# IMPROVING MEASUREMENT UNCERTAINTY IN CUSTODY TRANSFER MEASUREMENT SYSTEMS

**Reference No fg: 17027**

Pankaj Gupta
GAIL (India) Limited
Pk_gupta@gail.co.in

---

## ABSTRACT

Improving measurement uncertainty in custody transfer measurement systems is what every organization has been looking for. Technological advancements resulting in improved uncertainty of the products being developed and offered has enabled in achieving this goal. However, adoption of the methods/technology that already exist for custody transfer measurement systems may result in improvement in substantial improvement in the measurement uncertainty and operational efficiency. This paper talks about the use of HART Communication for custody transfer systems. HART protocol has been around since long and has offered powerful diagnostic tools for process industry. However its use in custody transfer measurement loops has many advantages which are elaborated in this this paper.

## KEY WORDS

HART protocol, Measurement Uncertainty, Digital Communication

## 1.0 INTRODUCTION

Custody Transfer measurement systems are the cash registers of any organization involved in custody transfer of hydrocarbons. A small measurement system error can result into huge financial implications on either buyer or seller side. This technical papers aims to explore the use of existing measurement system components in such a way so that total measurement uncertainty is improved without any additional/meagre expenditure. It aims to configure the existing system by tapping the unused potential of the system components as per recommended practices/standards resulting in improvement of measurement uncertainty. The paper restricts itself to Natural Gas custody transfer measurement systems, although it is applicable to other process applications as

## 2.0 TYPICAL NG CUSTODY TRANSFER MESUREMENT SYSTEM

A typical natural gas custody transfer measurement system consists of following components:

### 2.1 PRIMARY DEVICES

The primary device defines the basic type of meter used for gas measurement, including, but not limited to, an orifice, turbine, rotary or Ultrasonic meter. The gas quantity is measured by Primary Meter at Flowing or Line conditions ( At Line pressure and Temperature). Based on the principal used for determining/inferring the, electrical signal (analog or digital) representing primary process variable and having defined relationship with the flowing fluid is propagated to tertiary device, i.e flow computer for calculation of volumetric flow.

## 2.2 SECONDARY DEVICE

The secondary device provides Electrical representation of inputs process variables , including, but not limited to, static pressure, temperature, differential pressure, relative density, and other variables that are appropriate for inputs into the tertiary device. Gas composition is provided by the Gas chromatograph/ SCADA/ Manual input for calculation of compressibility factor at Base conditions and line conditions.

## 2.3 TERTIARY DEVICE

Each primary device requires a specific or properly configured tertiary device appropriate to the type of meter used. The tertiary device is an electronic computer, programmed to correctly calculate flow within specified limits, that receives information from the primary and/or secondary devices. Flow computer or Volume correction device implements various algorithms such as AGA8 calculations for calculation of compressibility along with other applicable algorithms like AGA3, AGA7, AGA9, AGA10 and other calculations for energy measurement as per applicable/prevailing/agreed measurement standards. These devices are type approved for custody transfer measurement from various international bodies like NMi, PTB etc. ensuring the integrity of implemented algorithm. Thus Measured or actual volume is then Converted to Standard Volume by converting it to base conditions of pressure and temperature (As per contractual provisions between the parties involved).

Each component in the measurement system has an important role to play and is associated with device accuracy/uncertainty. Total uncertainty of the system is dependent upon the individual variables uncertainty and increases with increase in the number of devices/operations/conversions.

In order to decrease the uncertainty in measurement, efforts need to be put in to reduce the number of conversions from field device (transmitter) to flow computer. Conventionally 4-20 mA loops have been used to transmit the field process parameter to control room devices like flow computers. This process involves conversion of the physical process variable to equivalent electrical 4-20 mA signal which then goes through the entire loop to finally arrive at Flow computer/Control system ADC. There it is again converted to Equivalent process value for further calculations. There is an accuracy/uncertainty statement in this process. Thus 4-20 mA signal emanating from the field transmitter is received by the Flow computer ADC within a tolerance band. It will be wonderful if the if the process values could be directly received by the flow computer ADC without any intermediate conversion.

