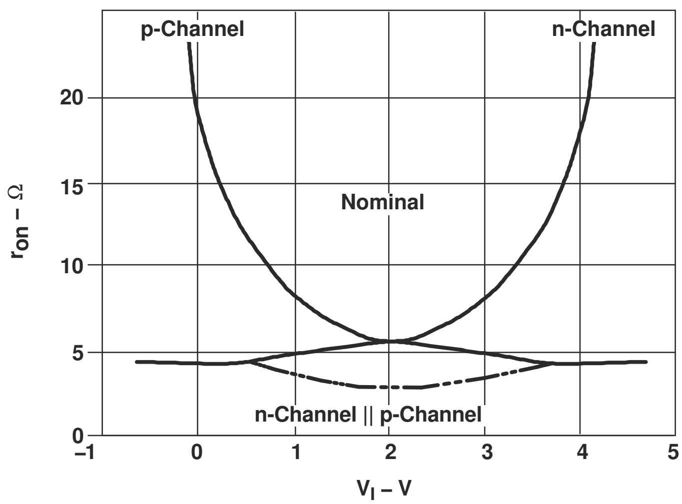
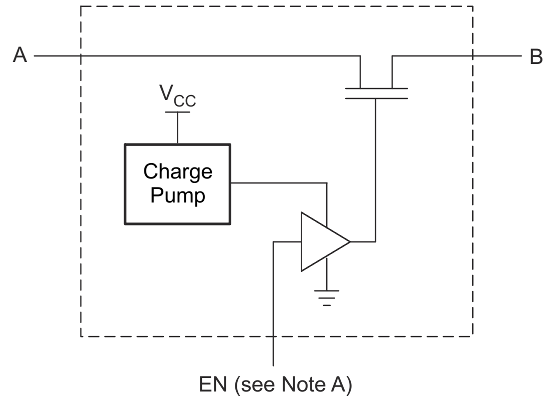


Figure 2-4. On-State Resistance vs Input Voltage for a Parallel n-/p-Channel FET Switch

A flat R_{ON} is especially important if $V_{I/O}$ signals must swing from rail to rail. However, the tradeoff is increased switch capacitance due to the additional P-channel transistor and associated bias circuitry.

2.3 NFET With Charge Pump

Some manufacturers offer N-channel signal switches with charge-pump-enabled pass transistors. A design of this type as shown in Figure 2-5 allows the gate voltage to be higher than V_{CC}. This increases V_{GS} above what is possible in noncharge-pump devices and allows signals at or above V_{CC} to be passed. A switch of this type has the advantage of low, relatively flat R_{ON} (over the signal range), without the addition of a P channel and while maintaining C_{io} values comparable to pure N-channel FET switches. This performance comes at the expense of increased I_{CC} (from a few µA to several mA in some cases). Examples include TMUX1072, TMUX136, TMUX15xx, and the CB3Q family.



Note A: EN is the internal enable signal applied to the switch.

Figure 2-5. Basic Structure of an NMOS Series Switch With the Charge Pump

See *Switches and muxes: What are common switch architectures?* more details on the basics of analog signal switches offered by Texas Instruments.

3 Analog Versus Digital Signal Switches

TI offers a wide variety of signal switches, and sometimes the nomenclature can be confusing to the point of implying limited functionality for a device or family. See details below on digital vs analog, bus switch and bi-directional functionality of switches.

- **Digital switch**. Designed to pass (or isolate) digital signal levels. May exhibit the capability to satisfactorily pass analog signals. Examples are CBT and CBTLV switch families.
- **Analog switch**. Designed to pass (or isolate) analog signals. Often exhibits good digital signal performance as well. Examples are TMUX11xx, TMUX61xx, TMUX12xx, TMUX15xx, CD4066B, CD74HCT4066, CD74HC4066, SN74HC4066, SN74LV4066A, and SN74LVC1G66 switches.

  TI's analog and digital bus switches are electrically equivalent and both share the common switch architectures found in the semiconductor industry.
- **Bus switch**. Digital switches designed for multi-bit switching in computing applications. Examples are CBT and CBTLV switch families.

Typically, the high channel count switches in the TI muxes and switches portfolio are labeled as "digital bus switches" because digital buses usually have many more signal paths than analog signal paths for their common use of transmitting 8, 16, and 32 bits of data. As TI's switch portfolio continues to expand this loose distinction between analog and digital devices are becoming irrelevant. More details can be found in *Switches and muxes: What are switches and multiplexers?*.

3.1 Bidirectional Switches

There are two meanings:

- The switch conducts equally well from source (S) to drain (D) or from drain (D) to source (S). Each channel has very similar characteristics in both directions and supports both analog and digital signals. TI analog switches and multiplexers are typically bidirectional (Figure 3-1).

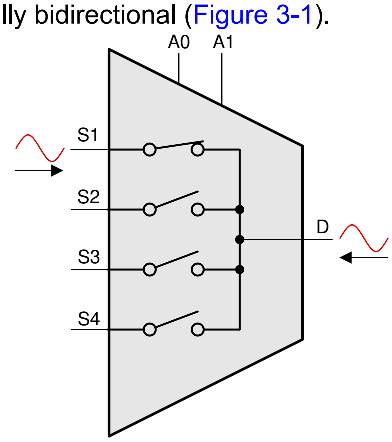


Figure 3-1. Bidirectional Signal Path

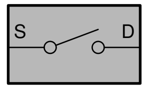
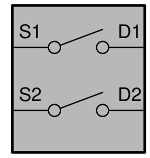
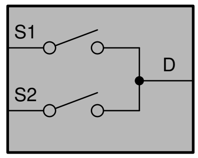
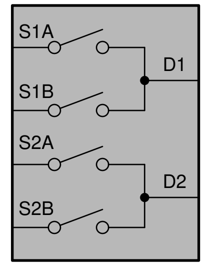
- Switch can be used in analog or digital applications.

See *Switches and muxes: Are switches and multiplexers bidirectional?* for more details.

3.2 Configuration and Channels

Switch **Configuration** defines the number of signals that can be selected and **Channel** defines the number of configurations (circuits) in a single device. Texas Instruments offers switches and multiplexers in different configurations and channel count. Table 3-1 shows the 1- and 2- channel configurations, but the number of channels may exceed.

Table 3-1. Configurations and Channels

		1-Channel	2-Channel
Configuration	1:1		
	2:1		

4 Signal Switch Specifications

It should be apparent that the most important switch characteristic depends on how it is used. For example, what V_{CC} levels are present, what amplitude signals are required to be passed, what is the maximum signal distortion limit for the system and so forth. These specifications are covered in more detail below:

- **Supply Voltage** : **Single power supply** - Device with only positive power supply pins with reference to ground. The voltage applied is labeled as V_{DD}, V_{CC}, V_+ and so forth. **Dual power supply** - Device with positive and negative supply pins with reference to ground. Voltage applied at the positive pin is labeled as V_{DD}, V_{CC}, V_+, and so forth, and at the negative pin is labeled as VSS, VEE, V-, and so forth. For noncharge-pump switches, V_{CC} determines the amplitude of the analog signals that can be passed without clipping. One or more of the gates of the pass transistors must be biased relative to the minimum and maximum values of the expected input voltage range. Switches, such as the TMUX61xx, MUX36Sxx, MUX36Dxx, and CD4000 series allow for biasing from two supplies, making it easy to pass both positive and negative signals. Switches like TMUX1072, SN3257-Q1, TMUX136, and the TMUX15xx, CB3Q family with integrated charge pumps can elevate the gate voltage above V_{CC} (at the expense of larger I_{CC}) and, thus, pass signals of a magnitude greater than V_{CC}.
- **Switch Control Signal Levels (V_{IH}/V_{IL})**: **V_{IH}** is the minimum voltage for the input control signal to achieve a *Logic 1* value and **V_{IL}** is the maximum voltage for the input control signal to remain a *Logic 0* value. Why are these important analog switch considerations? In most applications, the signal switch is controlled by the output of a digital source, therefore, the control signal levels, V_{IH} and V_{IL}, must be compatible with that source to ensure proper operation of the switch. To prevent digital logic control issues, the system must ensure that the output high (V_{OH}) logic output is higher than the input high (V_{IH}) logic input it is controlling. In addition, the output low (V_{OL}) of the logic output must be lower than the input low (V_{IL}) of the logic input it is controlling. See Figure 4-1 for this logic standard. Some components may not meet the standard, but having V_{IH} < V_{OH} and V_{Il} > V_{OL} ensures proper system operation.

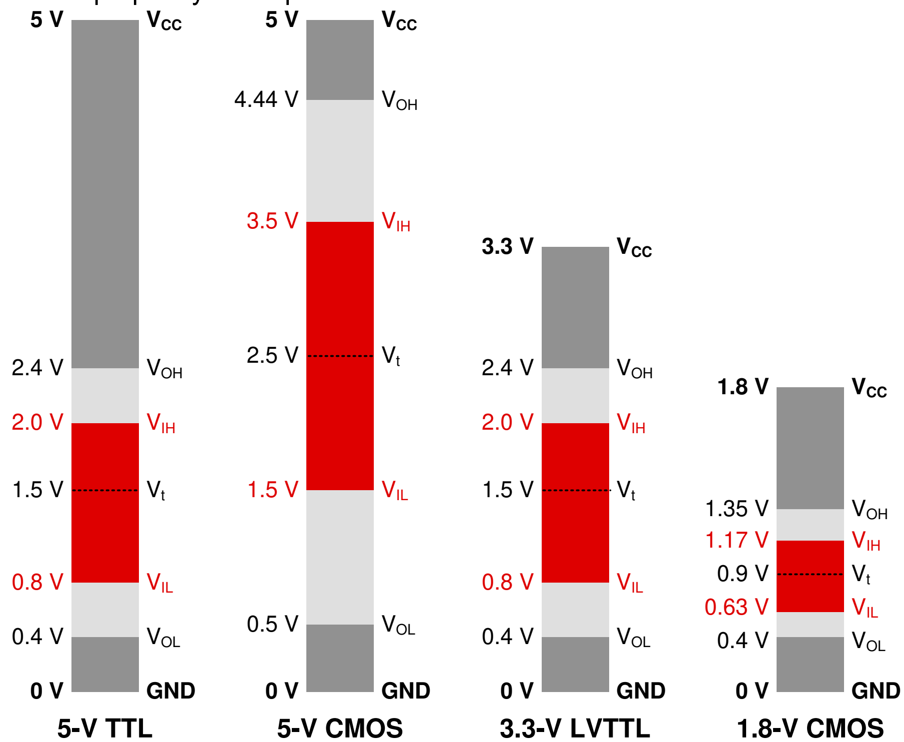


Figure 4-1. Logic Thresholds

- **ON Resistance (R_{ON})**: The resistance inserted into the signal path as a result of the switch path being turned on. Because it contributes to signal loss and degradation, low R_{ON} tradeoffs must be considered. Noncharge-pump switches achieve low R_{ON} with large pass transistors. These larger transistors lead to larger die sizes and increased C_{io}. This additional channel capacitance can be very significant as it limits the frequency response of the switch. As stated in Section 2.3, switches utilizing charge-pump technology can achieve low R_{ON} and C_{io}, but require significantly higher I_{CC}.

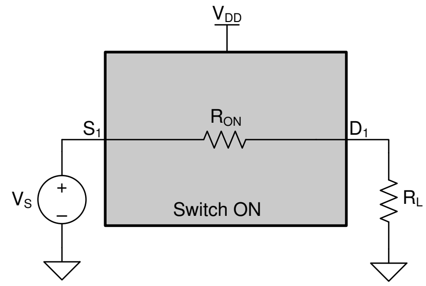


Figure 4-2. On-Resistance

- **Switch Output Level**: The maximum signal level a switch without a charge pump can pass is limited to the switch V_{CC}. Is there sufficient noise margin on the device downstream of the switch such that signal attenuation in the switch will not cause data errors? For instance, the N-channel transistor of a CBT device clamps the switch output at a little more than 1 V below the operating V_{CC}, making it unsuitable for 5-V CMOS high-level (V_{IH} = 3.5 V) signal transmission unless operated from at least 4.5-V V_{CC}.
- **ON/OFF Capacitance (C_{ON}/C_{OFF})**: The ON capacitive loading when a switch path is in the low impedance state. The OFF capacitive loading when a switch path is in the high impedance state. Total switch and load capacitance must be considered because it can affect response time, settling time and fanout limits. See more details in the application note: *Improve Stability Issues with Low CON Multiplexers*. C_{io} is the capacitance of an input/output (I/O) terminal of the device with the input conditions applied that, according to the product specification, establishes the high-impedance state at the output. This parameter is the internal capacitance encountered at an input/output (I/O) of the device. These values are established by the design, process, and package of the device.

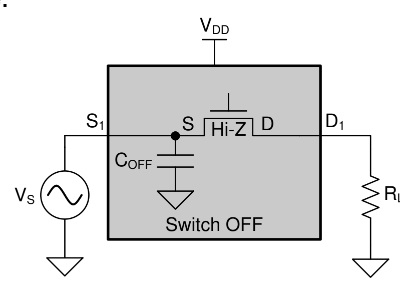


Figure 4-3. Source and Drain Off Capacitance

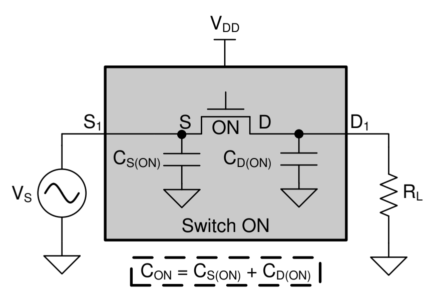


Figure 4-4. Source and Drain On Capacitance

- **Frequency Response**: All CMOS switches have an upper limit to the frequency that can be passed. No matter how low R_{ON} and C_{io} can be maintained in the chip manufacturing process, they still form an undesired low-pass filter that attenuates the switch output signal. **Bandwidth (BW)** of a switch is the frequency range of signals that can pass through the switch with no more than 3 dB of attenuation.

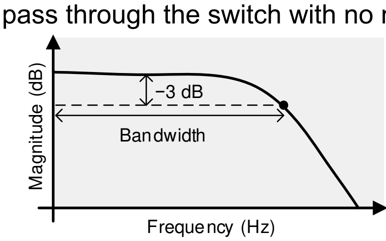


Figure 4-5. Bandwidth

- **Sine-Wave Distortion or Total Harmonic Distortion**. These are measurements of the linearity of the device. Nonlinearity can be introduced a number of ways (design, device physics, and so forth) but, typically, the largest contributor is R_{ON}. As shown in Figure 2-2 and Figure 2-4, R_{ON} varies with $V_{I/O}$ for all types of CMOS switches. Having a low R_{ON} is important, but a flat R_{ON} over the signal range is almost equally important.
- **Crosstalk**: There are two types of crosstalk to consider:
  - **Channel-to-channel crosstalk (X_{TALK})**: A measurement of unwanted signal coupling from an ON channel to an OFF channel. This is measured in a specific frequency and in specified in dB. The level of crosstalk is a measure of how well decoupled the switch control signal is from the switch output. Due to the parasitic capacitance of CMOS processes, changing the state on the control signal causes noise to appear on the output. In audio applications, this can be a source of the annoying pop that is sometimes heard when switching the unit on or off.

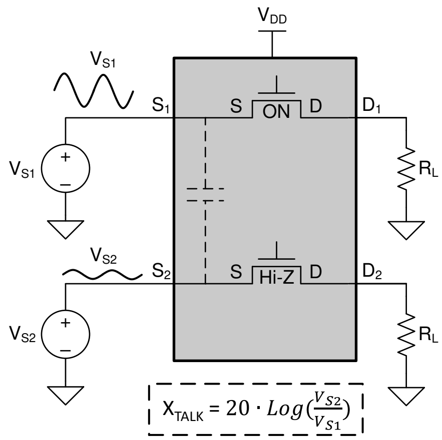


Figure 4-6. Channel-to-Channel Crosstalk

  - **Crosstalk between switches**. The level of crosstalk also is a measure of adjacent-channel rejection. As with control-to-output crosstalk, parasitic capacitance can couple the signal on one switch with that on another switch.
- **Charge Injection (Q_C)**: Charge injection is a measurement of unwanted signal coupling from the control (IN) input to the analog output. This is measured in coulomb (C) and measured by the total charge induced due to switching of the control input. TI specifies enable-to-output crosstalk and some competitors use this parameter. As with enable-to-output crosstalk, changing the state on the control pin causes a charge to be coupled to the channel of the transistor introducing signal noise. It is presented in this report for a relative comparison with the competition. See more details in *Prevent crosstalk with injection current control*.

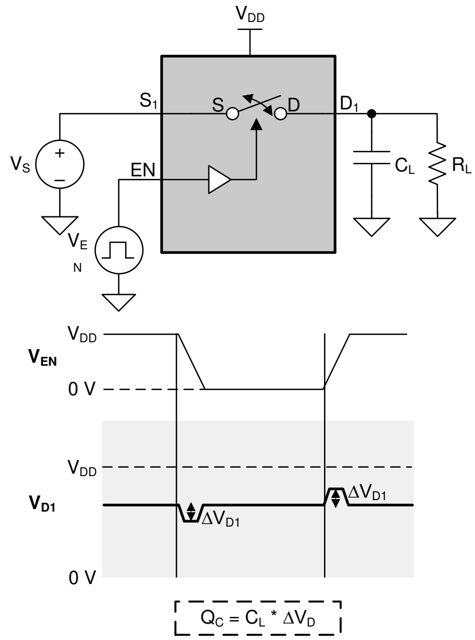


Figure 4-7. Charge Injection

- **Off Isolation**: A measurement OFF-state switch impedance. This is measured in dB at a specific frequency, with the corresponding channel in the OFF state.

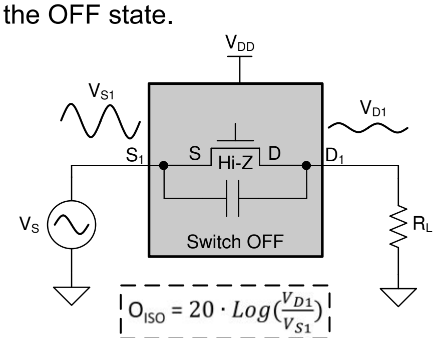


Figure 4-8. Off-Isolation

- **ON Leakage Current**: Leakage current measured at the input port in the ON state, with the corresponding output port in the ON state and the output being open (See Figure 4-9). Leakage current during the high-impedance state should be very small. Leakage current, if high, may load an isolated bus and corrupt the data.

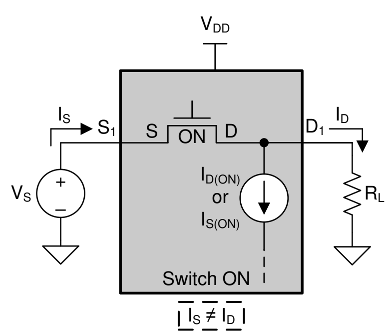


Figure 4-9. ON Leakage Current

- **OFF Leakage Current**: Leakage current measured at the input port, with the corresponding channel output in the OFF state under worst-case input and output conditions (See Figure 4-10) . Leakage current is an important parameter, as it contributes to DC errors both when the switch is ON and when it is OFF.

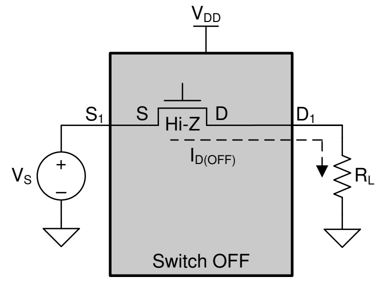


Figure 4-10. OFF Leakage Current

- **Break-Before-Make Time (t_{BBM})**: Ensures that in a multiplexer, two multiplexer paths are never electrically connected when the signal path is changed by the select input. Break before make delay is a safety feature that prevents two inputs from connecting when the device is switching. The output first breaks from the ON-state switch before making the connection with the next on-state switch. It guarantees that two multiplexer paths are never electrically connected when the signal path is changed by the select input. See Figure 4-11 for more details.

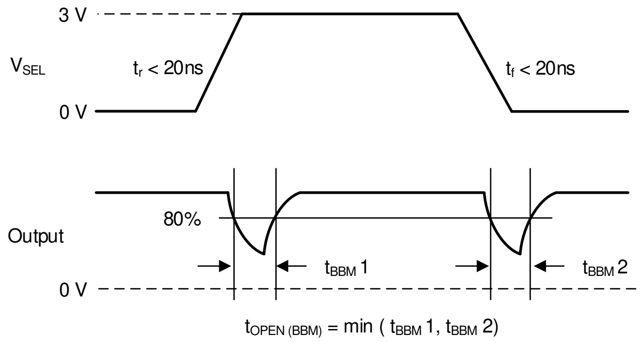


Figure 4-11. Break-Before-Make Time (t_{BBM})

- **Turn ON (t_{ON}) / Turn OFF (t_{OFF}) Time**: The time required for a switch path to be internally changed to an ON or OFF state. These parameters determine how quickly the switch can respond to a desired ON or OFF state (See Figure 4-12). In general, switch enable and disable times are not symmetrical. This is not usually an issue, as few applications require high control (enable) signal frequencies.

