R&D TECHNOLOGY FOCUS

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Pulse Sensors for Flow Measurement Devices and Applications

Neil Hannay explains flow meter sensor and pulse output types for efficient system operation.

Deciding on the best flow meter for a particular application can be problematic. There is such a wide array of sensing and output technology combinations, each with its advantages and disadvantages, that choosing the right one is an exacting process.

Flow meters have developed into many forms over the years, from mechanical devices – such as a turbine or rotating gear - which rely on measurement of a rotational component, to devices that use ultrasound and other advanced technologies. These meters generally use a sensor to relay the flow measurements to a reading device. Nearly all types of flowmeters, from ultrasonic to turbines, are offered with pulse output flow signals. Sensing components used in a flowmeter measure the movement or flow rate of the liquid or gas passing through the system. The pulse output signal from these devices is, in essence, an on/off switch which changes state at a frequency related to the fluid flow.

This technical review aims to go ‘back to basics’, providing a foundation understanding of typical output pulse types for flowmeters and drawing on examples of application, illustrating which output sensor works best in different environments. This will help you to make an informed decision when selecting the optimum output pulse type for your flow meter and the process application that it is operating within.

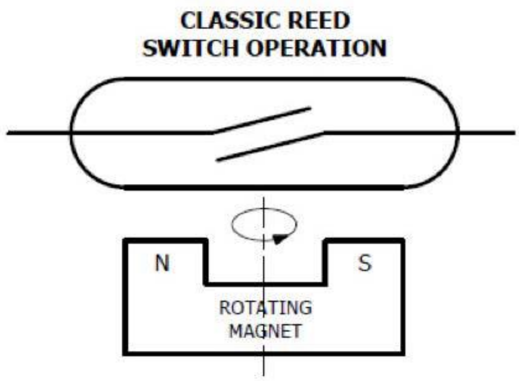
The input circuitries of flow indicators often have configuration routines to accommodate the device’s output. Pulse output sensors need to be connected to a suitable pulse counting read-out device and correctly configuring these connections is crucial for proper system operation. Such read-out devices have typically been a dedicated display, a programmable logic controller (PLC), or *LabVIEW* directly interfacing on a PC. We now also see increasingly popular options like Arduino and Raspberry Pi.

We will review different pulse outputs and sensors and discuss where they are advantageous, along with the best practices for connecting them to the desired read-out device.

Reed Switch

The reed switch represents the simplest form of pulse output. It is merely a magnetically operated mechanical device composed of two ferromagnetic reeds sealed within a glass envelope. They are typically inexpensive and easy to understand but are limited to lower frequencies. Reed switches can be used in hazardous areas provided there is no risk of extraneous voltages or currents being produced. In this environment, simple apparatus design can be suitable for safe operation as there is no possibility of these extraneous voltages or currents in a correctly designed circuit.

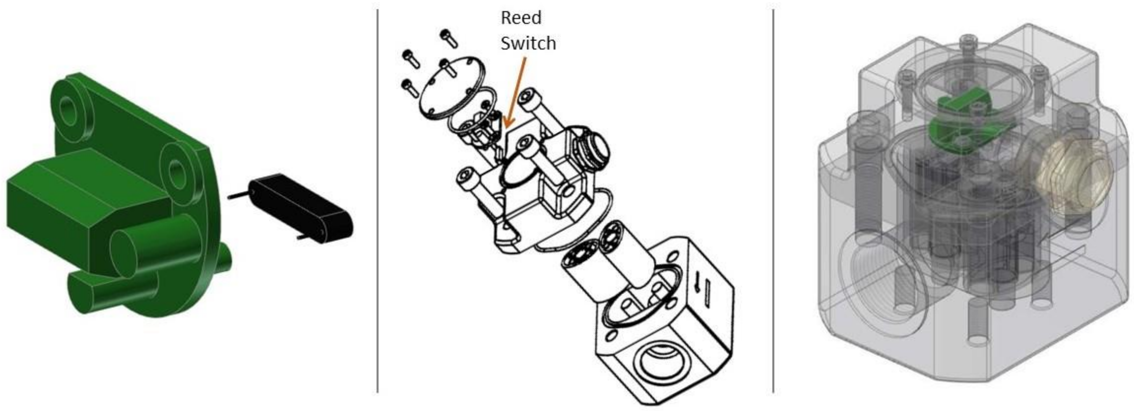
Reed switches are a desirable alternative to other sensors for applications where energy efficiency and low power consumption are essential. This is due to the mechanical design of the sensor that gives zero energy consumption while the switch is in a passive state. The reed switch essentially functions by switching the voltage offered to it, and if appropriately protected, this form of pulse output is perfect. The logging flow meter detects the voltage change when the switch closes. However, there are a few limitations to consider.



