



Department for
Science, Innovation
& Technology



Calibration of flowmeters via digital communication protocols

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Manchester, 2026-09-09



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Introduction To Project



- Flowmeters can be split into two broad categories

Mechanical Flowmeters

Direct physical motion generates pulses representing discrete measured volumes (e.g., Turbine, Positive Displacement).

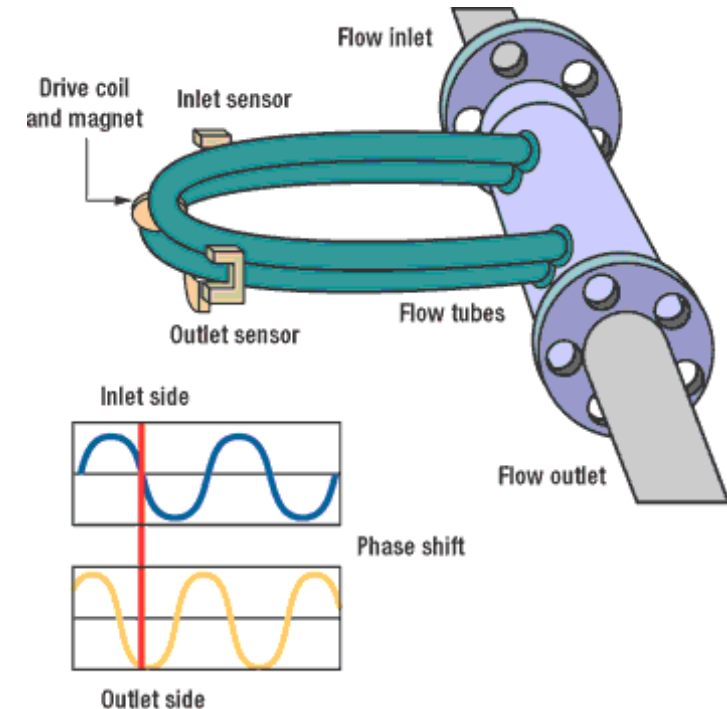
Modern Flowmeter Technologies

Infer the flowrate indirectly and can output data via analogue, frequency or digital protocols. Examples include Coriolis, Vortex and Ultrasonic Meters.

- There is a clear push in many industries towards digital infrastructure and modern flowmeters can help facilitate this.
- Most established calibration methods/standards are based around collection of analogue signals such as 4-20mA, or via pulse counting. Flowmeters may lack analogue/frequency outputs in the future – calibration methods are required.
- To address this gap, NEL has developed a research project which aims to explore calibration of flowmeters via digital communication protocols, with a particular focus on small volume proving.

Flowmeter Outputs and Digital Protocols

- Project will initially focus on Coriolis flowmeters.
- Coriolis meters typically offer several different output options for measurement data including:
 - **Analogue** : Flow rate is mapped to an analogue signal, typically 4-20 mA.
 - **Frequency**: A discrete frequency output, usually a square wave signal where the frequency is proportional to the live mass flowrate.
 - **Digital Communication Protocols** e.g. HART, Modbus, Foundation Fieldbus, PROFIBUS, PROFINET, Ethernet/IP etc.



Digital Protocols - Advantages and Disadvantages



Advantages

- Digital data more robust than analogue signals.
- Process and diagnostic data via a single output.
- Different network topologies are supported leading to simplified installations and reduced cable volume.
- Measurement data is available in high resolution in the appropriate units.
- Potentially faster scan cycle times (no multiplexing).

Disadvantages

- Limited calibration guidance.
- Often requires specialist knowledge or training.
- May require bespoke hardware or data acquisition software.
- Communication lag can be significant. Digital data can go through multiple gateways before being finally recorded.

Digital Communication Protocol Availability



	4-20 mA	Serial		Bus powered		Industrial Ethernet		
Coriolis Manufacturer	HART	Modbus RTU	PROFIBUS DP	PROFIBUS PA	Foundation Fieldbus	Modbus TCP	Ethernet IP	PROFINET
A	✓	✓	✓	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓	x	✓	✓
C	✓	✓	x	✓	✓	✓	✓	✓
D	✓	✓	✓	✓	✓	✓	✓	✓
E	✓	✓	x	x	✓	x	x	x
F	✓	✓	x	✓	x	x	x	✓
G	✓	✓	✓	x	x	✓	✓	✓
H	✓	✓	x	✓	✓	x	x	✓
I	✓	✓	✓	✓	✓	x	x	x
J	✓	✓	✓	x	x	✓	✓	✓

