M101 – Theory of Measuring Natural Gas

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Energy Nexus | Annual Technical Conference
Fuelling the Future

Theory of Measuring Natural Gas

- Description of natural gas and it’s important properties
- Present the most *common types* of natural gas meters approved in Canada for custody transfer
- Briefly explore each meter’s history
- Look at each meter’s measuring principle
- Review some installation requirements and why they are important to metering
- List relevant measurement standards

Theory of Measuring Natural Gas

- Natural gas is the earth's cleanest fossil fuel
- It naturally occurs in sedimentary basins
- In its natural state, it is odourless and colourless
- Processed natural gas consists primarily of methane (95% to 99%) with lesser amounts of ethane, propane, butane, pentanes and heavier hydrocarbons
- It is abundant - 1,268 trillion cubic feet of proven reserves or lasting over 200 years at today’s consumption rates

Helpful References for Natural Gas

- CGA Natural Gas 101: A great introduction to gas properties
- The CGA Playbook: *A guide to the industry and its priorities in Canada*

Important Properties of Natural Gas

- It is a compressible substance - Volume reduces under increasing pressure (Boyle's Law)
- It is temperature sensitive - Volume increases as temperature increases (Charles' Law)
- For consistency, we trade gas at a standard volume *vs* the actual volume measured inside the meter

Metering Natural Gas

- Meters are mechanical or electronic devices that are in most cases only capable of measuring actual volumes

- When flowing gas pressure and temperature are measured, actual measured volume can be converted to standard volume using mathematical equations or ratios

- The equation comes from the *Modified Ideal Gas Law*
  (combination of Charles' and Boyle's Laws)

- After much simplification, it practically looks like this…

Governing Equation for Gas Measurement

$$Vs = Vm \times Pf \times Tf \times Cf \times Zf$$

Vs is the standard volume

Vm is the volume registered by the meter

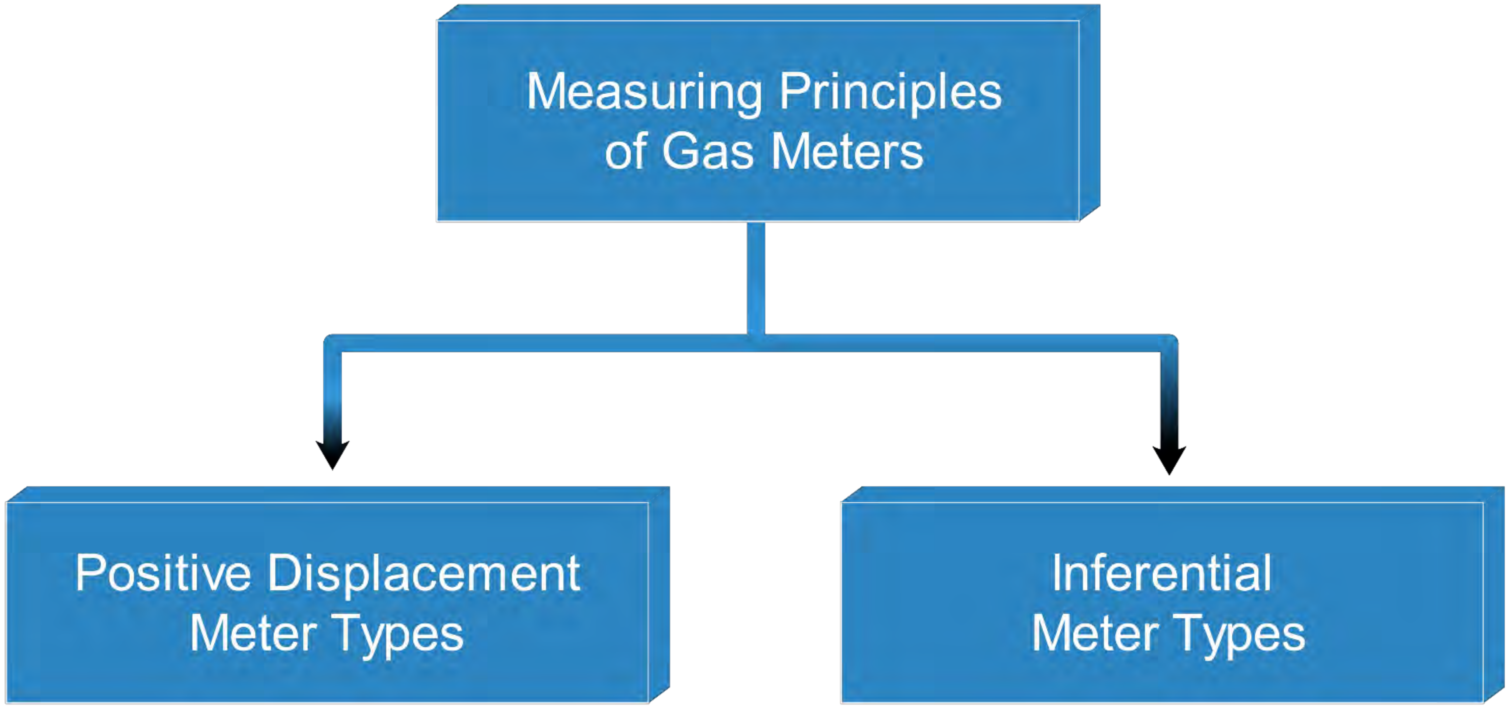
Pf is the pressure factor

Tf is the temperature factor

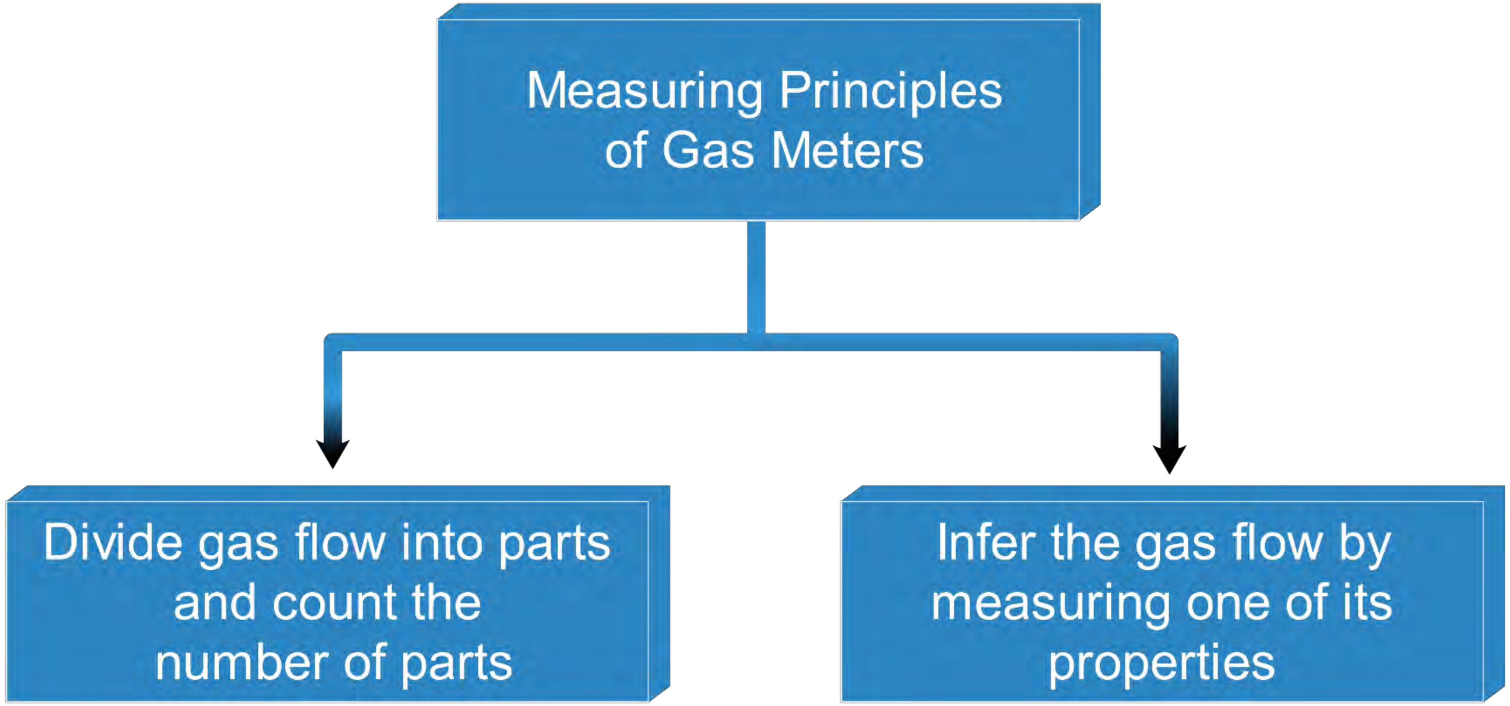
Cf is the calibration correction

Zf is the correction for non-ideal gas behaviour

Types of Meters in Natural Gas Measurement



Types of Meters in Natural Gas Measurement



Positive Displacement Meter Types

Positive Displacement Meter Types

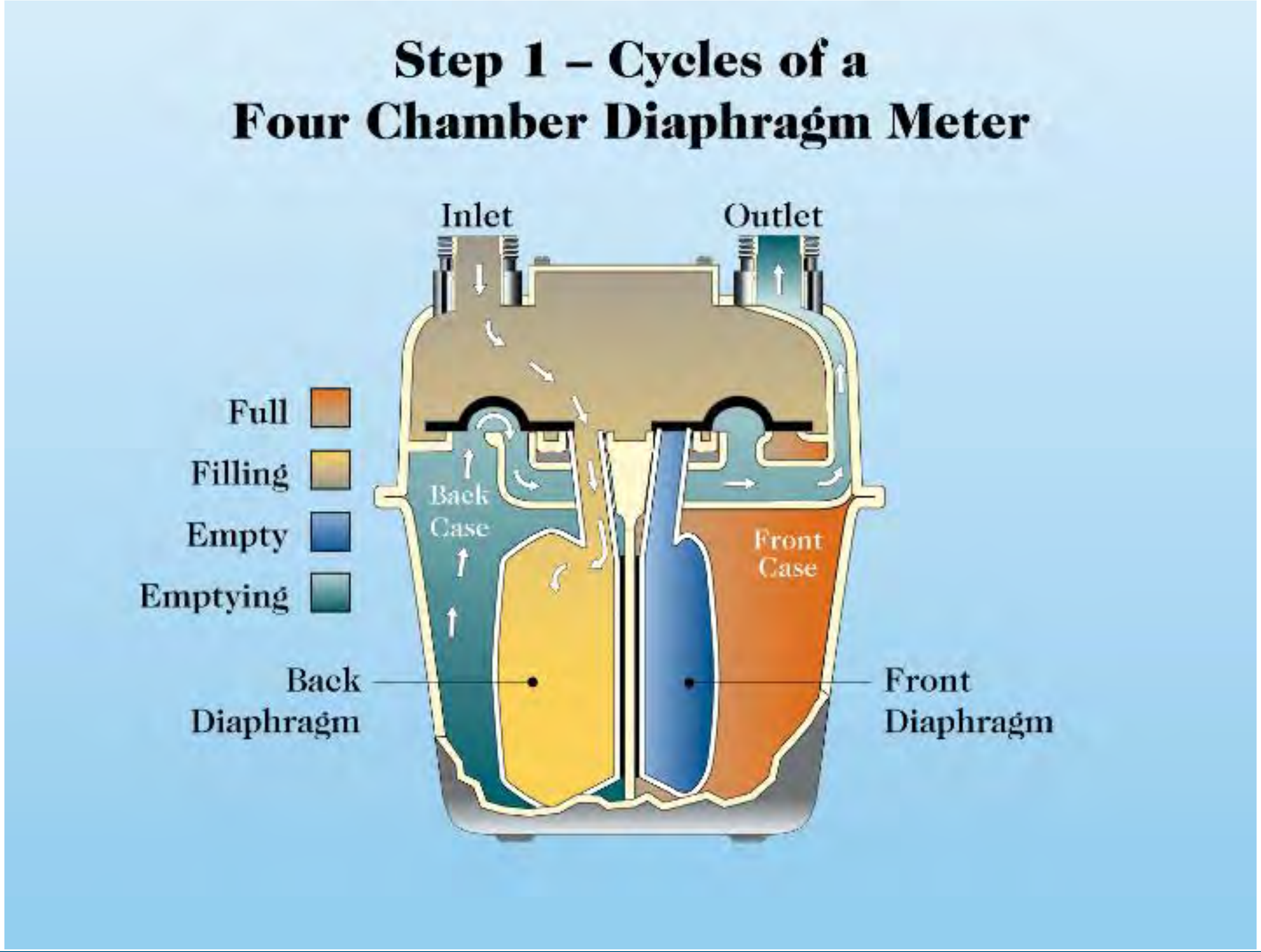
Diaphragm Meter Types

Positive Displacement Meter Types

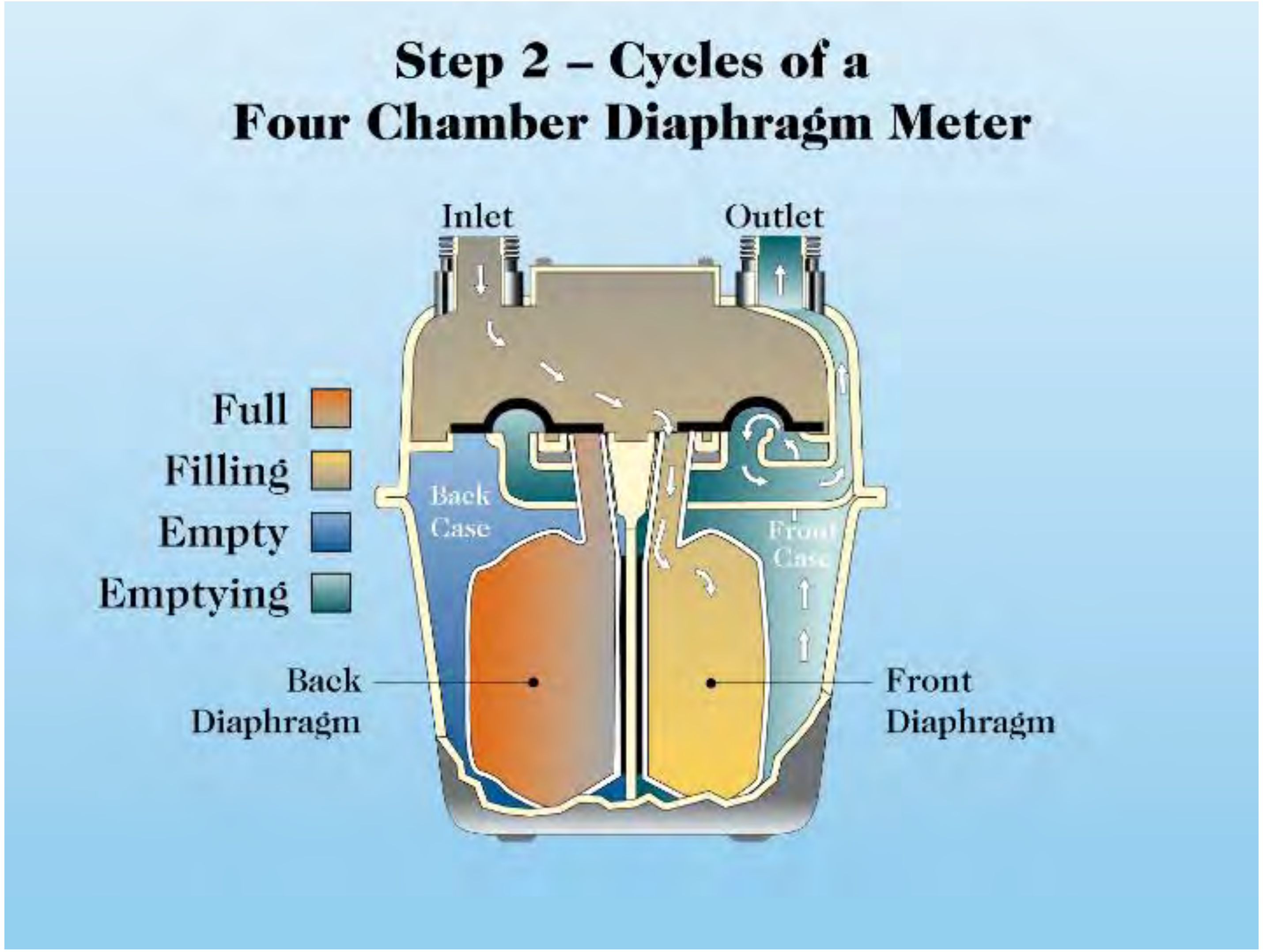
Diaphragm Meter History

- 1843 - First dry positive displacement meter by William Richards
- 1843+ - Thomas Glover later improved the design which became known as the Glover 2-diaphragm, slide valve, 4-chamber meter
- 1903 - Henry Sprague patented 2-diaphragm, 3-chamber, oscillating valve
- Today - both the 4-chamber and the 3-chamber are used

Diaphragm Meter Operation



Diaphragm Meter Operation



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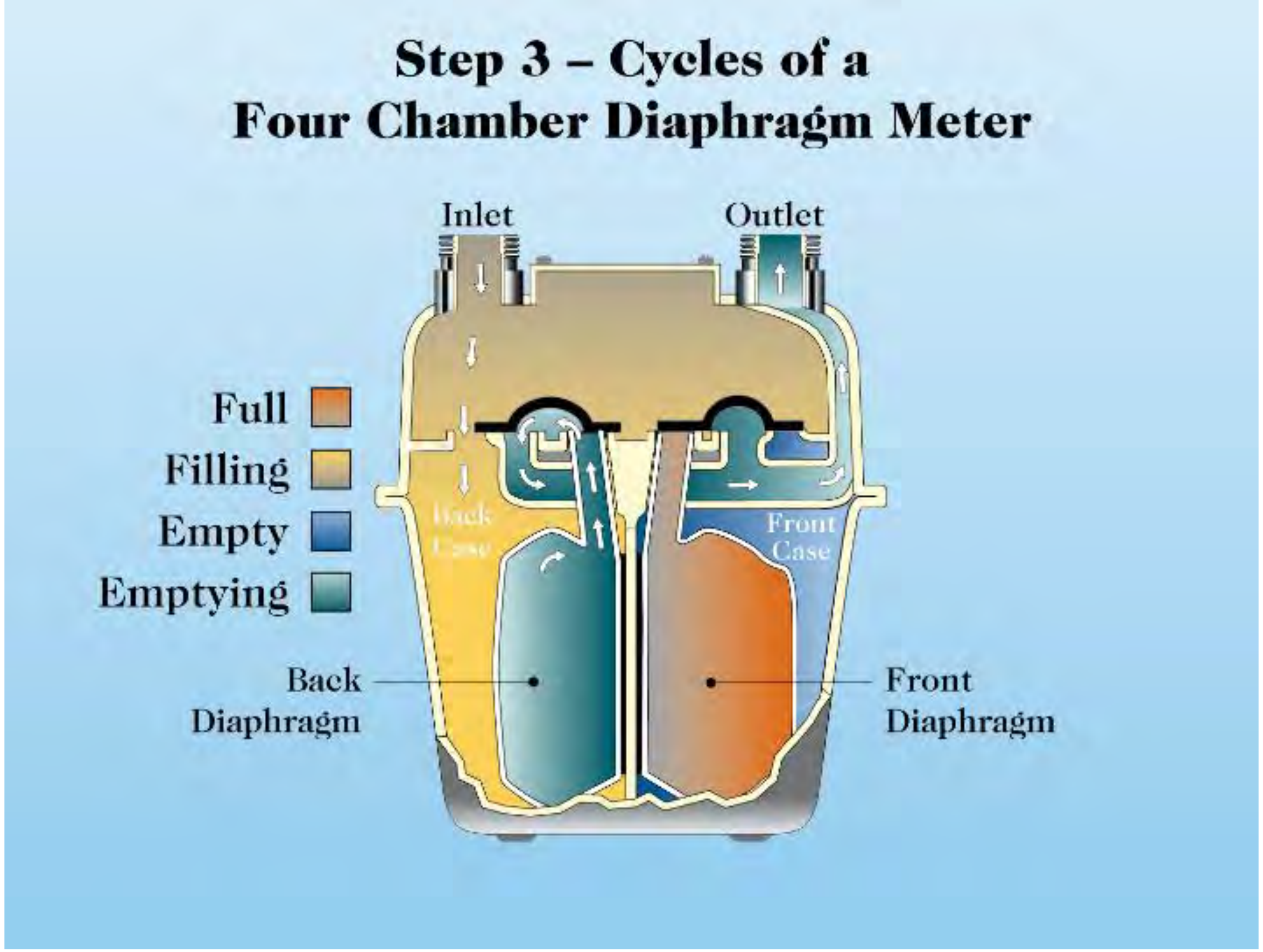
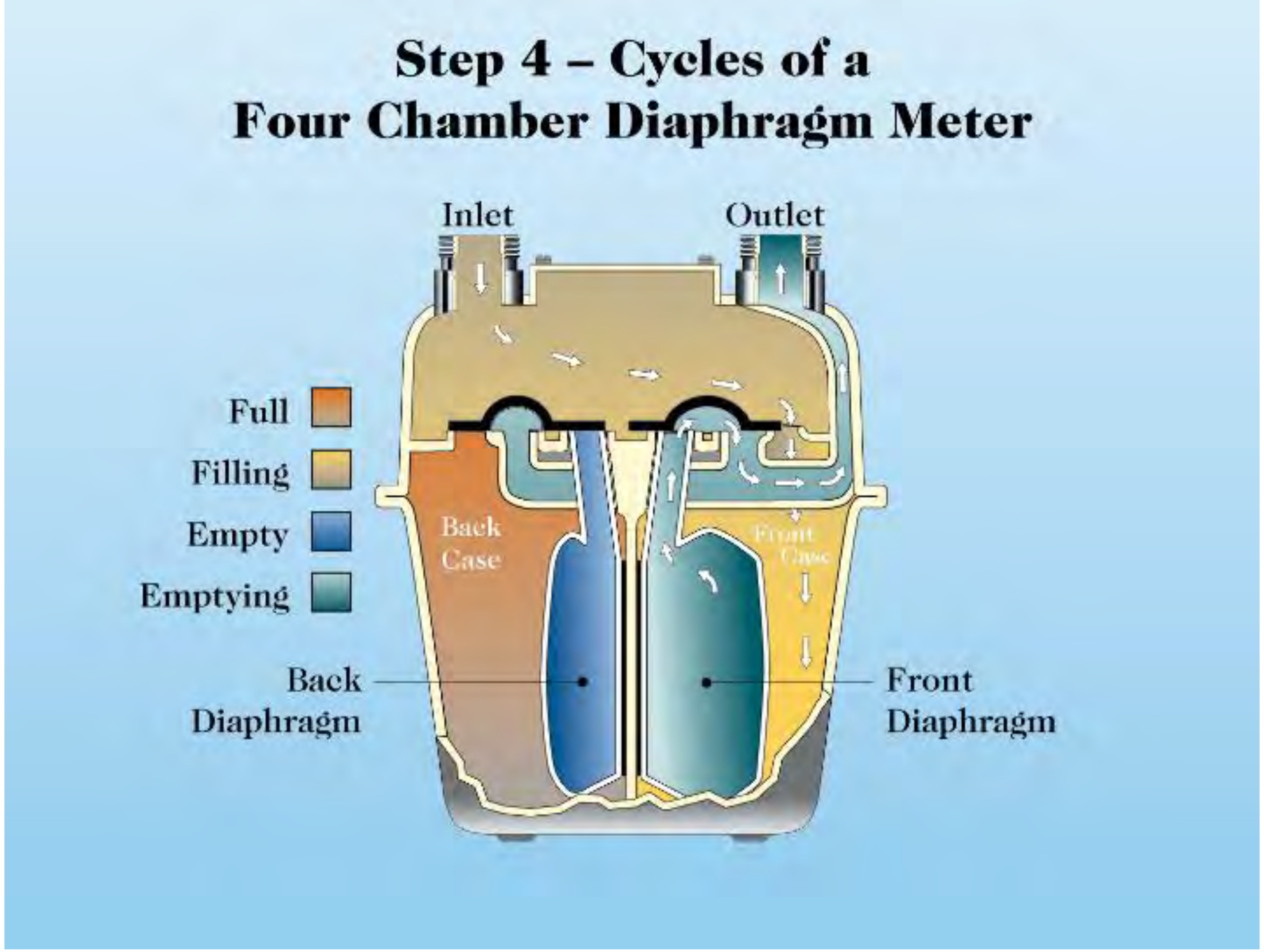
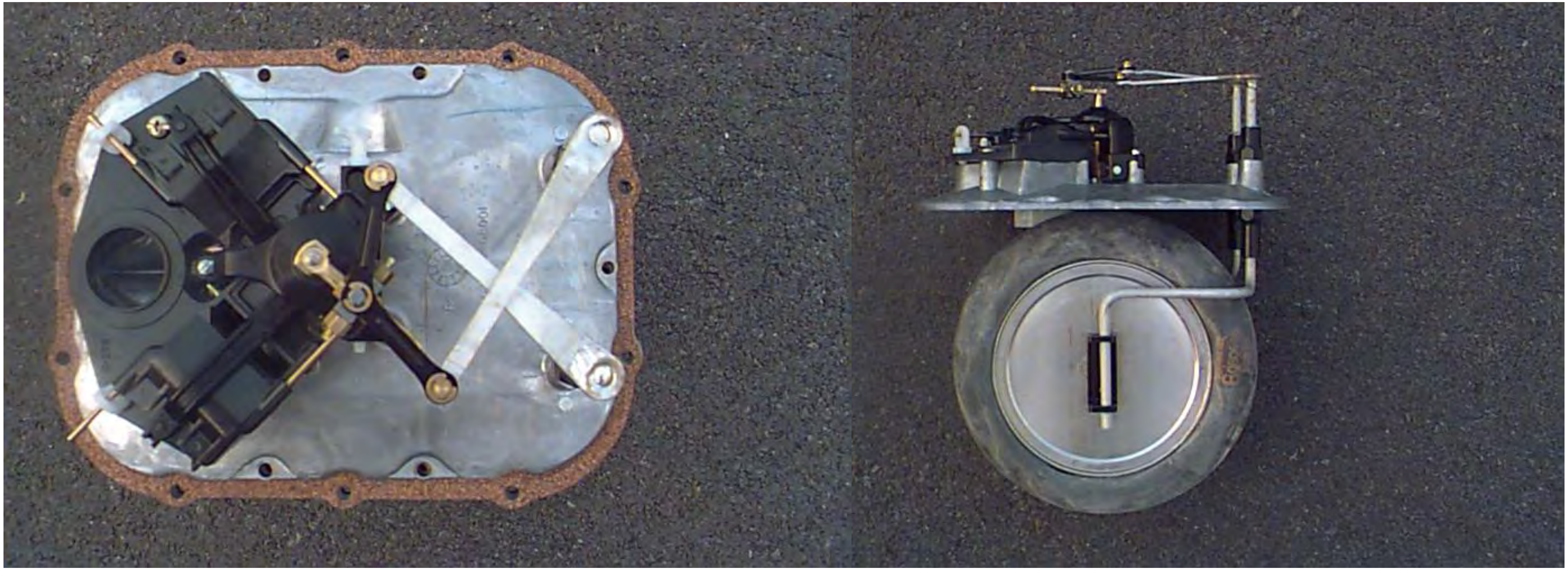


