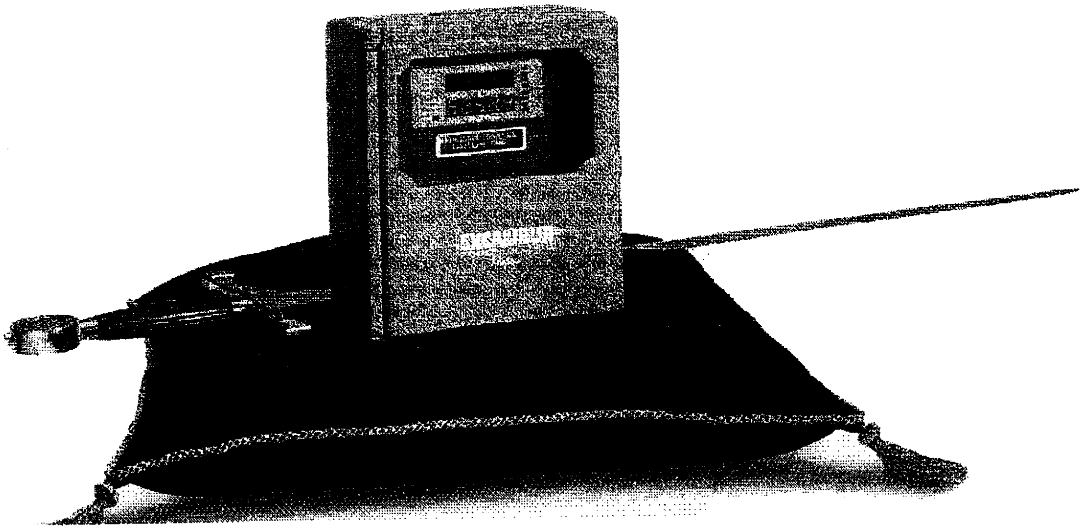
INSTRUCTION MANUAL SUPPLEMENT
for
Using HART Communications Protocol for Configuration, Calibration & Operation of the Excalibur 7000 Level Controller



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1. The HART Protocol General Information

1.1 Introduction To HART

This section introduces the main concepts of digital communications with field instruments and transmitters using the HART protocol.

The Excalibur 7000 fits the definition of an “intelligent”, or smart, field device in that it includes a microprocessor. This implies extra functionality over previous analog instruments. In this case the device is able to take a level measurement and interpolate a secondary measurement (volume or flow rate) from it. In addition to the ability to generate a secondary measurement the Excalibur includes many other features (multiple displays, alarms and PID control) that allow the user to obtain the functionality of several instruments in a single device. Finally, the smart instrument allows semiautomatic calibration and provides internal diagnostic and self-test functions to simplify maintenance procedures.

As well as giving better performance, this extra functionality reduces the amount of host (control system) processing and results in the reduction of a range of instruments to a single model with advantages in manufacturing and inventory management.

1.2 Configurators

To make use of these extra features, smart devices usually need a hand-held communicator for setting up and controlling the instrument. (The Excalibur 7000 also provides an operator interface located on the front panel of the instrument.) There are also a number of host software packages available.

A Device Descriptor, DD, has been written for the Model 275 Communicator to allow the user full access to the features of the instrument. Other devices and software packages will only have access to those features supported by the HART protocol Universal and Common-Practice commands.

In addition to providing overview information on the HART protocol this document provides detailed information on setting up, calibrating and operating the Excalibur 7000 using the Model 275 Communicator.

1.3 Digital Communication

The Excalibur 7000 and its communicator can be separated by a greater distance using properly-specified serial communications. This communication occurs over the same two wires already used to connect the instrument's analog output to the receiving device (recorder, distributed control system, control element, etc.). The HART protocol allows the analog and digital signals to co-exist on the same pair of wires without disrupting the analog signal.

The HART protocol option for the Excalibur 7000 provides the advantage of digital communications while retaining compatibility and reliability of analog signal inputs required by existing systems.

In addition to using digital communications to set up and control the Excalibur 7000, it becomes possible to read the measured variable over the communications link. Without modification, these instruments are ready for fully-digital system use.

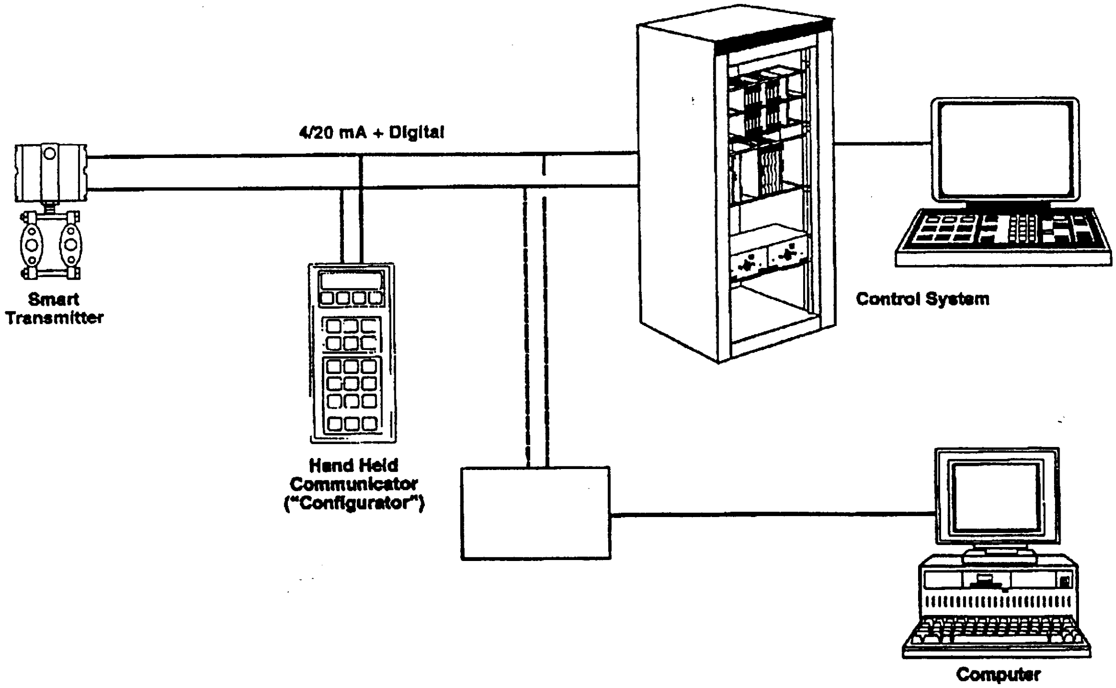

FIGURE 1.1 – Digital Communications

1.4 Reading the Variable by Digital Communication

Using digital communications to read the measured variable enables a single instrument to handle more than one measurement. For instance the Excalibur 7000 can interpolate a volume or flow rate measurement from the level measurement. And both the measured level and interpolated secondary measurement can be read in a single message. Also, you can monitor the status of the instrument every time a measurement is made, increasing the confidence and security of automatic control.

Reading the measured variable digitally preserves the accuracy by eliminating the process of digital-to-analog and analog-to-digital conversion of the 4-20 mA signal. However, the time taken to communicate the message adds an extra delay (dead time) to the measurement, which could adversely affect the control of fast loops. An advantage of the HART protocol is that the analog signal can continue to be used for control purposes in these situations.

1.5 Additional Information

Digital communication allows you to keep additional information in the Excalibur 7000 that can be read when required. The instrument can store process-related information such as tag number and a description of the measurement, and the instrument calibrated range and units, Or, it can give information about the device itself, acting as an electronic "label". Further, it can be used to keep records of maintenance-related activities such as the date of last calibration.

1.6 Multidrop Communication

If the measurement is read digitally, the analog 4 to 20 mA signal is no longer required. Therefore, you can connect multiple field devices to a single pair of wires, and individually read transmitter data. To do this, each device must have an address to which it will respond, and each request from the host must include the address as part of the message.

This can significantly reduce the cost of field wiring and host input interface electronics. However, the use of a cyclic scan means that each instrument is only examined at intervals. The cycle time for a complete scan may be too long for high-speed control loops.

In multidrop mode, the transmitter analog output is fixed at 4 mA to provide power to two-wire devices. Field devices are connected in parallel.

