

The Multiplexer

The multiplexer is a combinational logic circuit designed to switch one of several input lines to a single common output line

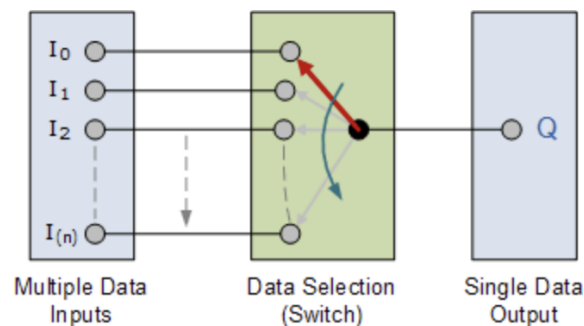
Multiplexing is the generic term used to describe the operation of sending one or more analogue or digital signals over a common transmission line at different times or speeds and as such, the device we use to do just that is called the multiplexer.

The *multiplexer*, shortened to “MUX” or “MPX”, is a combinational logic circuit designed to switch one of several input lines through to a single common output line by the application of a control signal. Multiplexers operate like very fast acting multiple position rotary switches connecting or controlling multiple input lines called “channels” one at a time to the output.

Multiplexers, or MUX’s, can be either digital circuits made from high speed logic gates used to switch digital or binary data or they can be analogue types using transistors, MOSFET’s or relays to switch one of the voltage or current inputs through to a single output.

The most basic type of multiplexer device is that of a one-way rotary switch as shown.

Basic Multiplexing Switch



The rotary switch, also called a wafer switch as each layer of the switch is known as a wafer, is a mechanical device whose input is selected by rotating a shaft. In other words, the rotary switch is a manual switch that you can use to select individual data or signal lines simply by turning its inputs “ON” or “OFF”. So how can we select each data input automatically using a digital device.

In digital electronics, multiplexers are also known as data selectors because they can “select” each input line, are constructed from individual Analogue Switches encased in a single IC package as opposed to the “mechanical” type selectors such as normal conventional switches and relays.

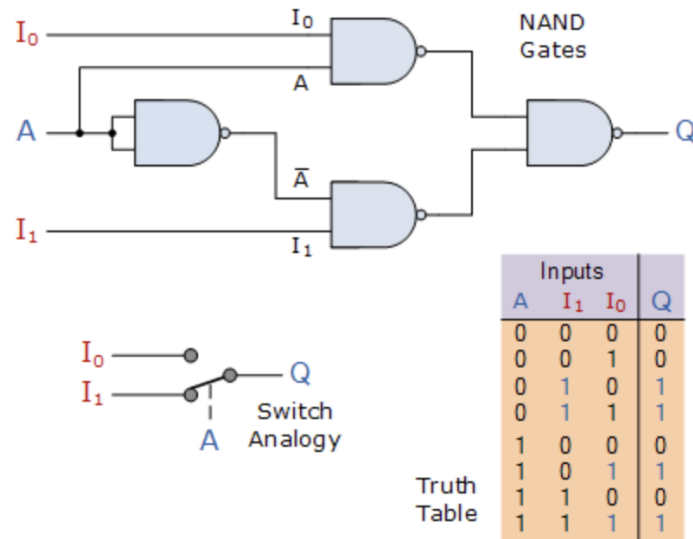
They are used as one method of reducing the number of logic gates required in a circuit design or when a single data line or data bus is required to carry two or more different digital signals. For example, a single 8-channel multiplexer.

Generally, the selection of each input line in a multiplexer is controlled by an additional set of inputs called *control lines* and according to the binary condition of these control inputs, either “HIGH” or “LOW” the appropriate data input is connected directly to the output. Normally, a multiplexer has an even number of 2^n data input lines and a number of “control” inputs that correspond with the number of data inputs.

Note that multiplexers are different in operation to *Encoders*. Encoders are able to switch an n-bit input pattern to multiple output lines that represent the binary coded (BCD) output equivalent of the active input.

We can build a simple 2-line to 1-line (2-to-1) multiplexer from basic logic NAND gates as shown.