Diaphragm Meter Operation



Diaphragm Meter Operation



One of many approaches to diaphragm meter technology

Helpful Diaphragm Meter References

- ANSI B109-1: Diaphragm type - Gas Displacement Meters (with a capacity of less than 500 Cubic Feet Per Hour)
- ANSI B109-2: Diaphragm type - Gas Displacement Meters (with a capacity of greater than 500 Cubic Feet Per Hour)
- S-G-02 - Specifications for the verification and reverification of diaphragm meters

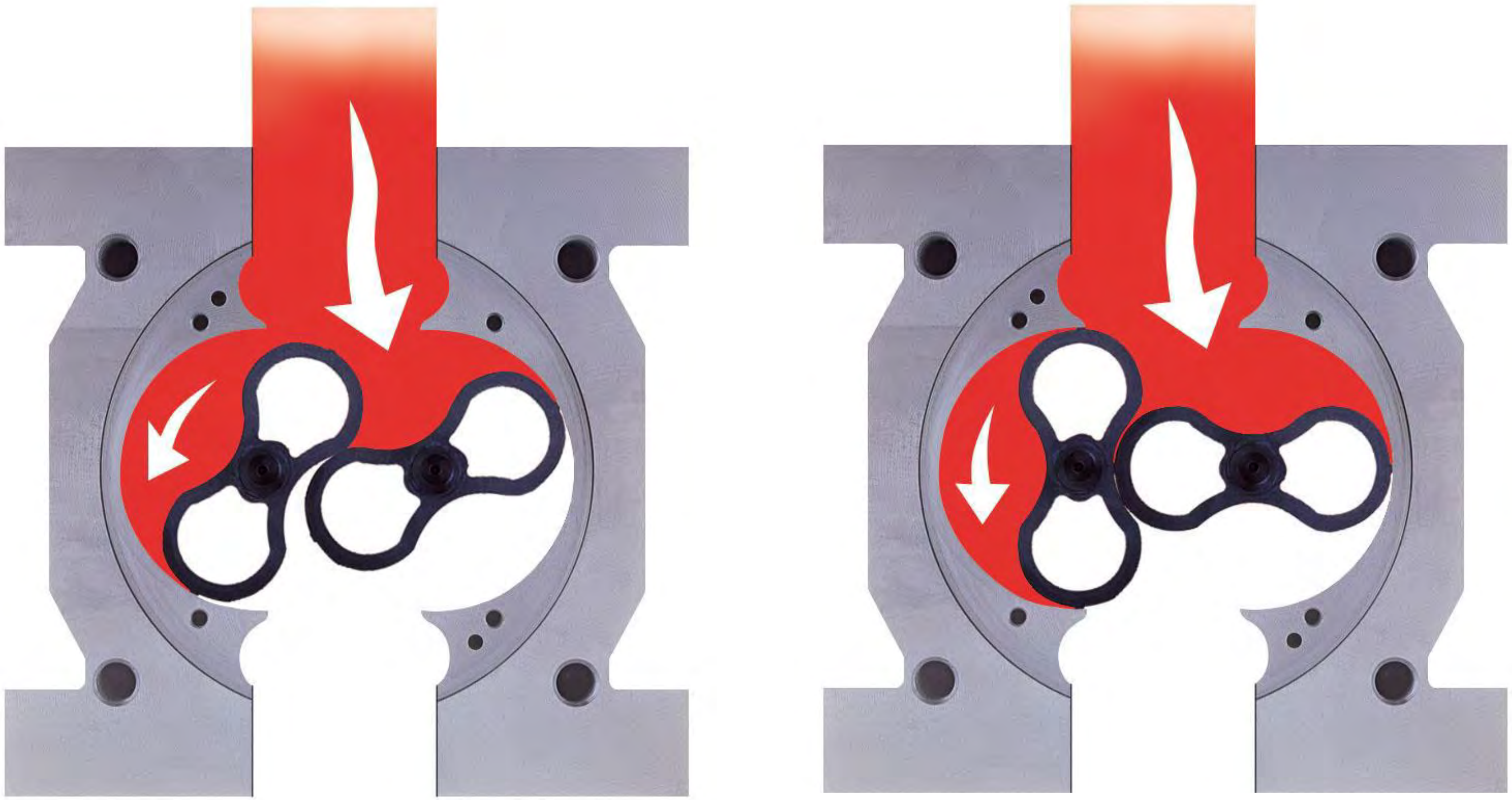
Rotary Meter Types

Positive Displacement Meter Types

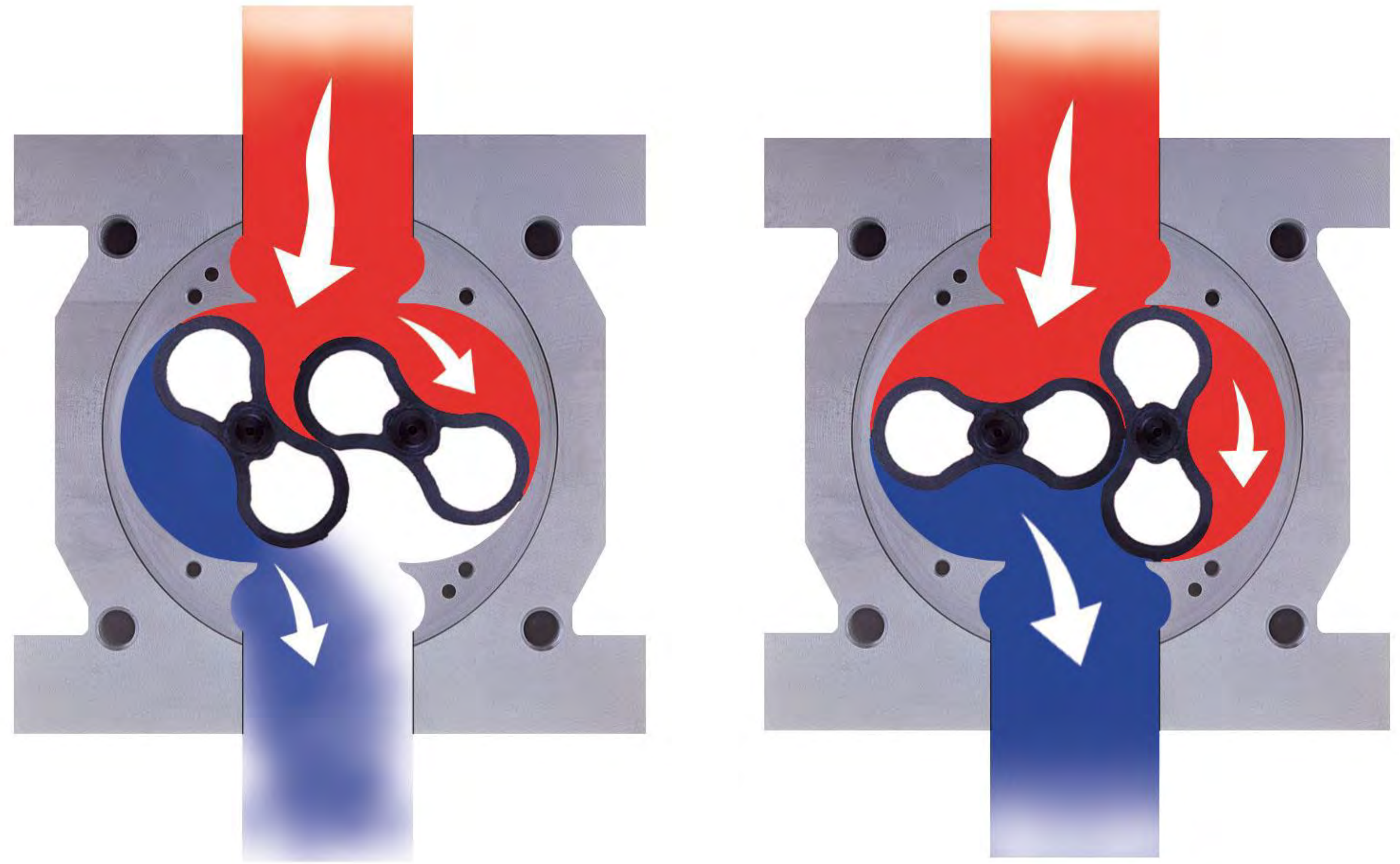
Rotary Meter History

- 1846 - Introduced by the Roots brothers in a water pump design
- 1920 - The first gas rotary meter was released using the lobed impeller model from the Roots brothers' design for gas service
- Over the years - There have been many improvements in materials, modular design, manufacturing and electronics

Principle of Operation - Rotary Meters



Principle of Operation - Rotary Meters



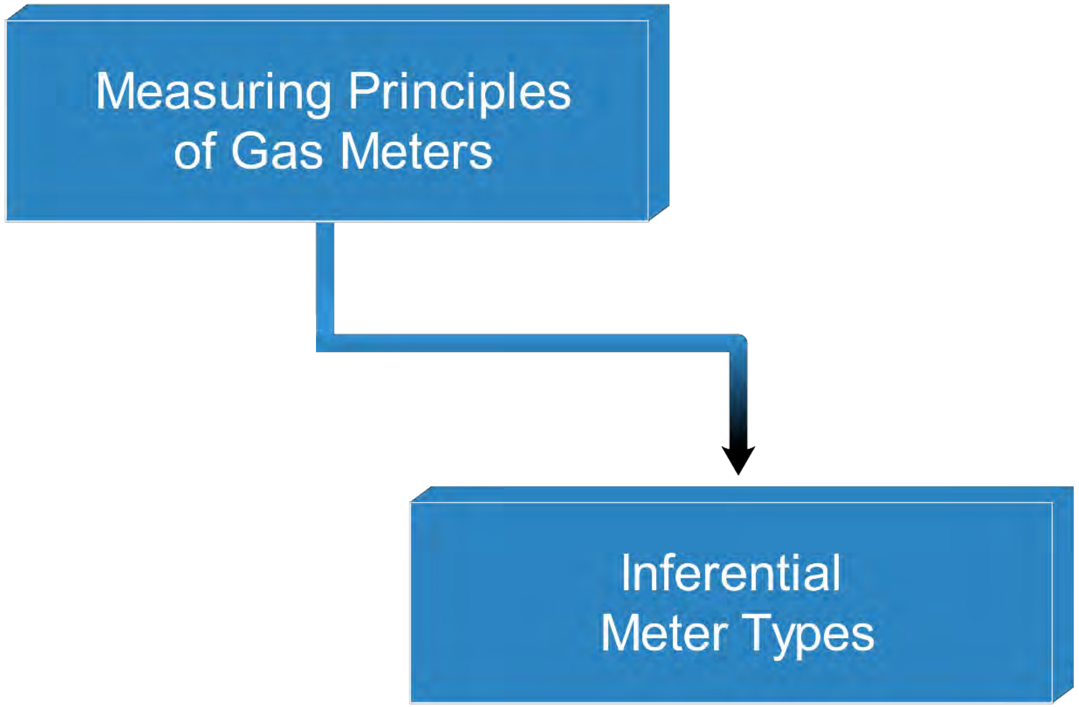
Rotary Meter with Electronic Volume Corrector

- Electronic Volume Corrector (EVC)
  - ✓Temperature correction
  - ✓Pressure correction
  - ✓Non-ideal correction
  - ✓Data logging
  - ✓Provides communications
  - ✓Battery powered
  - ✓Does the calculations and provides a standard volume

Helpful Rotary Meter References

- ANSI B109.3 Rotary-Type Gas Displacement Meter
- AGA XM1901 (parts 1-6) Rotary-Type Gas Displacement Meters
- EN 12480: Gas Meters-Rotary Displacement Gas Meters

Types Inferential Meters



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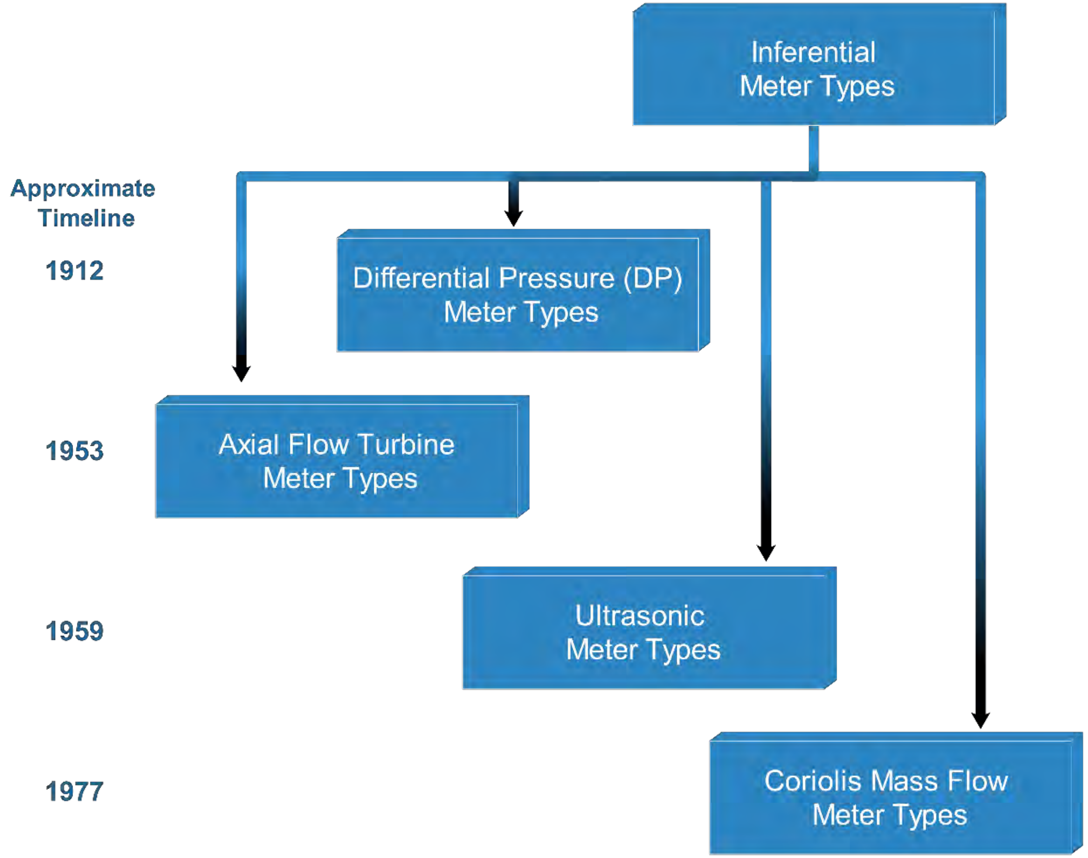
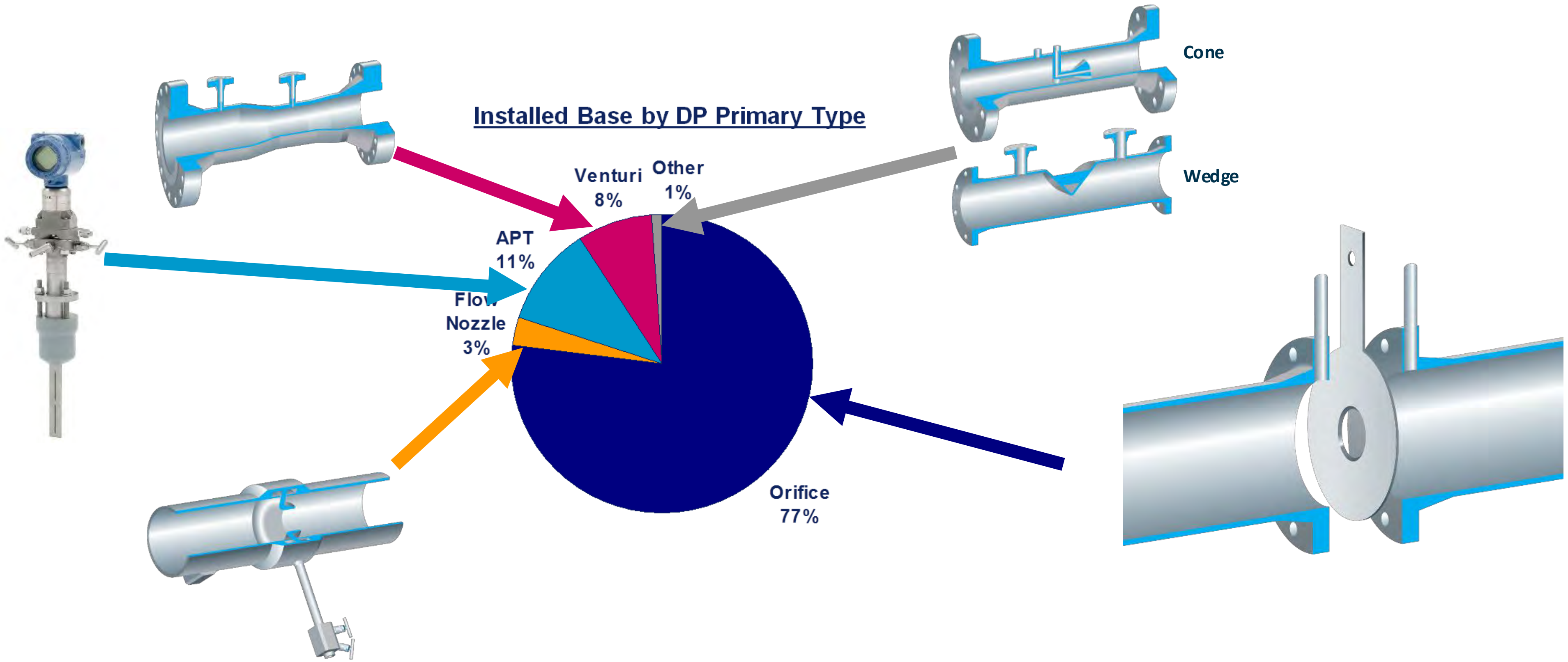
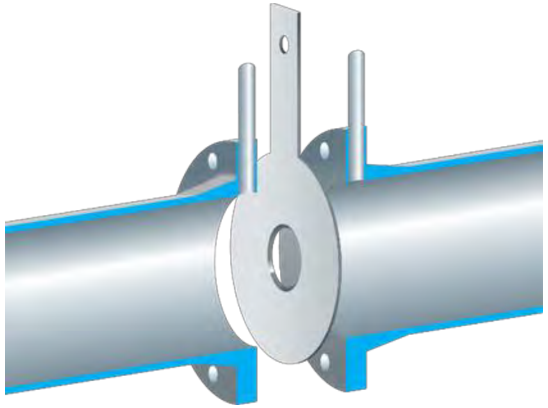


Differential Pressure (DP) Flowmeter Types



History of Orifice Meters

- 1890 - an orifice meter designed by Professor S.W. Robinson of Ohio State University was used to measure gas near Columbus, Ohio
- 1912 - The modern orifice meter for natural gas measurement was developed when Thomas Weymouth published an ASME paper on his orifice meter based on tests he had run since 1904
- The development of tables of coefficients and modeling equations could be used to predict orifice meter performance
- This allowed meters to be put in place without being flow calibrated so long as if they were dimensionally similar to the ones used in the tests



Complete Differential Pressure (DP) Flow Equation

$$Q_{mass} = N C_D Y_1 E d^2 \sqrt{DP(\rho)}$$

Varies with Flow (modeled)
C_D = Discharge coefficient
Y_1 = Gas expansion factor

