PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 53600
Electronics Techniques for Research

Now in PowerPoint!

Spring 2020 Semester

Prof. Matthew Jones

The usual ANNOUNCEMENT

- Obvious changes to the course:
  - No in-person lectures: you'll have to read the lecture notes yourself
  - No more labs: don't worry about it – your grade will be based on work done so far
  - Remaining assignments will try to cover topics that would have been explored in the lab
  - Second mid-term: simplest to cancel it
  - Final exam: I think it will be a 24 hour exam with written responses that can be easily sent by e-mail.
- Changes to grading scheme:
  - Old scheme: Assignments (30%) exams (40%) lab (30%)
  - New scheme: Assignments (50%) exams (25%) lab (25%)

The usual ANNOUNCEMENT

- Because there won't be any in-person lectures, you will have to read the lecture notes yourself.
- To demonstrate that you have read them, you will be required to answer *one or two simple questions* before the next lecture is posted.
- The question will probably be at the beginning and you just have to e-mail me the answer

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- To make this easy, please make your subject look like this:

"PHYS53600 Lecture xx questions Your Name"

- These will be the remaining part of your assignment grade.

More ANNOUNCEMENTS

- There will be a WebEx meeting on Thursday:
  https://purdue.webex.com/purdue/j.php?MTID=m12fb7ef31cd88d9ae95cf6ac1dd56e27
- Here are the relevant details:

  Meeting number: 618 382 745
  Meeting password: phys536
  Host key: not displayed

  Thursday, April 30, 2020
  10:30 am | Eastern Daylight Time (New York, GMT-04:00) | 1 hr 30 mins

- I just want to be available to answer any questions and to discuss the proposed content of the final exam…
- This is your opportunity to exert your influence…

LECTURE 28 QUESTIONS

1. *You might not realize it, but most digital thermostats are essentially PLC units.*

Describe (in general terms) the logic needed to control a furnace and an air conditioner to achieve a comfortable work environment.

a) *What are the inputs?*

b) *What are the control outputs?*

c) *What is the Human Machine Interface?*

Process Control and Automation

- After taking this course you might understand (at least in principle) how to design analog and digital circuits to perform a wide range of useful things…
- Just because you know how to design something doesn’t mean that you should design and build it…
- Most common problems have already been solved in multiple ways…
- Don’t re-invent the wheel!