As reed switches are mechanical devices, they have a finite lifespan, with fatigue and breakage likely after around 10^9 operations under ideal conditions. The contacts should be protected by a current-limiting component to prevent a voltage supply being directly switched, causing them to weld together. In hazardous atmospheres, this extra protection may prevent an intrinsically safe instrument from reading the contact closures and so should be removed.

Another potential issue exhibited in reed switches is a phenomenon called 'contact bounce'. This refers to the rapid opening and closing of the switch contacts which can be erroneously detected by the electronics as valid pulses.

Two solutions are available to resolve this. The first is to use a slow input to the connected equipment. This may be a 'slow speed' input on a PLC, or a small capacitor and resistor can be employed to prevent the bounce being seen by the instrument. A second method is to use software algorithms to ignore fast pulses. Several well-established methods are available to achieve this.



Reed Switch placement in an Oval Gear Flowmeter

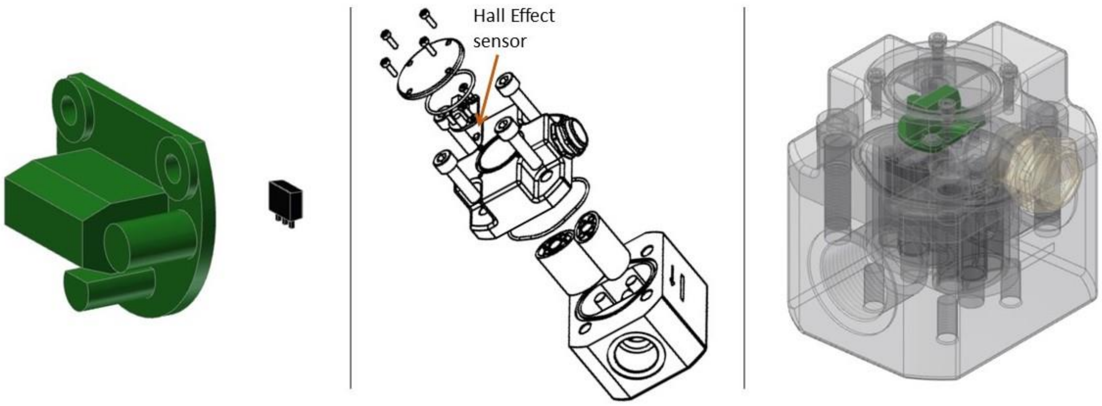
Reed Switch Features

Recommended Applications	• Oil and gas industry • Additives • Domestic water meters • Low power / battery operation • Remote metering	Not recommended for:	• Metallic containing liquids e.g. cast iron pumped system • High frequency/resolution flow measurement
Advantages	• No power required for operation • Simple two wire installation • Not vulnerable to electromagnetic interference • Simple Apparatus for Hazardous Atmospheres • Low cost	Disadvantages	• Limited frequencies • Finite life of operation • Bouncing of switch contacts • Magnetic activation
Trigger	• Rotating magnet	Maximum Frequency	• 1kHz

Hall Effect Transistor – NPN & PNP Pulse Outputs

A common movement sensor is the Hall effect sensor. This is a solid-state device which transduces a measurement of varying magnetic field strength into a pulse train which typically feeds an NPN or PNP transistor output configured as an open collector. Like a reed switch, the Hall effect sensor responds to a permanent magnet passing close to it.

These sensors contain an amplifier to process the small signal from the Hall effect internal component and therefore require power to operate, making them three-wire devices with positive, negative and pulse terminals. As there are no mechanical contacts to move, the output cannot bounce and can operate indefinitely at much higher frequencies than reed switches.