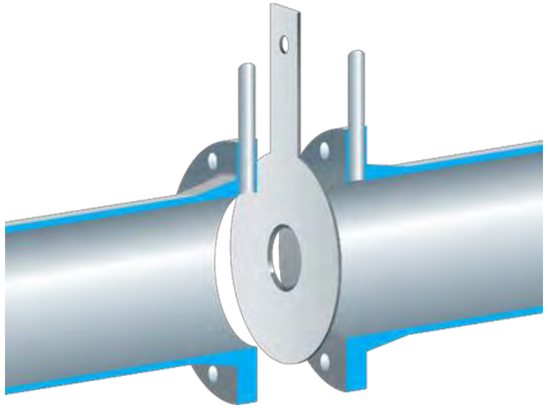
Varies with P & T
Density

Varies with Flow
DP - measured

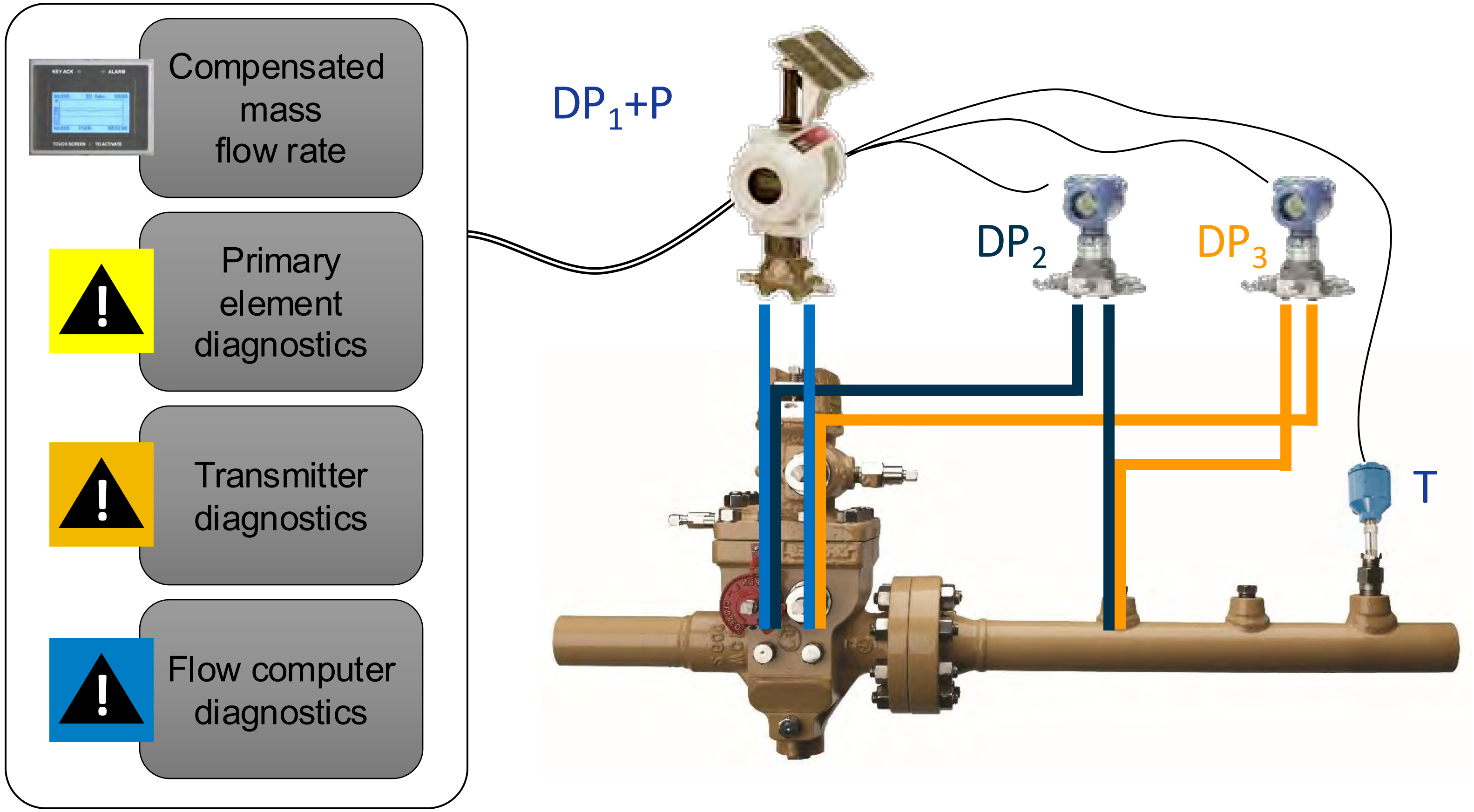
Varies with Temperature
E = Velocity of approach
d^2 = Bore diameter

$$= \frac{1}{\sqrt{1-\beta^4}}$$

$$\beta = \frac{d}{D}$$

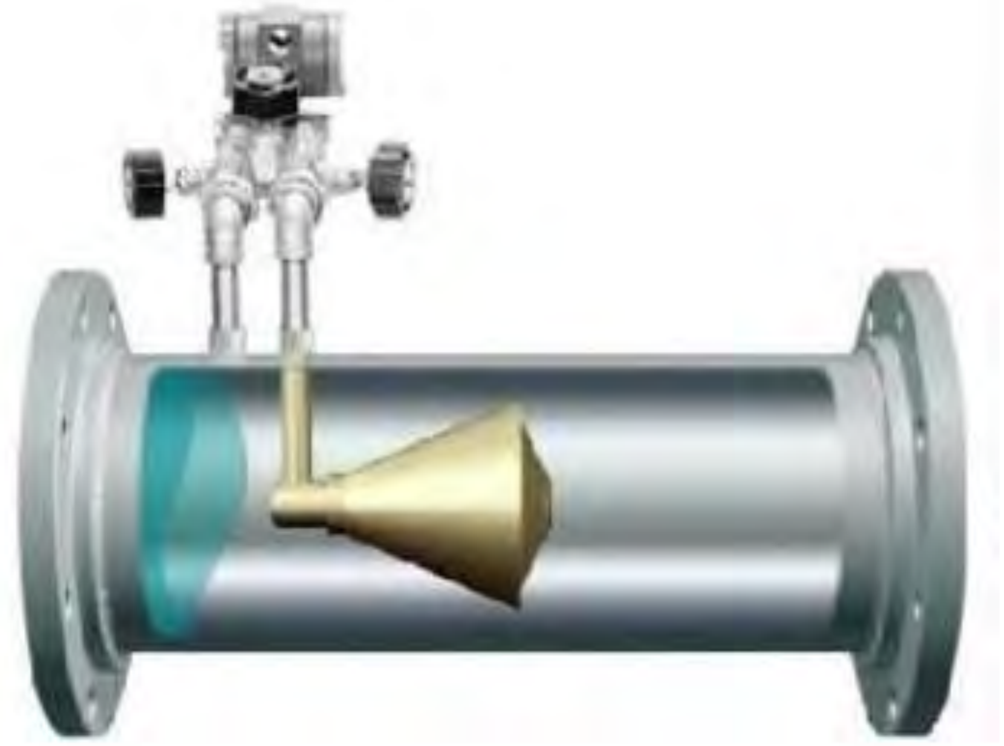


Smart DP System

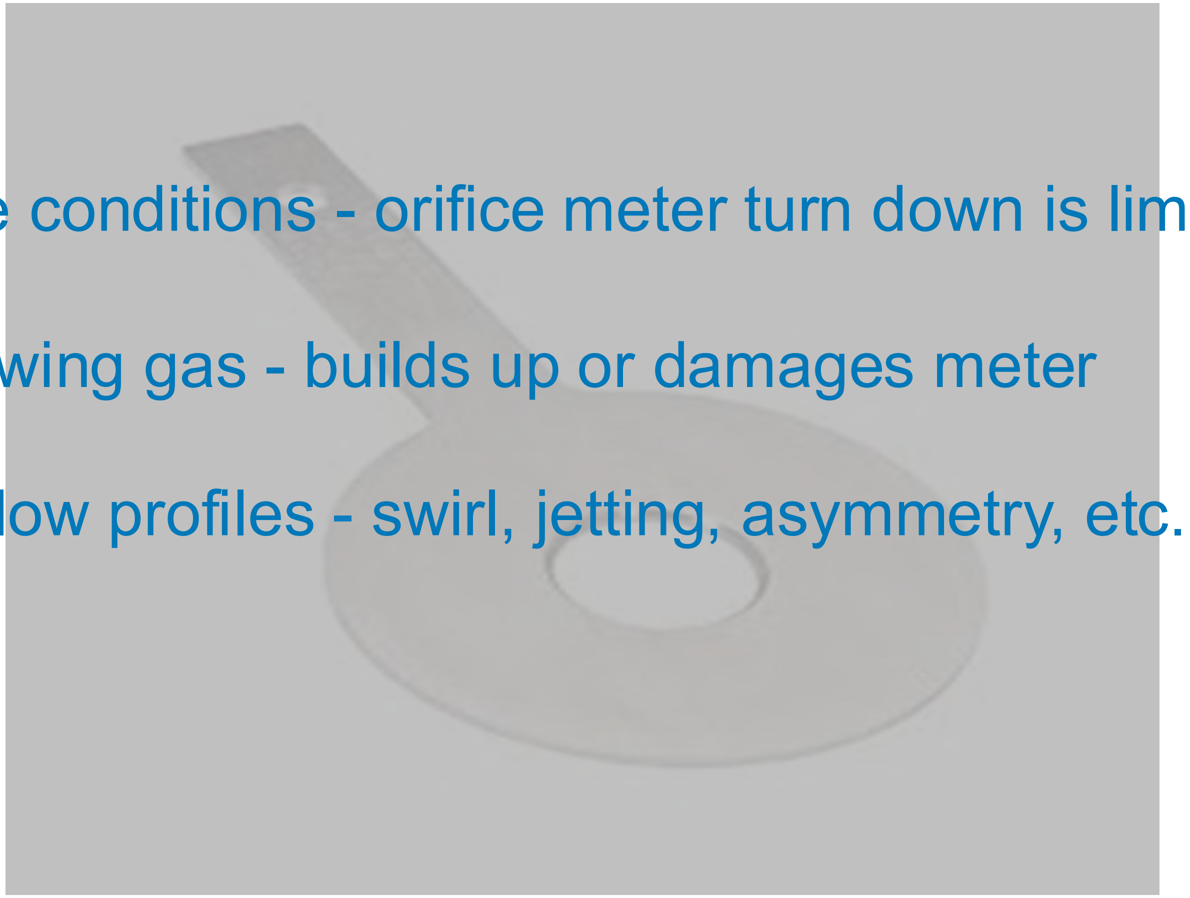


Cone Meter Basics and Features

- DP is created by a cone in the center of the pipe
- A high-pressure tap is located slightly upstream before the cone, while the low-pressure tap occurs in the downstream face of the cone
- Originally developed by McCrometer as V-Cone, now sold as generic cone meter by others
- Works well in dirty process fluids and wet gas
- MC requires meter to be calibrated to determine coefficients



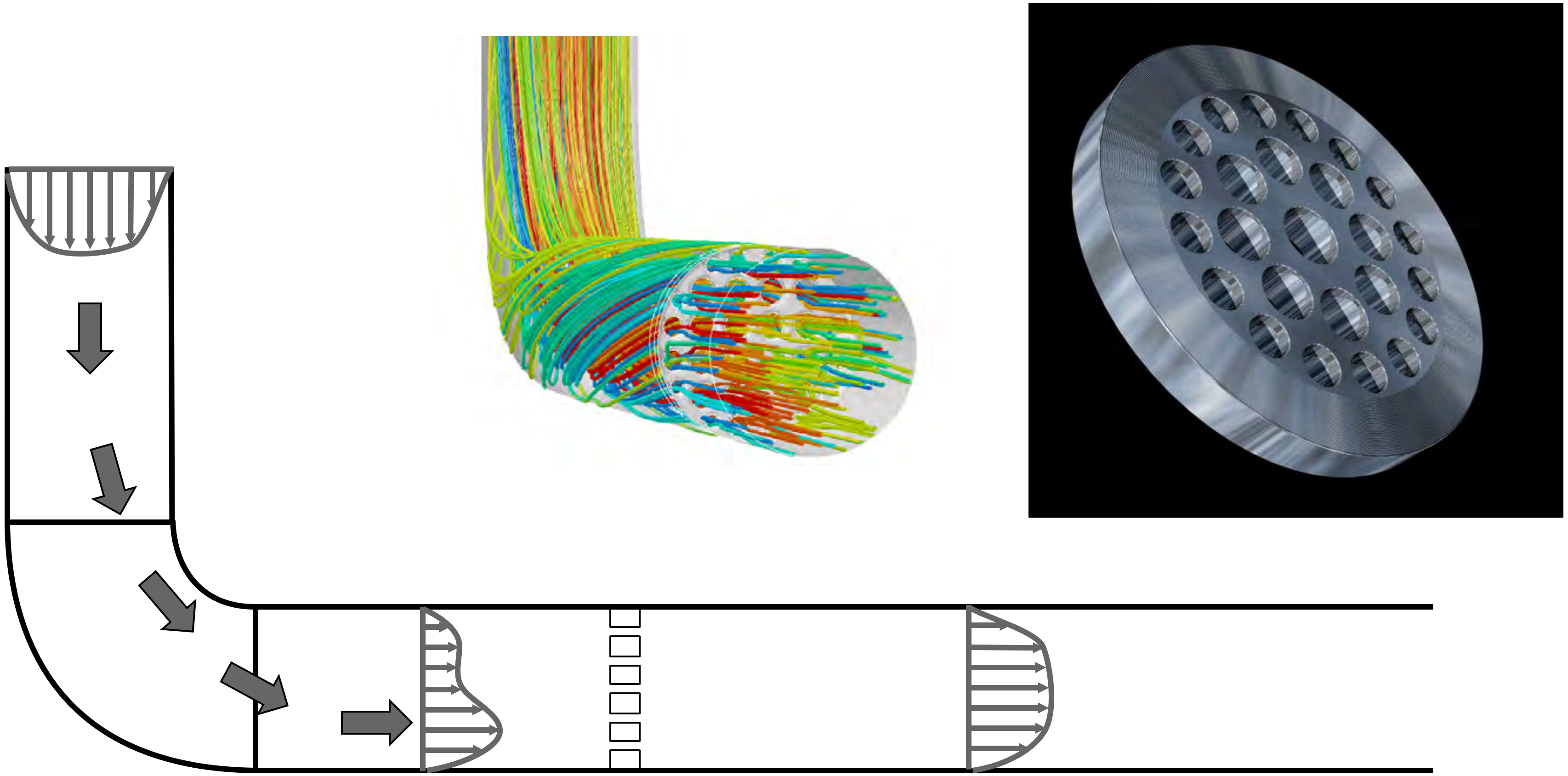
Effects on Meter Accuracy



- Out of range conditions - orifice meter turn down is limited (3:1)
- Debris in flowing gas - builds up or damages meter
- Unsuitable flow profiles - swirl, jetting, asymmetry, etc.

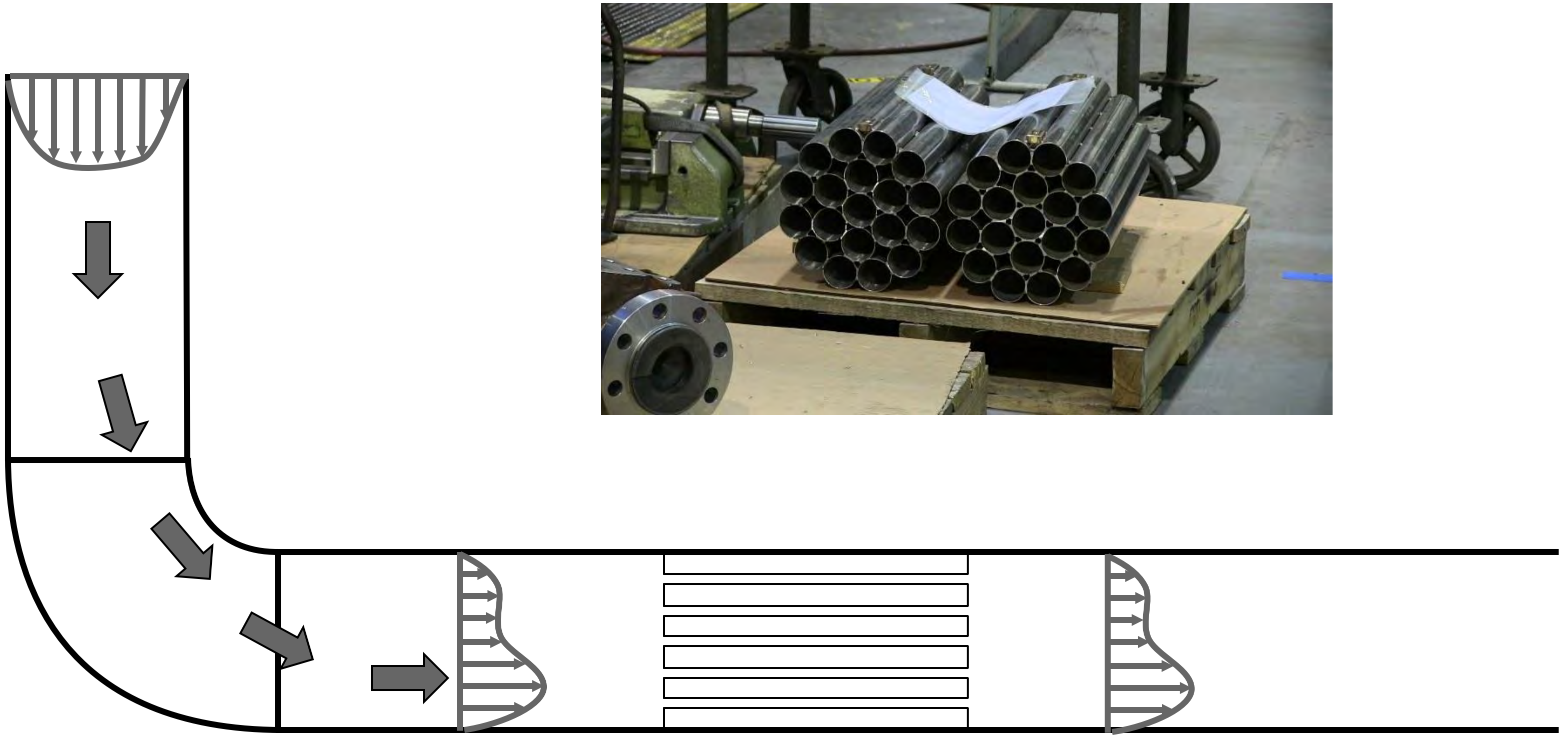
Flow Conditioners Needed

- Flow conditioners remove swirl ***and*** asymmetry



Straightening Vanes - Tube Bundles

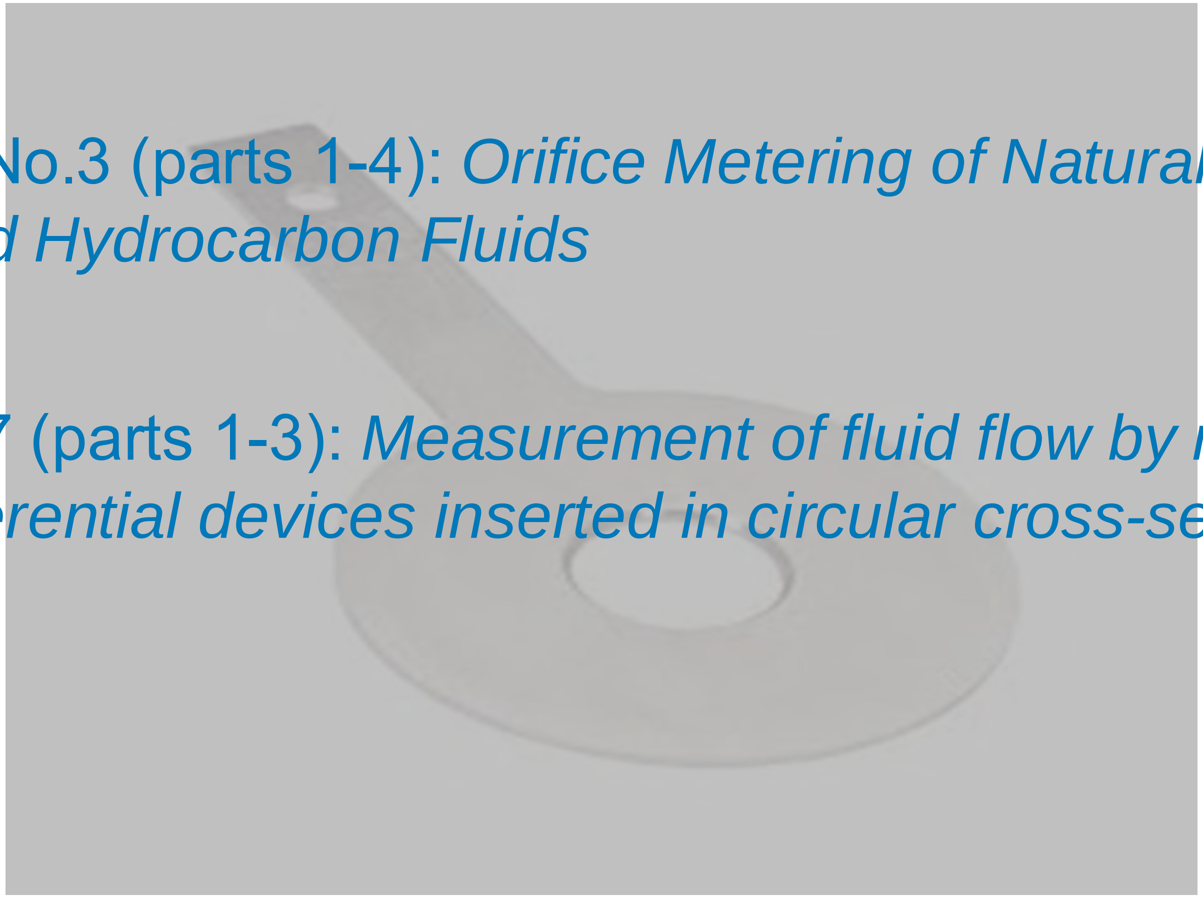
- Vanes and tube bundles remove swirl but ***not*** asymmetry



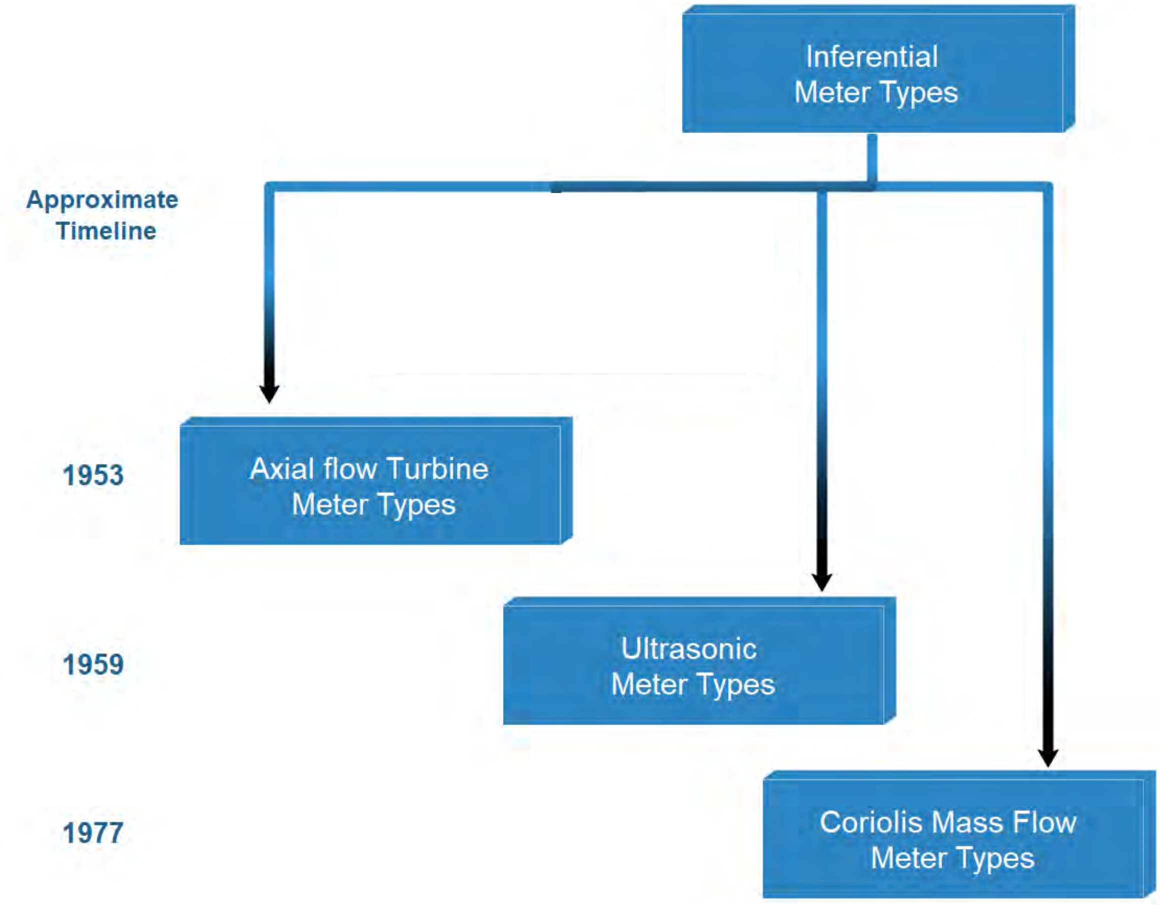
Helpful DP Meter References

- AGA Report No.3 (parts 1-4): *Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids*