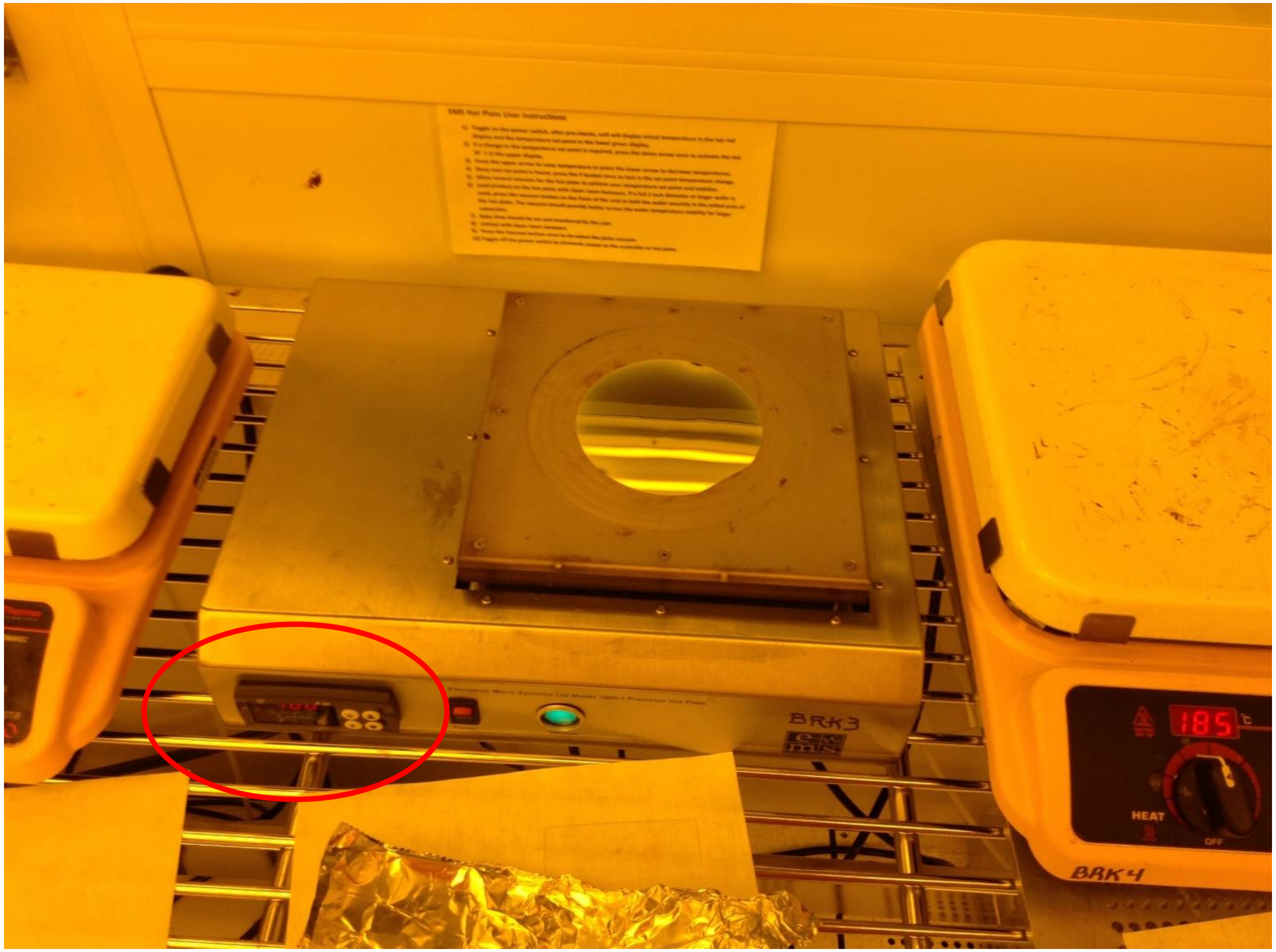
Process Control and Automation

- Instrumentation and data acquisition has been used in industrial applications since at least the 1960's
- A wide range of off-the-shelf solutions can be purchased at very reasonable prices
- Several industry standards have emerged:
  - Transducer interfaces
  - Communication protocols
  - Mechanical interfaces
  - User interfaces

Example

- A classic example of a process control application is temperature control
- For example, a precision hot-plate:
  - User specifies the desired temperature
  - A sensor measures the current temperature
  - A heater is turned on to increase the temperature or turned off to decrease the temperature
- Notice the time scales involved:
  - Temperature changes on the scale of seconds
  - Easy to implement a feedback loop that operates on the scale of milliseconds using a microcontroller

Example:



Process Control and Automation

- The typical feedback loops consists of the following steps:
  - Measure a physical quantity
    - This is almost always done by converting the physical quantity to a voltage and sampling an ADC
  - Determine an appropriate response
    - Turn on a heater? Turn off a heater?
  - Perform the necessary action
    - Increase voltage, decrease voltage, turn something on… turn something off…
  - Perform these steps continuously in a loop

The Importance of Standards

- The first step is to perform a measurement
- Measuring temperature is one (common) example but there are lots of other things that could be measured:
  - Vacuum pressure
  - Humidity
  - Volume (liquid level)
- The first standard to consider is how to interface a transducer with

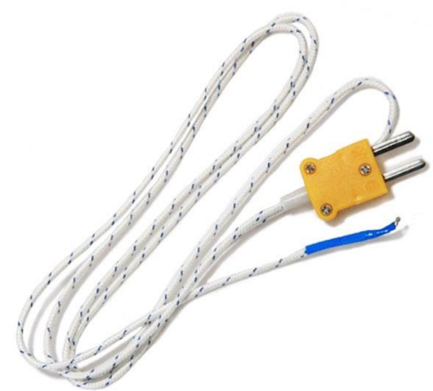
Temperature Measurement Standards

- There are several standard temperature transducers:
  - Thermocouples
  - Resistive Temperature Detectors
- Thermocouples:
  - Two dissimilar metals in contact develop a potential difference that depends on temperature
- RTD's:
  - Usually made out of a pure metal (eg, platinum)
  - Resistance varies in a very predictable way with temperature
- Thermistors:
  - Similar to RTD's but can be made of almost any material
  - Wider variety of nominal resistances
  - Varying levels of stability compared with RTD's

Temperature Measurement Standards

- Standard thermocouples use very specific combinations metal alloys:

Name	Metal alloys	Useful temperature range
"Type K"	Chromel®/Alumel®	0 to 1260 deg C
"Type J"	Iron/Constantan	0 to 760 deg C
"Type T"	Copper/Constantan	-200 to 370 deg C
"Type E"	Chromel®/Constantan	0 to 870 deg C
	…many others…	



Standard Transducer Outputs

- Other transducers produce a voltage or current proportional to some physical quantity
- Standard voltage/current ranges allow interoperability of equipment
  - Voltage output, 0-5 volts
  - Voltage output, 0-10 volts
  - Current output, 0-20 mA
  - Current output, 4-20 mA

Needs 3 wires (Voltage output, 0-5 volts; Voltage output, 0-10 volts; Current output, 0-20 mA)

Can work with only two wires (Current output, 4-20 mA)

Transducers

Gage/Absolute Pressure
0 to 5 Vdc Output
0-1 to 0-10,000 psi
0-70 mbar to 0-690 bar

SPECIFICATIONS

Excitation: 9 to 30 Vdc (<10 mA) (reverse polarity and overvoltage protected)

Output: 0 to 5 Vdc

Accuracy: ±0.25% FS BSL at 25°C; includes linearity, hysteresis and repeatability

Zero Offset: ±2% FSO; ±4% for 1 and 2 psi ranges

Span Setting: ±2% FSO; ±4% for 1 and 2 psi ranges

Total Error Band: ±2% FSO, includes linearity, hysteresis, repeatability, thermal hysteresis and thermal errors (except 1 psi = ±4.5% and 2 psi = ±3%)

Long-Term Stability (1 Year): ±0.25% typical

Relative humidity outdoor, indoor probe with 4-20mA output

Technical data

HUMIDITY SENSOR	
Measuring range	0 to 100 % RH
Accuracy	±2.5 % RH from 5 to 95 % at 23 °C
Resolution	0.1% RH
GENERAL TECHNICAL DATA	
Operating temperature	-30 to +80 °C
Channels	internal humidity sensor
Output	4-20 mA
Range of humidity sensor temperature compensation	all temperature range
Configuration of output	user adjustable from PC; measured range + value
Power	9-30 Vdc
Protection class	IP65 electronics; IP40 sensors
Dimensions	88,5 x 170 x 39,5 mm; stem length 75 mm
Weight	approx. 150 g
Warranty	3 years

