

Lab

WirelessHART instrument loop: *Question 91, completed objectives due by the end of day 5, section 4*

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Exam

*Day 5 of next section – Complete mastery of these objectives due by the next exam date*

*Specific objectives for the “mastery” exam:*

- Electricity Review: Calculate voltages and currents in an ideal AC transformer circuit
  - Determine proper AI block parameters to range a Fieldbus transmitter for a given application
  - Use decibels to calculate power gains and losses
  - Calculate instrument input and output values given calibrated ranges
  - Solve for a specified variable in an algebraic formula
  - Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
  - Motor/relay/3phase/PLC Review: Determine status of PLC discrete output given input switch conditions and a simple RLL program listing
  - INST241 Review: Determine suitability of different flow-measuring technologies for a given process fluid type
  - INST251 Review: Determine the effect of a component change on the gain of a pneumatic controller mechanism
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**Recommended daily schedule**

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Day 1

**Theory session topic:** FOUNDATION Fieldbus physical layer

Questions 1 through 20; answer questions 1-7 in preparation for discussion (remainder for practice)

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Day 2

**Theory session topic:** FOUNDATION Fieldbus data link layer

Questions 21 through 40; answer questions 21-27 in preparation for discussion (remainder for practice)

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Day 3

**Theory session topic:** FOUNDATION Fieldbus function blocks

Questions 41 through 60; answer questions 41-48 in preparation for discussion (remainder for practice)

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Day 4

**Theory session topic:** FOUNDATION Fieldbus device configuration and troubleshooting

Questions 61 through 80; answer questions 61-68 in preparation for discussion (remainder for practice)

Feedback questions (*81 through 90*) are optional and may be submitted for review at the end of the day

## How To . . .

**Access the worksheets and textbook:** go to the *Socratic Instrumentation* website located at <http://www.ibiblio.org/kuphaldt/socratic/sinst> to find worksheets for every 2nd-year course section organized by quarter, as well as both the latest “stable” and “development” versions of the *Lessons In Industrial Instrumentation* textbook. Download and save these documents to your computer.

**Maximize your learning:** complete all homework *before* class starts, ready to be assessed as described in the “Inverted Session Formats” pages. Use every minute of class and lab time productively. Follow all the tips outlined in “Question 0” as well as your instructor’s advice. Do not take constructive criticism personally. Make every reasonable effort to solve problems on your own before seeking help.

**Identify upcoming assignments and deadlines:** read the first page of each course worksheet.

**Relate course days to calendar dates:** reference the calendar spreadsheet file (`calendar.xlsx`), found on the BTC campus Y: network drive. A printed copy is posted in the Instrumentation classroom.

**Locate industry documents assigned for reading:** use the Instrumentation Reference provided by your instructor (on CD-ROM and on the BTC campus Y: network drive). There you will find a file named `00_index_OPEN_THIS_FILE.html` readable with any internet browser. Click on the “Quick-Start Links” to access assigned reading documents, organized per course, in the order they are assigned.

**Study for the exams:** Mastery exams assess specific skills critically important to your success, listed near the top of the front page of each course worksheet for your review. Familiarize yourself with this list and pay close attention when those topics appear in homework and practice problems. Proportional exams feature problems you haven’t seen before that are solvable using general principles learned throughout the current and previous courses, for which the only adequate preparation is independent problem-solving practice every day. Answer the “feedback questions” (practice exams) in each course section to hone your problem-solving skills, as these are similar in scope and complexity to proportional exams. Answer these feedback independently (i.e. no help from classmates) in order to most accurately assess your readiness.

**Calculate course grades:** download the “Course Grading Spreadsheet” (`grades_template.xlsx`) from the Socratic Instrumentation website, or from the BTC campus Y: network drive. Enter your quiz scores, test scores, lab scores, and attendance data into this Excel spreadsheet and it will calculate your course grade. You may compare your calculated grades against your instructors’ records at any time.

**Identify courses to register for:** read the “Sequence” page found in each worksheet.

**Receive extra instructor help:** ask during lab time, or during class time, or by appointment. Tony may be reached by email at [tony.kuphaldt@btc.edu](mailto:tony.kuphaldt@btc.edu) or by telephone at 360-752-8477.

**Identify job openings:** regularly monitor job-search websites. Set up informational interviews at workplaces you are interested in. Participate in jobshadows and internships. Apply to jobs long before graduation, as some employers take *months* to respond! Check your BTC email account daily for alerts.

**Impress employers:** sign the FERPA release form granting your instructors permission to share academic records, then make sure your performance is worth sharing. Document your project and problem-solving experiences for reference during interviews. Honor all your commitments.

**Begin your career:** participate in jobshadows and internships while in school to gain experience and references. Take the first Instrumentation job that pays the bills, and give that employer at least two years of good work to pay them back for the investment they have made in you. Employers look at delayed employment, as well as short employment spans, very negatively. Failure to pass a drug test is an immediate disqualifier, as is falsifying any information. Criminal records may also be a problem.

[file howto](#)

## General Values, Expectations, and Standards

Success in this career requires professional integrity, resourcefulness, persistence, close attention to detail, and intellectual curiosity. If you are ever in doubt as to the values you should embody, just ask yourself what kind of a person you would prefer to hire for your own enterprise. Those same values will be upheld within this program.

**Learning** is the purpose of any educational program, and a worthy priority in life. Every circumstance, every incident, every day here will be treated as a learning opportunity, every mistake as a “teachable moment”. Every form of positive growth, not just academic ability, will be regarded as real learning.

**Responsibility** means *ensuring* the desired outcome, not just *trying* to achieve the outcome. To be a responsible person means you *own* the outcome of your decisions and actions.

**Integrity** means being honest and forthright in all your words and actions, doing your very best every time and never taking credit for the achievement of another.

**Safety** means doing every job correctly and ensuring others are not endangered. Lab safety standards include wearing closed-toed shoes and safety glasses in the lab room during lab hours, wearing ear protection around loud sounds, using ladders to reach high places, using proper lock-out/tag-out procedures, no energized electrical work above 30 volts without an instructor present in the lab room, and no power tool use without an instructor present in the lab room.

**Diligence** in study means exercising self-discipline and persistence, realizing that hard work is a necessary condition for success. This means, among other things, investing the necessary time and effort in studying, reading instructions, paying attention to details, utilizing the skills and tools you already possess, and avoiding shortcuts. Diligence in work means the job is not done until it is done *correctly*: all objectives achieved, all problems solved, all documentation complete, and no errors remaining.

**Self-management** means allocating your resources (time, equipment, labor) wisely, and not just focusing on the closest deadline.

**Communication** means clearly conveying your thoughts and paying attention to what others convey, across all forms of communication (e.g. oral, written, nonverbal).

**Teamwork** means working constructively with your classmates to complete the job at hand. Remember that here the first job is *learning*, and so teamwork means working to maximize everyone’s learning (not just your own). The goal of learning is more important than the completion of any project or assignment.

**Initiative** means recognizing needs and taking action to meet those needs without encouragement or direction from others.

**Representation** means your actions reflect this program and not just yourself. Doors of opportunity for all BTC graduates may be opened or closed by your own conduct. Unprofessional behavior during tours, jobshadows, internships, and/or jobs reflects poorly on the program and will negatively bias employers.

**Trustworthiness** is the result of consistently exercising these values: people will recognize you as someone they can rely on to get the job done, and therefore someone they would want to employ.

**Respect** means acknowledging the intrinsic value, capabilities, and responsibilities of those around you. Respect is gained by consistent demonstration of valued behaviors, and it is lost through betrayal of trust.

## General Values, Expectations, and Standards (continued)

**Punctuality and Attendance:** late arrivals are penalized at a rate of 1% grade deduction per incident. Absence is penalized at a rate of 1% per hour (rounded to the nearest hour) except when employment-related, school-related, weather-related, or required by law (e.g. court summons). Absences may be made up by directing the instructor to apply “sick hours” (12 hours of sick time available per quarter). Classmates may donate their unused sick hours. Sick hours may not be applied to unannounced absences, so be sure to alert your instructor and teammates as soon as you know you will be absent or late. Absence on an exam day will result in a zero score for that exam, unless due to a documented emergency.

**Mastery:** any assignment or objective labeled as “mastery” must be completed with 100% competence (with multiple opportunities to re-try). Failure to complete by the deadline date caps your grade at a C-. Failure to complete by the end of the *next* school day results in a failing (F) grade for that course.

**Time Management:** Use all available time wisely and productively. Work on other useful tasks (e.g. homework, feedback questions, job searching) while waiting for other activities or assessments to begin. Trips to the cafeteria for food or coffee, smoke breaks, etc. must not interfere with team participation.

**Orderliness:** Keep your work area clean and orderly, discarding trash, returning tools at the end of every lab session, and participating in all scheduled lab clean-up sessions. Project wiring, especially in shared areas such as junction boxes, must not be left in disarray at the end of a lab shift. Label any failed equipment with a detailed description of its symptoms.

**Independent Study:** the “inverted” instructional model used in this program requires independent reading and problem-solving, where every student must demonstrate their learning at the start of the class session. Question 0 of every worksheet lists practical study tips. The “Inverted Session Formats” pages found in every worksheet outline the format and grading standards for inverted class sessions.

**Independent Problem-Solving:** make an honest effort to solve every problem before seeking help. When working in the lab, help will not be given unless and until you run your own diagnostic tests.

**Teamwork:** inform your teammates if you need to leave the work area for any reason. Any student regularly compromising team performance through absence, tardiness, disrespect, or other disruptive behavior(s) will be removed from the team and required to complete all labwork individually. The same is true for students found inappropriately relying on teammates.

**Communication:** check your email daily for important messages. Ask the instructor to clarify any assignment or exam question you find confusing, and express your work clearly.

**Academic Progress:** your instructor will record your academic achievement, as well as comments on any negative behavior, and will share all these records with employers if you sign the FERPA release form. You may see these records at any time, and you should track your own academic progress using the grade spreadsheet template. Extra-credit projects will be tailored to your learning needs.

**Office Hours:** your instructor’s office hours are by appointment, except in cases of emergency. Email is the preferred method for setting up an appointment with your instructor to discuss something in private.

**Grounds for Failure:** a failing (F) grade will be earned in any course if any mastery objectives are past deadline by more than one school day, or for any of the following behaviors: false testimony (lying), cheating on any assignment or assessment, plagiarism (presenting another’s work as your own), willful violation of a safety policy, theft, harassment, sabotage, destruction of property, or intoxication. These behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

file expectations

## Program Outcomes for Instrumentation and Control Technology (BTC)

### #1 Communication

Communicate and express concepts and ideas across a variety of media (verbal, written, graphical) using industry-standard terms.

### #2 Time management

Arrives on time and prepared to work; Budgets time and meets deadlines when performing tasks and projects.

### #3 Safety

Complies with national, state, local, and college safety regulations when designing and performing work on systems.

### #4 Analysis and Diagnosis

Analyze, evaluate, and diagnose systems related to instrumentation and control including electrical and electronic circuits, fluid power and signaling systems, computer networks, and mechanisms; Select and apply correct mathematical techniques to these analytical and diagnostic problems; Select and correctly use appropriate test equipment to collect data.

### #5 Design and Commissioning

Select, design, construct, configure, and install components necessary for the proper function of systems related to instrumentation and control, applying industry standards and verifying correct system operation when complete.

### #6 System optimization

Improve technical system functions by collecting data and evaluating performance; Implement strategies to optimize the function of these systems.

### #7 Calibration

Assess instrument accuracy and correct inaccuracies using appropriate calibration procedures and test equipment; Select and apply correct mathematical techniques to these calibration tasks.

### #8 Documentation

Interpret and create technical documents (e.g. electronic schematics, loop diagrams, functional diagrams, P&IDs, graphs, narratives) according to industry standards.

### #9 Independent learning

Select and research information sources to learn new principles, technologies, and techniques.

### #10 Job searching

Develop a professional resume and research job openings in the field of industrial instrumentation.

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## INST 262 Course Outcomes

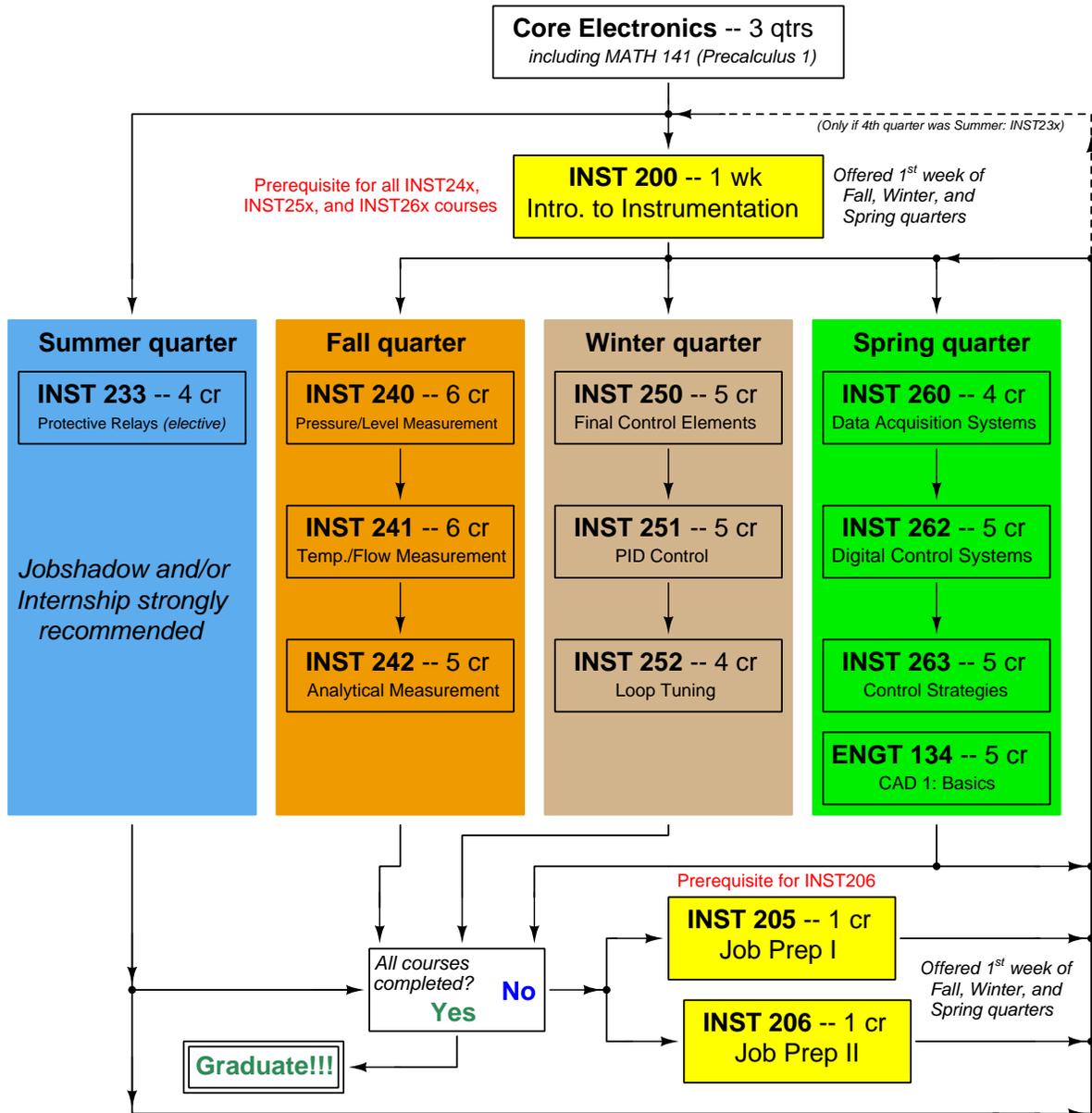
*Each and every outcome in this course is assessed at a mastery level (i.e. 100% competence)*

- Calculate voltages, currents, powers, and/or resistances in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Calculate voltages and currents in an ideal AC transformer circuit. [Ref: Program Learning Outcome #4]
- Identify proper controller action for a given process. [Ref: Program Learning Outcome #5]
- Predict the response of a single-loop control system to a component fault or process condition change, given a pictorial and/or schematic illustration. [Ref: Program Learning Outcome #4]
- Determine proper AI block parameters to range a Fieldbus transmitter for a given application. [Ref: Program Learning Outcome #5]
- Use decibels to calculate power gains and losses. [Ref: Program Learning Outcome #4]
- Identify specific instrument calibration errors (zero, span, linearity, hysteresis) from data in an “As-Found” table. [Ref: Program Learning Outcome #7]
- Calculate instrument input and output values given calibrated ranges. [Ref: Program Learning Outcome #7]
- Solve for specified variables in algebraic formulae. [Ref: Program Learning Outcome #4]
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms. [Ref: Program Learning Outcome #4]
- Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems. [Ref: Program Learning Outcome #3]
- Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all labwork. [Ref: Program Learning Outcomes #1 and #2]
- Connect a loop controller to the electronic transmitter and final control element of a pre-constructed process, then commission all components to form a working feedback control loop. [Ref: Program Learning Outcome #5]
- Generate an accurate loop diagram compliant with ISA standards documenting your team’s control system. [Ref: Program Learning Outcome #8]
- Commission and decommission a WirelessHART instrument. [Ref: Program Learning Outcome #5]
- Configure a digital indicator to poll instrument data via the Modbus/TCP protocol. [Ref: Program Learning Outcome #5]
- Research equipment manuals to sketch a complete circuit connecting a loop controller to either a 4-20 mA transmitter or a 4-20 mA final control element, with all DC voltages and currents correctly annotated, all electrical sources and loads properly identified, given components randomly selected by the instructor. [Ref: Program Learning Outcomes #5 and #9]
- Build a circuit to sense either pressure or vacuum using a differential pressure transmitter with HART

communication capability, reporting the sensed variable on an analog meter chosen by the instructor, setting the range values according to instructor specifications, capturing peak signal value using a digital multimeter, and capturing binary 0 and 1 bits using a digital oscilloscope. [Ref: Program Learning Outcome #5]

- Diagnose a random fault simulated by computer in a 4-20 transmitter circuit, logically justifying your steps before an instructor. [Ref: Program Learning Outcome #4]
- Diagnose a random fault placed in another team's control system by the instructor within a limited time using no test equipment except a multimeter, logically justifying your steps in the instructor's direct presence. [Ref: Program Learning Outcome #4]

# Sequence of second-year Instrumentation courses



The particular sequence of courses you take during the second year depends on when you complete all first-year courses and enter the second year. Since students enter the second year of Instrumentation at four different times (beginnings of Summer, Fall, Winter, and Spring quarters), the particular course sequence for any student will likely be different from the course sequence of classmates.

Some second-year courses are only offered in particular quarters with those quarters not having to be in sequence, while others are offered three out of the four quarters and must be taken in sequence. The following layout shows four typical course sequences for second-year Instrumentation students, depending on when they first enter the second year of the program:

### Possible course schedules depending on date of entry into 2nd year



file sequence

## General tool and supply list

### Wrenches

- Combination (box- and open-end) wrench set, 1/4" to 3/4" – *the most important wrench sizes are 7/16", 1/2", 9/16", and 5/8"; get these immediately!*
- Adjustable wrench, 6" handle (sometimes called "Crescent" wrench)
- Hex wrench ("Allen" wrench) set, fractional – 1/16" to 3/8"
- *Optional:* Hex wrench ("Allen" wrench) set, metric – 1.5 mm to 10 mm
- *Optional:* Miniature combination wrench set, 3/32" to 1/4" (sometimes called an "ignition wrench" set)

Note: *always maximize surface engagement on a fastener's head to reduce stress on that fastener. (e.g. Using box-end wrenches instead of adjustable wrenches; using the proper size and type of screwdriver; never using any tool that mars the fastener such as pliers or vise-grips unless absolutely necessary.)*

### Pliers

- Needle-nose pliers
- Diagonal wire cutters (sometimes called "dikes")

### Screwdrivers

- Slotted, 1/8" and 1/4" shaft
- Phillips, #1 and #2
- Jeweler's screwdriver set
- *Optional:* Magnetic multi-bit screwdriver (e.g. Klein Tools model 70035)

### Electrical

- Multimeter, Fluke model 87-IV or better
- Assortment of alligator-clip style jumper wires
- Soldering iron (10 to 40 watt) and rosin-core solder
- Resistor, potentiometer, diode assortments (from first-year lab kits)
- Package of insulated compression-style fork terminals (14 to 18 AWG wire size, #10 stud size)
- Wire strippers/terminal crimpers for 10 AWG to 18 AWG wire and insulated terminals
- *Optional:* ratcheting terminal crimp tool (e.g. Paladin 1305, Ferrules Direct FDT10011, or equivalent)

### Safety

- Safety glasses or goggles (available at BTC bookstore)
- Earplugs (available at BTC bookstore)

### Miscellaneous

- Simple scientific calculator (non-programmable, non-graphing, no conversions), TI-30Xa or TI-30XIIS recommended. Required for some exams!
- Portable personal computer capable of wired Ethernet connectivity, Wi-Fi connectivity, displaying PDF documents, creating text documents, creating and viewing spreadsheets, running PLC programming software (MS Windows only), and executing command-line utilities such as `ping`.
- Masking tape (for making temporary labels)
- Permanent marker pen
- Teflon pipe tape
- Utility knife
- Tape measure, 12 feet minimum
- Flashlight

file tools

## Methods of instruction

This course develops self-instructional and diagnostic skills by placing students in situations where they are required to research and think independently. In all portions of the curriculum, the goal is to avoid a passive learning environment, favoring instead *active engagement* of the learner through reading, reflection, problem-solving, and experimental activities. The curriculum may be roughly divided into two portions: *theory* and *practical*. All “theory” sessions follow the *inverted* format and contain virtually no lecture.

### Inverted theory sessions

The basic concept of an “inverted” learning environment is that the traditional allocations of student time are reversed: instead of students attending an instructor-led session to receive new information and then practicing the application of that information outside of the classroom in the form of homework, students in an inverted class encounter new information outside of the classroom via homework and apply that information in the classroom session under the instructor’s tutelage.

A natural question for instructors, then, is what their precise role is in an inverted classroom and how to organize that time well. Here I will list alternate formats suitable for an inverted classroom session, each of them tested and proven to work.

#### Small sessions

Students meet with instructors in small groups for short time periods. Groups of 4 students meeting for 30 minutes works very well, but groups as large as 8 students apiece may be used if time is limited. Each of these sessions begins with a 5 to 10 minute graded inspection of homework with individual questioning, to keep students accountable for doing the homework. The remainder of the session is a dialogue focusing on the topics of the day, the instructor challenging each student on the subject matter in Socratic fashion, and also answering students’ questions. A second grade measures each student’s comprehension of the subject matter by the end of the session.

This format also works via teleconferencing, for students unable to attend a face-to-face session on campus.

#### Large sessions

Students meet with instructors in a standard classroom (normal class size and period length). Each of these sessions begins with a 10 minute graded quiz (closed-book) on the homework topic(s), to keep students accountable for doing the homework. Students may leave the session as soon as they “check off” with the instructor in a Socratic dialogue as described above (instructor challenging each student to assess their comprehension, answering questions, and grading the responses). Students sign up for check-off on the whiteboard when they are ready, typically in groups of no more than 4. Alternatively, the bulk of the class session may be spent answering student questions in small groups, followed by another graded quiz at the end.

#### Correspondence

This format works for students unable to attend a “face-to-face” session, and who must correspond with the instructor via email or other asynchronous medium. Each student submits a thorough presentation of their completed homework, which the instructor grades for completeness and accuracy. The instructor then replies back to the student with challenge questions, and also answers questions the student may have. As with the previous formats, the student receives another grade assessing their comprehension of the subject matter by the close of the correspondence dialogue.

## Methods of instruction (continued)

In all formats, students are held accountable for completion of their homework, “completion” being defined as successfully interpreting the given information from source material (e.g. accurate outlines of reading or video assignments) and constructive effort to solve given problems. It must be understood in an inverted learning environment that students *will* have legitimate questions following a homework assignment, and that it is therefore unreasonable to expect mastery of the assigned subject matter. What is reasonable to expect from each and every student is a basic outline of the source material (reading or video assignments) complete with major terms defined and major concepts identified, plus a good-faith effort to solve every problem. Question 0 (contained in every worksheet) lists multiple strategies for effective study and problem-solving.

### Sample rubric for pre-assessments

- **No credit** = Any homework question unattempted (i.e. no effort shown on one or more questions); incomprehensible writing; failure to follow clear instruction(s)
- **Half credit** = Misconception(s) on any major topic explained in the assigned reading; answers shown with no supporting work; verbatim copying of text rather than written in student’s own words; outline missing important topic(s); unable to explain the outline or solution methods represented in written work
- **Full credit** = Every homework question answered, with any points of confusion clearly articulated; all important concepts from reading assignments accurately expressed in the outline and clearly articulated when called upon by the instructor to explain

*The minimum expectation at the start of every student-instructor session is that all students have made a good-faith effort to complete 100% of their assigned homework. This does not necessarily mean all answers will be correct, or that all concepts are fully understood, because one of the purposes of the meeting between students and instructor is to correct remaining misconceptions and answer students’ questions. However, experience has shown that without accountability for the homework, a substantial number of students will not put forth their best effort and that this compromises the whole learning process. Full credit is reserved for good-faith effort, where each student thoughtfully applies the study and problem-solving recommendations given to them (see Question 0).*

### Sample rubric for post-assessments

- **No credit** = Failure to comprehend one or more key concepts; failure to apply logical reasoning to the solution of problem(s); no contribution to the dialogue
- **Half credit** = Some misconceptions persist by the close of the session; problem-solving is inconsistent; limited contribution to the dialogue
- **Full credit** = Socratic queries answered thoughtfully; effective reasoning applied to problems; ideas communicated clearly and accurately; responds intelligently to questions and statements made by others in the session; adds new ideas and perspectives

*The minimum expectation is that each and every student engages with the instructor and with fellow students during the Socratic session: posing intelligent questions of their own, explaining their reasoning when challenged, and otherwise positively contributing to the discussion. Passive observation and listening is not an option here – every student must be an active participant, contributing something original to every dialogue. If a student is confused about any concept or solution, it is their responsibility to ask questions and seek resolution.*

## Methods of instruction (continued)

If a student happens to be absent for a scheduled class session and is therefore unable to be assessed on that day's study, they may schedule a time with the instructor to demonstrate their comprehension at some later date (before the end of the quarter when grades must be submitted). These same standards of performance apply equally make-up assessments: either inspection of homework or a closed-book quiz for the pre-assessment, and either a Socratic dialogue with the instructor or another closed-book quiz for the post-assessment.

## Methods of instruction (continued)

### Lab sessions

In the lab portion of each course, students work in teams to install, configure, document, calibrate, and troubleshoot working instrument loop systems. Each lab exercise focuses on a different type of instrument, with a limited time period typically for completion. An ordinary lab session might look like this:

- (1) Start of practical (lab) session: announcements and planning
  - (a) The instructor makes general announcements to all students
  - (b) The instructor works with team to plan that day's goals, making sure each team member has a clear idea of what they should accomplish
- (2) Teams work on lab unit completion according to recommended schedule:
  - (First day) Select and bench-test instrument(s), complete prototype sketch of project
  - (One day) Connect instrument(s) into a complete loop
  - (One day) Each team member drafts their own loop documentation, inspection done as a team (with instructor)
  - (One or two days) Each team member calibrates/configures the instrument(s)
  - (Remaining days, up to last) Each team member troubleshoots the instrument loop
- (3) End of practical (lab) session: debriefing where each team reports on their work to the whole class

### Troubleshooting assessments must meet the following guidelines:

- Troubleshooting must be performed *on a system the student did not build themselves*. This forces students to rely on another team's documentation rather than their own memory of how the system was built.
- Each student must individually demonstrate proper troubleshooting technique.
- Simply finding the fault is not good enough. Each student must consistently demonstrate sound reasoning while troubleshooting.
- If a student fails to properly diagnose the system fault, they must attempt (as many times as necessary) with different scenarios until they do, reviewing any mistakes with the instructor after each failed attempt.

file instructional

## Distance delivery methods

Sometimes the demands of life prevent students from attending college 6 hours per day. In such cases, there exist alternatives to the normal 8:00 AM to 3:00 PM class/lab schedule, allowing students to complete coursework in non-traditional ways, at a “distance” from the college campus proper.

For such “distance” students, the same worksheets, lab activities, exams, and academic standards still apply. Instead of working in small groups and in teams to complete theory and lab sections, though, students participating in an alternative fashion must do all the work themselves. Participation via teleconferencing, video- or audio-recorded small-group sessions, and such is encouraged and supported.

There is no recording of hours attended or tardiness for students participating in this manner. The pace of the course is likewise determined by the “distance” student. Experience has shown that it is a benefit for “distance” students to maintain the same pace as their on-campus classmates whenever possible.

In lieu of small-group activities and class discussions, comprehension of the theory portion of each course will be ensured by completing and submitting detailed answers for *all* worksheet questions, not just passing daily quizzes as is the standard for conventional students. The instructor will discuss any incomplete and/or incorrect worksheet answers with the student, and ask that those questions be re-answered by the student to correct any misunderstandings before moving on.