PROFI
NET

PROFI[®]
BUS



Digital Communication
Protocols

EtherNet/IP[™]

HART
COMMUNICATION PROTOCOL



Digital Protocol Comparison



Protocol	Physical Layer	Power & Data same Cable	Config file	Communication Speed	Max Cable Distance (without repeaters or switches)	Communication Model
HART	4-20 mA loop	Yes	Yes (DD)	1.2 kbps →	3 km	Host/Device (Request/Response)
Modbus RTU	Serial (RS-232/RS-485)	No	No	9.6 kbps to 115.2 kbps →→→	1.2 km	Client/Server (Request/Response)
Modbus TCP/IP	Ethernet	No (unless Ethernet-APL)	No	10 Mbps to 1GBps+ →→→→→	100m (1 km Ethernet-APL)	Client/Server (Request/Response)
PROFIBUS DP	Serial (RS-485)	No	Yes (GSD)	9.6 kbps to 12 Mbps →→→→	1.2 km	Master/Device (token passing)
PROFIBUS PA	MBP	Yes	Yes (GSD)	31.25 kbps →→	1.9 km	Master/Device (token passing)
Foundation Fieldbus H1	MBP	Yes	Yes (DD)	31.25 kbps →→	1.9 km	Publisher Subscriber
Ethernet/IP	Ethernet	No (unless Ethernet APL)	Yes (EDS)	10 Mbps to 1GBps+ →→→→→	100m (1 km Ethernet-APL)	Producer Consumer
PROFINET RT / IRT	Ethernet	No (unless Ethernet APL)	Yes (GSDML)	10 Mbps to 1GBps+ →→→→→	100m (1 km Ethernet-APL)	Provider Consumer

Digital Protocol Selection for Further Research



- To ensure a focused scope, decision was taken to focus on 1 or 2 digital protocols for research.
- The goal of the project is to try and prove a meter using a digital communication protocol. Desirable characteristics include:
 - Availability of protocol
 - Determinism
 - Communication speed and cycle time
 - Practical considerations
- Some protocols were ruled out for initial research due to various limitations and practical considerations
- **PROFINET** and **Modbus** were selected for further research



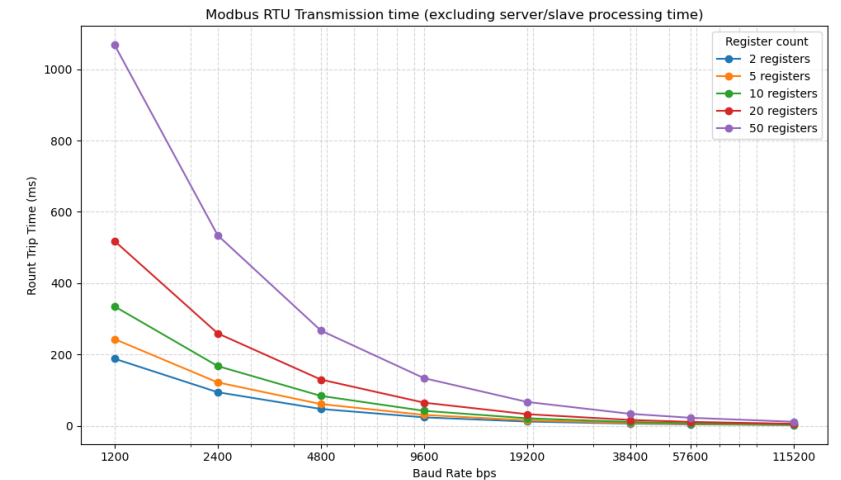
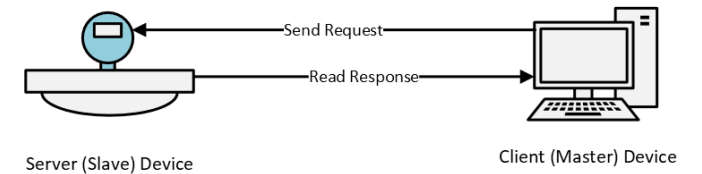
Digital Communication
Protocols