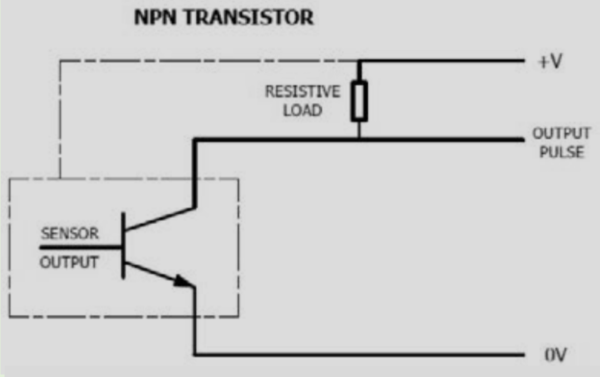
Hall Effect Sensor placement in an Oval Gear Flowmeter

Semiconductor Sensor Components

Many of the pulse output flow devices utilise transistors as they are highly reliable, low cost and give a clean high frequency pulse. In general, they are offered as open collector formats of NPN or PNP, which can be more specifically set as a Logic level, all of which can be read by modern day readout and monitoring electronics. Below we discuss the differences between these three common configurations.

NPN and PNP Transistor Pulse Outputs:

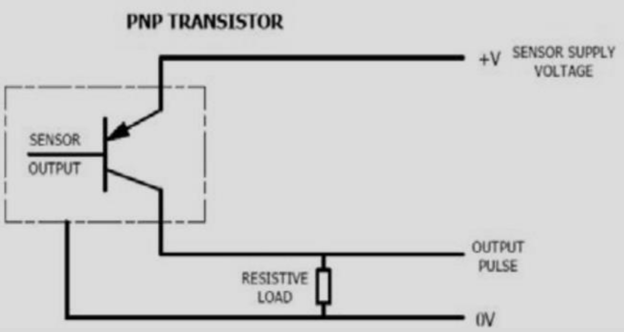
An Open Collector **NPN** output is configured like a switch to the 0V supply of the flow meter. It requires a 'Pull-Up' resistor connected to a positive voltage. When activated, the transistor 'sinks' current from the external resistor so that the voltage of the output is close to 0V. When a pull-up resistor is added to an external voltage, the advantage is the positive voltage need not be the supply voltage of the sensor, as shown right, but can be any chosen voltage within specified limits to suit the rest of the instrumentation network.



Flow Meter NPN Transistor

For example, using 24 volts can allow for safer transmission over longer distances. The exact value of the resistor is typically not critical, though it needs to be large enough to limit the current at the chosen voltage (within the specified limit), and small enough to provide sufficient current to activate the switch. Typical pull-up resistor values are between 1K and 50k Ohm.

An Open Collector **PNP** output is the mirror image of the NPN counterpart, providing a switch to the sensor supply voltage. It must be connected externally via a 'Pull-Down' resistor to 0V, enabling the output switch to 'source' current to the external resistor. Although more popular with many PLCs, in practice the PNP output has less flexibility compared to the NPN as its voltage range is predetermined by the supply. Typical pull-down resistor values are also between 1K and 50k Ohm.



Flow Meter PNP Transistor

These types of sensor are used extensively in mechanical flow meters due to their reliability, clean square wave and long life. They are also able to measure very high frequencies so often found in high-rate turbine systems where you can have in excess of 1kHz pulse generation required.

Bipolar transistors - NPN and PNP – are made of three alternating layers of P-type and N-type semiconductors (P-type meaning positive charge carriers and N-type meaning negative charge carriers). Taking the top layer as the positive terminal, the bottom layer as the negative terminal and the central layer as the 'base', the voltage between the base and the 'collector' (top layer for NPN, bottom layer for PNP) controls whether the transistor allows current to flow between the top and bottom layers. The top layer is called the collector for NPN transistors and the bottom layer the emitter, whereas for PNP transistors the reverse is true.

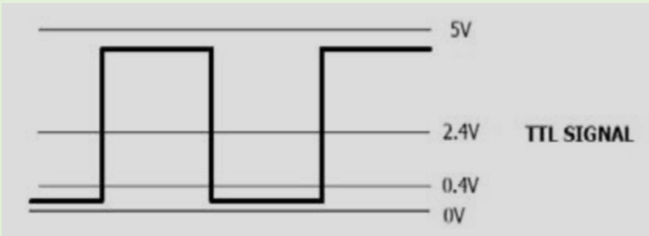
NPN and PNP bipolar transistors were developed in the 1940's and more recently are often replaced by open drain Field Effect Transistors (NFET and PFET). The term NPN and PNP is used by suppliers to indicate either type of transistor, as their practical operation is interchangeable. They can generally be distinguished by the direction of the arrow on the emitter of the component; it points outward on an NPN and inward on a PNP.