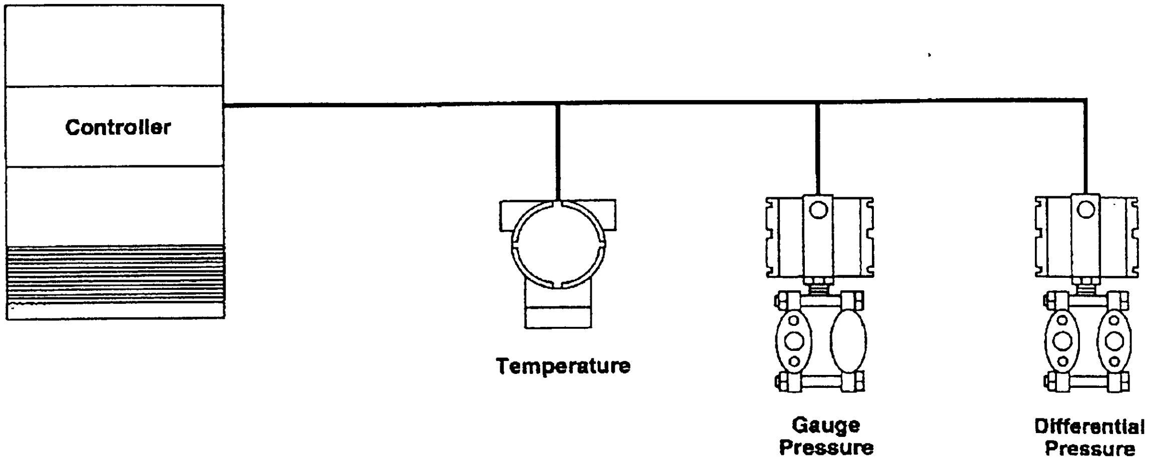

FIGURE 1.2 – Multidrop Communications

1.7 The HART Protocol

To efficiently use the extra features of digital communications with a range of different devices, a communications standard is needed. This standard has to include specifications for the physical form of transmission, transaction procedures, message structure, data formats, and a set of commands to perform the required functions.

The HART protocol was originally developed by Rosemont Inc. To encourage digital communication, Rosemont Inc. made the HART protocol open for everyone to use. The protocol is now supported by the independent, non-profit HART Communications Foundation. The complete specification and technical support is available from the foundation.

HART protocol uses the Bell 202 standard frequency shift keying (FSK) signal to communicate at 1200 baud, superimposed at a low level on the 4 to 20 mA analog measurement signal. Having an average value of zero, an FSK signal causes no interference with the analog value.

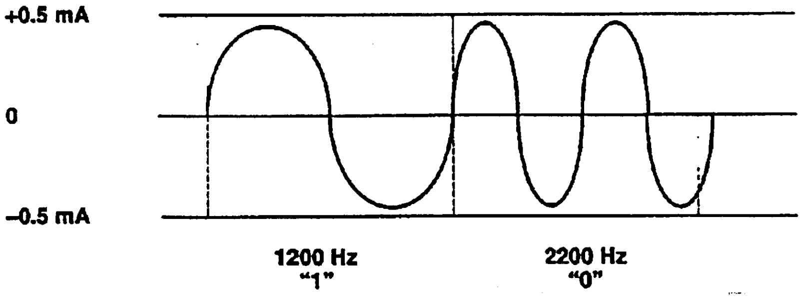

FIGURE 1.3 – FSK Signal Characteristics

Each message includes the address of its source and its destination, and has a checksum to allow the detection of any corruption of the message.

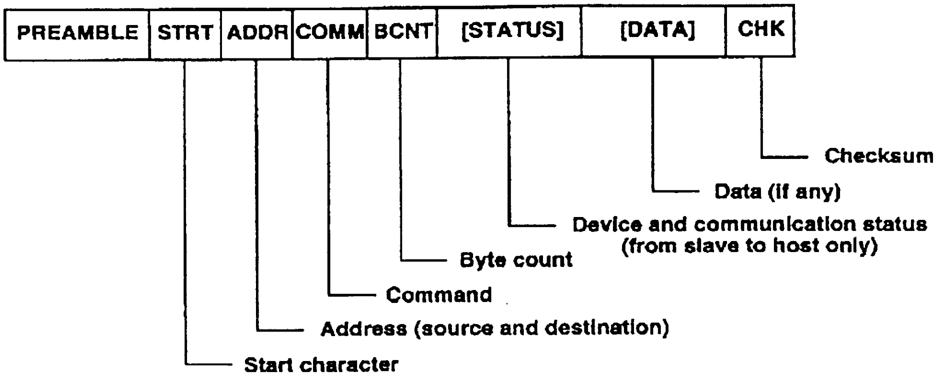

FIGURE 1.4 – HART Data Link Frame Format

HART protocol is a master-slave protocol. This means that a field device only replies when spoken to. But there can be two masters (a control system and a hand-held communicator, for example). Up to 15 slaves can be connected to a single multidrop line (in non-intrinsically-safe applications). The status of the field device is relayed as two or three reply message transactions are made each second.

1.8 HART Commands

The commands of the HART protocol are defined in three groups, as shown in the following paragraphs.

1.8.1 Universal Commands

The first group, Universal Commands, provide functions that are implemented in all field devices. These are as follows:

- Read manufacturer and device type
- Read primary variable (PV) and units
- Read current output and percent of range
- Read up to four pre-defined dynamic variables
- Write polling address
- Read or write 32-character message
- Read or write 8-character tag, 16-character descriptor, date
- Read PV sensor information
- Read transmitter range, units, damping time constant, etc.
- Read or write final assembly number

1.8.2 Common Practice Commands

The second group, Common-Practice Commands, provide functions common to many field devices, but not all. The commands implemented in the Excalibur 7000 are as follows:

- Read a selection of up to four dynamic variables
- Write damping time constant
- Write transmitter range values
- Reset configuration changed flag
- Set fixed output current
- Perform self-test
- Perform master reset
- Write PV units
- Read additional transmitter status
- Write sensor serial number
- Read or write dynamic variable assignments
- Write transmitter variable units
- Read transmitter variable information
- Write transmitter variable damping time constant
- Write transmitter variable sensor serial number
- Write number of response preambles
- Write burst mode transmitter variables
- Write burst mode command number
- Write burst mode control
- Read all dynamic variables

1.8.3 Device-Specific Commands

The third group, Device-Specific Commands, provide functions that are unique to the Excalibur 7000. These are as follows:

- Read and write measurement mode
- Read and write front panel display setup
- Read PID status, AutoTune mode, gain, reset and rate
- Read and write PID setpoint
- Write PID state
- Write PID AutoTune mode
- Write PID gain, reset and rate
- Write PID manual output
- Read vessel parameters (vessel type, radius, length & end depth)
- Write vessel type
- Write vessel dimensions
- Read and write weir type
- Read and Write weir width

- Read and write V-notch weir angle
- Read and write flume size
- Read and write strapping table point
- Write self-test mode
- Write low level trim
- Write high level trim
- Read alarm setup information
  (status, source, type, failsafe mode, relay, hi SP, low SP, delay on & delay off)
- Write alarm status
- Write alarm source
- Write alarm type
- Write alarm failsafe mode
- Write alarm relay selection
- Write alarm low setpoint
- Write alarm high setpoint
- Write alarm on time delay
- Write alarm off time delay
- Write sensor limits

2. The Physical Signal

2.1 Introduction

This section describes the physical signaling method and transmission medium of the HART protocol, which correspond to the physical layer of the OSI (English translation, International Standards Organization) protocol reference model.

2.2 Frequency-Shift Keying

HART protocol uses a frequency-shift keying technique to superimpose digital communications on the 4 to 20 mA current loop connecting the Excalibur 7000 to the receiving instrument (recorder, control element control system, etc.). Two different frequencies (1200 Hz and 2200 Hz respectively) are used to represent binary 1 and 0.

These sine-wave tones are superimposed on the DC signal at a low level. The average value of a sine-wave signal is zero. Therefore, no DC component is added to the existing 4 to 20 mA signal regardless of the digital data. Consequently, existing analog instruments continue to work as usual – low-pass filtering usually present effectively removes the communication signal. (A single-poll 10 Hz low-pass filter reduces the communication signal to a ripple of about ±0.01% of the full-scale analog signal).

Binary digits are transmitted at a data rate of 1200 baud. This means that a 1 is represented by a single cycle of 1200 Hz, while a 0 is represented by approximately two cycles of 2200 Hz.

This choice of signaling frequencies and transmission rate accords with the Bell 202 standard, one of several frequencies used to send digital information over telephone networks. In the USA, it is permissible to send this signal over the public telephone network. Unfortunately, this standard is not approved for use over European public telephone networks.

The HART protocol specifies that master devices (a host control system or hand-held terminal) transmit a voltage signal, whereas the slave (field) devices transmit a current signal. (Recall that the normal operation of a 2-wire transmitter is to control the loop current; it is easy to extend this control to include the small high-frequency component of the HART communications signal.)

The current signal is converted into a corresponding voltage by the loop load resistor. Therefore, all devices should use voltage-sensitive receiver circuits.

The HART communications signal levels are shown in the following table. All are peak-to-peak values.