EtherNet/IP™

Modbus

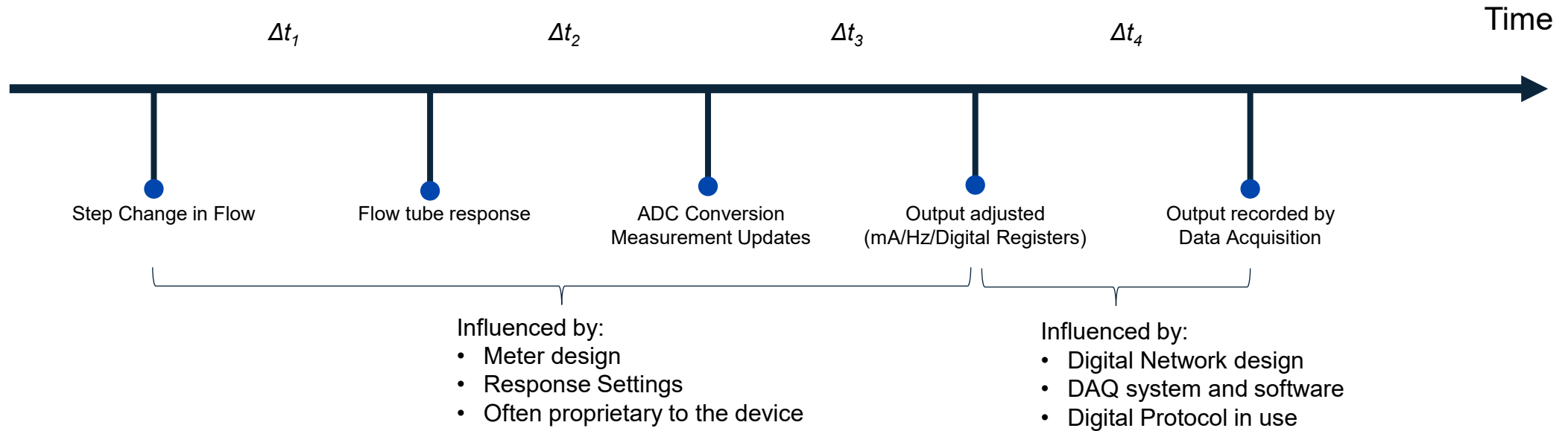
- First developed in 1979. Utilises a client/server (master/slave) polling model and data is exchange as frames.
- Supported on a variety of different devices and operates via both serial and ethernet physical layer.
- Transmission time for Modbus RTU can be significant and distance has a direct impact on signal integrity.
- Raw transmission speed can be improved using Modbus TCP/IP but is less deterministic than serial communication.
- Common digital protocol in flow measurement.



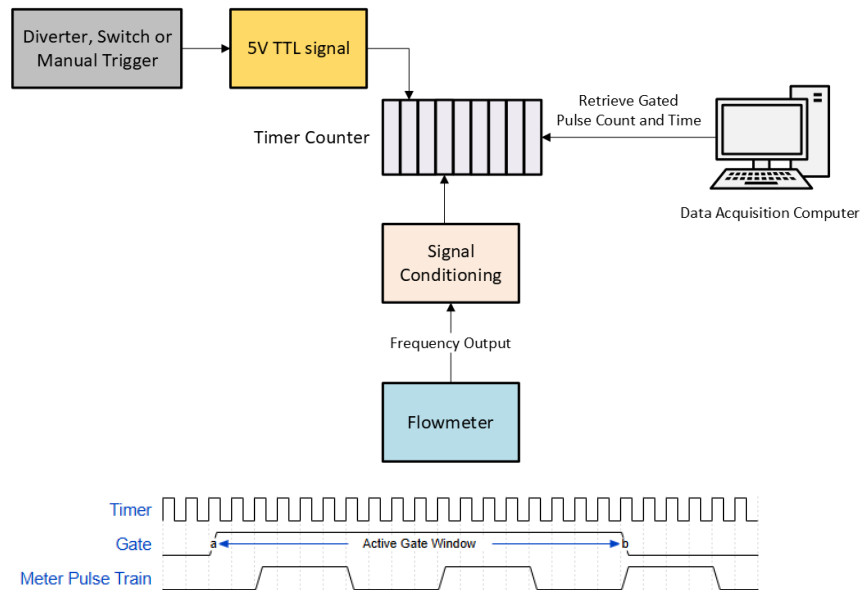
- Ethernet based protocol first introduced in 2003. Uses a provider-consumer communication model.
- Comprises of three communication classes:
 - **Non-Real Time (NRT)**. Uses standard TCP/IP for data that is not time critical.
 - **Real-Time (RT)**. Cycle times $\geq 250 \mu\text{s}$. Bypasses TCP/IP layers.
 - **Isochronous Real-Time (IRT)**. Supports ultra low cycle times down to $31.25 \mu\text{s}$ but requires dedicated hardware and switches.
- PROFINET RT ethernet frames are priority tagged – improved determinism
- Available as an option on most industrial Coriolis Flowmeters (PROFINET RT).



