MOSFET Switches

The MOSFET as a Switch

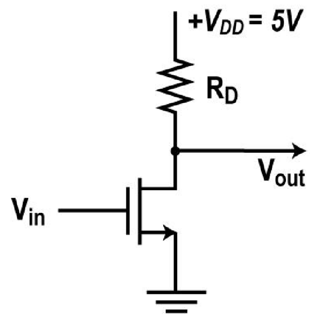
A MOSFET may be turned off or on and therefore used as a switch. When the MOSFET is cut-off, or non-conducting, its drain current is zero and it acts like an open switch. When the MOSFET is biased on by applying a voltage higher than the threshold voltage, the MOSFET conducts hard and acts like a closed switch.

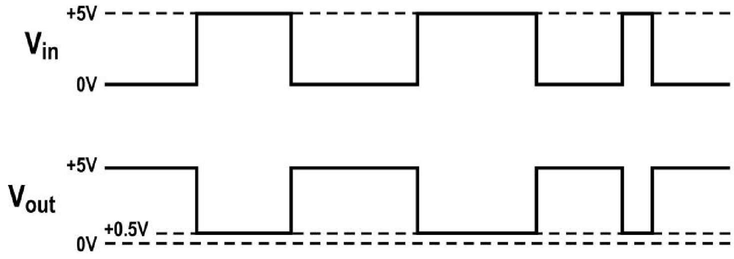
When the transistor is conducting, it does not represent a perfect short like a mechanical switch. However, its source-to-drain resistance, called “on” resistance (R_{on}), is very low. For small MOSFETs in integrated circuits, R_{on} is tens to thousands of ohms. For larger discrete power MOSFETs, R_{on} is a fraction of an ohm to several ohms.

MOSFET switches are used to turn other components, devices, or circuits off or on. MOSFET switches are also the main component of all digital logic circuits.

Basic MOSFET Switches

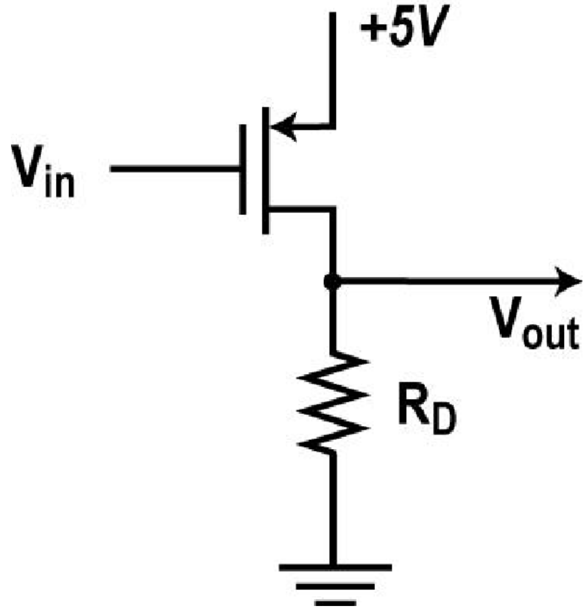
If the gate voltage is zero in the basic N-channel MOSFET switch with a load resistor, the MOSFET is off and the output is +5 volts as seen through the resistor. If +5 volts is applied to the gate, the threshold voltage (usually 0.5 to 3 volts depending upon the device characteristics) will be exceeded and the MOSFET will conduct. Since R_{on} is much lower than the drain resistor R_d, the output voltage will be very low, typically less than a few tenths of a volt.