Logic Level / Logic Output

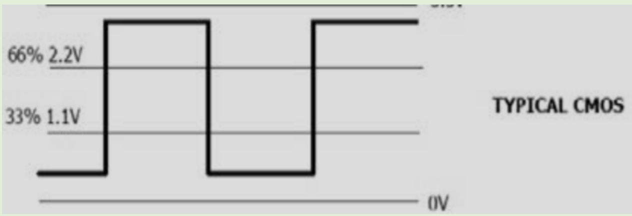
As electronic flowmeters with advanced communication abilities become more prevalent, there is the opportunity for industry to move to real-time flow measurement and transmission. But as communication protocols differ in different software systems, industry still tends to rely on pulse output as a ubiquitous method of flow signal transmission.

For electronic flow devices, such as ultrasonic, Coriolis or magnetic, you can gain in accuracy and remove the need for internal moving parts in contact with the fluid being measured. As direct rate measuring devices, they can communicate the flow measurement directly, but they typically also produce pulse outputs.

The design is usually an NPN or PNP output, requiring pull-up/down resistors as explained previously, but it can also be a more specific 'Logic Output'.



A logic output switches between predetermined voltage levels, which are interpreted as logic 'True' or 1 and logic 'False' or 0. The most common logic output devices are TTL and CMOS. TTL defines a logic 0 as an output below 0.4V, and a logic 1 as above 2.4V. Typically, a logic 0 output will be a few millivolts, while a logic 1 will be close to 5V.



CMOS is defined relative to an internal supply voltage (usually 3.3V or 5V) with a logic 0 below 33% of the supply voltage and a logic 1 above 66%. In practice, CMOS output will have a logic 0 output at virtually 0V and a logic 1 output close to the internal supply voltage.

Hall Effect Transistor Features

Recommended Applications	• Oil and gas industry • Chemical processing • Food production • Beverage dispensing	Not recommended for:	• Metallic containing liquids e.g. cast iron pumped system • Hazardous Atmospheres • Battery-powered systems
Advantages	• High frequency operation • Clean square wave pulse output • Long life of operation • Low cost	Disadvantages	• DC Power required for operation (i.e. three wire installation) • Not suitable for hazardous environments • Susceptible to electromagnetic interference • Magnetic activation
Trigger	• Rotating magnet	Maximum Frequency	• >100kHz

Optical Sensor

Optical sensors work by the interruption of an optical pathway by a mechanical element such as a turbine blade. Typically, a photodiode or phototransistor is used to sense the light output from an infrared emitting LED, with interruptions of the light signal resulting in output state changes. The output pulse train is usually conditioned with a ‘Schmitt trigger’ which introduces hysteresis to ensure clean transitions between output states.

Depending on the circuit design, the sensor normally outputs pulses via an open collector, NPN transistor.

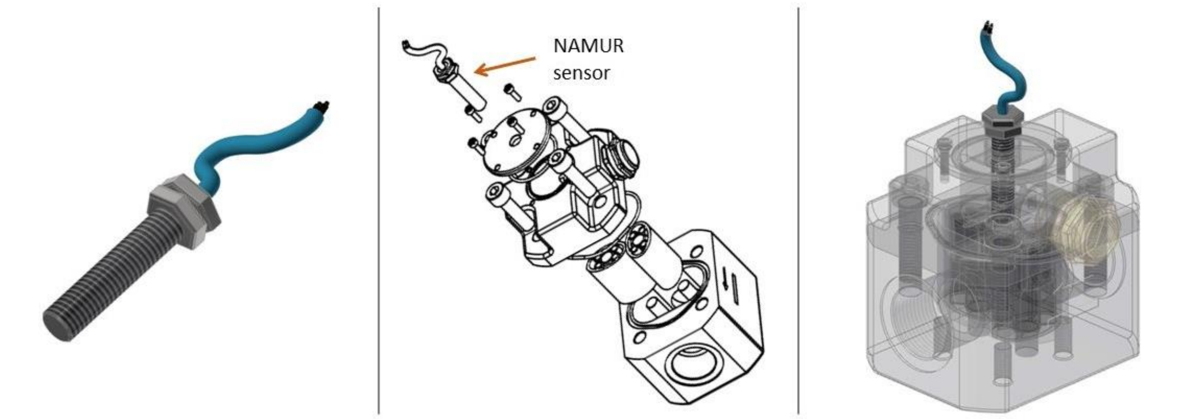
Optical sensor-based pulse outputs are generally used where magnetic based devices are not suitable. Optical sensors have the advantage of better low-end performance and higher output frequencies, as the impellors are lighter and can have many blades. Of course, they cannot be used with any fluid that affects the light path from the source to the sensor.