Master transmitted signal	min 400 mV max 600 mV
Slave transmitted signal	min 0.8 mA max 1.2 mA
Minimum slave signal, converted by a load of 230Ω Maximum slave signal, converted by a load of 1000Ω	184 mV 1320 mV
Receiver sensitivity (must receive correctly) Receiver threshold (must ignore)	120 mV to 2.0 V 0 to 80 mV

TABLE 2.1 – HART Communication Signal levels

The receiver sensitivity specification allows for some attenuation of the signal due to cable or other component effects. The receiver threshold specification reduces the likelihood of interference from external signals and prevents crosstalk for other HART signals running in adjacent cables or sharing less-than-ideal grounding or power supply systems.

2.3 Point-To-Point Operation

The Excalibur 7000 runs on local power to provide an active source for its 4 to 20 mA output and HART communications. The typical loop connection is as follows:

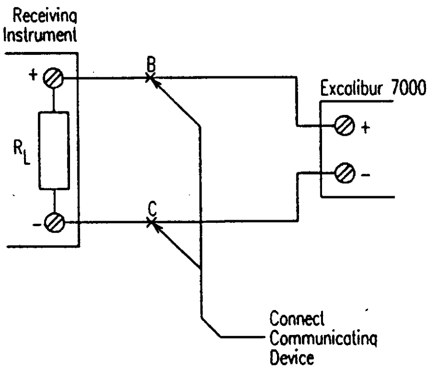

FIGURE 2.1 – Connection Diagram for Point-To-Point Application

A communicating device should be connected across the load resistor at points 'B' and 'C'.). The HART specification allows resistors between 2320 and 1100Ω.

Unless it is a field device, a HART communicating unit must not present any DC load to the line. Therefore, it should include, or be connected through, a capacitor of about 6.8 μF minimum.

2.4 Multidrop Operation

The HART protocol includes a destination address in each message. By setting each slave device to a different address, a number of such devices can be connected in parallel across a single pair of field wires. Each device only replies to messages directed to its address. Because the total of all the 4 to 20 mA analog signals would be meaningless, assigning a non-zero address sets the analog signal to 4 mA (enough to power a 2-wire device) and will reduce the total power requirement.

In point-to-point (single slave device) operation, the primary variable can be read either as an analog value, or by digital communication. In the multidrop mode, digital communication must be used to read the primary variable, because the analog signal is no longer available.

In principle, it is possible to mix 2-wire current loop and active-source devices in a multidrop scheme. But because of their different methods of connection, a third wire is needed in the field, as shown below:

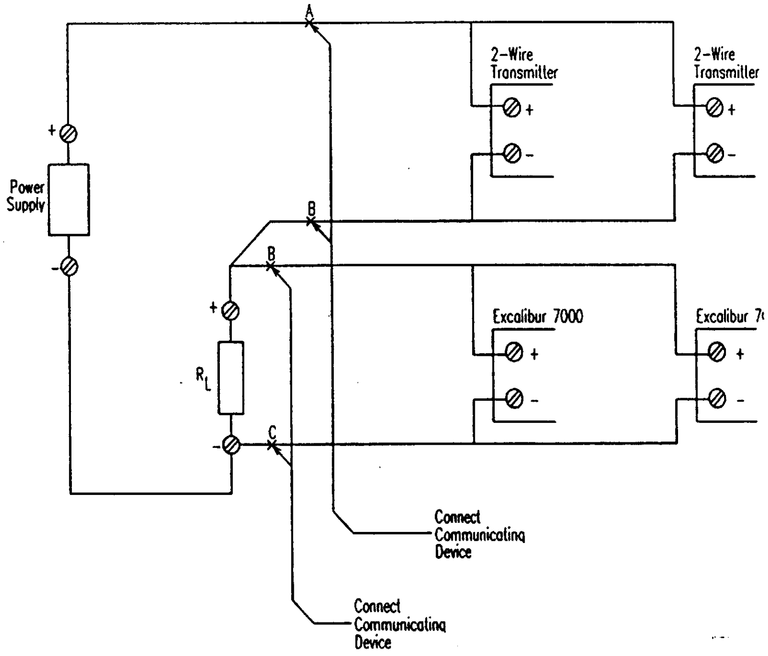

FIGURE 2.2 – Connect Diagram for Multidrop Operation (with mixed device types)

Because twisted triple cable is not readily available, this type of mixed system would have to be constructed using separate twisted pairs connected together at the load resistor.

A communicating device can still be connected across A and B, or across B and C, as in the normal case.

Primary master (including load resistor)	Shunt impedance (receiving) Maximum shunt impedance (sending) (must also not be greater than the value when receiving)	230 to 1100Ω 700Ω
Secondary master	Minimum shunt impedance (receiving) Maximum source impedance (sending)	5 KΩ 100Ω
Slave Device	Minimum shunt resistance Maximum shunt capacitance (see note)	100 KΩ 5000 pF
Miscellaneous devices (total)	Minimum shunt impedance Maximum series impedance	10 KΩ 100 Ω

TABLE 2.2 – Impedance Limits

Note
The 5,000 pF limit on the slave device shunt capacitance is a recommendation rather that an absolute limit. Devices having higher capacitance values must state their capacitance number (CN). The capacitance number is equal to the actual device capacitance divided by 5,000 pF. For example a device has a capacitance of 22,000 pF, hence a CN of 5.

A miscellaneous device is any passive instrument in the loop, such as a local indicator.

2.5 Signal Attenuation and Distortion – the 65 μs Limit

In any network containing resistance and capacitance, signals are delayed, or shifted in phase as they pass through. The amount of attenuation and delay depends on the frequency of the signal relative to the "cut-off" frequency of the network. To ensure reliable reception of the HART signal across the load resistor, the signal from the field device must not be attenuated by more than 3 dB (a factor of 0.707). This allows a small safety margin for the lowest transmitted signal (0.8 mA), the lowest permitted load resistor (230Ω) and the most insensitive receiver (120 mV) (see TABLE 2.1). In addition, the two signaling frequencies must no be delayed unequally by more than about 50 μs, or the composite waveform will be distorted and the data recovery circuits may fail to separate the two frequencies correctly.

To ensure that these conditions are met, the HART specification imposes a minimum cut-off frequency (3 dB attenuation) slightly above the highest HART signaling frequency. This is produced by a resistance-capacitance combination having an RC time-constant value of 65 μs. (This means: multiply together the circuit resistance R and the capacitance C. Include the units; remember, ohms ÷ farads = seconds, for example 250 Ω ÷ 0.1 μF = 25 μs.)

A HART system must be designed to have an RC time-constant of 65 μs or less. In a simple HART system, the resistance R is the sum of the load resistor and the cable resistance. The capacitance C is the sum of the cable capacitance and the capacitances of the connected devices. To allow high capacitance, keep the load resistor as low as possible – 250 Ω is a commonly used value. How this affects permissible number of devices and cable lengths is discussed below.

If there are other devices, such as a local current indicator or a chart recorder, in series with the loop, their series resistance (if it is not shunted by a capacitor at HART signal frequencies) needs to be added.

2.6 Cabling

The field wiring of a HART system should normally use a twisted pair cable, either shielded as a pair, or with a common shield over a cable containing multiple twisted pairs. In the latter case, it is important not to use the other pairs for signals that might interfere with the HART communication. (They can be used for other HART lines, or for pure analog lines providing the HART protocol limits on rate of change for analog signals are met -- analog signal bandwidth is discussed below.)

If the cable is more than a few meters, its resistance and capacitance may become significant in the RC time-constant limitation (see Signal Attenuation and Distortion above). Also, its resistance may be important in the loop voltage drop calculation required by any 2-wire system.

Cable parameters depend on conductor diameter, insulation type and thickness. Capacitance is measured from one conductor to all others and shield; resistance is for both conductors in series. Use values measured or specified for the particular cable used in installation. Typical values are as follows:

Computer-grade shielded twisted pair	65 pF/m	120 Ω/km
Industrial shielded twisted pair	150 pF/m	120 Ω/km
Shielded multicore cable	200 pF/m	120 Ω/km

TABLE 2.3 – Typical Cable Parameters

When using a single field device and a host with a 250 Ω load and no other significant resistance, 65 μs would allow 0.26 μF total capacitance. Allowing 0.01 μF (10,000 pF) for the host and field device, the cable capacitance could be up to 0.25 μF. However, if the cable resistance was 110 Ω, R becomes 360 Ω, which leads to a permitted total capacitance of only 0.18 μF. This would correspond to a cable length of 900 meters, at 200 pF/m. If you want to extend to the maximum HART cable length of 1,500 meters, the cable must be chosen carefully to have either lower capacitance or lower resistance (thicker conductors).