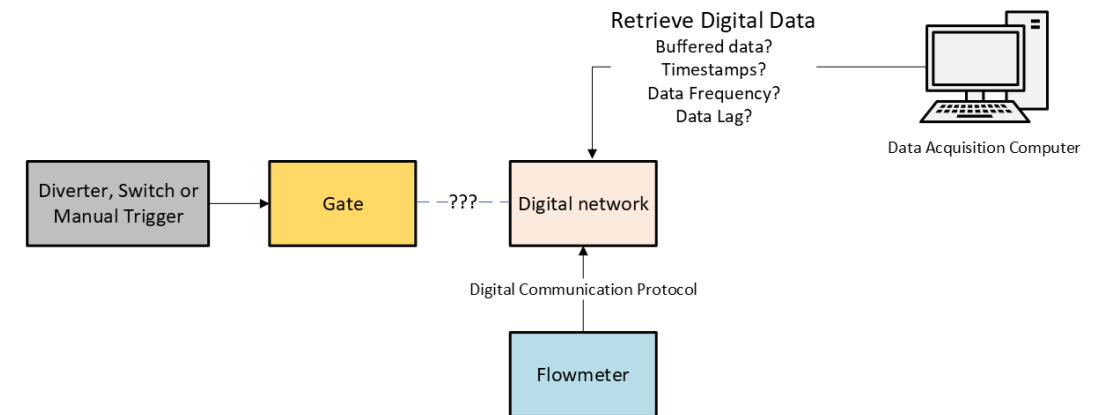
Digital Calibration Challenges - Dynamic Response



