
Lab

Data acquisition and transport over Ethernet: *Question 111*, **completed objectives due by the end of day 6**

Exam

Day 6 – only a simple calculator may be used!

Specific objectives for the "mastery" exam:

- Electricity Review: Calculate voltages and currents in a DC series-parallel resistor circuit given source and resistor values
- Sketch proper wire connections for a data acquisition unit to measure an analog sensor signal
- Convert between different numeration systems (decimal, binary, hexadecimal, octal)
- Calculate ADC (analog-digital converter) 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
- INST230 Review: Determine status of a relay logic circuit given a schematic diagram and switch stimulus conditions
- INST241 Review: Identify (American) wire colors for different thermocouple types
- INST250 Review: Convert between different pressure units (PSI, "W.C., bar, etc.) showing proper mathematical cancellation of units (i.e. the "unity fraction" technique)

Recommended daily schedule

Day 1

Theory session topic: Ethernet networks

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

Day 2

Theory session topic: IP, TCP, and UDP

Questions 21 through 40; answer questions 21-28 in preparation for discussion (remainder for practice)

Day 3

Theory session topic: HART and Modbus protocols

Questions 41 through 60; answer questions 41-50 in preparation for discussion (remainder for practice)

Day 4

Theory session topic: LabVIEW software programming (in computer lab)

Questions 61 through 80; answer questions 61-64 in preparation for discussion (remainder for practice)

Day 5

Theory session topic: Review for exam

Questions 81 through 100; answer questions 81-89 in preparation for discussion (remainder for practice)

Feedback questions *(101 through 110)* are optional and may be submitted for review at the end of the day

Day 6

Exam

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: come to school prepared each and every day – this means completing all your homework *before* class starts. Use every minute of class and lab time productively. Follow all the tips outlined in "Question 0" (in every course worksheet) as well as your instructor's advice. Don't ask anyone to help you solve a problem until you have made every reasonable effort to solve it on your own.

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.

Identify scholarship opportunities: check your BTC email in-box daily.

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, because your instructor broadcast-emails job postings to all students as employers submit them to BTC.

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 and Expectations

Success in this career requires: professional integrity, resourcefulness, persistence, close attention to detail, and intellectual curiosity. Poor judgment spells disaster in this career, which is why employer background checks (including social media and criminal records) and drug testing are common. The good news is that character and clear thinking are malleable traits: unlike intelligence, these qualities can be acquired and improved with effort. *This is what you are in school to do* – increase your "human capital" which is the sum of all knowledge, skills, and traits valuable in the marketplace.

Mastery: You must master the fundamentals of your chosen profession. "Mastery" assessments challenge you to demonstrate 100% competence (with multiple opportunities to re-try). Failure to complete any mastery objective(s) 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.

Punctuality and Attendance: You are expected to arrive on time and be "on-task" all day just as you would for a job. Each student has 12 hours of "sick time" per quarter applicable to absences not verifiably employment-related, school-related, weather-related, or required by law. Each student must confer with the instructor to apply these hours to any missed time – this is not done automatically. Students may donate unused "sick time" to whomever they specifically choose. You must contact your instructor and lab team members immediately if you know you will be late or absent or must leave early. Absence on an exam day will result in a zero score for that exam, unless due to a documented emergency.

Time Management: You are expected to budget and prioritize your time, just as you will be on the job. You will need to reserve enough time outside of school to complete homework, and strategically apply your time during school hours toward limited resources (e.g. lab equipment). Frivolous activities (e.g. games, social networking, internet surfing) are unacceptable when work is unfinished. Trips to the cafeteria for food or coffee, smoke breaks, etc. must not interfere with team participation.

Independent Study: This career is marked by continuous technological development and ongoing change, which is why *self-directed learning* is ultimately more important to your future success than specific knowledge. To acquire and hone this skill, all second-year Instrumentation courses follow an "inverted" model where lecture is replaced by independent study, and class time is devoted to addressing your questions and demonstrating your learning. Most students require a *minimum* of 3 hours daily study time outside of school. Arriving unprepared (e.g. homework incomplete) is unprofessional and counter-productive. Question 0 of every worksheet lists practical study tips.