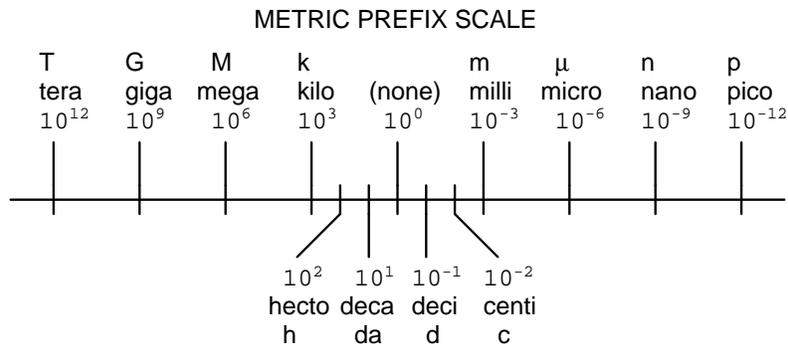
Labwork is perhaps the most difficult portion of the curriculum for a “distance” student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. “Distance” students must find a way to complete the required lab activities, either by arranging time in the school lab facility and/or completing activities on equivalent equipment outside of school (e.g. at their place of employment, if applicable). Labwork completed outside of school must be validated by a supervisor and/or documented via photograph or videorecording.

Conventional students may opt to switch to “distance” mode at any time. This has proven to be a benefit to students whose lives are disrupted by catastrophic events. Likewise, “distance” students may switch back to conventional mode if and when their schedules permit. Although the existence of alternative modes of student participation is a great benefit for students with challenging schedules, it requires a greater investment of time and a greater level of self-discipline than the traditional mode where the student attends school for 6 hours every day. No student should consider the “distance” mode of learning a way to have more free time to themselves, because they will actually spend more time engaged in the coursework than if they attend school on a regular schedule. It exists merely for the sake of those who cannot attend during regular school hours, as an alternative to course withdrawal.

## Metric prefixes and conversion constants

- **Metric prefixes**

- Yotta =  $10^{24}$  Symbol: Y
- Zeta =  $10^{21}$  Symbol: Z
- Exa =  $10^{18}$  Symbol: E
- Peta =  $10^{15}$  Symbol: P
- Tera =  $10^{12}$  Symbol: T
- Giga =  $10^9$  Symbol: G
- Mega =  $10^6$  Symbol: M
- Kilo =  $10^3$  Symbol: k
- Hecto =  $10^2$  Symbol: h
- Deca =  $10^1$  Symbol: da
- Deci =  $10^{-1}$  Symbol: d
- Centi =  $10^{-2}$  Symbol: c
- Milli =  $10^{-3}$  Symbol: m
- Micro =  $10^{-6}$  Symbol:  $\mu$
- Nano =  $10^{-9}$  Symbol: n
- Pico =  $10^{-12}$  Symbol: p
- Femto =  $10^{-15}$  Symbol: f
- Atto =  $10^{-18}$  Symbol: a
- Zepto =  $10^{-21}$  Symbol: z
- Yocto =  $10^{-24}$  Symbol: y



- **Conversion formulae for temperature**

- $^{\circ}\text{F} = (^{\circ}\text{C})(9/5) + 32$
- $^{\circ}\text{C} = (^{\circ}\text{F} - 32)(5/9)$
- $^{\circ}\text{R} = ^{\circ}\text{F} + 459.67$
- $\text{K} = ^{\circ}\text{C} + 273.15$

**Conversion equivalencies for distance**

- 1 inch (in) = 2.540000 centimeter (cm)
- 1 foot (ft) = 12 inches (in)
- 1 yard (yd) = 3 feet (ft)
- 1 mile (mi) = 5280 feet (ft)

**Conversion equivalencies for volume**

1 gallon (gal) = 231.0 cubic inches (in<sup>3</sup>) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm<sup>3</sup>)

**Conversion equivalencies for velocity**

1 mile per hour (mi/h) = 88 feet per minute (ft/m) = 1.46667 feet per second (ft/s) = 1.60934 kilometer per hour (km/h) = 0.44704 meter per second (m/s) = 0.868976 knot (knot – international)

**Conversion equivalencies for mass**

1 pound (lbm) = 0.45359 kilogram (kg) = 0.031081 slugs

**Conversion equivalencies for force**

1 pound-force (lbf) = 4.44822 newton (N)

**Conversion equivalencies for area**

1 acre = 43560 square feet (ft<sup>2</sup>) = 4840 square yards (yd<sup>2</sup>) = 4046.86 square meters (m<sup>2</sup>)

**Conversion equivalencies for common pressure units (either all gauge or all absolute)**

1 pound per square inch (PSI) = 2.03602 inches of mercury (in. Hg) = 27.6799 inches of water (in. W.C.) = 6.894757 kilo-pascals (kPa) = 0.06894757 bar

1 bar = 100 kilo-pascals (kPa) = 14.504 pounds per square inch (PSI)

**Conversion equivalencies for absolute pressure units (only)**

1 atmosphere (Atm) = 14.7 pounds per square inch absolute (PSIA) = 101.325 kilo-pascals absolute (kPaA) = 1.01325 bar (bar) = 760 millimeters of mercury absolute (mmHgA) = 760 torr (torr)

**Conversion equivalencies for energy or work**

1 british thermal unit (Btu – “International Table”) = 251.996 calories (cal – “International Table”) = 1055.06 joules (J) = 1055.06 watt-seconds (W-s) = 0.293071 watt-hour (W-hr) = 1.05506 x 10<sup>10</sup> ergs (erg) = 778.169 foot-pound-force (ft-lbf)

**Conversion equivalencies for power**

1 horsepower (hp – 550 ft-lbf/s) = 745.7 watts (W) = 2544.43 british thermal units per hour (Btu/hr) = 0.0760181 boiler horsepower (hp – boiler)

**Acceleration of gravity (free fall), Earth standard**

9.806650 meters per second per second (m/s<sup>2</sup>) = 32.1740 feet per second per second (ft/s<sup>2</sup>)

### Physical constants

Speed of light in a vacuum ( $c$ ) =  $2.9979 \times 10^8$  meters per second (m/s) = 186,281 miles per second (mi/s)

Avogadro's number ( $N_A$ ) =  $6.022 \times 10^{23}$  per mole ( $\text{mol}^{-1}$ )

Electronic charge ( $e$ ) =  $1.602 \times 10^{-19}$  Coulomb (C)

Boltzmann's constant ( $k$ ) =  $1.38 \times 10^{-23}$  Joules per Kelvin (J/K)

Stefan-Boltzmann constant ( $\sigma$ ) =  $5.67 \times 10^{-8}$  Watts per square meter-Kelvin<sup>4</sup> ( $\text{W}/\text{m}^2 \cdot \text{K}^4$ )

Molar gas constant ( $R$ ) = 8.314 Joules per mole-Kelvin (J/mol-K)

### Properties of Water

Freezing point at sea level =  $32^\circ\text{F} = 0^\circ\text{C}$

Boiling point at sea level =  $212^\circ\text{F} = 100^\circ\text{C}$

Density of water at  $4^\circ\text{C} = 1000 \text{ kg}/\text{m}^3 = 1 \text{ g}/\text{cm}^3 = 1 \text{ kg}/\text{liter} = 62.428 \text{ lb}/\text{ft}^3 = 1.94 \text{ slugs}/\text{ft}^3$

Specific heat of water at  $14^\circ\text{C} = 1.00002 \text{ calories}/\text{g} \cdot ^\circ\text{C} = 1 \text{ BTU}/\text{lb} \cdot ^\circ\text{F} = 4.1869 \text{ Joules}/\text{g} \cdot ^\circ\text{C}$

Specific heat of ice  $\approx 0.5 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Specific heat of steam  $\approx 0.48 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Absolute viscosity of water at  $20^\circ\text{C} = 1.0019 \text{ centipoise (cp)} = 0.0010019 \text{ Pascal-seconds (Pa}\cdot\text{s)}$

Surface tension of water (in contact with air) at  $18^\circ\text{C} = 73.05 \text{ dynes}/\text{cm}$

pH of pure water at  $25^\circ\text{C} = 7.0$  (*pH scale = 0 to 14*)

### Properties of Dry Air at sea level

Density of dry air at  $20^\circ\text{C}$  and 760 torr =  $1.204 \text{ mg}/\text{cm}^3 = 1.204 \text{ kg}/\text{m}^3 = 0.075 \text{ lb}/\text{ft}^3 = 0.00235 \text{ slugs}/\text{ft}^3$

Absolute viscosity of dry air at  $20^\circ\text{C}$  and 760 torr =  $0.018 \text{ centipoise (cp)} = 1.8 \times 10^{-5} \text{ Pascal-seconds (Pa}\cdot\text{s)}$

file conversion\_constants

**How to get the most out of academic reading:**

- Outline, don't highlight! Identify every major idea presented in the text, and express these ideas in your own words. A suggested ratio is one sentence of your own thoughts per paragraph of text read.
- Articulate your thoughts as you read (i.e. "have a conversation" with the author). This will develop *metacognition*: active supervision of your own thoughts. Note points of agreement, disagreement, confusion, epiphanies, and connections between different concepts or applications.
- Work through all mathematical exercises shown within the text, to ensure you understand all the steps.
- Imagine explaining concepts you've just learned to someone else. Teaching forces you to distill concepts to their essence, thereby clarifying those concepts, revealing assumptions, and exposing misconceptions. Your goal is to create the simplest explanation that is still technically accurate.
- Create your own questions based on what you read, as a teacher would to challenge students.

**How to effectively problem-solve and troubleshoot:**

- Rely on principles, not procedures. Don't be satisfied with memorizing steps – learn *why* those steps work. Each step should make logical sense and have real-world meaning to you.
- Sketch a diagram to help visualize the problem. Sketch a graph showing how variables relate. When building a real system, always prototype it on paper and analyze its function *before* constructing it.
- Identify what it is you need to solve, identify all relevant data, identify all units of measurement, identify any general principles or formulae linking the given information to the solution, and then identify any "missing pieces" to a solution. Annotate all diagrams with this data.
- Perform "thought experiments" to explore the effects of different conditions for theoretical problems. When troubleshooting, perform *diagnostic tests* rather than just visually inspect for faults.
- Simplify the problem and solve that simplified problem to identify strategies applicable to the original problem (e.g. change quantitative to qualitative, or visa-versa; substitute easier numerical values; eliminate confusing details; add details to eliminate unknowns; consider simple limiting cases; apply an analogy). Remove components from a malfunctioning system to simplify it and better identify the nature and location of the problem.
- Check for exceptions – does your solution work for *all* conditions and criteria?
- Work "backward" from a hypothetical solution to a new set of given conditions.

**How to manage your time:**

- Avoid procrastination. Work now and play later, every single day.
- Consider the place you're in when deciding what to do. If there is project work to do and you have access to the lab, do that work and not something that could be done elsewhere (e.g. homework).
- Eliminate distractions. Kill your television and video games. Turn off your mobile phone, or just leave it at home. Study in places where you can concentrate, like the Library.
- Use your "in between" time productively. Don't leave campus for lunch. Arrive to school early. If you finish your assigned work early, begin working on the next assignment.

**Above all, cultivate persistence,** as this is necessary to master anything non-trivial. The keys to persistence are (1) having the desire to achieve that mastery, and (2) realizing challenges are normal and not an indication of something gone wrong. A common error is to equate *easy* with *effective*: students often believe learning should be easy if everything is done right. The truth is that mastery never comes easy!

file question0

## Checklist when reading an instructional text

*“Reading maketh a full man; conference a ready man; and writing an exact man”* – Francis Bacon

Francis Bacon’s advice is a blueprint for effective education: reading provides the learner with knowledge, writing focuses the learner’s thoughts, and critical dialogue equips the learner to confidently communicate and apply their learning. Independent acquisition and application of knowledge is a powerful skill, well worth the effort to cultivate. To this end, students should read these educational resources closely, write their own outline and reflections on the reading, and discuss in detail their findings with classmates and instructor(s). You should be able to do all of the following after reading any instructional text:

Briefly **OUTLINE THE TEXT**, as though you were writing a detailed Table of Contents. Feel free to rearrange the order if it makes more sense that way. Prepare to articulate these points in detail and to answer questions from your classmates and instructor. Outlining is a good self-test of thorough reading because you cannot outline what you have not read or do not comprehend.

Demonstrate **ACTIVE READING STRATEGIES**, including verbalizing your impressions as you read, simplifying long passages to convey the same ideas using fewer words, annotating text and illustrations with your own interpretations, working through mathematical examples shown in the text, cross-referencing passages with relevant illustrations and/or other passages, identifying problem-solving strategies applied by the author, etc. Technical reading is a special case of problem-solving, and so these strategies work precisely because they help solve any problem: paying attention to your own thoughts (metacognition), eliminating unnecessary complexities, identifying what makes sense, paying close attention to details, drawing connections between separated facts, and noting the successful strategies of others.

Identify **IMPORTANT THEMES**, especially **GENERAL LAWS** and **PRINCIPLES**, expounded in the text and express them in the simplest of terms as though you were teaching an intelligent child. This emphasizes connections between related topics and develops your ability to communicate complex ideas to anyone.

Form **YOUR OWN QUESTIONS** based on the reading, and then pose them to your instructor and classmates for their consideration. Anticipate both correct and incorrect answers, the incorrect answer(s) assuming one or more plausible misconceptions. This helps you view the subject from different perspectives to grasp it more fully.

Devise **EXPERIMENTS** to test claims presented in the reading, or to disprove misconceptions. Predict possible outcomes of these experiments, and evaluate their meanings: what result(s) would confirm, and what would constitute disproof? Running mental simulations and evaluating results is essential to scientific and diagnostic reasoning.

Specifically identify any points you found **CONFUSING**. The reason for doing this is to help diagnose misconceptions and overcome barriers to learning.

## General challenges following a tutorial reading assignment

- Summarize as much of the text as you can in one paragraph of your own words. A helpful strategy is to explain ideas as you would for an intelligent child: as simple as you can without compromising too much accuracy.
- Simplify a particular section of the text, for example a paragraph or even a single sentence, so as to capture the same fundamental idea in fewer words.
- Where did the text make the most sense to you? What was it about the text's presentation that made it clear?
- Identify where it might be easy for someone to misunderstand the text, and explain why you think it could be confusing.
- Identify any new concept(s) presented in the text, and explain in your own words.
- Identify any familiar concept(s) such as physical laws or principles applied or referenced in the text.
- Devise a proof of concept experiment demonstrating an important principle, physical law, or technical innovation represented in the text.
- Devise an experiment to disprove a plausible misconception.
- Did the text reveal any misconceptions you might have harbored? If so, describe the misconception(s) and the reason(s) why you now know them to be incorrect.
- Describe any useful problem-solving strategies applied in the text.
- Devise a question of your own to challenge a reader's comprehension of the text.

## General follow-up challenges for assigned problems

- Identify where any fundamental laws or principles apply to the solution of this problem, especially before applying any mathematical techniques.
- Devise a thought experiment to explore the characteristics of the problem scenario, applying known laws and principles to mentally model its behavior.
- Describe in detail your own strategy for solving this problem. How did you identify and organized the given information? Did you sketch any diagrams to help frame the problem?
- Is there more than one way to solve this problem? Which method seems best to you?
- Show the work you did in solving this problem, even if the solution is incomplete or incorrect.
- What would you say was the most challenging part of this problem, and why was it so?
- Was any important information missing from the problem which you had to research or recall?
- Was there any extraneous information presented within this problem? If so, what was it and why did it not matter?
- Examine someone else's solution to identify where they applied fundamental laws or principles.
- Simplify the problem from its given form and show how to solve this simpler version of it. Examples include eliminating certain variables or conditions, altering values to simpler (usually whole) numbers, applying a limiting case (i.e. altering a variable to some extreme or ultimate value).
- For quantitative problems, identify the real-world meaning of all intermediate calculations: their units of measurement, where they fit into the scenario at hand. Annotate any diagrams or illustrations with these calculated values.
- For quantitative problems, try approaching it qualitatively instead, thinking in terms of "increase" and "decrease" rather than definite values.
- For qualitative problems, try approaching it quantitatively instead, proposing simple numerical values for the variables.
- Were there any assumptions you made while solving this problem? Would your solution change if one of those assumptions were altered?
- Identify where it would be easy for someone to go astray in attempting to solve this problem.
- Formulate your own problem based on what you learned solving this one.

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## Questions

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### Question 1

Read and outline the introductory and “FF Design Philosophy” sections of the “FOUNDATION Fieldbus Instrumentation” chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

- (1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A “Table of Contents” format works well for this.
- (2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author’s problem-solving strategies, etc.).
- (3) General principles, especially physical laws, referenced in the text.
- (4) Questions of your own you would pose to another reader, to challenge their understanding.
- (5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
- (6) Any points of confusion, and precisely why you found the text confusing.

[file i04556](#)

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### Question 2

Read and outline the “H1 FF Physical Layer” section of the “FOUNDATION Fieldbus Instrumentation” chapter in your *Lessons In Industrial Instrumentation* textbook.

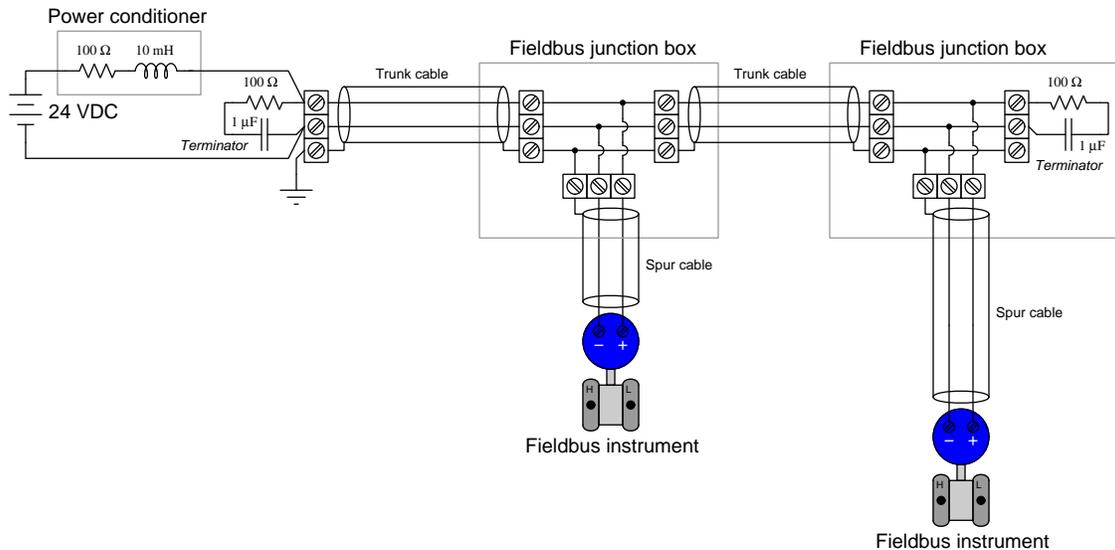
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[file i04557](#)

### Question 3

In both FOUNDATION Fieldbus H1 and Profibus PA, two fieldbus networks sharing the same physical layer (IEC 61158-2), *terminators* must be connected to both far ends of the cable. These terminators consist of a  $100\ \Omega$  resistor connected in series with a  $1\ \mu\text{F}$  capacitor. Also, any DC power supply must be connected through a *power conditioner* in order for the network to function. Both types of devices are shown in this diagram:



Answer the following questions about the terminators and power conditioner:

- What is significant about the size of the resistor in each terminator ( $100\ \Omega$ )?
- Why is each termination resistor connected in series with a  $1\ \mu\text{F}$  capacitor? Why not terminate with just a plain  $100\ \Omega$  resistor at each end of the network?
- What function does the power conditioner serve? Specifically, what is the purpose of the  $10\ \text{mH}$  inductor connected in series?
- Is the resistor necessary in the power conditioner network? Why or why not?

#### Suggestions for Socratic discussion

- If FOUNDATION Fieldbus H1 and Profibus PA share the same physical layer, does that mean the two types of instruments will work interchangeably on the two types of networks? Will a FF instrument be damaged by plugging it into a PA network, or visa versa? Why or why not?
- In order for a HART instrument to work, there must be at least  $250\ \text{ohms}$  of loop resistance present. Explain why this is, and also identify the equivalent feature within a FOUNDATION Fieldbus H1 network.
- Explain why the termination resistors used in digital networks such as RS-485 and Ethernet do *not* require series capacitors like the terminators in FF networks do.
- Can you use a digital multimeter (DMM) to detect the presence of FOUNDATION Fieldbus data signals? Why or why not?

- Predict the effects of a random electrical fault inserted into any portion of this segment.

[file i02433](#)

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#### Question 4

Read pages 31 through 34 of the “Wiring Guidelines for FOUNDATION Fieldbus Transmitters” document published by Foxboro (MI 020-360, July 1999), and answer the following questions:

How many different control loops exist in this process, and how many wire pairs were originally necessary to convey all the 4-20 mA analog signals to and from the DCS?

How many wire pairs are necessary to do the same control tasks using Fieldbus instruments, assuming a single H1 segment?

Explain why the manager’s original plan of using original wiring to create a single FF network was not practical, and then describe some alternative solutions.

#### **Suggestions for Socratic discussion**

- Would you consider the proposed Fieldbus wiring topology in the blend chest process to be daisy-chain, bus/spur, or chicken foot?
- What do you suppose the term “home run” means with reference to the multi-pair cable in this tutorial?
- In the proposal using five wire pairs to connect the FF devices to the DCS, how much voltage would be dropped along the length of each wire pair? Assuming a 24 VDC power source at the DCS, how much voltage would be left at the terminals of each FF device?
- In the proposal using five separate H1 networks, how many FF interface cards would be required at the DCS? Assuming eight channels per analog I/O card, how many analog cards would have been needed with the old 4-20 mA analog system?

[file i04558](#)

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### Question 5

Download a free FOUNDATION Fieldbus segment design tool from a Fieldbus instrument manufacturer's website or the Fieldbus Foundation website (<http://www.fieldbus.org>), and use this software to lay out a simple H1 segment complete with power supply, enough field instruments to make one working control loop, and coupling devices to connect the instruments together. I highly recommend *DesignMATE* software, which is a free download.

When you have the segment layout complete, use the "Print Screen" function of your personal computer to capture the screen image and save it as a graphic file. The instructor may collect some of these screenshots from you to display for the entire class.

#### **Suggestions for Socratic discussion**

- Describe some of the practical benefits that may come from using segment design software to plan a Fieldbus H1 segment.
- Would FOUNDATION Fieldbus segment design software work to plan a Profibus PA network? Why or why not?
- Intentionally introduce problems into your H1 segment to see how the design tool flags those errors. Examples include:
  - Excessive cable length
  - Too many terminating resistors
  - Too few terminating resistors
  - Wrong cable type for the application

[file i02434](#)

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### Question 6

Read and outline the "H1 FF Segment Troubleshooting" section of the "FOUNDATION Fieldbus Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

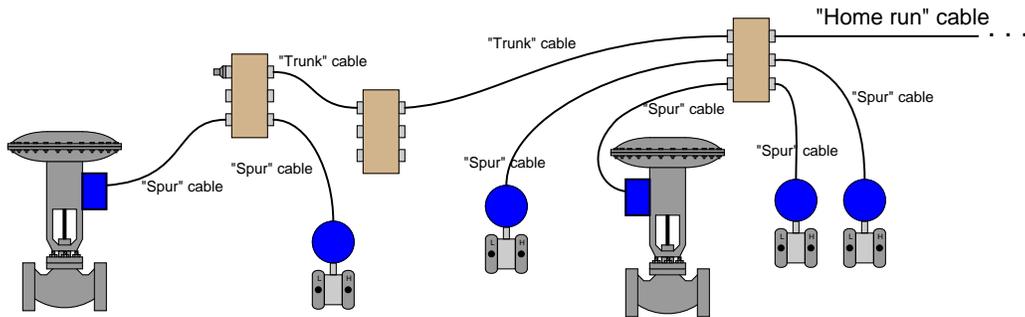
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- (5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
- (6) Any points of confusion, and precisely why you found the text confusing.

[file i04569](#)

## Question 7

FOUNDATION Fieldbus H1 cable is comprised of two ungrounded conductors surrounded by a grounded shield. Coupling devices provide easy connection points for new devices on the network segment:



Suppose the H1 segment shown above is newly-constructed, and you are asked to perform some basic tests on the cable to ensure there are no major problems before it is energized for the first time. Describe a simple way for you to electrically check for a *ground loop* in the trunk cable with as few steps as possible.

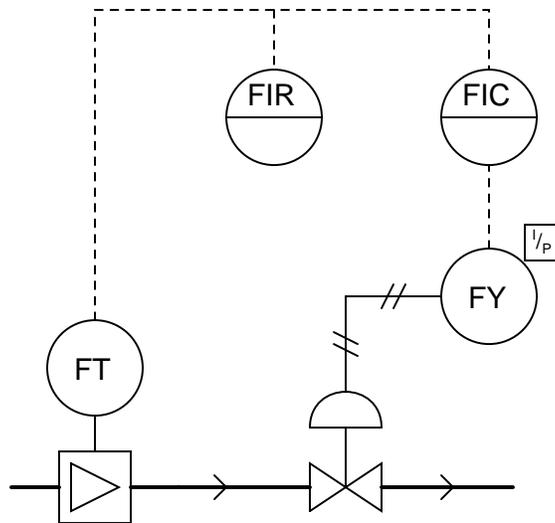
### Suggestions for Socratic discussion

- Explain exactly why a “ground loop” is so problematic in a cable system.
- Suppose an electrician wants to use a test instrument called a *megger* to check the integrity of a FOUNDATION Fieldbus H1 cable. His plan is to check for ground faults as well as shorts between the cable conductors and/or between the conductors and the cable shield. Do you agree with the electrician’s plan? Why or why not?
- When the segment is up and running, may we use a handheld multimeter to measure Fieldbus signal strength, in lieu of an oscilloscope? Why or why not?

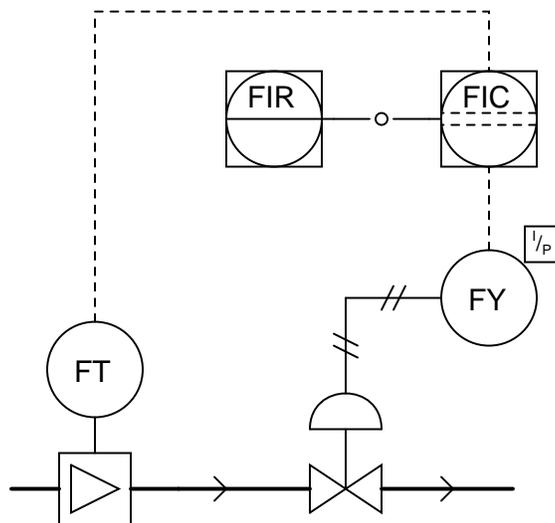
[file i04575](#)

Question 8

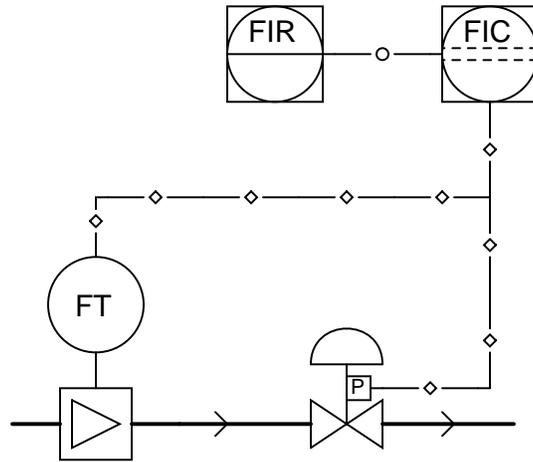
Identify all the components shown in this P&ID of an analog flow control system:



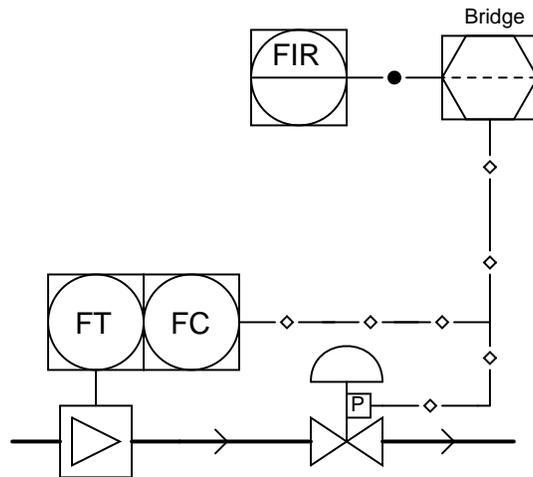
Identify all the components shown in this P&ID of the same flow control loop implemented using a DCS:



Identify all the components shown in this P&ID of the same flow control loop implemented using a device-level fieldbus and a DCS:



Finally, identify all the components shown in this P&ID of the same flow control loop implemented entirely with a device-level fieldbus:



In each of these control systems, identify where the control algorithm (PID calculations) take place.

**Suggestions for Socratic discussion**

- How are Fieldbus signal paths represented using ISA-standard symbols in P&IDs?
- What is the distinction in ISA-standard symbology between circles that are filled (solid black) versus circles that are unfilled, when those circles appear as part of a line symbol?