## 3.0 A TYPICAL CONVENTIONAL INSTRUMENT LOOP DIAGRAM (ANALOG 4-20mA)

A typical conventional instrument loop diagram (ANALOG 4-20mA) loop diagram is depicted in Figure-1.

A typical loop for metering Pressure/temperature/Differential Pressure input consists of following components:

1. Pressure/ Diff. Pressure/Temp Transmitter
2. Intrinsic safety Barrier
3. Flow Computer.

**(i) Pressure/ Diff. Pressure/Temp Transmitter**

A transmitter converts the process values to Linear 4-20 milli Ampere current signal at the transmitter level. The Physical process parameter produces some change in electrical characteristics of the transmitter electronics which is converted to equivalent milli- ampere signal by transmitter electronics.

**(ii) Intrinsic safety Barrier**

Intrinsic safety barrier is used to limit the amount of energy available in the hazardous location in case of any malfunction of any component of the loop. For example ,In case of any short circuit in the field equipment the amount of energy available in the field (hazardous atmosphere) is limited and clamped so that no ignition can take place even if hazardous mixture is available in the field.

At the same time it is expected that the Intrinsic safety barrier will replicate the exact mA signal from field side (Transmitter) to Safe area side (Flow Computer). Each barrier will have some accuracy specifications for its performance which means that the mA value transmitted from field transmitter to flow computer will be within some accuracy limit based on the instrument specifications.

**(iii) Flow Computer:**

The mA signal from the barrier is transmitted to Flow computer Analog input channel which consists of Analog to Digital convertor(ADC). The ADC has again some accuracy specifications and needs calibration. This ADC linearly converts the mA signal back to field process value.

## 4.0 UNDERLYING ISSUE

As so many components are involved in the transmission of the field signal ,thus the physical variable in the field may not be replicated exactly at the flow computer. The Value used for flow computation will be thus in variance with the value actually transmitted by the transmitter. This is best explained with the help of an example presented at Table-1 of Annexure-1, how this impacts flow measurement. It can be seen that in worst case scenario 50 Kg/cm2 will be read as 49.8475 Kg/cm2. This corresponds to -0.305 % of reading of process value which translates to -0.338% for flow.

**Issue faced in orifice metering :**

In case of Orifice metering systems, the Differential pressure input is the primary input corresponding to flow. Default keypad/ fallback value for the DP input is usually fixed as Zero in flow computer configuration. Diff. Pressure transmitter is calibrated in the field for defined range (SPAN) and same range is fed in the flow computer as scaled input for DPT ADC channel.

**Let us assume:**

**Diff. Pr. Transmitter URL: 20000 mmWC**

**DPT Calibrated Range: 10000 mmWC**

If the process conditions are unstable and demands excess flow beyond the calibrated span of DPT, the differential pressure input will saturate above a particular over range mA. In case of smart equipment based on the configuration it may be driven to either low or High saturation current. Although the transmitter may have URL much higher than the calibrated range, the Diff.

Pressure input will be saturated. This saturated input when reaches flow computer ADC, it may treat the value as invalid/alarm value (being out of normal 4-20 mA range). Thus default/Keypad value (normally configured as Zero) is used in flow calculation. This results in registering zero flow when the actual flow is beyond the calibrated range of DPT.

This holds good for other process parameters as well like pressure and temperature. Normally Default/Keypad/Fall-back values near to operating parameter values are defined for Pressure and Temperature inputs, thus detecting this mismeasurement may be difficult.

## 5.0 THE PROPOSED METHOD

Although HART communication protocol has been there for long, but its impact on custody transfer measurement system is still not tapped fully. Not all measurement loops are designed on HART loops even today. With the advancement of development in electronic field devices, highly accurate and stable devices using Highway Addressable Remote Transducer (HART) protocol are being used in field instrumentation.