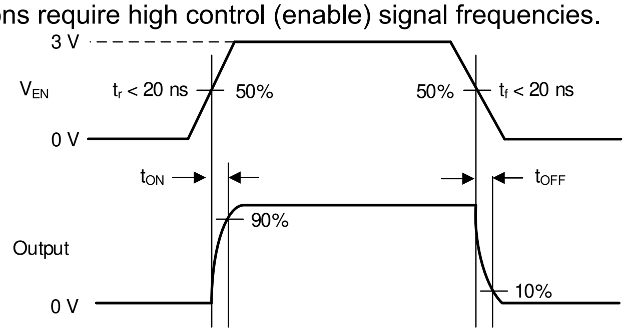


Figure 4-12. Turn-ON (t_{ON}) and Turn-OFF (t_{OFF}) Time

- **Propagation Delay (t_{pd})**: This parameter is negligible for all but the most critical timing budgets. When the switch is ON, the propagation delay through one or more of the pass transistors is minimal. TI specifies this number as the mathematical calculation of the typical R_{ON} times the load capacitance. See more details on switch timing characteristics in *Switches and muxes: What are timing characteristics?*.
- **1.8 V Control Logic**: Switches with this feature have a built-in voltage translator to prevent voltage mismatch between the supply rail and the control logic. V_{IH} and V_{IL} levels are compatible with the 1.8-V logic levels at any voltage supply. See the *Simplifying Design With 1.8 V logic MUXes and Switches Tech Note* for more information. Most of the new TMUX devices (for example: TMUX1108, TMUX1511 and non-TMUX parts like TS3A27518E, TS5A26542) come with the 1.8 V control logic feature. The built-in voltage translator prevents voltage mismatch between the supply rail of the TMUX device and the control logic of the processor. This feature enables the mux to be controlled directly by the processor through standard 1.8 V GPIO pins. This saves up to 18 mm^2 per select pin used.

- **Fail-safe Logic**: Ensures the switch stays off and the logic pin does not back-power VDD when the voltage on the signal pin is greater than VDD. TI switches with Fail-safe Logic will protect downstream components when a logic signal is present on the select pins while the switch is unpowered. This feature allows voltages on the control pins to be applied before the supply pin, protecting the device from potential damage. The switch maintains in a high-impedance state on the SEL logic pins preventing power from going through VDD during power sequencing. For example, the Fail-Safe Logic feature allows the select pins of the TMUX1574 to be ramped to 5.5 V while supply V_{DD} = 0 V. Additionally, the feature enables operation of the multiplexer with V_{DD} below the voltage on the select pins.
  - Protects mux and downstream ICs from damage.
  - Eliminates need for power sequencing solutions.
  - Reduces BOM count and cost Simplifies system design.
  - Improves system reliability.

  See more details in *What is fail-safe logic?*.

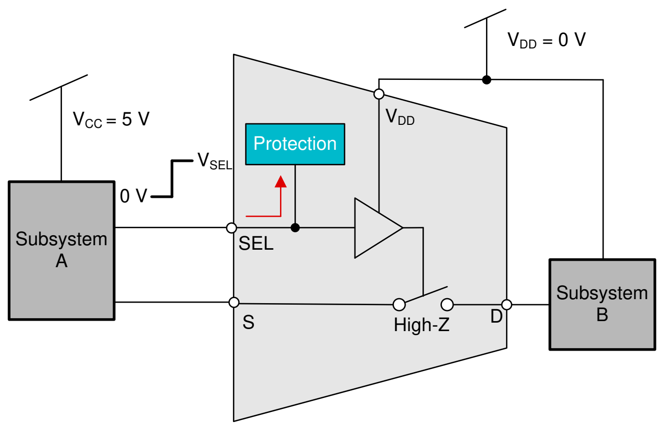


Figure 4-13. Fail-Safe Logic

5 Texas Instruments Analog Signal Switches and Multiplexers Portfolio

Texas Instruments offers a comprehensive portfolio of precision, protection, and general-purpose switches and multiplexers to support end-to-end signal chain needs.

This TI analog signal switch and multiplexer portfolio is intended to give a top level view of the characteristics and parameters that the device in that category have. The categories are not always mutually exclusive for example especially when referring to the protection category. Many of the devices in the protection category have some of the same low leakage / low R_{ON} parameters of the precision family yet add additional protection features.

The following sections highlight key features and applications of the precision, protection, and general-purpose switches and multiplexers.

5.1 Precision Switches and Multiplexers

TI offers a broad range of precision multiplexers and switches in different configurations to improve performance and minimize offset errors and signal distortion in high-accuracy measurement systems. The key differentiating features of these precision switches are:

- Low ON – Leakage (I_{ON})
- Low ON - Resistance (R_{ON})
- Low ON - Capacitance (C_{ON})
- Low Charge Injection (Q_C)

In addition to the above features, the TI analog precision switches also support 1.8 V control logic, fail safe logic and are available in ultra small packages: DQA (2.5 mm^2), RSV (4.68 mm^2).

Table 5-1 below shows performance specifications of analog precision switches:

Table 5-1. Analog Precision Switches and Multiplexers

V_{SIGNAL}	Part Number[(1)]	Configuration	R_{ON} (Typ) (Ω)	C_{ON} (pF)	Q_C (pC)	I_{ON} (µA)	Package/Pin
Low Voltage (V_{SIGNAL} < 24V)	TMUX1101/02	1:1, 1 channel	2	18	-1.5	0.002	SC70|5, SOT-23|5
	TMUX1121/22/23	1:1, 2 channel	1.9	17	-1.5	0.002	VSSOP/8
	TMUX1111/12/13	1:1, 4 channel	2	19	-1.5	0.002	TSSOP|16, UQFN|16
	TMUX1119	2:1, 1 channel	2.5	21	-6	0.004	SC70|6, SOT-23|6
	TMUX1136	2:1, 2 channel	1.8	20	-6	0.002	USON|10, VSSOP|10
	TMUX1133	2:1, 3 channel	2	20	-1	0.002	TSSOP|16
	TMUX1134	2:1, 4 channel	2	20	-1	0.002	TSSOP|20
	TMUX1104	4:1, 1 channel	2.5	40	1.5	0.0035	USON|10, VSSOP|10
	TMUX1109	4:1, 2 channel	2.5	35	1	0.003	TSSOP|16, UQFN|16
	TMUX1108	8:1, 1-channel	2.5	65	1	0.004	TSSOP|16, UQFN|16
Mid Voltage (24V < V_{SIGNAL} < 100V)	TMUX6121/22/23	1:1, 2 channel	120	4.2	0.15	0.0004	VSSOP|10
	TMUX6111/12/13	1:1, 4 channel	120	4.2	0.6	0.0005	TSSOP|16, WQFN|16
	TMUX6119	2:1, 1 channel	120	4.3	0.19	0.0004	SOT-23|8
	TMUX6136	2:1, 2 channel	120	5.5	-0.4	0.0004	TSSOP|16
	TMUX6104	4:1, 1 channel	125	5	0.35	0.001	TSSOP|14
	MUX36S04	4:1, 2 channel	125	6.7	0.3	0.0033	TSSOP | 16, WQFN | 16
	MUX36S08	8:1, 1 channel	125	9.4	0.3	0.0033	TSSOP | 16, WQFN | 16
	MUX36D08	8:1, 2 channel	125	8.7	0.31	0.0053	QFN | 32, SOIC | 28, TSSOP | 28, WQFN | 32
	MUX36S16	16:1, 1 channel	125	13.5	0.31	0.0053	QFN | 32, SOIC | 28, TSSOP | 28, WQFN | 32

(1) The TMUX11xx, TMUX61xx, MUX36xxx, and MUX5xx family of switches and multiplexers all have a transmission gate architecture.

5.2 Protection Switches and Multiplexers

TI offers a broad range of protection multiplexers and switches in different configurations to protect upstream and downstream components from and during fault conditions while maximizing signal integrity. The key differentiating features of these protection switches are:

- **Powered Off Protection**: Protects switch and isolates signal path when signals are present at the I/O pins and VDD = 0 V. See the *Eliminate Power Sequencing With Powered-off Protection Signal Switched Tech Note* and *Simplify power sequencing with powered-off protection* for more information. 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 with the following features.
  - 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.

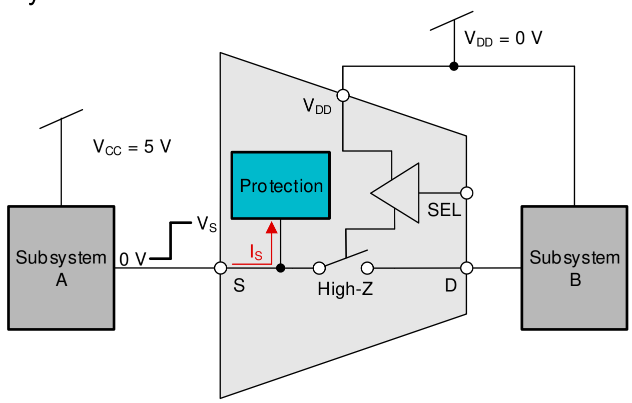


Figure 5-1. Powered-off Protection

- **Over Voltage Protection / Fault Detection** : When the input voltage $V_{I/O}$ exceeds the defined threshold voltage V_{TH}, the switch enters the high impedance state, isolates signal path, and protects downstream components. To improve the safety and longevity of a system TI offers an overvoltage or over temperature feature. When a voltage on the COM pin exceeds the overvoltage threshold V_{OVP_TH}, the open drain output FLT (fault) pin pulls the pin low to indicate an overvoltage event has been detected. The open drain output will release the FLT pin when the voltage on the COM pin returns below the V_{OVP_TH}. This can be used by a processor to turn off the mux or implement other safety features. Similarly, when the junction temperature of the device exceeds the overtemperature detection threshold T_{OTD_TH}, the open drain output FLT pin pulls the pin low to indicate an overtemperature event has been detected. The open drain output releases the FLT pin when the junction temperature returns below the T_{OTD_TH}. As both features use the same FLT pin, safety procedures have to consider both causes of fault.

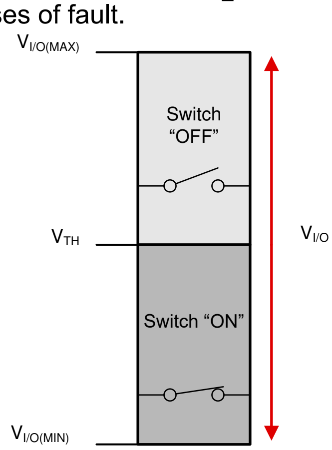


Figure 5-2. Overvoltage Protection

These bidirectional switches and multiplexers with powered-off protection can be used to isolate I/O signal paths from system power rails to resolve bus contention issues, reduce power sequencing design complexity and save system power. In addition to the above features, most of the protection switches also support 1.8 V control logic and fail safe logic (to prevent power from going through V_{CC} during power sequencing) and are available in ultra small packages: RSV (4.68 mm^2).

Table 5-2 below shows performance specification of analog protection switches:

Table 5-2. Analog Protection Switches and Multiplexers

V_{CC}	Part Number	Configuration	R_{ON} (Typ) (Ω)	Package/Pin	Features
Low Voltage (V_{SIGNAL}< 24V)	TMUX1511	1:1, 4 channel	2	TSSOP | 14, UQFN | 16	1.8-V compatible control inputs, Fail-safe logic, Supports JTAG signals, Supports SPI signals, Supports input voltage beyond supply
	TMUX154E	2:1, 2 channel	6	UQFN | 10, VSSOP | 10	1.8-V compatible control inputs, Powered-off protection, Supports I^2C signals, Supports input voltage beyond supply
	TMUX1574	2:1, 4 channel	2	SOT-23-THN | 16, TSSOP | 16, UQFN | 16	1.8-V compatible control inputs, Fail-safe logic, Supports JTAG signals, Supports SPI signals, Supports input voltage beyond supply
	TMUX136	2:1, 2 channel	4.6	UQFN | 10	1.8-V compatible control inputs, Supports I^2C signals
	TMUX1072	2:1, 2 channel	6	UQFN | 12, VSSOP | 10	1.8-V compatible control inputs, Supports I^2C signals, Supports input voltage beyond supply
	TS5A3159A	2:1, 2 channel	0.7	DSBGA | 6, SC70 | 6, SOT-23 | 6	Powered-off protection, Break-before-make
	SN74CBTLV3257	2:1, 4 channel	5	SOIC | 16, SSOP | 16, TSSOP | 16, TVSOP | 16, UQFN | 16, VQFN | 16	Powered-off protection, Supports JTAG signals, Supports SPI signals
	TS5A3359	3:1, 1channel	0.7	DSBGA | 8, VSSOP | 8	Powered-off protection, Break-before-make
	SN74CBT3305C (1)	1:1, 2 channel	3	SOIC | 8, TSSOP | 8	Supports I^2C signals, Undershoot protection
	SN74CBTD3306C	1:1, 2 channel	3	SOIC | 8, TSSOP | 8	Signal path translation, Undershoot protection
	SN74CB3Q3257	2:1, 4 channel	4	SSOP | 16, TSSOP | 16, TVSOP | 16, VQFN | 16	Powered-off protection, Supports JTAG signals, Supports SPI signals, Supports input voltage beyond supply
	SN74CBTLV1G125 (1)	1:1, 1 channel	5	SOT-23 | 5, SC-70 | 5	Powered-off protection
	SN74CB3T1G125 (1)	1:1, 1 channel	5	SC70 | 5, SOT-23 | 5	Powered-off protection, Signal path translation
	SN74CBTLV3126	1:1, 4 channel	5	SOIC | 14, SSOP | 16, TSSOP | 14, TVSOP | 14, VQFN | 14	Powered-off protection, Supports JTAG signals, Supports SPI signals
	TS3A27518E	2:1, 6 channel	4.4	TSSOP | 24, WQFN | 24	Powered-off protection, Break-before-make, Supports SPI signals, Supports JTAG signals, 1.8-V compatible control inputs
Mid Voltage (24 V < V_{SIGNAL} < 100 V)	MPC509	4:1, 2 channel	1300	SOIC | 16, PDIP | 16	Dual supply, Break-before-make, Overvoltage protection, Powered-off protection
	MPC508	8:1, 1 channel	1300	SOIC | 16, PDIP | 16	
	MPC507	8:1, 2 channel	1300	SOIC | 28	
	MPC506	16:1, 1 channel	1300	SOIC | 28	

(1) See Appendix A for analog performance of CBTand CBTLV family.

5.3 General Purpose Switches and Multiplexers

TI offers a broad portfolio of bidirectional general-purpose switches and multiplexers across a wide voltage range, channel count and configuration that are typically used in low-frequency or digital (ON or OFF) applications where size and BOM optimization or both are most important.

Table 5-3 below shows performance specifications of general purpose multiplexer family of devices:

Table 5-3. General-Purpose Switches and Multiplexers

V_{SIGNAL}	Part Number	Configuration	R_{ON} (Typical) (Ω)	Package/Pin	Features
Low Voltage (V_{SIGNAL}< 24 V)	TMUX1247	2:1, 1 channel	3	SC70 | 6	1.8-V compatible control inputs, Break-before-make, Fail-safe logic
	TMUX1219	2:1, 1 channel	3	SC70 | 6, SOT-23 | 6	
	TMUX1204	4:1, 1 channel	9	USON | 10, VSSOP | 10	
	TMUX1209	4:1, 2 channel	5	TSSOP | 16, UQFN | 16	
	TMUX1208	8:1, 1 channel	5	TSSOP | 16, UQFN | 16	
	SN74LVC2G66	1:1, 2 channel	6	DSBGA | 8, SM8 | 8, VSSOP | 8	Supports I2C signals
	TS5A3157	2:1, 1 channel	5.5	DSBGA | 6, SC70 | 6, SOT-23 | 6	Break-before-make
	TS5A23157	2:1, 2 channel	10	UQFN | 10, VSSOP | 10	Break-before-make, Supports I2C signals
	CD74HC4053 (1)	2:1, 3 channel	45	PDIP | 16, SOIC | 16, SO | 16, TSSOP | 16	Break-before-make
	SN74LV4053A (1)	2:1, 3 channel	23	PDIP | 16, QFN| 16, SOIC | 16, SOP | 16, TSSOP | 16, CDIP | 16	Support mixed-mode voltage operation on all ports
	SN74LVC1G3157 (1)	2:1, 1 channel	6	SC70 | 6, SOT-23 | 6, SON | 6, DSBGA | 6, X2SON | 6	Break-before-make
	CD4051B (1)	8:1, 1 channel	125	PDIP | 16, SOIC | 16, SO | 16, TSSOP | 16	Break-before-make
	TS12A4514	1:1, 1 channel	6.5	PDIP | 8, SOIC | 8, SOT-23 | 5	Break-before-make
Mid Voltage (24 V < V_{SIGNAL} < 100V)	MUX509	4:1, 2 channel	125	SOIC | 16, TSSOP | 16	Break-before-make
	MUX508	8:1, 1 channel	125	SOIC | 16, TSSOP | 16	
	MUX507	8:1, 2 channel	125	SOIC | 28, TSSOP | 28	
	MUX506	16:1, 1channel	125	SOIC | 28, TSSOP | 28	

(1) See Appendix A for analog performance of HC, LV, LVC and CD400 family.

5.4 Automotive Switches and Multiplexers

Table 5-4 below shows performance specification of automotive (AECQ100) switches:

Table 5-4. Automotive Switches and Multiplexers – AECQ100

Configuration	Part Number	Package/Pin	Features
1:1, 1 channel	TS5A3166-Q1	SC70 | 5	Low R_{ON} (<10 Ω), Powered-off protection
	SN74LVC1G66-Q1	SC70 | 5, SOT-23 | 5	Low R_{ON} (<10 Ω)
	SN74CBTLV1G125-Q1	SOT-23 | 5	Low R_{ON} (<10 Ω), Powered-off protection
1:1, 2 channel	SN74LVC2G66-Q1	VSSOP | 8	Low R_{ON} (<10 Ω), Supports I2C signals
1:1, 4 channel	CD4066B-Q1	SOIC | 14	Low C_{ON} (<10 pF)
	CD74HCT4066-Q1	SOIC | 14, TSSOP | 14 52 mm2: 6 x 8.65 (SOIC | 14),	Low C_{ON} (<10 pF)
2:1, 1 channel	TS5A3159-Q1	SOT-23 | 6	Break-before-make, Low R_{ON} (<10 Ω)
	SN74LVC1G3157-Q1	SC70 | 6, SOT-23 | 6	Low R_{ON} (<10 Ω)
2:1, 2 channel	TS5A22364-Q1	VSSOP | 10	Low R_{ON} (<10 Ω), Break-before-make, Supports negative voltages
	TS5A3357-Q1	VSSOP | 10	Low R_{ON} (<10 Ω), Break-before-make, Supports I2C signals
2:1, 4 channel	SN3257-Q1	SOT-23-THN | 16, TSSOP | 16	Low R_{ON} (<10 Ω), 1.8-V compatible control inputs, Break-before-make, Fail-safe logic, Integrated pulldown resistor on logic pin, Powered-off protection, Supports SPI signals, Supports input voltage beyond supply
2:1, 6 channel	TS3A27518E-Q1	TSSOP | 24, WQFN | 24	Low R_{ON} (<10 Ω), Powered-off protection, Break-before-make, Supports SPI signals, Supports JTAG signals, 1.8-V compatible control inputs
4:1, 2 channel	TS3A5017-Q1	VQFN | 16	Powered-off protection, Supports SPI signals
	SN74LV4052A-Q1	SOIC | 16, TSSOP | 16	Low C_{ON} (<10 pF)
8:1, 1 channel	TMUX1308-Q1	SOT-23-THN | 16, TSSOP | 16	1.8-V compatible control inputs, Break-before-make, Current injection control
	SN74HC4851-Q1	SOIC | 16, TSSOP | 16	Current Injection Control
	SN74LV4051A-Q1	SOIC | 16, SOIC | 16, TSSOP | 16	Low R_{ON} (<10 Ω), Break-before-make
	CD74HCT4051-Q1	SOIC | 16	Low C_{ON} (<10 pF), Break-before-make
16:1, 1 channel	CD74HCT4067-Q1	SOIC | 24	Low C_{ON} (<10 pF), Break-before-make

6 Digital Signal Switches and Multiplexers Performance

For digital switches and multiplexers, in addition to the signal switch specifications highlighted in Section 4, the following features also need to be considered:

- Number of bits required to be switched. With TI's wide variety of signal switches, it is possible to switch between 1 to 32 bits at the same time with a single device. For instance, the LVC1G66 or CBT1G125 can be used to switch a single bit, while the CBTLV16211 is capable of switching 24 bits total in banks of 12. Or, by tying the adjacent enable pins together, it is possible to control 24 bits with one enable signal.
- Special features. TI offers bus switches with special features, such as an integrated diode for single-component level shifting (CBTD), active clamps for undershoot protection (CBTK), Schottky-diode clamps for undershoot protection (CBTS), a bus-hold option (CBTH) for holding floating or unused I/O pins at valid logic levels, and an integrated-series-resistor option (CBTR) to reduce signal-reflection noise.

Table 6-1 summarizes the digital performance characteristics of TI signal switches from which generalities can be derived regarding switch-family performance. For exact parameters, refer to the respective data sheets.