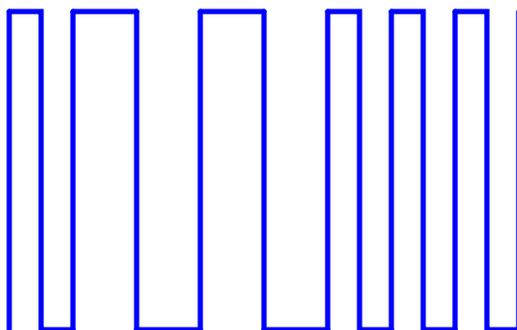
file i02423

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Question 9

Decode the following serial data streams, each one encoded using a different method:

(Manchester encoding)



(FSK encoding)



**Suggestions for Socratic discussion**

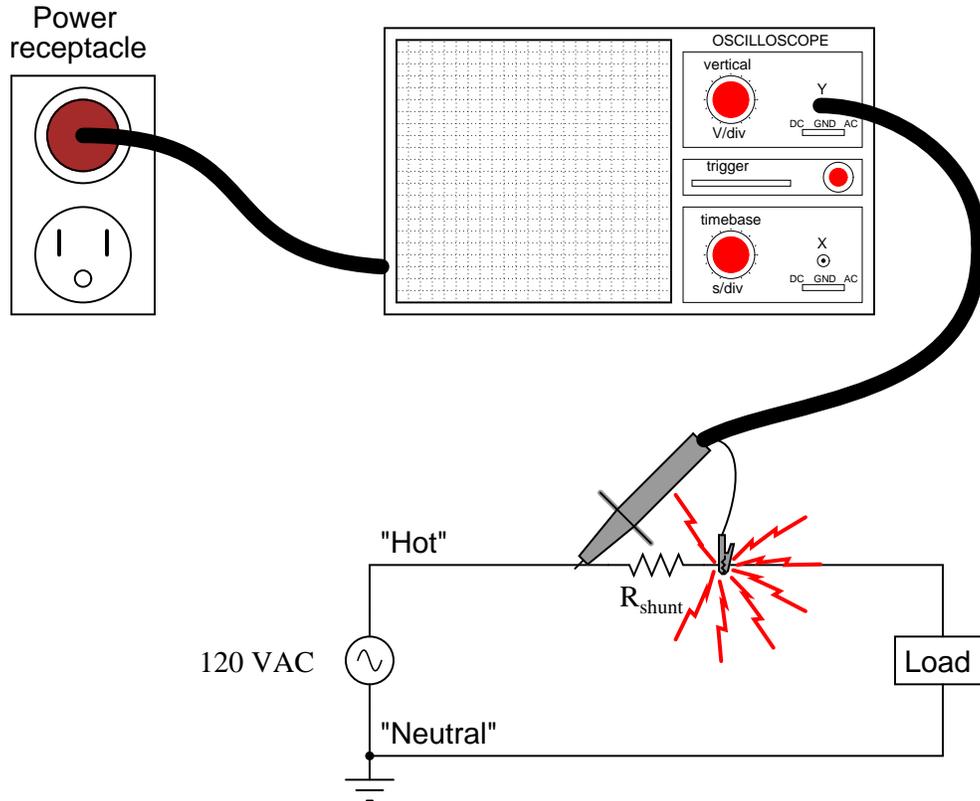
- Assuming a common time scale for both data streams shown, which of the two has the highest *bit rate*?
- Assuming a common time scale for both data streams shown, which of the two has the highest *baud rate*?

[file i02919](#)

Question 10

Most oscilloscopes can only directly measure voltage, not current. One way to measure AC current with an oscilloscope is to measure the voltage dropped across a *shunt resistor*. Since the voltage dropped across a resistor is proportional to the current through that resistor, whatever wave-shape the current is will be translated into a voltage drop with the exact same wave-shape.

However, one must be very careful when connecting an oscilloscope to any part of a grounded system, as many electric power systems are. Note what happens here when a technician attempts to connect the oscilloscope across a shunt resistor located on the "hot" side of a grounded 120 VAC motor circuit:

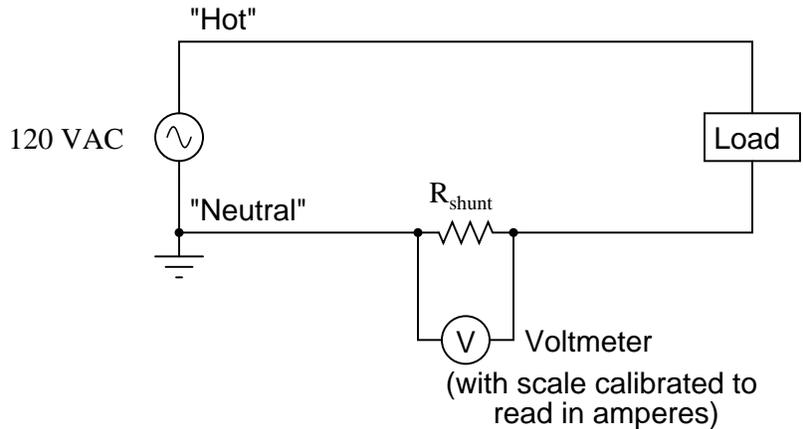


Explain why sparks fly when an oscilloscope is connected to the AC circuit as shown. Also, describe a safer way to perform this current measurement.

[file i03474](#)

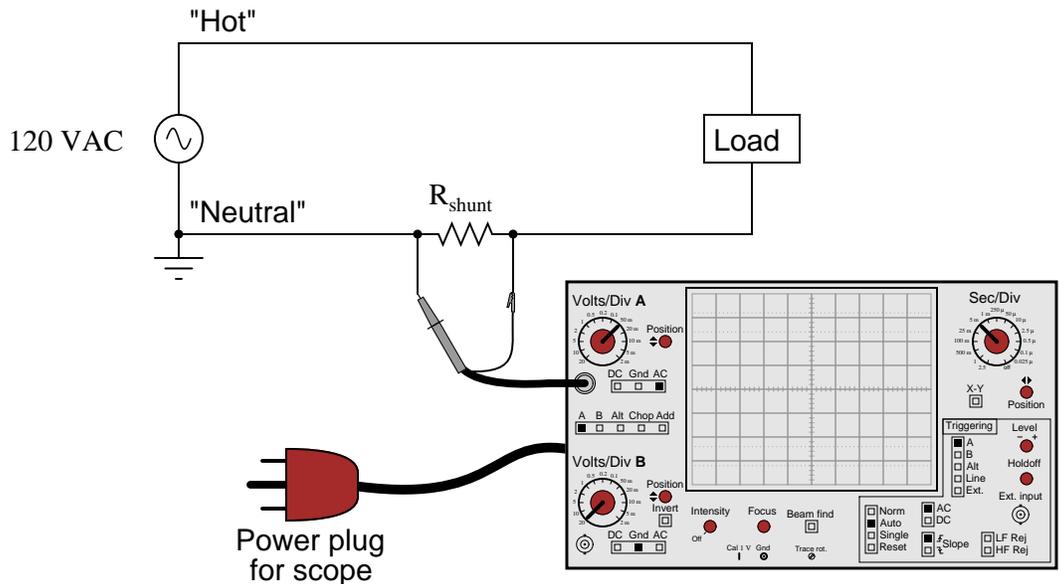
Question 11

*Shunt resistors* are low-value, precision resistors used as current-measuring elements in high-current circuits. The idea is to measure the voltage dropped across this precision resistance and use Ohm's Law ( $I = \frac{V}{R}$ ) to infer the amount of current in the circuit:



Since the schematic shows a shunt resistor being used to measure current in an AC circuit, it would be equally appropriate to use an oscilloscope instead of a voltmeter to measure the voltage drop produced by the shunt. However, we must be careful in connecting the oscilloscope to the shunt because of the inherent ground reference of the oscilloscope's metal case and probe assembly.

Explain why connecting an oscilloscope to the shunt as shown in this second diagram would be a bad idea:



Next, identify a better method of measuring current in this circuit.  
[file i03469](#)

Question 12

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Question 13

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Question 14

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Question 15

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Question 16

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Question 17

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Question 18

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Question 19

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Question 20

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Question 21

Read and outline the “H1 FF Data Link Layer” section of the “FOUNDATION Fieldbus Instrumentation” chapter in your *Lessons In Industrial Instrumentation* textbook.

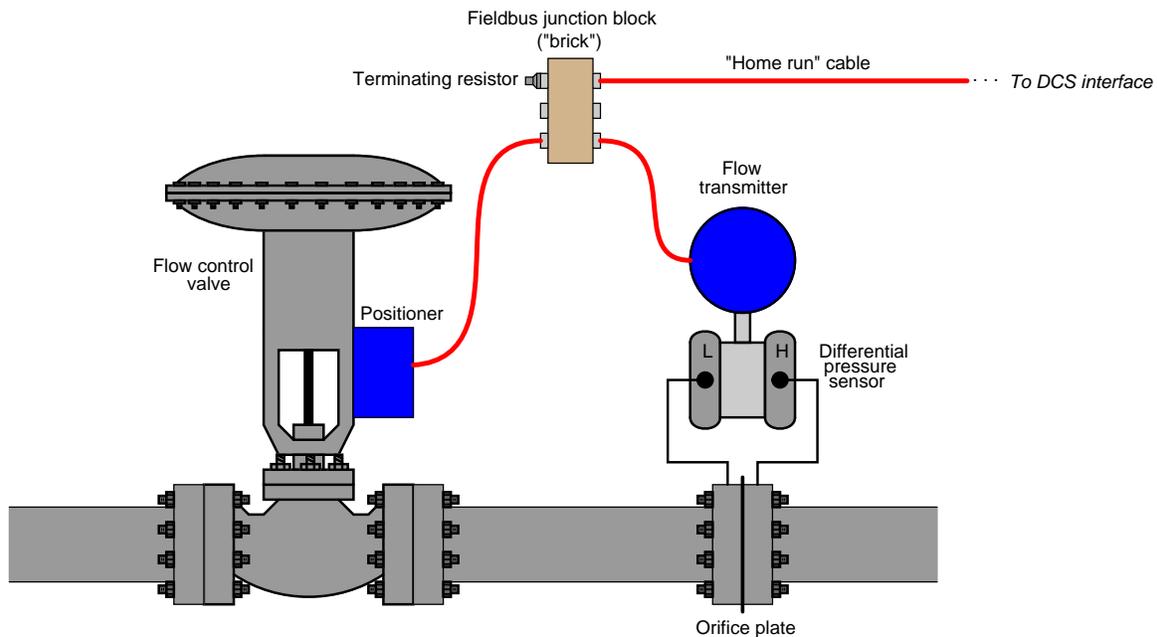
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

- (1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A “Table of Contents” format works well for this.
- (2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author’s problem-solving strategies, etc.).
- (3) General principles, especially physical laws, referenced in the text.
- (4) Questions of your own you would pose to another reader, to challenge their understanding.
- (5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
- (6) Any points of confusion, and precisely why you found the text confusing.

[file i04559](#)

## Question 22

The only active devices on the following FF H1 segment are the flow transmitter, the control valve, and the H1 interface card on the DCS I/O rack:



Supposing the H1 card on the DCS acts as the Link Active Scheduler (LAS) and that the PID control function resides in the control valve positioner, describe the sequence of events necessary to make the control loop work (i.e. reading the process variable signal, computing the controller output, moving the valve stem, updating setpoint from human operator).

### Suggestions for Socratic discussion

- Suppose the LAS stops working. How will this impact the operation of the Fieldbus segment?
- Identify which of the communication events you list are *cyclic* and which are *acyclic*.
- Suppose the PID control function resides within the transmitter rather than in the valve positioner. How would this affect the sequence of events on this H1 network segment?
- Suppose this flow control loop is the "slave" (or "secondary") loop in a cascade control strategy, where some other controller on the FF segment is the "master" ("primary"), the output of this master PID function generating remote setpoint values for the flow controller. How would the sequence of events change from what they are when the flow controller's setpoint comes from a human operator?

file i04570

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## Question 23

The different *Virtual Communication Relationships* or *VCRs* in FOUNDATION Fieldbus H1 networks can be hard to understand without illustrative examples. In order to make better sense of how the *Publisher/Subscriber*, *Client/Server*, and *Source/Sink* communication models work, we will match these VCR types to the following classroom interactions between an instructor and students. In each of these cases, identify who plays the role of the LAS, and which VCR is being implemented:

### Scenario #1

The instructor calls upon students one at a time to voluntarily share any progress they have made on their lab projects. Some students give a report, while others pass. When each student is finished with their turn, the instructor calls upon the next student. There is no student-to-student dialogue.

### Scenario #2

The instructor is playing the role of a moderator in a debate between two students in a classroom. Neither student is allowed to speak unless directed to by the instructor, and each one has a limited time to speak once they begin. The two debaters are listening to each other's arguments, responding to the points raised, confirming correct comprehension of what they heard, and asking questions of each other.

### Scenario #3

The instructor is managing a classroom exercise where groups of students are studying probability and random processes. Five different students have been asked to each roll a pair of dice ten times and tally the total count. The instructor gives the five students enough time to roll their dice and tally the results, then calls upon each one of these students (one at a time) to report their tally. A sixth student in the classroom listens to each of the five students' tallies and then calculates the average value. After waiting another short interval, the instructor then calls upon the sixth student to report the calculated average.

<b>Suggestions for Socratic discussion</b>
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- In the Publisher/Subscriber example, who is publishing data and who is subscribing to it? Are there any people in the room who overhear published data but are not subscribed to that data?
- In the Client/Server example, who plays the role of the Client and who plays the role of the Server?
- Extend these analogies to include a failure of the LAS, with a backup LAS taking over.

[file i02437](#)

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### Question 24

Suppose we have an H1 Fieldbus segment with 6 devices connected. The LAS, of course, maintains these addresses in its “Live List” so it knows who to send tokens to:

- Address 24: Multi-channel temperature transmitter
- Address 33: Control valve positioner
- Address 35: Control valve positioner
- Address 40: Pressure transmitter
- Address 88: Level transmitter
- Address 107: Local indicator

If someone were to connect a new device with an address of 249, how would the LAS ever know it was there, and how would it get added to the Live List? Conversely, how does a device fall off the Live List?

#### Suggestions for Socratic discussion

- Suppose someone were to plug a new device into one of the coupler ports on this H1 segment, and this new device happened to have a pre-assigned address of 40. What would happen as a result?
- Suppose someone were to plug a new device into one of the coupler ports on this H1 segment, and this new device happened to have a pre-assigned address falling within the FUN/NUN address range. What would happen as a result?

[file i04571](#)

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### Question 25

Suppose you wished the LAS in an H1 Fieldbus segment to skip addresses 55 through 233, inclusive. Determine the necessary FUN and NUN values to make this happen, and also determine whether or not there might be any unintended consequences of setting FUN and NUN values in a segment.

#### Suggestions for Socratic discussion

- Explain why FUN and NUN values even exist in Fieldbus systems. What possible use or benefit are they to the operation of the system?
- Show how it is possible to develop a solution method for this type of problem by *simplifying the original problem*. Instead of skipping addresses 55 through 233, what address range could you imagine skipping which would make the FUN and NUN values so simple as to be obvious? How then will this simpler example help you in calculating FUN and NUN values for *any* given address range?

[file i04572](#)

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Question 26

On the job, an instrument technician is in the process of troubleshooting a problem in a newly commissioned and operating H1 Fieldbus segment. Deciding to check for the presence of termination resistors in the segment (in case one or both of them has been forgotten), he connects his ohmmeter across the “Fieldbus” terminals of the nearest transmitter connected on that segment and expects to measure 100 ohms.

Identify what is wrong with this technician’s diagnostic strategy.

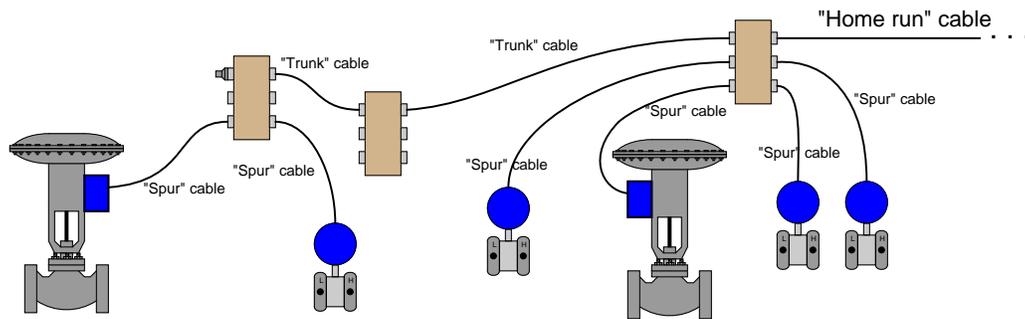
**Suggestions for Socratic discussion**

- If an ohmmeter is not the correct tool to check terminator resistance, what is?
- Suppose an H1 segment was lacking a terminator resistor at its far end. Describe how this lack of a terminator could cause network communication problems in that segment, referencing CD and PT messages in your explanation.

[file i04573](#)

## Question 27

FOUNDATION Fieldbus H1 cable is comprised of two ungrounded conductors surrounded by a grounded shield. Coupling devices provide easy connection points for new devices on the network segment:



Suppose the H1 segment shown above is newly-constructed, and you are asked to perform some basic tests on the cable to ensure there are no major problems before it is energized for the first time. Describe a simple way for you to electrically test the whole length of the segment “trunk” for open or short faults in as few steps as possible.

### Suggestions for Socratic discussion

- Suppose a design engineer from a test and measurement company approached you to learn more about FOUNDATION Fieldbus, in order to design a cable tester specifically for testing H1 segments. What tests should such a tester automatically perform, and how exactly would it do so?
- Suppose all the cabling in the segment shown above is Type C cable according to the Fieldbus standard. How much length will be allowed in this network, and where is that length measured?
- Explain what a *Megger* (a type of electrical test instrument) is, and how such a device could be properly used to test a Fieldbus H1 segment cable. Also identify how improper use of a “Megger” could actually harm the Fieldbus devices.

[file i04574](#)

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### Question 28

In digital communication networks using a *token passing* arbitration model, each device on the network is given its own time to transmit by means of a special message called a “token.” After each device is finished transmitting, it gives up its token to the next device on the token list. This way, different nodes on the network never “collide” as they do in Ethernet because only one has permission to transmit at any given time.

The FOUNDATION Fieldbus H1 standard also uses the concept of tokens for managing communication between devices. However, the tokens in Fieldbus are never passed along from device to device as is standard in token-passing networks. Describe how tokens *are* used in the H1 protocol.

#### Suggestions for Socratic discussion

- Explain why the absence of “collisions” is an important feature of FOUNDATION Fieldbus H1 networks, especially as they relate to mission-critical process control systems.
- Explain how collisions are avoided in a master-slave network such as Modbus over RS-485.
- Explain how collisions are avoided in a TDMA network such as GSM (used for cell phones) and *WirelessHART*.
- Explain how collisions are managed in a CSMA/CD network such as Ethernet.
- Explain how collisions are managed in a CSMA/BA network such as DeviceNet.
- Explain how collisions are managed in a CSMA/CA network such as Wi-Fi.
- Explain why the CSMA/CA arbitration protocol used in Wi-Fi networks would be totally inappropriate for Fieldbus.

[file i02438](#)

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### Question 29

In FOUNDATION Fieldbus H1, there are three distinct classes of bus communication (Virtual Communication Relationships, or *VCRs*):

- Publisher / Subscriber
- Client / Server
- Source / Sink (also called Report Distribution)

Explain how each of these works, and identify the types of data exchanged by each in a Fieldbus network.

[file i02439](#)

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### Question 30

Explain why every H1 FOUNDATION Fieldbus network segment should have at least a primary *and* a “backup” LAS device. On a related note, is *every* type of FOUNDATION Fieldbus device capable of being configured as an LAS?

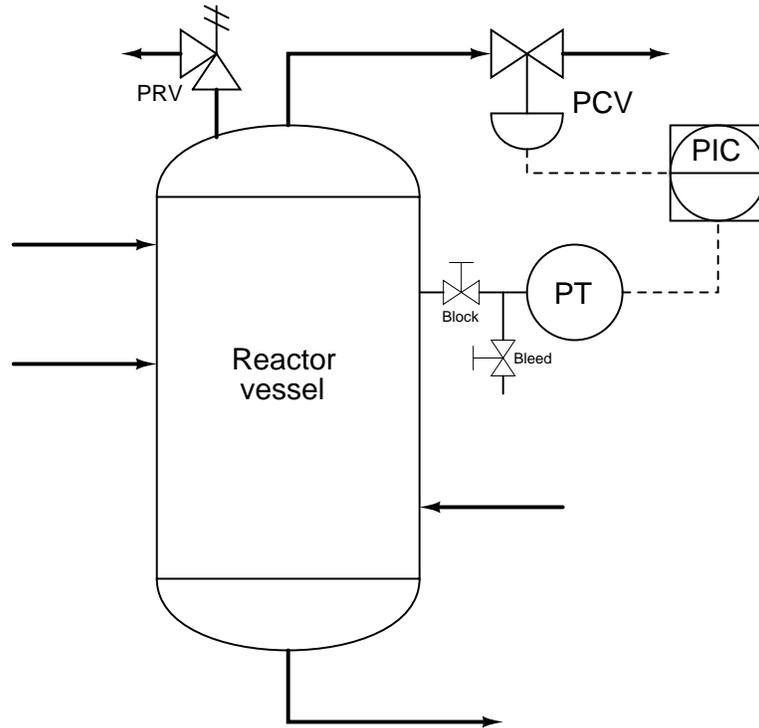
#### Suggestions for Socratic discussion

- If a device is configured to be a backup LAS, what communication events does it ordinarily participate in that non-backup devices do not participate in?

[file i02436](#)

Question 31

The amount of pressure inside this high-pressure chemical reactor vessel is controlled by a pressure control valve (PCV) at top, and is measured by a “DP” style of pressure transmitter connected to the reactor through a “block-and-bleed” valve manifold:



Suppose an instrument technician is told to remove the pressure transmitter from service in order to check its calibration. Explain what will happen (and why!) if a technician happens to close the transmitter's block valve and open the bleed valve while the pressure controller (PIC) is in automatic mode.

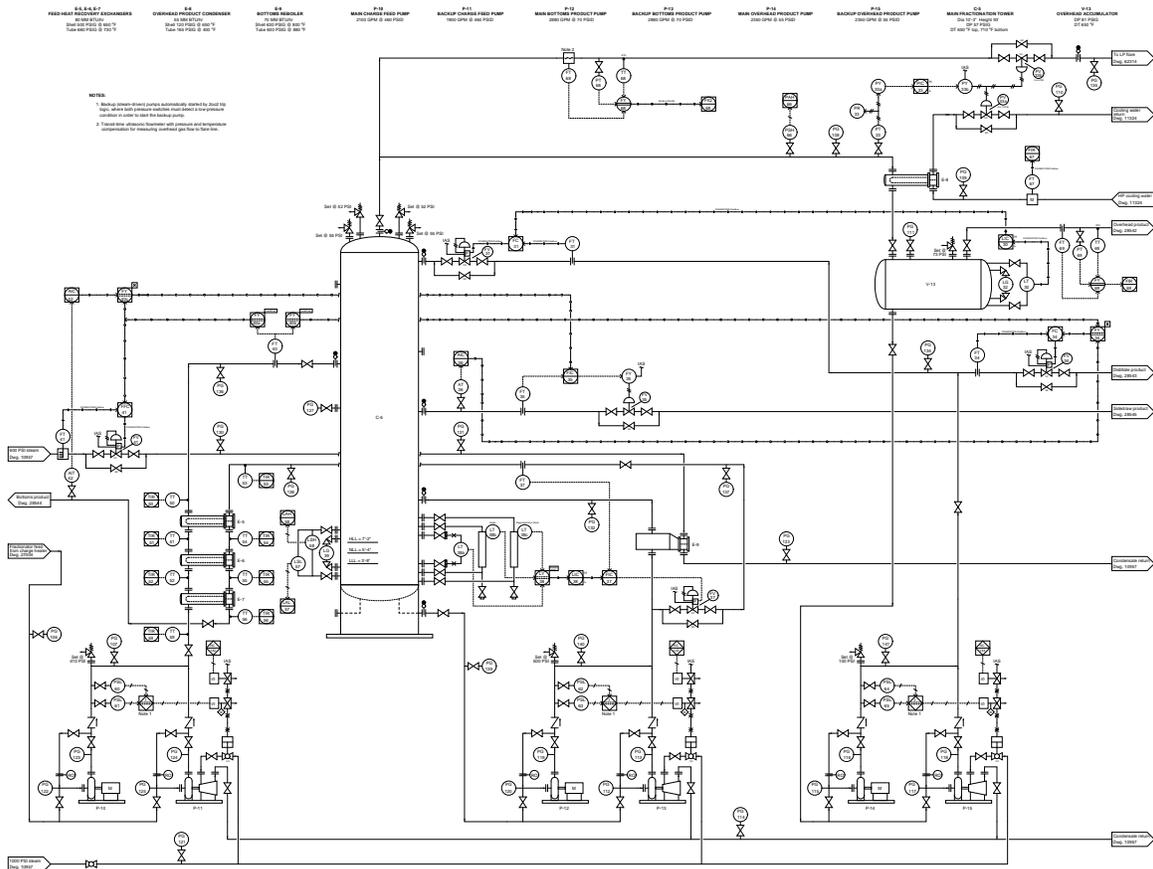
**Suggestions for Socratic discussion**

- Describe a better way of removing the transmitter from service!
- If this pressure control loop were implemented on FOUNDATION Fieldbus, would it be best to have a minimum number of devices on the H1 segment? Why or why not?

[file i04576](#)

Question 32

Examine the overhead product pressure control loop (#33) in this distillation system (in the upper-right corner of the P&ID). Suppose PR-33 shows a pressure of 48.1 PSI, while PIC-33 shows a pressure of 50.0 PSI (equal to setpoint):



Identify which faults could account for the pressure indication discrepancy:

Fault	Possible	Impossible
PR-33 calibration error		
PT-33 calibration error		
PIC-33 (input) calibration error		
PY-33a calibration error		
PY-33b calibration error		
PV-33a calibration error		
PV-33b calibration error		

file i03514

Question 33

Question 34

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Question 35

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Question 36

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Question 37

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Question 38

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Question 39

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Question 40

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Question 41

Read and outline the “FF Function Blocks” section of the “FOUNDATION Fieldbus Instrumentation” chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

- (1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A “Table of Contents” format works well for this.
- (2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author’s problem-solving strategies, etc.).
- (3) General principles, especially physical laws, referenced in the text.
- (4) Questions of your own you would pose to another reader, to challenge their understanding.
- (5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
- (6) Any points of confusion, and precisely why you found the text confusing.

file i04560

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## Question 42

Read selected portions of the *Foundation Fieldbus Blocks* document published by Rosemount (document 00809-0100-4783, revision BA) and answer the following questions:

The Analog Input (AI) function block has two outputs. Identify what each one does, and what internal functions of the AI block drive each one.

Identify the purposes of the following parameters which must be configured for each Fieldbus Analog Input (AI) function block: **Channel**, **L\_Type**, **XD\_Scale**, and **OUT\_Scale**.

Nearly every FF function block supports a *Manual* mode (not just the PID control block!). Explain what this mode does, and why someone might wish to make use of it.

Both the AI and the PID blocks provide a feature called *filtering*. Explain what this feature is and why it might be useful in a real process control application.

### Suggestions for Socratic discussion

- Explain how the ability to put *any* and *every* Fieldbus function block into “manual” mode might not only be confusing to someone on the job, but potentially dangerous as well.
- Suppose you were commissioning a multivariable Fieldbus instrument on a system, where more than one of those variables would be used in the control scheme (i.e. FF function blocks would depend on inputs from more than one variable coming from this particular transmitter). How could you set up this control strategy, given that the AI function block seems to handle only one channel of data?
- A common source of confusion regarding the **L\_Type** AI block parameter are the settings *Direct* versus *Indirect*. These are often wrongly interpreted as synonymous with “direct” and “reverse” action. Identify the true meanings of the “Direct” and “Indirect” settings for the **L\_Type** parameter, and explain how these meanings are completely different than direct/reverse action.
- Suppose an engineer programming a DCS to utilize data from a Fieldbus instrument connects a line between the AI block’s **OUT\_D** terminal and some other function block residing in another device that will take action on that data. Will this data be communicated over the network segment using a *Publisher/Subscriber*, *Client/Server*, or *Source/Sink* VCR?

file i04577

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Question 43

Search through the reference manual for the Rosemount model 848T Fieldbus temperature transmitter (document 00809-0100-4697, revision CB) and answer the following questions:

Describe the two different types of analog input function blocks offered in this transmitter, and their respective purposes.

Describe the purpose of the other function block offered in this Fieldbus transmitter, identifying some practical applications for it in real control systems.