2-input Multiplexer Design



The input A of this simple 2-1 line multiplexer circuit constructed from standard NAND gates acts to control which input (I_0 or I_1) gets passed to the output at Q .

From the truth table above, we can see that when the data select input, A is LOW at logic 0, input I_1 passes its data through the NAND gate multiplexer circuit to the output, while input I_0 is blocked. When the data select A is HIGH at logic 1, the reverse happens and now input I_0 passes data to the output Q while input I_1 is blocked.

So by the application of either a logic "0" or a logic "1" at A we can select the appropriate input, I_0 or I_1 with the circuit acting a bit like a single pole double throw (SPDT) switch.

As we only have one control line, (A) then we can only switch 2^1 inputs and in this simple example, the 2-input multiplexer connects one of two 1-bit sources to a common output, producing a 2-to-1-line multiplexer. We can confirm this in the following Boolean expression.

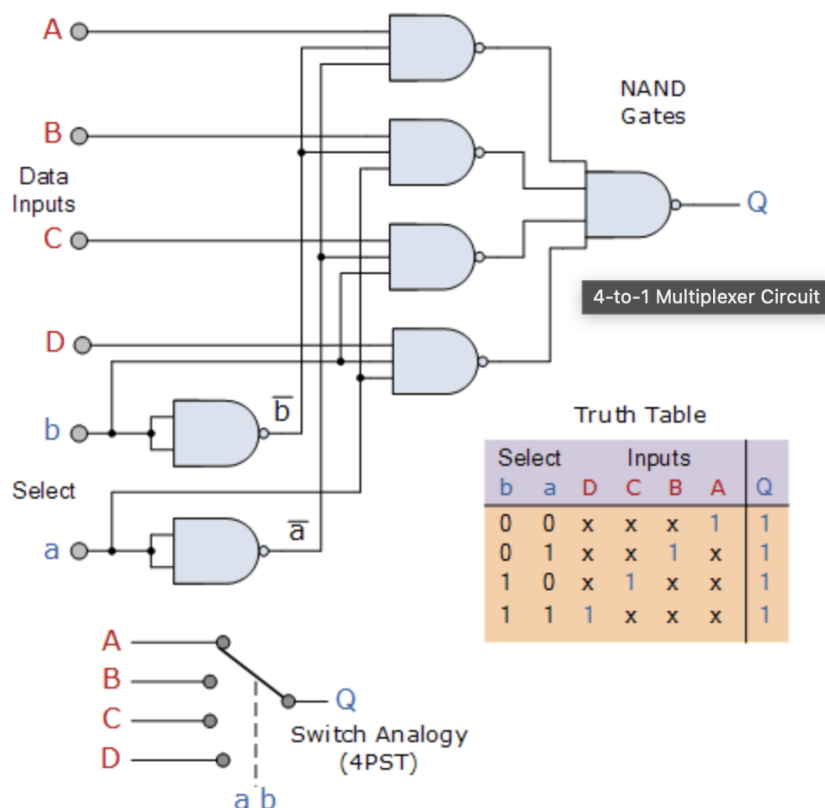
$$Q = \bar{A} \cdot \bar{I_0} \cdot I_1 + \bar{A} \cdot I_0 \cdot I_1 + A \cdot I_0 \cdot \bar{I_1} + A \cdot I_0 \cdot I_1$$

and for our 2-input multiplexer circuit above, this can be simplified too:

$$Q = \bar{A} \cdot I_1 + A \cdot I_0$$

We can increase the number of data inputs to be selected further simply by following the same procedure and larger multiplexer circuits can be implemented using smaller 2-to-1 multiplexers as their basic building blocks. So for a 4-input multiplexer we would therefore require two data select lines as 4-inputs represents 2^2 data control lines give a circuit with four inputs, I_0, I_1, I_2, I_3 and two data select lines A and B as shown.