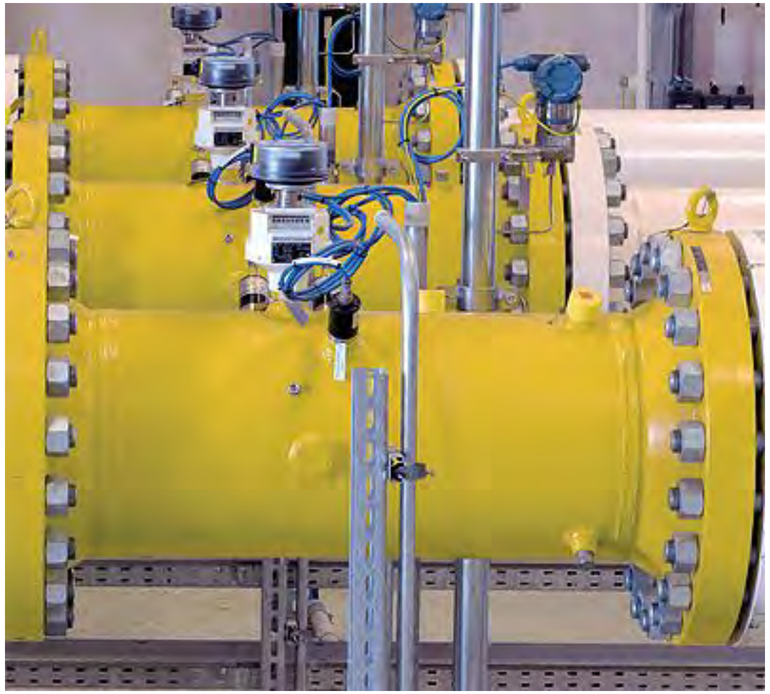
- ISO/IEC 5167 (parts 1-3): *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*



Types of Inferential Meters



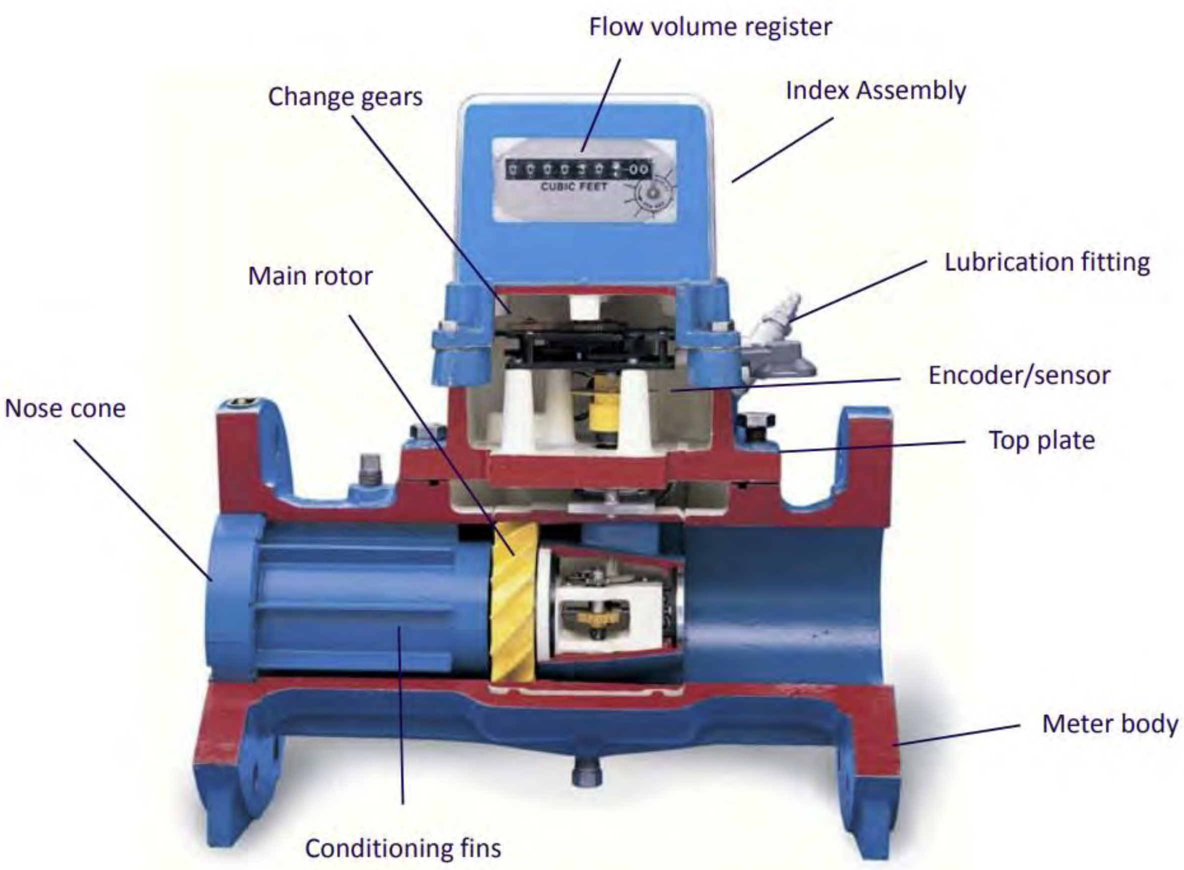
Gas Turbine Meters



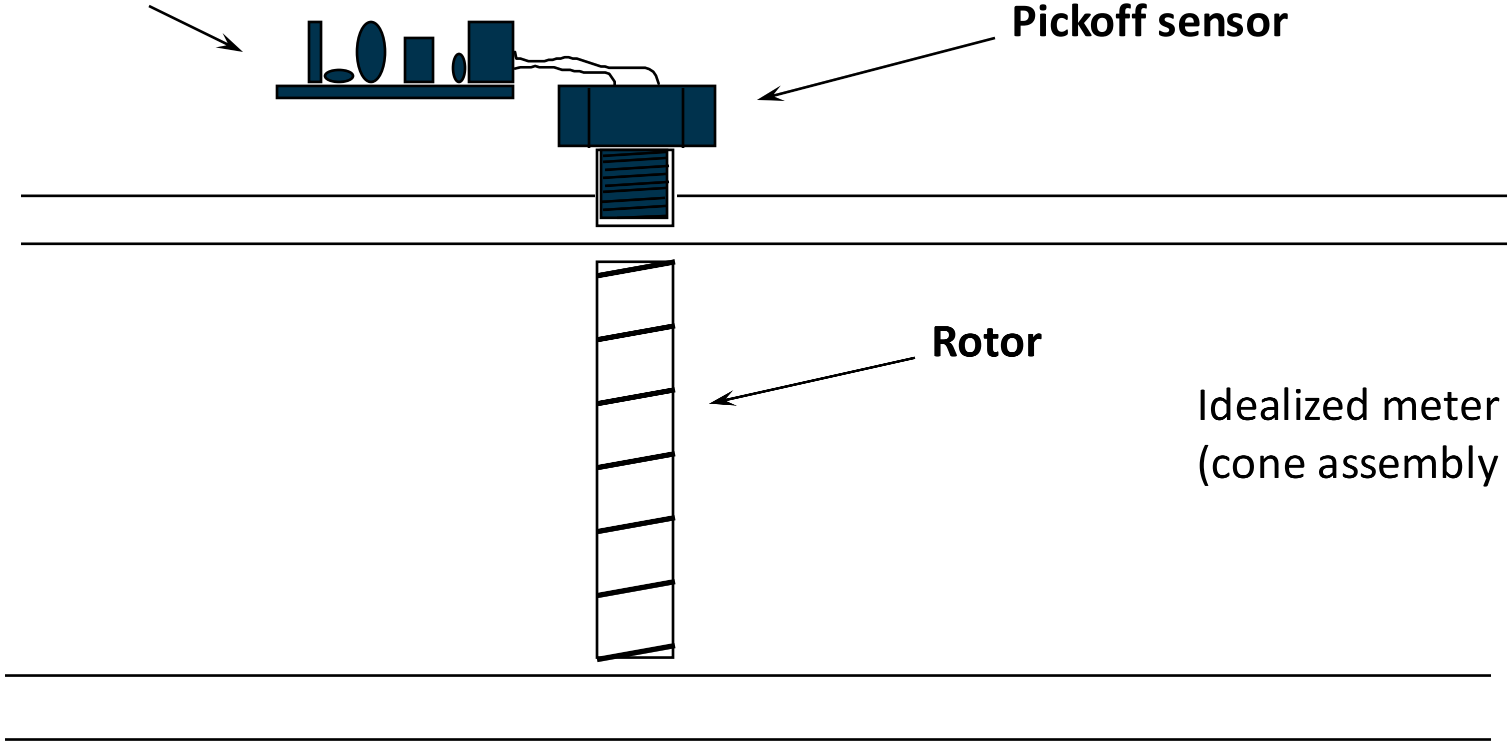
Gas Turbine Meter History

- 1790 - Reinhard Woltman credited with the invention of the first turbine meter
- 1953 - The history of using turbine meters to measure gas flow starts
- 1963 - Rockwell introduced a turbine meter to the gas industry
- 1973 - Became widely accepted by the gas industry
- 1973+ Range from ¾ inch to 24 inch and larger with 5 to 1450psi applications

Turbine Meter Operation

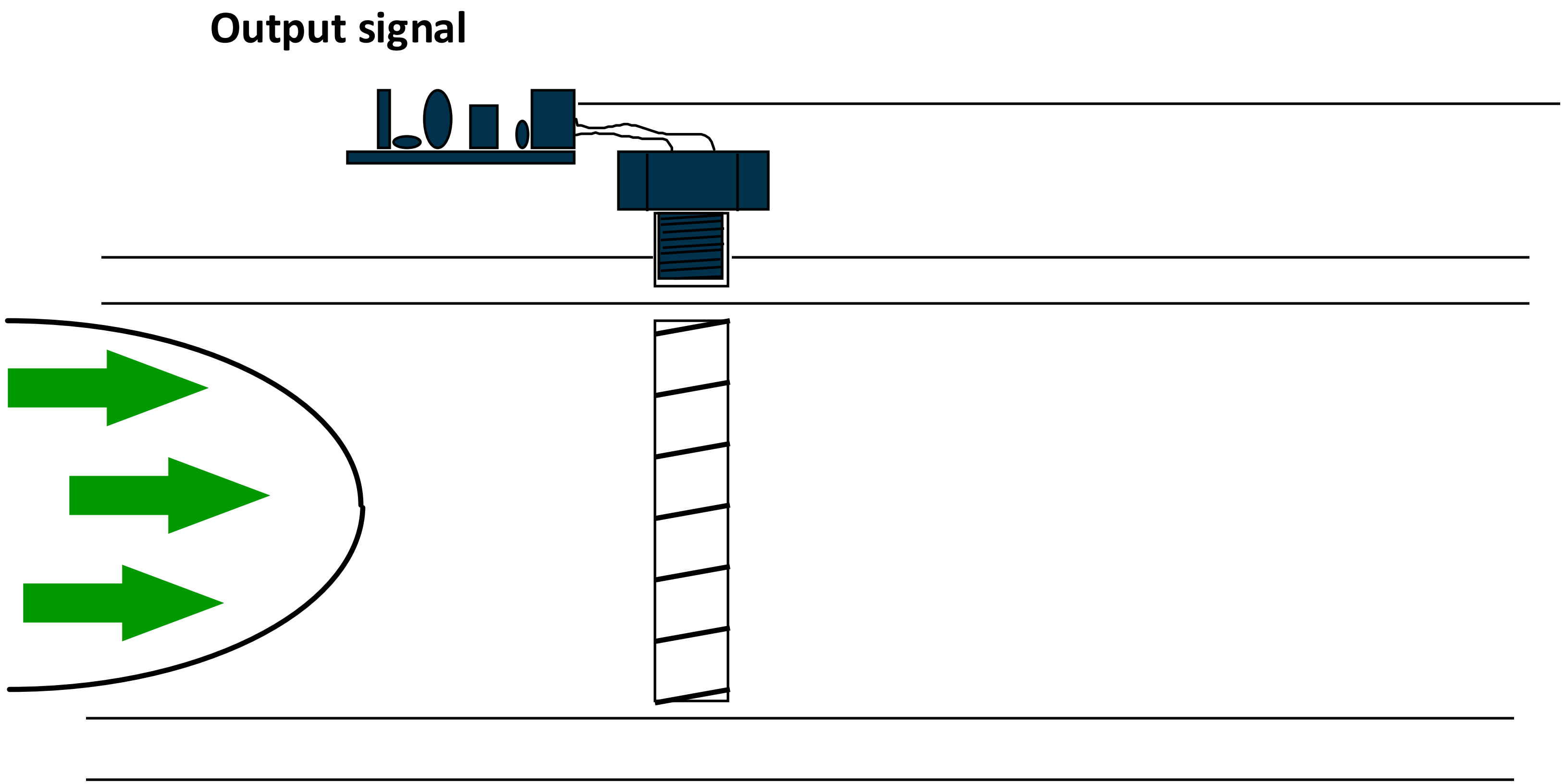


Turbine Meter Operation



Idealized meter
(cone assembly not shown)

Turbine Meter Operation



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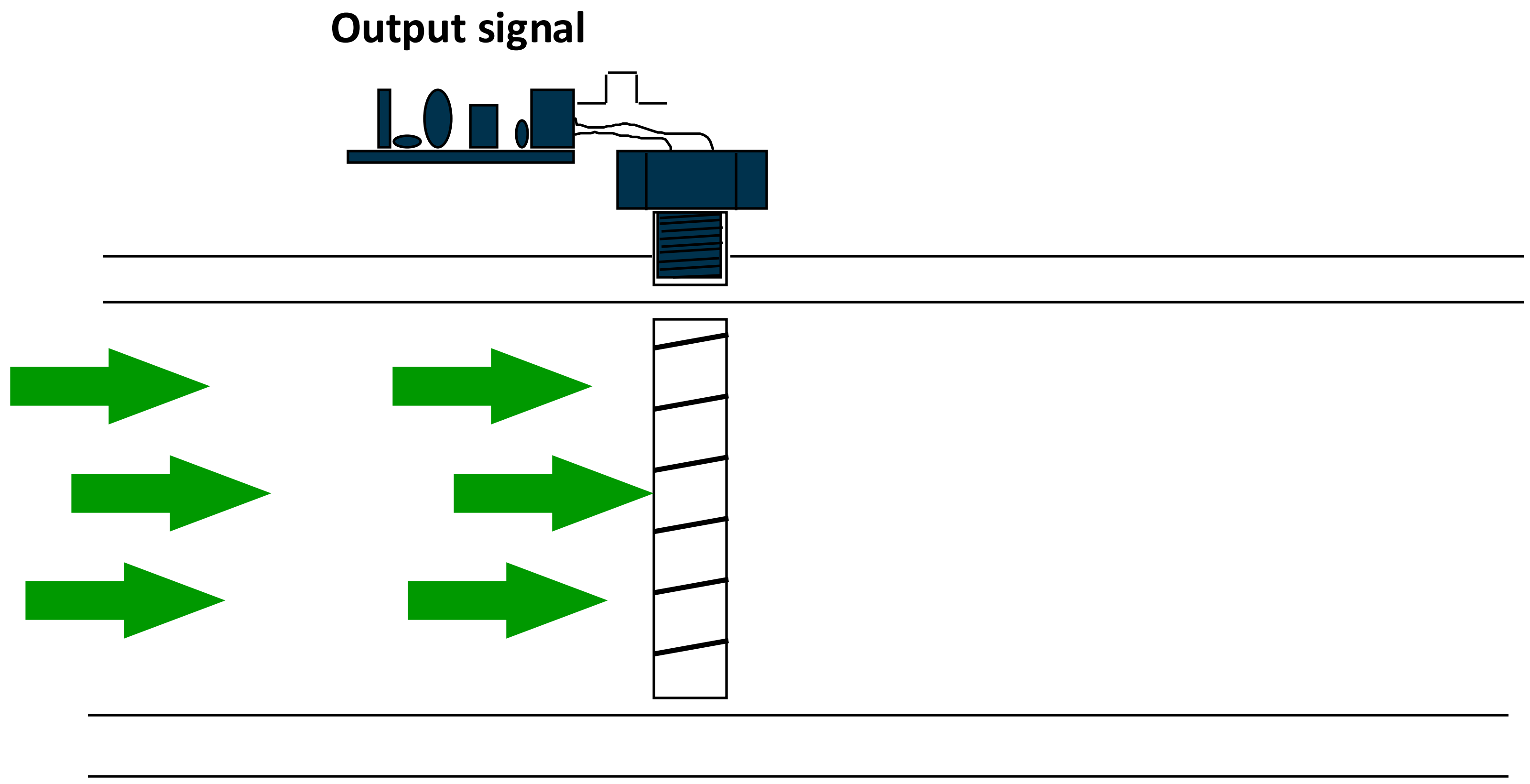

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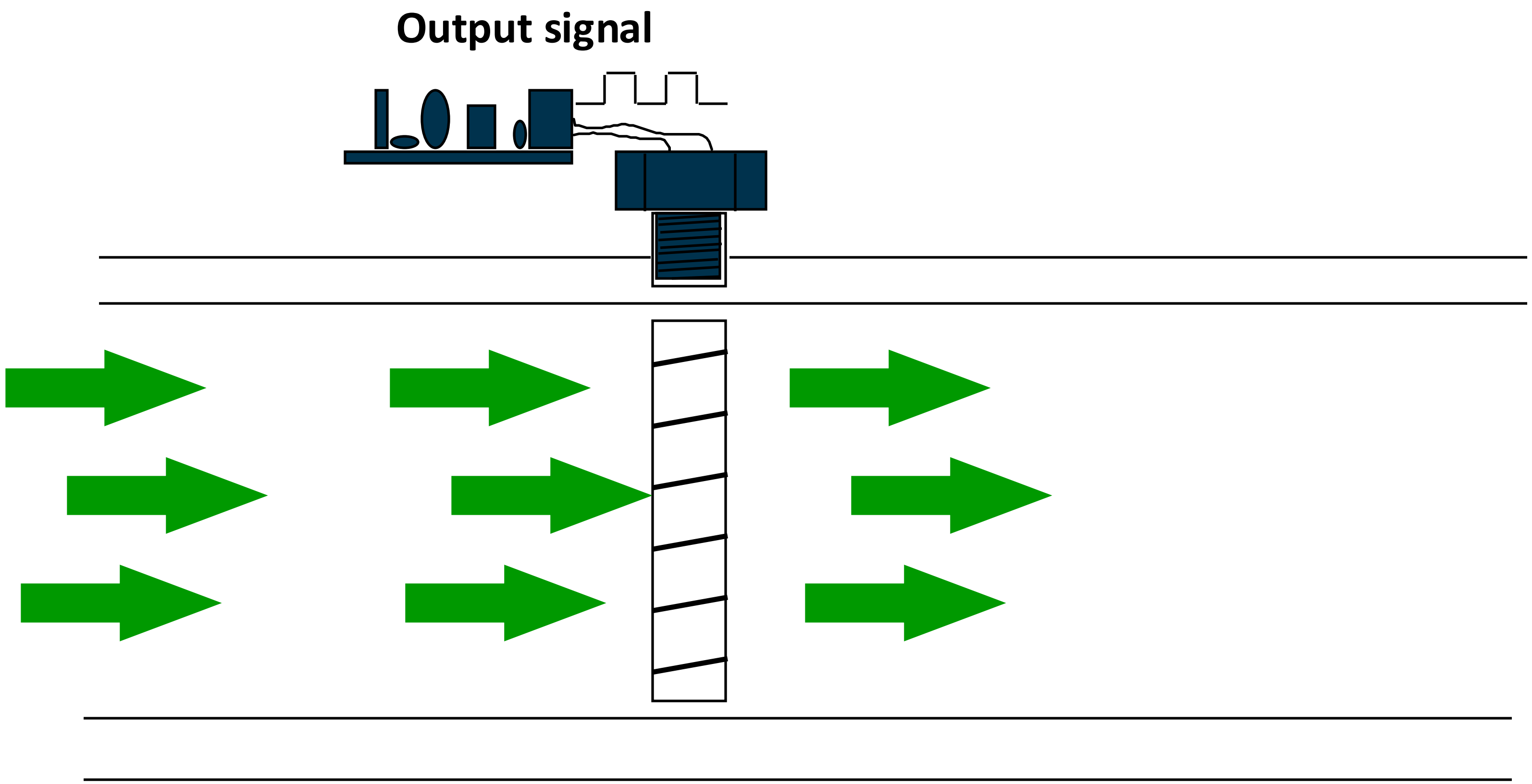

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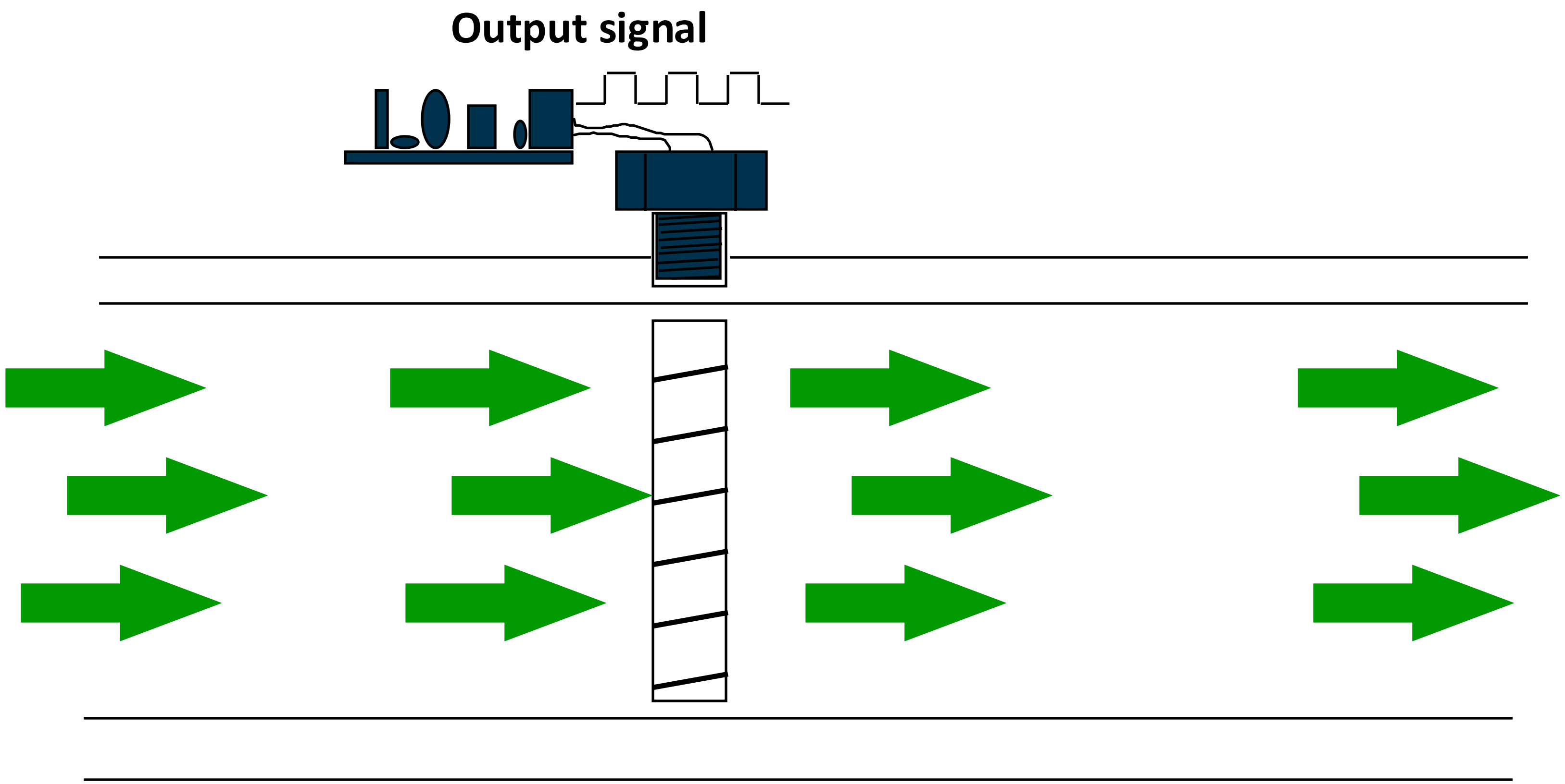