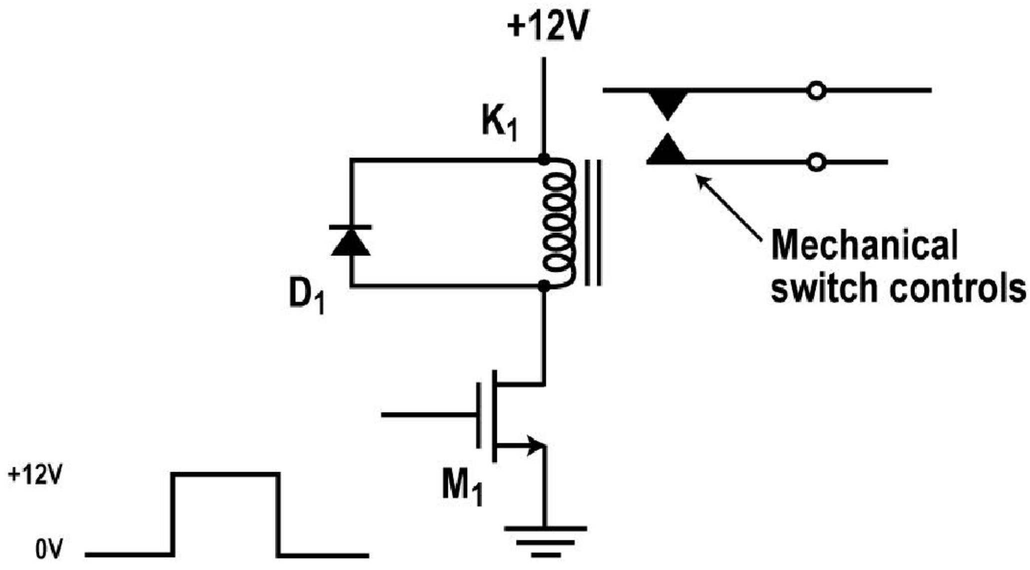


Basic P-Channel MOSFET Switches

In a switch using a P-channel MOSFET, if the gate voltage is +5 volts, the voltage between the source and gate is zero since both are at +5 volts. The MOSFET will be off and the output voltage will be zero. If the gate is grounded or made zero volts, the gate will be more negative than the source. The threshold will be exceeded and the MOSFET will conduct. This will cause almost +5 volts to appear across the resistor.



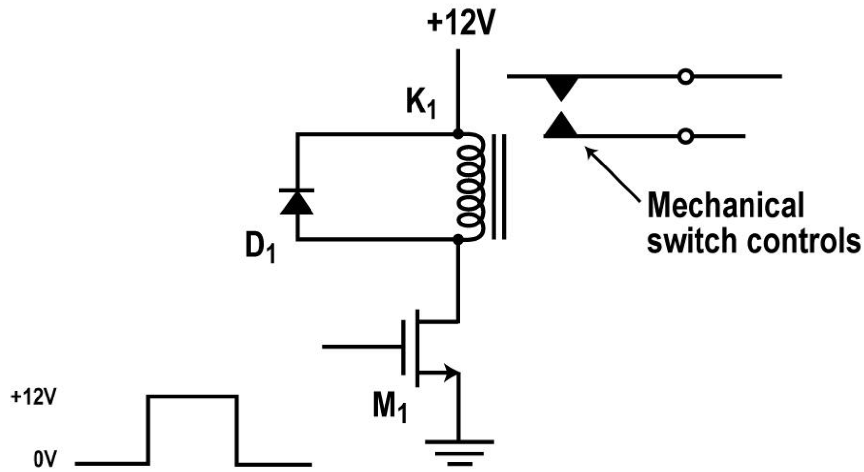
Common MOSFET Switch Applications



A MOSFET switch can be used to turn a relay K_1 off or on. With zero volts on the gate, M_1 is off and the relay is not energized.

If the gate is made more positive than the threshold, M_1 will conduct and nearly the full +12 volts will be applied to the relay coil causing the contacts to be closed.