Industrial Automation Standards

- Standard modules exist for many sensor readout and process control applications
- Typical examples:

- Standard mechanical interfaces
  - "Deutsches Institut fur Normung" (DIN)

Mechanical Standards

¼ DIN standard:

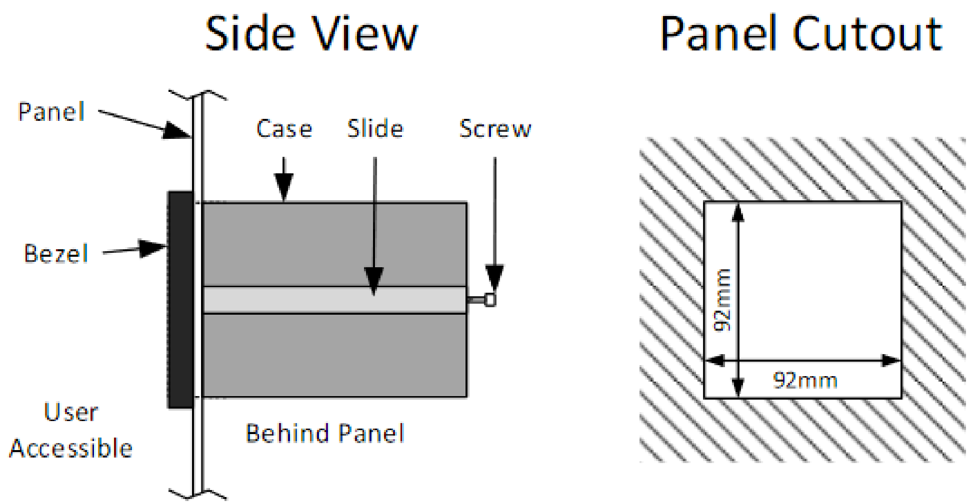
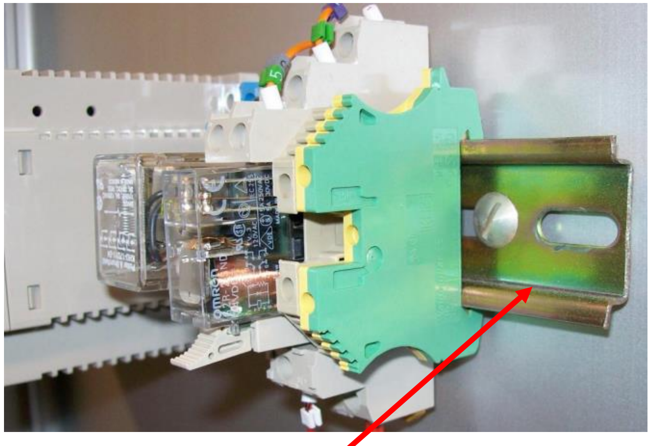


Figure 1 - Side and Panel Cutout Views

- Any equipment that conforms to the ¼ DIN standard will fit

Mechanical Standards

- DIN rail mounting standards (IEC/EN 60715)