Optical Sensor Features			
Recommended Applications	• Food production • Beverage dispensing • Fuel monitoring	Not recommended for:	• Optically opaque liquids • Hazardous Atmospheres
Advantages	• High frequency operation • Clean square wave pulse output • Not influenced by magnetic fields • Long life of operation • Low cost	Disadvantages	• DC Power required for operation (i.e. three wire installation) • Not suitable for hazardous environments • Can be susceptible to interference from bright light sources
Trigger	• Rotating impellor breaking light beam	Maximum Frequency	• >100kHz

NAMUR Sensor

NAMUR sensors are proximity sensors that conform to the NAMUR standard for process automation. They provide a digital output signal, are intrinsically safe, offer fault detection capabilities, and ensure compatibility with NAMUR-compliant control systems.

The NAMUR sensor is a two-wire device that operates with a constant voltage supply, characteristically 8Vdc. As the flow though the meter varies, the resistance of the NAMUR sensor changes. Typically, the current trigger points are <1.2mA to >2.1mA as the target passes the sensor. These devices are commonly employed with specialist flow meters in hazardous areas due to the sensor’s very low power consumption and the ease of remotely monitoring any resistance/current changes. Converters to standard outputs are available for compatibility.



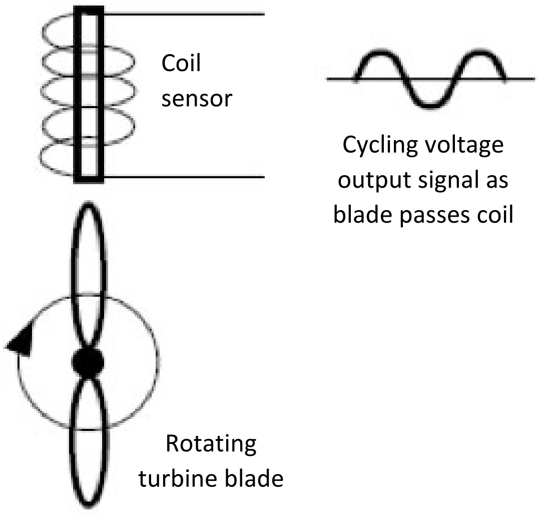
NAMUR Sensor placement in an Oval Gear Flowmeter

NAMUR sensors are used in process industries such as chemical plants, oil and gas refineries, and pharmaceutical manufacturing, where intrinsic safety and reliable signals are critical requirements.

NAMUR Sensor Features

Recommended Applications	• Explosive Atmospheres • Chemical processes • Oil and Gas industry	Not recommended for:	• Metallic containing liquids e.g. cast iron pumped system • Battery-powered systems
Advantages	• Intrinsically safe design • Long life of operation	Disadvantages	• DC Power required for operation (i.e. three wire installation) • Magnetic / Inductive activation • Expensive
Trigger	• Rotating magnet	Maximum Frequency	• 1.5kHz

Magnetic Coil



If a magnet moves in front of a coil, a current flows in the coil, generating a voltage across it. Implemented in a flowmeter, the magnet and the coil are stationary in the sensor, and a magnetic turbine blade alters the magnetic coupling sufficient to induce a voltage swing. Though the induced voltages are typically low levels (around 10 millivolts), they are cyclical and easily detectable. If the environment in which the sensor operates is electrically 'noisy', the signal should be amplified or converted to a more robust level prior to transmission. As indicated earlier for NPN, low voltage pulses do not travel well over long distances, so coils are not recommended for low frequency operation. More advanced technology has tended to see the magnetic coil fall behind in industrial application.