In a system with ten multidropped (CN=5) transmitters, the attached devices total 225 μF (10 x 25,000 pF + 5,000 pF) leaving only 0.005 μF for cable capacitance. In this case, the permissible cable length would be only 25 to 75 meters, depending on cable type. (The cable resistance is negligible in this case.)

2.7 Grounding

To prevent interference by external signals, ground the system properly. The signal loop and the cable should be grounded at only one point. The cable shield must not be connected to the instrument case unless it is isolated from ground. The common ground point will usually be at or near the primary master (for example, the control system).

2.8 Analog Signal Bandwidth

To avoid interference with the superimposed HART communication signal, a 40 dB/decade attenuation filter limits the rate of change of the analog output of a HART-compatible transmitter above 25 Hz. The HART receiver is specified to reject any signal that could be produced by a 16 mA square wave passing through such a filter.

2.9 Intrinsic Safety (IS) Barriers

Systems using IS barriers require a loop voltage drop check, and reduction of supply voltage to passive barriers by 0.6 V to allow headroom for the HART signal. This avoids clipping by the zener diodes. The series resistance of the barrier must be included in the RC time-constant calculation, and there may also be some parallel capacitance from the barrier. For more complex active barriers, different considerations apply.

3. Commands

3.1 Introduction

The details of coding, message structure and transaction processing are covered by the HART protocol specifications and are part of the basic software structure of most host devices. These commands correspond to layer 7 – application layer – of the OSI protocol reference model.

This section is concerned with the content of the Command, Status and Data fields of the general message structure of the HART commands

3.2 Command

The command byte contains an integer (0 to hex FF or decimal 255) representing one of the HART commands. 254, and expansion code, is followed by an additional byte allowing more than 256 different commands to be defined if necessary.

HART commands are defined in three groups: “universal”, “common practice” and “device-specific”.

3.2.1 Universal Commands

Universal commands provide functions that are implemented in all field devices. The Excalibur 7000 implements all of the commands in this group. These commands are:

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)	DATA IN REPLY (TYPE)		
0	Read unique identifier	none	Byte 0	“254” (expansion	
			Byte 1	manufacturer id code	
			Byte 2	mfr.’s device type code	
			Byte 3	number of preambles	
			Byte 4	universal cmd revision	
			Byte 5	xmtr specific cmd rev	
			Byte 6	software revision	
			Byte 7	hardware revision	(H)
			Byte 8	device function flags	(B)
			Byte 9-11	device ID number	
1	Read primary variable	none	Byte 0	PV units code	
			Byte 1-4	primary variable	(F)

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)			DATA IN REPLY (TYPE)		
2	Read current and percent of range	none			Byte 0-3	current (mA)	(F)
					Byte 4-7	percent of range	(F)
3	Read current and four (predefined) dynamic variables	none			Byte 0-3	current (mA)	(F)
					Byte 4	PV units code	
					Byte 5-8	primary variable	(F)
					Byte 9	SV units code	
					Byte 10-13	second variable	(F)
					Byte 14	TV units code	
					Byte 15-18	third variable	(F)
					Byte 19	4V units code	
					Byte 20-23	fourth variable	(F)
6	Write polling addr	Byte 0	polling addr			as in command	
11	Read unique ident. Associated with tag	Byte 0-5	tag	(A)		as command 0	
12	Read message	none			Byte 0-23	message	(A)
13	Read tag descriptor, date	none			Byte 0-5	tag	(A)
					Byte 6-17	descriptor	(A)
					Byte 18-20	date	(D)
14	Read PV sensor information	none			Byte 0-2	sensor serial number	
					Byte 3	units code for sensor limits and min span	
					Byte 4-7	upper sensor limit	(F)
					Byte 8-11	lower sensor limit	(F)
					Byte 12-15	minimum span	(F)
15	Read output information	none			Byte 0	alarm select code	
					Byte 1	transfer function code	
					Byte 2	PV/range units code	
					Byte 3-6	upper range value	(F)
					Byte 7-10	lower range value	(F)
					Byte 11-14	damping value (sec)	(F)
					Byte 15	write-protect code	
					Byte 16	private-label distributor code	
16	Read final assembly number	none			Byte 0-2	final assembly number	
17	Write message	Byte 0-23	message	(A)			
18	Write tag, descriptor, date	Byte 0-5	tag	(A)		as in command	
		Byte 6-17	descriptor	(A)			
		Byte 18-20	date	(D)			
19	Write final assembly number	Byte 0-2	final assembly number			as in command	

Data types:

A	ASCII string (packed 4 characters per 3 bytes)
B	Bit-mapped flags (bit 0 = multisensor device; bit 1 = EEPROM control required)
C	Date (day, month, year-1990)
F	Floating point (4 bytes IEEE 754)
H	Integers xxxx yyy(xxxx = hardware re., yyy = physical signaling code0

Unmarked items are 8-, 18- or 24-bit integers

TABLE 3.1 – Universal Commands

3.2.2 Common-Practice Commands

Common-practice commands provide functions common to many field devices, but not all. The table below shows those commands implemented in the Excalibur7000 Level Control

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)			DATA IN REPLY (TYPE)		
33	Read up to four transmitter variables	Byte 0	xmtr var code for slot #1		Byte 0	xmtr var code for slot #1	
		Byte 1	xmtr var code for slot #2		Byte 1	units code for slot #1	
		Byte 2	xmtr var code for slot #3		Byte 2-5	var for slot #1	(F)
		Byte 3	xmtr var code for slot #4		(response truncates after last requested var)		
					Byte 6	xmtr var code for slot #2	
					Byte 7	units code for slot #2	
					Byte 8-11	var for slot #2	(F)
					Byte 12	xmtr var code for slot #3	
					Byte 13	units code for slot #2	
					Byte 14-17	var for slot #3	(F)
					Byte 18	xmtr var code for slot #4	
					Byte 19	units code for slot #4	
					Byte 20-23	var for slot #4	(F)
34	Write damping value	Byte 0-3	damping value (sec)	(F)		as in command	
35	Write range values	Byte 0	range units code			as in command	
		Byte 1-4	upper range value	(F)			
		Byte 5-8	lower range value	(F)			
38	Reset "configuration changed" flag		none			none	
40	Enter/Exit fixed current mode	Byte 0-3	current (mA) (0=exit)	(F)		as in command	
41	Perform transmitter self test		none			none	
42	Perform master reset		none			none	
44	Write PV units	Byte 0	PV units code			as in command	
48	Read additional transmitter status	none			Bytes 0-1	additional status	
49	Write PV sensor serial number	Byte 0-2	sensor serial number			as in command	
50	Read dynamic variable assignments		none		Byte 0	PV transmitter variable code	
					Byte 1	SV transmitter variable code	
					Byte 2	TV transmitter variable code	
					Byte 3	4V transmitter variable code	

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)		DATA IN REPLY (TYPE)	
51	Write dynamic variable assignments	Byte 0	PV transmitter variable code		as in command
		Byte 1	SV transmitter variable code		
		Byte 2	TV transmitter variable code		
		Byte 3	4V transmitter variable code		
53	Write transmitter variable unites	Byte 0	xmtr variable code		as in command
		Byte 1	xmtr var units code		
54	Read transmitter variable information	Byte 0	xmtr variable code	Byte 0	xmtr variable code
				Byte 1-3	xmtr var sensor s/n
				Byte 4-	xmtr var limits units code
				Byte 5-8	xmtr var upper limit (F)
				Byte 9-12	xmtr var lower limit (F)
				Byte 13-16	xmtr var damping value (F) (sec)
55	Write transmitter variable damping value	Byte 0	xmtr variable code		as in command
		Byte 1-4	xmtr var damping value (sec) (F)		
56	Write transmitter variable sensor serial number	Byte 0	xmtr variable code		as in command
		Byte 1-3	xmtr var sensor s/n		
59	Write number of response preambles	Byte 0	number of response preambles		as in command
107	Write burst mode transmitter variables	Byte 0	xmtr var code for slot #1		as in command
		Byte 1	xmtr var code for slot #2		
		Byte 2	xmtr var code for slot #3		
		Byte 3	xmtr var code for slot #4		
108	Write burst mode command number	Byte 0	burst mode command number		as in command
109	Burst mode control	Byte 0	burst mode control code (0=exit, 1=enter)		as in command

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)		DATA IN REPLY (TYPE)		
110	Read all dynamic variables		none	Byte 0 Byte 1-4 Byte 5 Bytes 6-9 Byte 10 Byte 11-14 Byte 15 Byte 16-19	PV units code PV value SV units code SV Value TV units code TV value 4V units code 4V value	 (F) (F) (F) (F)

Data types:

A	ASCII string (packed 4 characters per 3 bytes)
B	Bit-mapped flags (bit 0 = multisensor device; bit 1 = EEPROM control required)
C	Date (day, month, year-1990)
F	Floating point (4 bytes IEEE 754)
H	Integers xxxx yyy(xxxx = hardware re., yyy = physical signaling code0

Unmarked items are 8-, 18- or 24-bit integers

TABLE 3.2 – Common-Practice Commands

3.2.3 Excalibur 7000 Specific Commands

Device specific commands provide functions that are unique to the Excalibur 7000. The table below shows these commands.