Table 6-1. Summary of Digital Performance

Part Number (1)	V_{CC}	R_{ON}	t_{pd} (2)	t_{ON} (3)	t_{OFF} (4)	V_{IH} (control inputs)	V_{IL} (control inputs)	C_i (control)	C_{io} (on)	C_{io} (off)
TMUX1209	1.08-5.5 V	5-9 Ω	_	60 ns	45 ns	1.8-V CMOS	1.8-V CMOS	1 pF	42 pF	38 pF
TMUX1511	1.5-5.5 V	2 Ω	67 ps	20 µs	4 µs	1.8-V CMOS	1.8-V CMOS	3 pF	3.3-6 pF	2.4-4 pF
CD4066	3-18 V	200-1300 Ω	7-40 ns	15-70 ns	15-70 ns	approximately. 0.7 × V_{CC}	approximately. 0.2 × V_{CC}	5-7.5 pF	_	8 pF
CD74HC4066	2-10 V	15-142 Ω	4-90 ns	8-150 ns	12-225 ns	5-V CMOS	5-V CMOS	10 pF	_	5 pF
CD74HCT4066	4.5-5.5 V	25-142 Ω	4-18 ns	4-18 ns	9-36 ns	5-V TTL	5-V TTL	10 pF	_	5 pF
SN74HC4066	2-6 V	30-150 Ω	3-75 ns	18-225 ns	22-250 ns	5-V CMOS	5-V CMOS	3-10 pF	_	9 pF
LVC1G66	1.65-5.5V	3-30 Ω	0.6-2 ns	1.5-10 ns	1.4-10 ns	5-V CMOS	5-V CMOS	2 pF	13 pF	6 pF
LV4066A	2-5.5 V	21-225 Ω	0.3-18 ns	1.6-32 ns	3.2-32 ns	5-V CMOS	5-V CMOS	1.5 pF	_	5.5 pF
CBT3125	4-5.5 V	5-22 Ω	0.25-0.35 ns	1.8-5.6 ns	1-4.6 ns	5-V TTL/LVTTL	5-V TTL/ LVTTL	3 pF	_	4 pF
CBTLV3125	2.3-3.6 V	5-40 Ω	0.15-0.25 ns	2-4.6 ns	1-4.2 ns	LVTTL/2.5-V CMOS	LVTTL/ 2.5-V CMOS	2.5 pF	_	7 pF

(1) Data are based on data-sheet parameters for the parts tested for this application report. Refer to the respective data sheets for specific parameters and load conditions.
(2) t_{pd} is the same as t_{PLH}/t_{PHL}. The switch contributes no significant propagation delay other than the RC delay of the typical on-state resistance of the switch and the load capacitance when driven by an ideal voltage source (zero output impedance).
(3) t_{ON} is the same as t_{PZL}/t_{PZH}.
(4) t_{OFF} is the same as t_{PLZ}/t_{PHZ}.

7 Applications

The examples below show some common applications of signal switches and multiplexers:

7.1 SPI Multiplexing

Common applications that require the features of the multiplexer like the TMUX1574 and SN3257-Q1 include multiplexing various protocols from a possessor or MCU such as SPI, eMMC, I2S, or standard GPIO signals. These devices provides superior isolation performance when the device is powered. The added benefit of powered-off protection allows a system to minimize complexity by eliminating the need for power sequencing in hot-swap and live insertion applications. The example shown in Figure 7-1 illustrates the use of the SN3257-Q1 to multiplex an SPI bus to multiple flash memory devices.

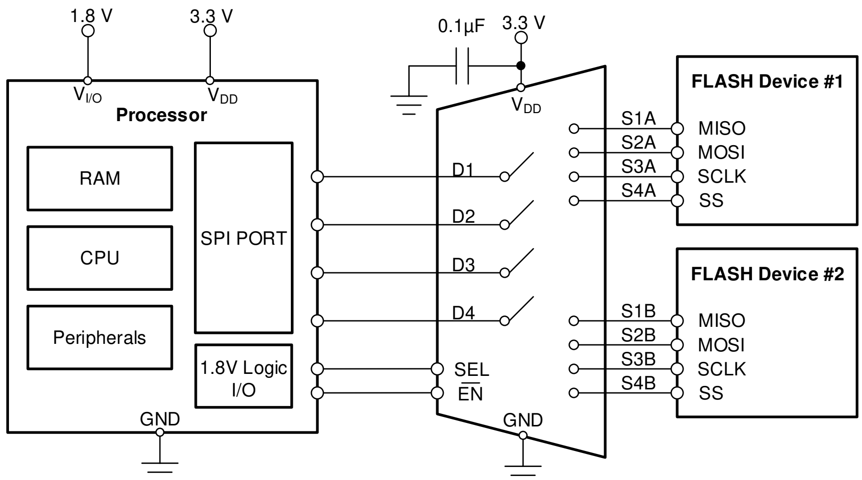


Figure 7-1. Multiplexing Flash Memory

One useful application of multiplexers is isolating various protocols from a possessor or MCU such as JTAG, SPI, or standard GPIO signals. Switch like the TMUX1511 provides excellent isolation performance when the device is powered. The added benefit of powered-off protection allows a system to minimize complexity by eliminating the need for power sequencing in hot-swap and live insertion applications

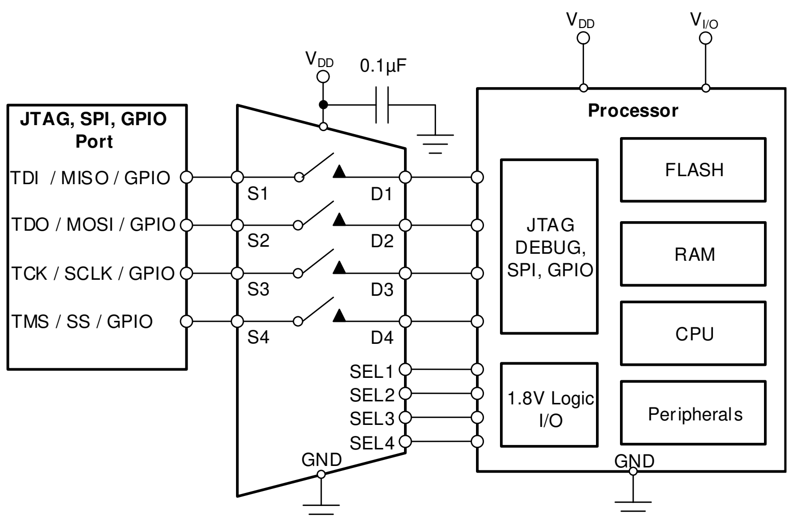


Figure 7-2. Isolation of JTAG, SPI, and GPIO Signals

7.2 Multiplexing Signals to External ADC

Figure 7-3 shows a 16-bit, 4 input, multiplexed, data-acquisition system. This example is typical in industrial applications that require low distortion for precision measurements. The circuit uses the ADS8864, a 16-bit, 400- kSPS successive-approximation-resistor (SAR) analog-to-digital converter (ADC), along with a precision amplifier, and a 4 input multiplexer (TMUX1104).

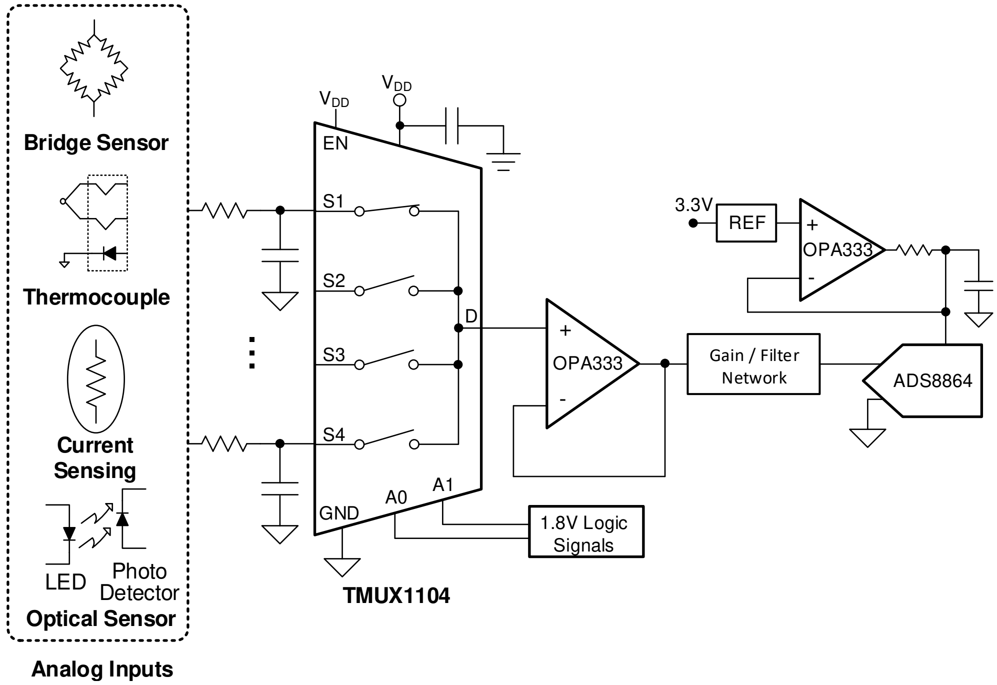


Figure 7-3. Multiplexing Signals to External ADC

7.3 Switchable Op Amp Gain Setting

One example application of the multiplexer is to change an Op Amp from unity gain setting to an inverting amplifier configuration. Utilizing a switch like the TMUX1219 allows a system to have a configurable gain and allows the same architecture to be utilized across the board for various inputs to the system.

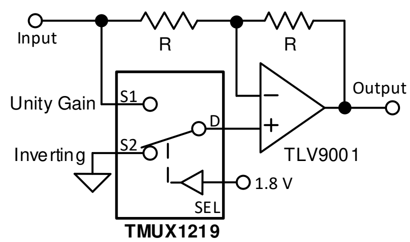


Figure 7-4. Switchable Op Amp Gain Setting

7.4 Multiplexing Body Control Module (BCM) Inputs

Automotive BCMs are complex systems designed to manage numerous functions such as lighting, door locks, windows, wipers, turn signals and many more inputs. The BCM monitors these physical switches and controls power to various loads within the vehicle. A CMOS multiplexer can be used to multiplex the inputs and minimize the number of GPIO or ADC inputs needed by an onboard MCU. The TMUX1308-Q1 features multiplexing various physical switches in a body control module (BCM) or electronic control unit (ECU). Figure 7-1 shows a typical BCM system using the TMUX1308-Q1 to multiplex system inputs.

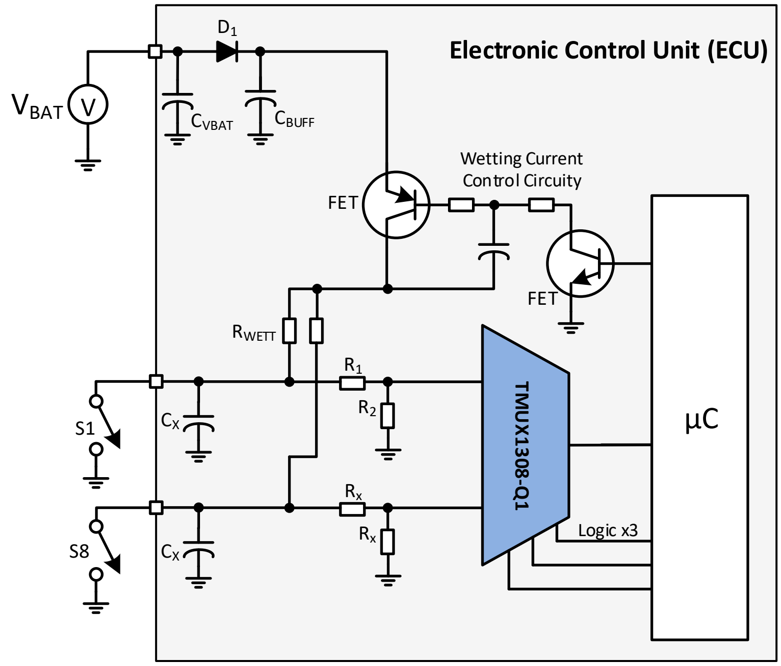


Figure 7-5. Multiplexing BCM Inputs

8 Summary

Factors that go into selecting a signal switch can be numerous (low r_{on}, low leakage, channel count, switch configuration, powered- off protection, and so forth). This application report has presented the various TI signal-switch architecture, highlighted the key features and examples of protection, precision and general-purpose switches and multiplexers to support end-to-end signal chain needs and provided example applications of switches to aid the designer in selecting the right TI signal switch.

9 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision B (April 2020) to Revision C (August 2021)	Page
• Updated the numbering format for tables, figures and cross-references throughout the document	4

Changes from Revision A (March 2020) to Revision B (April 2020)	Page
• Updated Figure 27: *Switchable Op Amp Gain Setting*	23

Changes from Revision * (October 2001) to Revision A (March 2020)	Page
• Updated Application Report with new TMUX signal switches and multiplexers	1

A Appendix A

A.1 Analog Performance – CD, HC, CBT, LVC, and LV

Table A-1. V_{CC} Above 5.5 V

Parameter [(1)]	Better Performance		
R_{ON} (typical to maximum)	CD74HC4066 15-126 Ω	CD74HC4066[(2)] 30 Ω	CD4066 200-550 Ω
R_{ON} (peak) (typical to maximum)	SN74HC4066[(2)] 50 Ω (typical)	CD74HC4066 not specified	CD4066 not specified
Frequency response	CD74HC4066[(3)] 200 MHz	CD4066 40 MHz	SN74HC4066[(3)] 30 MHz
THD/Sine-wave distortion	CD74HC4066 0.008%	SN74HC4066[(3)] 0.05%	CD4066 0.4%
Crosstalk (enable to output)	SN74HC4066 20 mV	CD4066 50 mV	CD74HC4066 550 mV
Crosstalk (between switches)	CD4066 -50 dB at 8 MHz	CD74HC4066[(3)] -72 dB at 1 MHz	SN74HC4066[(3)] -45 dB at 1 MHz
Feedthrough attenuation	CD74HC4066[(3)] -72 dB at 1 MHz	CD4066 -50 dB at 1 MHz	SN74HC4066[(3)] -42 dB at 1 MHz

(1) Data are based on data-sheet parameters for the parts tested for this application report. Refer to the respective data sheets for specific parameters and load conditions.
(2) Specification at V_{CC} = 6 V.
(3) Specification at V_{CC} = 4.5 V.

Table A-2. V_{CC} = 4.5 V

Parameter [(1)]	Better Performance					
R_{ON} (typical to maximum)	LVC1G66 3-10 Ω	CBT3125[(2)] 5-15 Ω	LV4066A 21-100 Ω	CD74HC/ HCT4066 25-142 Ω	SN74HC4066 50-106 Ω	CBT3125[(3)] 5-1000 Ω
R_{ON} (peak) (typical to maximum)	CBT3125[(2)] [(3)] 10 Ω	LVC1G66 6-15 Ω	LV4066A 31-125 Ω	CD74HC/ HCT4066[(3)] 50-70 Ω	SN74HC4066 70-215 Ω	CBT3125[(3)] 1000 Ω
Frequency response	CBT3125[(2)] [(3)] >200 MHz	LVC1G66 195 MHz	CD74HC/ HCT4066[(4)] 200 MHz	LV4066A 50 MHz	SN74HC4066 30 MHz	
THD/Sine-wave distortion	LVC1G66 0.01%	CD74HC/ HCT4066 0.023%	CBT3125[(2)] [(3)] 0.035%	SN74HC4066 0.05%	LV4066A 0.1%	
Crosstalk (enable to output)	SN74HC4066 15 mV	LV4066A 50 mV	LVC1G66 100 mV	CBT3125[(3)] 120 mV	CD74HCT4066 130 mV	CD74HC4066 200 mV
Crosstalk (between switches)	CD74HC/HCT4066 -72 dB	LVC2G66 -58 dB	CBT3125[(2)] [(3)] -53 dB	SN74HC4066 -45 dB	LV4066A -45 dB	
Feedthrough attenuation	CD74HC/HCT4066 -72 dB	LVC1G66 -58 dB	SN74HC4066 -42 dB	LV4066A -40 dB	CBT3125[(3)] -36 dB	

(1) Data are based on data-sheet parameters for the parts tested for this application report. Refer to the respective data sheets for specific parameters and load conditions.
(2) CBT3125, $0 \le V_{I/O} \le (V_{CC} - 2\ V)$.
(3) Value from application report measurement. Not specified in data sheet.
(4) Ranked here due to load variation from other devices in this report.

Table A-3. V_{CC} = 3 V

Parameter [(1)]	Better Performance				
R_{ON}(typical to maximum)	LVC1G666-15 Ω	CBTLV31255-15 Ω	LV4066A29-190 Ω	CD74HC4066[(2)]Not specified	SN74HC4066[(2)]Not specified
R_{ON} (peak)(typical to maximum)	CBTLV3125[(3)]15-20 Ω	LVC1G6612-20 Ω	LV4066A57-225 Ω	CD74HC4066[(2)]Not specified	SN74HC4066[(2)]Not specified
Frequency response	CBTLV3125[(3)]>200 MHz	LVC1G66175 MHz	CD74HC4066[(2)]Not specified	LV4066A35MHz	SN74HC4066[(1)]Not specified

Table A-3. V_{CC} = 3 V (continued)

Parameter [(1)]	Better Performance				
THD/Sine-wave distortion	LVC1G660.015%	CD74HC4066[(2)]Not specified	SN74HC4066[(2)]Not specified	CBTLV3125[(3)]0.09%	LV4066A0.1%
Crosstalk(enable to output)	SN74HC4066[(2)]Not specified	LV4066A20 mV	LVC1G6670 mV	CBTLV3125[(3)]70 mV	CD74HC4066[(2)]Not specified
Crosstalk(between switches)	CD74HC4066[(2)]Not specified	LVC2G66-58 dB	CBTLV3125[(3)]-49 dB	SN74HC4066[(2)]Not specified	LV4066A-45 dB
Feedthrough attenuation	CD74HC4066[(2)]Not specified	LVC1G66-58 dB	CBTLV3125-52 dB	SN74HC4066[(2)]Not specified	LV4066A-40 dB

(1) Data are based on data-sheet parameters for the parts tested for this application report. Refer to the respective data sheets for specific parameters and load conditions.
(2) Position in table based on estimated performance. Information not specified in data sheet.
(3) Value from application report measurement. Not specified in data sheet.

Table A-4. V_{CC} = 2.5 V

Parameter [(1)]	Better Performance				
R_{ON}(typical to maximum)	LVC1G66 9-20 Ω	CBTLV3125 5-40 Ω	LV4066A 38-225 Ω	CD74HC4066[(2)] Not specified	SN74HC4066[(3)] 150 Ω
R_{ON} (peak)(typical to maximum)	CBTLV3125[(4)] 15-45 Ω	LVC1G66 20-30 Ω	LV4066A 143-600 Ω	CD74HC4066[(2)] Not specified	SN74HC4066[(3)] 320 Ω
Frequency response	CBTLV3125[(4)] >200 MHz	LVC1G66 120 MHz	CD74HC4066[(2)] Not specified	LV4066A 30 MHz	SN74HC4066[(2)] Not specified
THD/Sine-wave distortion	LVC1G66 0.025%	CD74HC4066[(2)] Not specified	SN74HC4066[(2)] Not specified	LV4066A 0.1%	CBTLV3125[(4)] 0.11%
Crosstalk(enable to output)	SN74HC4066[(2)] Not specified	LV4066A 15 mV	CBTLV3125[(2)] 30 mV	LVC1G66 50 mV	CD74HC4066[(2)] Not specified
Crosstalk(between switches)	CD74HC4066[(2)] Not specified	LVC2G66 -58 dB	CBTLV3125 -45 dB	SN74HC4066[(2)] Not specified	LV4066A -45 dB
Feedthrough attenuation	CD74HC4066[(2)] Not specified	LVC1G66 -58 dB	CBTLV3125 -52 dB	SN74HC4066[(2)] Not specified	LV4066A -40 dB

(1) Data are based on data-sheet parameters for the parts tested for this application report. Refer to the respective data sheets for specific parameters and load conditions.
(2) Position in table based on estimated performance. Information not specified in data sheet.
(3) Data at V_{CC} = 2 V.
(4) Value from application report measurement. Not specified in data sheet.