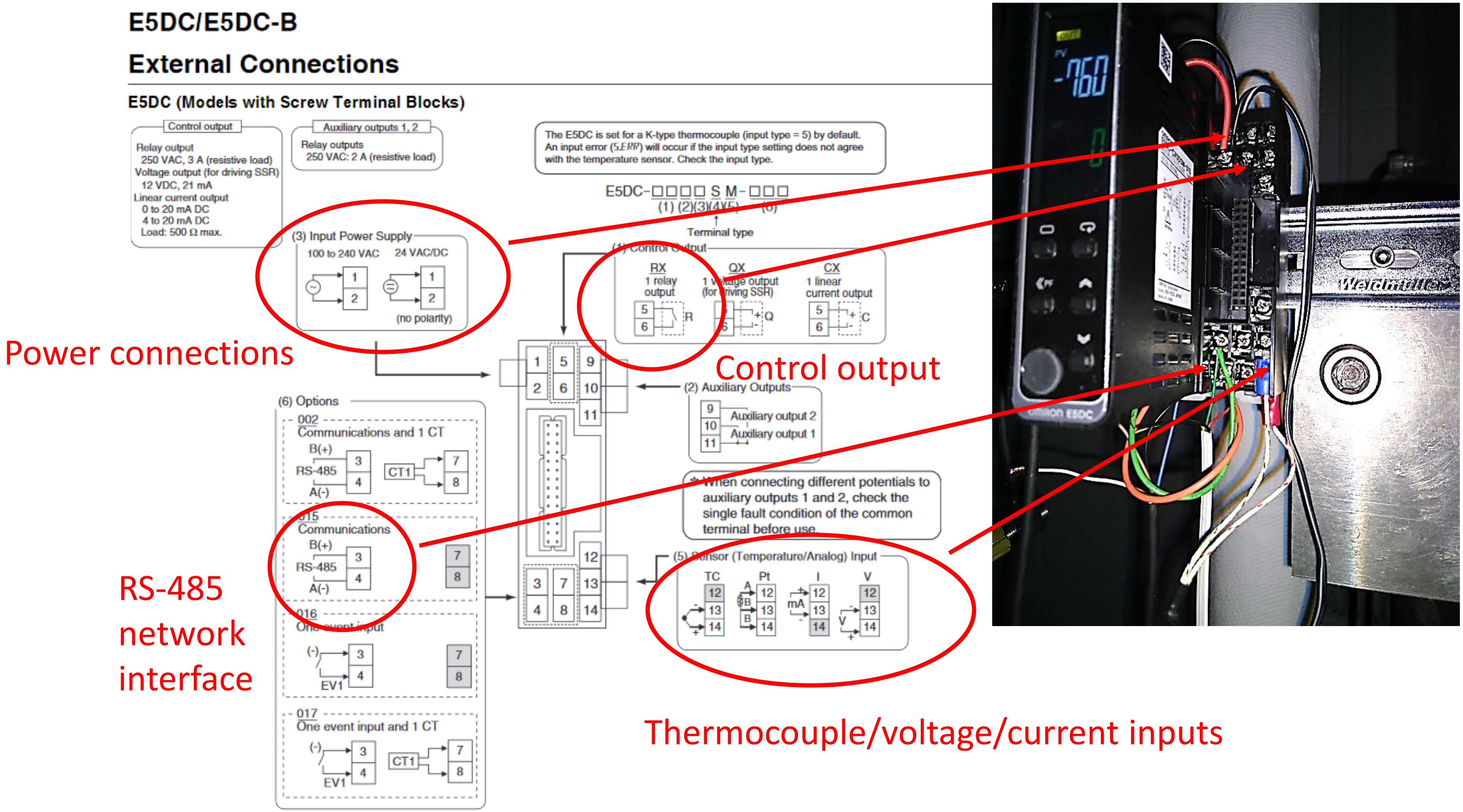


Standard 35 mm mounting rail

Typical Electrical Interfaces

- Usually lots of screw terminals on the back:

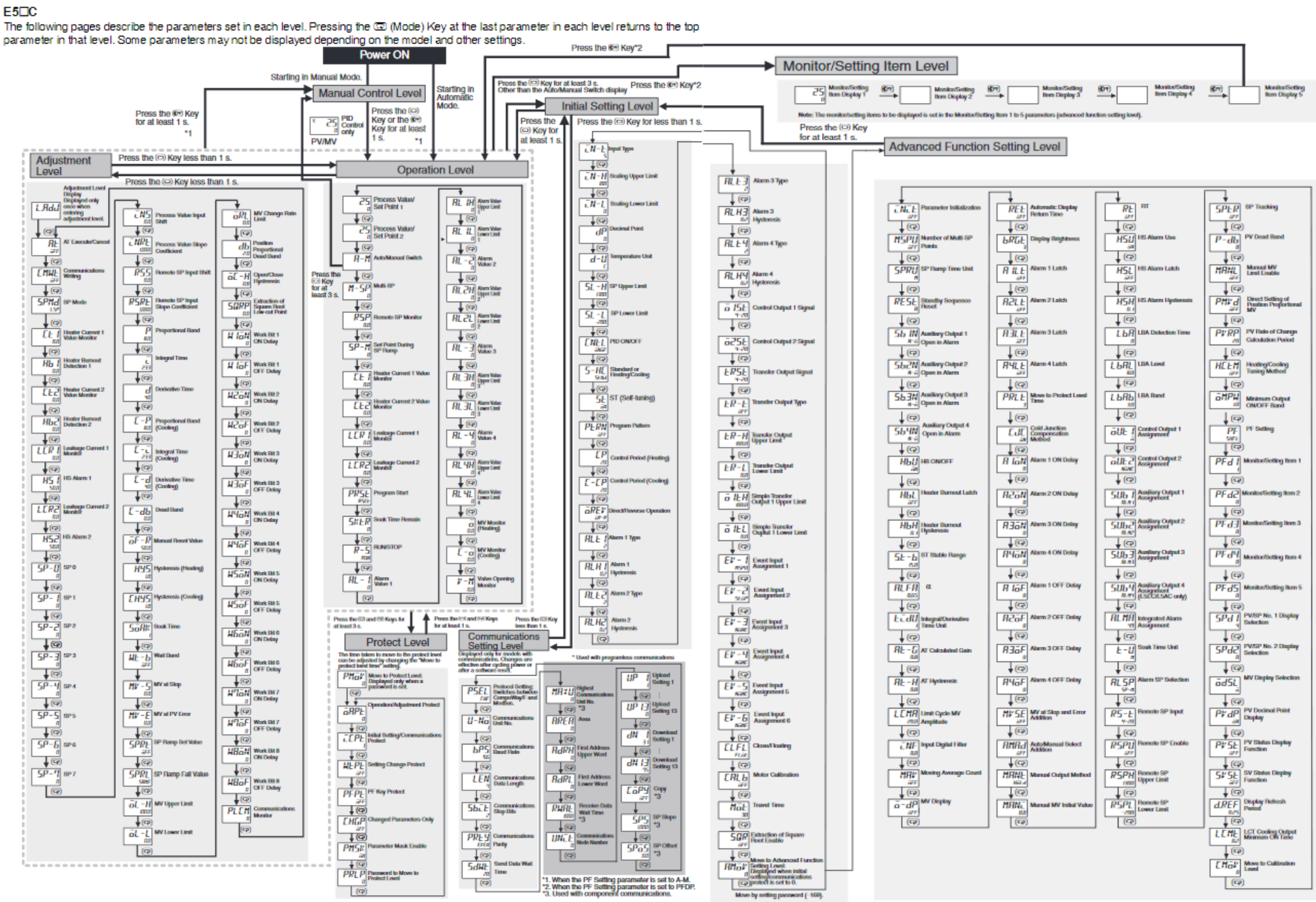
Typical Electrical Interfaces



Human Machine Interface (HMI)