Independent Problem-Solving: The best instrument technicians are versatile problem-solvers. General problem-solving is arguably the most valuable skill you can possess for this career, and it can only be built through persistent effort. This is why you must take every reasonable measure to *solve problems on your own* before seeking help. It is okay to be perplexed by an assignment, but you are expected to apply problem-solving strategies given to you (see Question 0) and to precisely identify where you are confused so your instructor will be able to offer targeted help. Asking classmates to solve problems for you is folly – this includes having others break the problem down into simple steps. The point is to learn how to *think on your own.* When troubleshooting systems in lab you are expected to run diagnostic tests (e.g. using a multimeter instead of visually seeking circuit faults), as well as consult the equipment manual(s) before seeking help.

Initiative: No single habit predicts your success or failure in this career better than personal initiative, which is why your instructor will demand *you do for yourself rather than rely on others to do for you.* Examples include setting up and using your BTC email account to communicate with your instructor(s), consulting manuals for technical information before asking for help, regularly checking the course calendar and assignment deadlines, avoiding procrastination, fixing small problems before they become larger problems, etc. If you find your performance compromised by poor understanding of prior course subjects, re-read those textbook sections and use the practice materials made available to you on the Socratic Instrumentation website – don't wait for anyone else to diagnose your need and offer help.

Safety: You are expected to work safely in the lab just as you will be on the job. This includes wearing proper attire (safety glasses and closed-toed shoes in the lab at all times), implementing lock-out/tag-out procedures when working on circuits with exposed conductors over 30 volts, using ladders to access elevated locations, and correctly using all tools. If you need to use an unfamiliar tool, see the instructor for directions.

Orderliness: You are expected to keep your work area clean and orderly just as you will be on the job. This includes discarding trash and returning tools at the end of every lab session, and participating in all scheduled lab clean-up sessions. If you identify failed equipment in the lab, label that equipment with a detailed description of its symptoms.

Teamwork: You will work in instructor-assigned teams to complete lab assignments, just as you will work in teams to complete complex assignments on the job. As part of a team, you must keep your teammates informed of your whereabouts in the event you must step away from the lab or will be absent for *any* reason. Any student regularly compromising team performance through lack of participation, absence, tardiness, disrespect, or other disruptive behavior(s) will be removed from the team and required to complete all labwork individually for the remainder of the quarter. The same is true for students found relying on teammates to do their work for them.

Cooperation: The structure of these courses naturally lends itself to cooperation between students. Working together, students significantly impact each others' learning. You are expected to take this role seriously, offering real help when needed and not absolving classmates of their responsibility to think for themselves or to do their own work. Solving problems for classmates and/or explaining to them what they can easily read on their own is unacceptable because these actions circumvent learning. The best form of help you can give to your struggling classmates is to share with them your tips on independent learning and problem-solving, for example *asking questions* leading to solutions rather than simply providing solutions for them.

Grades: Employers prize trustworthy, hard working, knowledgeable, resourceful problem-solvers. The grade you receive in any course is but a *partial* measure of these traits. What matters most are the traits themselves, which is why your instructor maintains detailed student records (including individual exam scores, attendance, tardiness, and behavioral comments) and will share these records with employers if you have signed the FERPA release form. You are welcome to see your records at any time, and to compare calculated grades with your own records (i.e. the grade spreadsheet available to all students). You should expect employers to scrutinize your records on attendance and character, and also challenge you with technical questions when considering you for employment.

Representation: You are an ambassador for this program. Your actions, whether on tours, during a jobshadow or internship, or while employed, can open or shut doors of opportunity for other students. Most of the job opportunities open to you as a BTC graduate were earned by the good work of previous graduates, and as such you owe them a debt of gratitude. Future graduates depend on you to do the same.

Responsibility For Actions: If you lose or damage college property (e.g. lab equipment), you must find, repair, or help replace it. If you represent BTC poorly to employers (e.g. during a tour or an internship), you must make amends. The general rule here is this: *"If you break it, you fix it!"*

Non-negotiable terms: disciplinary action, up to and including immediate failure of a course, will result from academic dishonesty (e.g. cheating, plagiarism), willful safety violations, theft, harassment, intoxication, destruction of property, or willful disruption of the learning (work) environment. Such offenses are grounds for immediate termination in this career, and as such will not be tolerated here.

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Course Syllabus

INSTRUCTOR CONTACT INFORMATION:

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DEPT/COURSE #: INST 260

CREDITS: 4 **Lecture Hours:** 20 **Lab Hours:** 52 **Work-based Hours:** 0

COURSE TITLE: Data Acquisition Systems

COURSE DESCRIPTION: This course reviews digital theory learned in the first year (Core Electronics) courses, building upon that foundation to explore industrial data busses (including Ethernet) and indicating, datalogging, and SCADA systems. **Pre/Corequisite course:** INST 200 (Introduction to Instrumentation) **Prerequisite course:** MATH&141 (Precalculus 1) with a minimum grade of "C"

COURSE OUTCOMES: Commission, analyze, and efficiently diagnose instrumented systems using data acquisition units and industry-standard protocols to transport process data over wired and wireless networks.