A.2 SN74CBT Characteristics

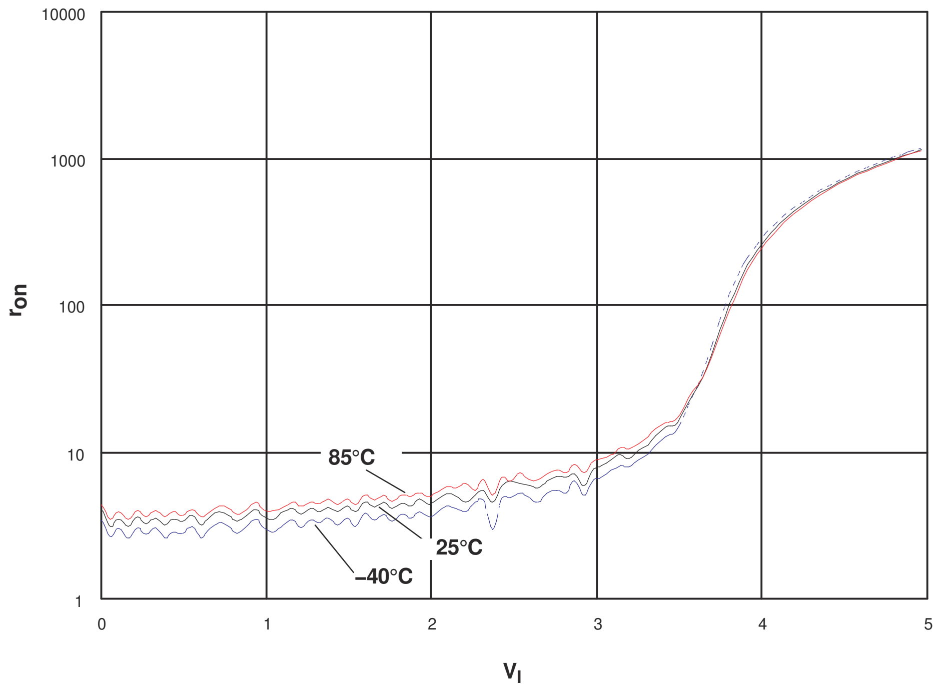


Figure A-1. Log r_{on} vs V_I, V_{CC} = 5 V (SN74CBT3125)

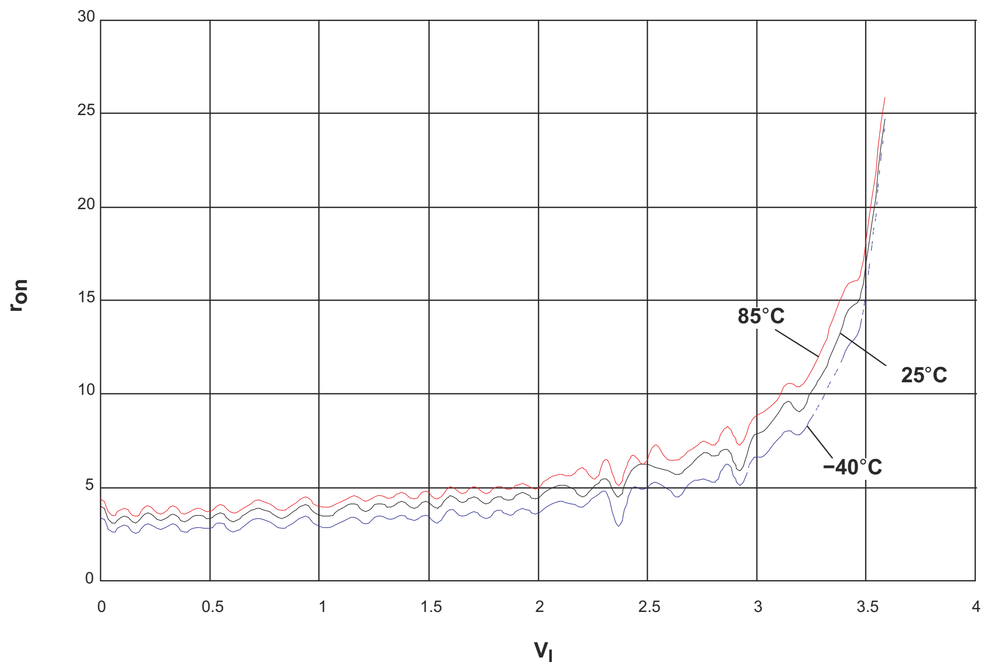


Figure A-2. r_{on} vs V_I, V_{CC} = 5 V (SN74CBT3125)

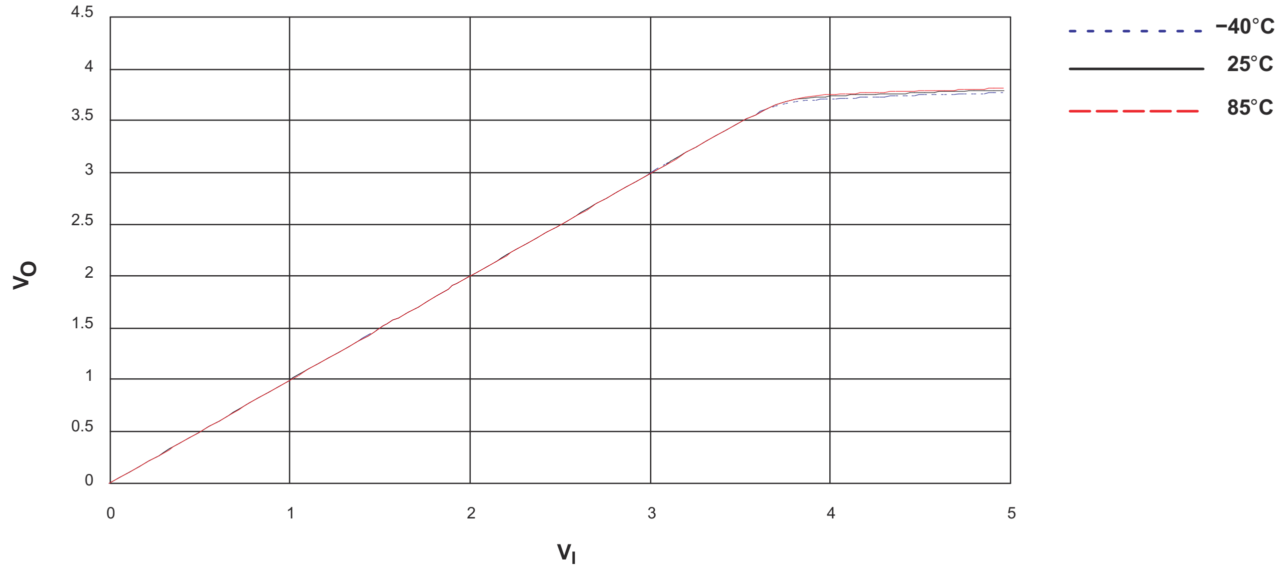


Figure A-3. V_I vs V_O, V_{CC} = 5 V (SN74CBT3125)

Table A-5. SN74CBT3125 Analog Parameter Measurement Data

V_{CC} (1)	Frequency Response	Sine-Wave Distortion	Total Harmonic Distortion	Crosstalk		Charge Injection	Feedthrough
		1 kHz		Between Switches	Enable to Output		
5 V	>200 MHz	0.035%	0.15%	-53 dB	120 mV	7.2 pC	-36 dB

(1) Postcharacterization measurement for SN74CBT3125

A.3 CD74HCT Characteristics

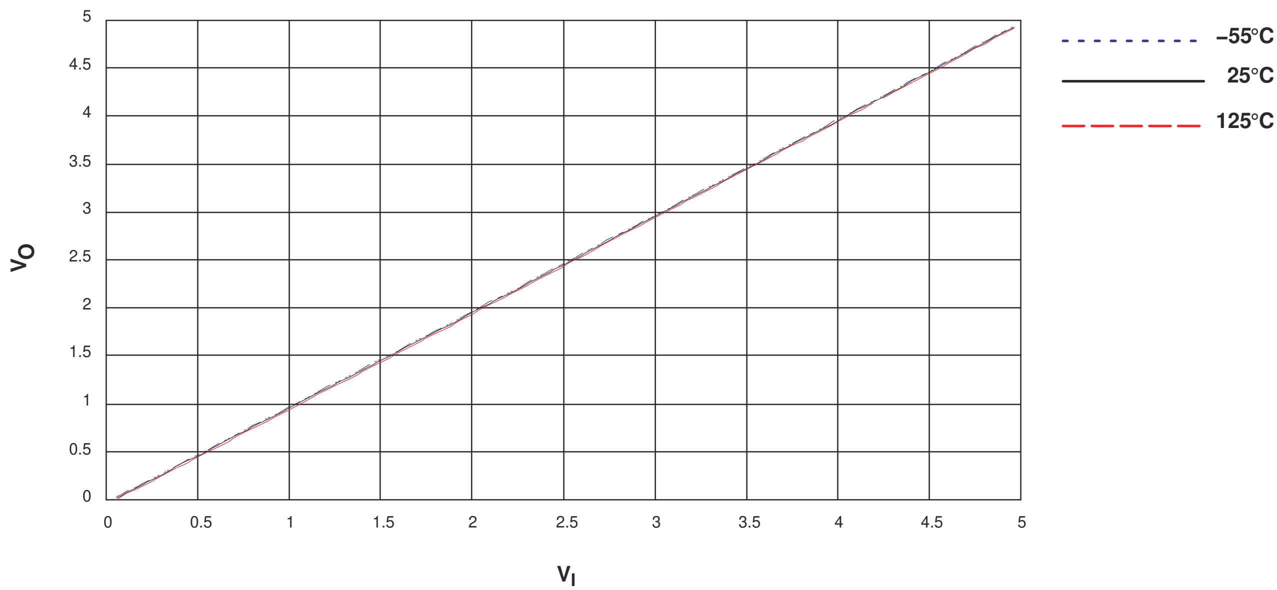


Figure A-4. V_I vs V_O, V_{CC} = 5 V (CD74HCT4066)

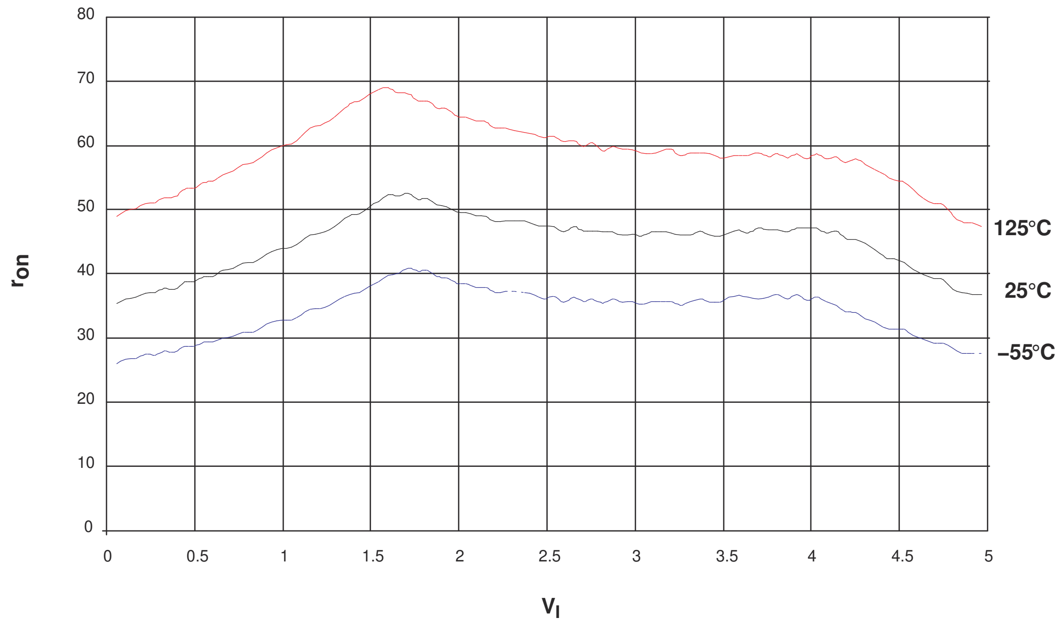


Figure A-5. r_{on} vs V_I, V_{CC} = 5 V (CD74HCT4066)

Table A-6. CD74HCT4066 Analog Parameter Measurement Data

V_{CC} (1)	Frequency Response	Total Harmonic Distortion	Crosstalk		Charge Injection(2)	Feedthrough
		1 kHz	Between Switches	Enable to Output		
4.5 V	200 MHz	0.023%	-72 dB	130 mV	8.1 pC	-72 dB

(1) Data-sheet values for CD74HCT4066, except as noted.
(2) Post-characterization measurement for CD74HCT4066.

A.4 CD74HC Characteristics

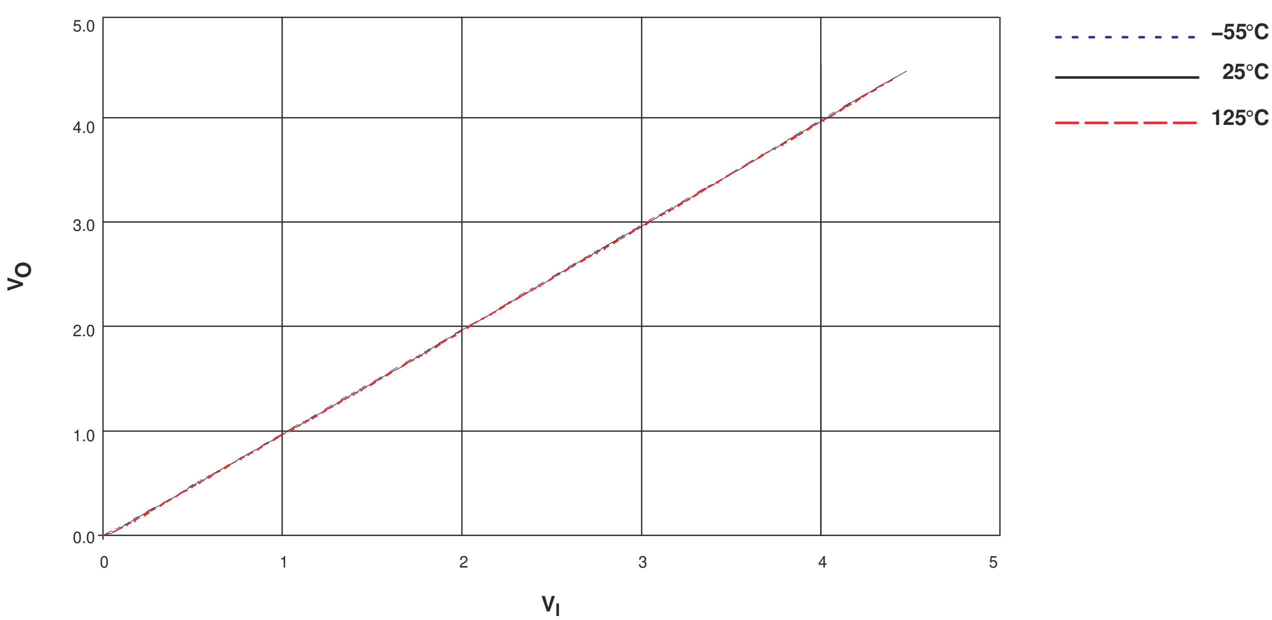


Figure A-6. V_I vs V_O, V_{CC} = 4.5 V (CD74HC4066)

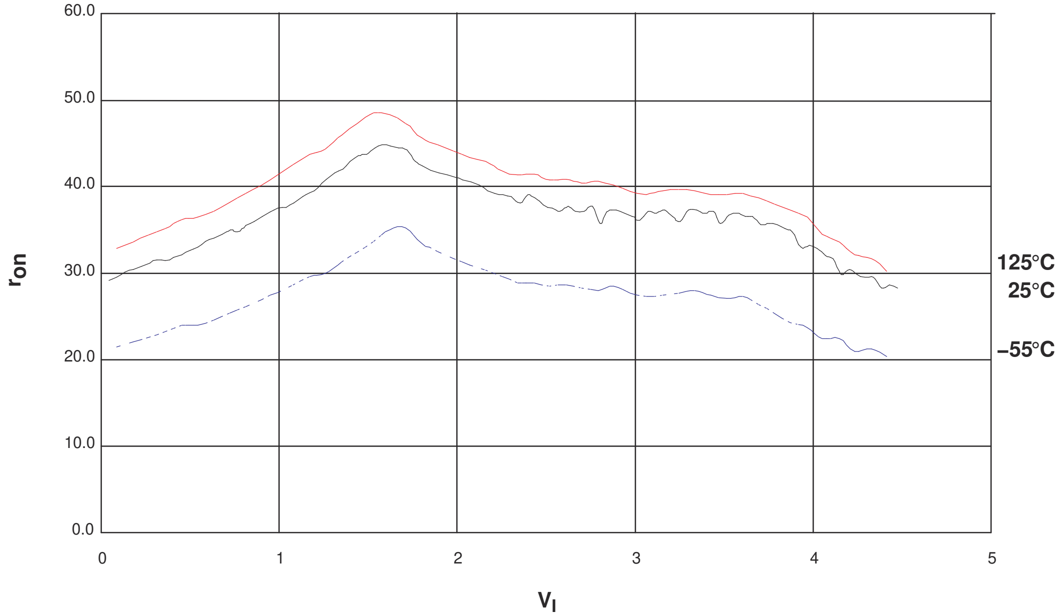


Figure A-7. r_{on} vs V_I, V_{CC} = 4.5 V (CD74HC4066)

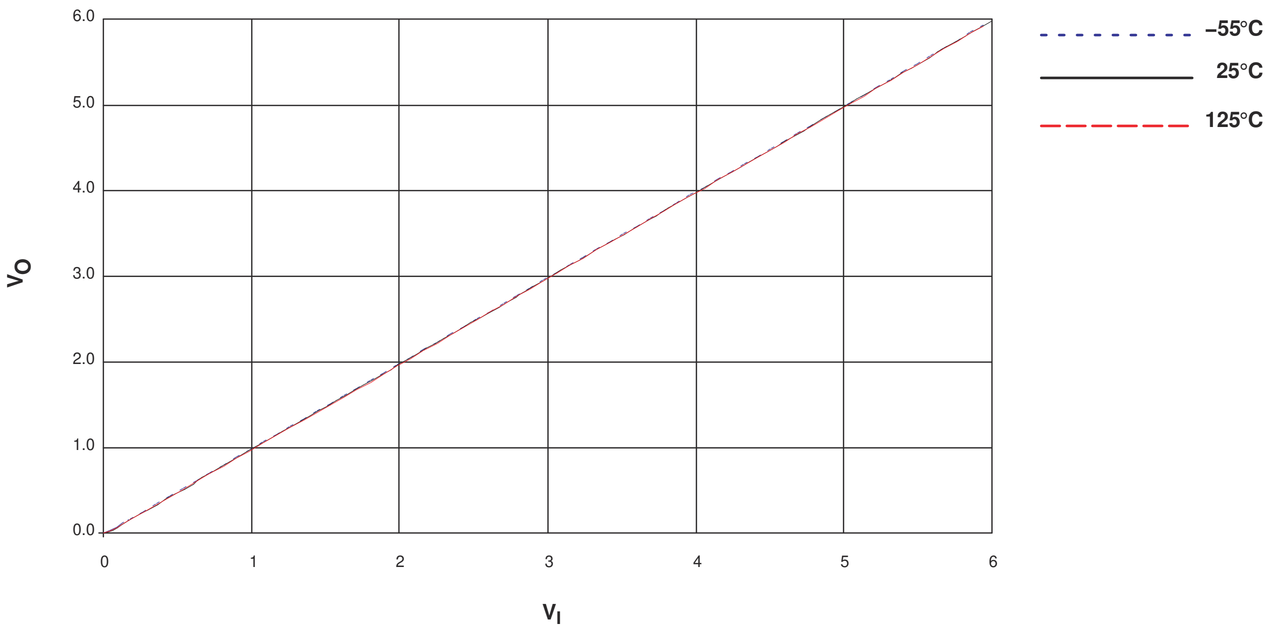


Figure A-8. V_O vs V_I, V_{CC} = 6 V (CD74HC4066)

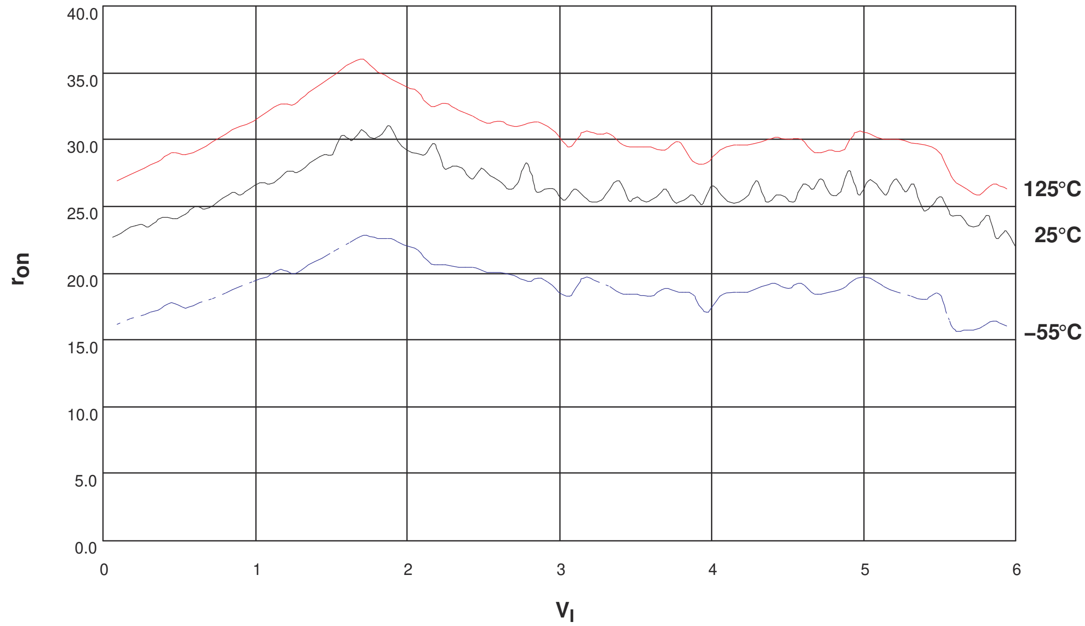


Figure A-9. r_{on} vs V_I, V_{CC} = 6 V (CD74HC4066)

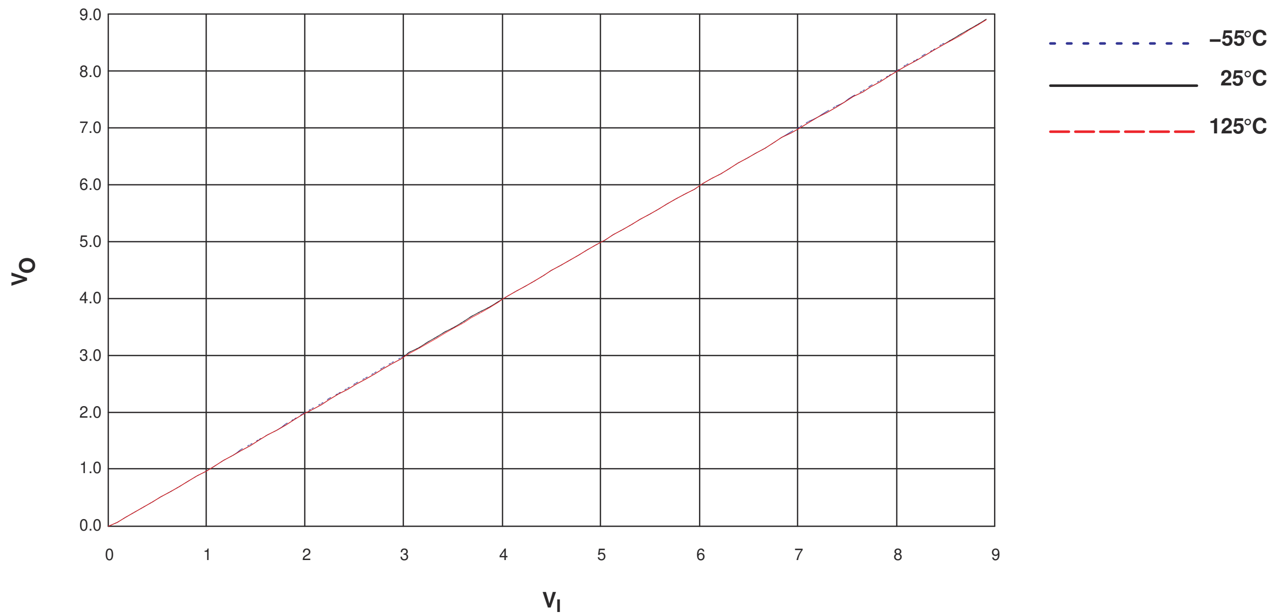


Figure A-10. V_O vs V_I, V_{CC} = 9 V (CD74HC4066)