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)		DATA IN REPLY (TYPE)		
130	Read measurement mode		none	Byte 0	Measurement mode code	
131	Write measurement mode	Byte 0	Measurement mode code		as in command	
132	Read display setup		none	Byte 0 Byte 1 Byte 2 Byte 3	PV display variable code SP display variable code VFD top line variable code VFD bottom line variable code	
133	Write display setup	Byte 0 Byte 1 Byte 2 Byte 3	PV display var code SP display var code VFD top line var code VFD bottom line var code		as in command	
134	Read PID operation		none	Byte 0 Byte 1 Byte 2 Byte 3-6 Byte 7-10 Byte 11-14 Byte 15-18	PID status (on/off) 0 AutoTune mode PID output value PID gain constant PID reset constant PID rate constant	 (F) (F) (F) (F)

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)		DATA IN REPLY (TYPE)	
135	Read PID setpoint		none	Byte 0 Byte 1-4	PID setpoint units code PID setpoint value (F)
136	Write PID state	Byte 0	PID status code		as in command
137	Write PID setpoint	Byte 0 Byte 1-4	PID setpoint units code PID setpoint value (F)		as in command
138	Write AutoTune Mode	Byte 0	AutoTune mode code		as in command
139	Write PID tuning parameters	Byte 0-3 Byte 4-7 Byte 8-11	PID gain constant (F) PID reset constant (F) PID rate constant (F)		as in command
140	Write PID manual output	Byte 0-3	PID manual output value (F)		as in command
141	Write PID control variable	Byte 0	PID controlled variable code		as in command
144	Read vessel parameters		none	Byte 0 Byte 1 Byte 2-5 Byte 6-9 Byte 10-13	Vessel type code Vessel dimensions units code Tank radius (F) Tank height/length (F) End cap depth (F)
145	Write vessel type	Byte 0	Vessel type code		as in command
146	Write vessel dimensions	Byte 1 Byte 2-5 Byte 6-9 Byte 10-13	Vessel dimensions units code Tank radius (F) Tank height/ length (F) End cap depth (F)		as in command
148	Read weir type		none	Byte 0	Weir type code
149	Write weir type	Byte 0	Weir type code		as in command
150	Read weir width		none	Byte 0 Byte 1-4	Weir width units code Weir width (F)
151	Write weir width	Byte 0 Byte 1-4	Weir width units code Weir width (F)		as in command
152	Read V-notch angle		none	Byte 0	V-notch angle code
153	Write V-notch angle	Byte 0	V-notch angle code		as in command
154	Read strapping table value	Byte 0	Strapping table index	Byte 0 Byte 1-4	Strapping table index Strapping table value (F)
155	Write strapping table value	Byte 0 Byte 1-4	Strapping table index Strapping table value (F)		as in command

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)			DATA IN REPLY (TYPE)		
156	Write test control	Byte 0	Test code			as in command	
159	Write low level trim	Byte 0	level units code			as in command	
		Byte 1-4	Level value	(F)			
160	Write high level trim	Byte 0	level units code				
		Byte 1-4	Level value	(F)			
162	Read alarm information	Byte 0	Alarm pointer		Byte 0	Alarm pointer	
					Byte 1	Alarm status	
					Byte 2	Alarm source	
					Byte 3	Alarm type	
					Byte 4	Alarm failsafe mode	
					Byte 5	Alarm relay number	
					Byte 6-9	Alarm hi setpoint	(F)
					Byte 10-13	Alarm low setpoint	(F)
					Byte 14-17	Alarm time delay on	(F)
					Byte 18-21	Alarm time delay off	(F)
163	Write alarm status	Byte 0	Alarm pointer			as in command	
		Byte 1	Alarm status				
164	Write alarm source	Byte 0	Alarm pointer			as in command	
		Byte 1	Alarm source				
165	Write alarm type	Byte 0	Alarm pointer			as in command	
		Byte 1	Alarm type				
166	Write alarm mode	Byte 0	Alarm pointer			as in command	
		Byte 1	Alarm failsafe mode				
167	Write alarm relay	Byte 0	Alarm pointer			as in command	
		Byte 1	Alarm relay number				
168	Write alarm low setpoint	Byte 0	Alarm pointer			as in command	
		Byte 1-4	Setpoint value	(F)			
169	Write alarm high setpoint	Byte 0	Alarm pointer			as in command	
		Byte 1-4	Setpoint value	(F)			
170	Write alarm on time delay	Byte 0	Alarm pointer			as in command	
		Byte 1-4	Time delay (sec)	(F)			
171	Wrote alarm off time delay	Byte 0	Alarm pointer			as in command	
		Byte 1-4	Time delay (sec)	(F)			
172	Read flume size		none		Byte 0	Flume size code	
173	Write flume size	Byte 0	Flume size code			as in command	

COMMAND NUMBER AND FUNCTION		DATA IN COMMAND (TYPE)			DATA IN REPLY (TYPE)
174	Write sensor limits	Byte 0 Byte 1 Byte 25	Measurement code Units code Maximum measured value	 (F)	as in command

Data types:

A	ASCII string (packed 4 characters per 3 bytes)
B	Bit-mapped flags (bit 0 = multisensor device; bit 1 = EEPROM control required)
C	Date (day, month, year-1990)
F	Floating point (4 bytes IEEE 754)
H	Integers xxxx yyy(xxxx = hardware re., yyy = physical signaling code0

Unmarked items are 8-, 18- or 24-bit integers

TABLE 3.3 –Excalibur 7000 Specific Commands

3.3 Status

Status is included only in messages from the Excalibur 7000. It consists of two bytes of bit-coded information. The first byte indicates communications errors, if any. Otherwise if communications were good, this byte may indicate the status of the received command (such as a busy device, or a command not recognized). The second byte indicates the operational state of the Excalibur 7000.

Some of the status indications are applicable to any transaction. Others are specific to particular commands. See the following paragraphs and the full HART specifications for more details.

3.3.1 Status Coding

b7	b6	b5	b4	b3	b2	b1	b0

First byte

Bit 7 = 1	communications error(s)
Bit 6 = 1	parity error
Bit 5 = 1	overrun error
Bit 4 = 1	framing error
Bit 3 = 1	checksum error
Bit 2	(reserved)
Bit 1 = 1	receiver buffer overflow
Bit 0	(undefined)

Second byte is all 0's

First byte

Bit 7 = 0	command error
Bits 6 - 0	error number (not bit mapped)

Single Meaning Command Error Codes

0	no command specific error
1	(undefined)
2	invalid selection
3	passed parameter too large
4	passed parameter too small
5	too few data bytes received
6	transmitter-specific command error
7	in write-protect mode
8 - 15	command specific error (see table below)
16	access restricted
32	device is busy
64	command not implemented

Multiple Meaning Command Error Codes

error code	cmd	meaning
8	34	value set to nearest 0.1 second
	55	value set to nearest 0.1 second
9	35	lower range value too high
10	35	lower range value too low
11	35	upper range value too high
	40	in multidrop mode
	53	invalid variable code
12	35	upper range value too low
	137	invalid units selection
	146	invalid units selection
	150	invalid units selection
	159	invalid units selection
	160	invalid units selection
	174	invalid units selection
14	35	warning – span too small

Second byte

Bit 7 = 1	device malfunction
Bit 6 = 1	configuration changed
Bit 5 = 1	cold star
Bit 4 = 1	more status available (see below)
Bit 3 = 1	output current fixed
Bit 2 = 1	analog output saturated
Bit 1 = 1	variable (not primary) out of limits
Bit 0 = 1	primary variable out of limits

When bit-4 (HEX 0x10) is set in the second status byte the common-practice command "Read additional transmitter status" (Command 48) can be used to read two additional status bytes. These bytes are bit-mapped as shown below:

First byte

Bit 7 = 1	(undefined)
Bit 6 = 1	(reserved)
Bit 5 = 1	(reserved)
Bit 4 = 1	PFM failure
Bit 3 = 1	calibration failure
Bit 2 = 1	(undefined)
Bit 1 = 1	(undefined)
Bit 0 = 1	(undefined)

Second byte

Bit 7 = 1	analog output alarm #2 tripped
Bit 6 = 1	analog output alarm #1 tripped
Bit 5 = 1	PID setpoint alarm #2 tripped
Bit 4 = 1	PID setpoint alarm #1 tripped
Bit 3 = 1	process variable alarm #4 tripped
Bit 2 = 1	process variable alarm #3 tripped
Bit 1 = 1	process variable alarm #2 tripped
Bit 0 = 1	process variable alarm #1 tripped

3.4 Data

Not all commands or responses contain data. For those that do, up to 25 bytes can be included. Data may be represented as:

Integers - 8, 16 or 24 bits, unsigned
Floating point numbers - IEEE 754 floating point format (32 bits)

ASCII character strings - 4 characters packed into each 3 bytes
Items from a standard list - coded as 8-bit integers

The number of bytes of data and the data format for each item are specified for each command. Refer to Tables 3.1, 3.2 and 3.3 for details.