Digital Calibration Challenges - Timing and Gating

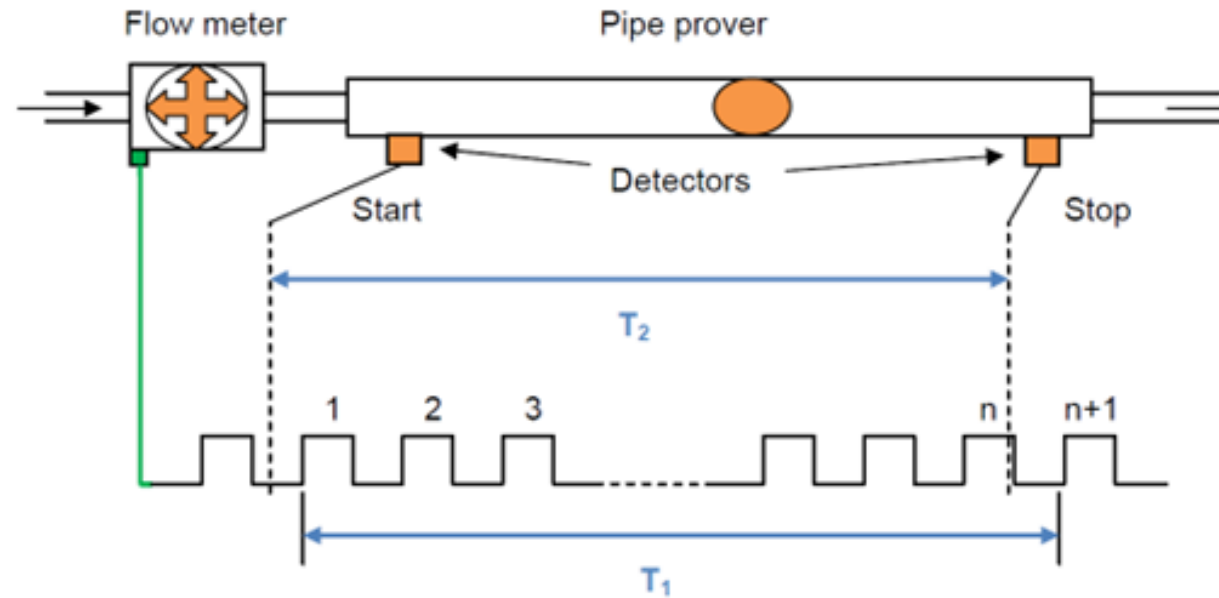


Existing Gating Methodology



Digital Gating Challenges

Digital Calibration Challenges – Small Volume Proving



Development of Digital Calibration DAQ System

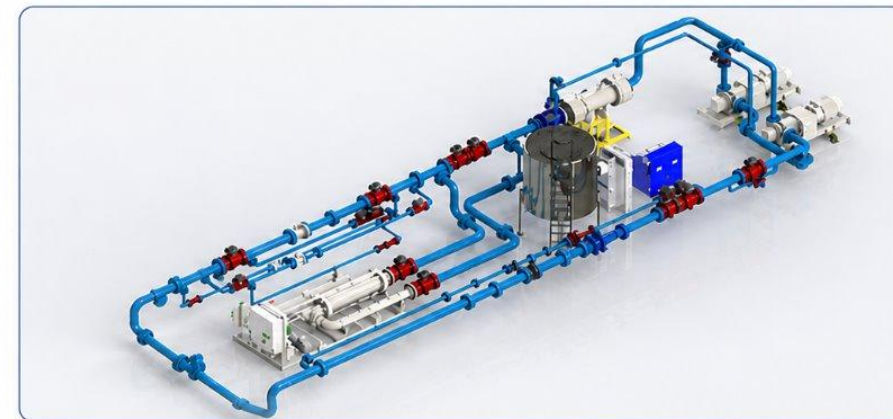
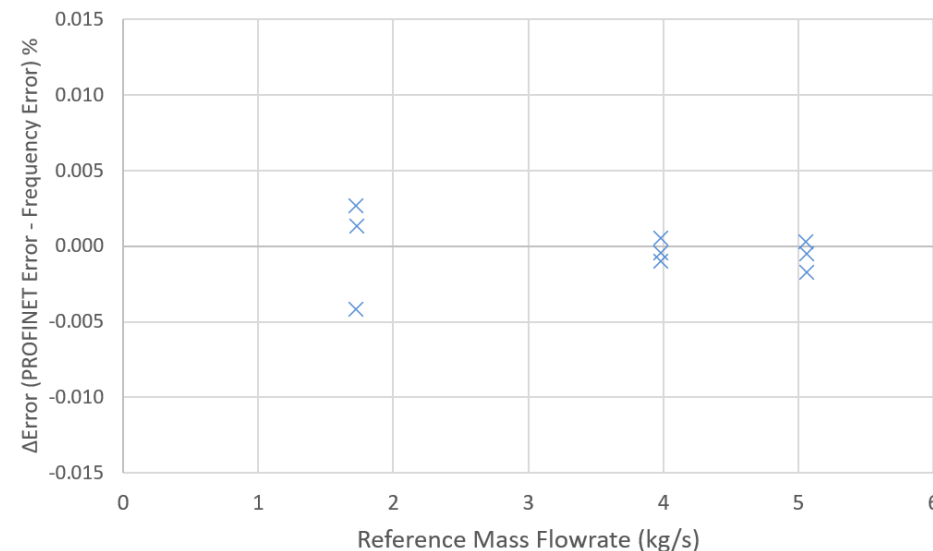


- A DAQ system has been developed to log digital data with a focus on:
 - Optimised network design
 - Timestamping of digital flow data
 - Timestamping of gate events (e.g. prover detector switches)
 - Buffering and storage of data
 - Post processing of data
- Designed to work alongside our existing flow facilities and DAQ
- Initial approach will be to attempt proving of Coriolis meters using standard transmitter functionality.