The HART communication protocol is based on the Bell 202 telephone communication standard and operates using the frequency shift keying (FSK) principle. The digital signal is made up of two frequencies— 1,200 Hz and 2,200 Hz representing bits 1 and 0, respectively. Sine waves of these two frequencies are superimposed on the direct current (dc) analog signal cables to provide simultaneous analog and digital communications (Figure1). Because the average value of the FSK signal is always zero, the 4–20 mA analog signal is not affected.

Figure 1: Simultaneous Analog and Digital Communication

HART devices can operate in one of two network configurations—point-to- point or multidrop.

### 5.1 POINT TO POINT:

In point-to-point mode, the traditional 4–20 mA signal is used to communicate one process variable, while additional process variables, configuration parameters, and other device data are transferred digitally using the HART protocol (Figure2). The 4–20 mA analog signal is not affected by the HART signal and can be used for control in the normal way. The HART communication digital signal gives access to secondary variables and other data that can be used for operations, commissioning, maintenance, and diagnostic purposes.

### 5.2 MULTIDROP MODE:

The HART communication protocol enables several instruments to be connected on the same pair of wires in a multidrop network configuration (Figure8). The current through each field device is fixed at a minimum value (typically 4 mA) sufficient for device operation. The analog loop current does not change in relation to the process and thus does not reflect the primary variable. Communications in multidrop mode are entirely digital. All process values are transmitted digitally. In multi-drop mode, all field device polling addresses are >0, and the current through each device is fixed to a minimum value (typically 4 mA).

Let us go back to the Illustrative example1. It is assumed that the loop is designed in HART Multidrop mode. In this case it can be seen that transmitter outputs digital signal corresponding to process value of (50kg/cm2) instead of 12 mA current signal. The current signal is fixed at 4 mA.

This digital process variable value of 50kg/cm2 reaches Intrinsic safety barrier as input from hazardous area transmitter and is transmitted to safe area flow computer HART input without getting effected. As Complete loop is configured on HART communication the flow computer receives the digital process value directly as 50 KG/cm2 which is now used for flow calculation.

Thus if the conventional loop is compared with the HART loop, a definitive improvement in accuracy can be ensured. Thus the conventional loop, in a worst case scenario for illustrated example , may result in under measurement to the tune of -0.338 % as compared to HART Multidrop Mode pertaining to pressure measurement loop only. Similar contributions may be expected from temperature measurement loop. Thus overall measurement uncertainty would be far beyond -0.3 %

Similarly In case of Orifice metering systems with:

Diff. Pr. Transmitter URL: 20000 mmWC

Diff. Pr. Transmitter Calibrated Range: 10000 mmWC

If the process conditions are unstable and demands excess flow beyond the calibrated span of DPT , transmitter still reads the process value and communicates the same to flow computer for flow calculation. This hold good for DP input ranges upto URL. Thus flow computer will keep on registering the flow values.

## 6.0 CONCLUSION

Fiscal measurement systems are the cash registers of any organization involved in custody transfer of hydrocarbons . It is desirable to reduce the uncertainty of measurement on different accounts so that accurate Quantity Transaction Records are available. Efforts are being made on continuous basis to improve the measurement uncertainty in the custody transfer measurement systems. Majority of the existing systems are already equipped with instruments which have capabilities which are underutilized. Optimal configuration and exploitation of the unused potential of systems can definitely improve the measurement uncertainty. A system consisting of hardware which is configured for conventional analog measurement can be configured to use digital communication protocols like HART to improve measurement uncertainty.

## REFERENCES

*[1] HART Communication Foundation. " HART Field Communication Protocol Specification".*

*[2] Bell System Technical Reference: PUB 41212, "Data Sets 202S and 202T interface Specification", July 1976.*

*[3] HART Field Communications Protocol, Application Guide ,HCF LI 34*

*[4] HART Communication Protocol, HCL_LIT-054,Revision 1.1*

## Illustrative example

### Impact analysis on flow computation – Signal transmission from field device to flow computer:

**Analog Transmission Loop for pressure measurement**

- Analog Loop for Static Pressure Measurement:
- Calibrated Span: 0-100 Kg/cm2
- Operating Pressure: 50 Kg/cm2

It is assumed that the transmitter is operating in such a way that 12 m Amp is being transmitted for representing 50 kg/cm2 .