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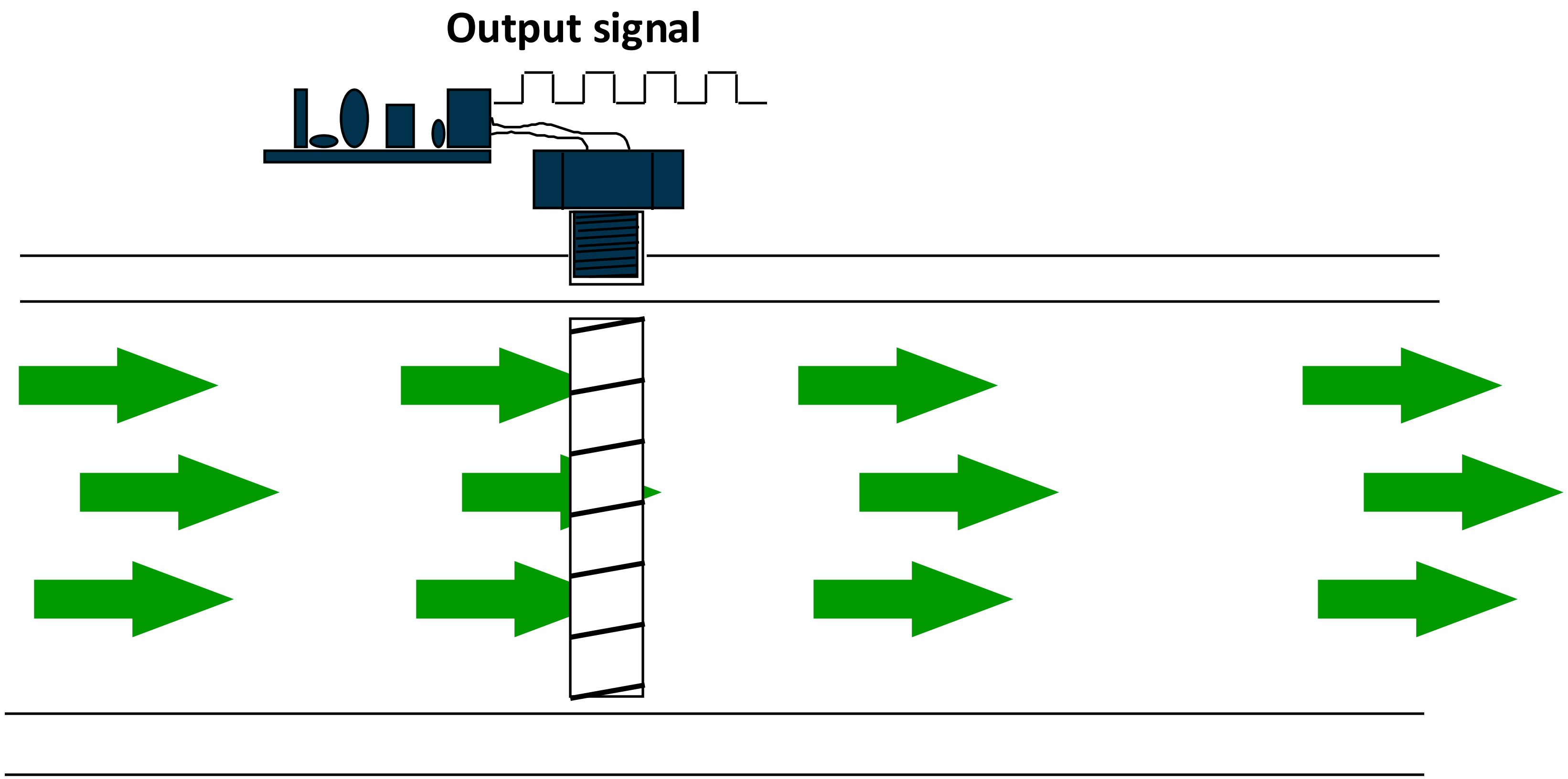

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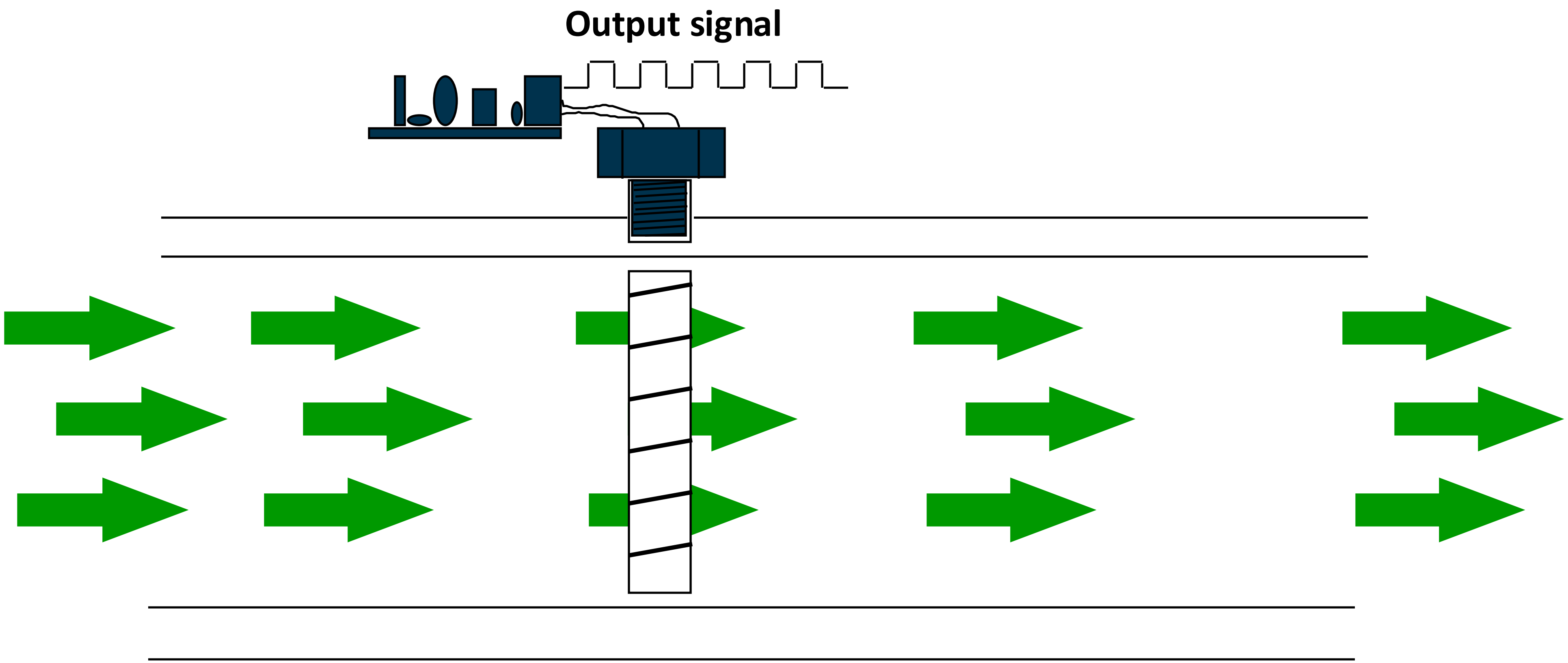

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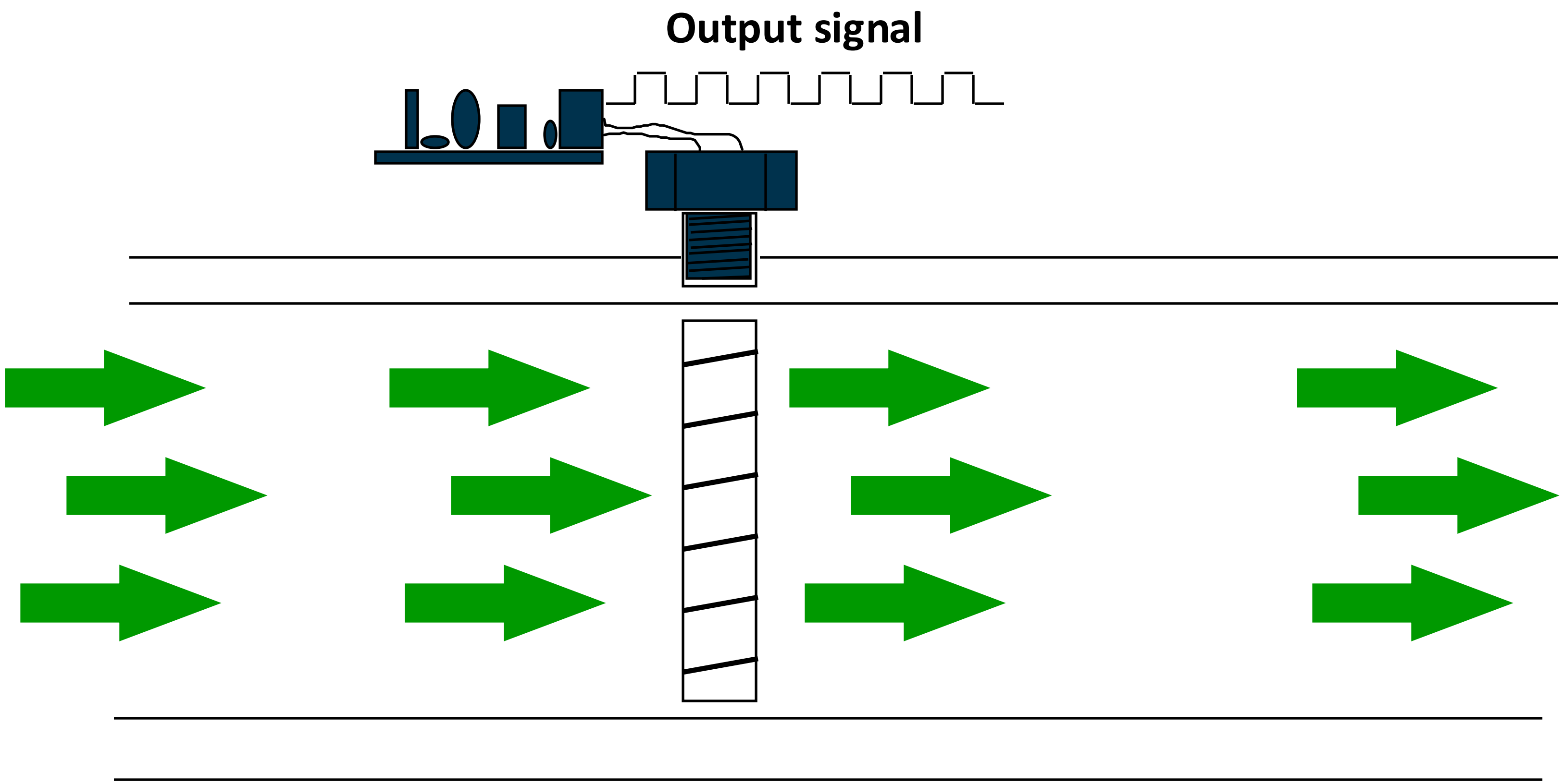

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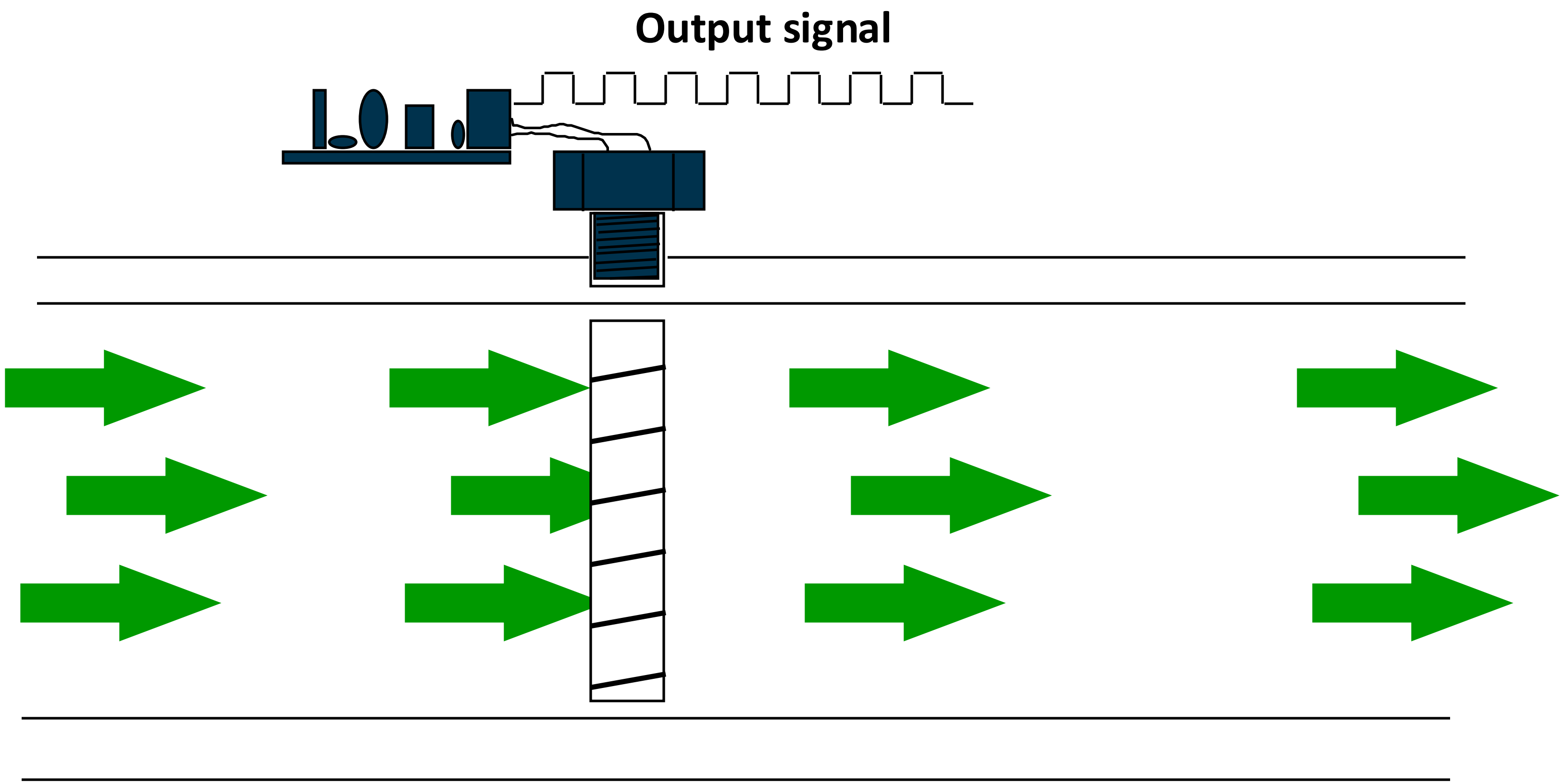

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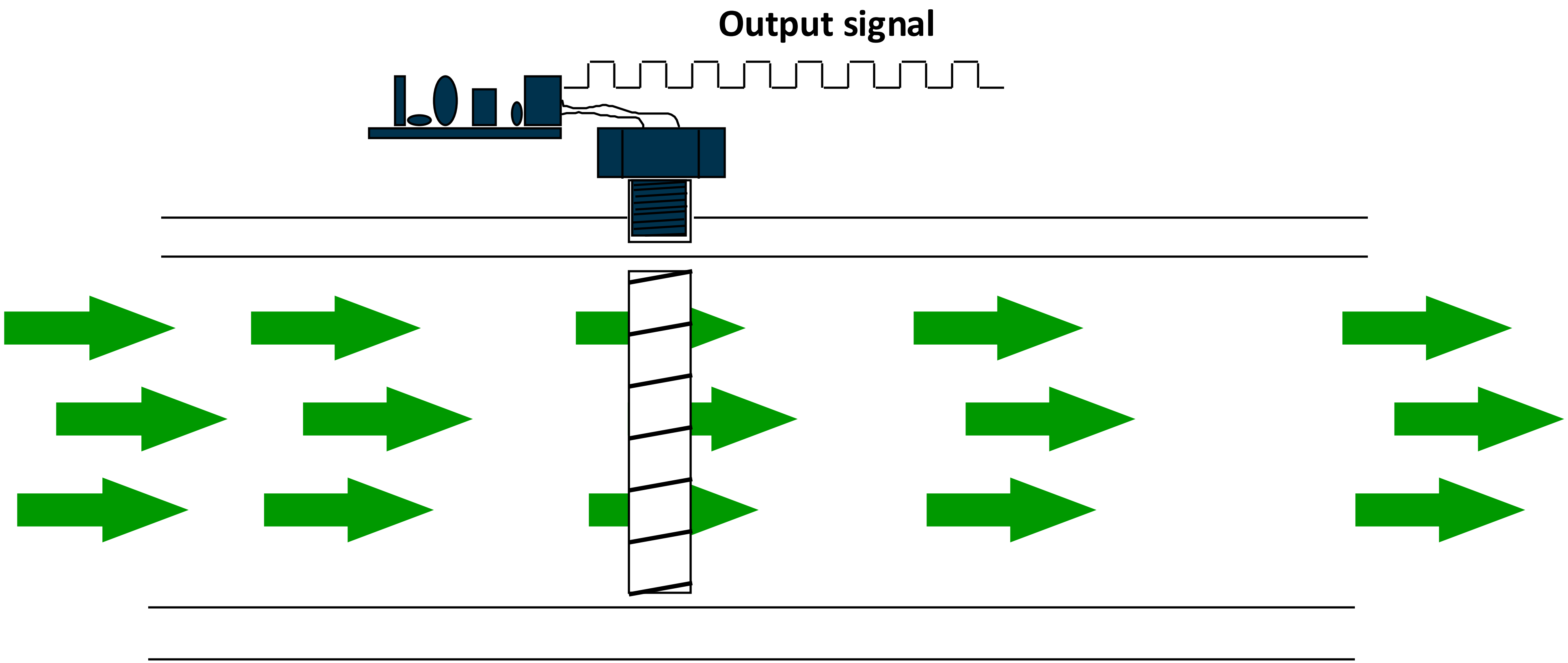

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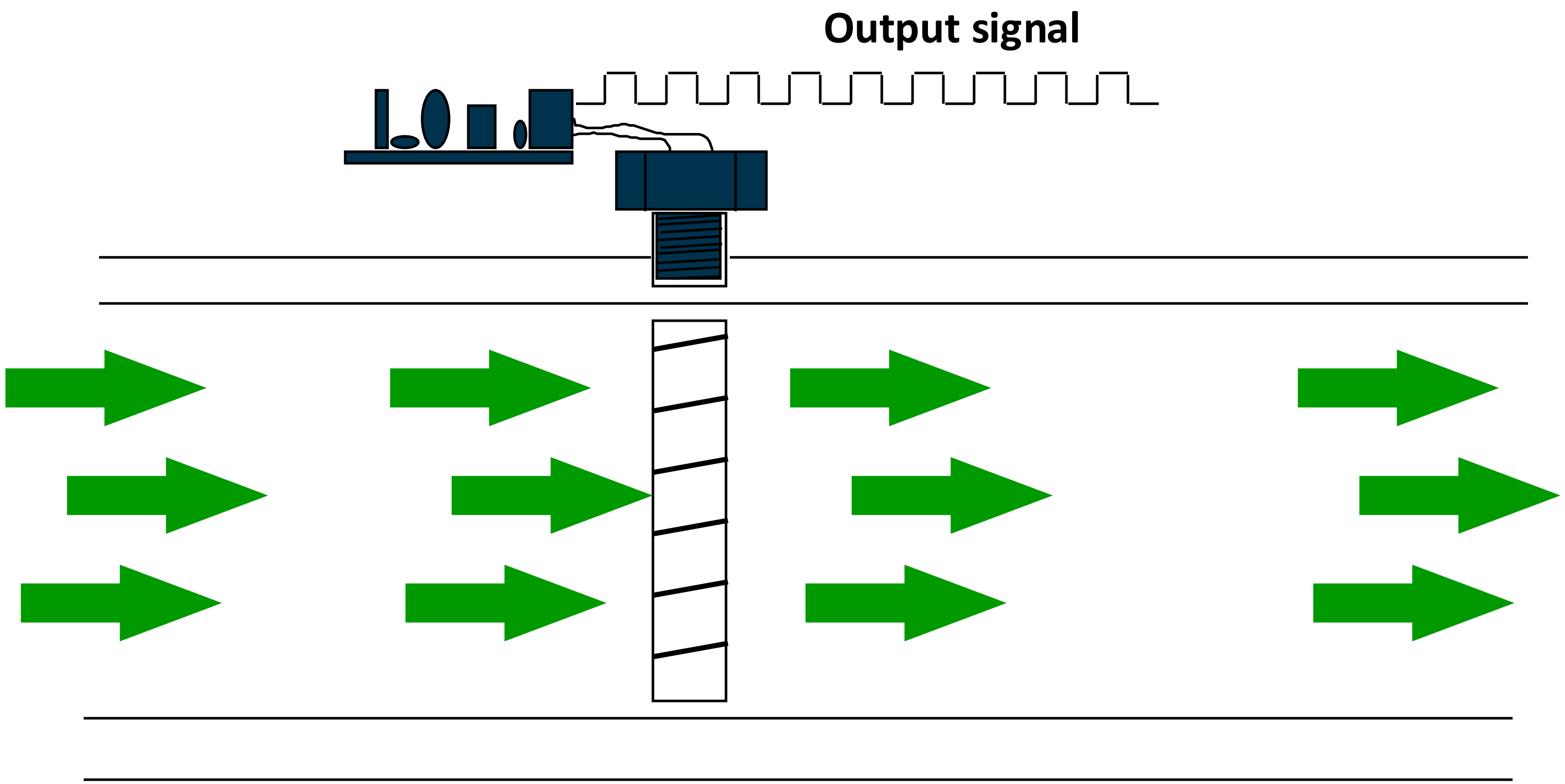

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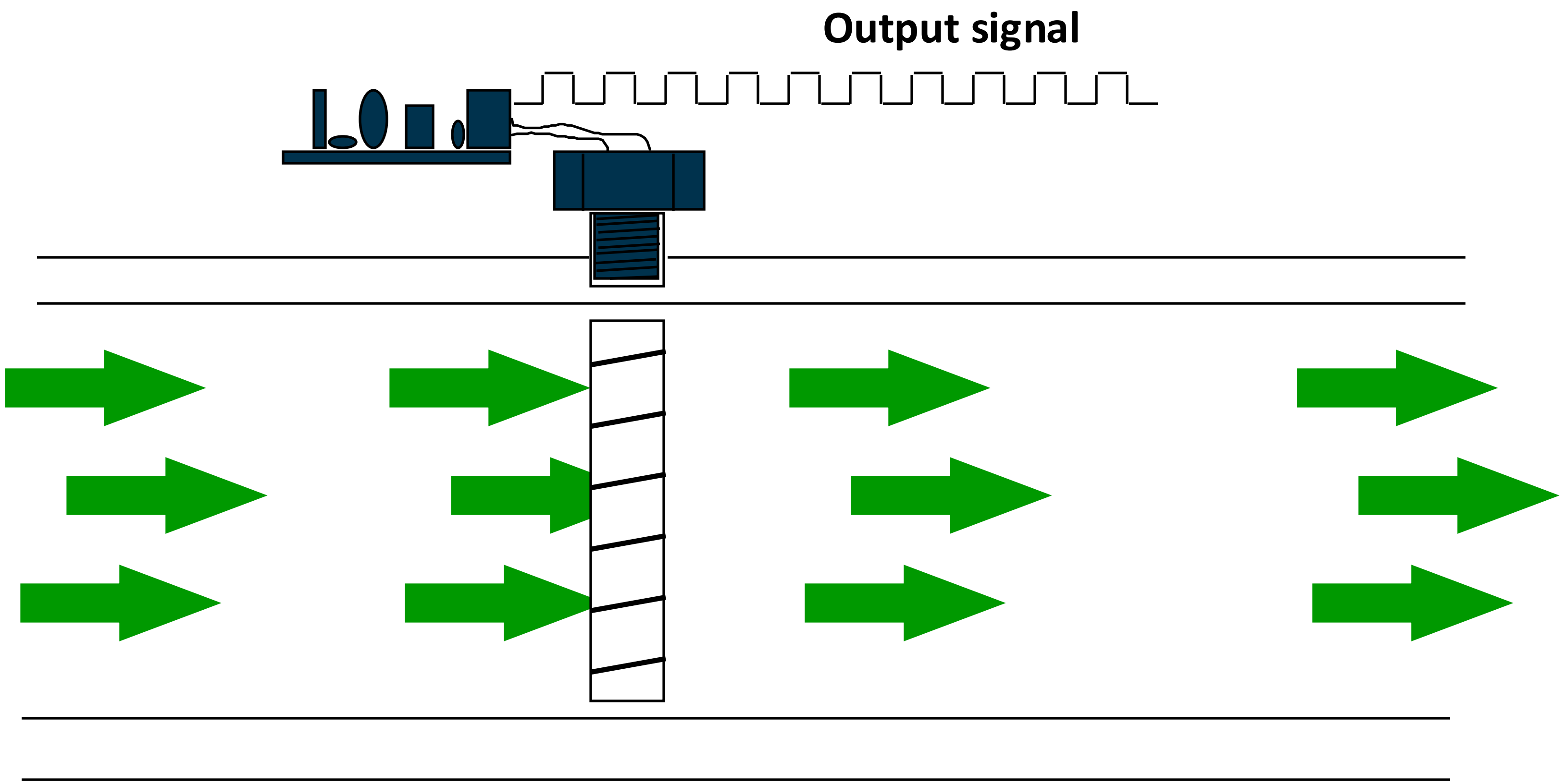