3.4.1 Items from a List

Data items, for which a choice is made from a list of alternatives, are coded to correspond to each alternative. The HART specification includes standard enumeration for the following types of information:

Manufacturer identification
Device type (codes are specific to each manufacturer)
Units
Transfer function (0 = linear; 1 = square root)
Material
Alarm selection (0 = high; 1 = low)
Write protect (0 = not write protected; 1 = write protected)
Burst mode control (0 = burst mode off: 1 = burst mode on)
Physical signaling (0= Bell 202 is only option, so far)

There are also many device-specific lists. For example, there is a list for specific materials or function options. Refer to the full HART specifications for lists of allocated code numbers. The lists below show the Excalibur 7000 specific lists:

Measurement modes

1	level only
2	level and volume
3	level and flow

Transmitter variables

0	level
1	volume
2	flow
3	PID output
4	PID setpoint

Vessel types

0	vertical cylinder w/flat ends
1	vertical cylinder w/conical bottom
2	horizontal cylinder w/flat ends
3	horizontal cylinder w/elliptical ends
4	horizontal cylinder w/hemispherical ends
5	sphere
6	user strapping table

Open channel flow element types

0	v-notch weir
1	Parshall flume
2	rectangular weir
3	contracted weir
4	Cipolletti weir
5	user defined (strapping table)

V-notch weir angles

0	22½ degrees
1	30 degrees
2	45 degrees
3	60 degrees
4	90 degrees
5	120 degrees

Parshall flume throat widths

0	one inch
1	two inch
2	three inch
3	six inch
4	nine inch
5	twelve inch
6	eighteen inch
7	two foot
8	three foot
9	four foot
10	five foot
11	six foot
12	eight foot
13	ten foot
14	twelve foot

Alarm selection codes

0	process variable alarm #1
1	process variable alarm #2
2	process variable alarm #3
3	process variable alarm #4
4	PID setpoint alarm #1
5	PID setpoint alarm #2
6	analog output alarm #1
7	analog output alarm #2

Alarm types

1	fixed differential
2	adjustable differential
3	(reserved)
4	(reserved)
5	(reserved)
6	(Reserved)

Alarm failsafe

0	low level failsafe (LLFS)
1	high level failsafe (HLFS)

4. Operation with the Model 275 Communicator

A Device Description (DD) has been written for Excalibur 7000 that can be programmed into the Fisher - Rosemont Model 275 Hand-Held Communicator. The DD can be programmed into the user's Model 275 by any authorized programming site. The Model 275 can also be used in the "generic" mode, but this restricts the user to only those features/functions supported by universal commands and those common-practice commands that are implemented in the Excalibur 7000.

It is not the intent of this document to instruct the user in the basic operation of the Model 275. Therefore before proceeding it is recommended that the user read the instruction manual supplied with the communicator and familiarize themselves with its basic operation.

4.1 Menu Tree

When properly connected to the analog output loop of an Excalibur 7000 equipped with the HART communications option the Model 275 Communicator will establish communications and then transfer to the "online" menu. This menu is the top level of the of the instrument's menu tree. From this point the user can navigate to the various sub-menus that can then be used to review and/or change values in the instrument's data base.

4.2 Online Menu

The top level menu for any instrument that successfully connects to the Model 275 Communicator is the "Online" menu. This menu then leads to sub-menus that are functionally grouped to help the user find the area of interest. In the case of the Excalibur 7000 DD the Online menu points to six sub-menus that either provide for the display of variables, or configuration data, or point to additional sub-menus.

The Online menu is as follows:

1. Process Variables
2. Diagnostics
3. Calibration
4. Configuration
5. Operation
6. Review

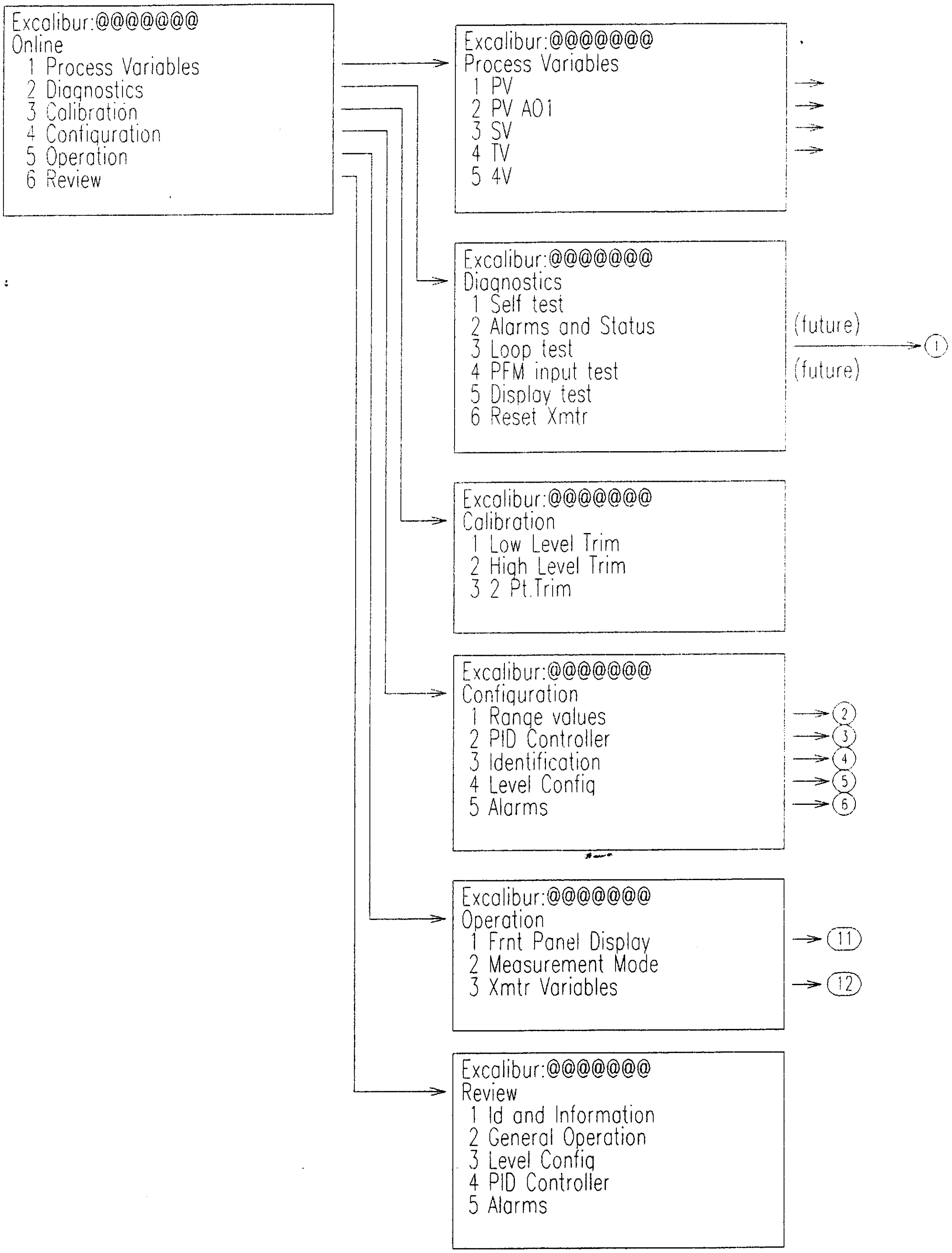

FIGURE 4.1 – Menu Tree

4.2.1 Changing the Measurement Mode

5	2

The first item that needs to set when placing an Excalibur 7000 into service is the measurement mode. The instrument always measures level, but it also has the ability to interpolate either volume or flow rate from the level measurement.

1. From the Online Menu, select *Operation.*
2. From the Operation Menu, select *Measurement Mode.*
3. From the Measurement Mode Menu, select among the list of measurement modes. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

4.2.2 Changing the PID Control State

4	2	1

Another primary selection to be made is the state, on/off, of the optional PID control. With the PID control turned off the instrument functions as an indicating transmitter, and with it on it functions as a PID controller. This selection is made by turning the PID output on or off.