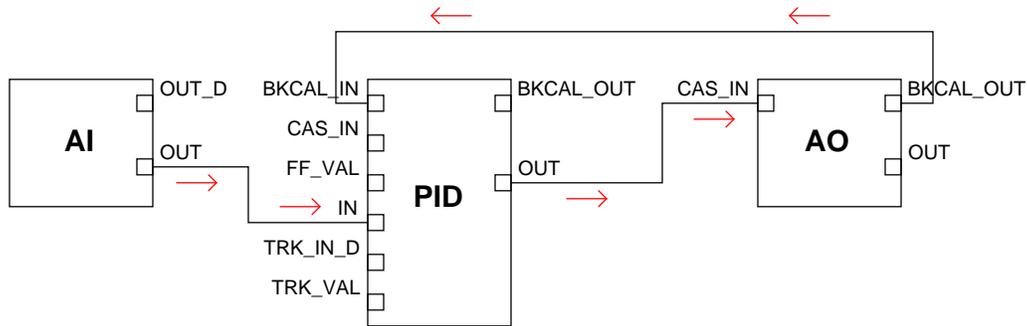
Is this transmitter model a Link Master device (i.e. does it have the capability of being the LAS for a network segment)? Note that you will have to look outside Appendix D to answer this question!

Locate the section of the manual describing how to configure individual Analog Input function blocks (entitled “Monitoring Temperature Points Individually”), and identify the specific parameters it recommends you to configure in each of those Analog Input blocks. Also, explain why the procedure directs you to set the `MODE_BLK.TARGET` parameter both before and after making changes to the other parameters in the AI block.

file i04578

#### Question 44

Many FOUNDATION Fieldbus function blocks are equipped with “back calculation” inputs and outputs. An example of these I/O channels in use is the following PID controller scheme, where an analog input (AI) function block sends process data to a PID controller block, which then sends its output signal to an analog output (AO) block. Arrows have been added to this function block diagram to show the direction of data flow:



What purpose does such a feedback data path serve? What would be wrong with simply connecting the output of the PID controller function block to the input of the analog out block, with no feedback from the analog out block at all?

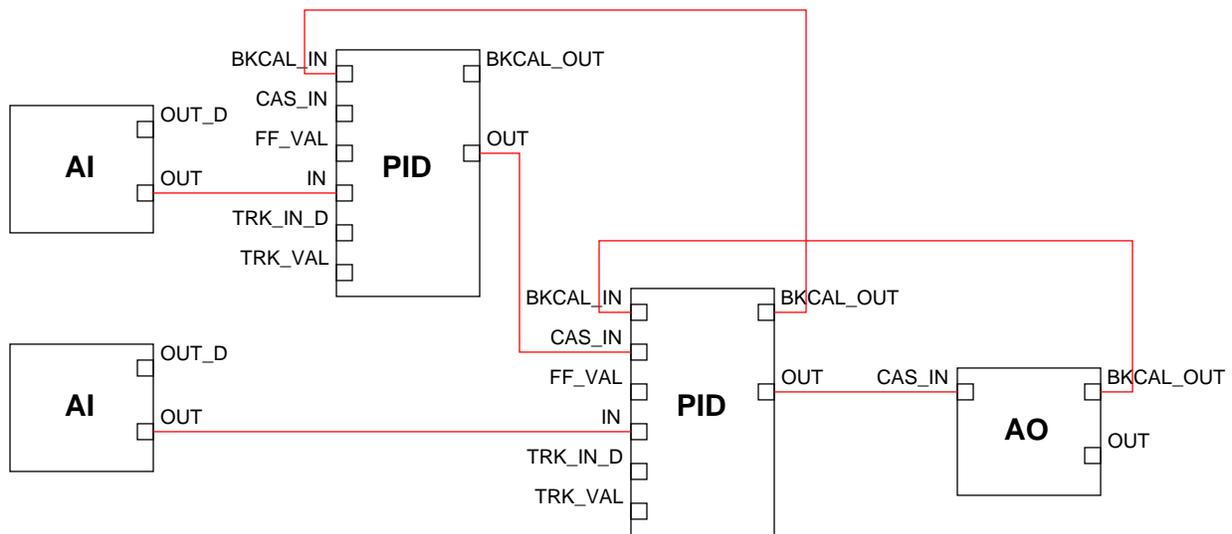
#### Suggestions for Socratic discussion

- Explain what the numerical value of the BKCAL\_OUT signal would mean if the AO function block resided within a FOUNDATION Fieldbus electronic valve positioner.
- Explain what the numerical value of the BKCAL\_OUT signal would mean if the AO function block resided within a FOUNDATION Fieldbus VFD (Variable Frequency motor Drive).
- Would it be possible to build a working control loop with just a PID function block and an AO function block, since there seems to be a feedback loop between these two function blocks?

[file i02425](#)

## Question 45

In Fieldbus function block programming, signals are linked from one function to another by lines drawn between the respective inputs and outputs. An example of this is the following *cascade* PID control strategy, where the output of one PID controller (the “master”) determines the setpoint for another PID controller (the “slave”). Lines drawn between the function blocks show which outputs connect to which inputs:



An important concept to grasp in Fieldbus function block programming is that these connections not only carry signal values, but signal *statuses* as well. That is, each signal in a function block programming environment carries with it a status code to indicate how valid that signal is.

Identify the three status conditions for signals in a FOUNDATION Fieldbus system, and also explain what the term *status propagation* means with reference to function block programming.

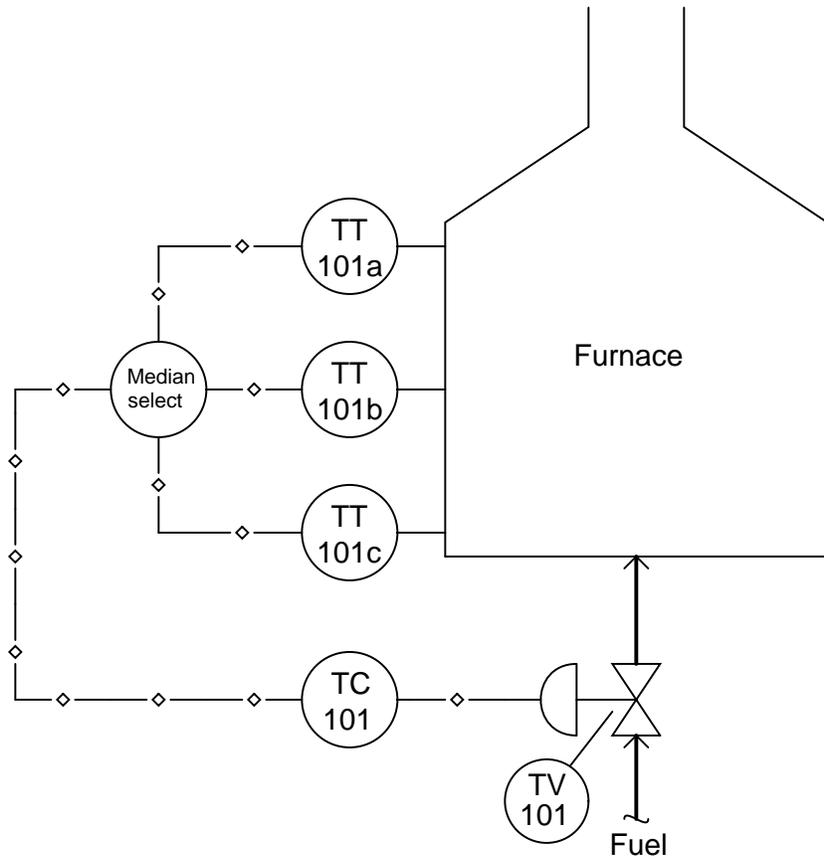
### Suggestions for Socratic discussion

- A useful analytical technique for any complex control system is to annotate the diagram with arrowheads showing the directions of all data pathways between devices or functions. Show how this helps you analyze the control strategy diagram shown in this question.
- For those who have studied *cascade control* strategies, identify which of the PID function blocks is the master and which is the slave in this FF function block program.
- What status value does the output of a block placed into “manual” mode carry?
- What status value does the output of a block placed into “out of service” mode carry?
- Suppose the valve positioner executing the AO function block experiences a problem, causing its BKCAL\_OUT signal to switch to a “Bad” status value. How will this status change affect the operation of this function block program?
- Suppose the slave PID function block is switched into Manual mode. How will this mode change affect the operation of this function block program?

[file i02443](#)

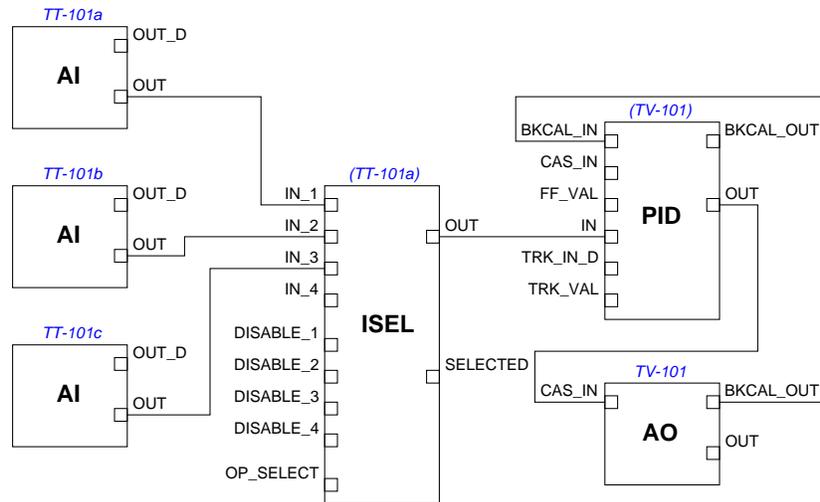
Question 46

Suppose we wished to implement a temperature controller with triple-redundant transmitters using FOUNDATION Fieldbus. A general P&ID of the control scheme is shown here:

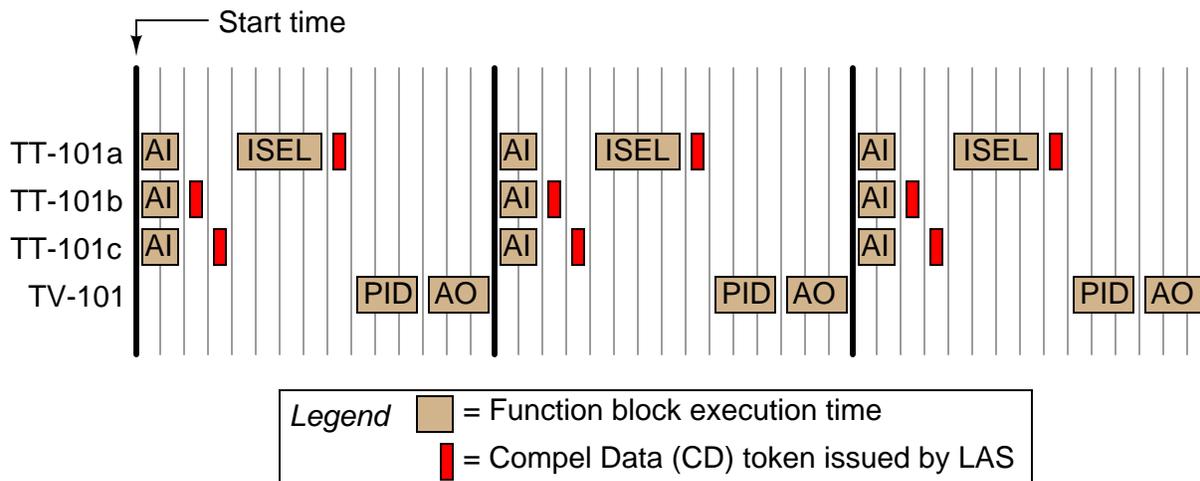


The “median select” relay selects the temperature transmitter’s signal that lies *between* the other two. This way, neither a high-signal failure nor a low-signal failure in any one temperature transmitter will cause the temperature controller to take false action. Any single transmitter failure will merely cause a maintenance alarm, and the control system will continue to act as it should.

There is more than one way to divide these functions among the various field instruments. This Fieldbus function block diagram shows one way (note the italicized instrument tag names above each block):



With these function block assignments, the sequence of function block execution and Fieldbus data communication will look something like what is shown in this timing diagram:



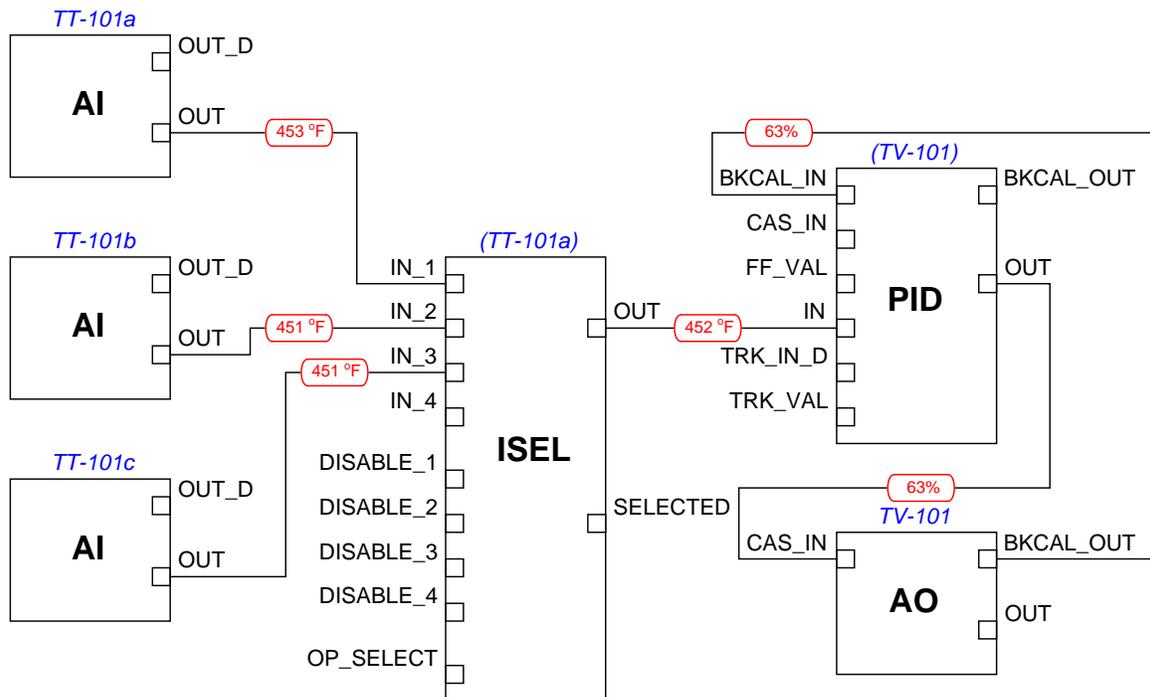
Answer the following questions about this timing sequence:

- Identify the length of a *macrocycle* in the timing diagram.
- Identify the purpose of each Compel Data (CD) token transmitted by the LAS.
- Explain why there is no CD token transmitted by the LAS between the PID and AO function block execution times.
- During what periods of time are unscheduled (acyclic) communications allowed to take place?
- Do you see any way to reallocate any function blocks to different field devices to gain more reliability for the control system?

file i02445

## Question 47

Examine this “live” display of a FOUNDATION Fieldbus control strategy where multiple temperature transmitters are used to redundantly measure the same physical point in a chemical reactor:



Based on the signal values shown in this “live” display of the function block diagram, identify the selection type parameter value (SEL\_TYPE) set in the ISEL function block.

Also, explain how such a “live” display of a control system’s function block diagram could be useful as a diagnostic tool, if you were tasked with troubleshooting a malfunctioning process control loop.

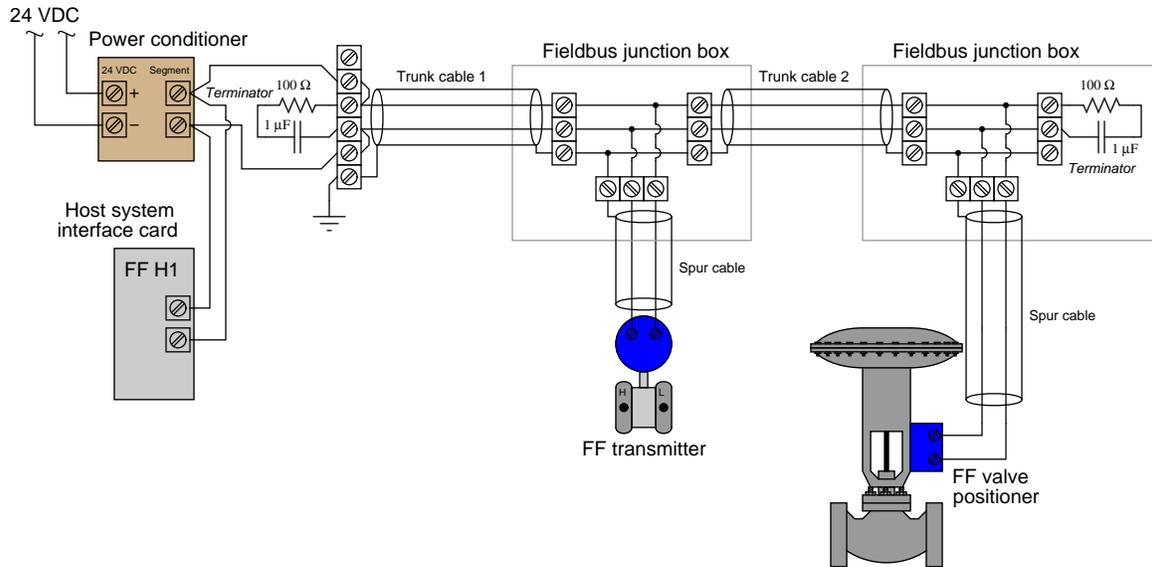
### Suggestions for Socratic discussion

- Identify the value output by the ISEL block if its SEL\_TYPE parameter were set differently.
- How would a faulted temperature sensor be revealed in this “live” function block diagram display?
- How would a faulted final control element be revealed in this “live” function block diagram display?
- How would a PID function block left in manual mode be revealed in this “live” function block diagram display?
- Identify the effect(s) of placing the lower AI function block in “OOS” mode.
- Identify the effect(s) of placing the ISEL function block in “OOS” mode.
- Identify the effect(s) of placing the AO function block in “OOS” mode.
- Identify the effect(s) of placing the upper AI function block in “manual” mode.
- Identify the effect(s) of placing the ISEL function block in “manual” mode.
- Identify the effect(s) of placing the AO function block in “manual” mode.

[file i02550](#)

Question 48

A newly-constructed H1 Fieldbus segment seems to have a problem. The host system (an Emerson DeltaV DCS) recognizes the control valve positioner, but fails to recognize the pressure transmitter when it is connected to the segment. The pressure transmitter does not even come up on the Emerson system as a “decommissioned” device – there simply isn’t any acknowledgment from the DCS at all that another device exists on the segment. A diagram of the system appears here:



The first step you take in diagnosing this problem is to measure DC voltage with your voltmeter at the terminals of the valve positioner. There, you measure a steady 21.7 volts DC.

Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
Trunk cable 1 failed open		
FF transmitter failed open		
Transmitter spur cable failed open		
Positioner spur cable failed open		
Trunk cable 1 failed shorted		
FF transmitter failed shorted		
Transmitter spur cable failed shorted		
Positioner spur cable failed shorted		
24 VDC source dead		

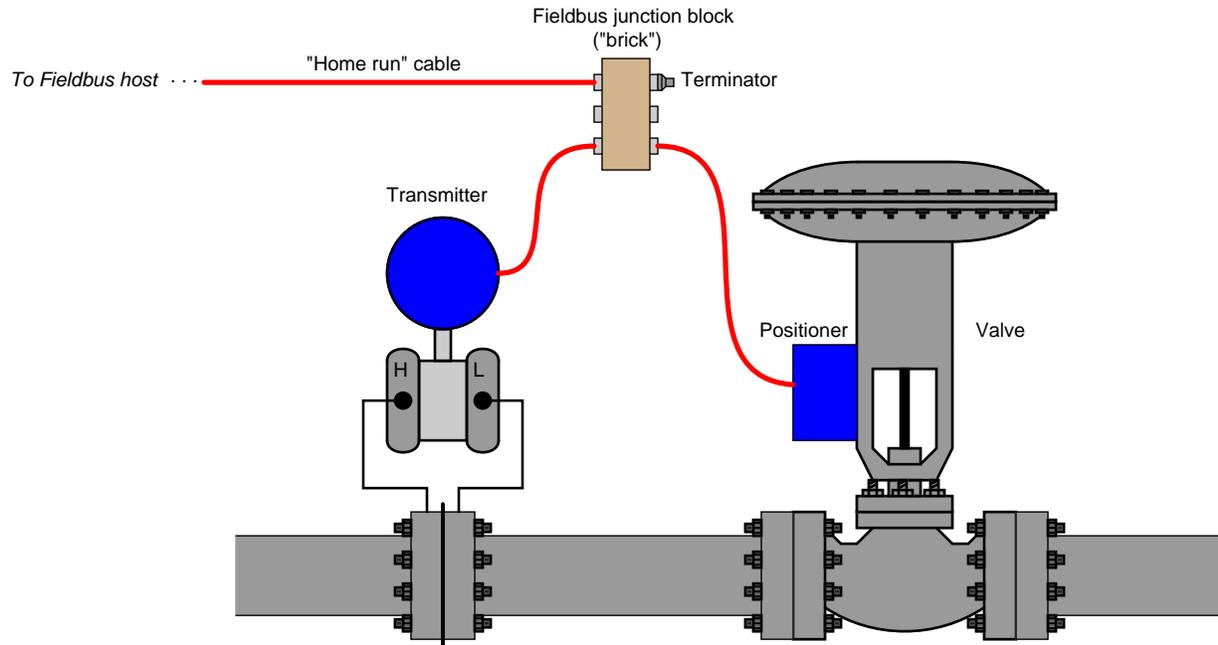
Also, identify one fault not included on this list that is capable of independently accounting for all measurements and symptoms.

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

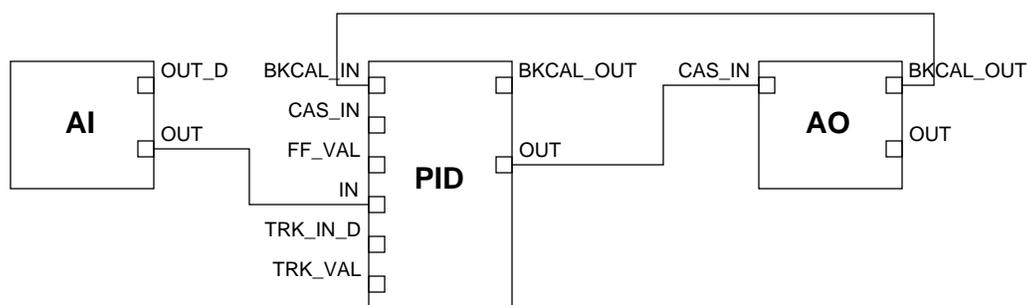
[file i04589](#)

Question 49

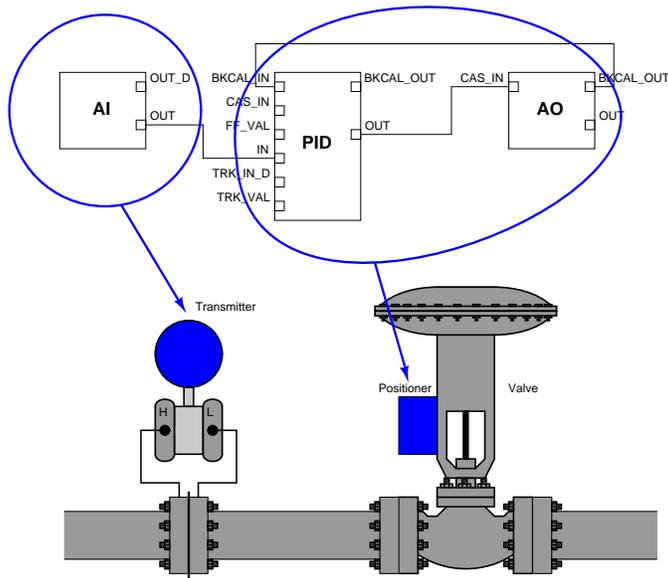
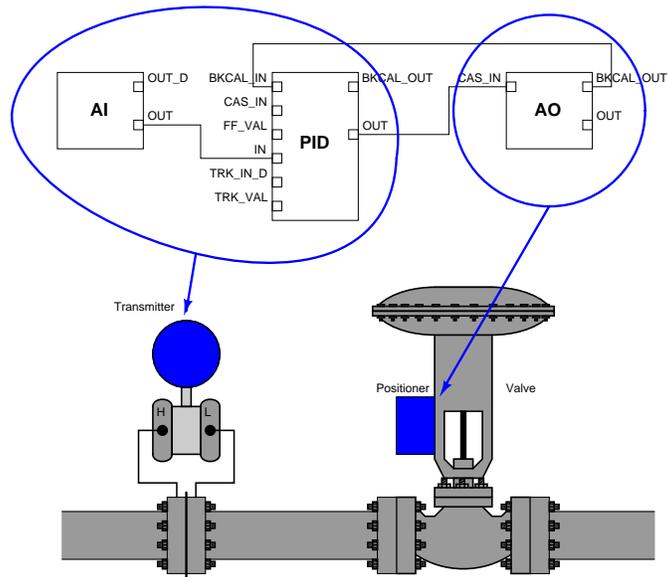
Suppose we wished to build a liquid flow control loop using FOUNDATION Fieldbus H1 devices. Of course, we will need a flow transmitter to measure liquid flow, and a flow control valve to throttle the liquid, but we will not need a separate controller device because all Fieldbus transmitters and valve positioners have the capacity to implement control algorithms themselves. The physical layout of our flow control system might look like this:



The control algorithm, consisting of function blocks interconnected to perform all the necessary data conversion and processing tasks, will look like this:



Does it matter whether the PID function block resides within the Fieldbus transmitter or within the Fieldbus valve positioner? Either configuration is possible, but are they equally practical? Why or why not? Both options are shown in the following illustrations:



[file i02442](#)

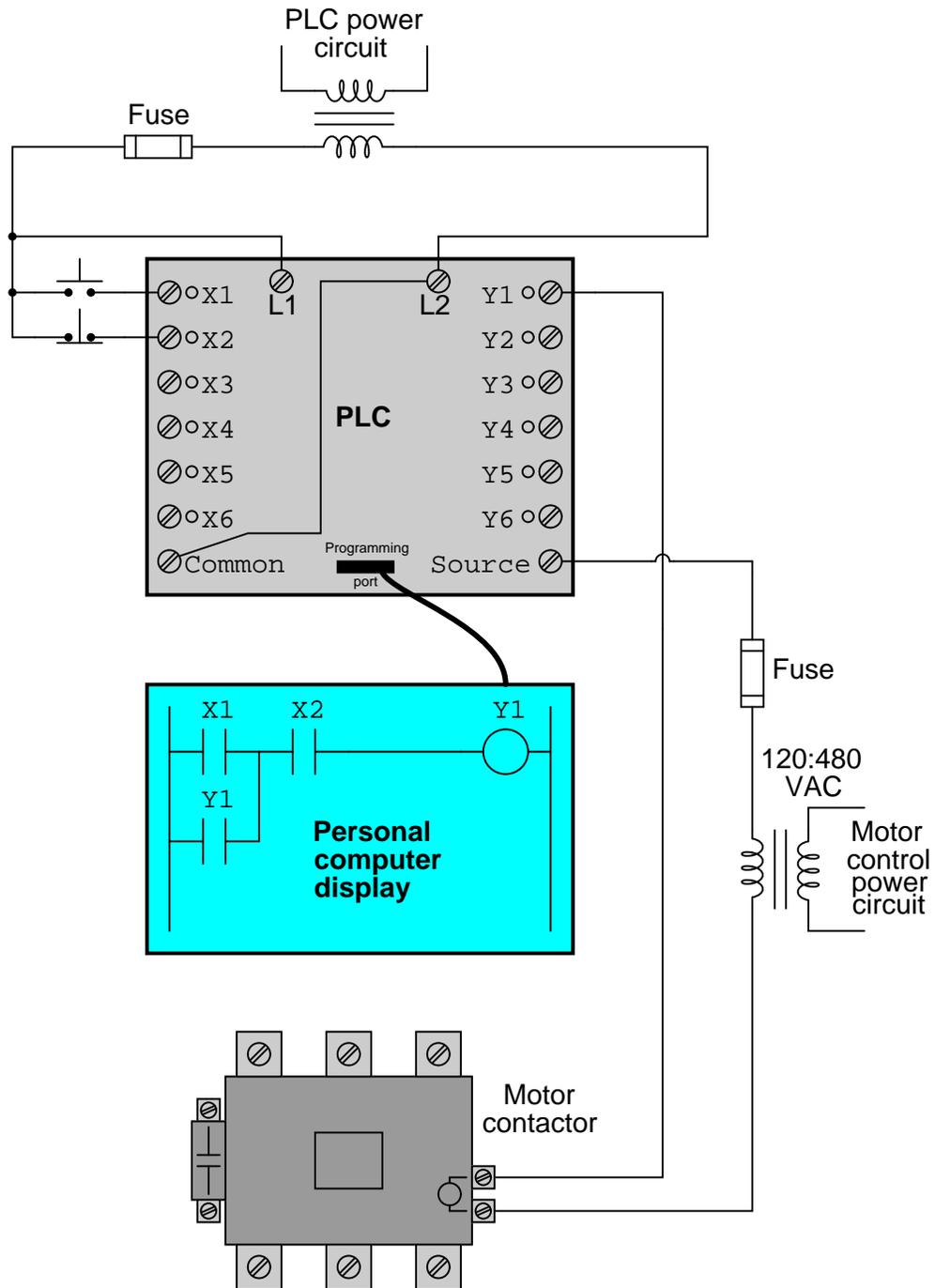
Question 50

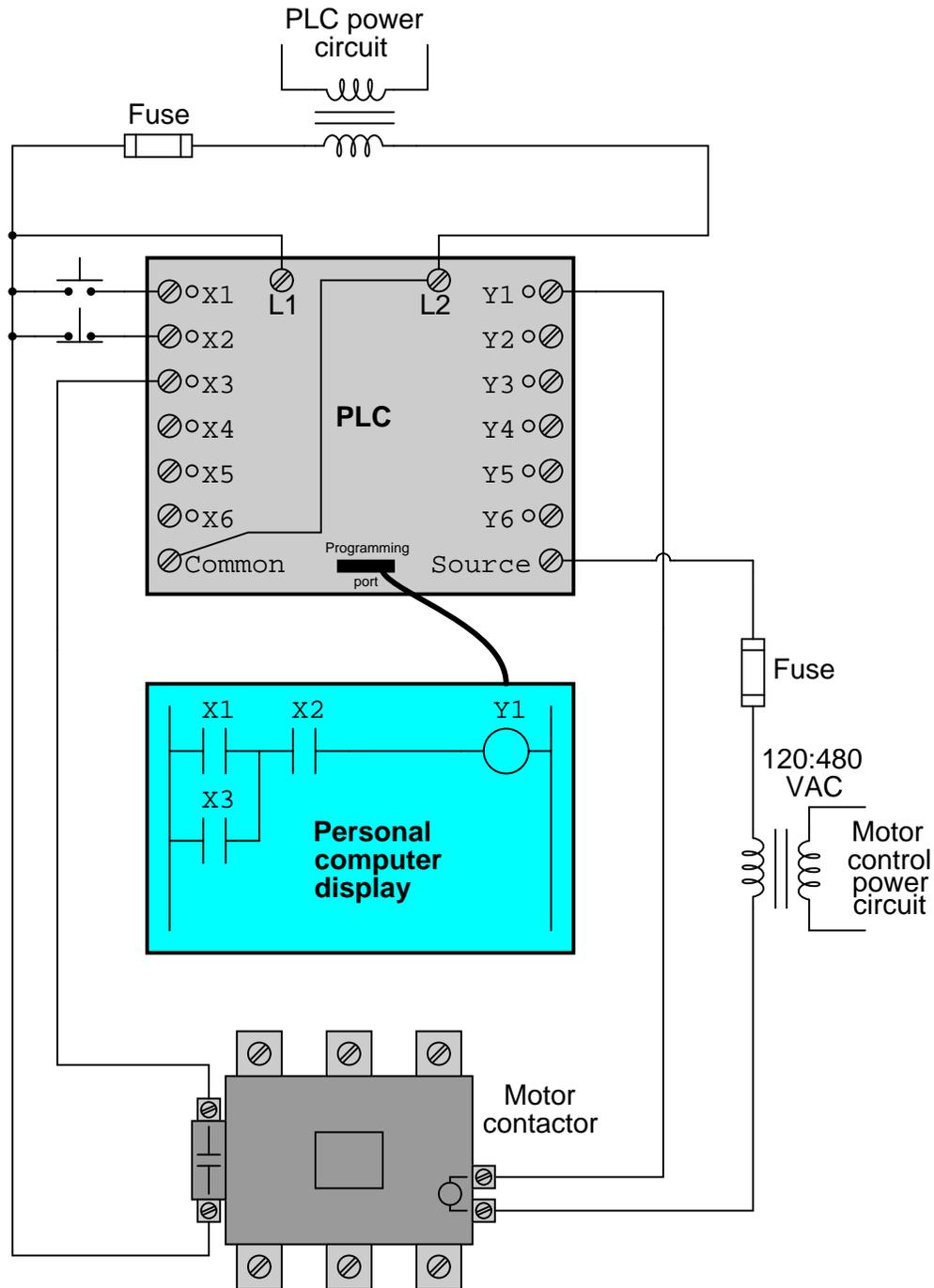
In addition to supporting a wide array of general-purpose function blocks for control programming, each FOUNDATION Fieldbus device also contains other blocks specific to that device: one *Resource Block* and one *Transducer Block*. What purposes do these other blocks serve, and how do they differ from general function blocks such as AO, AI, PID, etc.?