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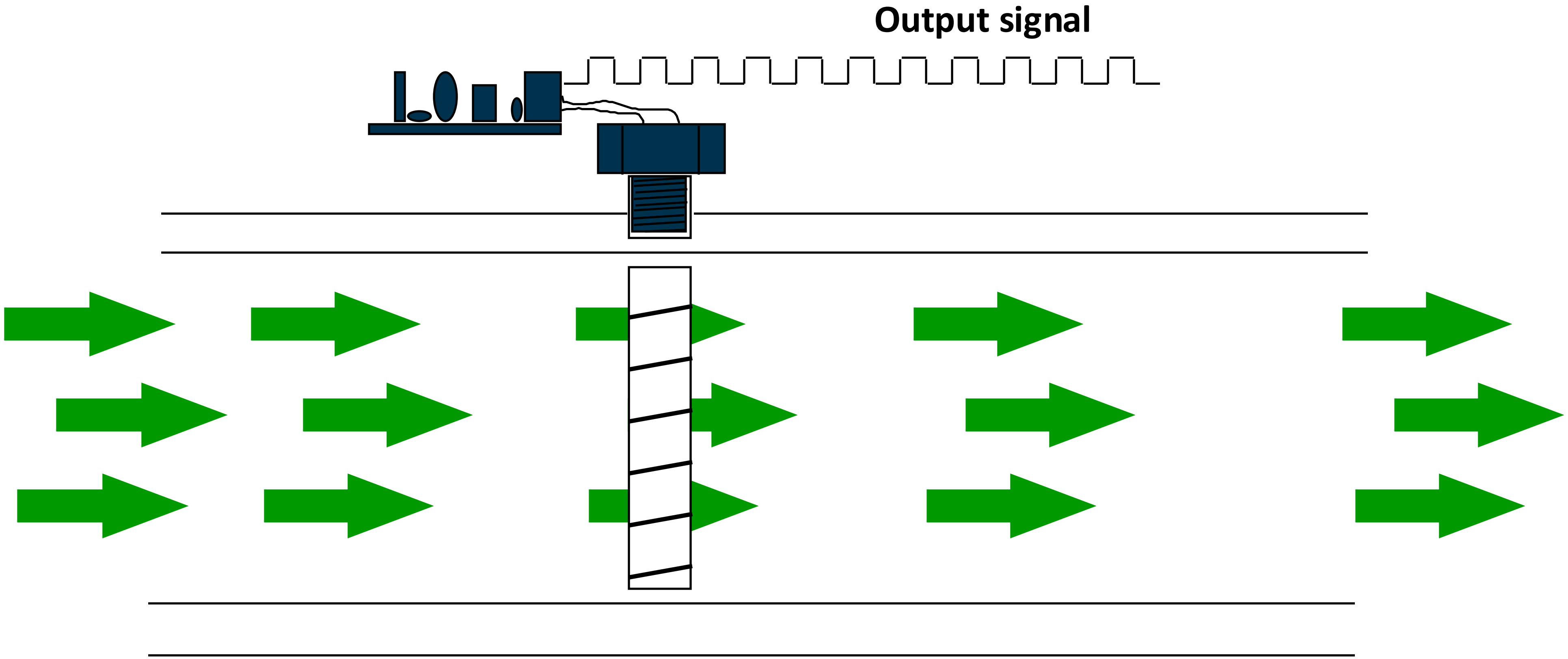

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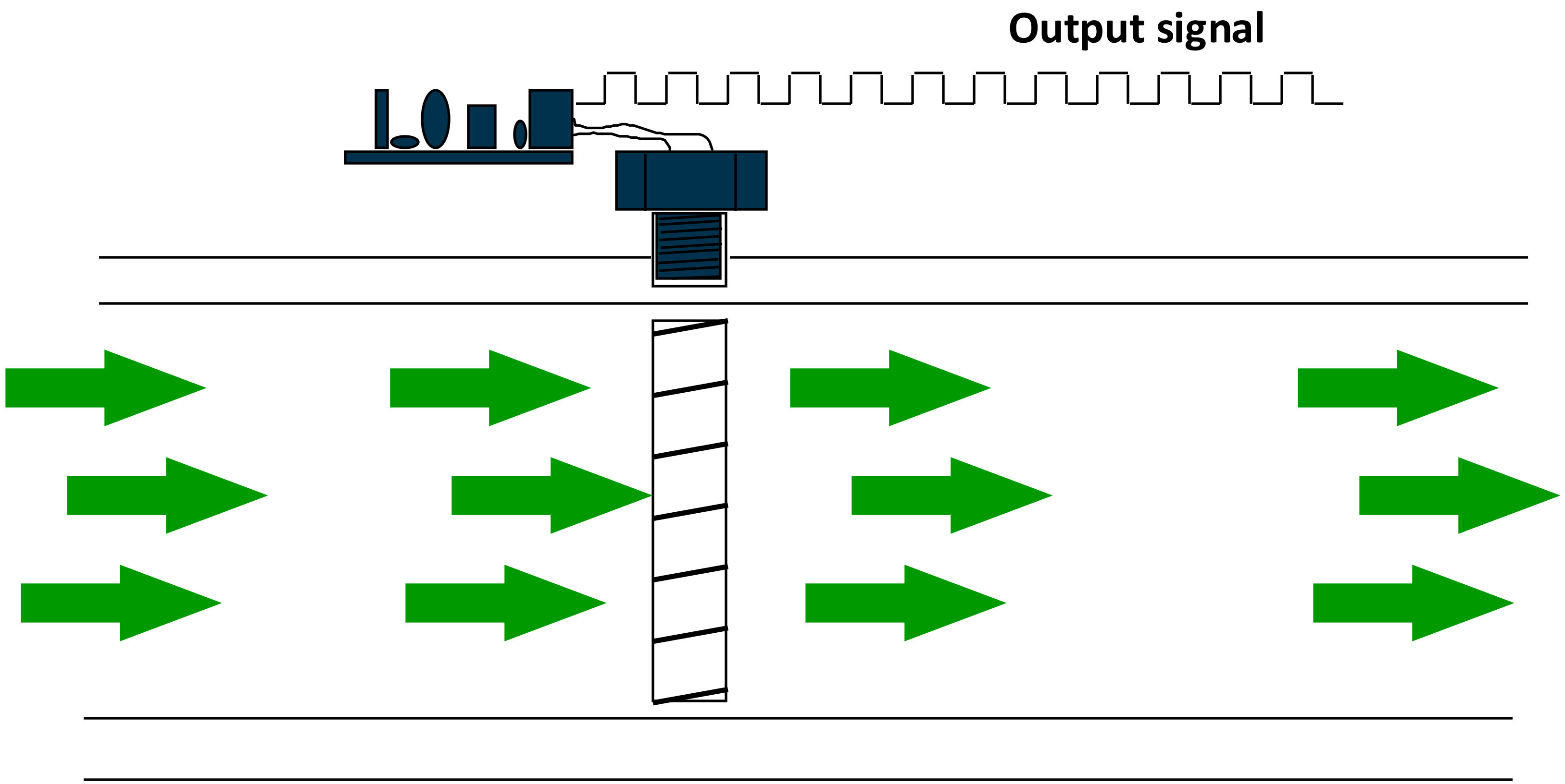

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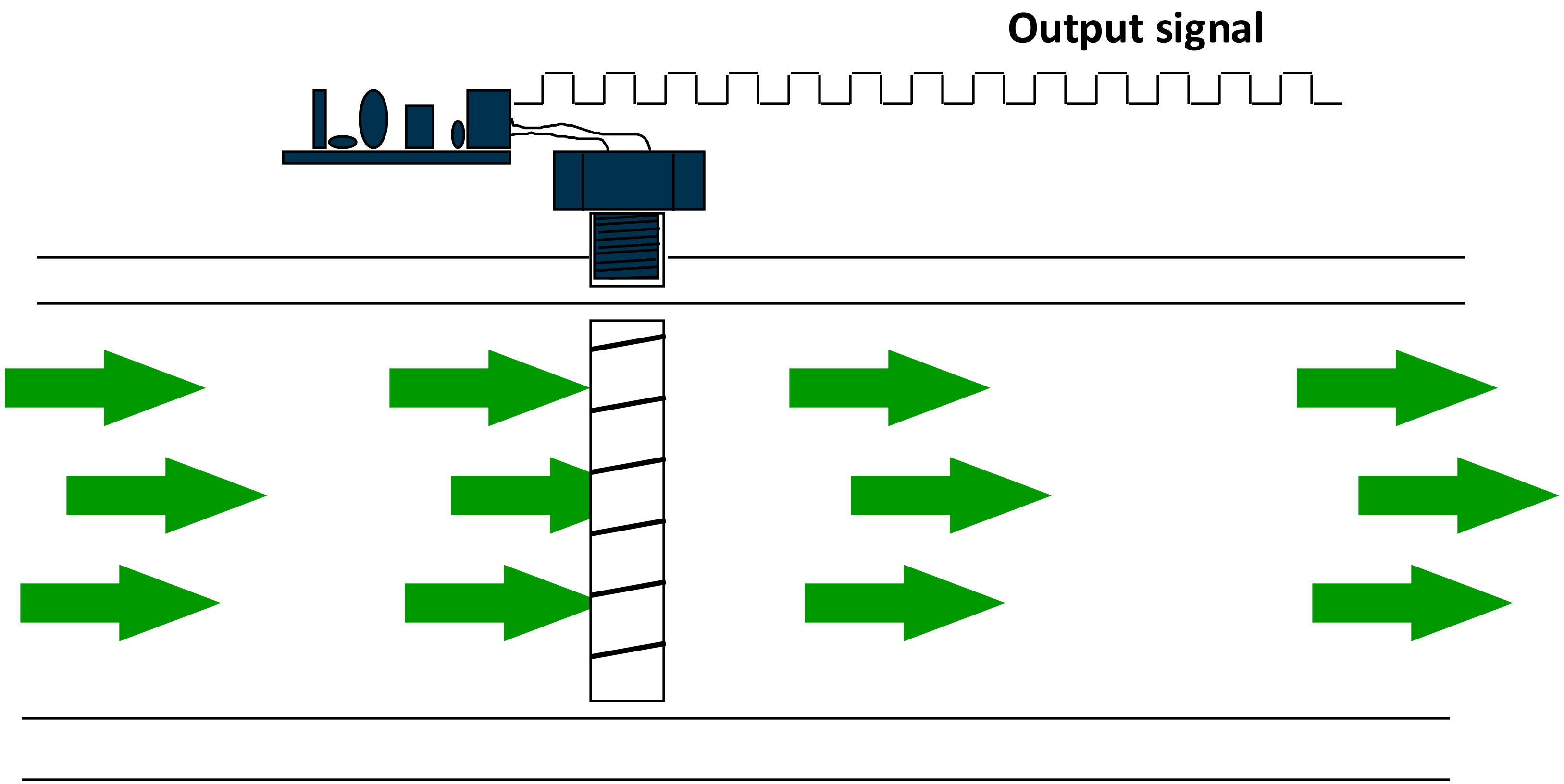

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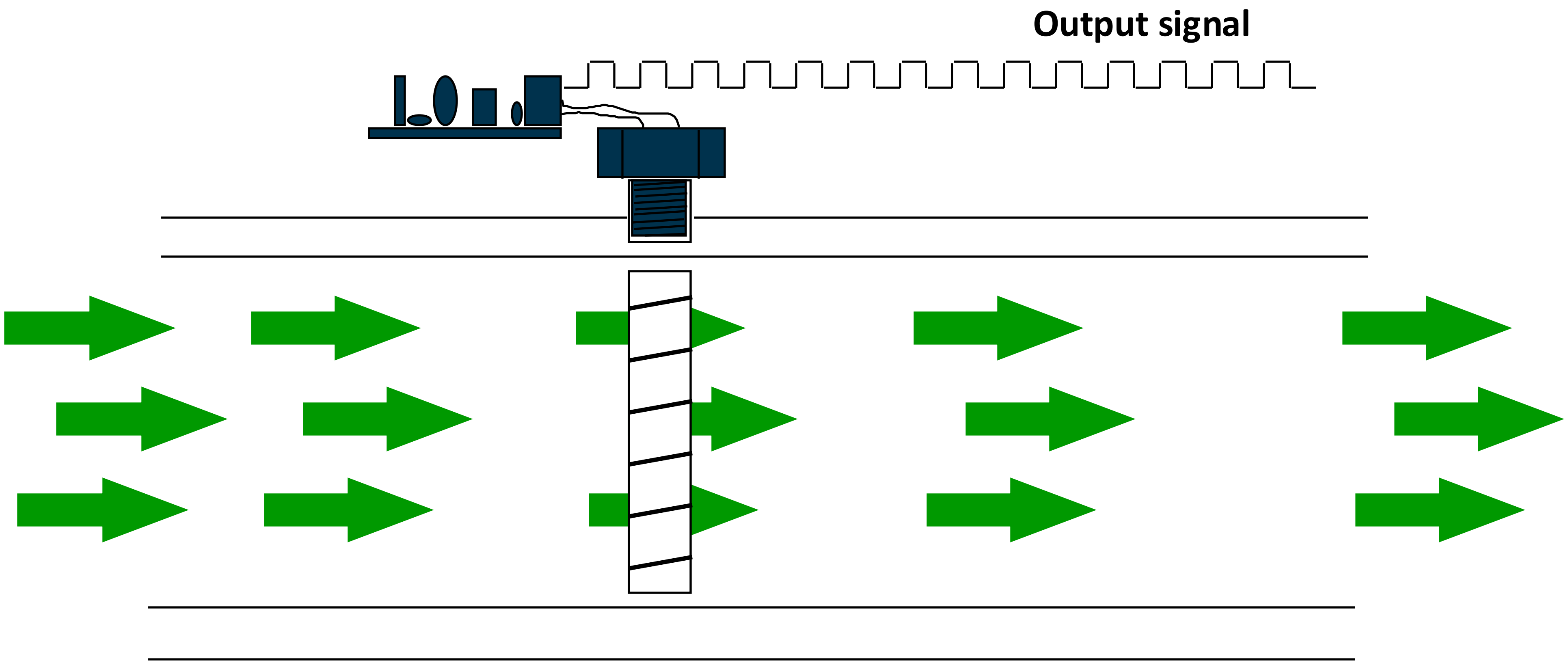

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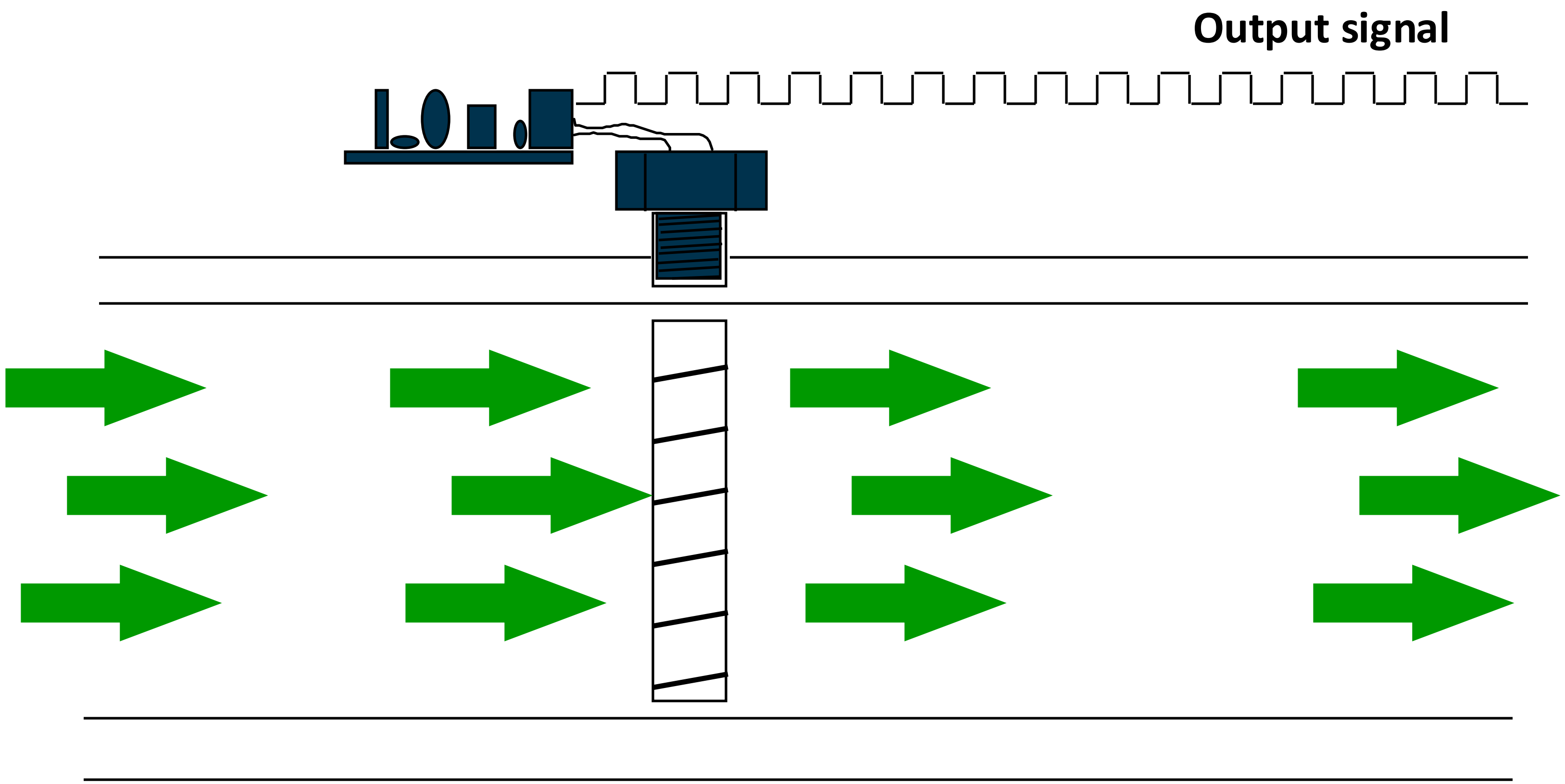

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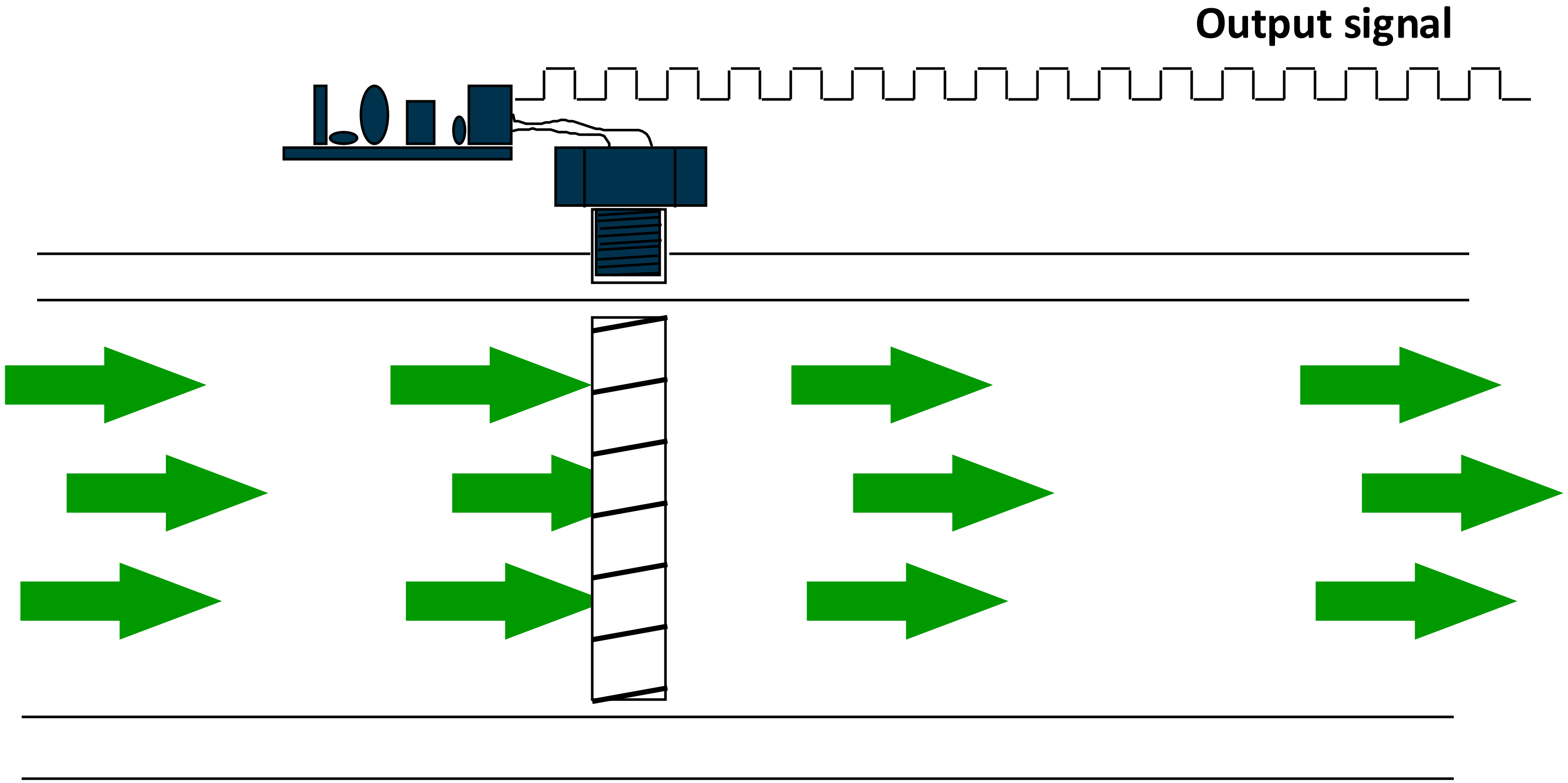