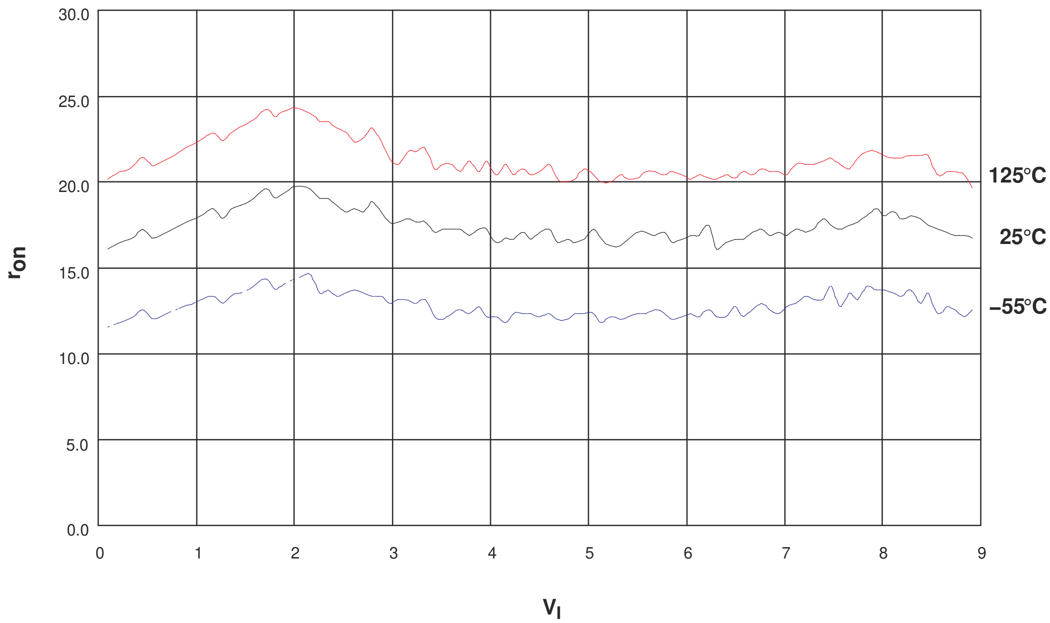


Figure A-11. r_{on} vs V_I, V_{CC} = 9 V (CD74HC4066)

Table A-7. CD74HC4066 Analog Parameter Measurement Data

V_{CC} (1)	Frequency Response	Total Harmonic Distortion	Crosstalk		Charge Injection(2)	Feedthrough
		1 kHz	Between Switches	Enable to Output		
4.5 V	200 MHz	0.022%	-72 dB	200 mV	6.2 pC	-72 dB
9 V	200 MHz	0.008%	N/A	550 mV	9.0 pC	N/A

(1) Data-sheet values for CD74HC4066, except as noted.
(2) Post characterization measurement for CD74HC4066.

A.5 SN74HC Characteristics

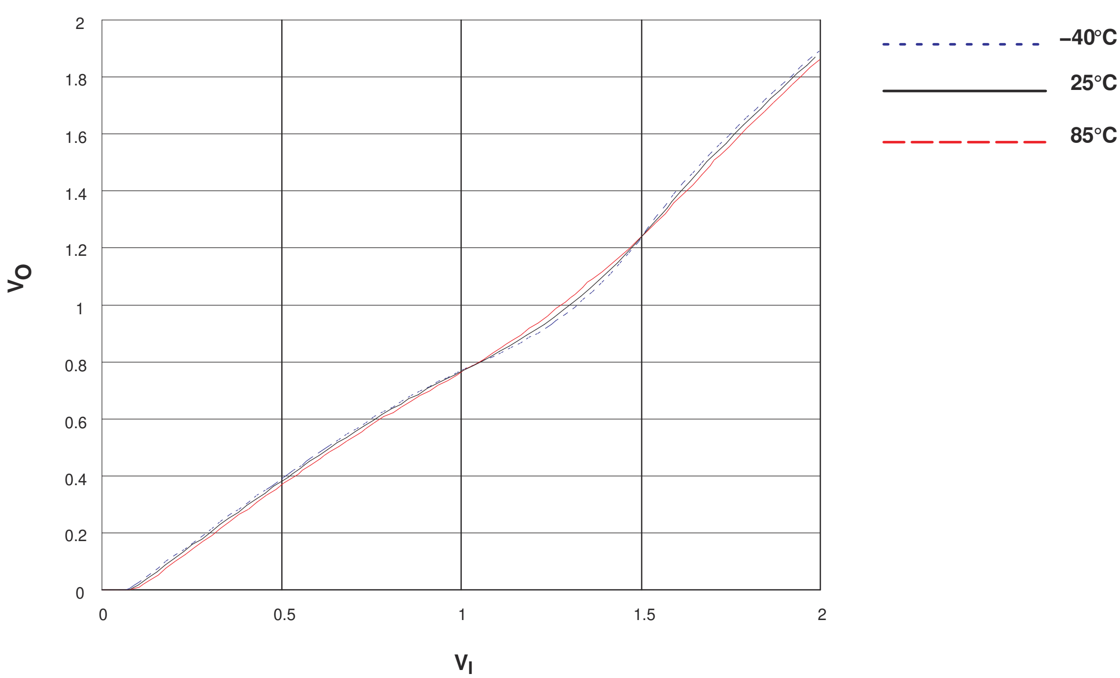


Figure A-12. V_O vs V_I, V_{CC} = 2 V (SN74HC4066)

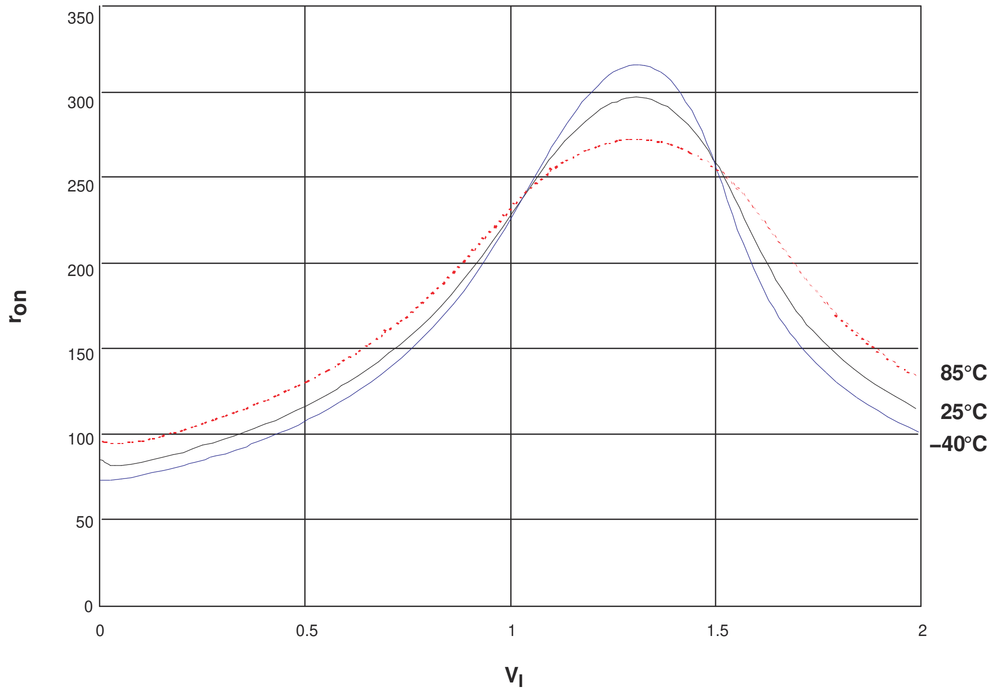


Figure A-13. r_{on} vs V_I, V_{CC} = 2 V (SN74HC4066)

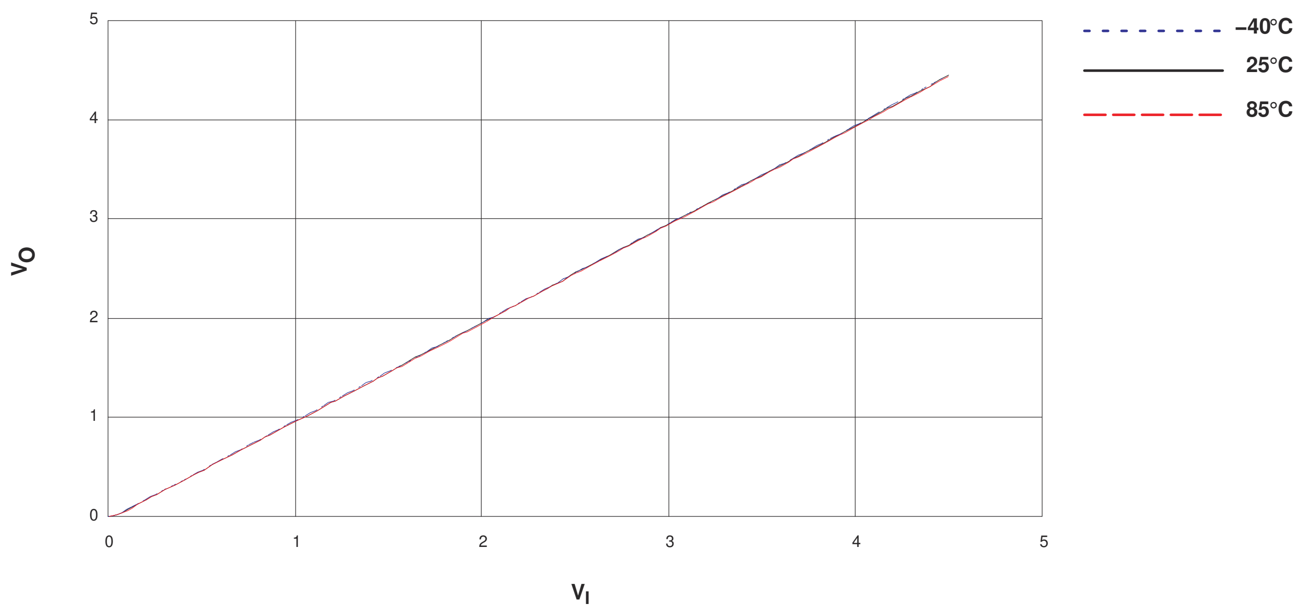


Figure A-14. V_O vs V_I, V_{CC} = 4.5 V (SN74HC4066)

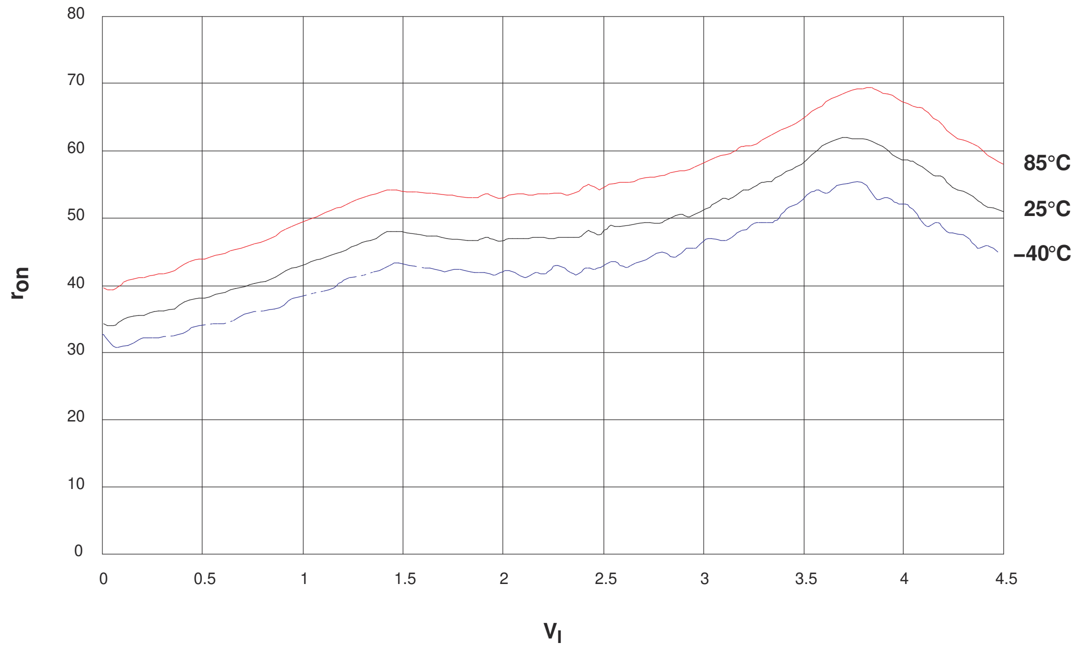


Figure A-15. r_{on} vs V_I, V_{CC} = 4.5 V (SN74HC4066)

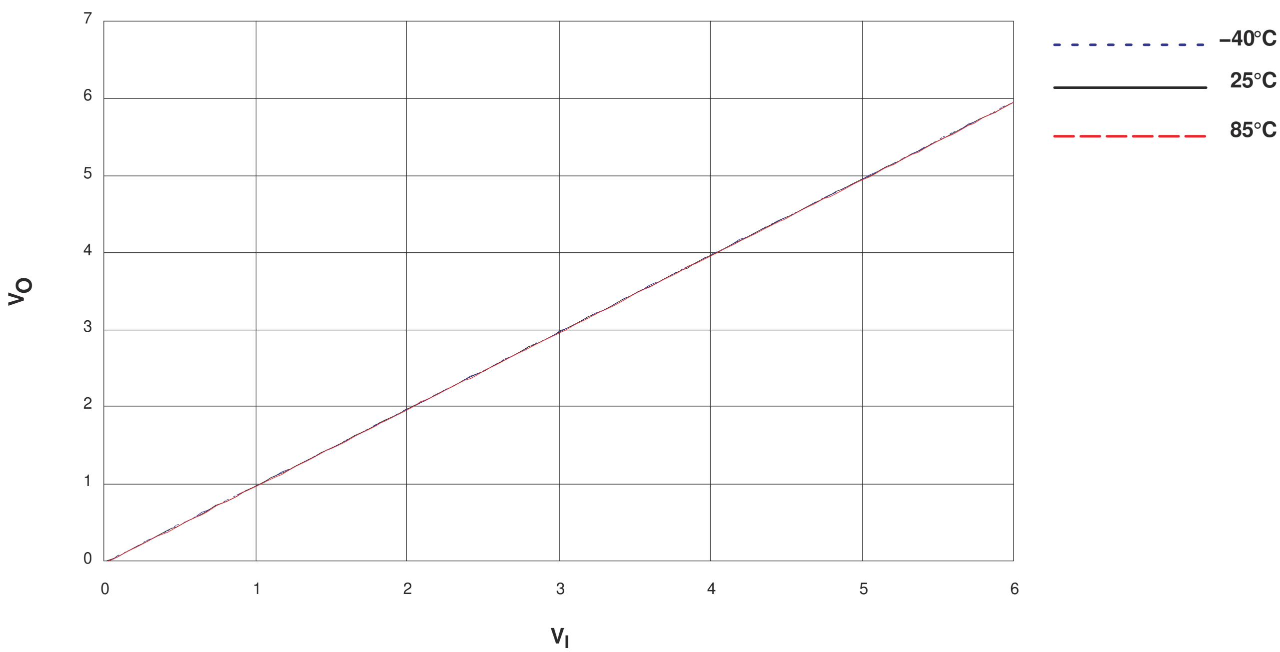


Figure A-16. V_O vs V_I, V_{CC} = 6 V (SN74HC4066)

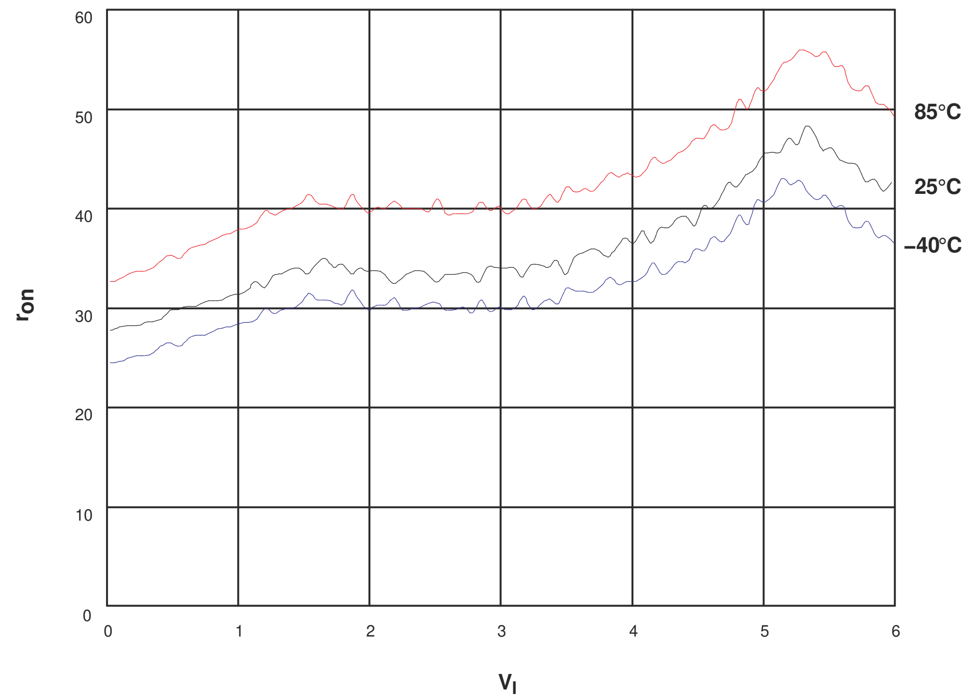


Figure A-17. r_{on} vs V_I, V_{CC} = 6 V (SN74HC4066)

Table A-8. SN74HC4066 Analog Parameter Measurement Data

V_{CC} (1)	Frequency Response	Sine-Wave Distortion	Crosstalk		Charge Injection(2)	Feedthrough
		1 kHz	Between Switches	Enable to Output		
2 V	N/A	N/A	N/A	N/A	3.8 pC	N/A
4.5 V	30 MHz	0.05%	-45 dB	15 mV	5.9 pC	-42 dB
6 V	N/A	N/A	N/A	20 mV	7.9 pC	N/A

(1) Data-sheet values for SN74HC4066, except as noted.
(2) Post characterization measurement for SN74HC4066.