[file i02444](#)

Question 51

Examine these two different PLC-based motor control programs and wiring diagrams:



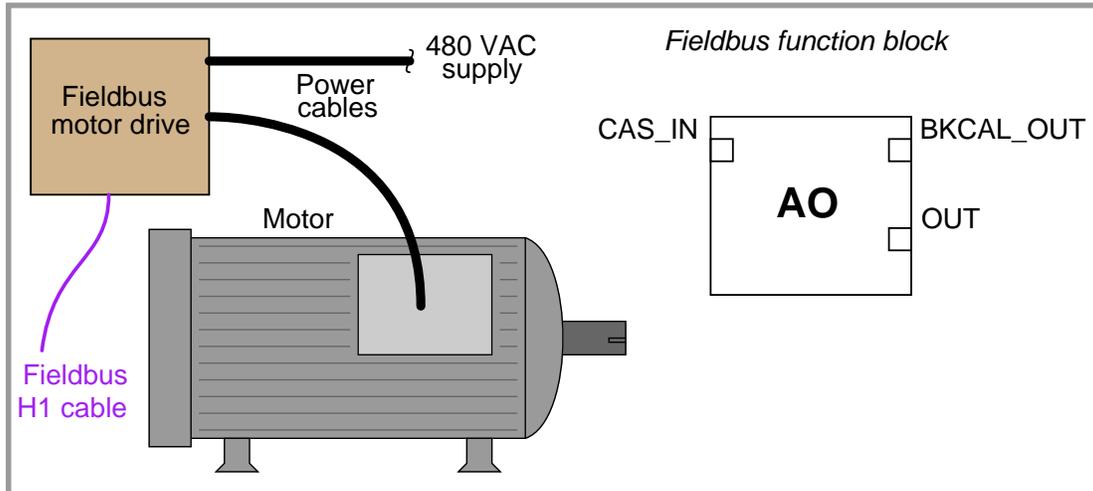
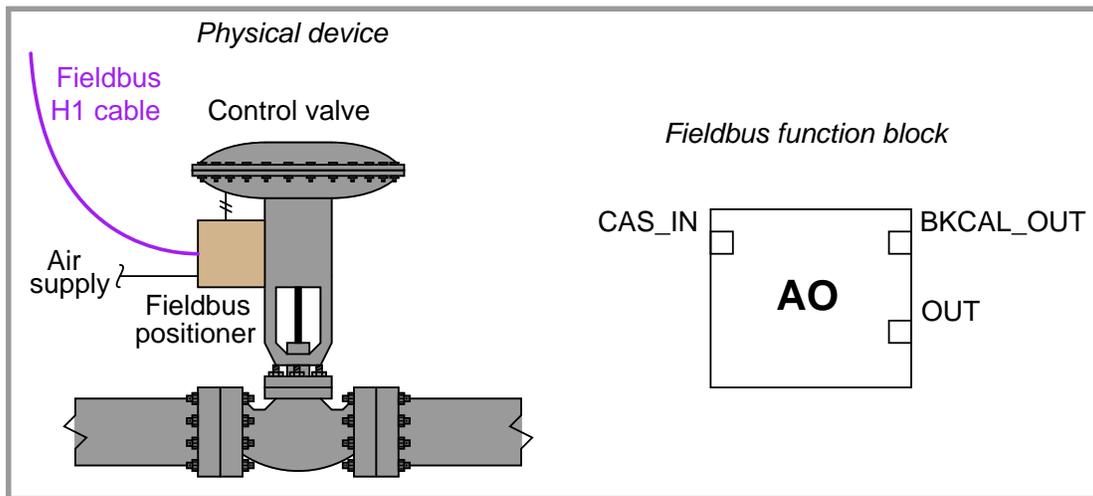


Under normal operating conditions, these two motor control systems will perform identically. However, they will act differently under abnormal conditions. Identify one such “abnormal” condition that will cause these two systems to act differently, and explain what that difference is.

file i02424

Question 52

For each of these FOUNDATION Fieldbus final control elements (valve positioner and variable-frequency motor drive), explain what the BKCAL\_OUT signal from the respective AO function blocks represent:



Furthermore, identify how a FOUNDATION Fieldbus AO function block responds differently in *Cascade*, *Auto*, and *Manual* modes.

**Suggestions for Socratic discussion**

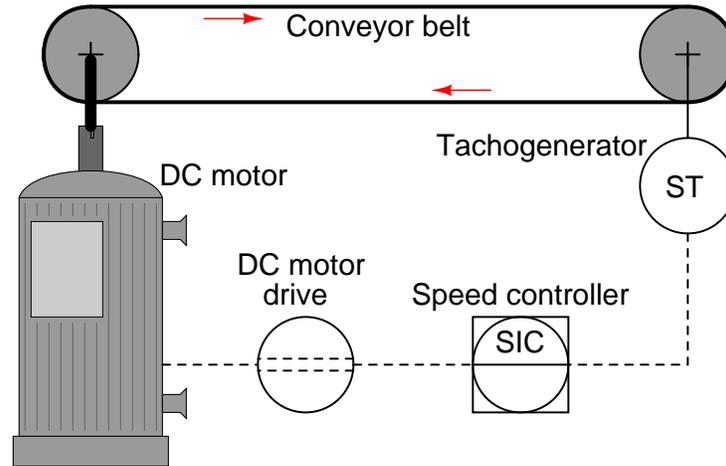
- In each example, identify a circumstance which could cause the “back calculation” signal value to not equal the input signal value.
- FOUNDATION Fieldbus AO function blocks support the ability to limit the rate-of-change of an AO block’s “setpoint” value. Explain how this feature might be useful in either of these (valve, motor) control applications.

[file i04579](#)

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Question 53

The speed of a conveyor belt is controlled by a PID loop, where conveyor speed is sensed by a tachogenerator, and power is throttled to a DC motor to drive the conveyor. A “tachogenerator” is nothing more than a small DC generator, whose output voltage is directly proportional to the rotational speed of its shaft:



Explain what will happen (and why!) if a technician happens to disconnect the wires leading to the tachogenerator’s screw terminals while the conveyor is running and the speed controller is in automatic mode.

Next, explain a safer way for the technician to remove the tachogenerator wires while keeping the conveyor running.

**Suggestions for Socratic discussion**

- For those who have studied PID control and process characteristics, do you think this conveyor belt process will be naturally *self-regulating*, *integrating*, or *runaway*? How do you think the speed controller’s PID parameters should be tuned?

[file i04580](#)

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Question 54

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Question 55

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Question 56

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Question 57

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Question 58

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Question 59

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Question 60

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Question 61

Read and outline the “H1 FF Device Configuration and Commissioning” section of the “FOUNDATION Fieldbus Instrumentation” chapter in your *Lessons In Industrial Instrumentation* textbook.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

- (1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A “Table of Contents” format works well for this.
- (2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author’s problem-solving strategies, etc.).
- (3) General principles, especially physical laws, referenced in the text.
- (4) Questions of your own you would pose to another reader, to challenge their understanding.
- (5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
- (6) Any points of confusion, and precisely why you found the text confusing.

[file i04568](#)

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## Question 62

Visit the FOUNDATION Fieldbus website (<http://www.fieldbus.org>) and download a configuration file set for any FF device you choose. I recommend a transmitter or a control valve positioner, but the choice is really yours. The file comes as a single archive (compressed `.zip` format), which when unpacked gives you these three files:

- *Device Description file in binary format* (`.ffo` extension)
- *Device Description file in ASCII format* (`.sym` extension)
- *Capability file in ASCII format* (`.cff` extension)

Use a text editor such as Notepad (on Windows operating systems) to view both ASCII-format files, perusing both files to identify what types of information both of them contain:

The `.sym` DD file contains:

The `.cff` Capability file contains:

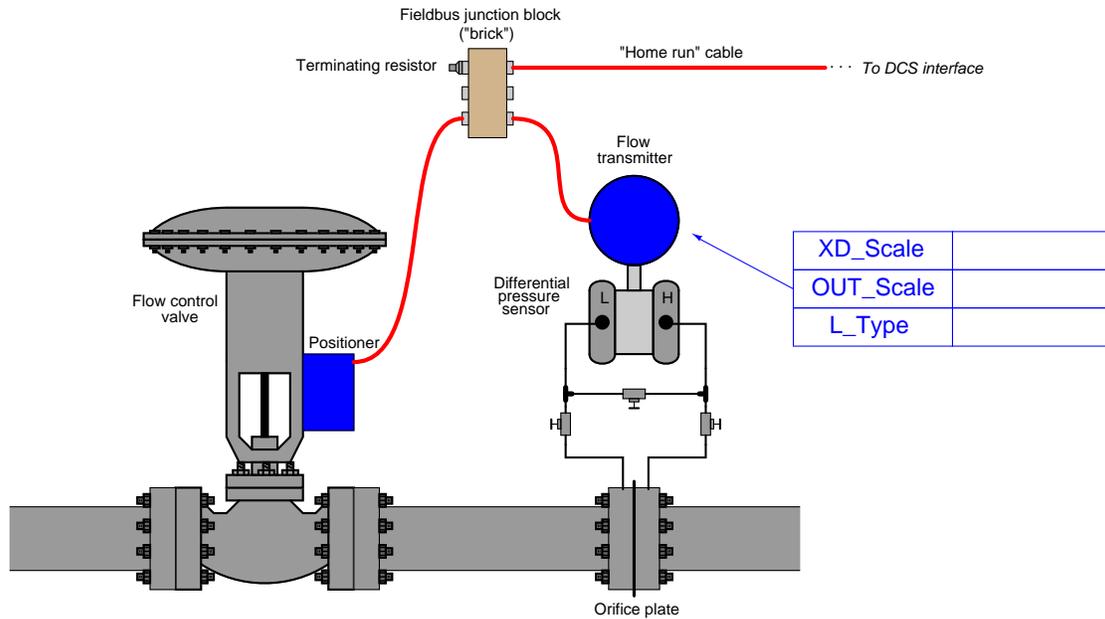
### **Suggestions for Socratic discussion**

- Is there any data within these ASCII-readable files that you find familiar, based on your experience working with Fieldbus instruments, or studying their function blocks?
- Explain why you will not be able to find a *Value* `.cff` file available for download on the Fieldbus Foundation website.

[file i04591](#)

Question 63

Suppose a FOUNDATION Fieldbus pressure transmitter is used to measure flow through a process line by sensing differential pressure generated by an orifice plate. The orifice's rated pressure range is 0 to 100 inches water column, while flowing 0 to 740 liters per minute of liquid. The operator needs to see the flow rate in units of LPM, and does not care to see or know the differential pressure directly sensed by the transmitter:



Complete the configuration table in the above illustration, showing the proper XD\_Scale, OUT\_Scale, and L\_Type parameter values to make the transmitter function as it should in this application.

Also, determine the direction of flow through this process line, and the proper settings (open or shut) for the three hand valves between the orifice plate and the transmitter while the system is operating normally.

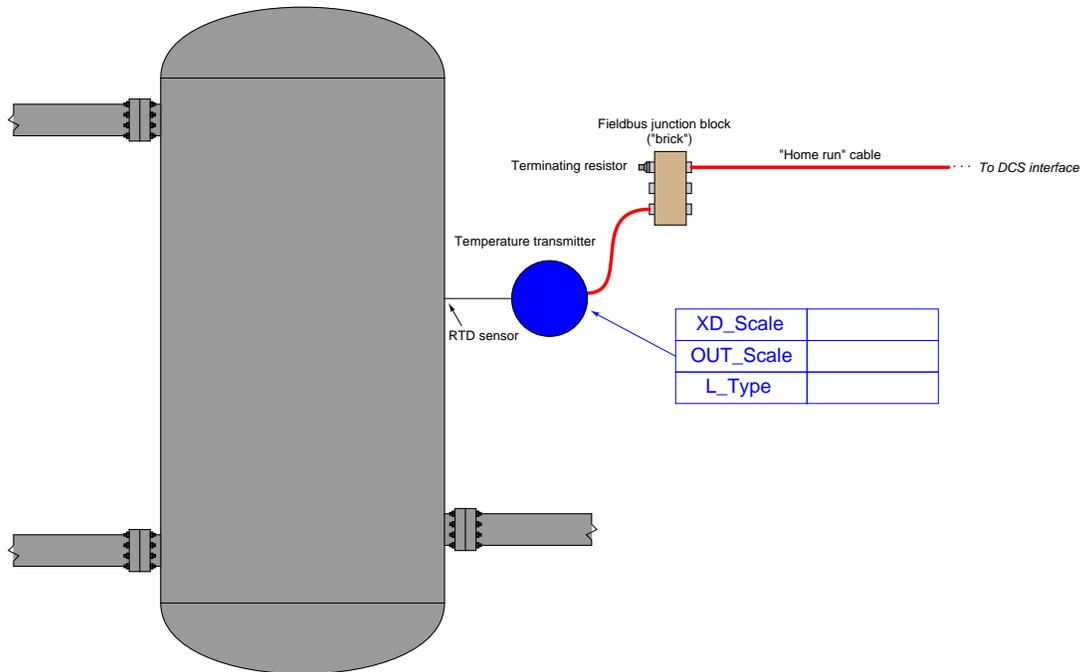
**Suggestions for Socratic discussion**

- For those who have studied flow measurement, explain how an orifice plate works to measure fluid flow.
- Suppose the orifice plate is changed for one having a larger bore diameter (i.e. it generates less pressure differential for the same amount of flow). What, if anything, would have to be re-configured in the FF flow transmitter to accommodate the new orifice plate?

[file i04594](#)

## Question 64

Suppose a FOUNDATION Fieldbus temperature transmitter will be used to measure how close the liquid inside a vessel approaches the boiling point of water (212 degrees Fahrenheit). The transmitter senses temperature using an RTD sensor over an expected range of 40 °F to 200 °F, but we wish the operations personnel to see a temperature display ranging from -172 to -12 (the number of degrees below the boiling point of 212 °F).



Complete the configuration table in the above illustration, showing the proper XD\_Scale, OUT\_Scale, and L\_Type parameter values to make the transmitter function as it should in this application.

### Suggestions for Socratic discussion

- If the XD\_Scale were set to a range of 40 to 212 degrees and the OUT\_Scale set to a range of -172 to 0 degrees, would it work for this application? Explain why or why not.

[file i04719](#)

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Question 65

Suppose a Rosemount model 3095MV FOUNDATION Fieldbus transmitter is executing an analog input (AI) function block with the following parameters:

- Channel = 1
- L\_type = Indirect
- XD\_Scale = 20 to 150 inches H<sub>2</sub>O
- OUT\_Scale = 0 to 375 gallons

Calculate the following AI function block values when this transmitter senses a differential pressure of 109.2 inches H<sub>2</sub>O:

- FIELD\_VAL = \_\_\_\_\_
- PV signal output by AI block = \_\_\_\_\_

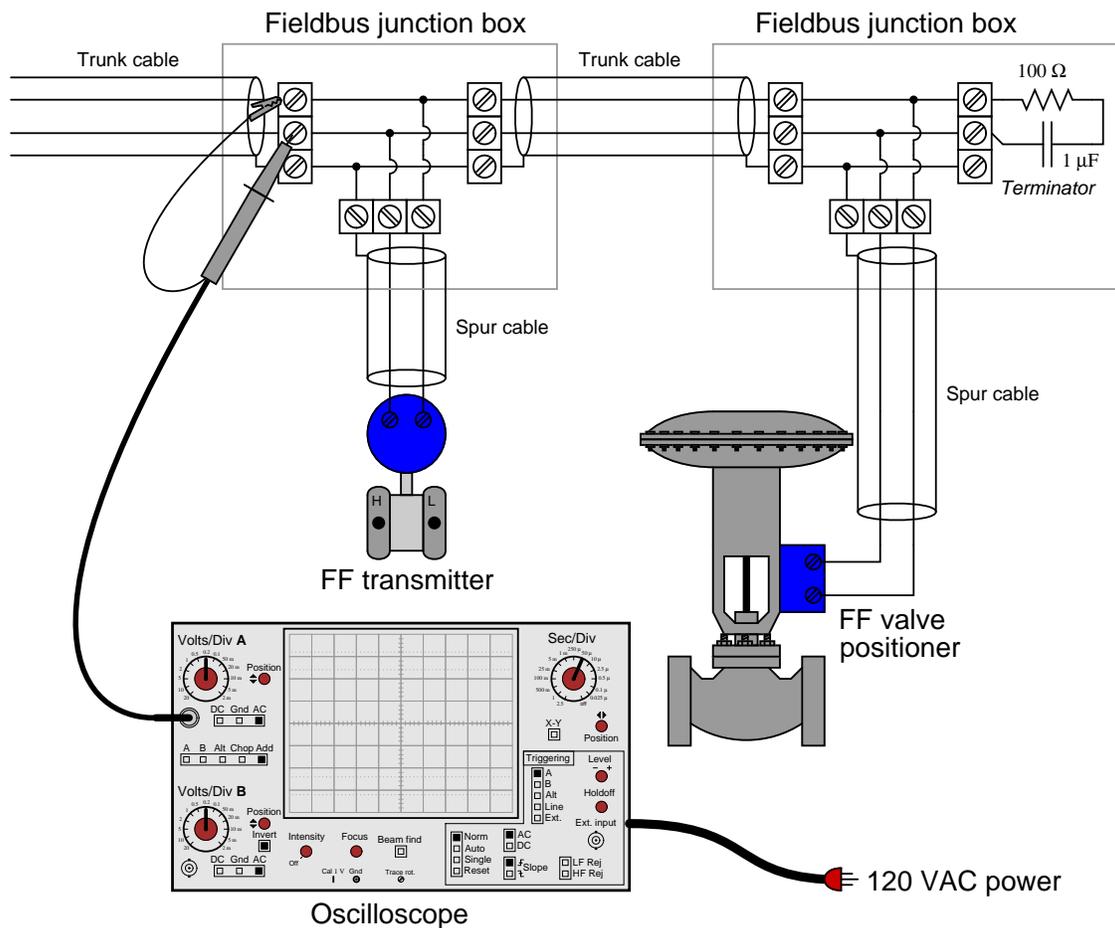
**Suggestions for Socratic discussion**

- What would the new values be if the L\_Type parameter were set to *direct* instead of *indirect*?
- What would the new values be if the L\_Type parameter were set to *indirect square root* instead of *indirect*?
- What would this transmitter be sensing if the Channel parameter had a value of 2 instead of 1?

[file i03645](#)

## Question 66

Suppose an instrument technician connects an oscilloscope to a FOUNDATION Fieldbus segment as shown with the intention of viewing the signal:



Explain what is wrong with this setup, and what problems it might cause in the segment. Correspondingly, how *should* the oscilloscope be connected to the segment cable?

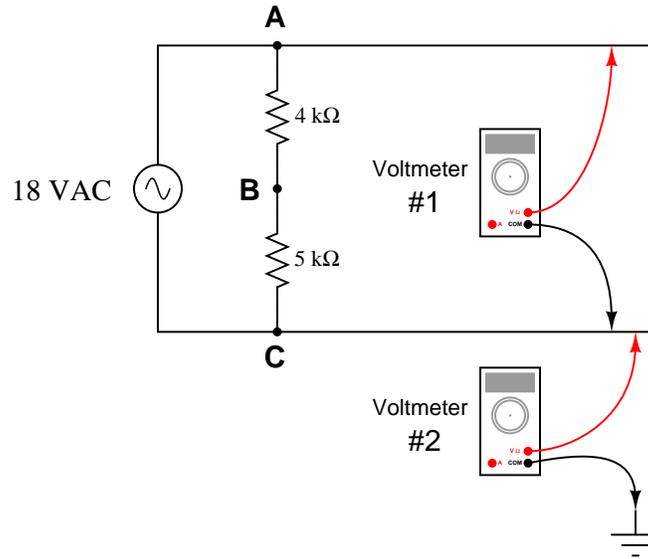
### Suggestions for Socratic discussion

- Explain how this improper use of an oscilloscope could even pose a *safety* hazard to the technician if used on a different kind of circuit (something other than a Fieldbus H1 segment).
- An all-too-common practice to overcome this problem involves powering the oscilloscope through an *isolation transformer* so that its AC supply is ungrounded. Explain how this solution overcomes the measurement problem seen in the diagram, and also explain why this practice can be unsafe.

[file i00890](#)

Question 67

Determine what these two voltmeters will register with the circuit grounded at three different points (each grounding scenario considered one at a time, not simultaneously). Note that neither voltmeter moves, nor are any of their test leads moved, between scenarios. The only difference is where we connect earth ground to the circuit:



Grounded at:	VM #1	VM #2
Point A only		
Point B only		
Point C only		

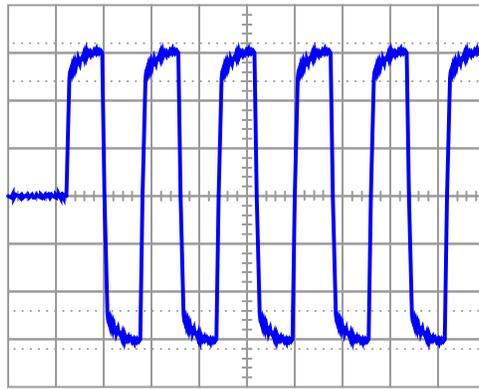
**Suggestions for Socratic discussion**

- FOUNDATION Fieldbus H1 networks are floating (neither conductor grounded). Given this fact, explain how voltmeter measurements might be useful in determining the existence of a grounded H1 segment conductor.
- What would happen if points A and B were simultaneously grounded? How about points B and C? How about points A and C?

[file i03649](#)

Question 68

A healthy FOUNDATION Fieldbus signal should look something like this when captured on the display of an oscilloscope:

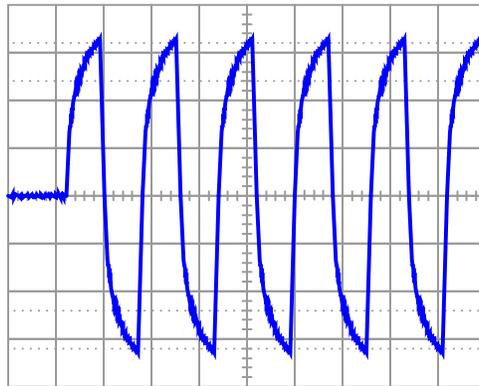


100 mV/div

40  $\mu$ s/div

Examine the following waveforms displayed by an oscilloscope showing FOUNDATION Fieldbus signals, and determine what fault(s) might cause each one. Be sure to explain the rationale behind each diagnosis!

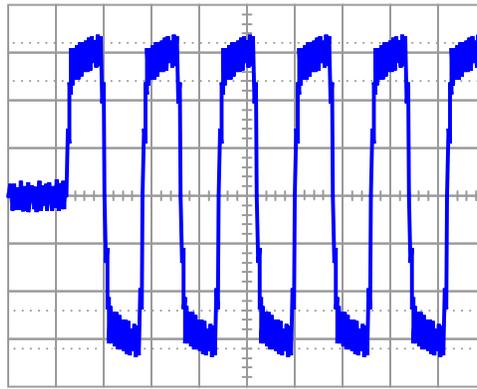
**Example #1:**



200 mV/div

40  $\mu$ s/div

### Example #2:



100 mV/div

40 μs/div

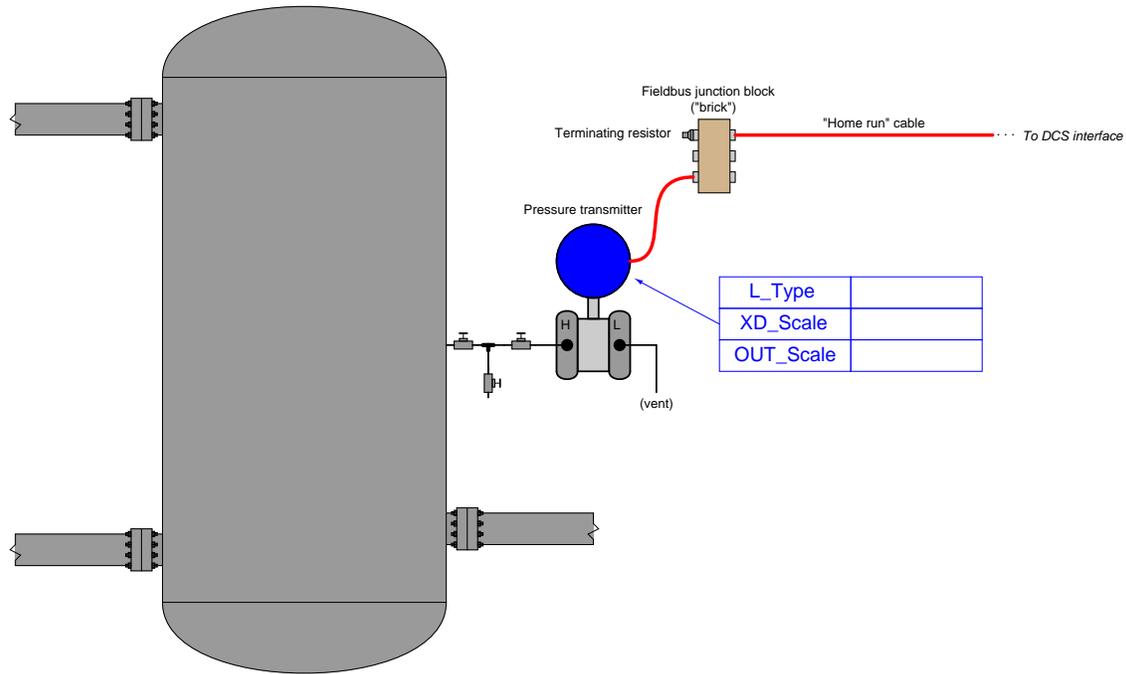
#### Suggestions for Socratic discussion

- In each of the captures, the data stream represented by the Fieldbus signal is the same. Identify these data stream bits, explaining how you know their identities for certain.
- Explain how we can tell whether each edge of the waveform is a real (clocked) data bit, or if some of them are merely reversals in setup of the next bit.
- Do you think it would be possible to use a digital multimeter (DMM) instead of an oscilloscope and obtain the same diagnostic information? In other words, is it necessary to see the actual *shape* of the waveform in order to diagnose the FF segment problem?