Spike Suppression Diode

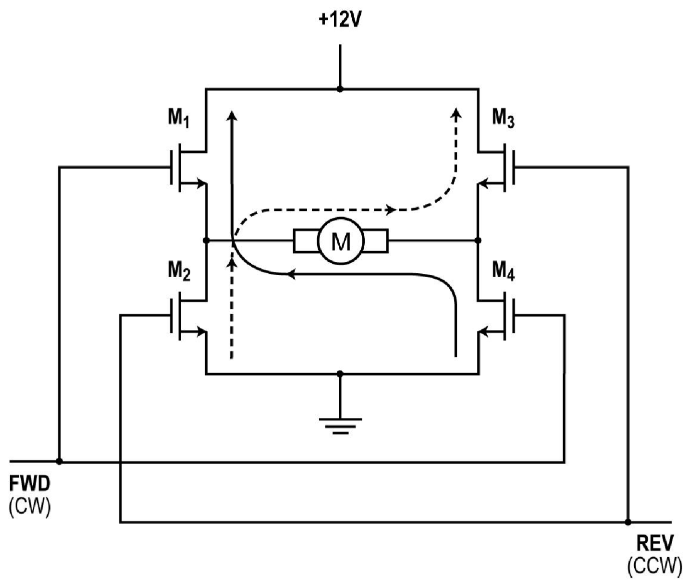


The diode D_1 across the relay coil is used to prevent damage to the MOSFET which can be destroyed by the high voltage produced by the inductive kick of the relay coil when the MOSFET turns off. The magnetic field will collapse inducing a very high voltage spike across the coil. The polarity of this voltage spike is such that the diode will conduct and clamp the coil voltage to about 0.7 volts thus protecting the MOSFET. The diode is called a spike suppression diode.

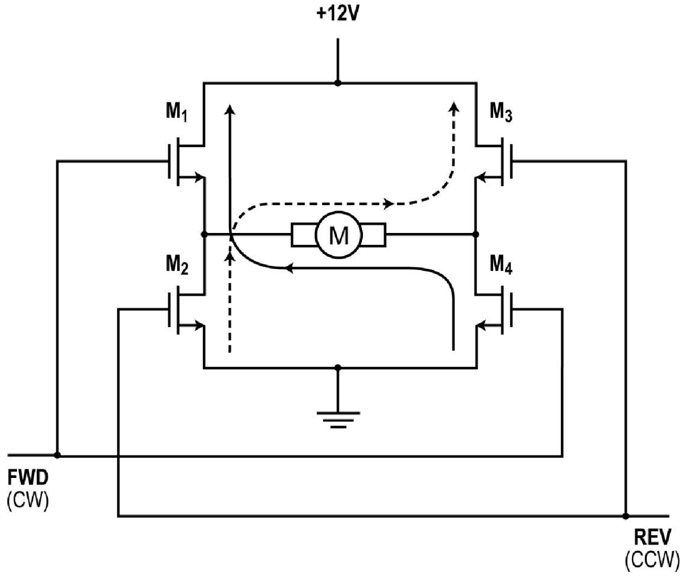
Bridge Configuration: Forward Input

In the MOSFET switch application, four MOSFETs are connected in an H or bridge configuration. A DC motor is connected as the load on the bridge.

When M_1 and M_4 are biased on by applying a +12 volt signal to the FWD, or forward control input, and M_2 and M_3 are off, current will flow from ground up through M_4 through the motor from right to left then through M_1 to +12 volts. The motor will turn in one direction, for example, clockwise (CW) which we can call the forward direction.