**(i) Intrinsic Safety Barrier :**

transmission accuracy specification : 20 µ A (0.02 mA)

This 12 mA signal reaches Intrinsic safety barrier as input from hazardous area transmitter and is transmitted to safe area flow computer analog input.

**(ii) Flow Computer:**

Flow Computer ADC Accuracy : ± 0.02% of FSD at 23°C (73°F).( 0.0044 mA).
Input Range: 0 to 22 mA
Flow computer analog input received: (12 +/- 0.02 )mA i.e. 11.98 to 20.02 mA ( 49.875 Kg/cm2 to 50.125 Kg/cm2).

Assuming that 49.875 Kg/cm2 corresponding to 11.98 mA reaches flow computer input channel.

Process value used for flow computation : 49.8475 Kg/cm2 to 49.9025 Kg/cm2) corresponding to (11.9756 mA to 11.9844 mA).

**Assumptions:**

Only signal transmission from field device to tertiary device is used for illustration.

Other effects like:

- Reference accuracy including linearity, hysteresis and repeatability
- Stability
- Ambient temperature effects
- Line pressure effects
- Vibration effects
- Power supply effects
- Mounting position effects etc. have not been considered.

Complete Uncertainty calculation as per GUM/ISO 5168 or any other international standard is not considered.

Only pressure loop has been considered in the illustrative example. Similar calculation for other parameters like temperature , differential pressure ,if considered , the worst case scenario impact will be more severe.

***Table-1***

| Description | HART | CASE-I | CASE-II |
|---|---|---|---|
| Uncorrected Flow rate (ACM/hr) | 1000 | | |
| Line Pressure(Kg/cm2g) | 50 | 49.8475 | 49.9025 |
| Line Temperature (Deg C) | 25 | | |
| Base Pressure(Kg/cm2g) | 1.033227 | | |
| Base Temperature(Deg C) | 15.56 | | |
| Gas Composition | | | |
| Methane | 84.91 | | |
| Ethane | 6.4 | | |
| Propane | 3.47 | | |
| i-Butane | 0.15 | | |
| n-Butane | 0.15 | | |
| i-Pentane | 0.1 | | |
| n-Pentane | 0.1 | | |
| Hexane | 0.07 | | |
| Nitrogen | 0.15 | | |
| Carbon Di Oxide | 4.5 | | |
| Base Compressibility | 0.997257 | | |
| Line Compressibility | 0.879672 | 0.88002 | 0.879895 |
| Standard Flow rate (SCM/Hr) | 54221.39 | 54038.01 | 54104.13 |
| **% Diff. wrt HART Transmission Mode** | | **-0.33822** | **-0.21627** |