[file i01511](#)

Question 69

Suppose a FOUNDATION Fieldbus pressure transmitter will be used to measure vacuum in a process vessel. The transmitter will be connected to the vessel through an impulse line connected to the “High” port. The operator, in turn, expects to be able to read vacuum as a negative pressure value (i.e. a vacuum of 5 PSI registers as  $-5$  PSI on the operator’s display):



The desired measurement range for this transmitter is 0 PSI to  $-12$  PSI. Complete the configuration table in the above illustration, showing the proper `XD_Scale`, `OUT_Scale`, and `L_Type` parameter values to make the transmitter function as it should in this application.

Also, determine the proper settings (open or shut) for the three hand valves between the process vessel and the transmitter while the system is operating normally.

**Suggestions for Socratic discussion**

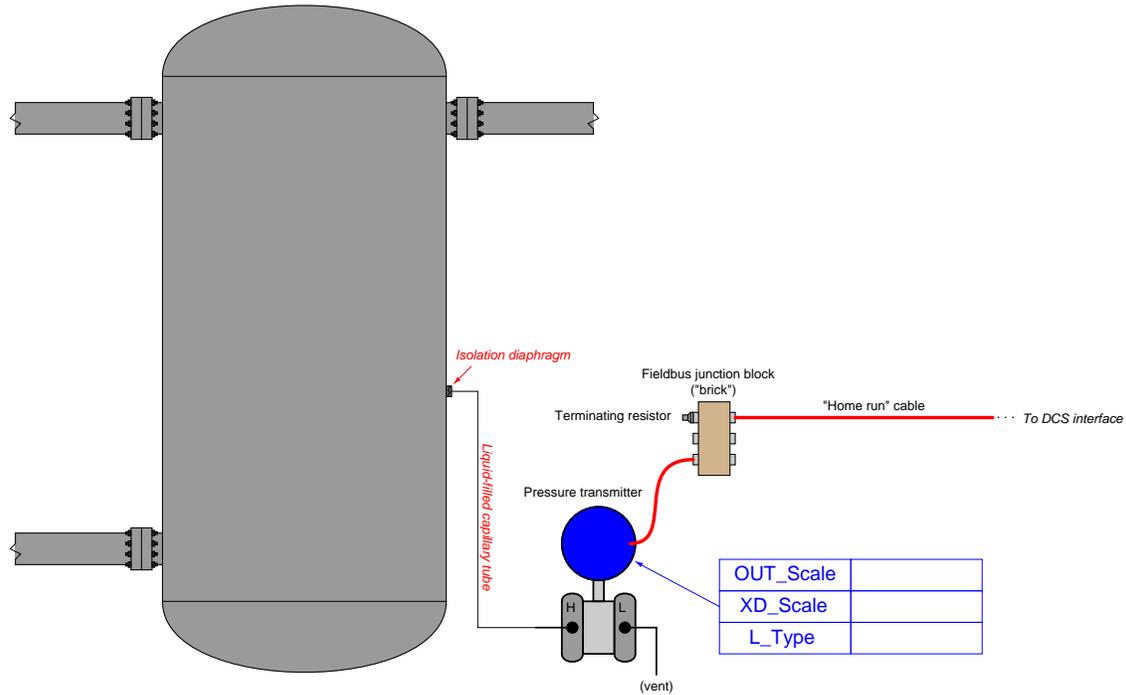
- Explain why process transmitters with analog (4-20 mA) outputs do not have `XD_Scale` and `OUT_Scale` parameters like Fieldbus transmitters.

[file i04593](#)

Question 70

Suppose a FOUNDATION Fieldbus pressure transmitter will be used to measure pressure in a process vessel. The transmitter will be connected to the vessel through a liquid-filled capillary tube connected to the “High” port. The difference in height between the isolation diaphragm and the transmitter causes an additional 3.6 PSI to be applied to the transmitter’s “High” port (due to the weight of the fill fluid) than what is actually inside the vessel.

The transmitter needs to be ranged so that a pressure range of 0 to 75 PSI of gas pressure inside the vessel displays as 0 to 75 PSI to any operator looking at the DCS display, without the pressure error (offset) caused by the liquid-filled capillary tube.



Complete the configuration table in the above illustration, showing the proper XD\_Scale, OUT\_Scale, and L\_Type parameter values to make the transmitter function as it should in this application.

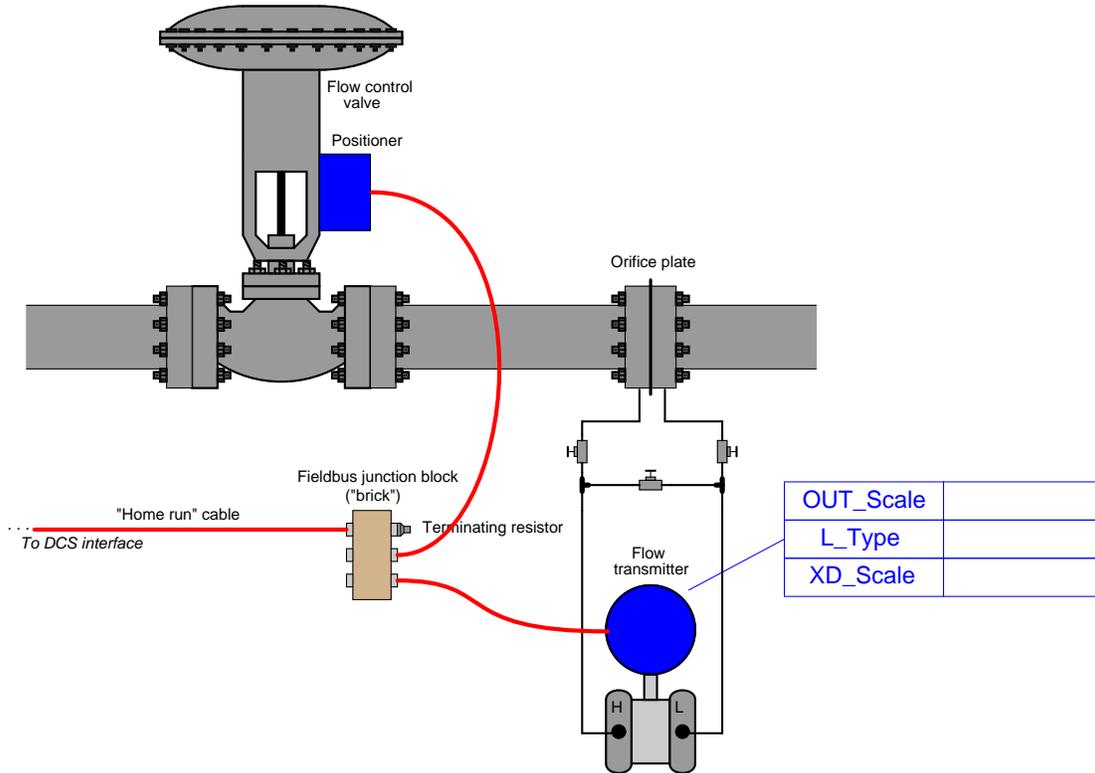
**Suggestions for Socratic discussion**

- Suppose the pressure transmitter were relocated to an elevation equal in height with the pressure tap on the side of the vessel. What should the proper XD\_Scale, OUT\_Scale, and L\_Type parameters be for this application?

[file i01838](#)

Question 71

Suppose a FOUNDATION Fieldbus pressure transmitter will be used to measure flow through a process line by sensing differential pressure generated by an orifice plate. The orifice's rated pressure range is 0 to 125 inches water column, while flowing 0 to 230 gallons per minute of liquid. Due to the differential pressure sensor being mounted at a substantial level below the pipe's centerline, the weight of the liquid inside each of the impulse lines applies an extra 38 inches of water column pressure to both sides of the transmitter ("High" and "Low" equally). The operator needs to see the flow rate in units of GPM, and does not care to see or know the differential pressure directly sensed by the transmitter:



Complete the configuration table in the above illustration, showing the proper XD\_Scale, OUT\_Scale, and L\_Type parameter values to make the transmitter function as it should in this application.  
[file i01840](#)

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Question 72

Suppose a FOUNDATION Fieldbus pressure transmitter is connected to the bottom of a vessel containing a liquid half as dense as water, for the purpose of measuring liquid height inside the vessel based on hydrostatic pressure. For every foot of liquid height, 6 inches water column pressure is sensed by the transmitter.

Determine the proper configuration parameters for this Fieldbus instrument's Analog Input (AI) block, assuming we wish this transmitter to report liquid height over a range of 0 to 18 feet:

L_Type	
XD_Scale	
OUT_Scale	

[file i01217](#)

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Question 73

Suppose a FOUNDATION Fieldbus pressure transmitter is connected to the bottom of a water storage tank, for the purpose of measuring water volume stored inside the tank based on hydrostatic pressure. The tank is shaped like a vertical cylinder, 10 feet in diameter and 20 feet high.

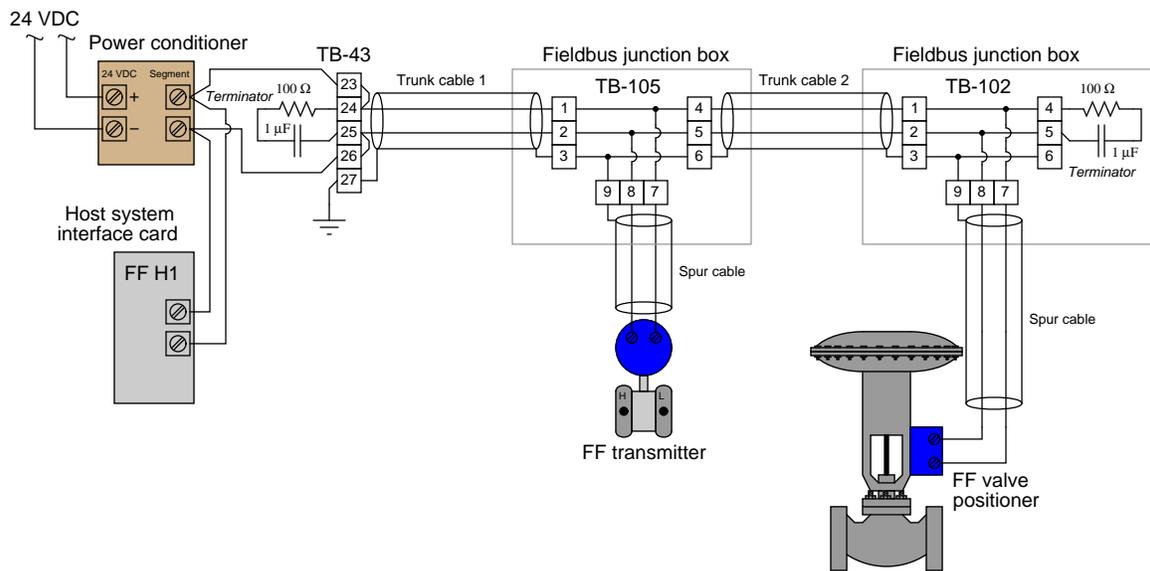
Determine the proper configuration parameters for this Fieldbus instrument's Analog Input (AI) block, assuming we wish this transmitter to report liquid height over a range of 0 to 15 feet, expressed in units of cubic feet:

L_Type	
XD_Scale	
OUT_Scale	

[file i01220](#)

Question 74

A new H1 Fieldbus segment seems to have a problem, and you suspect one of the Fieldbus cable conductors has become grounded. A diagram of the system appears here:



Identify the diagnostic value of each of the following tests in determining whether or not a conductor has become grounded in this operating network segment. If the measurement is a good test, mark it as “Indicative.” If the measurement tells you nothing about the state of the conductor, mark it as “Indeterminate.”

Measurement	Indicative	Indeterminate
AC current between chassis ground and TB43-27		
DC voltage between TB43-24 and TB43-25		
AC voltage between TB105-2 and TB105-5		
AC voltage between TB102-7 and TB102-9		
AC voltage between TB102-4 and TB102-5		
AC voltage between TB105-8 and TB105-9		
Resistance between TB102-1 and TB102-2		

For each of the “Indicative” measurements, specify what value of measurement would positively indicate a grounded conductor.

**Suggestions for Socratic discussion**

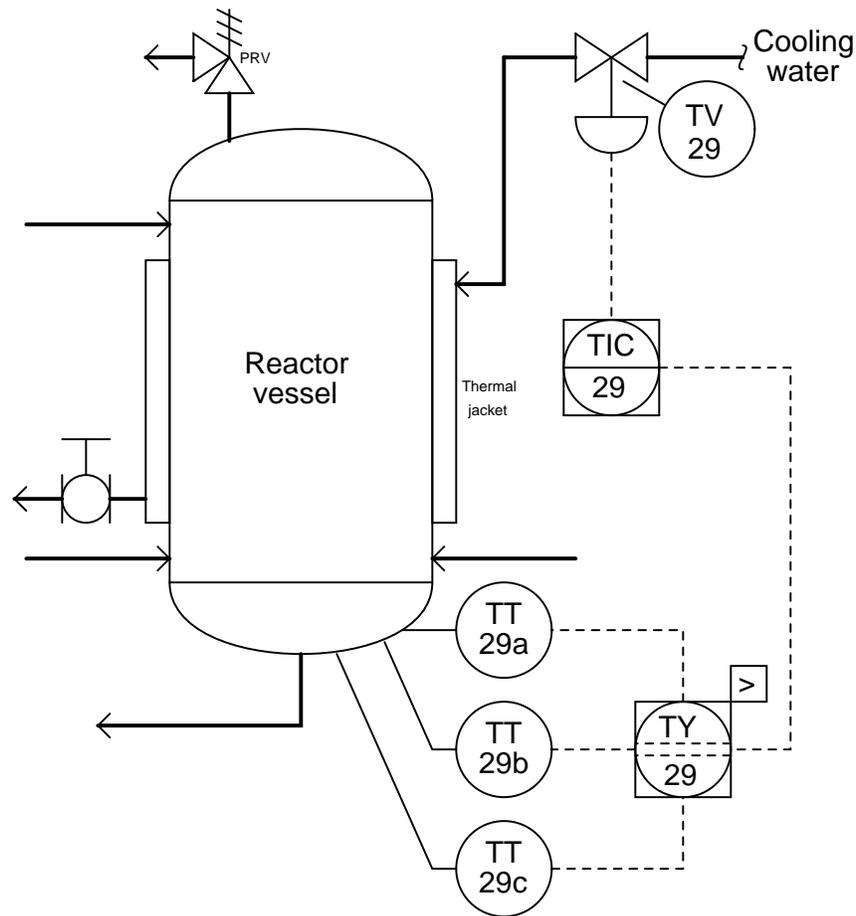
- An assumption being made here is that the multimeter is highly discriminating between AC and DC voltage values. Is there a way you can test your own DMM to see how well it discriminates between AC and DC voltage?
- Suppose a you measured a strong Fieldbus signal (700 mV) between terminal TB102-2 and earth ground. Where could the ground fault be to cause this signal measurement?
- Suppose a you measured a weak Fieldbus signal (5 mV) between terminal TB105-1 and earth ground. Where could the ground fault be to cause this signal measurement?

[file i04596](#)

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Question 75

The temperature inside this chemical reactor vessel is controlled by a temperature control valve (TV) at top, and is measured by redundant temperature transmitters sending their signals through a “high-select” function:



Explain what will happen (and why!) if a technician temporarily disconnects temperature transmitter 29c from its sensing element in such a way that the transmitter outputs a *low* signal.

**Suggestions for Socratic discussion**

- Suppose these were FOUNDATION Fieldbus temperature transmitters rather than analog temperature transmitters. Would the effects of disconnecting TT-29c from the Fieldbus segment be the same? Why or why not?

[file i04595](#)

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Question 76

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Question 77

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Question 78

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Question 79

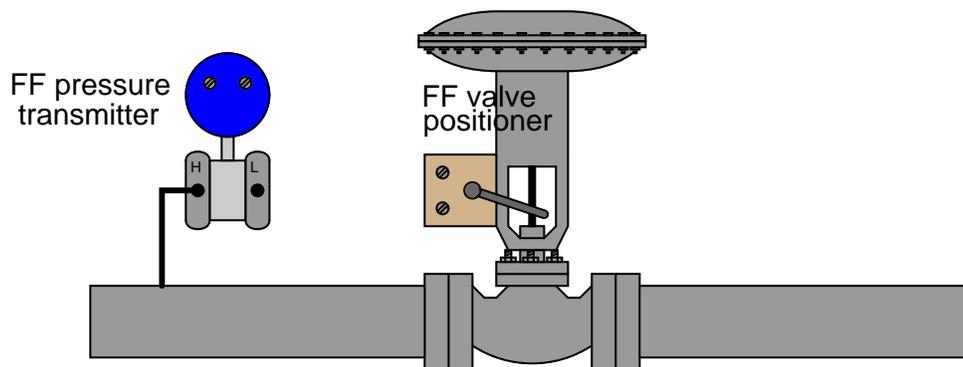
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Question 80

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Question 81

Suppose you were tasked with the assignment of connecting two FOUNDATION Fieldbus (FF) devices together onto their own network: one transmitter and one control valve. You know that no additional controller device is needed, because either one of these field devices is also capable of executing the PID control algorithm on its own. Each device has a pair of connection terminals where the Fieldbus network wiring connects:



Sketch the wiring and any other components necessary to the basic operation of this FOUNDATION Fieldbus network (power supply, power supply isolator, termination resistors) connected to these Fieldbus devices so that they will be able to function as their own control loop. Be sure to show individual wires rather than single-line cables in your sketch! The point of this question is to probe your understanding of FOUNDATION Fieldbus network wiring.

file i03517

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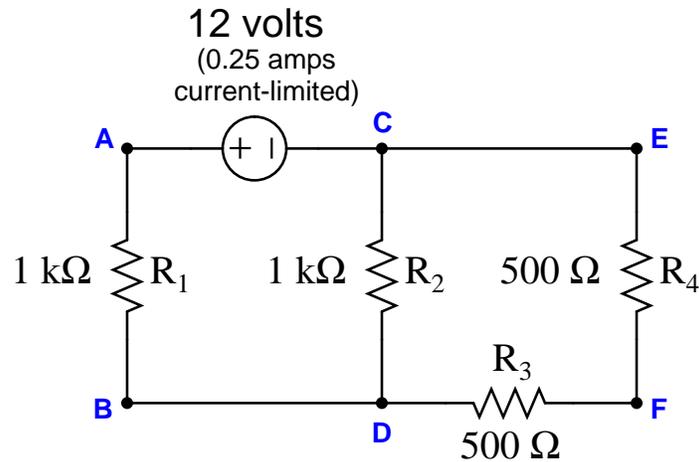
Question 82

Suppose an electrician decides to check a newly installed FOUNDATION Fieldbus H1 segment trunk cable for short-circuit faults by clipping the test leads of an insulation tester (often referred to by the brand name “Megger”) between the (+) and (–) terminals of the segment cable accessible in a junction box, then using the insulation tester to measure resistance. The electrician knows to shut off the DC power to the network first so that the DC voltage does not interfere with his resistance test.

Explain why the electrician’s method of cable testing is very risky, especially for any Fieldbus devices connected to the segment.

Question 83

Suppose a voltmeter registers 9 volts between test points **A** and **D** in this series-parallel circuit:



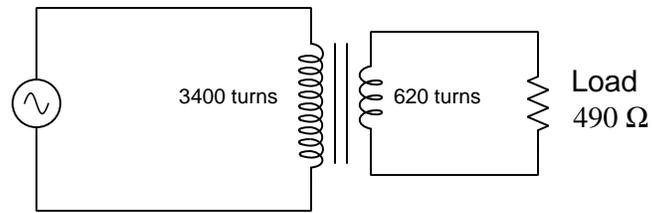
Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
$R_1$ failed open		
$R_2$ failed open		
$R_3$ failed open		
$R_4$ failed open		
$R_1$ failed shorted		
$R_2$ failed shorted		
$R_3$ failed shorted		
$R_4$ failed shorted		
Voltage source dead		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

Question 84

Calculate all voltages and all currents in this transformer circuit, assuming a load current of 31 mA:



- $V_{primary} =$
- $V_{secondary} =$
- $I_{primary} =$
- $I_{secondary} =$

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Question 85

Suppose you are asked to calibrate a FOUNDATION Fieldbus pH transmitter, sensing the pH of water flowing through a pipe. The water treatment process it is a part of must be kept running and not shut down while you do this task.

The company's standard maintenance procedure for this loop tells you to place the pH transmitter's Analog Input function block in "Manual" mode during the calibration so that pH values it senses while being calibrated do not get sent to the PID function block and mess things up for the operating process. The Analog Input function block's "Manual" mode essentially freezes its signal to the PID function block at the last value it was outputting while it was running normally.

You are familiar with placing PID controllers in manual mode when performing such tasks, but you are unfamiliar with doing the same thing to the Analog Input function block in a Fieldbus system. Are these two steps equivalent to one another, or is there some advantage to doing it one way versus the other?

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Question 86

In this equation there is a **mistake**:

$$\frac{6}{x+2} - \frac{x-4}{x+2} = \frac{6-x-4}{x+2}$$

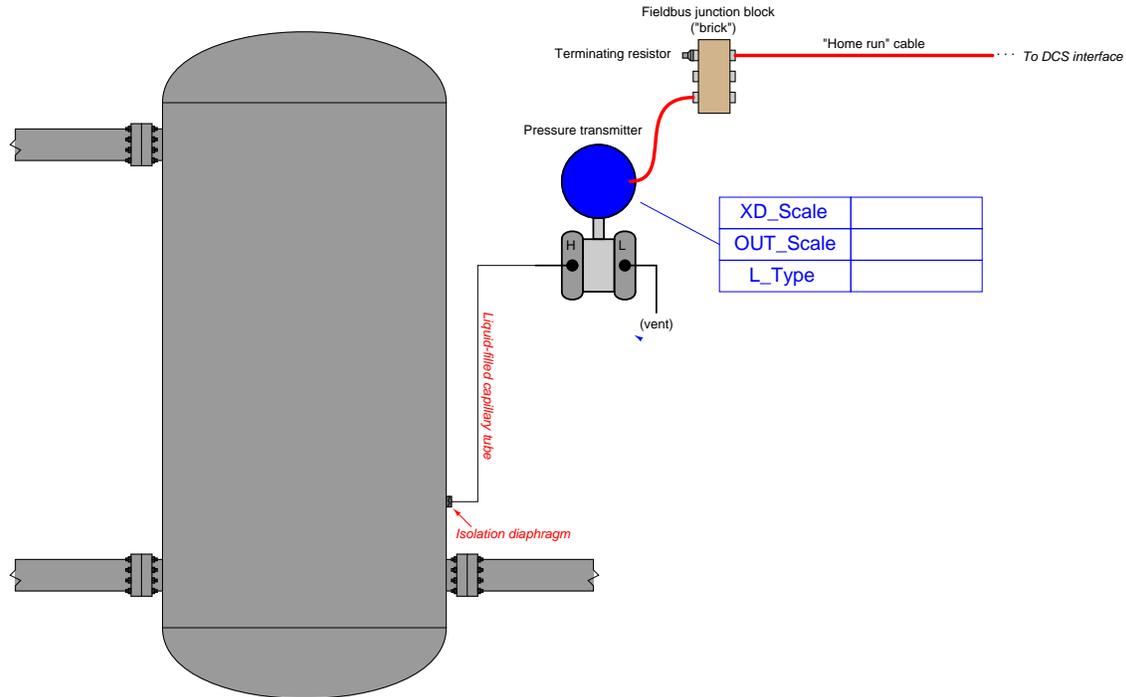
Identify the mistake, and re-write the right-hand side of the equation so the two sides are truly equal. Be sure to show all your work!

$$\frac{6}{x+2} - \frac{x-4}{x+2} =$$

Question 87

Suppose a FOUNDATION Fieldbus pressure transmitter will be used to measure pressure in a process vessel. The transmitter will be connected to the vessel through a liquid-filled capillary tube connected to the “High” port. The difference in height between the isolation diaphragm and the transmitter causes 1.7 PSI less pressure (i.e. 1.7 PSI of vacuum) to be applied to the transmitter’s “High” port (due to the weight of the fill fluid) relative to the actual pressure inside the vessel. In other words, with zero pressure inside the vessel, the transmitter will sense  $-1.7$  PSI.

The transmitter needs to be ranged so that a pressure range of 50 to 100 PSI of gas pressure inside the vessel displays as 50 to 100 PSI to any operator looking at the DCS display, without the pressure error (offset) caused by the liquid-filled capillary tube.

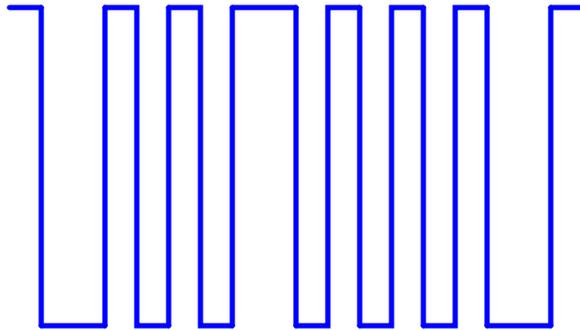


Complete the configuration table in the above illustration, showing the proper XD\_Scale, OUT\_Scale, and L\_Type parameter values to make the transmitter function as it should in this application.

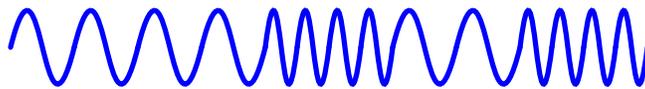
Question 88

Decode the following serial data streams, each one encoded using a different method:

(Manchester encoding)



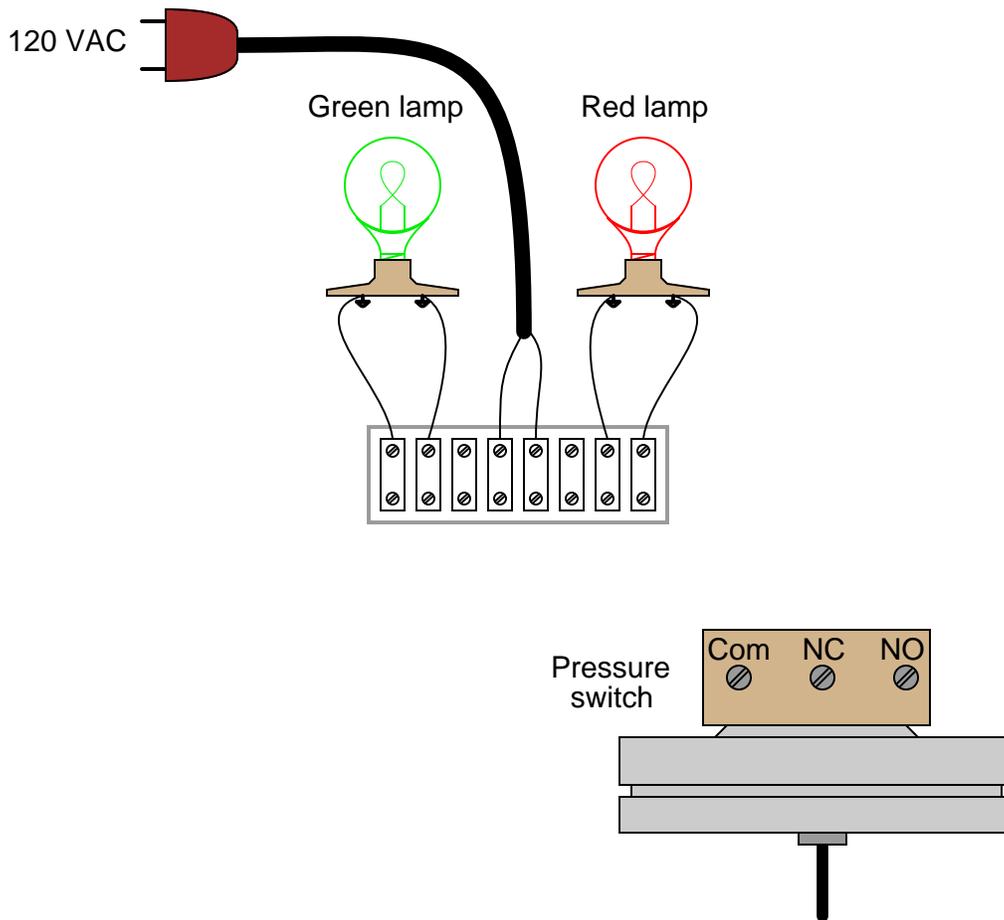
(FSK encoding)



Question 89

Sketch the necessary wiring to make this pressure switch control two lamps in the following manner:

- High process pressure: red lamp on and green lamp off
- Low process pressure: Green lamp on and red lamp off

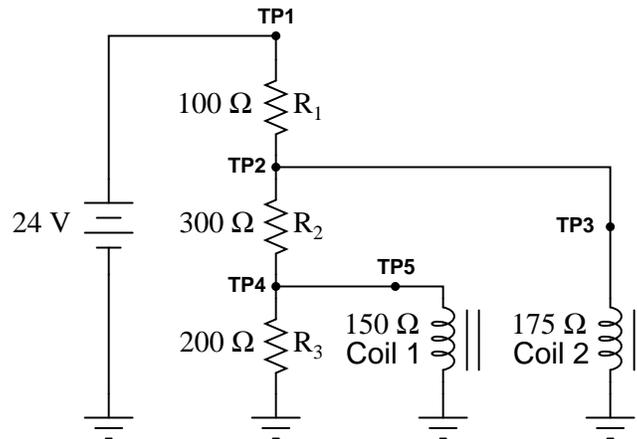


Hint: remember that the “normal” status of a switch is defined as the status of *minimum stimulus*: when the switch is exposed to the lowest possible degree of process stimulation (in this particular case, to the lowest possible pressure).