Initial Commissioning and Next Steps

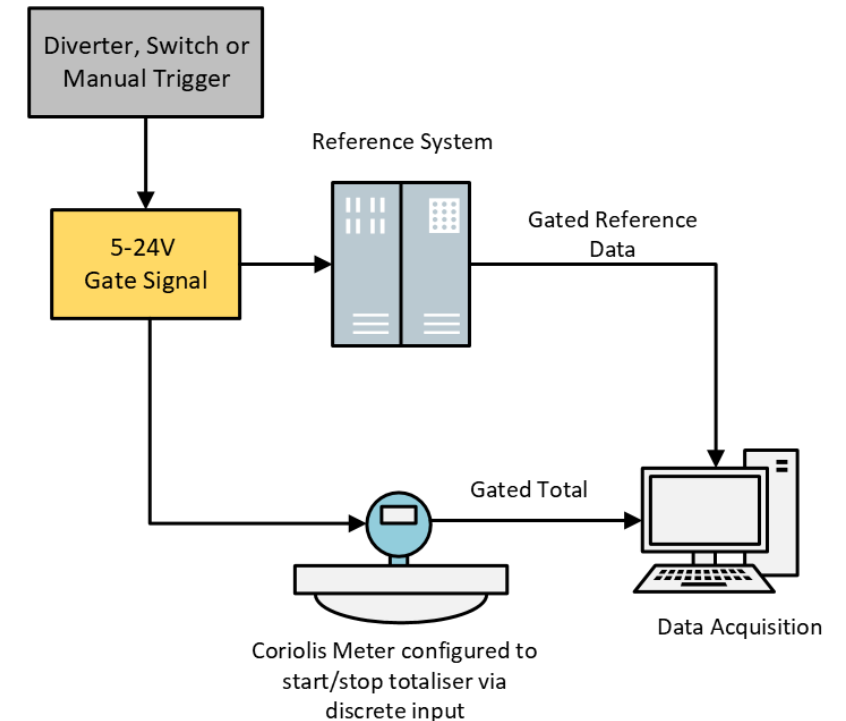
- Completed basic commissioning in a master meter flow loop using PROFINET enabled Coriolis meter.
- Good agreement between outputs (totalised mass error difference within 0.01%).
- Collection times were sufficient to collect 10,000 pulses (>180s) which may mask any synchronisation errors with the digital data.
- Next step – conduct small volume proving trials



Alternative Digital Calibration Approaches

Starting/Stopping Flowmeter Totalisers

- Many modern flowmeters support start/stop/reset of their internal totalisers via remote commands or physical discrete inputs
- Several considerations with this approach
 - Delay between processing of changes to discrete input and start/stop of totaliser could be significant
 - Adds complexity to calibration setup
 - Availability of functionality across meters and manufacturers

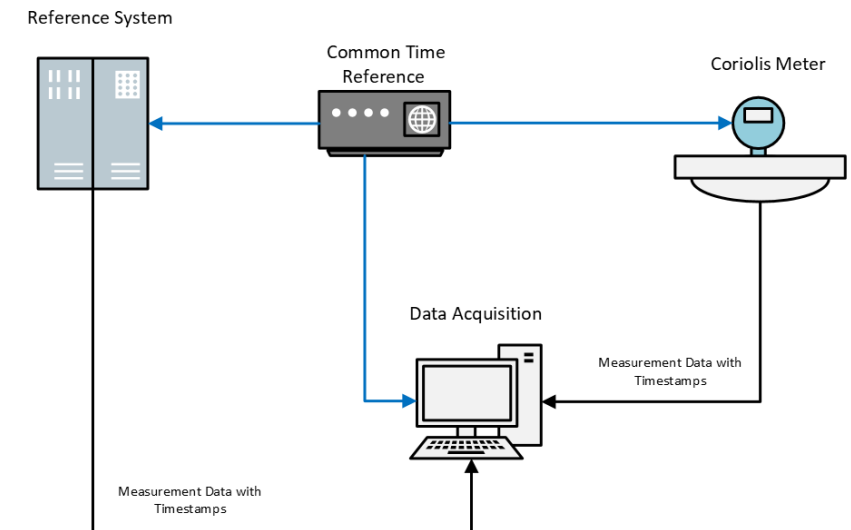


Alternative Digital Calibration Approaches

Clock Synchronisation and Data Buffering

- Timestamped data stored directly on the meter transmitter
- Both the meter and the reference system clocks would need to be synchronised.
- Implementation may require deeper access to the meter transmitter.

Method	Potential Accuracy	Physical Layer	Hardware Required	Cost	Complexity
Manual	>1s	n/a	n/a	Negligible	Low
NTP (public internet)	10-100 ms	Ethernet	Standard ethernet cables, switches and software	Low	Low
NTP (LAN and GPS)	<2ms	Ethernet	As above plus NTP server, GPS receiver and dedicated LAN	Moderate	Moderate
IRIG-B	<1 μ s	Coaxial cable	IRIG-B decoder cards or interfaces, coaxial cables	Moderate to High	Moderate
PTP	<1 μ s	Ethernet	PTP compatible switches, ethernet cables and network interface cards	High	High
White Rabbit	<1 ns	Fibre Optic	Specialised high-end hardware, fibre optic cabling	Very High	Very High



Thank you



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