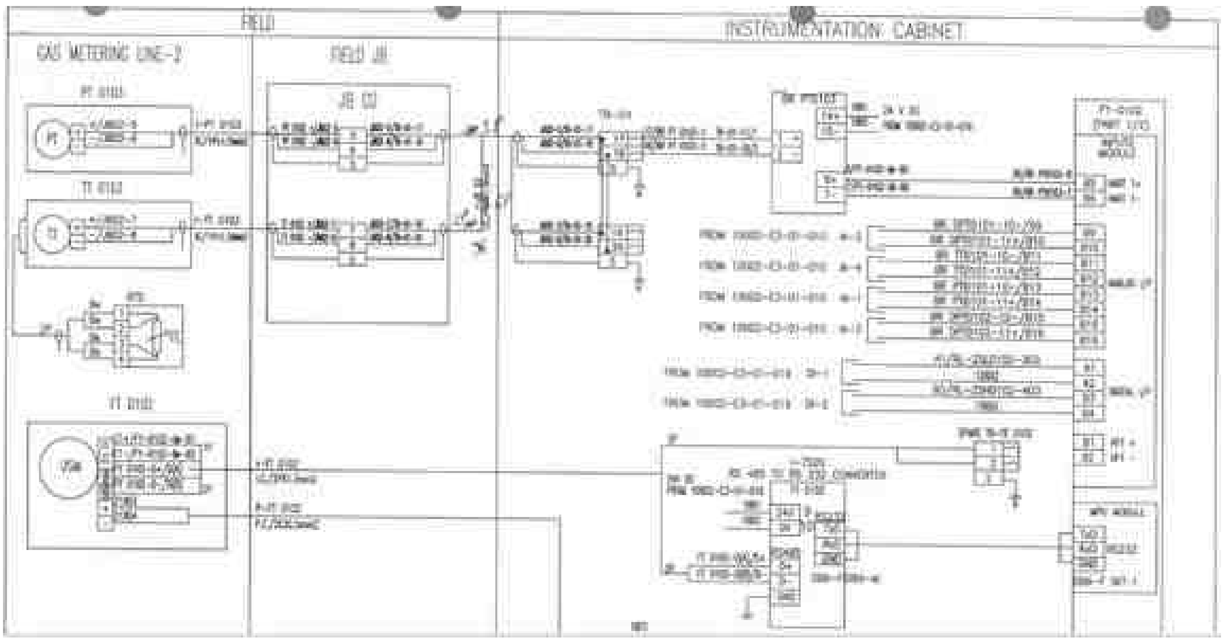


***Figure:1 A typical loop diagram from field instrument (Secondary) to flow computer (Tertiary)***

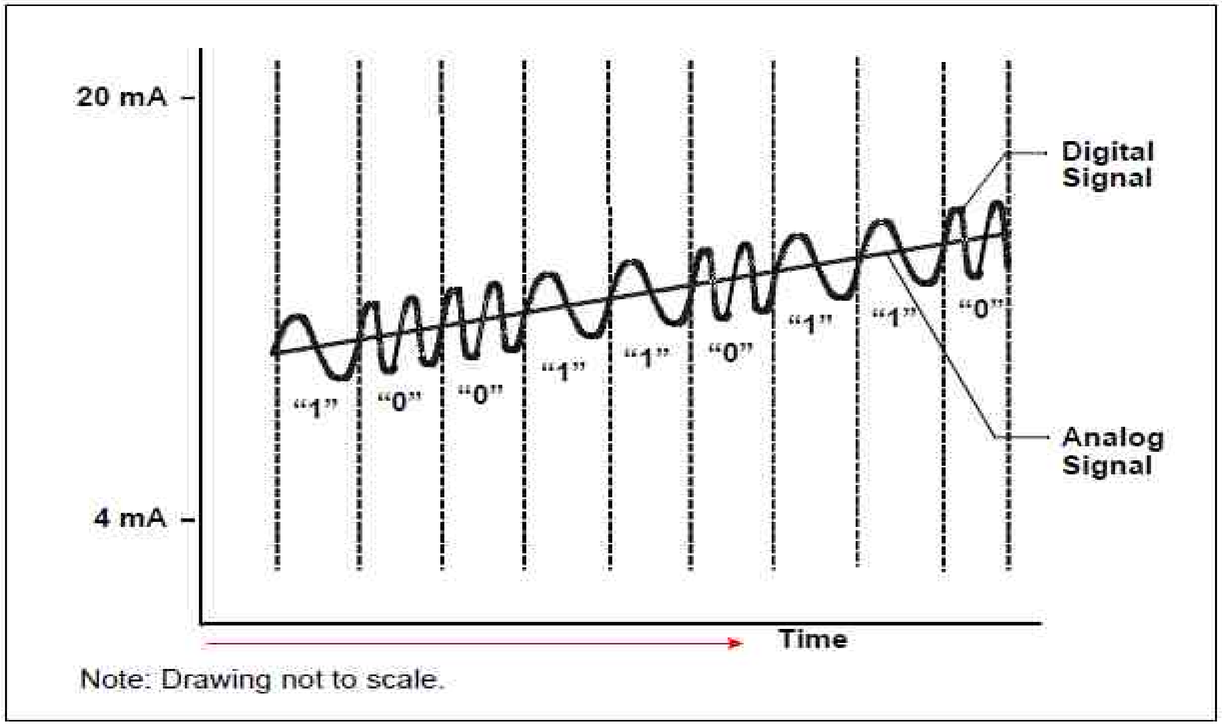


*Figure:2 Simultaneous Analog and Digital Communication*

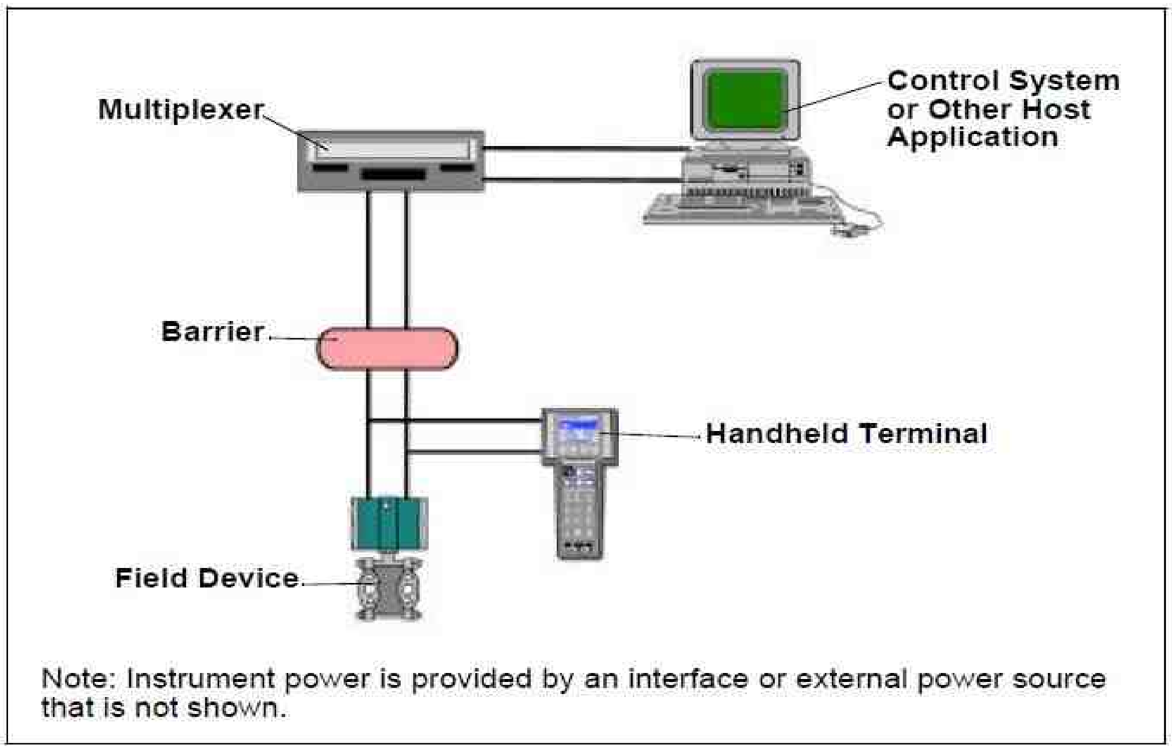


*Figure:3 Point to Point Mode of Operation*

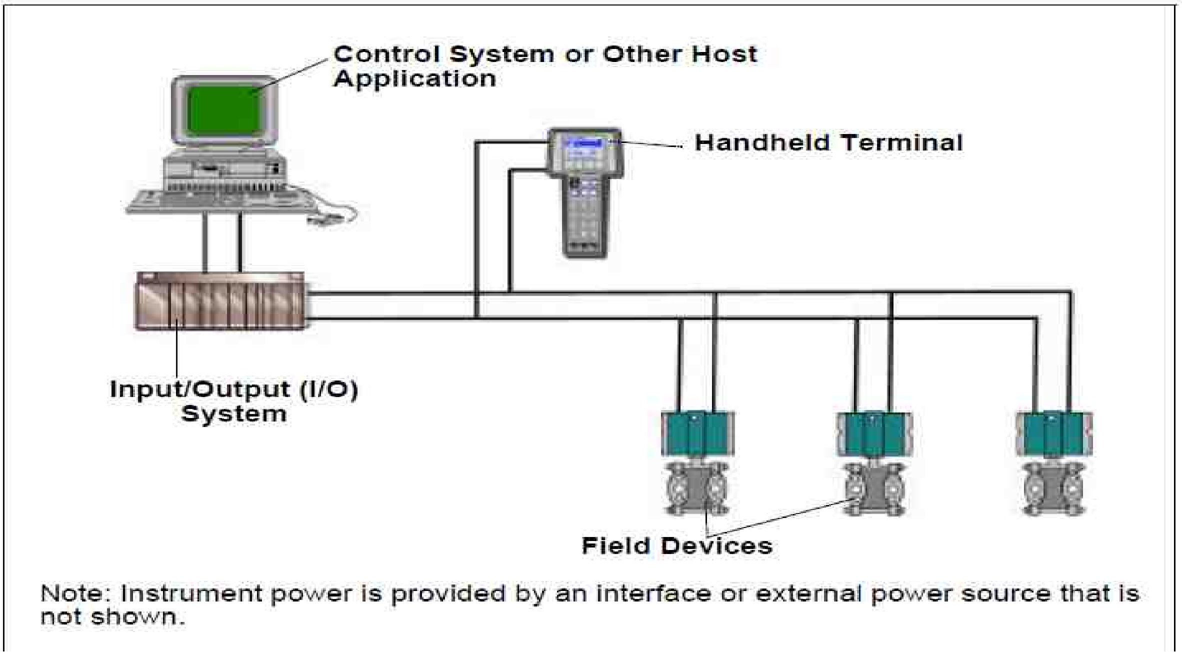


***Figure:4  Multidrop Mode of Operation***

# Presenting Author Biodata

**Name** : Pankaj Gupta

**Designation** : Chief Manager

**Company** : GAIL (India) Limited

**Qualification** : MBA (marketing), B.E. (Instrumentation Engg)

**Area of Expertise** **:**More than 15 years of experience in Instrumentation Maintenance and Flow measurement. Responsible for maintenance and