[file i03250](#)

Question 90

A piece of laboratory equipment uses a voltage divider to reduce voltage to two electromagnet coils from a higher-voltage source. Coil #1 is supposed to receive 2.91 volts and coil #2 is supposed to receive 13.11 volts:



One day, something goes wrong with this circuit. The magnetic field from coil #1 suddenly becomes very weak, yet there is still a magnetic field coming from coil #2. The technician who looked at this problem before you took two voltage measurements and then gave up: 12.61 volts at test point TP3 and 41.7 millivolts at test point TP4. You left your multimeter back at the shop, which means you cannot take any more voltage measurements. However, since you are more determined than the former technician, you proceed to identify the following from the two measurements already taken:

- Two components or wires in the circuit that you know cannot be failed either open or shorted, besides the 24 volt source which is obviously operational.
- One component or wire in the circuit you think could possibly be bad, and the type of failure it would be (either open or shorted).

**Lab Exercise – introduction**

Your task is to commission and de-commission a *WirelessHART* field instrument, recording and/or controlling variables within that instrument using the Modbus protocol. Each lab team will commission one *WirelessHART* instrument (field device), and each person on that team will read or write one variable within that device. Troubleshooting will be done on a PID-controlled process commissioned during a previous lab exercise, which may or may not be related at all to the *WirelessHART* instrument you commission in this exercise.

The following table of objectives show what you and your team must complete within the scheduled time for this lab exercise. Note how some of these objectives are individual, while others are for the team as a whole:

Objective completion table:

<b>Performance objective</b>	<b>Grading</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>Team</b>
Record serial number of device	(ungraded)	–	–	–	–	
Team meeting	mastery	–	–	–	–	
<i>WirelessHART</i> instrument commissioned	mastery	--	--	--	--	
Data displayed/controlled via Modbus	mastery					-----
Circuit design challenge	mastery					-----
Troubleshooting	mastery					-----
<i>Safety and professionalism</i>	deduction					
<i>Lab percentage score</i>	proportional					-----
Decommission and lab clean-up	(ungraded)	--	--	--	--	

The “proportional” score for this activity is based on the number of attempts require to master each objective. Every failed attempt is marked by a 0, and every pass by a 1. The total number of 1 marks divided by the total number of marks (both 1’s and 0’s) yields a percentage value. Team objectives count as part of every team member’s individual score. The *Safety and professionalism* deduction is a flat –10% per instance, levied on occasions of unprofessional or unsafe conduct.

**It is essential that your team plans ahead what to accomplish each day. A short (10 minute) team meeting at the beginning of each lab session is a good way to do this, reviewing what’s already been done, what’s left to do, and what assessments you should be ready for. There is a lot of work involved with building, documenting, and troubleshooting these working instrument systems!**

As you and your team work on this system, you will invariably encounter problems. You should always attempt to solve these problems as a team before requesting instructor assistance. If you still require instructor assistance, write your team’s color on the lab whiteboard with a brief description of what you need help on. The instructor will meet with each team in order they appear on the whiteboard to address these problems.

## Lab Exercise – objectives and expectations

Each objective is assessed at the *mastery* level, which means it is not complete until it meets *all* expectations. Re-tries are allowed, but failed attempts will be recorded and factored into your score for this lab exercise.

### Record serial number of device

Your *WirelessHART* device is portable and will likely be moved to different locations during the commissioning process. For this reason it is important to track which team is responsible for which device, and having the instructor record the serial number from your team's device is a good way to do this. This same serial number will be verified when you decommission the device and return it to storage.

### Team meeting and prototype sketch

Read the lab exercise documentation and discuss with your teammates the objectives to be achieved and the time allotted to do so. Formulate a plan to achieve these objectives and draft a prototype design for the system you intend to build. Then, meet with your instructor to present your team's action plan and prototype design. *This prototype sketch should be annotated with all expected physical parameters (e.g. voltage polarities, current directions, fluid pressures, etc.).* Be prepared to answer all manner of questions about your team's goals, planned schedule of work, available resources, and prototype design, including analysis of the design for specific faults and condition changes. Do not begin construction until your design has been analyzed and approved! Note that multiple meetings may be required if the instructor's assistance is needed to select components influencing your design.

### WirelessHART instrument commissioned

Establish wireless (i.e. radio) communication between a *WirelessHART* field instrument and the Gateway using the appropriate *Network ID* and *Join Key* (both unique to the Gateway) as well as a *HART long tag* name unique to your team. The instrument's *update rate* should be appropriately set as well.

### Data displayed/controlled via Modbus

Each student must configure the *WirelessHART* Gateway and data display device (e.g. HMI) to either display or control one variable within the field instrument, a task requiring *mapping* of that instrument variable to a specified Modbus register. Both the variable and the Modbus register must be unique to each student.

### Circuit design challenge

Build a circuit with a HART differential pressure transmitter responding properly to applied pressure/vacuum, using an analog multimeter to register the transmitter's analog signal and a digital oscilloscope to register the transmitter's digital (HART) signal.

### Troubleshooting

Logically diagnose the nature and location of a fault placed in a working system that your team did not build. This will be limited in time, with each student passing or failing individually.

## Lab Exercise – objectives and expectations (continued)

### Lab percentage score

Successful completion of the lab exercise requires demonstrated mastery of all objectives. A percentage value is based on the number of attempts required to achieve mastery on these objectives: the number of objectives divided by the number of total attempts equals the percentage. Thus, a perfect lab percentage score is possible only by completing all objectives on the first attempt. Marks given for team objectives factor into each individual's score. If one or more members of a team repeatedly compromise team performance, they may be removed from the team and required to complete remaining lab exercises alone.

Deductions from this percentage value will be levied for instances of unsafe or unprofessional conduct (see below), the final result being the lab percentage score.

### Safety and professionalism (deduction)

In addition to completing the specified learning objectives in each lab exercise, each student is responsible for abiding by all lab safety standards and generally conducting themselves as working professionals (see the *General Values, Expectations, and Standards* page near the beginning of every worksheet for more detail). Expectations include maintaining an orderly work environment and returning all tools and test equipment by the end of every school day (team), as well as following clear instructions (e.g. instructions given in equipment manuals, lab documentation, verbally by the instructor), communicating with teammates, formulating a plan to complete the lab project in the allotted time, and productively managing time. As with the other objectives, chronic patterns of poor performance in this domain may result in the offending student being removed from the team. Deductions to the lab percentage score will *not* be made for performance already graded such as tardiness and attendance.

## General format and philosophy

This lab exercise is *project-based*: the instructor serves as the project engineer, while each student's role is to implement the standards set for the project while budgeting time and resources to complete it by the deadline date. Students perform real work as part of the lab exercise, managing their work day and functioning much the same as they will on the job. The tools and equipment and materials used are all industry-standard, and the problems encountered are realistic. This instructional design is intentional, as it is proven effective in teaching project management skills and independent working habits.

When you require the instructor's assistance to answer a question or to check off an objective, write your name (or your team's name) on the lab room whiteboard. Questions take priority over checkoffs, so please distinguish questions from other requests (e.g. writing a question-mark symbol “?” after your name makes this clear). **There will be times when you must wait for extended periods** while the instructor is busy elsewhere – instant service is an impossibility. Adequate time *does* exist to complete the lab exercise if you follow all instructions, communicate well, and work productively. Use all “down time” wisely: filling it with tasks not requiring the instructor's assistance such as other lab objectives, homework, feedback questions, and job searches.

Remember that the lab facility is available to you at all hours of the school day. Students may perform non-hazardous work (e.g. circuit work at less than 30 volts, documentation, low air pressures, general construction not requiring power tools) at *any time during the school day* without the instructor's presence so long as that work does not disturb the learning environment for other students.

**DO NOT TAKE SHORTCUTS** when completing tasks! Learning requires focused attention and time on task, which means that most “shortcuts” actually circumvent the learning process. Read the lab exercise instructions, follow all instructions documented in equipment manuals, and follow all advice given to you by your instructor. Make a good-faith effort to solve all problems on your own *before* seeking the help of others. Always remember that this lab exercise is just a means to an end: no one *needs* you to build this project; it is an activity designed to develop marketable knowledge, skills, and self-discipline. In the end it is your *professional development* that matters most, not the finished project!

## Lab Exercise – team meeting

An important first step in completing this lab exercise is to **meet with your instructor** as a team to discuss safety concerns, team performance, and specific roles for team members. If you would like to emphasize exposure to certain equipment (e.g. use a particular type of control system, certain power tools), techniques (e.g. fabrication), or tasks to improve your skill set, this is the time to make requests of your team so that your learning during this project will be maximized.

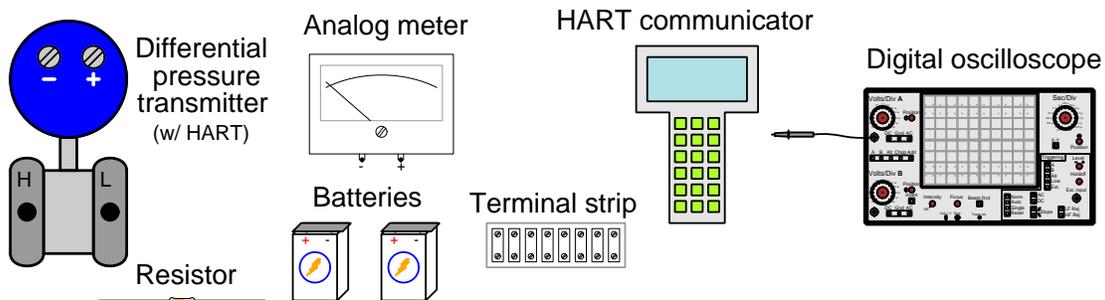
For example, if a team member lacks experience using personal computers, this lab exercise is an excellent opportunity to gain those skills. It is *strongly* recommended that those team members with the least computer experience be the people to do all the initial configuration work while those with more experience merely supervise.

Remember, the purpose of this lab exercise is not to complete it in the least amount of time, but rather for every team member to gain new knowledge and skill. This is why tasks should not necessarily be assigned with *maximum efficiency* in mind as they would at a workplace, but rather with *maximum learning* in mind because this is a school.

## Lab Exercise – circuit design challenge

Connect a loop-powered “smart” differential pressure transmitter (4-20 mA output with HART communication ability) to a DC voltage source and an analog meter such that the meter will indicate an increasing signal when a certain stimulus is applied to the transmitter, setting the transmitter’s pressure measurement range as specified by the instructor. Additionally, connect a digital oscilloscope to this circuit and use it to capture one of the digital messages communicated between the transmitter and the HART communicator. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, etc.) “Alligator” clips are permitted for making connections to battery terminals only.

This exercise tests your ability to correctly identify pressure port functions on a differential pressure transmitter, to navigate a “smart” instrument’s parameters using a communicator, to properly interpret terminal connections on a field instrument for signal and power, to use an analog multimeter to measure 4-20 mA loop current, to use a DMM to capture peak signal amplitude, to use a digital oscilloscope to capture FSK data, and to interpret that FSK-encoded digital data.



The following components and materials will be available to you: assorted 2-wire 4-20 mA HART differential pressure **transmitters** calibrated to ranges 0-30 PSI or less, equipped with Swagelok compression tube connectors at the “high” and “low” ports ; lengths of **plastic tube** with ferrules pre-swaged ; **terminal strips** ; lengths of **hook-up wire** ; 250  $\Omega$  (or approximate) **resistors** ; analog **meters** ; **batteries** ; **HART communicator** ; digital **oscilloscope**. You must provide your own tools and digital multimeter (DMM) as well as a copy of this page for your instructor to mark objectives.

**SEQUENCE:** (1) Instructor chooses criteria; (2) You build, power, and test circuit; (3) Instructor verifies all objectives satisfied.

**Transmitter range** (instructor chooses):      LRV = \_\_\_\_\_      URV = \_\_\_\_\_

**Meter options** (instructor chooses):      \_\_\_ Voltmeter (1-5 VDC)    *or*    \_\_\_ Ammeter (4-20 mA)

**Signal increases with...** (instructor chooses):      \_\_\_ Positive pressure    *or*    \_\_\_ Vacuum (suction)

**HART signal captured** (instructor verifies):      \_\_\_ (peak FSK signal voltage read on DMM)

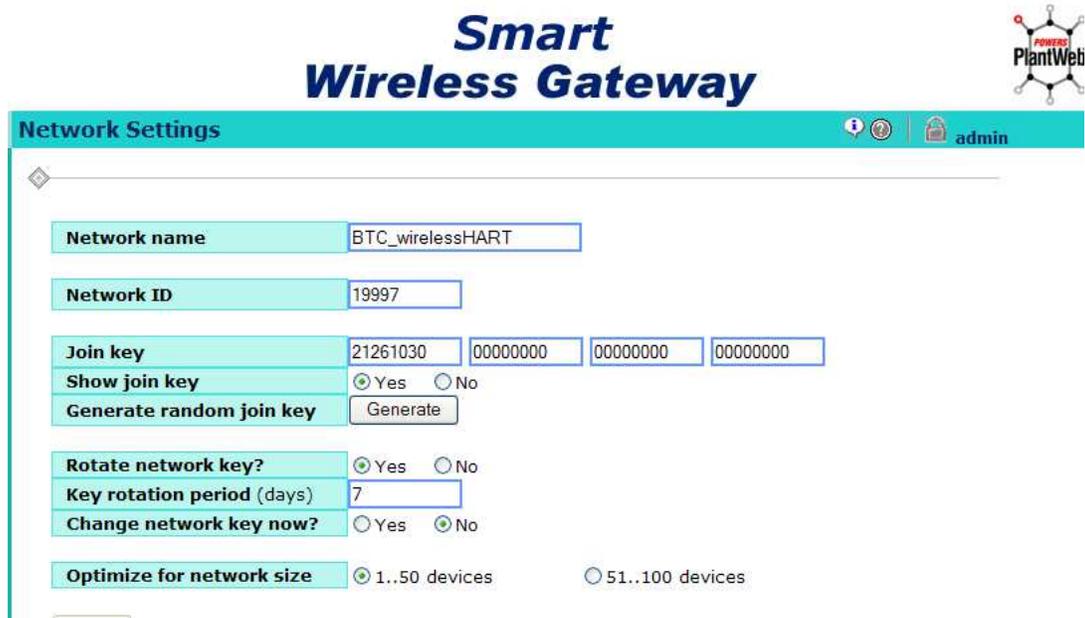
**HART signal captured** (instructor verifies):      \_\_\_ (correctly read FSK “0” and “1” bits on scope)

Study references: the “Analog Electronic Instrumentation” chapter of *Lessons In Industrial Instrumentation*, particularly the sections on loop-powered transmitters and current loop troubleshooting. Also, the “Basic Concept of HART” subsection of the “The HART Digital/Analog Hybrid Standard” section of the “Digital Data Acquisition and Networks” chapter of the same book. Your DMM manual will provide instructions on capturing peak signal values.

## Lab Exercise – commissioning a *WirelessHART* instrument

Detailed instructions for commissioning a *WirelessHART* instrument are found in the manuals for that instrument and/or in the manual for the Gateway device. You will need a HART communicator connected directly to the field instrument to configure it, and then web browser software pointed to the IP address of the Gateway (on the Ethernet network) to monitor the status of the field instrument. No special software is needed on your personal computer to access the Gateway’s parameters – any web browser will do, because the Gateway has a built-in web server.

An essential step in the commissioning of a *WirelessHART* field device is to program it with the appropriate *Network ID* and *Join Key*. The Network ID is a number unique to each *WirelessHART* radio Gateway, and the Join Key is another (much larger!) number used to authenticate each field device. You may think of the Network ID as a “login name” and the Join Key as the “password” for a *WirelessHART* device to connect to the Gateway.



The screenshot shows the 'Smart Wireless Gateway' web interface. The title 'Smart Wireless Gateway' is prominently displayed in blue. To the right is the 'PlantWeb' logo. Below the title is a teal header bar with 'Network Settings' on the left and 'admin' on the right. The main content area has a light blue background and contains several configuration fields:

- Network name:** BTC\_wirelessHART
- Network ID:** 19997
- Join key:** 21261030, 00000000, 00000000, 00000000
- Show join key:**  Yes  No
- Generate random join key:** Generate
- Rotate network key?:**  Yes  No
- Key rotation period (days):** 7
- Change network key now?:**  Yes  No
- Optimize for network size:**  1..50 devices  51..100 devices

Network ID numbers are very important in applications where multiple *WirelessHART* networks coexist: where groups of field devices are assigned to different Gateways despite being close enough to each other to form a single “mesh” network. The unique Network ID number for each Gateway keeps their respective radio networks separate from each other.

Join Keys are an important security feature of *WirelessHART*, ensuring a new device cannot join the mesh network unless it is supposed to. Without the proper Join Key, a new *WirelessHART* device will be rejected from a Gateway’s mesh network even if strong radio communication exists. The Join Key is more than just a password, though: it serves as the encryption key to secure all data communicated between the field device and the Gateway during the commissioning process. The Network Key is another 128-bit encryption key used to secure data communications on the mesh network. Whereas the Join Key is required to initially connect with a Gateway and thereby join the Gateway’s mesh radio network, the Network Key is required to stay connected with that Gateway over time. The Network Key is updated to the field device after successful commissioning, and may be periodically randomized to ensure even better security.

It should be noted that the Join Key is a very long hexadecimal number, and is shown as *four different numerical fields* rather than as one long number (similar to the way credit card numbers are typically shown as four groups of four digits each, to make it more readable to humans). Be sure to note the Join Key as it appears on the web page of the Gateway (in four fields), and then enter those four number groups into the *WirelessHART* device in that same order.

You will also need to assign a *HART long tag* to uniquely identify your field device on the network. This is the “tagname” used to identify the device on the *WirelessHART* network. Note that the “short” HART tag is not referenced by the Gateway, and so you must be sure to set the “long” HART tag instead. You must choose an ISA-standard tag for your instrument (e.g. PT-25 for a pressure transmitter in loop #25). This tag will not only identify your field device on the *WirelessHART* network, but also form the first portion of each variable name within that device.

Another important parameter to set is the *Update Rate*, which tells the device how often it should transmit data to the Gateway. It is recommended you set this rate to the quickest value (i.e. shortest time) during commissioning because fast updates make troubleshooting easier. The update rate may be adjusted at any time after commissioning through the Gateway, and does not require the use of a hand-held HART communicator.

After setting the instrument’s HART long tag, Update Rate, Network ID, and Join Key parameters, the instrument is ready to be commissioned. It is recommended that you bring the instrument to its field location and then power it up (i.e. plug the battery into the instrument) while the instrument has a clear radio pathway to the Gateway antenna. Powering up the *WirelessHART* instrument enables it for acceptance into the Gateway’s radio network. When setting up multiple field devices, the device with the best pathway to the Gateway antenna should be powered up first, so it may be commissioned first and thereby act as a repeater for commissioning the other field devices. If you have a HART communicator connected to the field device during commissioning, you may monitor certain parameters such as *Join Status*, *Radio State*, *Join Mode*, *Number of Advertisements Heard*, and *Number of Join Attempts* to check its progress. You may also issue a “Force Join” command through the HART communicator to any field device struggling to join the network.

To optimize the radio pathway between the field device and the Gateway antenna, you should mount it at least several feet above ground level, away from any metal objects (especially those parallel to the antenna), and be sure to maintain the device’s antenna parallel to the Gateway’s antenna (vertical up or vertical down) for optimum RF signal coupling.

#### **Common mistakes:**

- Neglecting to consult the manufacturer’s documentation for field instruments (e.g. how to commission them).
- Failing to set the HART long tag in the device prior to commissioning. The result will be that the device comes up on the network (displayed on the Gateway web page) as a cryptic MAC address rather than an intelligible instrument tag.
- Using invalid characters (such as periods) in the HART long tag. HART long tags should be limited to letters, numbers, and dash symbols (e.g. TT-36 for Temperature Transmitter number 36).
- Trying to commission the field device while not in clear sight of the Gateway antenna.
- Mounting the device in an area where good communication is hindered (e.g. blocked by metal objects, located too close to ground, device antenna not parallel with Gateway antenna).
- Failing to set the Update Rate to a quick value, thereby impeding diagnosis of problems.
- Not waiting long enough (several minutes) for the device to commission, once powered up in the field.
- Not enabling “Active Advertising” on the Gateway for fast commissioning of devices.
- Trying to commission a collection of field-mounted transmitters in the wrong order (i.e. beginning with the transmitter farthest from the Gateway, rather than beginning with the nearest transmitter as you should to build the strongest “mesh” network).

**Commissioning a new WirelessHART instrument should take no more than an hour for a team doing it for the very first time, assuming they follow the instructions shown in the manual.**

## Lab Exercise – exchanging data using Modbus

The *WirelessHART* Gateway device provides a user-defined “map” between field instrument data points and standard Modbus registers, configured within the Gateway device using a web browser pointed to the Gateway’s IP address. Since every *WirelessHART* instrument is a multi-variable device, each team member will choose their own variable within that instrument to read or write via Modbus.

First, you will need to identify the variable within the field instrument that you wish to monitor or control. A list of those variables may be browsed using the maintenance- or administrative-level access functions within the Gateway. Once the variable’s name is identified, you may enter that variable name and its associated Modbus address in the Modbus mapping table. *WirelessHART* variable names typically follow the convention of the device HART tag (user-defined) followed by a “period” symbol and then additional characters specifying the variable within that device (e.g. TT-37.PV represents the “primary variable” within temperature transmitter 37; FT-4.SV represents the “secondary variable” within flow transmitter 4). Since the Gateway uses the period symbol as a delimiter between the device tagname and the variable name within the device, the device tagname cannot contain any periods.

Next, you will need to choose a Modbus register to “map” to the chosen *WirelessHART* device variable. Modbus register addresses are decimal values which you may freely choose within these ranges:

Address range (decimal)	Purpose
00001 to 09999	Discrete output bits (“coils”), <i>read/write</i>
10001 to 19999	Discrete input bits (“contacts”), <i>read-only</i>
30001 to 39999	16-bit analog input registers, <i>read-only</i>
40001 to 49999	16-bit “holding” registers, <i>read/write</i>

When reading or writing your variable from a Modbus master device connected to the Gateway, that device will reference the Modbus register address you chose and entered into the Gateway’s mapping table. For example, if you assigned your temperature transmitter’s primary variable (TT-37.PV) to Modbus register 30005, the Modbus master device tasked with reading that variable will read Modbus register 30005 within the Gateway to find that data.

Finally, you will need to program a Modbus master device to read or write data over a wired network to the Modbus register mapped to the *WirelessHART* variable in the Gateway’s mapping table. For this you may choose to program one of the networked PLCs in the lab, or one of the networked HMI (Human-Machine Interface) “touch panels” in the lab. Both types of Modbus master devices require specialized software to program, which has been pre-loaded into various computer workstations in the lab.

For students seeking additional challenge, I recommend programming a general-purpose computer to read or write Modbus data rather than programming a PLC or an HMI to do the same. PLCs and HMIs are made to be fairly easily programmed, but writing code to instruct a general-purpose computer is a more challenging task. If you have coding experience, you may wish to program a computer in C or C++ using the free `libmodbus` library of Modbus access functions. A recommended computing platform to do this is the *Raspberry Pi* single-board computer running the Linux operating system, or a regular personal computer running the same OS. Your *Lessons In Industrial Instrumentation* textbook provides sample code (in the C language) showing how multiple 16-bit integer numbers may be read from a Modbus device using `libmodbus` function calls. Both lab exercises (temperature and flow measurement) for the INST241 course include information on how to use the Raspberry Pi computing platform (including many common command-line instructions useful for manipulating files).

Note: when writing code to read or write Modbus registers, you will have to contend with an idiosyncrasy of Modbus called *relative addressing*. Your *Lessons In Industrial Instrumentation* textbook also explains this in detail.

Some important details about Modbus communication and variable mapping are listed here:

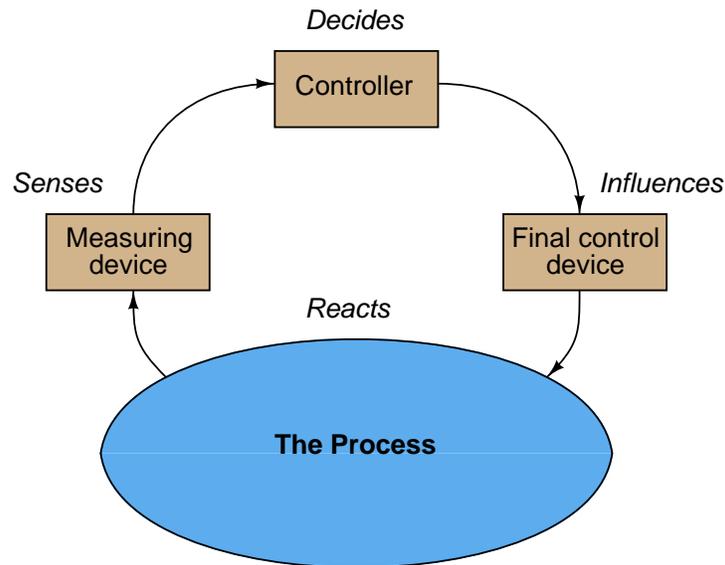
- Every Modbus slave device is programmed with a Modbus address (not to be confused with the *register* address for device variables). This is how the Modbus master is able to distinguish one Modbus device from another on a broadcast network. The *WirelessHART* Smart Wireless Gateway is a Modbus slave, and as such is assigned a Modbus address to identify it to any Modbus master devices. You will need to reference this Modbus slave address when programming your Modbus master device to read or write data.
- The Emerson Smart Wireless Gateway provides two different Modbus communication paths: one through Ethernet (Modbus/TCP protocol) and another through RS-485 (Modbus RTU). You may use either path for your lab exercise. All networked PLCs and HMI panels in our lab use Ethernet communications (i.e. Modbus/TCP). A single PLC or HMI with an RS-485 serial port may be wired to the Gateway for Modbus RTU communication.
- Modbus registers suitable for process variables are 16 bits in length. If you are accessing a 32-bit variable inside a *WirelessHART* device, *two* consecutive Modbus registers will be occupied. The Modbus mapping table will only show the first of the two registers, however. For example, if TT-37.PV is a 32-bit floating-point value mapped to Modbus register 30005, the register pair 30005 and 30006 will be used. This means the next free Modbus register will be 30007. This, obviously, becomes very important when multiple people are configuring the Gateway to map their individual variables. It is also important when configuring a Modbus master device to read from or write to these registers, because that device will have to deal with two Modbus registers at a time.
- The Smart Wireless Gateway provides multiple options for formatting field device data into 16-bit Modbus registers. The field device's Primary, Secondary, Tertiary, and Quaternary Variables (.PV, .SV, .TV, and .QV, respectively) are all 32-bit floating-point numbers in their native form, but the Gateway provides the option of representing those values as 32-bit integers. This option is found on the Gateway's "Modbus Communication" page as a one-of-three choice, that choice being global for the entire Gateway:
  - **Float** Floating-point numbers maintained in their original 32-bit floating-point form.
  - **Round** Floating-point numbers rounded to the nearest 32-bit integer value.
  - **Scale** Floating-point numbers scaled as 32-bit integers using the formula  $y = Ax - (B - 32768)$ . The values of  $A$  (gain) and  $B$  (offset) may be set globally on the Modbus Communication page (not recommended), or individually for each variable on the Modbus Mapping page.
- Primary, Secondary, Tertiary, and Quaternary Variables (.PV, .SV, .TV, and .QV, respectively) are mapped to real-world variables within the HART instrument, using the HART communicator. *WirelessHART* exploits the multi-variable nature of the HART communication standard, allowing a wide range of variables to be communicated between the Gateway and the *WirelessHART* field device. You are not limited, however, to these four variables (.PV through .QV) in a HART device. If you take the time to explore the commissioned device through the Gateway's web page, you will see a great multitude of variables accessible within it, each variable specified by name and data type (e.g. floating-point, integer, boolean, etc.). To map any of these HART variables to a Modbus register, you will need to prepend the HART tag to that variable name so as to distinguish it from the same variable within another HART device on the same wireless network.