1. From the Online Menu, select *Configuration.*
2. From the Configuration Menu, select *PID Controller.*
3. From the PID Controller Menu, select *PID Output.*
4. From the PID Output Menu, select the desired state. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2)to send the information to the instrument.

4.2.3 Configuring the Level Measurement

The primary measurement, level, requires that three items be set to determine how the measurement is made and converted to engineering units for display.

4.2.3.1 Changing the Units

4	4	1

The units available include inches, feet, millimeters, centimeters and meters.

1. From the Online Menu, select *Configuration.*

2. From the Configuration Menu, select *Level Config.*
3. From the Level Config Menu, select *Level Units.*
4. From the Level Units Menu, select among the list of optional units. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

4.2.3.2 Changing the Measurement Damping

4	4	2

The damping time constant has a range of allowable values of 0.0 to 100.0 seconds. Also, since the interpolated measurements are derived from the level measurement they will be affected by this damping.

1. From the Online Menu, select *Configuration.*
2. From the Configuration Menu, select *Level Config.*
3. From the Level Config Menu, select *Damping.*
4. Using the numerical keys, enter a damping time constant, in seconds. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

4.2.3.3 Changing the Maximum Level

4	4	3

The maximum level represents the highest valid level measurement that can be made. It is based on the geometry of the particular installation. This value is typically the top of the vessel or the top of the open channel flow element. The value is entered in the current engineering units.

1. From the Online Menu, select *Configuration.*
2. From the Configuration Menu, select *Level Config.*
3. From the Level Config Menu, select *Maximum Level.*
4. Using the numerical keys, enter a maximum level. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

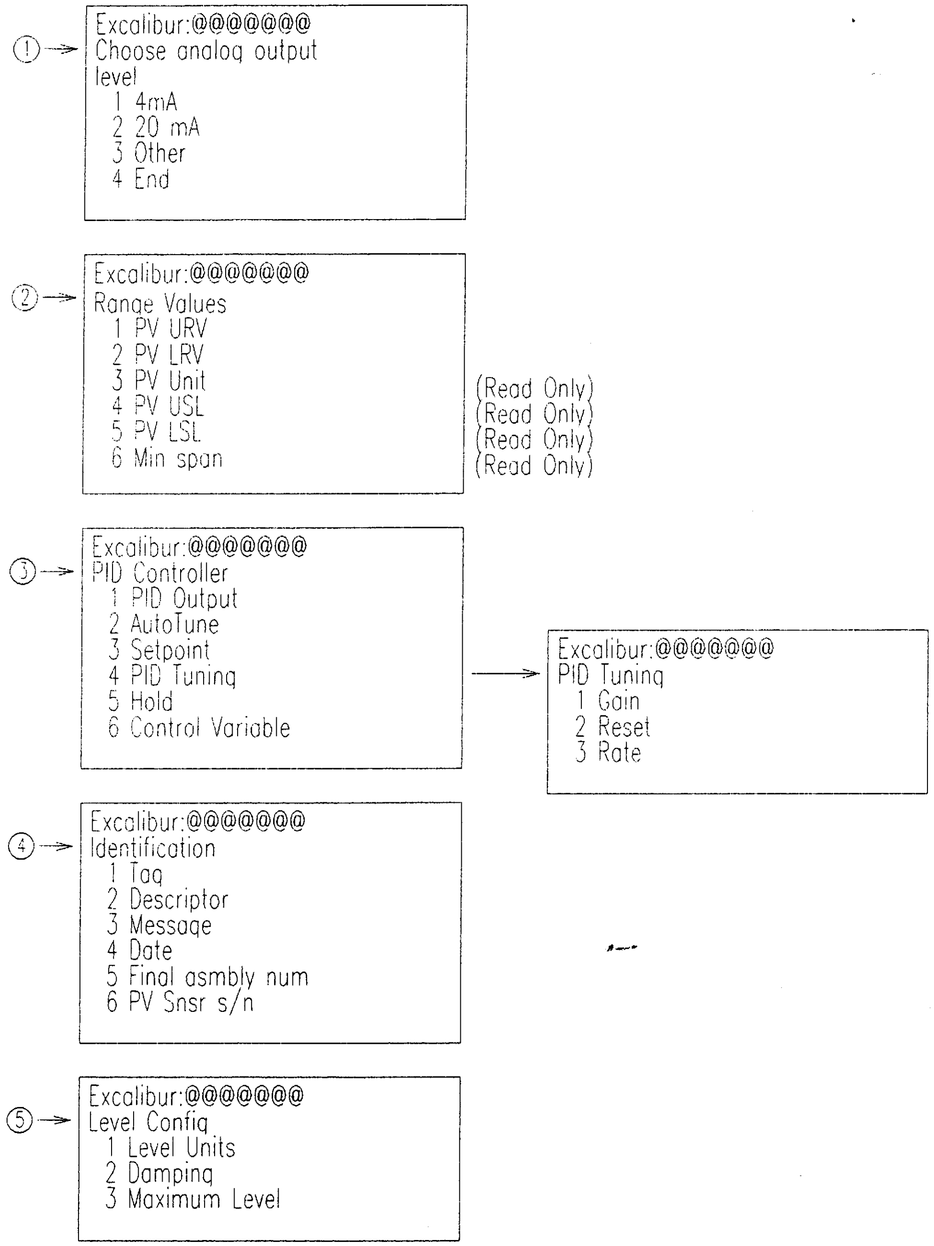

FIGURE 4.2 – Menu Tree, continued

4.2.4 Calibrating the PFM Input

In order to be able to make an accurate level measurement the Excalibur 7000 must know two levels. The two points must differ from each other by 5% of the maximum setting. A procedure is provided to perform a calibration of both points and individual entries to adjust the individual points are also provided.

4.2.4.1 Two Point Input Calibration Procedure

3	3

This procedure requires the establishment of two know levels. The accuracy will improve as the span between the two points increases, therefore it is recommended that these points be as far apart a is practical.

1. From the Online Menu, select *Calibration.*
2. From the Calibration Menu, select *2 Pt. Level Trim.*
3. Establish a know low level and press **[OK].**
4. Using the numerical keys, enter the level, in the engineering units selected for the level display. Press **[ENTER]** (F4) to enter the new information.
5. Establish a known high level, at least 5% of the maximum level greater than the low level above, and press **[OK]**.
6. Using the numerical keys, enter the level, in the engineering units selected for the level display. Press **[ENTER]** (F4) to enter the new information.

4.2.4.2 Low Level Input Calibration

3	1

This procedure requires the establishment of a known low level. The accuracy will improve as the span between the two calibration points increases, therefore it is recommended that this level be as far below the high level calibration point as is practical.

1. From the Online Menu, select *Calibration.*
2. From the Calibration Menu, select *Low Level Trim.*
3. Establish a know low level and press **[OK].**
4. Using the numerical keys, enter the level, in the engineering units selected for the level display. Press **[ENTER]** (F4) to enter the new information.