A.6 CD4066B Characteristics

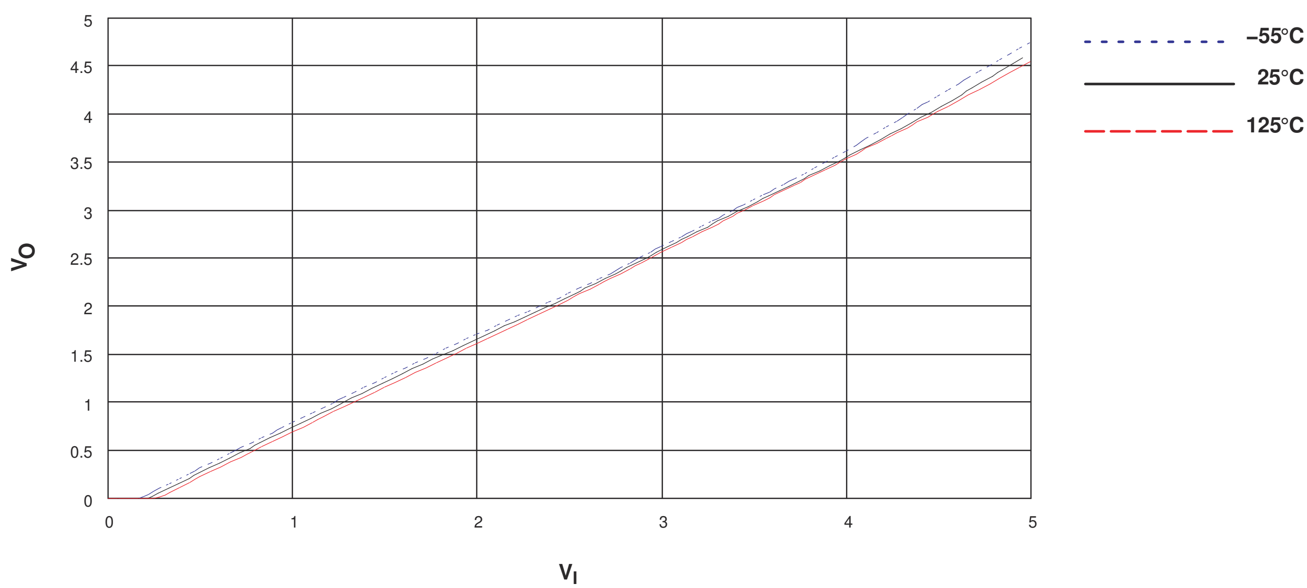


Figure A-18. V_O vs V_I, V_{CC} = 5 V (CD4066B)

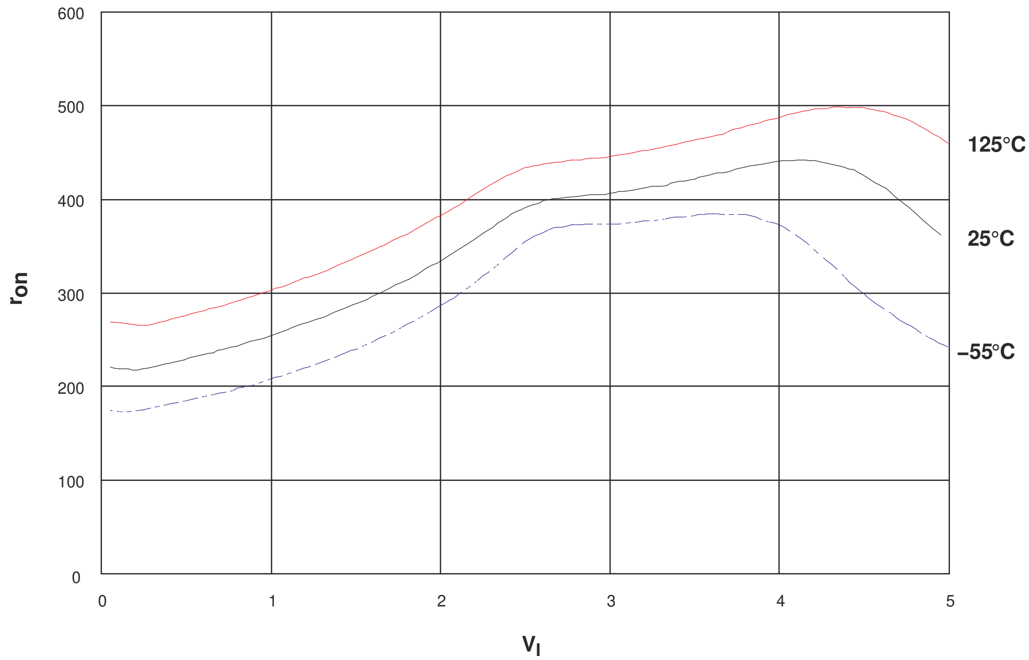


Figure A-19. r_{on} vs V_I, V_{CC} = 5 V (CD4066B)

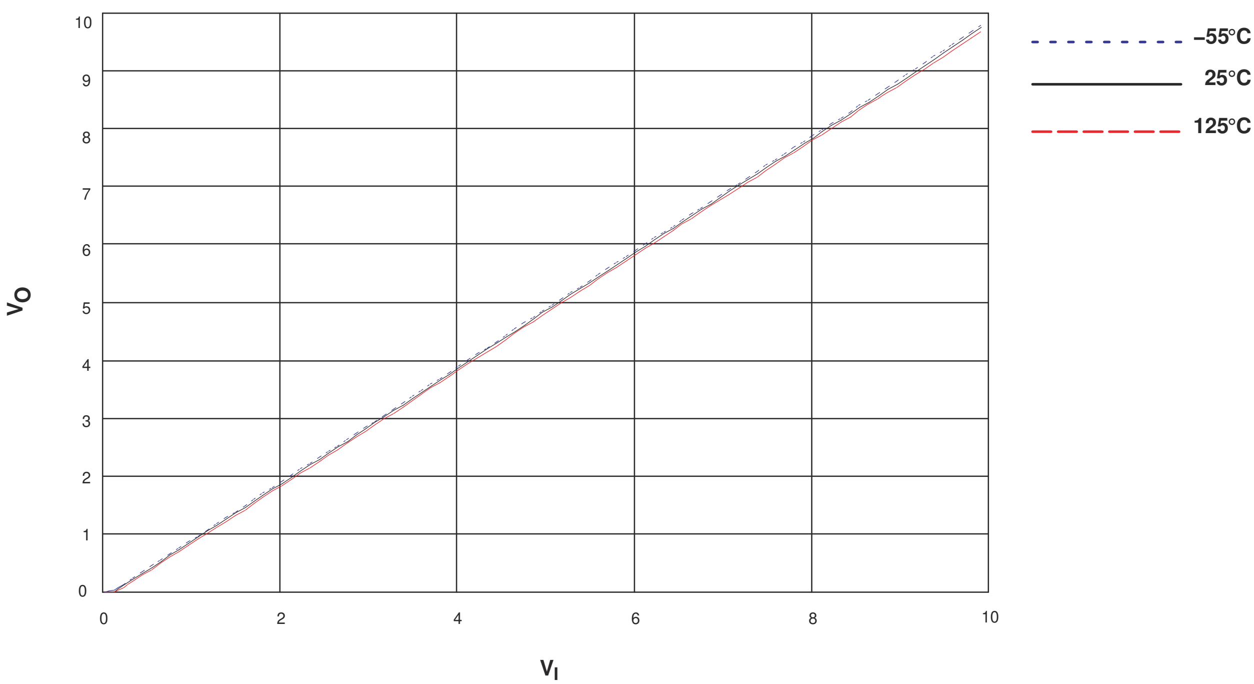


Figure A-20. V_O vs V_I, V_{CC} = 10 V (CD4066B)

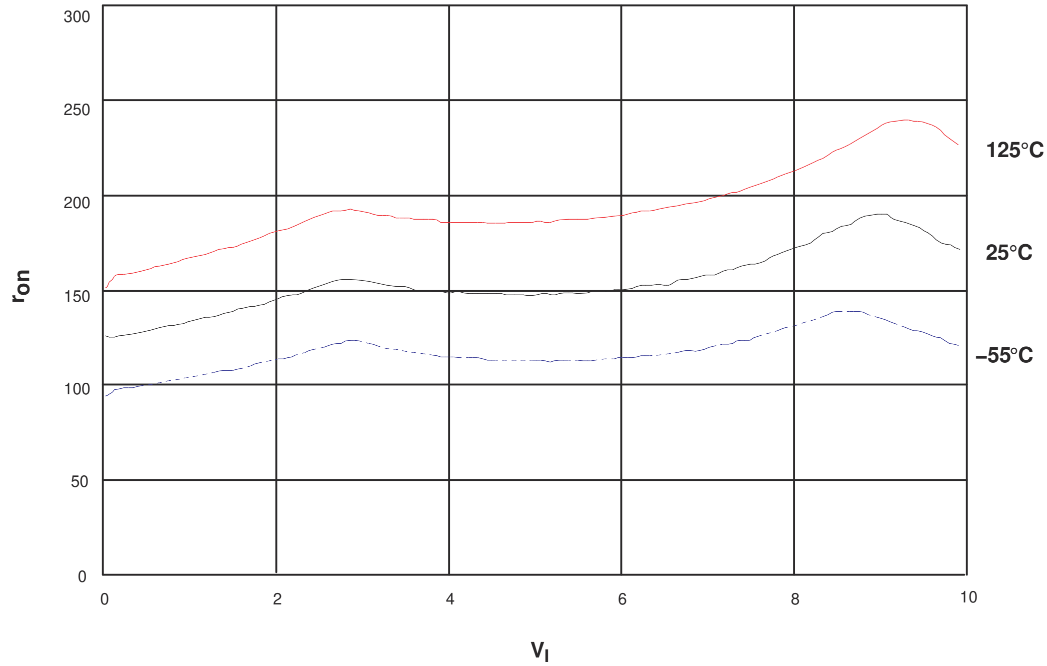


Figure A-21. r_{on} vs V_I, V_{CC} = 10 V (CD4066B)

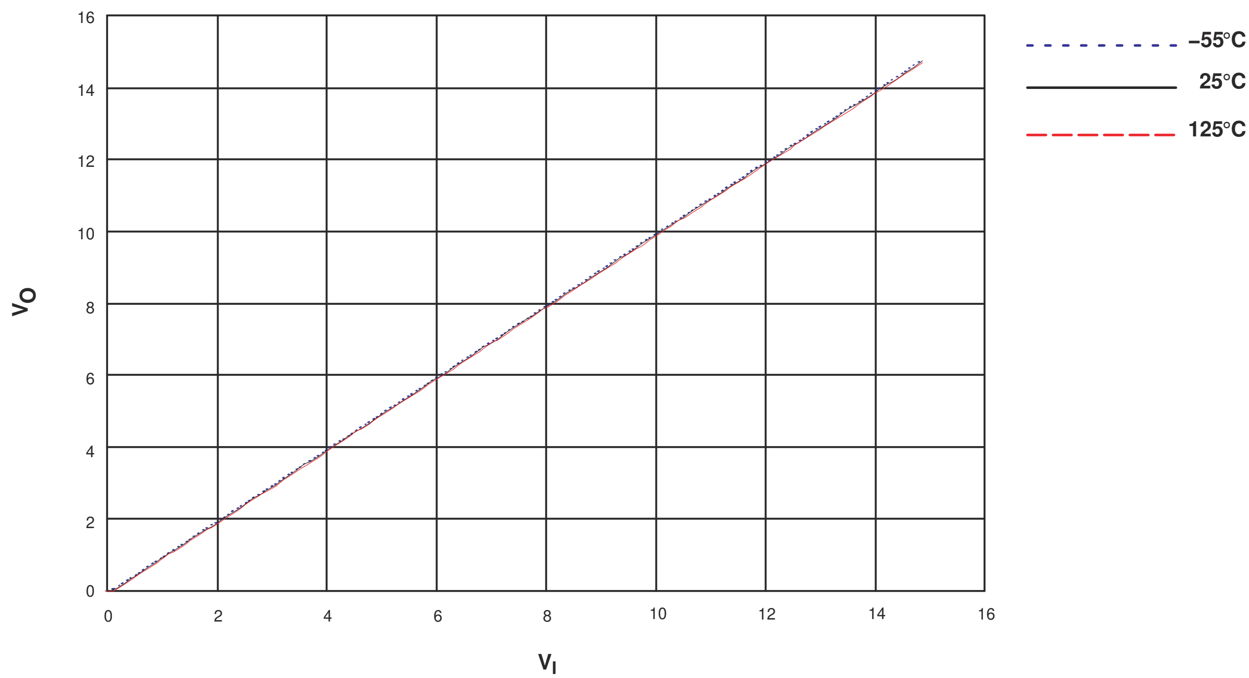


Figure A-22. V_O vs V_I, V_{CC} = 15 V (CD4066B)

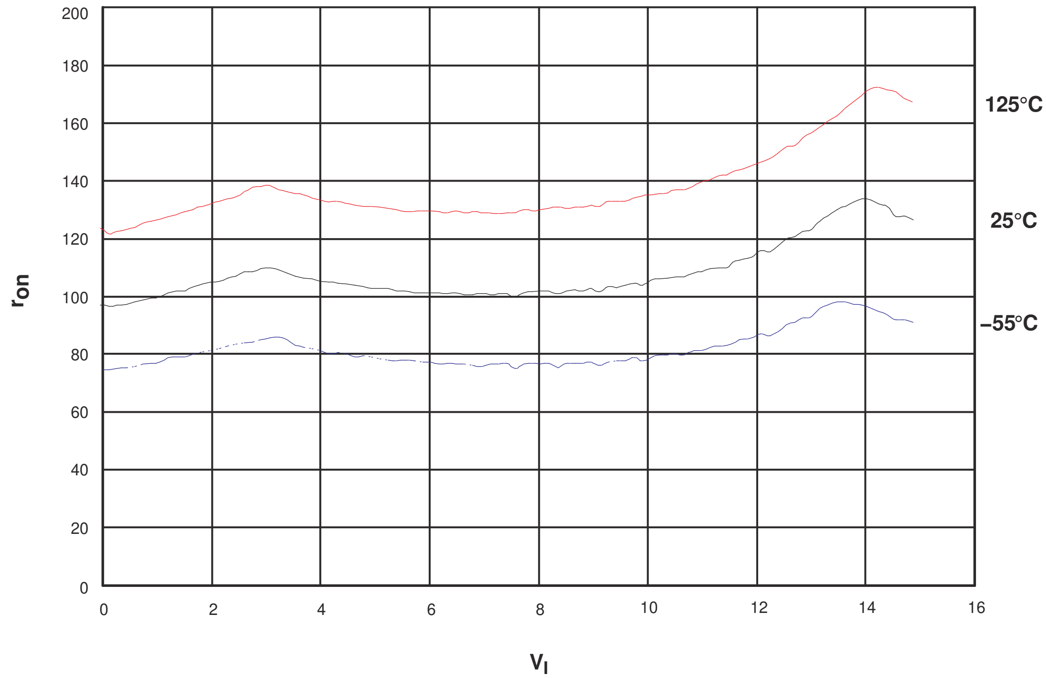


Figure A-23. r_{on} vs V_I, V_{CC} = 15 V (CD4066B)

Table A-9. CD4066B Analog Parameter Measurement Data

V_{CC}/V_{SS} (1)	Frequency Response	Total Harmonic Distortion	Crosstalk		Charge Injection(2)	Feedthrough
		1 kHz	Between Switches	Enable to Output		
5 V/-5 V	40 MHz	0.04%	-50 dB at 8 MHz	50 mV		-50 dB at 1 MHz
10 V/0 V	141 MHz(2)	0.032%(2)	-75 dB(2)	35 mV(2)	18.8 pC	-65 dB(2)

(1) Data-sheet values for CD4066B, except as noted.
(2) Post characterization measurement for CD4066B. Frequency response, THD, crosstalk, and feedthrough measured using load conditions specified in Appendix A, in order to make a more valid comparison with other devices in this report.

A.7 LV-A Characteristics

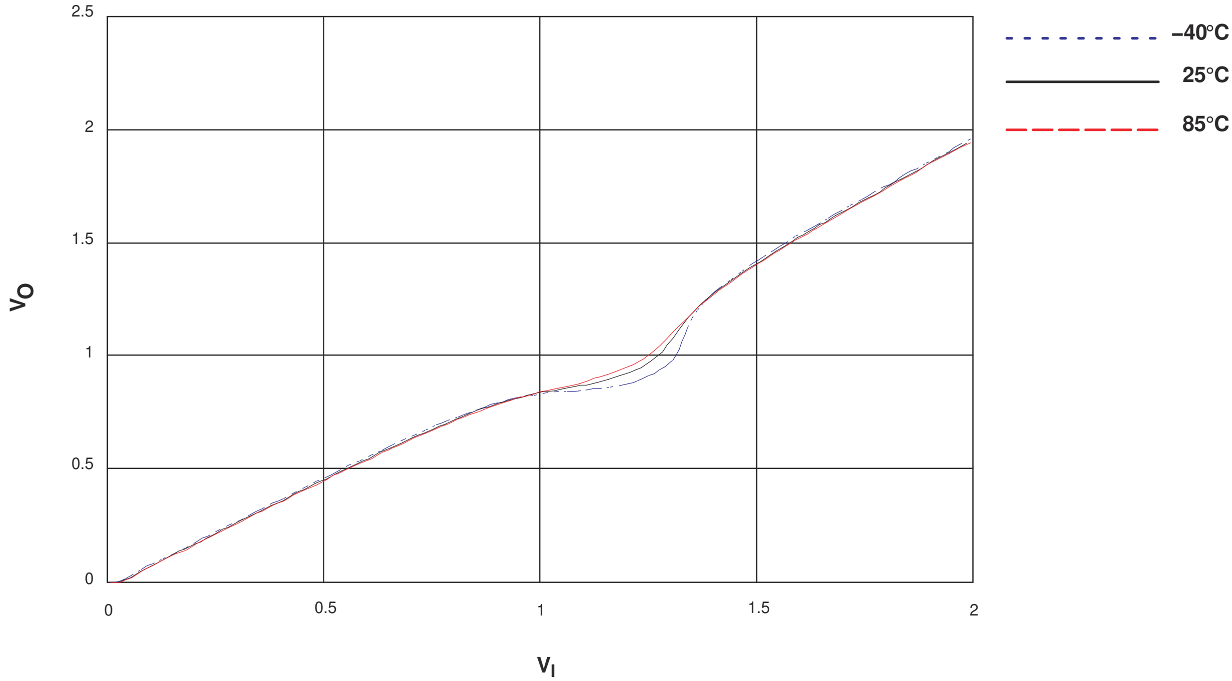


Figure A-24. V_O vs V_I, V_{CC} = 2 V (SN74LV4066A)

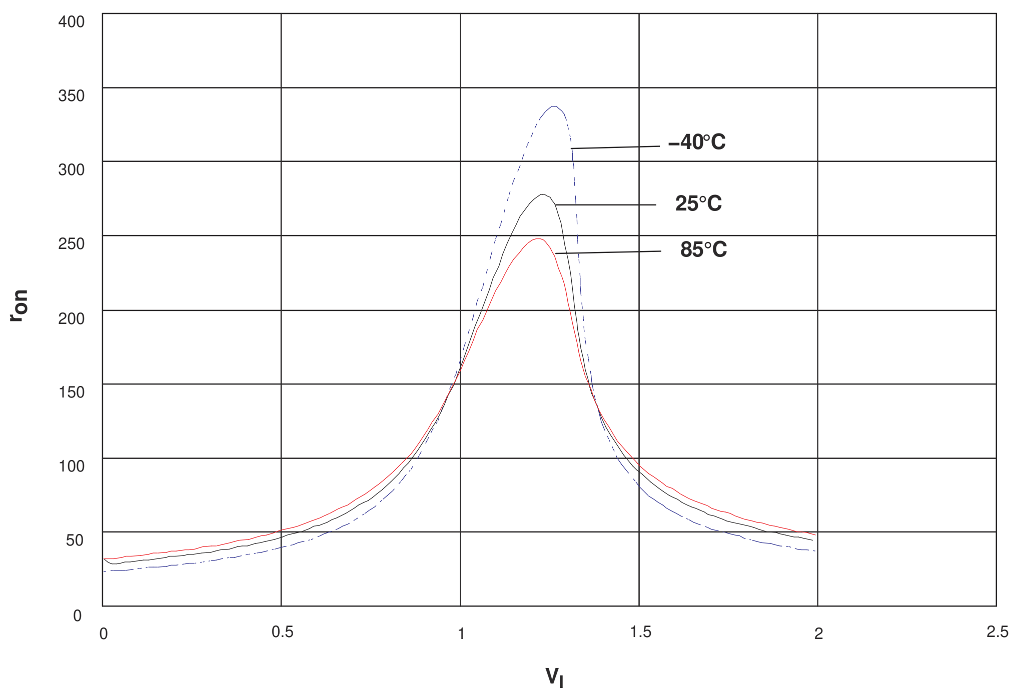


Figure A-25. r_{on} vs V_I, V_{CC} = 2 V (SN74LV4066A)

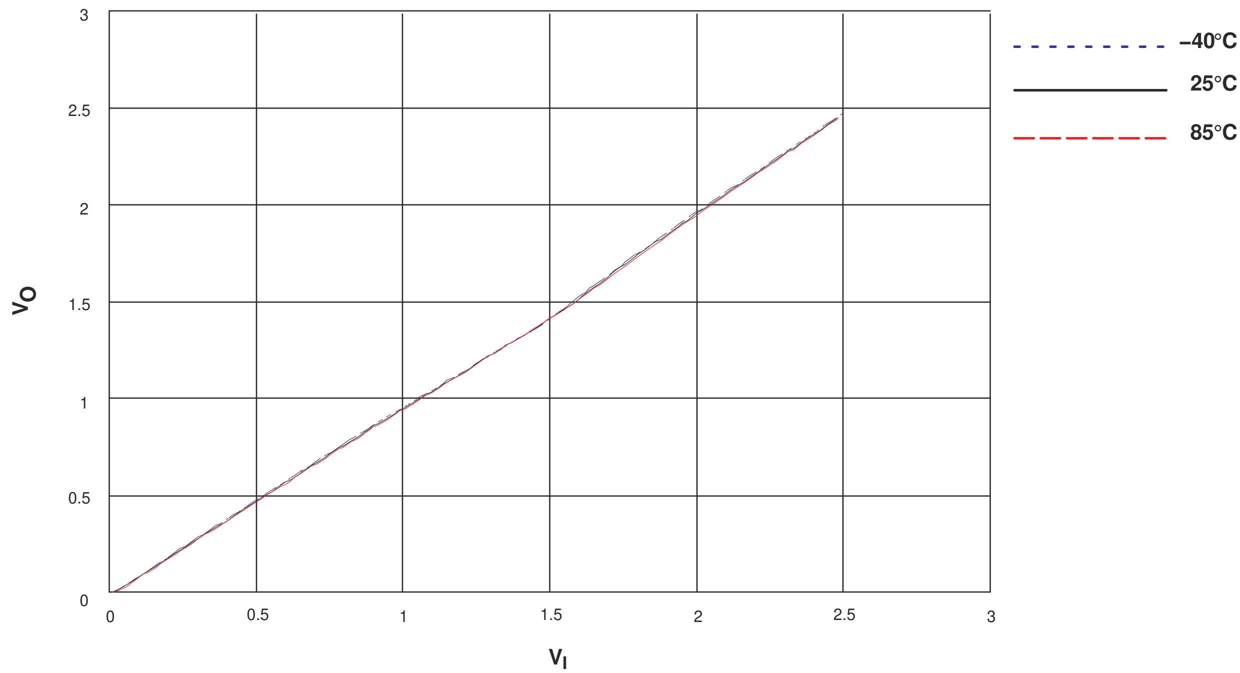


Figure A-26. V_O vs V_I, V_{CC} = 2.5 V (SN74LV4066A)