Magnetic Coil Features

Recommended Applications	• Superseded by newer technologies • Can be used in intrinsically safe applications (with appropriate 'packaging')	Not recommended for:	• Low frequency operation • Low flows
Advantages	• No power requirement • Low cost	Disadvantages	• Old technology • Requires intelligent technology in the circuit/ control panel to transmit into high-grade pulse • Can be susceptible to interference in an electrically 'noisy' environment
Trigger	• Magnetic element / material passing at speed	Maximum Frequency	• >1kHz

Summary

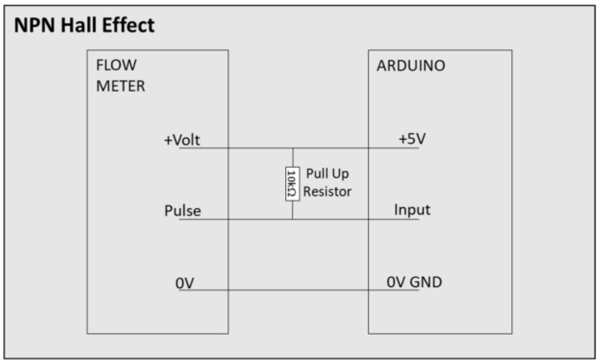
Providing some of the key functions, advantages and disadvantages of these sensors in this article should prove a useful comparison to guide your decision as to the optimum output for your flow measurement requirements. There are additional parameters that users would need to consider to ensure the correct sensors and configuration meet the requirements of the customer's installation, and we always recommend discussing these with the supplier.

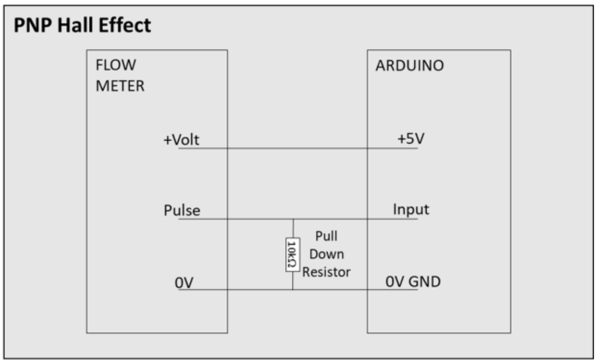
Best Practice - Interfacing a Pulse Flow Meter to an Arduino Uno

The Arduino Uno is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. In the context of what we are discussing here, Arduino Uno electronic devices can be used to monitor a digital flow meter using pulse output for flow measurement. This board can be interfaced with other Arduino boards, Arduino shields and Raspberry Pi boards.

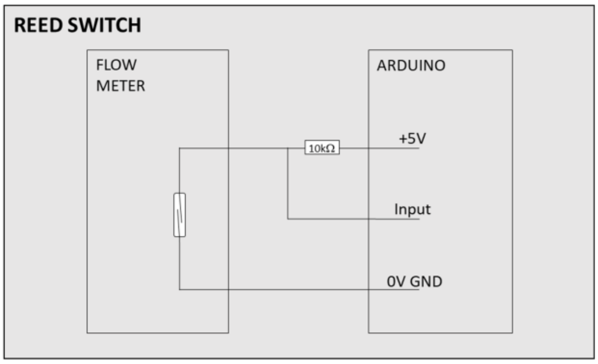
Each type of digital pulse output flowmeter requires specific interface circuitry to deliver an oscillating voltage around an input pin on the Arduino. A 5 Volt Arduino's input pins have a decision level of about 2.5V, therefore the voltage from the pulse flowmeter must swing sufficiently either side of this value to be registered by the Arduino.

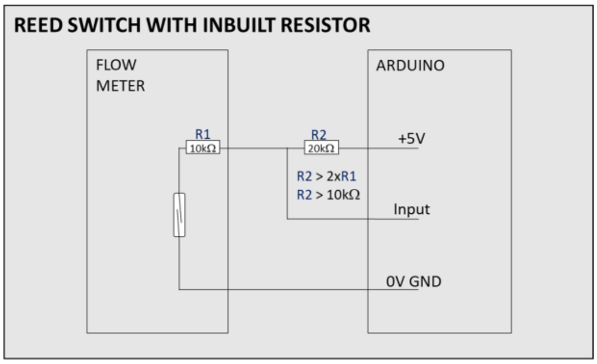
Example Installation Wiring





Note: For NPN the 10K Ohm resistor can be omitted if the Arduino's internal pull-up resistor is enabled





Software Considerations

When working with an Arduino board, the connected input pin must be configured as a digital input in the Arduino software. Depending on the specific requirements, various methods can be used to process the state of the input pin and extract the necessary flow information. By implementing appropriate software techniques or incorporating additional hardware components, such as debouncing circuits or utilising software debounce algorithms, the impact of contact bounce on the flow measurement can be minimised, resulting in more accurate and consistent readings.