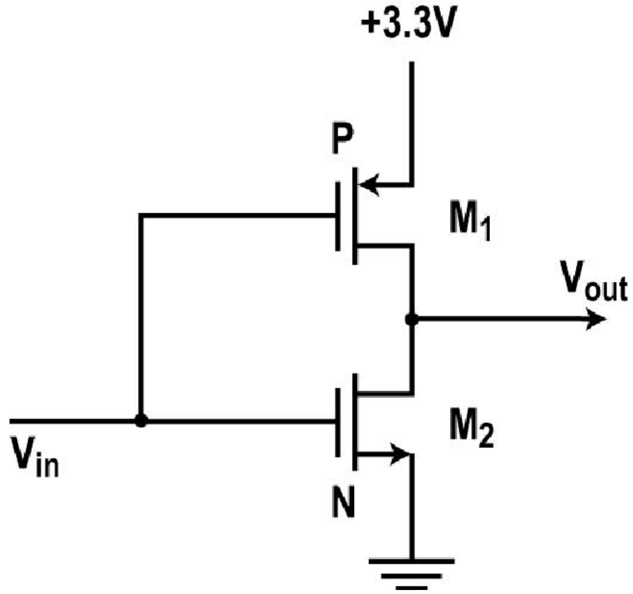


Bridge Configuration: Reverse Input



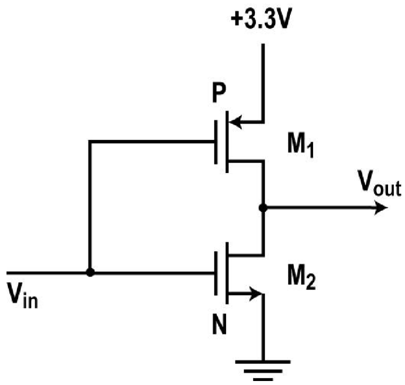
If M_1 and M_4 are biased off while M_2 and M_3 are turned on by a +12 volt input on the REV or reverse input, current will flow from ground up through M_2 through the motor from left to right then through M3 to +12 volts. The motor will turn in the opposite direction or reverse direction or counter clockwise (CCW). An example of this circuit is the insert and eject system in a VCR, CD, or DVD player.

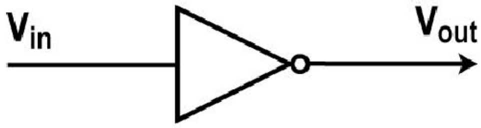
Complementary MOS



Complementary MOS, or CMOS, is a circuit that uses both N and P-channel MOSFETs in the same circuit. The most common arrangement is shown here. It is called a CMOS inverter and is the basis for almost all MOSFET digital logic circuits.

Complementary MOS as a Logic Inverter





Logic invertor symbol

If the input is zero, M_2, the N-channel device, is off while the P-channel device, M_1, is on. M_1 is on because its gate is more negative than the source (in this case, zero) so the threshold is exceeded. The output is +3.3 volts as seen through the low on-resistance of M_1.

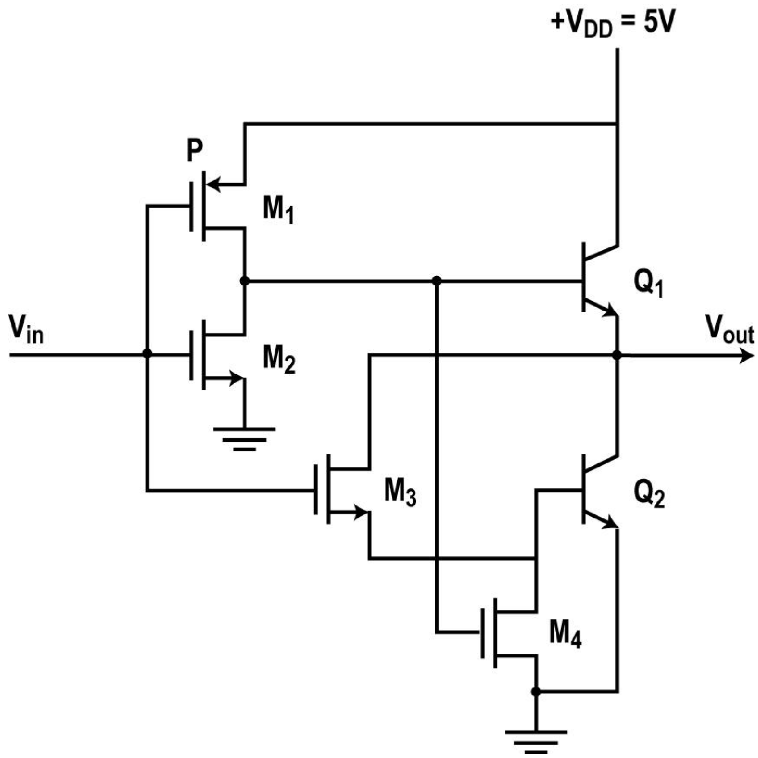
If the input is +3.3 volts, M_1 is off since both gate and source are at the same potential. M_2 turns on since its gate threshold is exceeded. The output voltage is near zero volts.