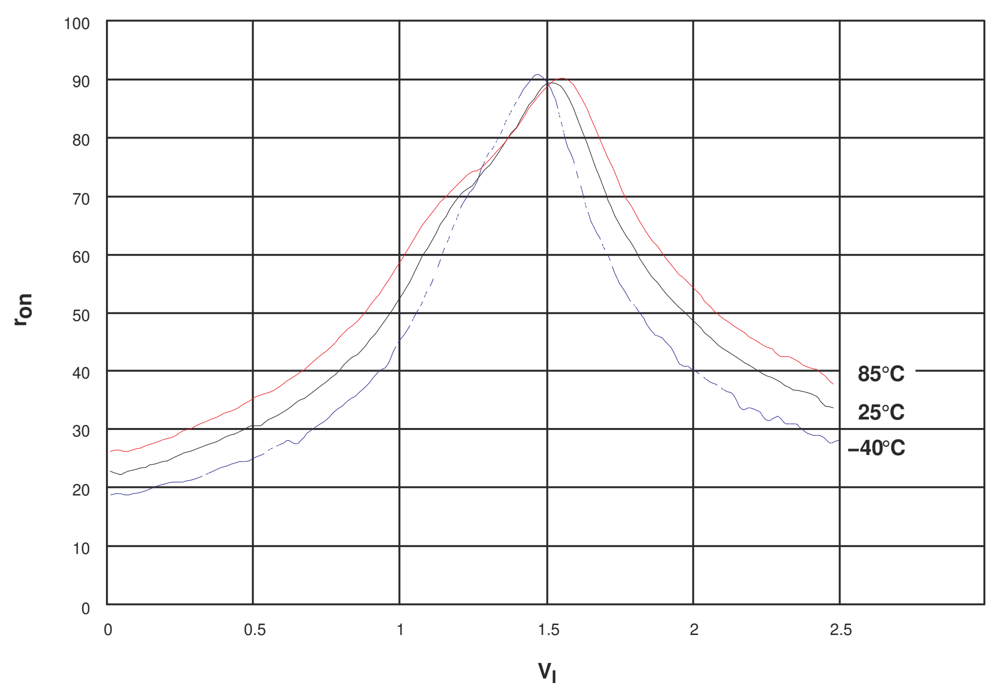


Figure A-27. r_{on} vs V_I, V_{CC} = 2.5 V (SN74LV4066A)

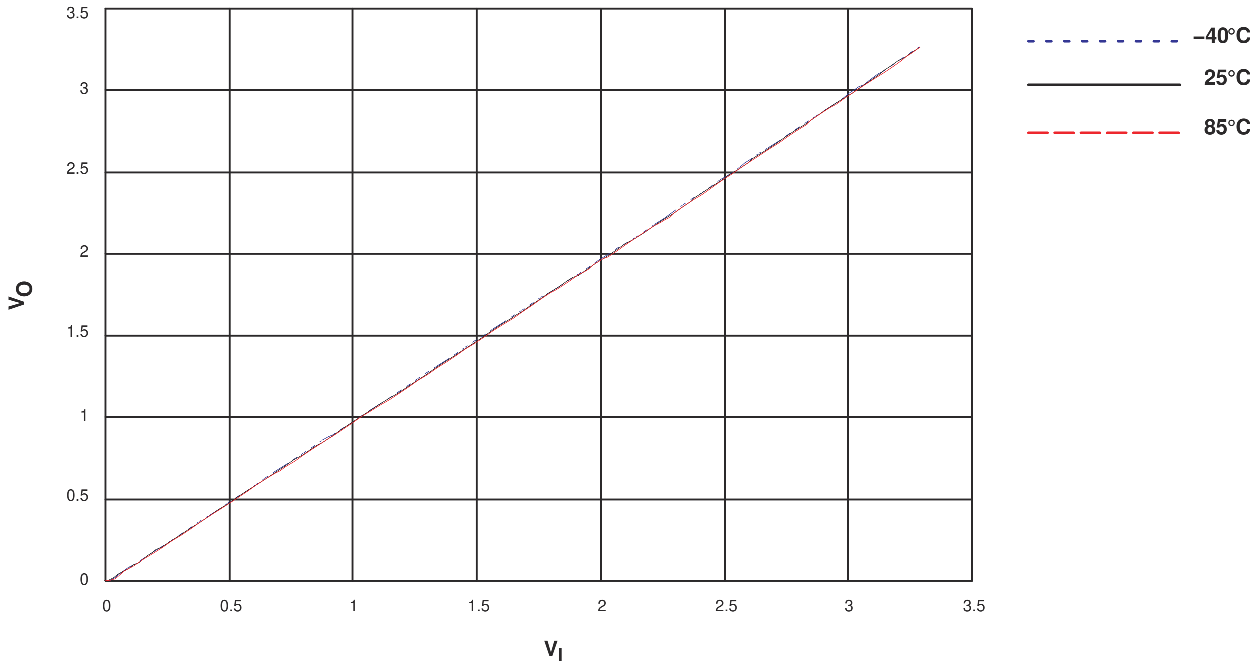


Figure A-28. V_O vs V_I, V_{CC} = 3.3 V (SN74LV4066A)

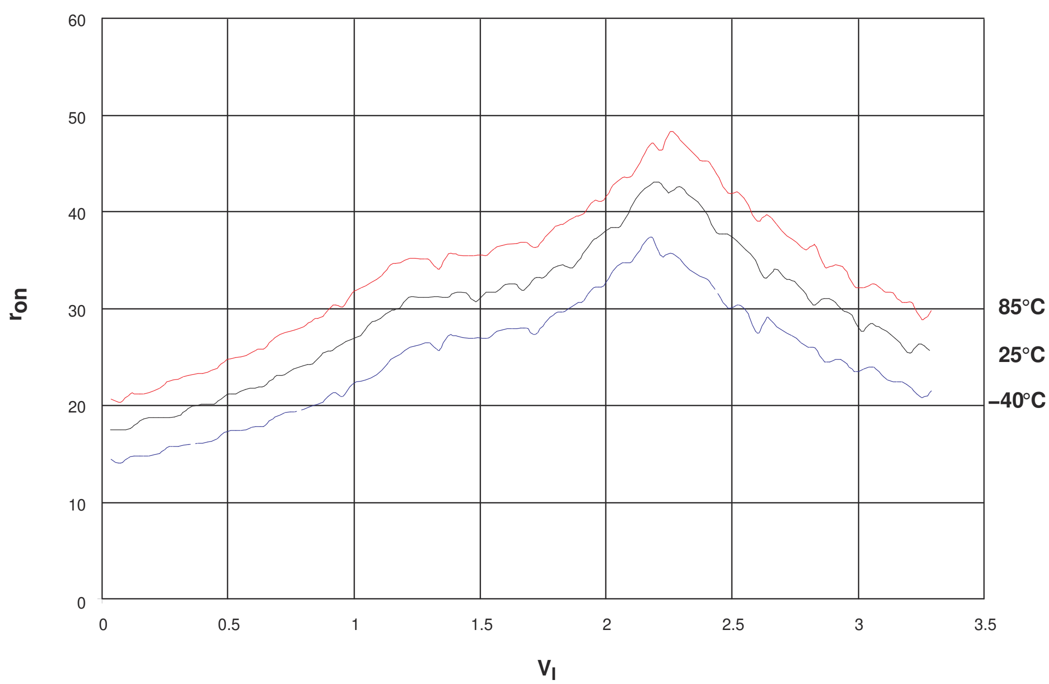


Figure A-29. r_{on} vs V_I, V_{CC} = 3.3 V (SN74LV4066A)

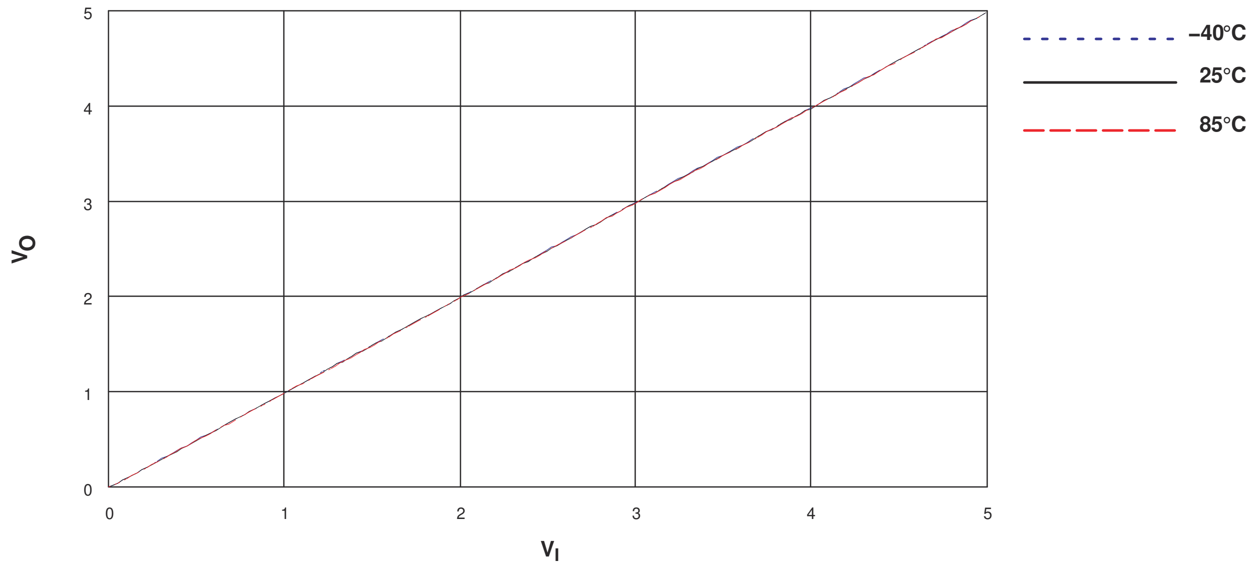


Figure A-30. V_O vs V_I, V_{CC} = 5 V (SN74LV4066A)

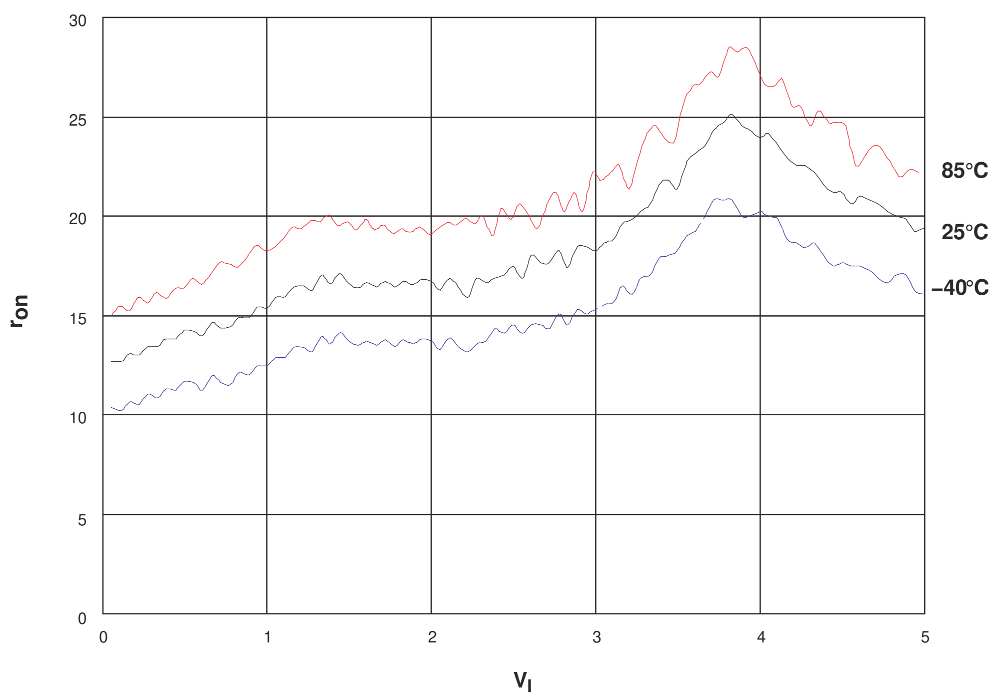


Figure A-31. r_{on} vs V_I, V_{CC} = 5 V (SN74LV4066A)

Table A-10. SN74LV4066A Analog Parameter Measurement Data

V_{CC} (1)	Frequency Response	Sine-Wave Distortion	Crosstalk		Charge Injection(2)	Feedthrough
		1 kHz	Between Switches	Enable to Output		
2.3 V	30 MHz	0.1%	-45 dB	15 mV	2.1 pC	-40 dB
3 V	35 MHz	0.1%	-45 dB	20 mV	2.7 pC	-40 dB
4.5 V	50 MHz	0.1%	-45 dB	50 mV	3.0 pC	-40 dB

(1) Data-sheet values for SN74LV4066A, except as noted.
(2) Post characterization measurement for SN74LV4066A.

A.8 LVC Characteristics

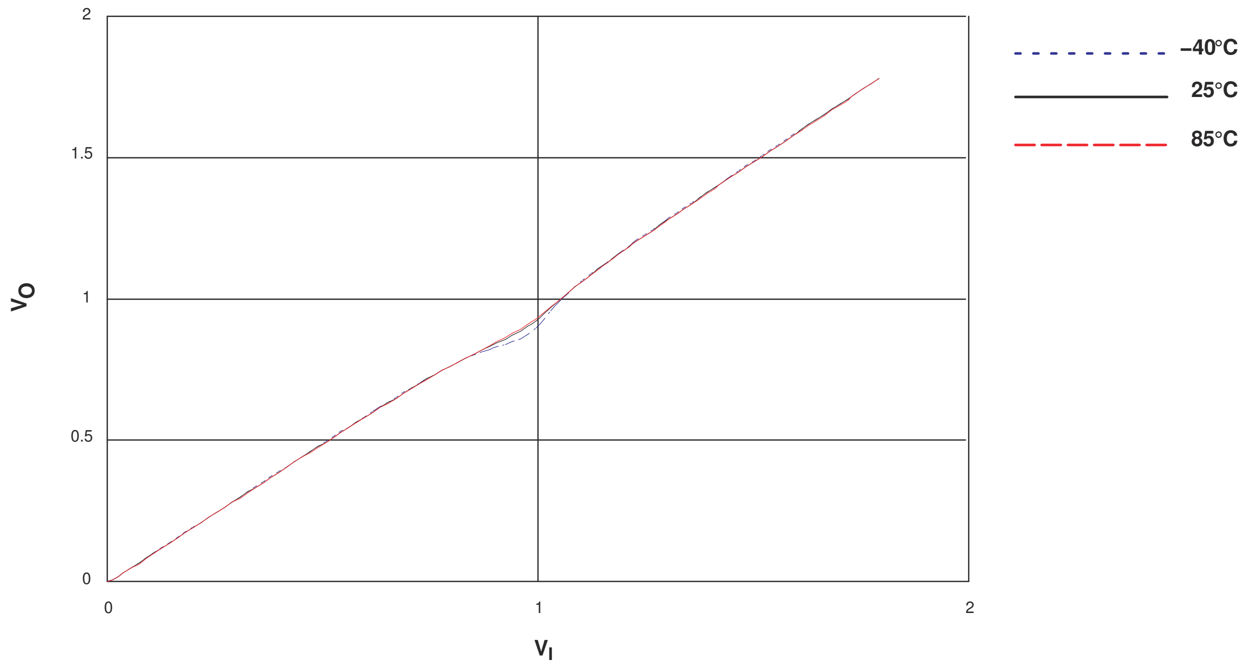


Figure A-32. V_O vs V_I, V_{CC} = 1.8 V (SN74LVC1G66)

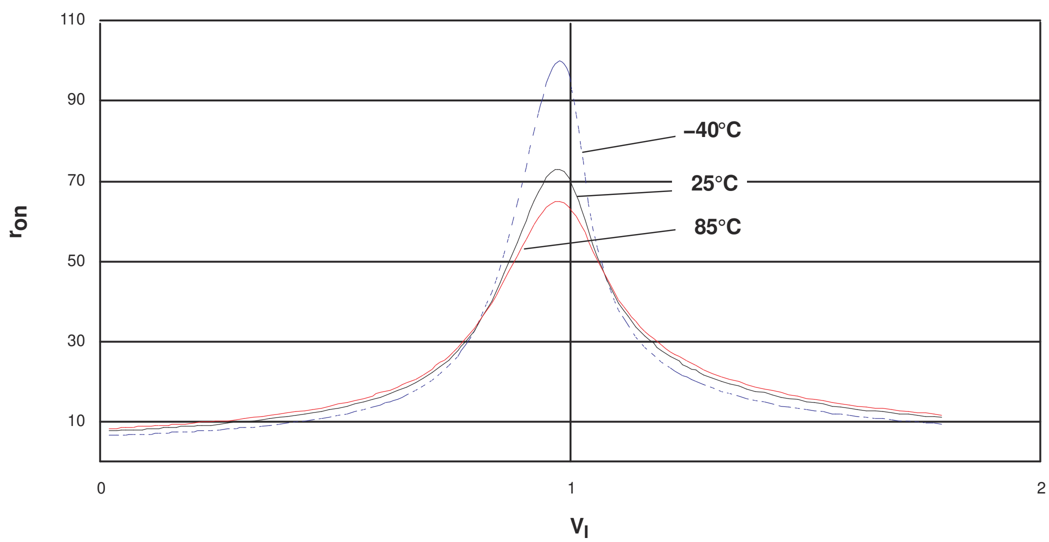


Figure A-33. r_{on} vs V_I, V_{CC} = 1.8 V (SN74LVC1G66)

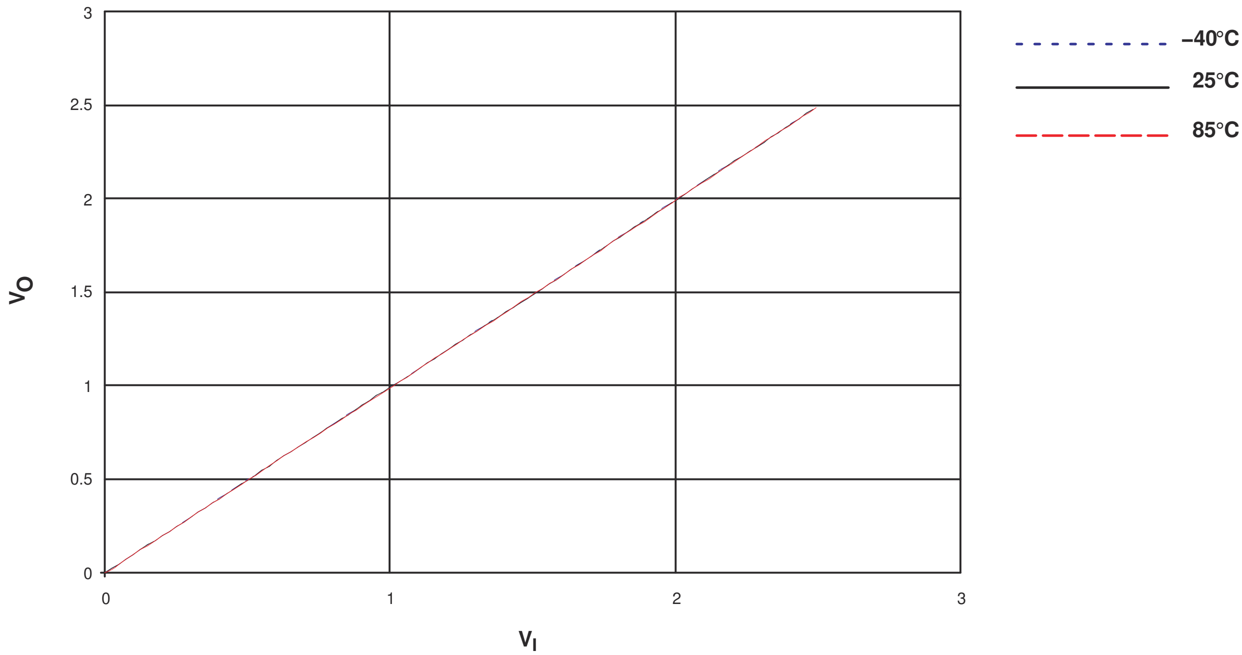


Figure A-34. V_O vs V_I, V_{CC} = 2.5 V (SN74LVC1G66)

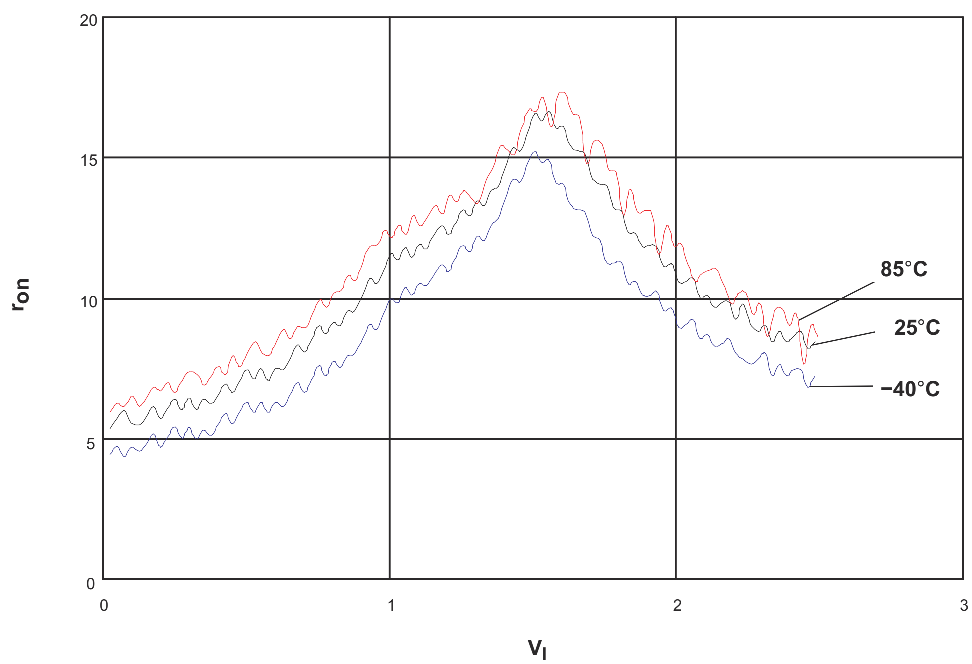


Figure A-35. r_{on} vs V_I, V_{CC} = 2.5 V (SN74LVC1G66)