upkeep of Custody Transfer measurement systems of India's largest Gas utility, GAIL (India) Limited, A Maharatna enterprise of Govt of India. Maintenance of Various metering systems ( Ultrasonic, Turbine and Orifice) as per international standards .

**Significant Achievements:**

1. Certified "Functional Safety Engineer " Level 1 in accordance with IEC 61511:2003 by TUV SUD South Asia Pvt. Ltd.
2. Installation and commissioning of, first of its kind in south east Asia ,High pressure natural gas Calibration facility for Ultrasonic and turbine meter sizes varying from 2 " to 20 " . The system is designed and certified by Netherland Meet institute, Netherlands for Ultrasonic and Turbine meter proving.
3. Development of Policies and procedures for Custody transfer measurement systems in GAIL in line with relevant international standards and best practices.
4. Upgradation of Control System packages for RB211 and Allison KC5 and KB5 fleet of GAIL (India) Limited.

**Number of Papers Published in Journals:**

**Number of Papers Published in Conferences:**

1. Terminal Automation at GAIL Hazira and associated Terminals , published in $5^{th}$ knowledge sharing seminar held at GAIL GTI Noida, 2012

2. Integration of Upgraded Unit Control Panels of Gas Turbine Generators ( 02 GTGs) and Gas Turbine Compressors(10 GTCs) with Fire and Gas detection and online CO2 weighing system along with Centralized HMI system at GAIL Hazira, published in $5^{th}$ knowledge sharing seminar held at GAIL GTI Noida, 2012