The circuit is a logic inverter. Its common logic symbol is shown on the right.

BiCMOS

BiCMOS is a combination of bipolar transistors and CMOS inverters and logic circuits. The bipolar transistors are used as output circuits because they can drive more current and have heavier loads than integrated MOSFETs.

In the BiCMOS inverter, M_1 and M_2 form a standard CMOS inverter. M_3 and M_4 are used to switch the output transistors Q_1 and Q_2 off and on.

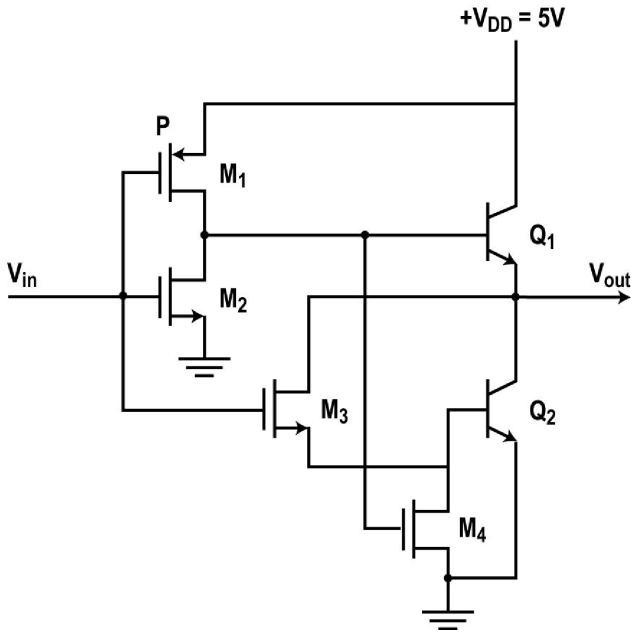


BiCMOS as Logic Outputs

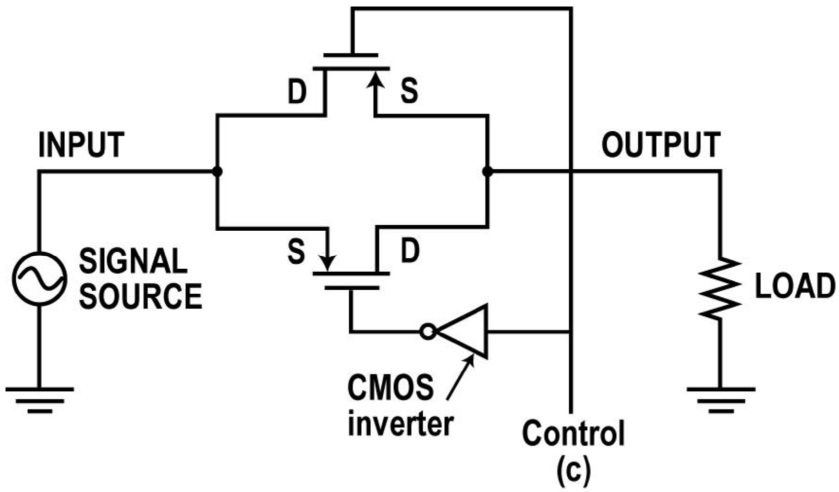
When the input is zero, M_1 is on and supplies base current to Q_1. Q_1 turns on and provides nearly the full +5 volts at the output. The output from M_1 also biases M_4 on keeping Q_2 from conducting.

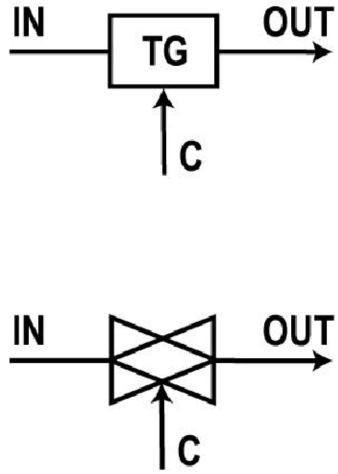
If the input is +5 volts, M_2 conducts and clamps the base of Q_1 to ground keeping if from conducting. The positive input also biases M_3 on. This supplies base current to Q_2 turning it on. The output is the saturation voltage of Q_2 which is only a few tenths of a volt.