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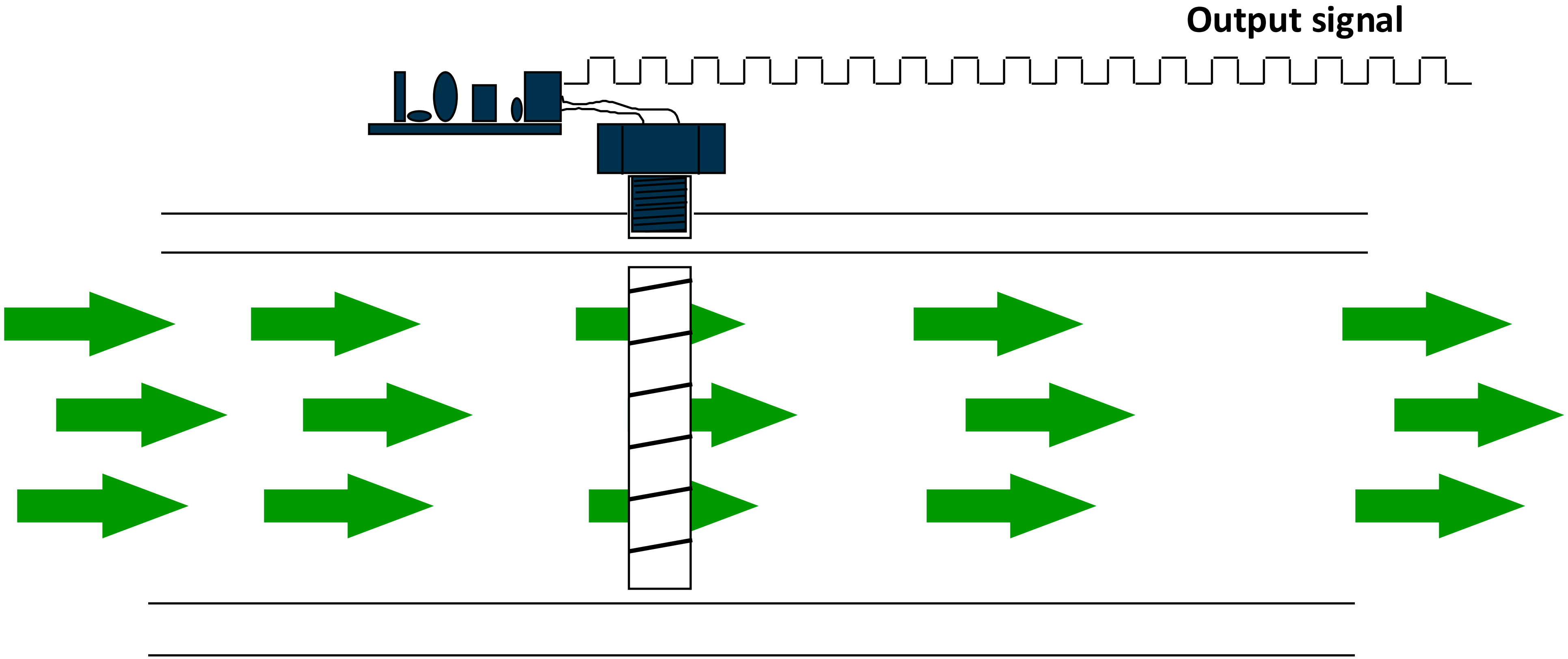

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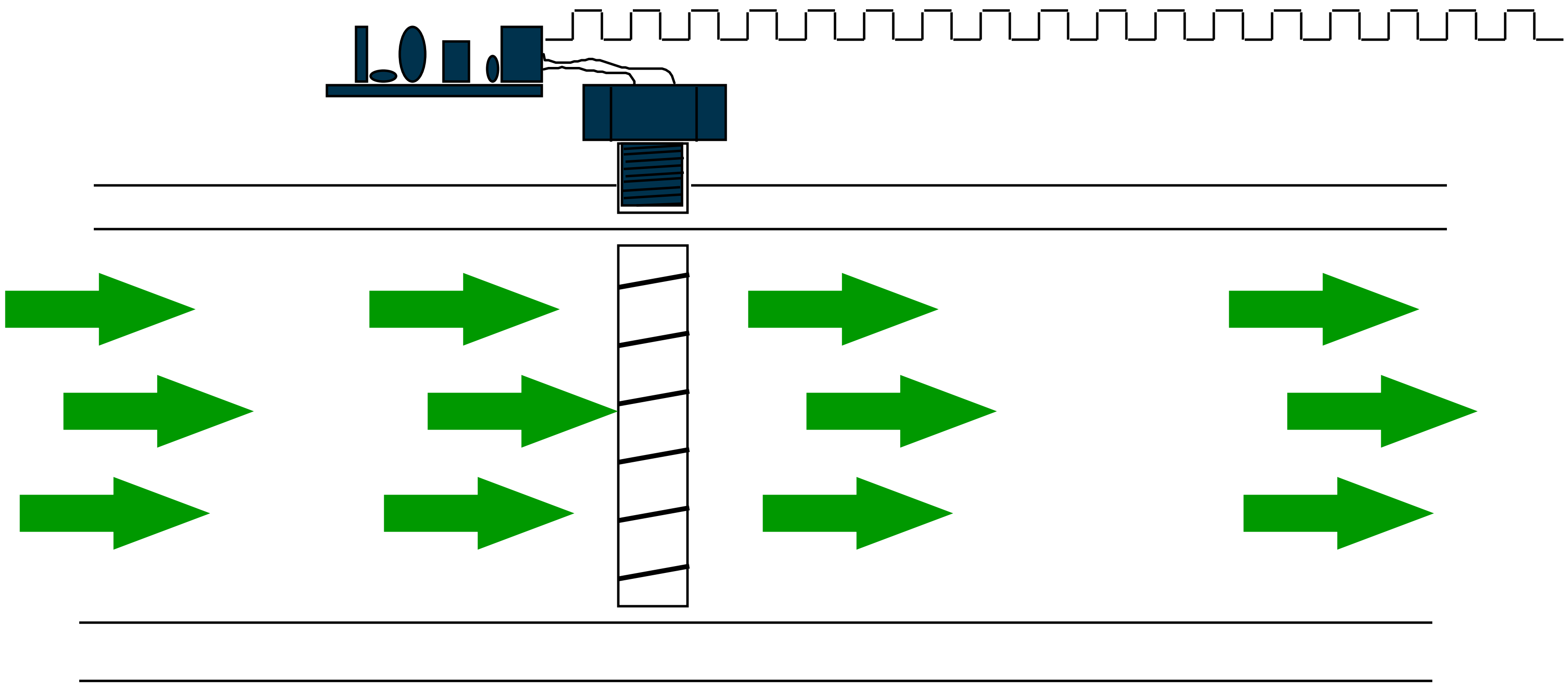
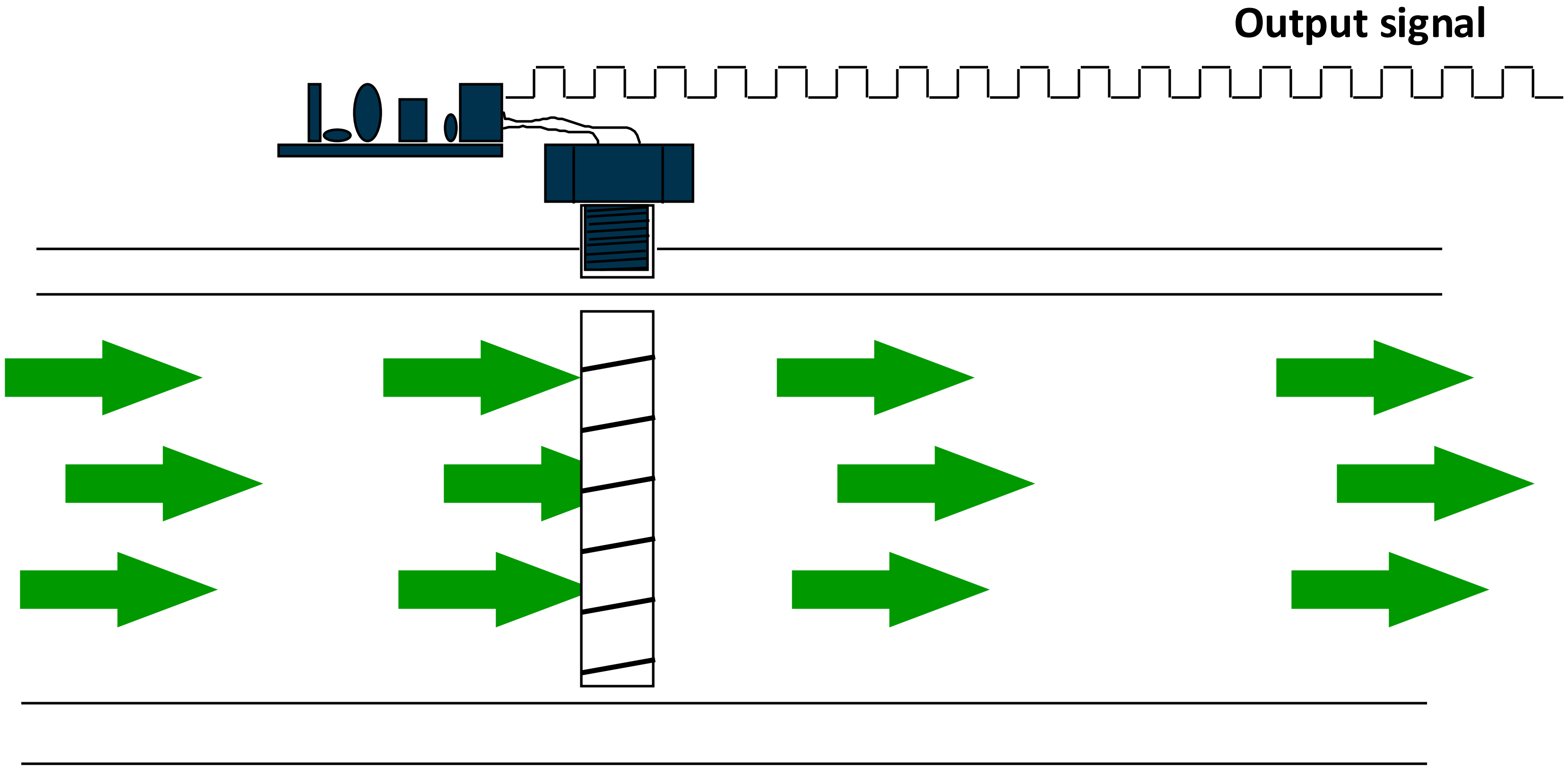
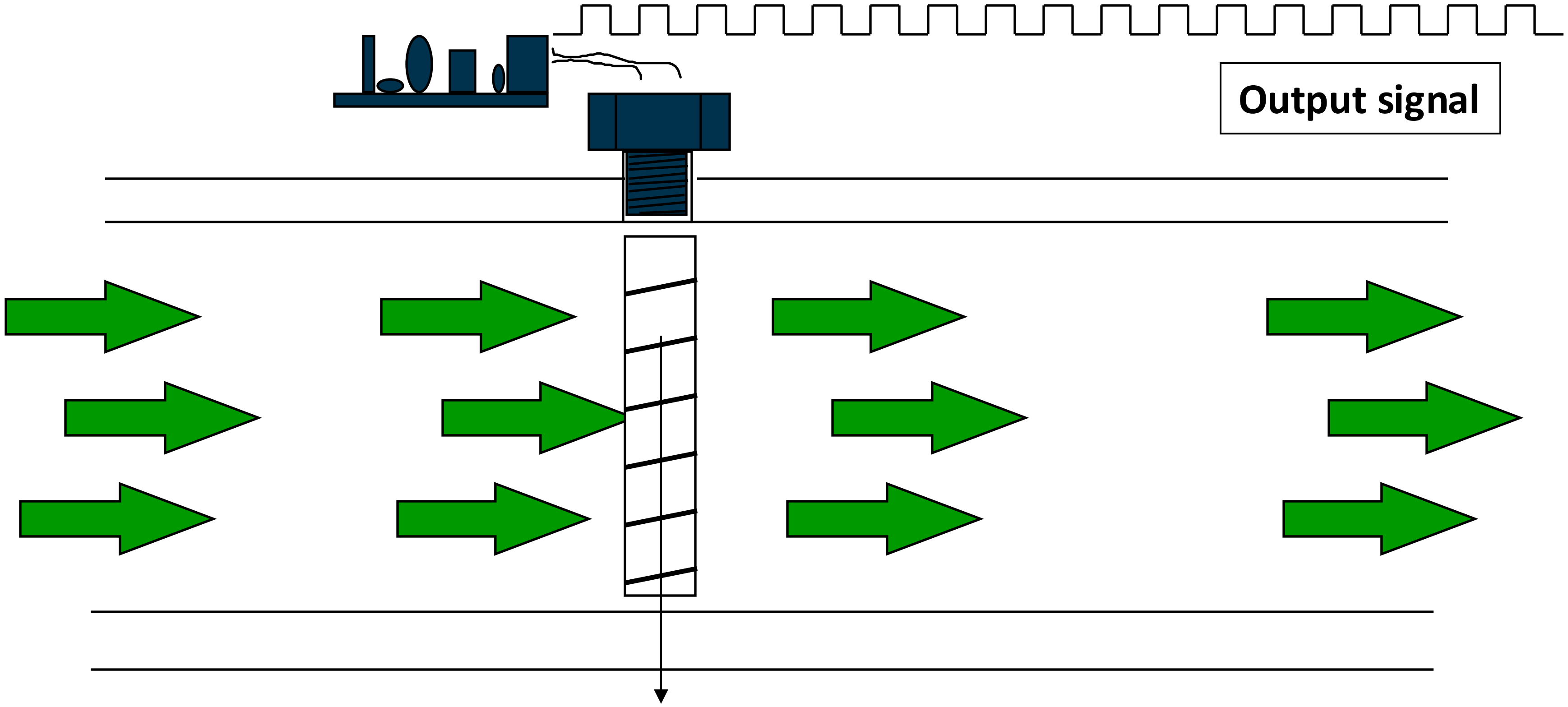


Turbine Meter Operation

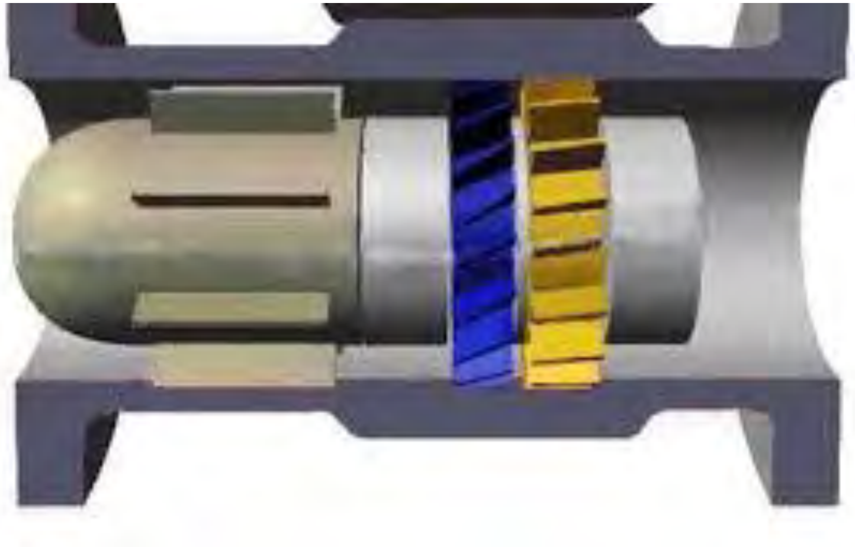


Turbine Meter Operation

Each pulse produced represents "x" units of fluid passing through the meter. The value of "x" differs for all meters, even ones nominally the same size. The number of pulses per unit volume is known as the meters "K" Factor



Dual Rotor Turbine Meter

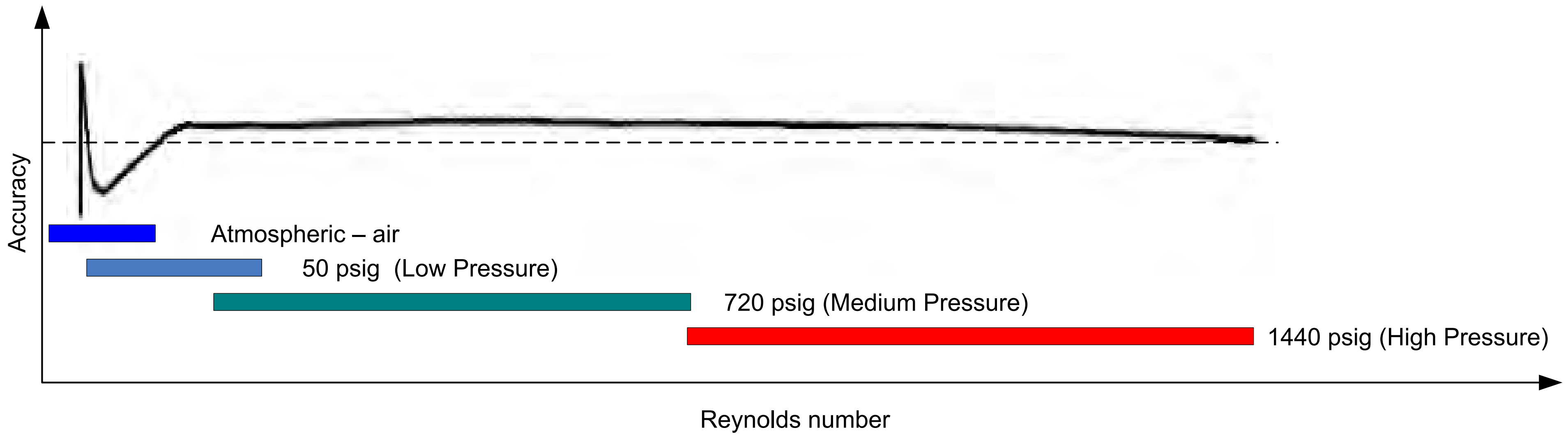


Cut-away of a dual rotor turbine gas meter

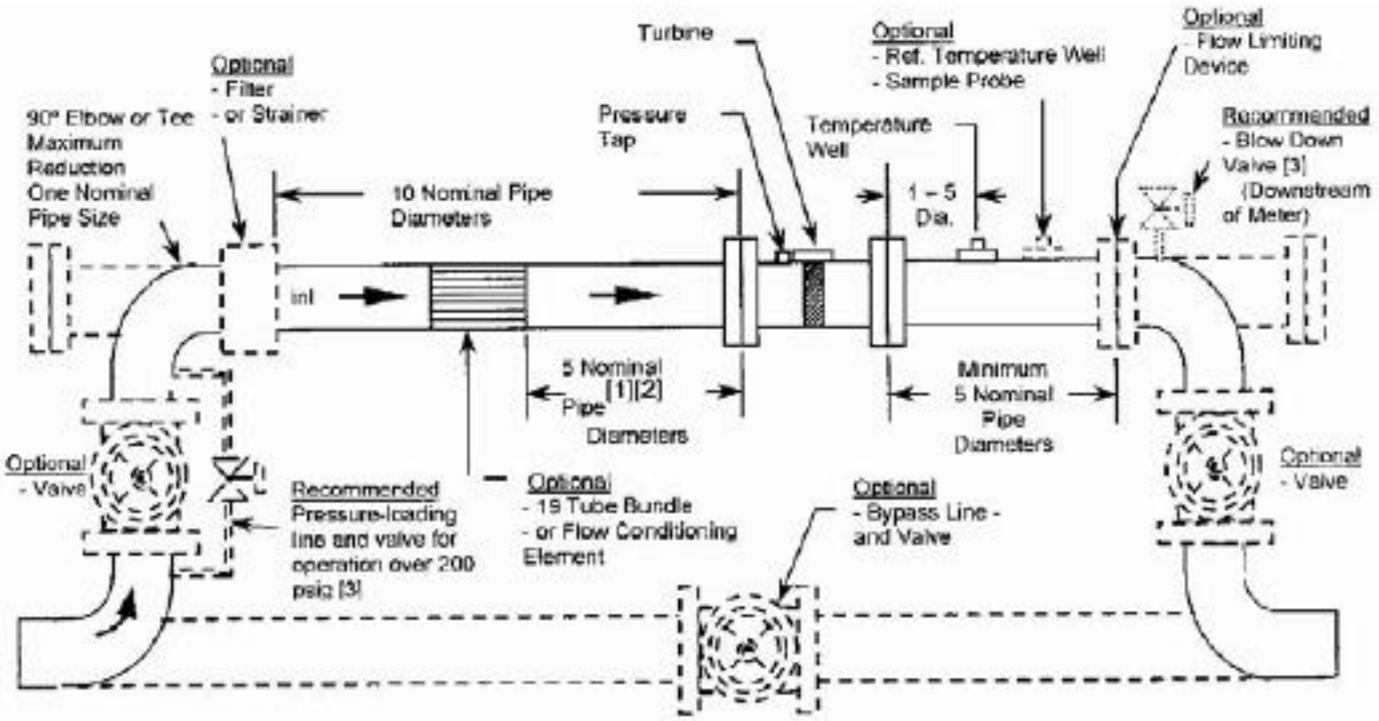
Effects on Meter Accuracy

- Insufficient flow for meter operation - flow less than Qmin
- Flow pulsations - mechanical parts sometimes cannot respond quickly enough to changes
- Debris in flowing gas - binds or damages meter
- Unsuitable flow profiles - swirl, jetting, asymmetry, etc.
- Operating at pressure significantly higher or lower than calibration pressure

Performance Measured Using Reynolds Number



Typical Turbine Meter Installation



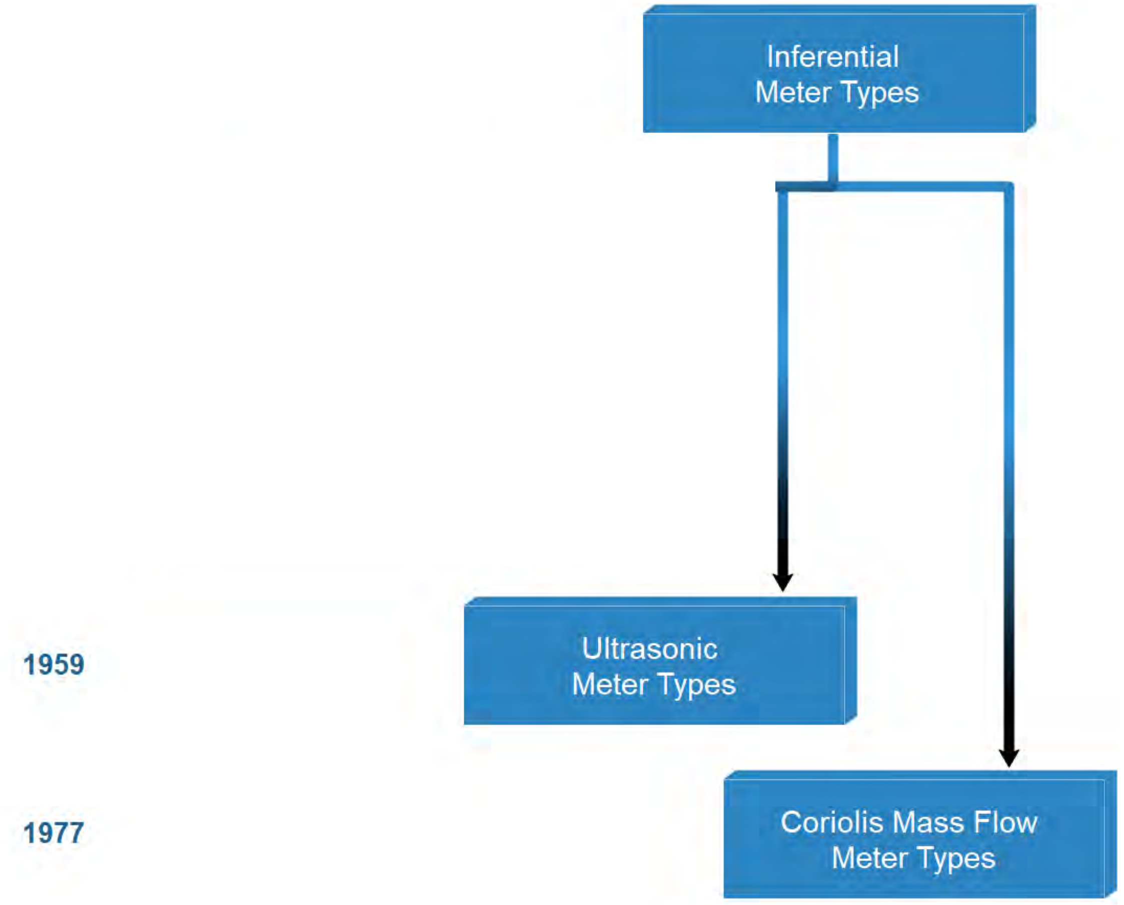
NOTES: [1] Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
[2] No pipe connections or protrusions allowed within this upstream section.
[3] Size of pressure loading line and valve to be the same as recommended blow down valve sizing, (see Table 1).