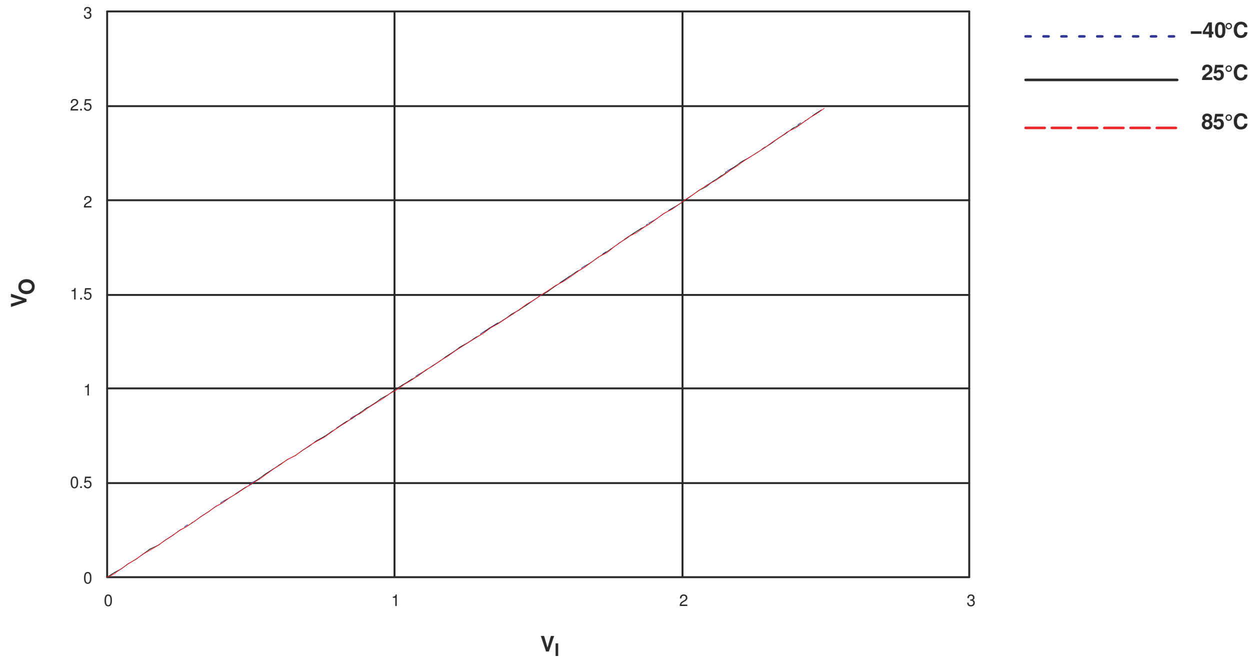


Figure A-36. V_O vs V_I, V_{CC} = 3.3 V (SN74LVC1G66)

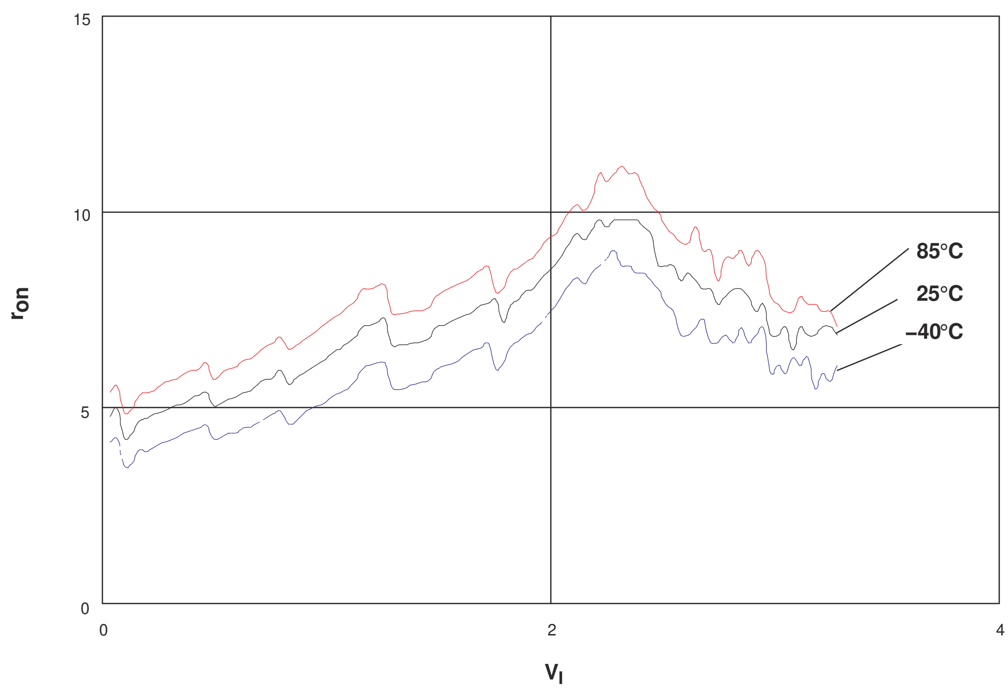


Figure A-37. r_{on} vs V_I, V_{CC} = 3.3 V (SN74LVC1G66)

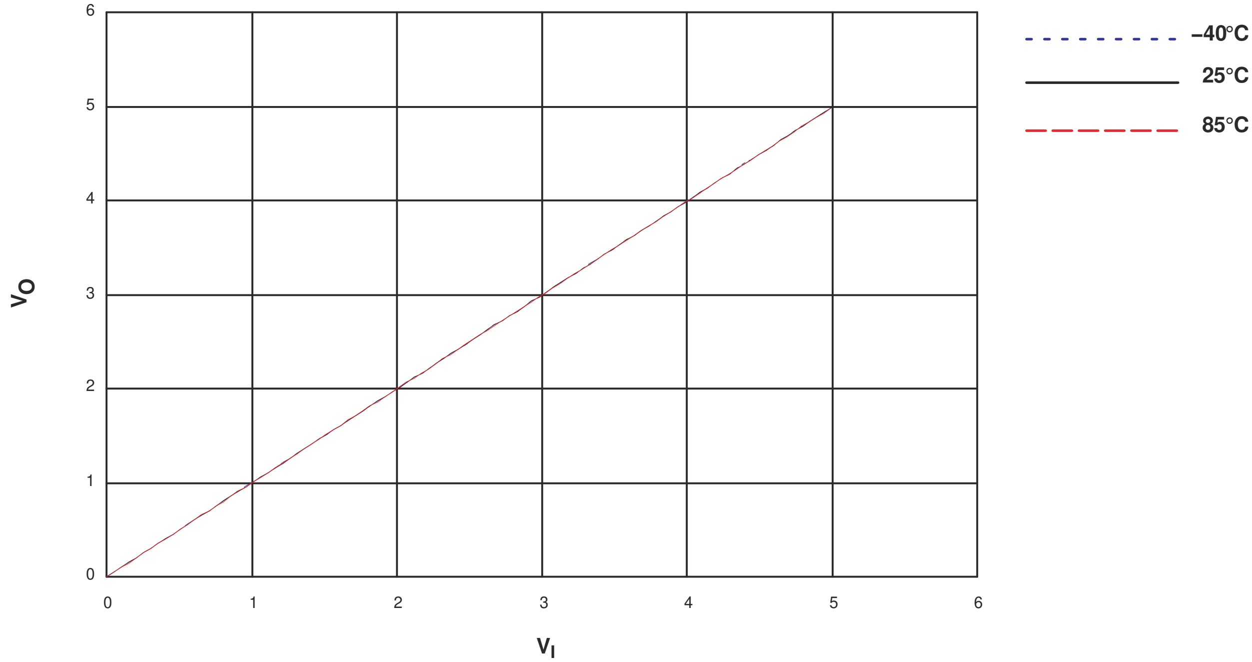


Figure A-38. V_O vs V_I, V_{CC} = 5 V (SN74LVC1G66)

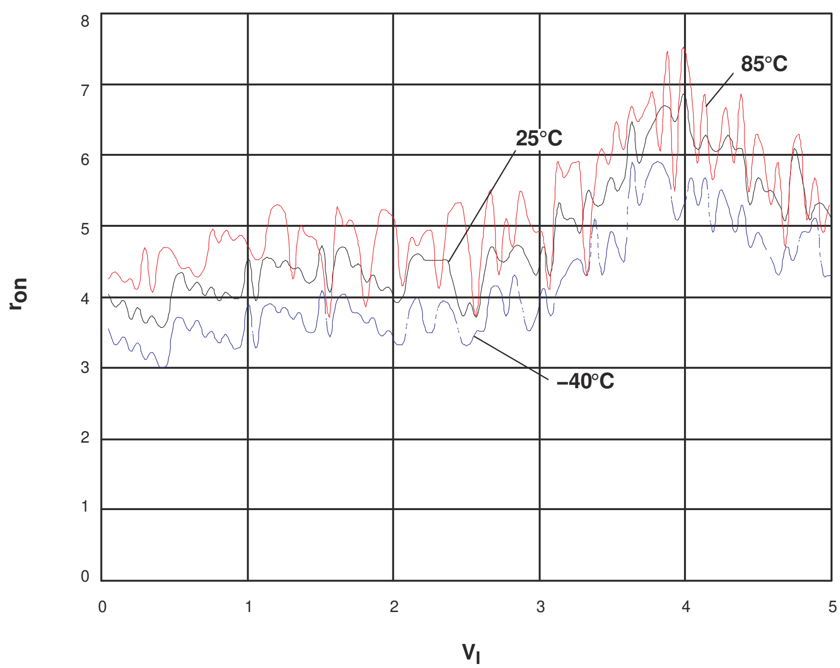


Figure A-39. r_{on} vs V_I, V_{CC} = 5 V (SN74LVC1G66)

Table A-11. SN74LVC1G66 Analog Parameter Measurement Data

V_{CC} (1)	Frequency Response	Sine-Wave Distortion		CrosstalkEnable to Output	Charge Injection(2)	Feedthrough
		1 kHz	10 kHz			
1.8 V	35 MHz	0.1%	0.15%	35 mV	2.5 pC	-42 dB
2.5 V	120 MHz	0.025%	0.025%	50 mV	3.0 pC	-42 dB
3 V	175 MHz	0.015%	0.015%	70 mV	3.3 pC	-42 dB
4.5 V	195 MHz	0.01%	0.01%	100 mV	3.5 pC	-42 dB

(1) Data-sheet values for SN74LVC1G66, except as noted.
(2) Post characterization measurement for SN74LVC1G66.

A.9 CBTLV Characteristics

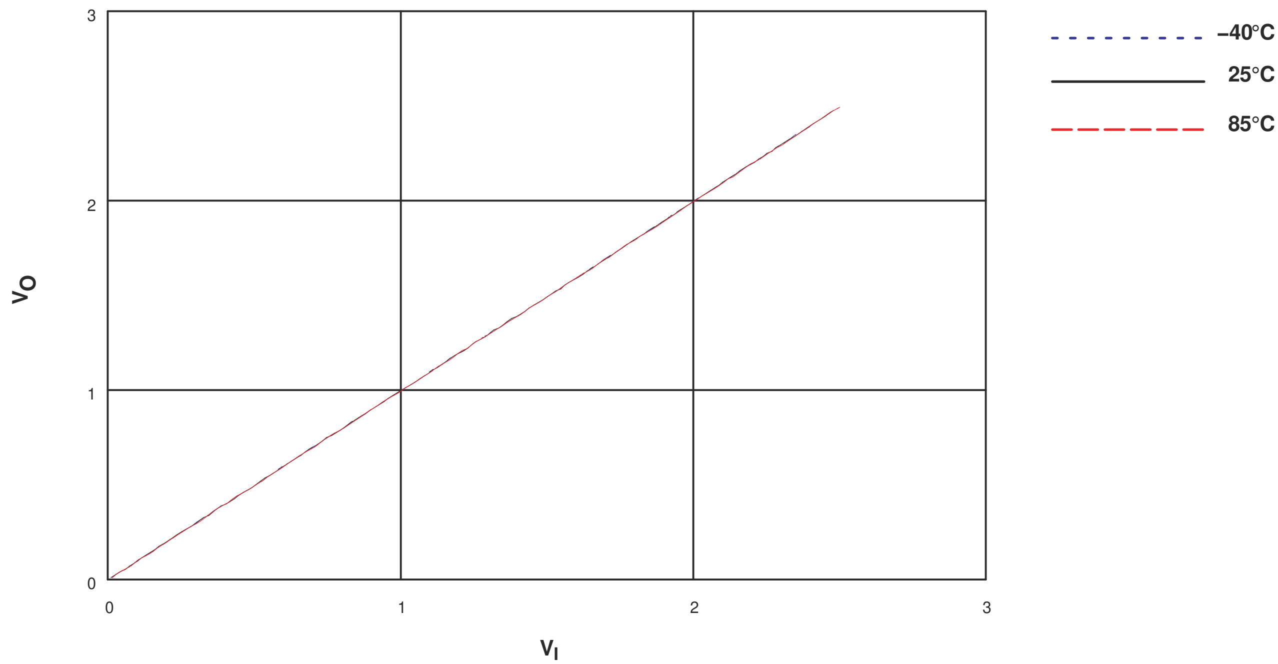


Figure A-40. V_O vs V_I, V_{CC} = 2.5 V (SN74CBTLV3125)

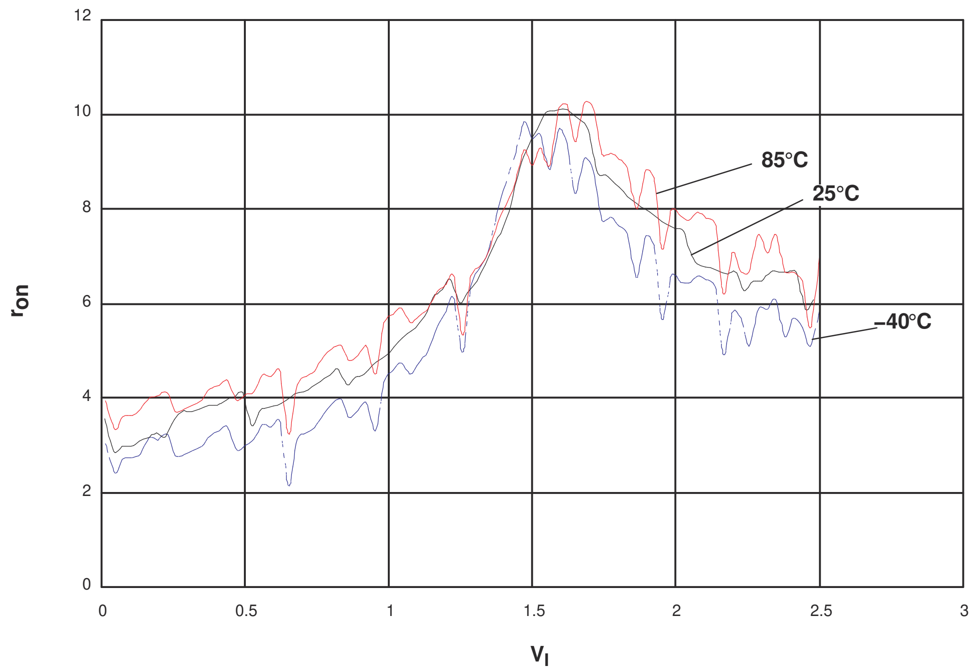


Figure A-41. r_{on} vs V_I, V_{CC} = 2.5 V (SN74 CBTLV3125)

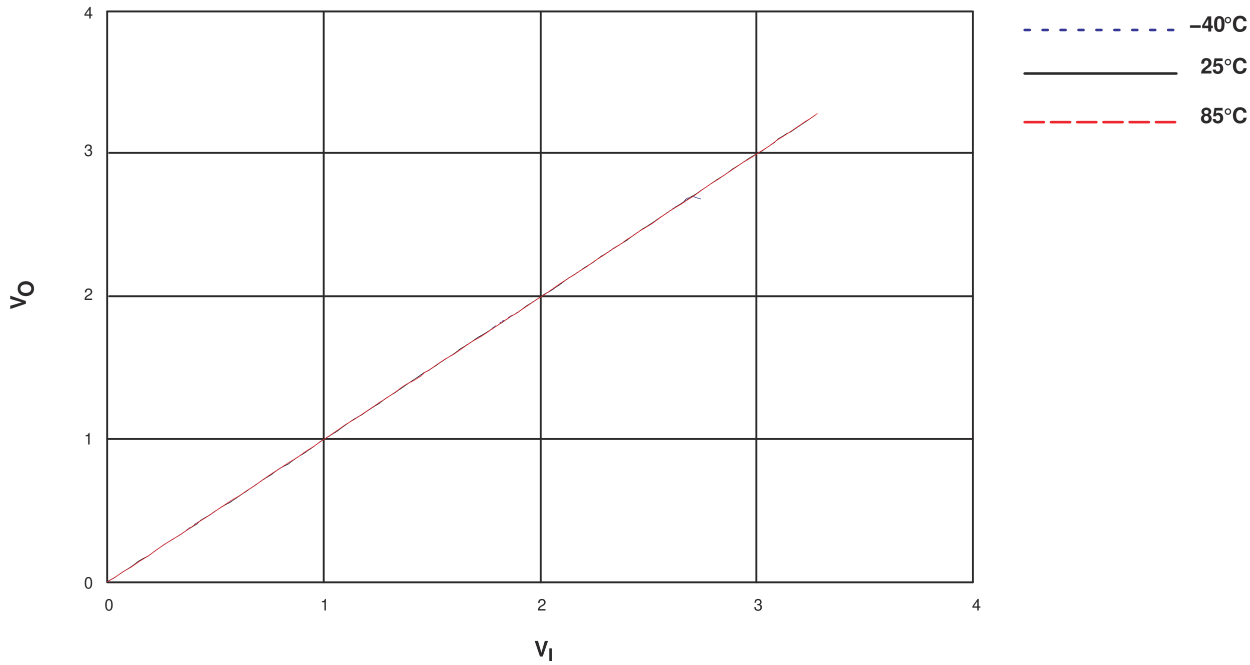


Figure A-42. V_O vs V_I, V_{CC} = 3.3 V (SN74CBTLV3125)

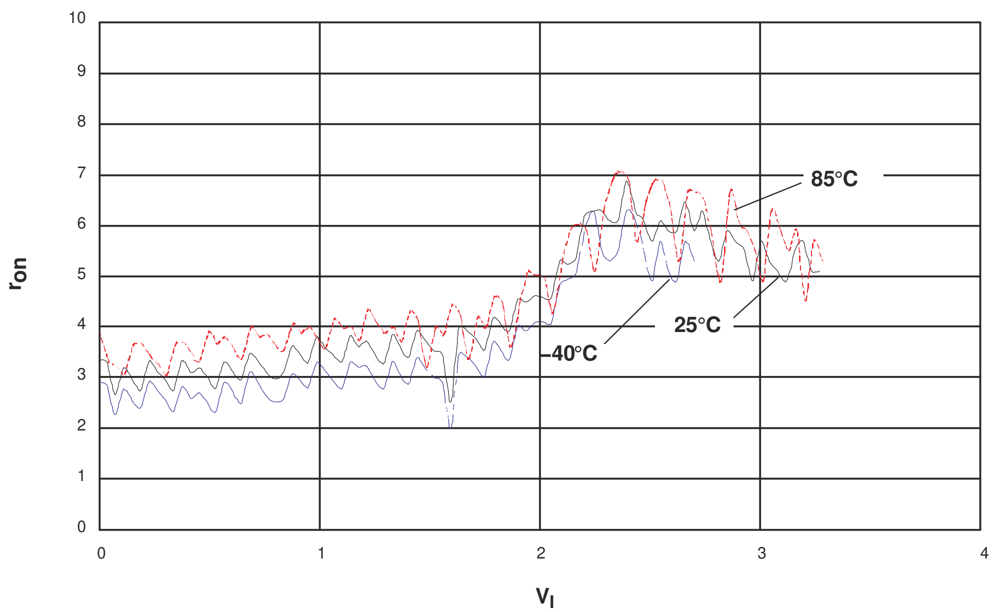


Figure A-43. r_{on} vs V_I, V_{CC} = 3.3 V (SN74CBTLV3125)

Table A-12. SN74CBTLV3125 Analog Parameter Measurement Data

V_{CC} (1)	Frequency Response	Sine-Wave Distortion	Total Harmonic Distortion	Crosstalk		Charge Injection	Feedthrough
		1 kHz	1 kHz	Between Switches	Enable to Output		
2.5 V	>200 MHz	0.089%	0.11%	-45 dB	30 mV	12.1 pC	-52 dB
3.3 V	>200 MHz	0.033%	0.09%	-49 dB	70 mV	15.5 pC	-52 dB

(1) Post characterization measurement for CBTLV3125.