- The functionality can often be fully programmed by the controls on the front panel
- But this might consist of only 3 or 4 buttons…
  - Simple operations like adjusting the “set point” might be straight forward
  - Configuration of alarm limits and responses might be more complicated
  - Important part of the documentation provided with the device

HMI Example

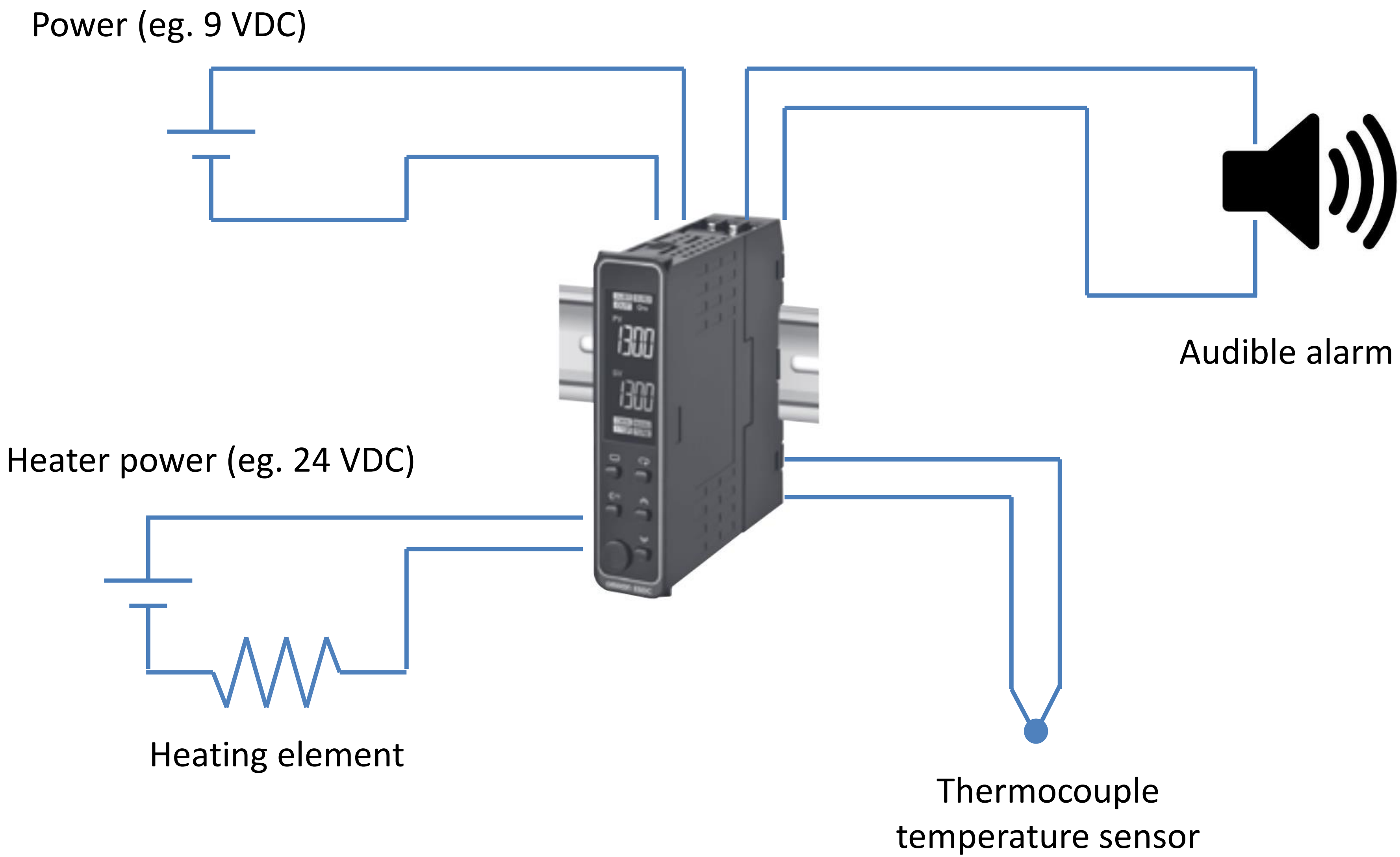


E5□C
The following pages describe the parameters set in each level. Pressing the (Mode) Key at the last parameter in each level returns to the top parameter in that level. Some parameters may not be displayed depending on the model and other settings.
Power ON
Manual Control Level
Operation Level
Adjustment Level
Initial Setting Level
Monitor/Setting Item Level
Advanced Function Setting Level
Protect Level
Communications Setting Level

Typical Application

- Such modules can be used to provide autonomous closed-loop control of a device like a heater by means of relays (electrically controlled switches)
  - Relay is on when measured temperature is less than the set point
  - Relay is off when measured temperature is greater than the set point
  - On/off time is limited to be at least 20 seconds

Typical Application



Communication Standards

- What if you want to log the measured sensor parameters?
- Many devices provide standard communication protocols over RS-485 networks.
- Control of the UART interface:
  - Baud rate (eg, 9600, 38400, 115200 baud)
  - Parity bit (even, odd, none)
  - Stop bit (1 or 2)
  - Character size (almost always 8 bits)
- Various standard communication protocols
  - Modbus RTU, Modbus ASCII (Industry standard)
  - CompoWay (Vendor specific)

Modbus Communications

- Each device is assigned a unique address 0..255
  - A few special addresses are reserved
- Each device stores its operating parameters in internal “registers” numbered 1..32767
- MODBUS functions allows you to read or write individual registers or ranges of registers
- Errors in message transmission are detected using a Cyclic-Redundancy-Check (CRC) algorithm
  - You can google for the details of how to calculate the 16-bit CRC used to validate the messages…

Modbus Communications

Function 03 (03hex) Read Holding Registers

Read the binary contents of holding registers in the slave.