AGA Report No.7

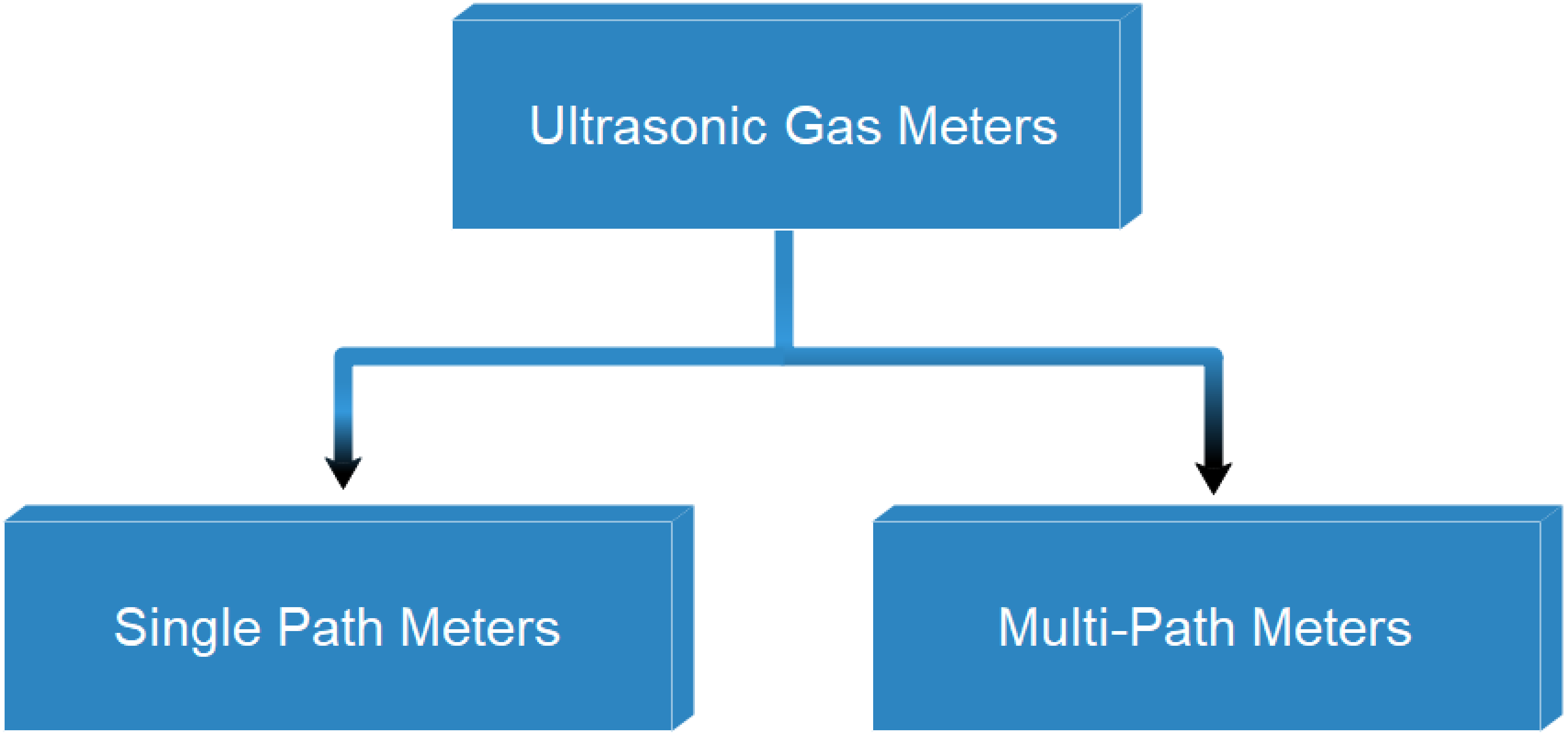
Helpful Turbine Meter References

- AGA Report No.*7: Measurement of Gas by Turbine Meter* - (also applies to ultrasonic and coriolis meters if frequency output is used)
- ISO 9951: *Measurement of gas flow in closed conduits - turbine meters*

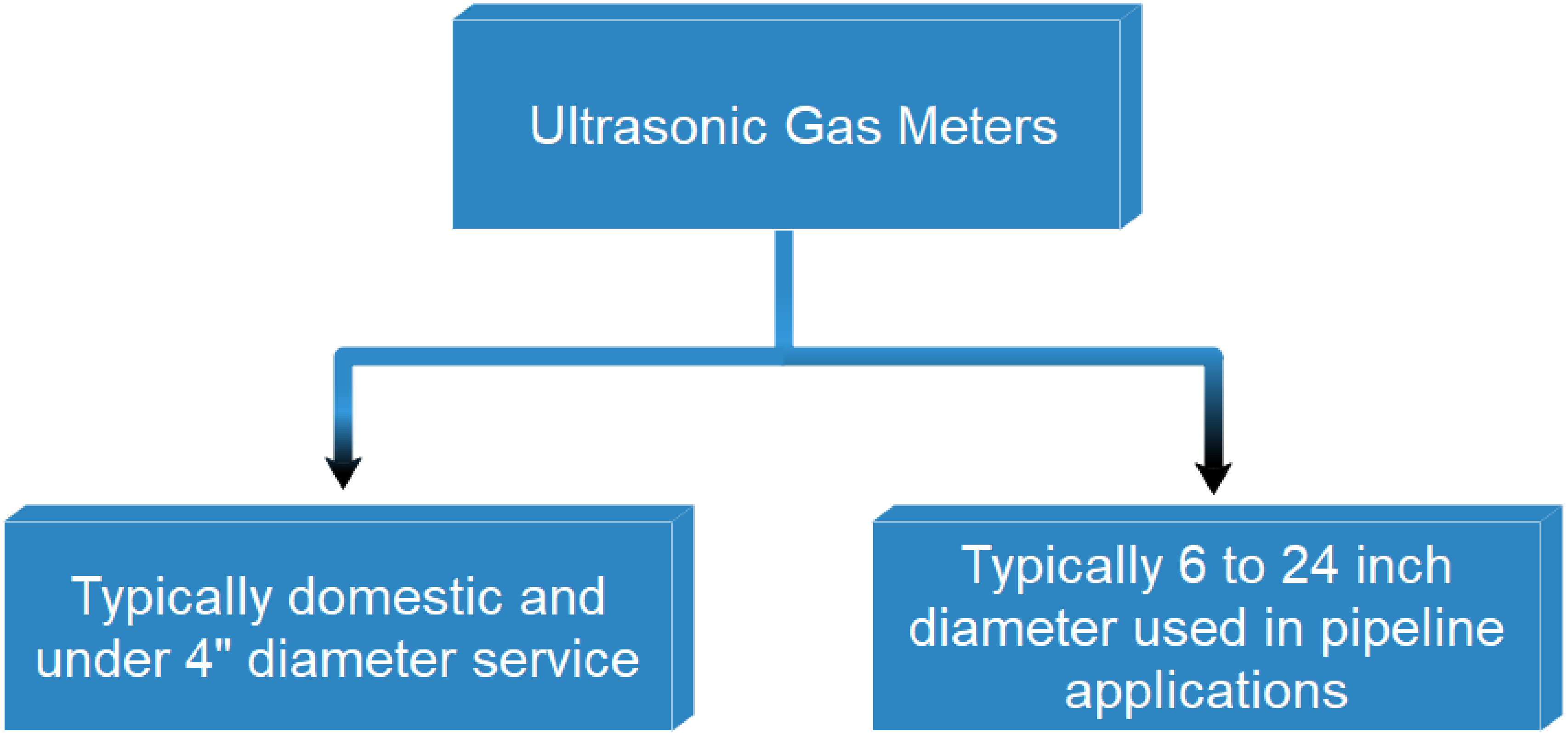
Types of Meters in Natural Gas Measurement



Ultrasonic Gas Meter Types



Ultrasonic Gas Meter Types



Ultrasonic Gas Meter Types

Ultrasonic Gas Meters

Ultrasonic Gas Meter Types

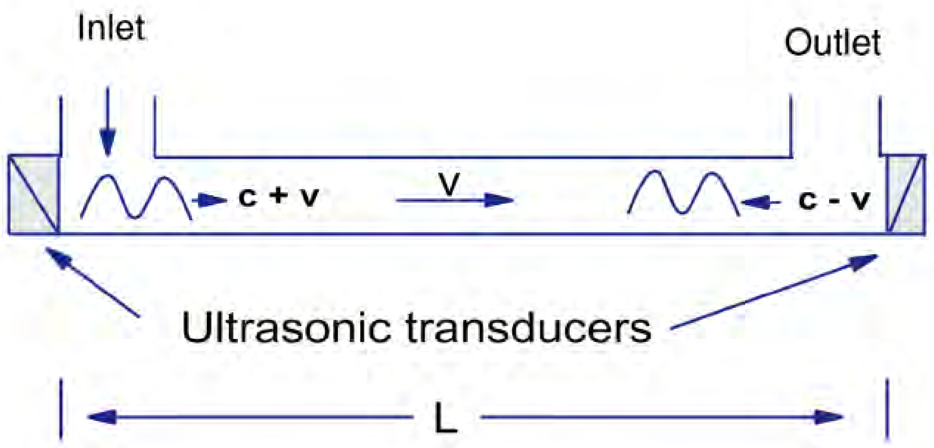
Ultrasonic Gas Meters

Single Path Ultrasonic Meter History

- 1990's - Current design concept developed when British Gas announced a "competition" to select a new gas meter for domestic service
  - ✓ Two promising designs selected for further development
- 1995 - First model approval in Canada - another recently
- 2002 - Approval of higher flow commercial size single path meters

Single Path Ultrasonic Meter Operation

- Time of Flight - Velocity in flow tube is determined based upon the transit time of sound waves
- Ultrasonic / piezoelectric transducers generate and detect sound waves
  - Pulses flowing with the gas velocity speed-up
  - Pulses flowing against the gas velocity slow down
- Difference = gas speed within the known area
- Volume = (Velocity x Area) / Time

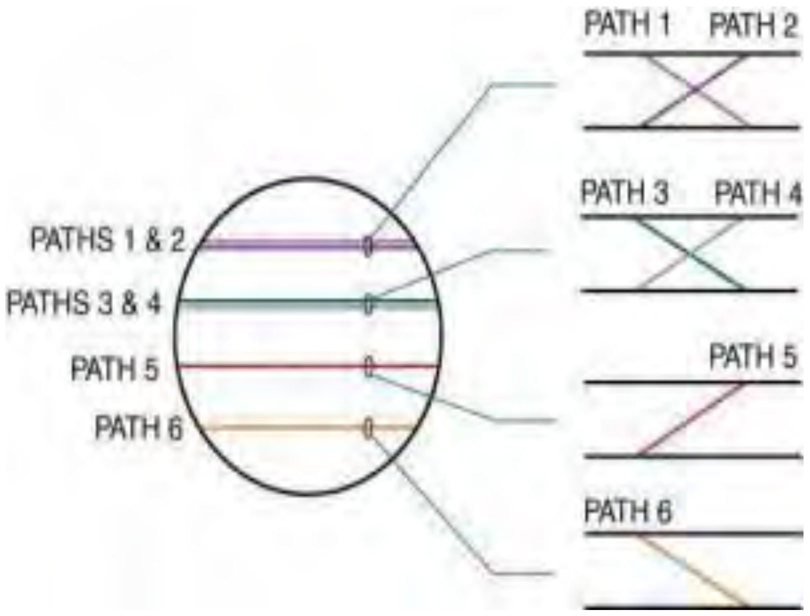


Multi-path Ultrasonic Meters

Ultrasonic Gas Meters

Multi-Path Ultrasonic Meters

- Also uses time of flight principle
- Various path designs are used - crossing paths, bouncing paths, star shaped paths
- Have little effect on gas flow profiles
- Some models are slightly flow profile sensitive
- Most provide flow profile diagnostics



Helpful Ultrasonic Meter References

- AGA Report No.10: *Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases*
- AGA Report No. 9: *Measurement of Gas by Multipath Ultrasonic Meters*
- ISO 17089-1: *Measurement of fluid flow in closed conduits - Ultrasonic meters for gas*

Types of Meters in Natural Gas Measurement

Inferential
Meter Types

1977

Coriolis Mass Flow Meter History

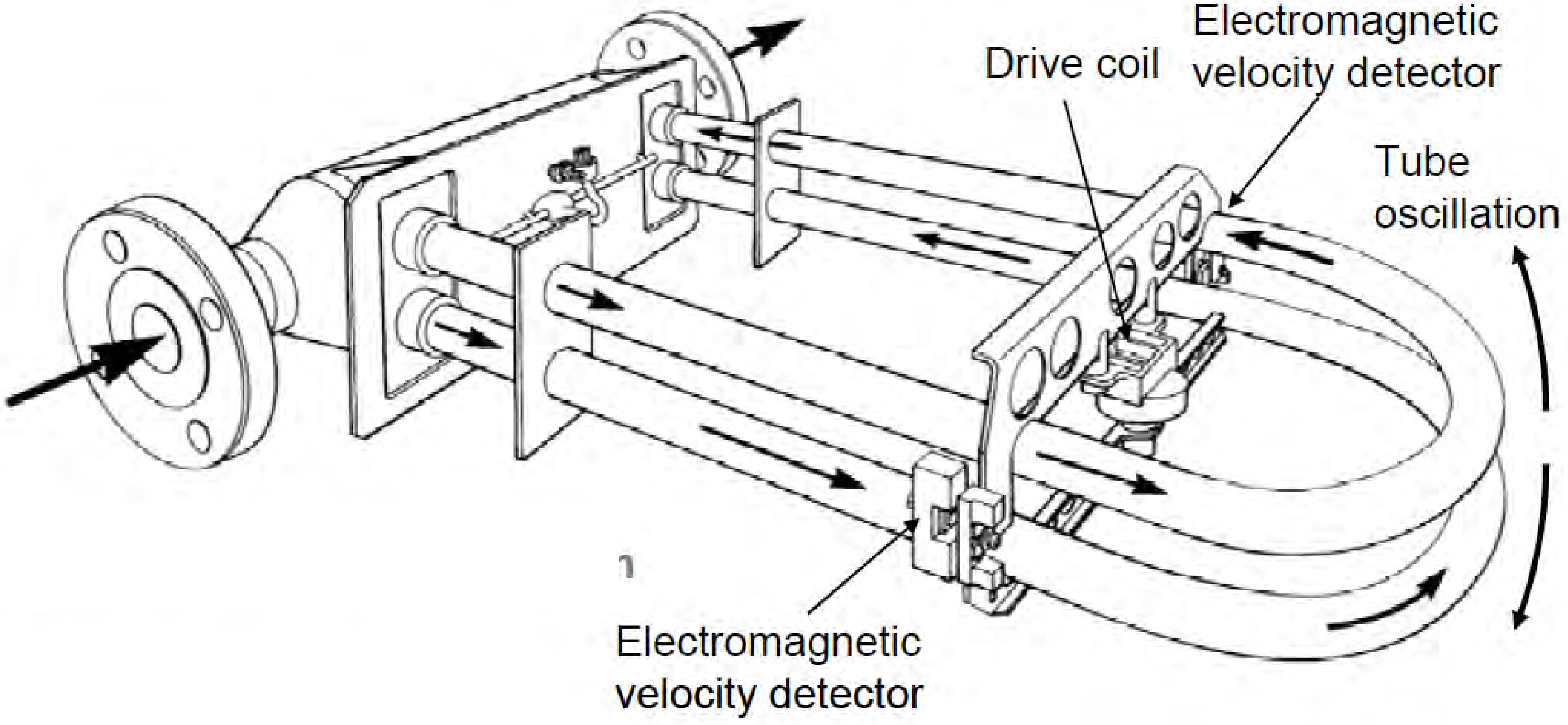
- 1977 - Coriolis mass flow meters were first brought onto the market
  - ✓ At that time, all coriolis meters used a bent tube construction which was patented by the inventors
- 1987 - Other meter manufacturers developed straight tube coriolis meter types
- Now - All sorts of tube shapes

Coriolis Mass Flow Meter

U-shaped bent tube designs

Straight tube designs

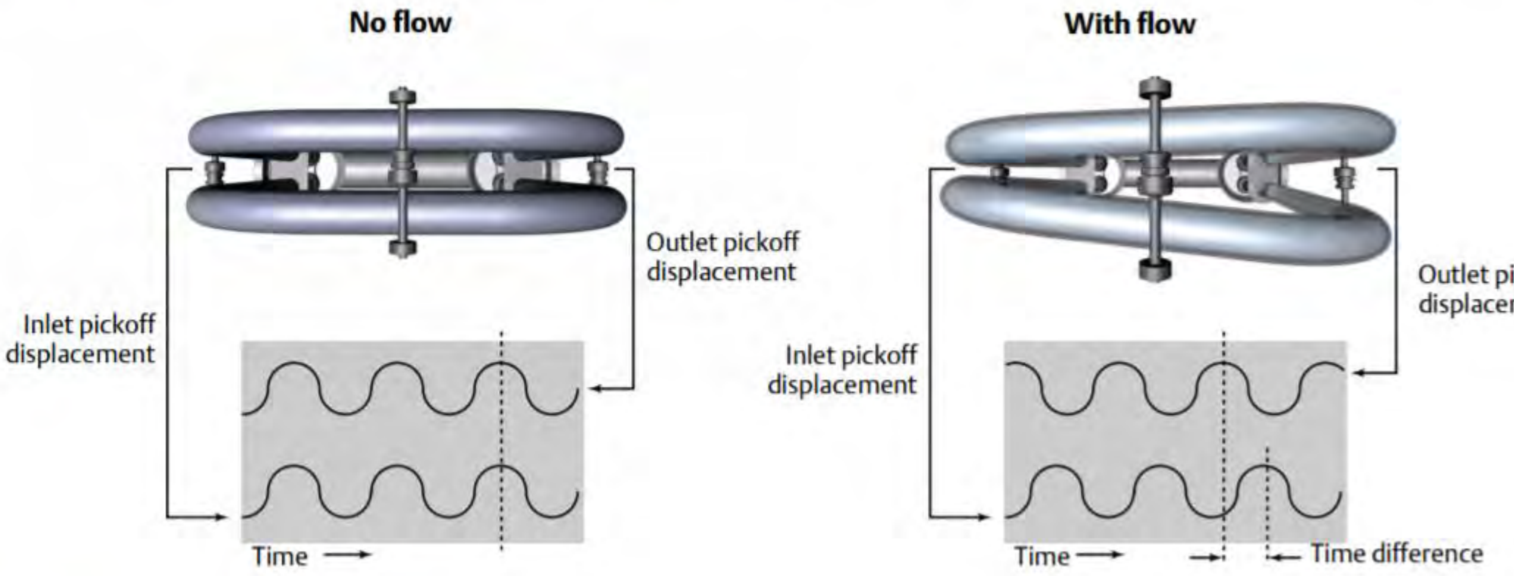
Coriolis Mass Flow Meters



Coriolis Mass Flow Meter Operation

Mass flow measurement

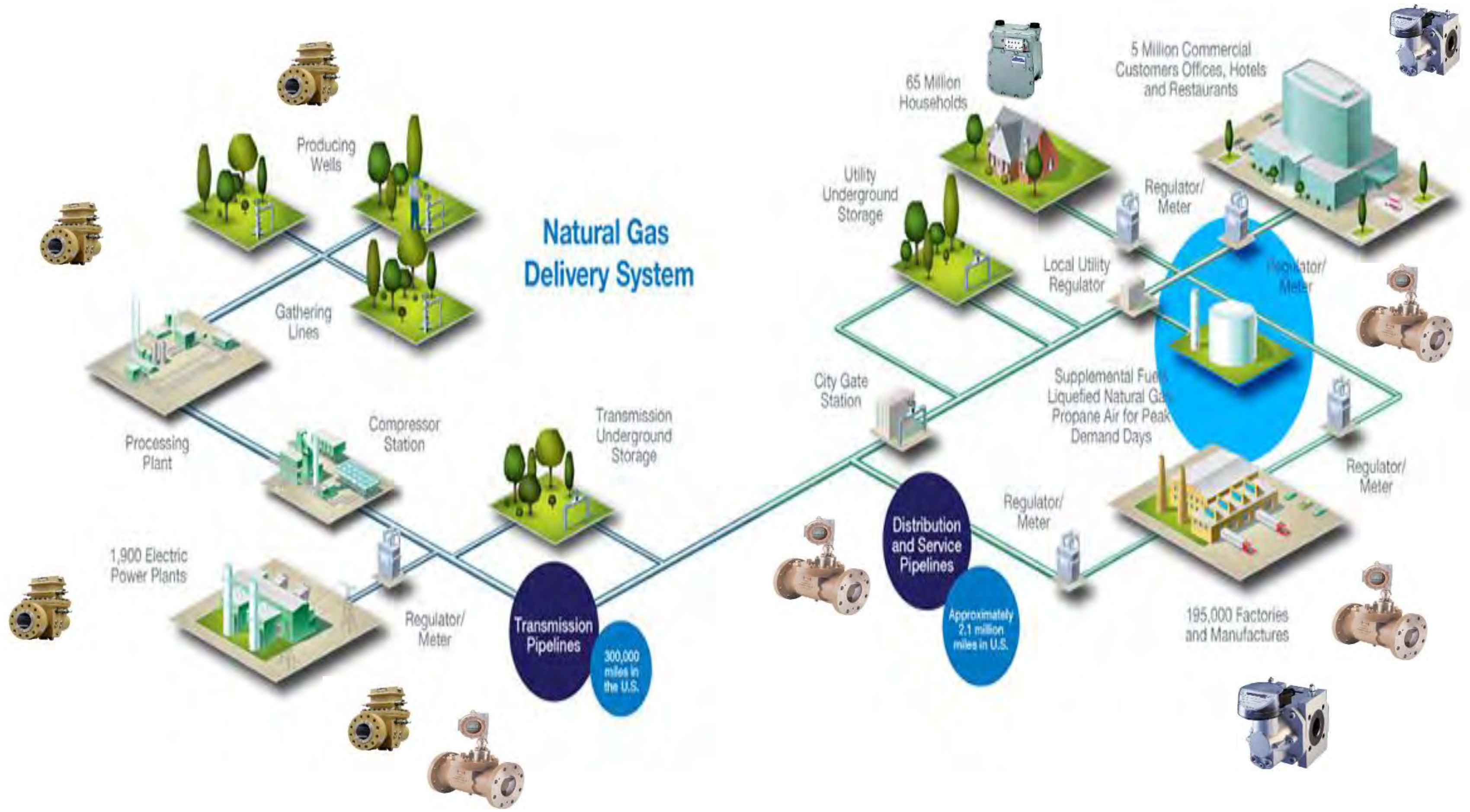
The measuring tubes are forced to oscillate producing a sine wave. At zero flow, the two tubes vibrate in phase with each other. When flow is introduced, the Coriolis forces cause the tubes to twist resulting in a phase shift. The time difference between the waves is measured and is directly proportional to the mass flow rate.



Helpful Coriolis Meter References

- AGA Report No.11: *Measurement of Natural Gas by Coriolis Meter*
- AGA Report No.5: *Fuel Gas Energy Metering* (1996) provides for units of gas volume or mass-to-energy equivalents
- AGA Report No.8: *Compressibility Factor of Natural Gas and Related Hydrocarbon Gases* (applies to all meter types)
- ISO 10790: *Measurement of fluid flow in closed conduits - guidance to the selection, installation and use of coriolis meters*

Where are the Various MC Approved Meters Found?



Acknowledgment

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Questions?