#### Common mistakes:

- Crowding Modbus registers, by not allowing enough space between them. If the variable to be read is floating-point (32-bit) or a long integer (32 bit), it will require *two* consecutive Modbus registers, so the next Modbus register needs to be numbered at least 2 greater than the previous register.
- Incorrect byte-swapping at the Modbus master device polling the Gateway. The Modbus standard does not specify exactly how the 32 bits of a floating-point number are to be divided amongst two 16-bit Modbus registers, and so some manufacturers do weird byte-ordering (e.g. CDAB instead of ABCD) of their floating-point variables. Check the byte-swapping options on your master device to make sure it matches that of the Gateway, or else all floating-point data will appear scrambled.

## Notes on troubleshooting feedback control loops

Recall that every feedback control loop consists of four basic elements: an element that *senses* the process variable (e.g. primary sensing element, transmitter), an element that *decides* what how to regulate this process variable (e.g. a PID controller), an element that *influences* the process variable (e.g. a control valve, motor drive, or some other final control device), and finally the process itself which *reacts* to the final control device's actions:



You can check each element of your feedback control loop by comparing its input with its output to see if each element is doing what it should:

- (1) **Decision-making:** Carefully examine the controller faceplate, looking at the values of PV, SP, and Output. Is the controller taking appropriate action to force PV equal to SP? In other words, is the Output signal at a value you would expect if the controller were functioning properly to regulate the process variable at setpoint? If so, then the controller's action and tuning are most likely not at fault. If not, then the problem definitely lies with the controller.
- (2) **Sensing:** Compare the controller's displayed value for PV with the actual process variable value as indicated by local gauges, by feel, or by any other means of detection. If there is good correspondence between the controller's PV display and the real process variable, then there probably isn't anything wrong with the measurement portion of the control loop (e.g. transmitter, impulse lines, PV signal wiring, analog input of controller, etc.). If the displayed PV disagrees with the actual process variable value, then something is definitely wrong here.
- (3) **Influencing:** Compare the controller's displayed value for Output with the actual status of the final control element. If there is good correspondence between the controller's Output display and the FCE's status, then there probably isn't anything wrong with the output portion of the control loop (e.g. FCE, output signal wiring, analog output of controller, etc.). If the controller Output value differs from the FCE's state, then something is definitely wrong here.
- (3) **Reacting:** Compare the process variable value with the final control element's state. Is the process doing what you would expect it to? If so, the problem is most likely not within the process (e.g. manual valves, relief valves, pumps, compressors, motors, and other process equipment). If, however, the process is not reacting the way you would expect it to given the final control element's state, then something is definitely awry with the process itself.

## Lab Exercise – decommissioning and clean-up

The final step of this lab exercise is to decommission only the *WirelessHART* portions of your team's system and re-stock those components back to their proper storage locations, the purpose of which being to prepare the system for the next lab exercise. Leave all the analog (4-20 mA) instruments in place, so that the system operates as it did before this lab exercise. Perform general clean-up of your lab space, disposing of all trash, placing all tools back in their proper storage locations, sweeping up bits of wire off the floor and out of junction boxes, etc.

### Leave the following components in place, mounted on the racks:

- Large control valves and positioners
- I/P transducers
- Large electric motors
- Large variable-frequency drive (VFD) units
- Cables inside conduit interconnecting junction boxes together
- Pipe and tube fittings (do not unscrew pipe threads)
- Supply air pressure regulators

Finally, you shall return all *WirelessHART* system components to the configurations at the start of this lab exercise. This includes transmitter ranges, Gateway Modbus mapping, etc.

[file i03627](#)

## Answers

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Answer 1

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Answer 2

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Answer 3

**Partial answer:**

- What is significant about the size of the resistor in each terminator (100  $\Omega$ )?
  - Why is each termination resistor connected in series with a 1  $\mu\text{F}$  capacitor? Why not terminate with just a plain 100  $\Omega$  resistor at each end of the network? *Capacitive coupling is necessary because the network also carries DC power.*
  - What function does the power conditioner serve? Specifically, what is the purpose of the 10 mH inductor connected in series? *The power conditioner blocks the fieldbus communication signals from being shorted out by the DC voltage source.*
  - Is the resistor necessary in the power conditioner network? Why or why not? *It is there for current limiting and also anti-resonance.*
- 

Answer 4

Thirteen wire pairs, servicing six control loops

Just a single wire pair would (ideally) suffice for these six loops

A single H1 segment is not feasible in this case since the “home run” wire gauge is too small and cannot carry the total Fieldbus device current without suffering excessive voltage drop along its length.

Installation of a repeater at the field (junction box) end would reduce “home run” cable current and voltage drop to minimal levels. Alternatively, multiple wire pairs in the “home run” cable could be used to create multiple H1 networks, joining together to the DCS through “bridge” devices at the other end.

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Answer 5

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Answer 6

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Answer 7

Hint: use an ohmmeter!

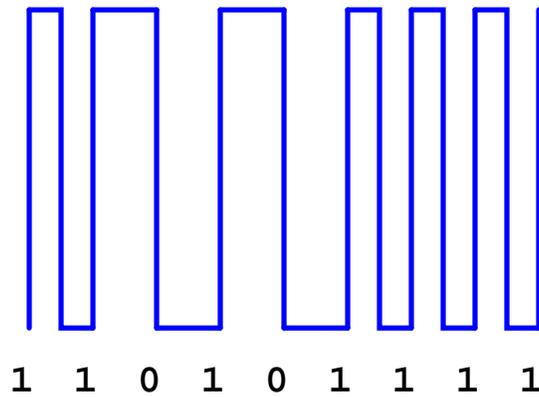
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Answer 8

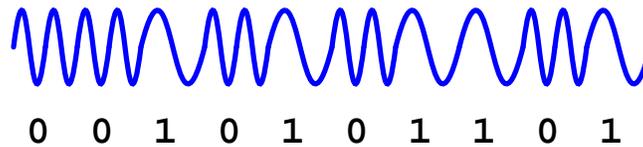
In the analog control system, the PID calculations take place in a front-panel mounted controller in the main control room area. In the DCS systems, the PID calculations take place in the DCS controller, which is located in some auxiliary location, behind the panel. In the pure fieldbus system, control takes place in the flow transmitter itself.

Follow-up question: what purpose is served by the “bridge” device in the last system?

(Manchester encoding)



(FSK encoding)



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Answer 10

Remember that an oscilloscope probe's reference clip is connected to the chassis of the oscilloscope, which in turn is connected to earth ground through the ground prong of the 120 VAC line power plug. This means the "hot" side of the AC circuit under test is being shorted directly to earth ground through the oscilloscope!

A better way to configure the oscilloscope to measure current is to set it up for *differential* measurement, where two channels and two probes are used, the oscilloscope's display set to show the difference between the two channels' signals.

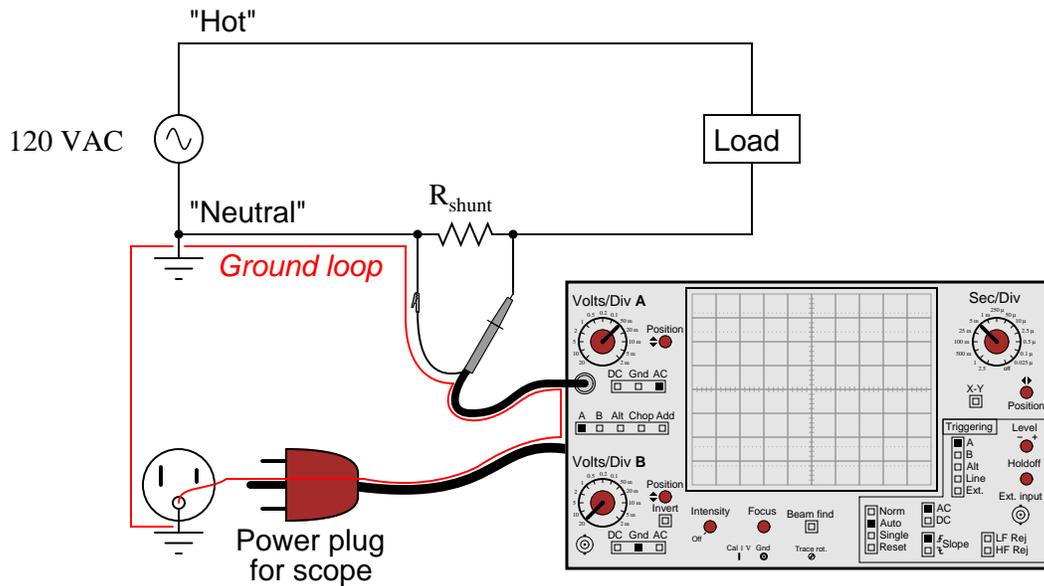
An entirely different approach would be to use a *current transformer* (CT) to sense current in the test circuit, with the CT's secondary current passing through a low-resistance shunt and one channel of the oscilloscope measuring that shunt resistor's voltage drop. Here, grounding through the oscilloscope is not an issue because the current transformer provides galvanic isolation between the test circuit and the oscilloscope.

Answer 11

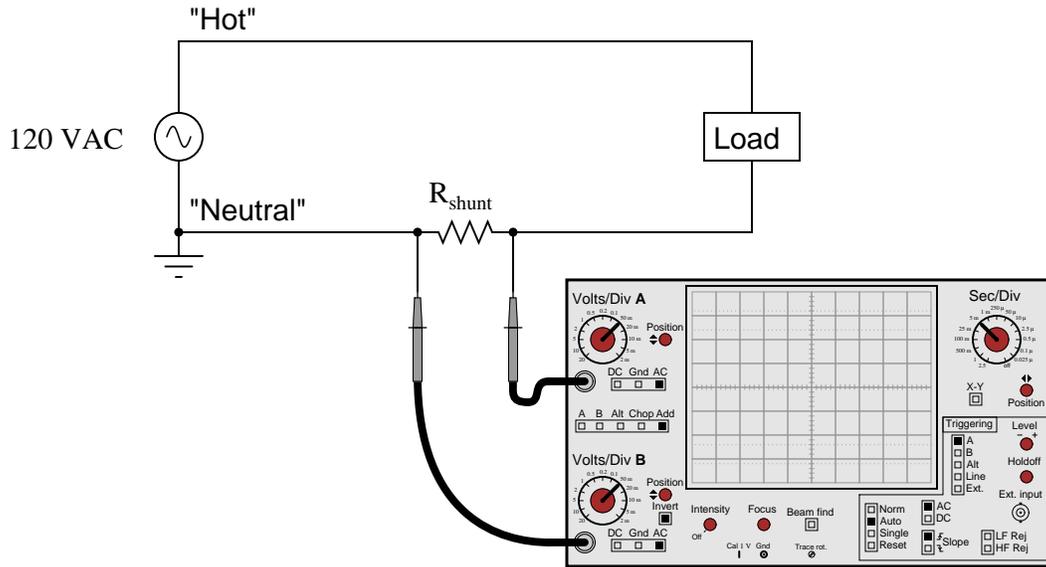
This would be a bad idea because the oscilloscope's ground clip would attempt to bypass current around the shunt resistor, through the oscilloscope's safety ground wire, and back to the grounded terminal of the AC source. Not only would this induce measurement errors, but it could damage the oscilloscope as well.

The ground-referenced clip on an oscilloscope probe is a constant source of potential trouble for those who do not fully understand it! Even in scenarios where there is little or no potential for equipment damage, placing an earth ground reference on a circuit via the probe clip can make for very strange circuit behavior and erroneous measurements. Problems like this frequently occur when new students attempt to connect their oscilloscopes to circuits powered by signal generators whose outputs are also earth-ground referenced.

As for a better test technique, the most obvious answer is to reverse the probe connections: ground clip on the left-hand terminal and probe tip on the right-hand terminal. However, even this might not be the best idea, since it creates a "ground loop" between the oscilloscope and the ground connection at the AC source:



Ground loops are to be avoided in measurement circuits because they may be the source of some very strange effects, including the coupling of noise voltage from entirely unrelated circuits to the one being measured. To avoid this problem, the best solution for measuring the voltage dropped across the shunt resistor is to use two scope probes and set the scope up for *differential* voltage measurement:



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Answer 12

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Answer 13

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Answer 14

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Answer 15

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Answer 16

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Answer 17

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Answer 18

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Answer 19

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Answer 20

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Answer 21

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Answer 22

- (1) LAS (DCS H1 card) issues a CD token to the flow transmitter
- (2) Flow transmitter publishes the process variable (flow) value
- (3) Control valve positioner receives (“subscribes to”) to the PV data
- (4) PID algorithm compares PV with the last SP and calculates Output value
- (5) Valve moves to match new Output value
- (6) During unscheduled time, the LAS issues a Pass Token (PT) message to each device in turn
- (7) At the valve positioner’s turn, the PID algorithm requests new operator SP value from the DCS
- (8) At the DCS’s turn, it transmits (“serves”) the new SP value to the PID algorithm

---

Answer 23

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Answer 24

Hint: the PN (Probe Node) token!

---

Answer 25

FUN = 55 ; NUN = 179

---

Answer 26

There is definitely more than one thing wrong here!

---

Answer 27

Hint: connect an ohmmeter to the two cable conductors at the host end while a fellow technician removes the far terminator and stands ready with a jumper wire and a hand-held radio (to communicate with you).

---

Answer 28

The Link Active Scheduler (LAS) grants *delegated tokens* to individual devices connected to the Fieldbus network. There are two basic token types issued by the LAS:

(1) A *Compel Data* (CD) token which requests an immediate broadcast of specific data from a specific device.

(2) A *Pass Token* (PT) which grants a specific device permission to transmit for a limited amount of time called the *maximum hold time*. When the chosen device is finished, or when the token time runs out (whichever comes first), the device returns the token to the LAS. If unscheduled time still remains, the LAS will issue another time-limited token to the next device.

In both cases, the token gets sent from the LAS to another device, then exclusive permission to transmit returns to the LAS.

---

Answer 29

**Partial answer:**

Publisher / Subscriber: scheduled communication whereby the Link Active Scheduler (LAS) calls upon a specific device on the network to transmit specific data for time-critical control purposes. The message calling for this data is called a Compel Data (CD) request. Multiple devices on the network “subscribing” to this published data receive it simultaneously.

Client / Server: unscheduled communication between individual devices enabled whenever the LAS grants a Pass Token (PT) to a device. Each device maintains a queue (list) of data requests issued by other devices (clients), and responds to them in order. By responding to client requests, the device acts as a server. Likewise, each device can use this time to act as a client, posting their own requests to other devices, which will act as servers when they receive the token from the LAS.

Source / Sink: unscheduled communication from one device to a “group address” representing many devices, enabled whenever the LAS grants a Pass Token (PT) to a device.

---

Answer 30

Most Fieldbus segments have two LAS-enabled devices: a primary and a backup. However, the Fieldbus standard allows for up to 8 LAS-enabled devices (one primary and 7 backups!). Some host systems, though, do not allow the enabling of all 8 LAS-capable devices. Emerson’s DeltaV DCS, for example, only allows for two: the primary and a single backup LAS.

If there is only one LAS and it fails, the Fieldbus segment will stop working. This is why it is important to have redundant Link Master devices on each H1 segment. A “Link Master” device is nothing more than a basic Fieldbus device with LAS capability. FOUNDATION Fieldbus H1 supports multiple Link Masters on a network, the one with the lowest-number address automatically becoming the Link Active Scheduler.

The Fieldbus H1 interface card on the host system (usually a DCS) is usually configured as the LAS device in a Fieldbus system, with one of the field instruments serving as the backup LAS. Note that some Fieldbus instruments do *not* have backup LAS capability, so you must be sure to choose your field devices carefully to ensure at least one of them has this capability!

---

Answer 31

The device labeled “PRV” will begin to make a very loud noise . . . and the technician might die. And you thought this was going to be a boring, academic exercise?!

Seriously, be prepared to explain exactly *why* these very bad things might happen in this system.

---

Answer 32

<b>Fault</b>	<b>Possible</b>	<b>Impossible</b>
PR-33 calibration error	✓	
PT-33 calibration error		✓
PIC-33 (input) calibration error	✓	
PY-33a calibration error	✓	
PY-33b calibration error		✓
PV-33a calibration error		✓
PV-33b calibration error		✓

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Answer 33

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Answer 34

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Answer 35

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Answer 36

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Answer 37

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Answer 38

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Answer 39

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Answer 40

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Answer 41

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Answer 42

**Partial answer:**

The `XD_Scale` high and low values are necessary to convert the channel value (from the instrument's transducer block) into a percentage (the `FIELD_VAL`). The `OUT_Scale` high and low values are necessary to convert this percentage-based `FIELD_VAL` into a scaled PV value, when the linearization type is set to "Indirect" or "Indirect Square Root." Otherwise, if the linearization type is set to "Direct," the PV output by the AI block will simply be equal to the channel value.

---

Answer 43

Parameters to set in each AI block (from page 3-5):

- `Channel` (options = 1 through 8)
- `L_Type` (options = direct, indirect, indirect square root)
- `XD_Scale` (options = upper range value, lower range value, unit, etc.)
- `OUT_Scale` (options = upper range value, lower range value, unit, etc.)
- Alarm limits and priorities

---

Answer 44

Consider this scenario: the final control device suffers a mechanical problem and stops responding to the PID controller's output signal. The utility of a "back calculation" signal should be easier to understand now.

---

Answer 45

The three status conditions are easy to research – I'll let you do that! Status propagation means that the status of a signal will "propagate" from the originating function block to subsequent function blocks in the program so that they make take appropriate actions.

---

Answer 46

**Partial answer:**

- Identify the length of a *macrocycle* in the timing diagram. *The period the entire sequence takes to repeat: from thick bar to thick bar in the timing diagram.*
- Explain why there is no CD token transmitted by the LAS between the PID and AO function block execution times. *Both blocks reside in the same field instrument and therefor do not need to communicate to each other over the bus.*
- Do you see any way to reallocate any function blocks to different field devices to gain more reliability for the control system? *Sure! (What???) You expect a detailed answer here?)*

---

Answer 47

I won't reveal any answers here, but I will suggest you explore the "Online" mode in the Emerson DeltaV DCS Control Studio utility to see a working example of how live signal values may be displayed in a function block diagram.

---

Answer 48

**Partial answer:**

Fault	Possible	Impossible
Trunk cable 1 failed open		
FF transmitter failed open	√	
Transmitter spur cable failed open		
Positioner spur cable failed open		√
Trunk cable 1 failed shorted		
FF transmitter failed shorted		
Transmitter spur cable failed shorted		
Positioner spur cable failed shorted		
24 VDC source dead		√

---

Answer 49

With the PID block resident in the transmitter, both the PID output and the back calculation signal must be communicated over the Fieldbus network. With the PID block resident in the valve positioner, only the PV signal needs to be communicated over the Fieldbus network. Thus, it is customary to place the PID function block in the final control element rather than in the transmitter to minimize scheduled (cyclic) Fieldbus communications. This allows for faster macrocycle times.

You should never place the PID block in the host (DCS) system unless that host is an actual Fieldbus device whose processing time is included in the LAS schedule. In most systems, this is not the case. If PID calculations are being done in a non-Fieldbus device, those calculations will not necessarily be available to the other Fieldbus devices when needed, causing non-deterministic behavior.

On a similar note, while it is possible to place the PID block for a control loop inside a field device for a completely different loop (e.g. the PID control block for flow control loop 101 residing within temperature transmitter 106, on the same segment), this may cause problems later on when that other field device fails or must be removed for maintenance. The totally distributed nature of FOUNDATION Fieldbus processing makes loop documentation very challenging, because it is now possible for "unrelated" field devices to be given critical roles in control loops!

---

Answer 50

The Resource Block contains all the specific parameters and characteristics for a field device. The algorithm implemented by the Resource Block is unique to the device and may vary from manufacturer to manufacturer.

The Transducer Block handles direct I/O interfacing with sensors or output mechanisms on the device. Examples would include the differential capacitance cell on a Rosemount 3051 differential pressure transmitter; or the I/P, feedback potentiometer, and pressure sensors on a Fisher DVC6000 valve positioner.

At first it may seem as though the Transducer block would be redundant to the AI or AO blocks. However, it is not. The AI and AO blocks are *generic* function blocks designed to homogeneously connect with other general-purpose function blocks. The Transducer Block is specific to the particular device. AI and AO function blocks interface with Transducer blocks to provide a generic connection point to other function blocks.

Transducer blocks are not just essential for basic device operation, but they are also necessary for AO function blocks to generate “back calculation” output signals. For instance, the pressure sensor and stem position feedback potentiometer inputs on a Fisher DVC6000 valve positioner are used to generate the back-calculation signal value coming from any AO function block configured to it. These inputs are how the positioner “knows” the valve is responding.

---

Answer 51

The latter system “reads back” the motor’s status from the auxiliary contact on the contactor, rather than from a bit internal to the PLC (Y1). This gives it the ability to “sense” what is going on in the real world.

Imagine a case where the motor control power circuit fuse blew, preventing the motor contactor from energizing even when PLC output Y1 activates. The internally-latched PLC program would blissfully maintain an energized condition on Y1 output after someone presses the Start pushbutton even though the motor is not running (and will suddenly start if anyone replaces the blown fuse!). The externally-latched PLC program refuses to latch output Y1 on unless it senses the contactor has actually energized, making it a safer system.

A similar system of external latching is used on electric clothes dryers, to latch the motor control circuit on only when an external speed switch senses drum rotation. This prevents the unwanted condition of continuous motor and heater operation in the event of a broken belt (which would prevent the drum from turning).

---

Answer 52

For the valve positioner, the `BKCAL_OUT` signal represents actual valve stem position (assuming the positioner has a feedback mechanism to sense valve position). Otherwise, this signal based on the `OUT` value representing air pressure applied to the valve actuator.

For the motor drive, the `BKCAL_OUT` signal represents actual motor speed (assuming the drive has speed feedback from the motor). Otherwise, this signal based on the `OUT` value representing the frequency of power applied to the motor.

In *Cascade* mode, the AO function block follows the value of the signal sent to it through its `CAS_IN` input (from another FF function block). In *Auto* mode, the AO block holds steady at a setpoint value entered manually into the block. In *Manual* mode, the AO block outputs a fixed value and ignores the setpoint value.

---

Answer 53

The conveyor belt will suddenly “run away,” surging to full speed. A safer method would be to place the speed controller in manual mode first before disconnecting the tachogenerator wires.

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Answer 54

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Answer 55

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Answer 56

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Answer 57

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Answer 58

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Answer 59

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Answer 60

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Answer 61

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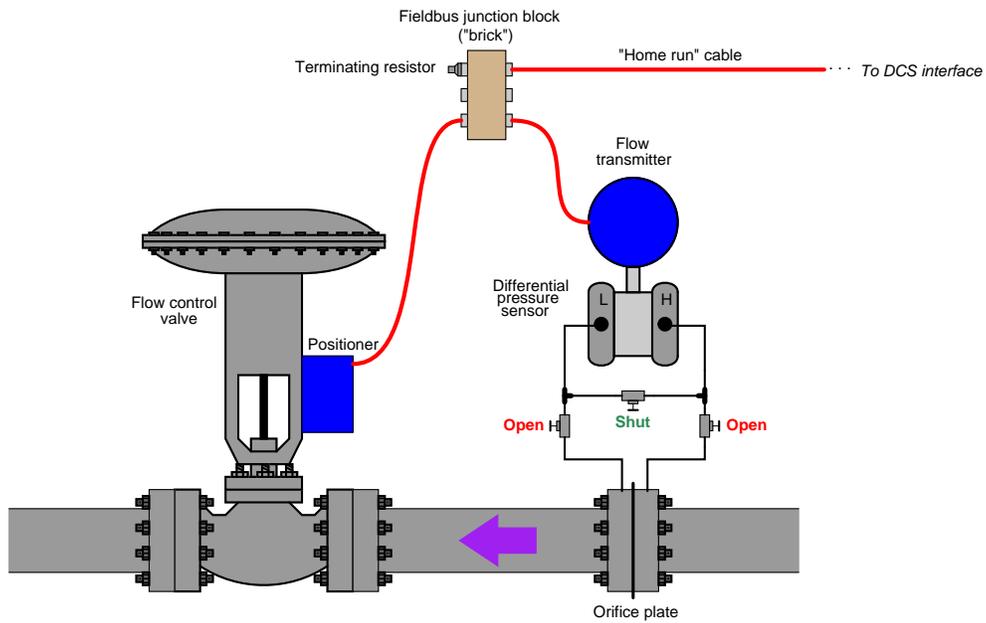
Answer 62

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Answer 63

**Partial answer:**

The L.Type parameter needs to be set to “Indirect Square Root”.



---

Answer 64

XD\_Scale = 40 to 200 degrees Fahrenheit

OUT\_Scale = -172 to -12 degrees (below boiling)

L\_Type = Indirect

---

Answer 65

- FIELD\_VAL = **68.615 %**
  - PV signal output by AI block = **257.3 gallons**
- 

Answer 66

Connecting a line-powered oscilloscope to a FF segment in this manner creates a *ground fault* in the system, which could (at worst) shut down communication throughout the entire segment!

---

Answer 67

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Answer 68

The data stream is 101010101010, based on what we know about Manchester encoding in general and FOUNDATION Fieldbus signals in particular.

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Answer 69

The L\_Type parameter needs to be set to “Direct”.

---

Answer 70

OUT\_Scale = 0 to 75 PSI

XD\_Scale = 3.6 to 78.6 PSI

L\_Type = Indirect

---

Answer 71

OUT\_Scale = 0 to 230 GPM

L\_Type = Indirect Square Root

XD\_Scale = 0 to 125 inches water column

The height difference between the pipe and the transmitter is completely irrelevant, because the extra pressure applied to each port is done so *equally* and therefore cancels at the transmitter, since the transmitter is inherently a *differential* pressure device.

---

Answer 72

L_Type	Indirect
XD_Scale	0 to 108 inches WC
OUT_Scale	0 to 18 feet

---

Answer 73

L.Type	Indirect
XD_Scale	0 to 180 inches WC
OUT_Scale	0 to 1178.1 cubic feet

---

Answer 74

Measurement	Indicative	Indeterminate
AC current between chassis ground and TB43-27		✓
DC voltage between TB43-24 and TB43-25		✓
AC voltage between TB105-2 and TB105-5		✓
AC voltage between TB102-7 and TB102-9	✓	
AC voltage between TB102-4 and TB102-5		✓
AC voltage between TB105-8 and TB105-9	✓	
Resistance between TB102-1 and TB102-2		✓

If when measuring AC voltage between TB102-7 and TB102-9, you detect 0 volts, it means the positive conductor is grounded. If measuring between the same two points you detect full FF signal voltage, it means the negative conductor is grounded.

If when measuring AC voltage between TB105-8 and TB105-9, you detect 0 volts, it means the negative conductor is grounded. If measuring between the same two points you detect full FF signal voltage, it means the positive conductor is grounded.

---

Answer 75

There probably will not be any effect at all from doing this, as the high-select function only sends the *highest* temperature signal to the controller. Of course, this means if TE-29c happened to sense a hotter temperature than the other elements and then was disconnected, the control system would see a small drop in temperature (as it now selected the next-highest transmitter's signal) and would send a bit more cooling water to the jacket as designed.

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Answer 76

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Answer 77

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Answer 78

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Answer 79

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Answer 80

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Answer 81

This is a graded question – no answers or hints given!

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Answer 82

This is a graded question – no answers or hints given!

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Answer 83

This is a graded question – no answers or hints given!

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Answer 84

This is a graded question – no answers or hints given!

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Answer 85

This is a graded question – no answers or hints given!

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Answer 86

This is a graded question – no answers or hints given!

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Answer 87

This is a graded question – no answers or hints given!

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Answer 88

This is a graded question – no answers or hints given!

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Answer 89

This is a graded question – no answers or hints given!

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Answer 90

This is a graded question – no answers or hints given!

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Answer 91

Students choosing the Emerson “THUM” *Wireless*HART adapter will encounter extra challenges. Here are some things to know about the THUM as a HART device:

- **HART addressing** – The THUM’s HART address is 63, whereas the wired HART device it connects to is HART address 0. You may communicate with either device using a HART communicator connected to the same location in the circuit (across the loop resistance works well) simply by specifying the polling address in the communicator (63 = talk with THUM ; 0 = talk with wired HART device).
- **Appearance on the Gateway** – if the THUM wirelessly connects to the Gateway as a sole device (i.e. no wired HART device connected to the THUM), the THUM appears on the Gateway’s device list under its own long HART tag name. If the THUM wirelessly connects to the Gateway while connected to a wired HART device, the THUM’s HART tag name appears nowhere, replaced instead by the wired HART device’s *Message* text field. I’m assuming the use of the “Message” field as a tag name stems from the fact that old HART devices didn’t support a long HART tag name, and so the THUM exploits the long-form Message field as a place to write a long tag name.
- **Voltage drop** – the THUM is very thrifty on power, passing the 4-20 mA current signal to the wired HART device while only dropping a couple of volts to “scavenge” power off that signal! This may take students by surprise as they measure DC voltage in the wired circuit during troubleshooting.