Request
The request message specifies the starting register and quantity of registers to be read.

Example of a request to read 0…1 (register 40001 to 40002) from slave device 1:

Field Name	RTU (hex)	ASCII Characters
Header	None	: (Colon)
Slave Address	01	0 1
Function	03	0 3
Starting Address Hi	00	0 0
Starting Address Lo	00	0 0
Quantity of Registers Hi	00	0 0
Quantity of Registers Lo	02	0 2
Error Check Lo	C4	LRC (F A)
Error Check Hi	0B	
Trailer	None	CR LF
Total Bytes	8	17

Data sent to the device

Response
The register data in the response message are packed as two bytes per register, with the binary contents right justified within each byte. For each register the first byte contains the high-order bits, and the second contains the low-order bits.

Example of a response to the request:

Field Name	RTU (hex)	ASCII Characters
Header	None	: (Colon)
Slave Address	01	0 1
Function	03	0 3
Byte Count	04	0 4
Data Hi	00	0 0
Data Lo	06	0 6
Data Hi	00	0 0
Data Lo	05	0 5
Error Check Lo	DA	LRC (E D)
Error Check Hi	31	None
Trailer	None	CR LF
Total Bytes	8	19

Data received from the device

Modbus Communications

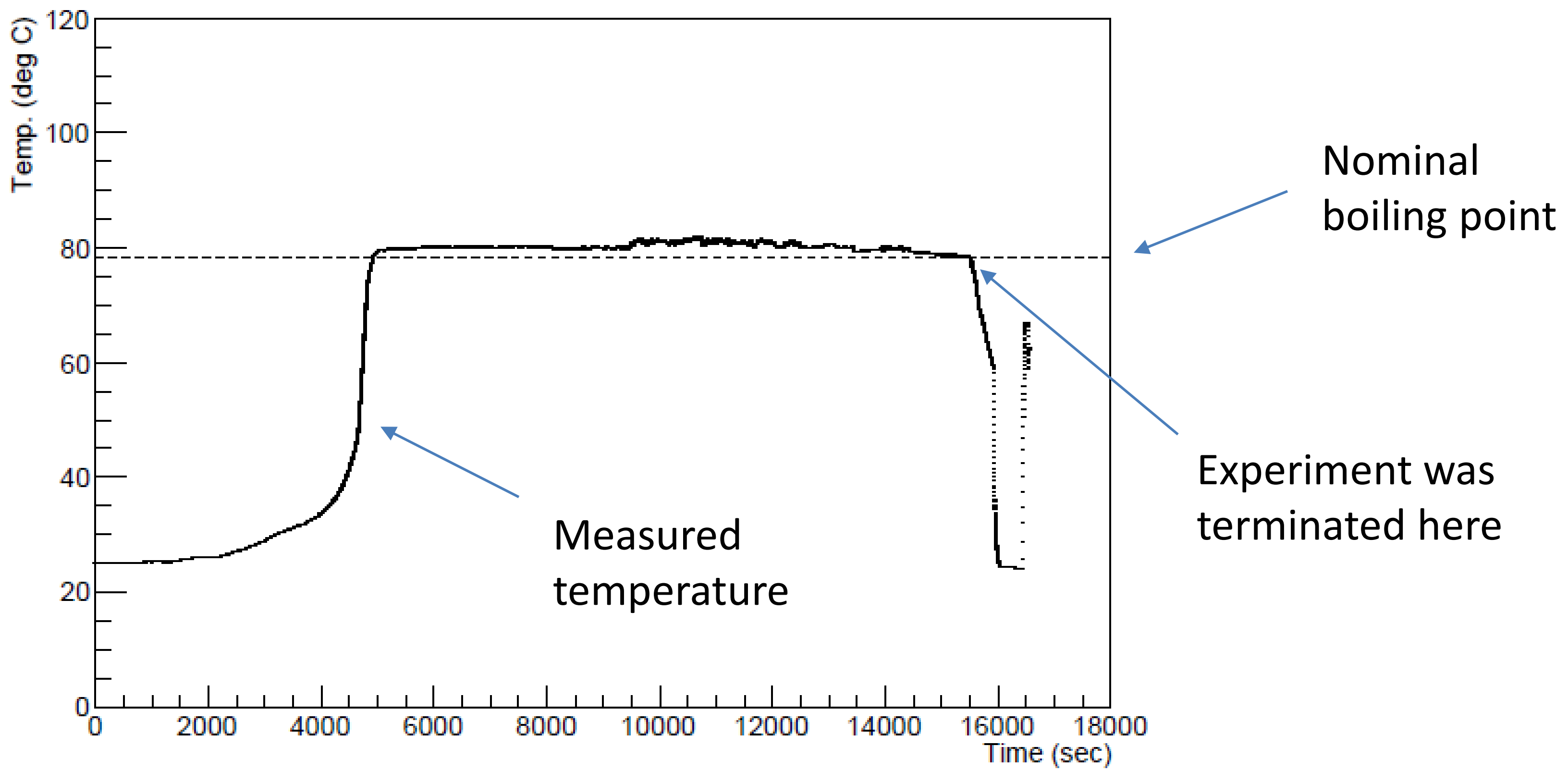
- Example registers:

Address		Parameter name	Setting (monitor) value	Level
Four-byte mode	Two-byte mode			
0000	2000	PV	Temperature: Use the specified range for each sensor. Analog: Scaling lower limit – 5% FS to Scaling upper limit + 5% FS	Operation
0002	2001	Status*1*2	Refer to *5-2 Status* for details.	
0004	2002	Internal Set Point*1	SP lower limit to SP upper limit	
0006	2003	Heater Current 1 Value Monitor	H'00000000 to H'00000226 (0.0 to 55.0)	
0008	2004	MV Monitor (Heating)	Standard: H'FFFFFFCE to H'0000041A (–5.0 to 105.0) Heating and cooling: H'00000000 to H'0000041A (0.0 to 105.0)	
000A	2005	MV Monitor (Cooling)	H'00000000 to H'0000041A (0.0 to 105.0)	
0106	2103	Set Point	SP lower limit to SP upper limit	
0108	2104	Alarm Value 1	H'FFFFF831 to H'0000270F (–1999 to 9999)	
010A	2105	Alarm Value Upper Limit 1	H'FFFFF831 to H'0000270F (–1999 to 9999)	
010C	2106	Alarm Value Lower Limit 1	H'FFFFF831 to H'0000270F (–1999 to 9999)	
010E	2107	Alarm Value 2	H'FFFFF831 to H'0000270F (–1999 to 9999)	
0110	2108	Alarm Value Upper Limit 2	H'FFFFF831 to H'0000270F (–1999 to 9999)	
0112	2109	Alarm Value Lower Limit 2	H'FFFFF831 to H'0000270F (–1999 to 9999)	
0404	2402	PV	Temperature: Use the specified range for each sensor. Analog: Scaling lower limit – 5% FS to Scaling upper limit + 5% FS	
0406	2403	Internal Set Point*1	SP lower limit to SP upper limit	
0408	2404	Multi-SP No. Monitor	H'00000000 to H'00000007 (0 to 7)	
040C	2406	Status*1*2	Refer to *5-2 Status* for details.	
040E	2407	Status*3	Refer to *5-2 Status* for details.	
0410	2408	Status 2*1*2	Refer to *5-2 Status* for details.	
0412	2409	Status 2*1*3	Refer to *5-2 Status* for details.	
0420	2410	Decimal Point Monitor	H'00000000 to H'00000003 (0 to 3)	

This one is the process variable (ie, the temperature)

Example

Distilling Methanol at atmospheric pressure:



Programmable Logic Controllers

- Sometimes you need more sophisticated control over a piece of equipment
- Examples:
  - A liquid CO_2 refrigerator needs to carefully control temperature and pressure or else you might accidentally destroy the seals in a pump
  - Control of superconducting solenoid
- Response time is often slow (milliseconds) compared to the speed of typical microprocessors (microseconds)
- Fully autonomous monitoring and control
  - Independent of any external computer or network