4-to-1 Channel Multiplexer



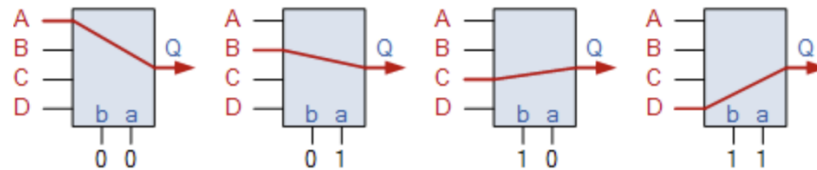
The Boolean expression for this 4-to-1 **Multiplexer** above with inputs A to D and data select lines a, b is given as:

$$Q = \bar{a}\bar{b}A + \bar{a}bB + a\bar{b}C + abD$$

In this example at any one instant in time only ONE of the four analogue switches is closed, connecting only one of the input lines A to D to the single output at Q. As to which switch is closed depends upon the addressing input code on lines "a" and "b".

So for this example to select input B to the output at Q, the binary input address would need to be “a” = logic “1” and “b” = logic “0”. Thus we can show the selection of the data through the multiplexer as a function of the data select bits as shown.

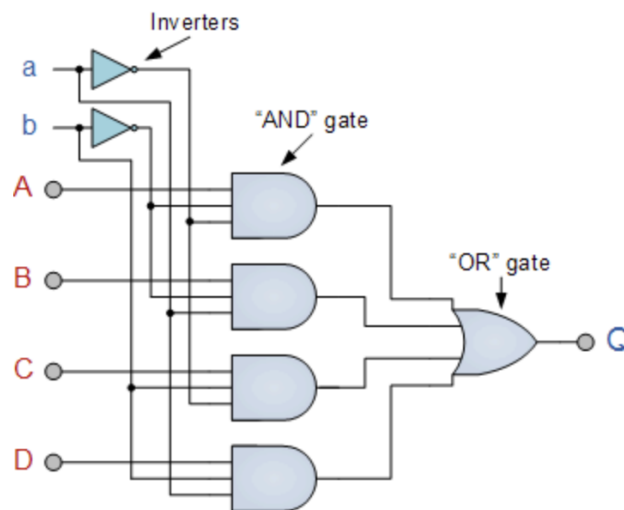
Multiplexer Input Line Selection



Adding more control address lines, (n) will allow the multiplexer to control more inputs as it can switch 2^n inputs but each control line configuration will connect only ONE input to the output.

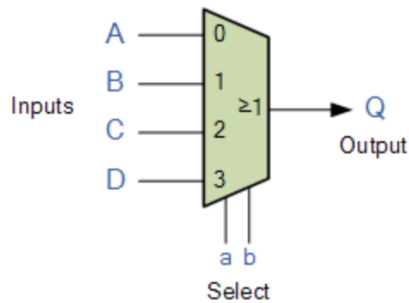
Then the implementation of the Boolean expression above using individual logic gates would require the use of seven individual gates consisting of AND, OR and NOT gates as shown.

4 Channel Multiplexer using Logic Gates



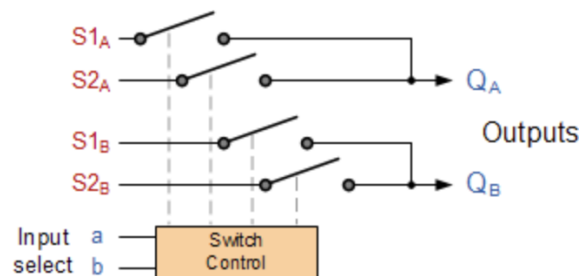
The symbol used in logic diagrams to identify a multiplexer is as follows:

Multiplexer Symbol



Multiplexers are not limited to just switching a number of different input lines or channels to one common single output. There are also types that can switch their inputs to multiple outputs and have arrangements or 4-to-2, 8-to-3 or even 16-to-4 etc configurations and an example of a simple Dual channel 4 input multiplexer (4-to-2) is given below:

4-to-2 Channel Multiplexer

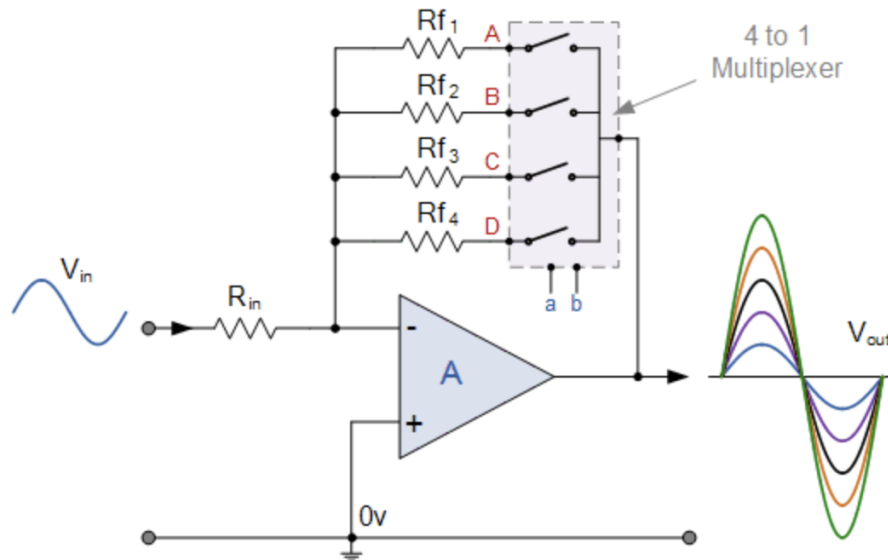


Here in this example the 4 input channels are switched to 2 individual output lines but larger arrangements are also possible. This simple 4-to-2 configuration could be used for example, to switch audio signals for stereo pre-amplifiers or mixers.

Adjustable Amplifier Gain

As well as sending parallel data in a serial format down a single transmission line or connection, another possible use of multi-channel multiplexers is in digital audio applications as mixers or where the gain of an analogue amplifier can be controlled digitally, for example.

Digitally Adjustable Amplifier Gain



Here, the voltage gain of the inverting operational amplifier is dependent upon the ratio between the input resistor, R_{IN} and its feedback resistor, R_f as determined in the Op-amp tutorials.

A single 4-channel (Quad) SPST switch configured as a 4-to-1 channel multiplexer is connected in series with the resistors to select any feedback resistor to vary the value of R_f . The combination of these resistors will determine the overall voltage gain of the amplifier, (A_v). Then the voltage gain of the amplifier can be adjusted digitally by simply selecting the appropriate resistor combination.

Digital multiplexers are sometimes also referred to as “Data Selectors” as they select the data to be sent to the output line and are commonly used in communications or high speed network switching circuits such as LAN’s and Ethernet applications.

Some multiplexer IC's have a single inverting buffer (NOT Gate) connected to the output to give a positive logic output (logic "1", HIGH) on one terminal and a complimentary negative logic output (logic "0", LOW) on another different terminal.

It is possible to make simple multiplexer circuits from standard AND and OR gates as we have seen above, but commonly multiplexers/data selectors are available as standard i.c. packages such as the common TTL 74LS151 8-input to 1 line multiplexer or the TTL 74LS153 Dual 4-input to 1 line multiplexer. Multiplexer circuits with much higher number of inputs can be obtained by cascading together two or more smaller devices.

Multiplexer Summary

Then we can see that **Multiplexers** are switching circuits that just switch or route signals through themselves, and being a combinational circuit they are memoryless as there is no signal feedback path. The multiplexer is a very useful electronic circuit that has uses in many different applications such as signal routing, data communications and data bus control applications.

When used with a demultiplexer, parallel data can be transmitted in serial form via a single data link such as a fibre-optic cable or telephone line and converted back into parallel data once again. The advantage is that only one serial data line is required instead of multiple parallel data lines. Therefore, multiplexers are sometimes referred to as "data selectors", as they select the data to the line.

Multiplexers can also be used to switch either analogue, digital or video signals, with the switching current in analogue power circuits limited to below 10mA to 20mA per channel in order to reduce heat dissipation.

In the next tutorial about combinational logic devices, we will look at the reverse of the **Multiplexer** called the Demultiplexer which takes a single input line and connects it to multiple output lines.