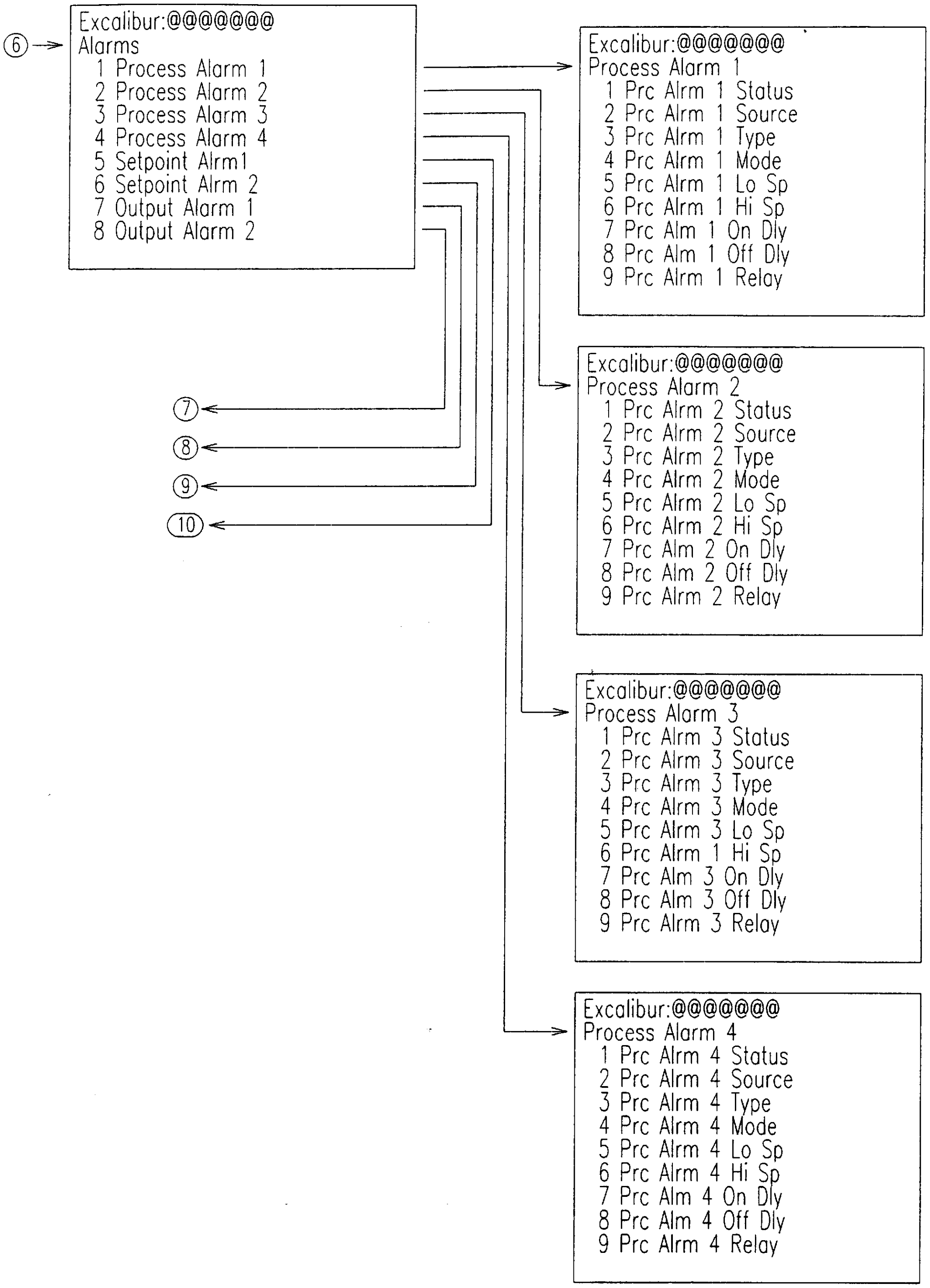

FIGURE 4.3 – Menu Tree, continued

4.2.4.3 High Level Input Calibration

3	2

This procedure requires the establishment of a known high level. The accuracy will improve as the span between the two calibration points increases, therefore it is recommended that this level be as far above the low level calibration point as is practical.

1. From the Online Menu, select *Calibration.*
2. From the Calibration Menu, select *High Level Trim.*
3. Establish a know high level and press **[OK].**
4. Using the numerical keys, enter the level, in the engineering units selected for the level display. Press **[ENTER]** (F4) to enter the new information.

4.2.5 Configuring the Volume Measurement

If the measurement mode is set to Level & Volume then in addition to configuring the level measurement, the volume measurement must be configured also. These items determine how the level measurement is interpolated into its equivalent volume and converted to engineering units for display.

4.2.5.1 Changing the Units

4	5	1

The units available include gallons, imperial gallons, liters, barrels cubic feet, cubic yards and cubic meters.

1. From the Online Menu, select *Configuration.*
2. From the Configuration Menu, select *Volume Config.*
3. From the Volume Config Menu, select *Level Units.*
4. From the Volume Units Menu, select among the list of optional units. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

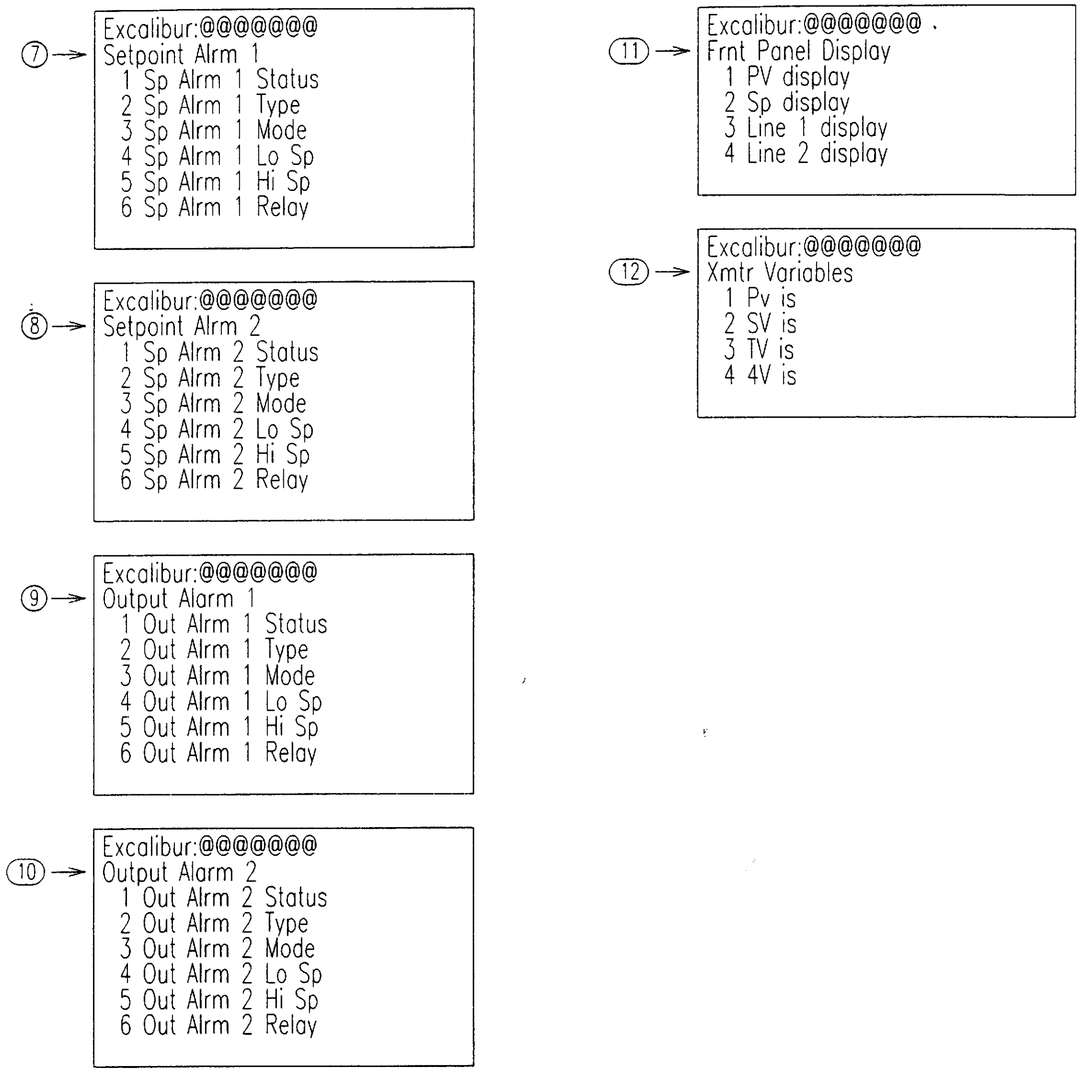

FIGURE 4.4 – Menu Tree, continued

4.2.5.2 Changing the Vessel Type

4	**5**	**2**

The available vessel types are vertical cylinder with flat ends, vertical cylinder with conical bottom, horizontal cylinder with flat ends, horizontal cylinder with elliptical ends, horizontal cylinder with hemispherical ends, sphere and user defined strapping table.

1. From the Online Menu, select *Configuration.*
2. From the Configuration Menu, select *Volume Config.*

3. From the Volume Config Menu, select *Vessel Type.*
4. From the Volume Type Menu, select among the list of optional vessel geometry's. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

4.2.5.3 Changing the Vessel Parameters

Each vessel geometry requires a number of dimensions to be specified so that the total volume can be calculated and the level measurement interpolated to the equivalent volume.

4.2.5.3.1 Changing the Dimensions of a Vertical Cylinder with Flat Ends

A vertical cylinder vessel type requires that the height (length) and radius be specified.

4.2.5.3.1.1 Changing the Vessel Height

4	5	3	1

This value is entered in the current level display units.

1. From the Online Menu, select *Configuration.*
2. From the Configuration Menu, select *Volume Config.*
3. From the Volume Config Menu, select *V Cyl Params.*
4. From the V Cyl Params Menu, select *Length.*
5. Using the numerical keys, enter the vessel height. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

4.2.5.3.1.2 Changing the Vessel Radius

4	5	3	2

This value is entered in the current level display units.

1. From the Online Menu, select *Configuration.*
2. From the Configuration Menu, select *Volume Config.*
3. From the Volume Config Menu, select *V Cyl Params.*

4. From the V Cyl Params Menu, select *Radius*.
5. Using the numerical keys, enter the vessel height. Press **[ENTER]** (F4) to enter the new information, and press **[SEND]** (F2) to send the information to the instrument.

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