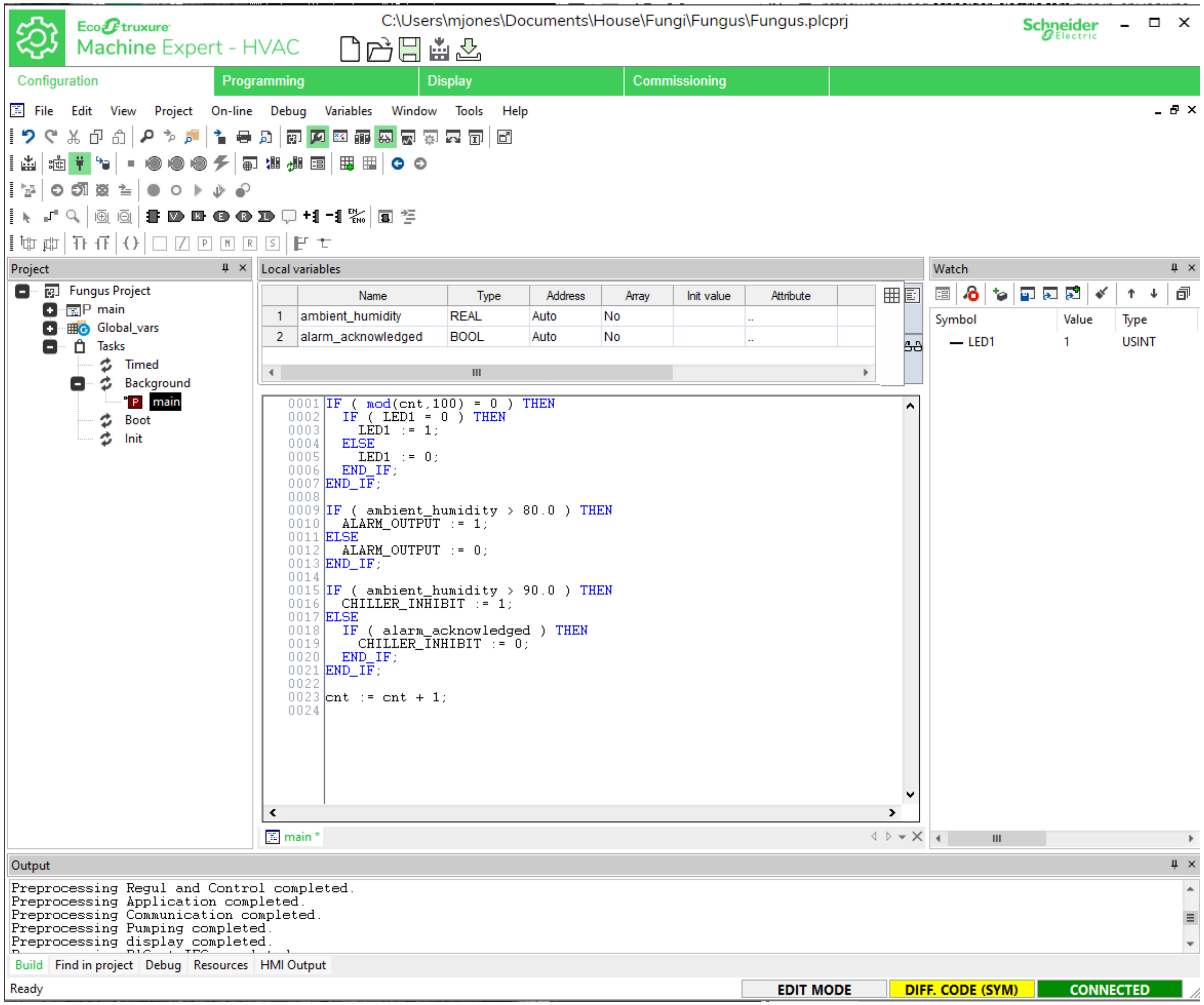
Programmable Logic Controllers

- Commonly used for industrial automation/control applications
- Example:

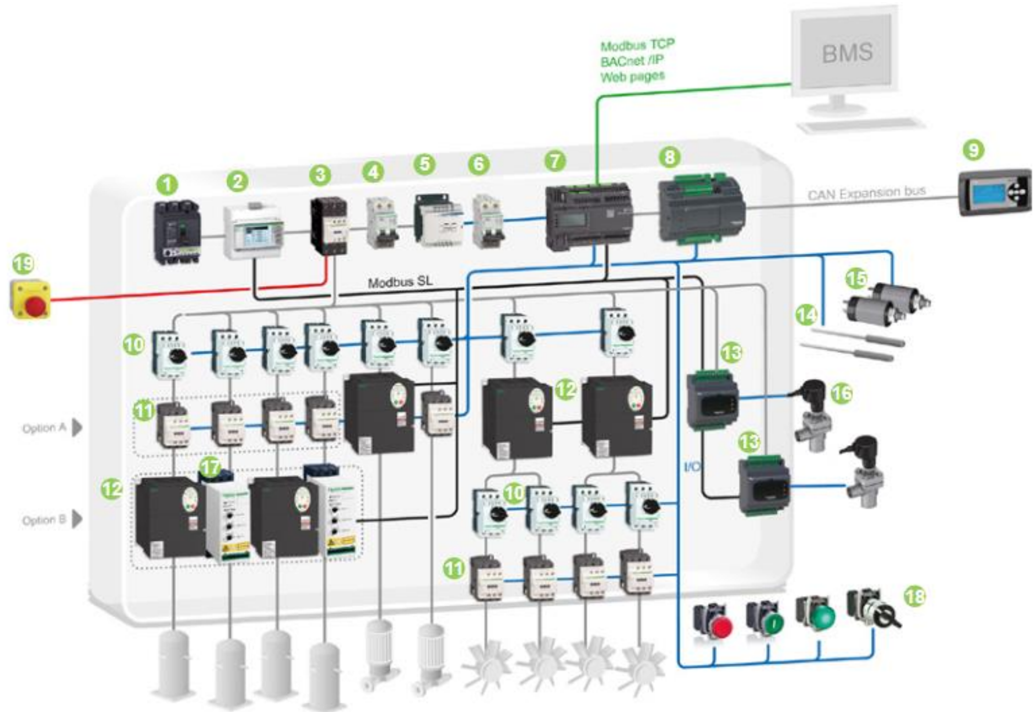
- 6 discrete inputs (digital logic)
- 6 discrete outputs (relays)
- 5 analog input (0-5 V, 0-10 V, 0-20 mA, 4-20 mA, etc…)
- 5 analog output

- Standard DIN rail mounting
- Control logic executed on internal microprocessor
- Code generated using a proprietary development environment

Programmable Logic Controllers



Scalable Industrial Applications



HVAC/Chiller/Modbus SL/Modicon M172 performance logic controller

Solution breakdown

1 **Compact NSX** circuit breaker
2 **iEM3000** energy meter
3 **TeSys D contactor**
4 **C60L-MA** modular circuit breaker
5 **Phaseo** switch mode power supply
6 **C60L-DC DC** circuit breaker
7 **Modicon M172 performance** logic controller
8 **Modicon M172** I/O module
9 **Modicon M171** remote display
10 **TeSys GV2L** magnetic circuit breaker
11 **TeSys D** contactor
12 **Altivar 212** variable speed drive, for 0.75 to 75 kW (1.0 to 100 hp) motors
13 **Modicon M171** electronic expansion valve driver
14 **Modicon TM1S●●●●** humidity and temperature probes
15 **Telemecanique XMLP** pressure sensors
16 Electronic expansion valve
17 **Altistart 01** soft starter
18 **Harmony XB4/XB5** signaling units
19 **Harmony XALK** Emergency stop push button

Summary

- This was supposed to provide examples of common instrumentation problems
- It is often faster/easier/cheaper to buy industry standard solutions rather than build them yourself
- Sophisticated data acquisition systems can be built by just attaching wires to screw terminals
- PLC’s are widely used when autonomous monitoring/control/safety is required.