BiCMOS circuits are widely used as logic outputs on many digital CMOS integrated circuits such as microprocessors.



Transmission Gate





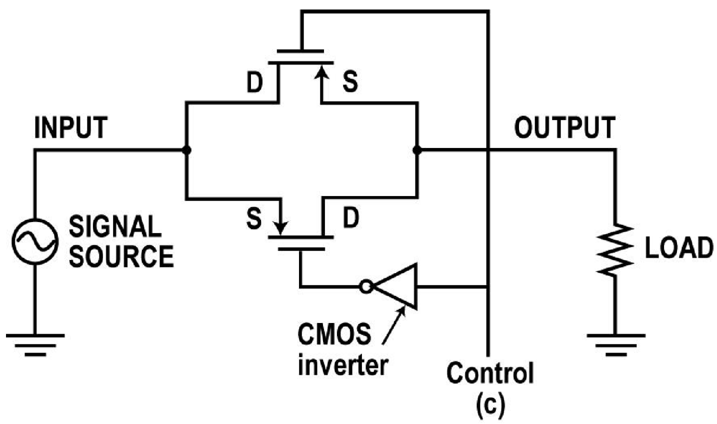
Another form of MOSFET switch is the transmission gate (TG). The MOSFET switches used in the CMOS inverter are in parallel with the output load while the TG is used as a series switch.

The symbols shown on the right are sometimes used to represent transmission gates in schematic diagrams.

Transmission Gate Operation

A TG is made with a single N-channel MOSFET in parallel with a single P-channel MOSFET. The drain of one is connected to the source of the other. The TG acts like a single pole single throw (SPST) switch.

The control signal is applied directly to the N-type gate and the complement logic level is applied to the P-type gate via the CMOS inverter.

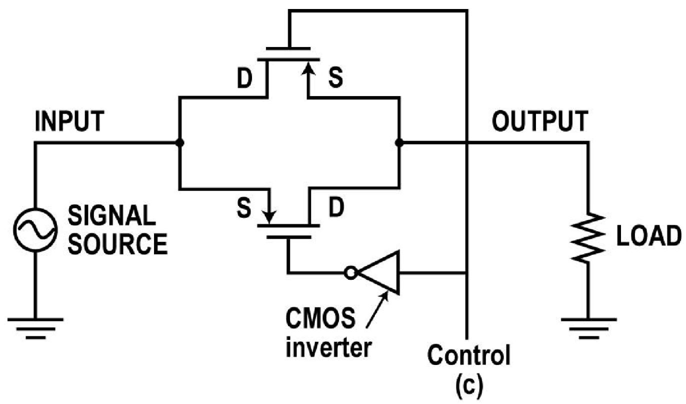


Transmission Gate Input Control

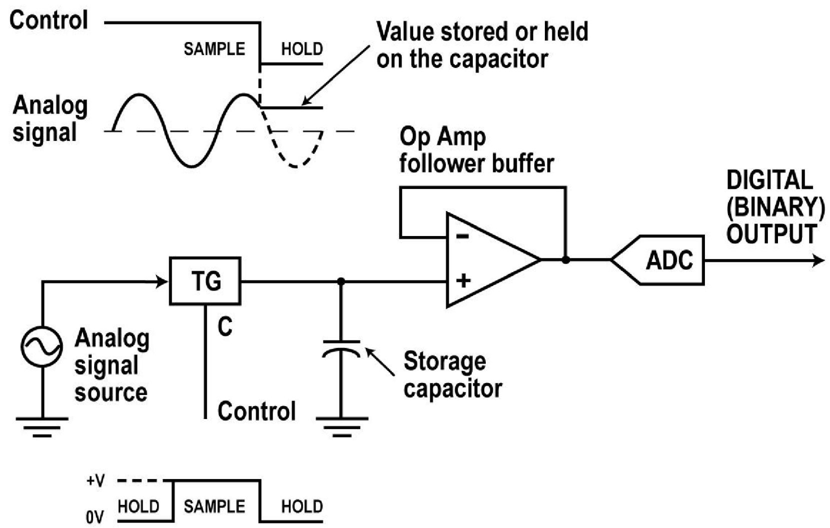
With a positive input on the control line, both MOSFETs conduct thereby allowing the input to pass through to the output. The input signal may be positive or negative and it will appear across the load less the small voltage drop across the "on" resistance of the MOSFETs.

If the control input is made zero, both MOSFETs cut off and no signal passes.

The TG is actually bidirectional in that the input and output are interchangeable.



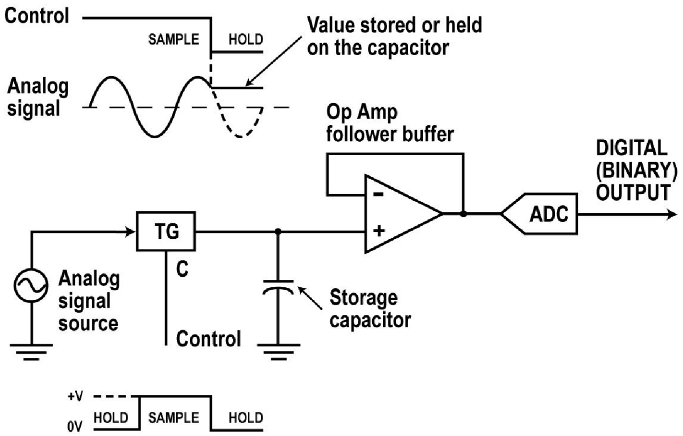
Transmission Gate Applications



A common application of a transmission gate is to connect an analog signal to a storage capacitor. This circuit is called a sample/hold or S/H circuit. It is used ahead of some types of analog-to-digital converters (ADC) to temporarily store a sample of the input signal at a designated time.

Note: For more information on sample/hold circuits, see the WRE module, Data Conversion Part 2.

Transmission Gate as a Sample/Hold Circuit



With the control input at zero, the TG is off and no signal appears on the capacitor.

When the control input goes to positive, the TG conducts and connects the analog input voltage to the capacitor. The charge on the capacitor tracks or follows the input.

When the control input goes back to zero, the MOSFET turns off. The capacitor then stores or holds the last value of voltage it sees before the transistor turns off. This voltage is buffered by an op amp follower before being applied to the ADC for conversion to digital.

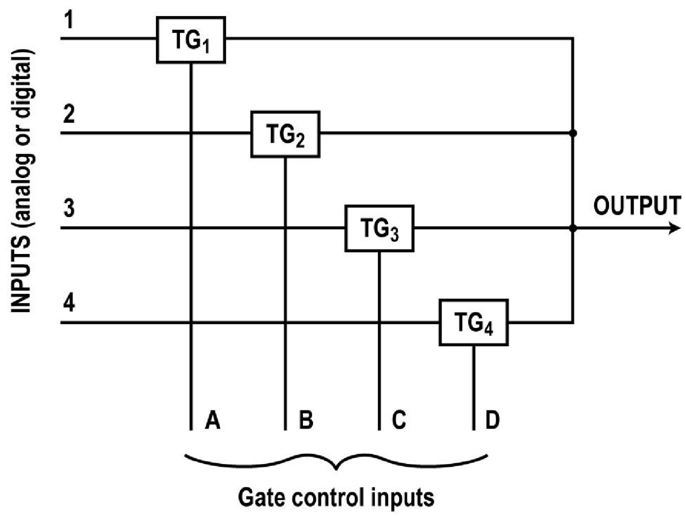
Transmission Gate Digital Application

One common digital application is called a multiplexer or data selector. One of several input signals from multiple sources can be selected to appear at the single output.

If all gate control inputs are zero, the output is zero.

To select an input to be passed to the output, a positive voltage is applied to the desired TG control input. If input B is made positive, TG_2 is turned on and input 2 appears at the output.

The control inputs are always set up so that only one TG is enabled at a time.



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