COURSE OUTCOME ASSESSMENT: Data acquisition system commissioning, analysis, and diagnosis outcomes are ensured by measuring student performance against mastery standards, as documented in the Student Performance Objectives. Failure to meet all mastery standards by the next scheduled exam day will result in a failing grade for the course.

STUDENT PERFORMANCE OBJECTIVES:

- Without references or notes, within a limited time (3 hours total for each exam session), independently perform the following tasks. Multiple re-tries are allowed on mastery (100% accuracy) objectives, each with a different set of problems:
  → Calculate voltages and currents in a DC series-parallel resistor circuit given source and resistor values, with 100% accuracy (mastery)
  → Sketch proper wire connections for a data acquisition unit to measure an analog sensor signal, with 100% accuracy (mastery)
  → Convert between different numeration systems (decimal, binary, hexadecimal, octal), with 100% accuracy (mastery)
  → Calculate ADC (analog-digital converter) input and output values given calibrated ranges, with 100% accuracy (mastery)
  → Solve for specified variables in algebraic formulae, with 100% accuracy (mastery)
  → Determine the possibility of suggested faults in simple circuits given measured values (voltage, current), schematic diagrams, and reported symptoms, with 100% accuracy (mastery)
  → Predict the response of networked instrumentation systems to component faults and changes in process conditions, given pictorial and/or schematic illustrations
  → Sketch proper power and signal connections between individual instruments to fulfill specified control system functions, given pictorial and/or schematic illustrations of those instruments
- In a team environment and with full access to references, notes, and instructor assistance, perform the following tasks:
  → Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems
  → Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all labwork
  → Construct and commission a working data acquisition system consisting of a DAQ unit, signal wiring, Ethernet wiring and components, and a personal computer running DAQ software
  → Generate accurate schematic diagrams documenting your team's DAQ system
- Independently perform the following tasks with 100% accuracy (mastery). Multiple re-tries are allowed with different specifications/conditions each time):
  → Design and build a circuit responding to changes in either light intensity or ambient temperature
  → Diagnose a random fault placed in another team's data acquisition system by the instructor within a limited time using no test equipment except a multimeter and network diagnostic utilities on the personal computer, logically justifying your steps in the instructor's direct presence

COURSE OUTLINE: A course calendar in electronic format (Excel spreadsheet) resides on the Y: network drive, and also in printed paper format in classroom DMC130, for convenient student access. This calendar is updated to reflect schedule changes resulting from employer recruiting visits, interviews, and other impromptu events. Course worksheets provide comprehensive lists of all course assignments and activities, with the first page outlining the schedule and sequencing of topics and assignment due dates. These worksheets are available in PDF format at `http://www.ibiblio.org/kuphaldt/socratic/sinst`

- INST260 Section 1 (Digital data acquisition and serial communication): 4 days theory and labwork
- INST260 Section 2 (Serial network standards): 4 days theory and labwork
- INST260 Section 3 (Industrial networking): 5 days theory and labwork + 1 day for proportional Exam

METHODS OF INSTRUCTION: Course structure and methods are intentionally designed to develop critical-thinking and life-long learning abilities, continually placing the student in an active rather than a passive role.

- **Independent study:** daily worksheet questions specify *reading assignments*, *problems* to solve, and *experiments* to perform in preparation (before) classroom theory sessions. Open-note quizzes and work inspections ensure accountability for this essential preparatory work. The purpose of this is to convey information and basic concepts, so valuable class time isn't wasted transmitting bare facts, and also to foster the independent research ability necessary for self-directed learning in your career.
- **Classroom sessions:** a combination of *Socratic discussion*, short *lectures*, *small-group* problem-solving, and hands-on *demonstrations/experiments* review and illuminate concepts covered in the preparatory questions. The purpose of this is to develop problem-solving skills, strengthen conceptual understanding, and practice both quantitative and qualitative analysis techniques.
- **Lab activities:** an emphasis on constructing and documenting *working projects* (real instrumentation and control systems) to illuminate theoretical knowledge with practical contexts. Special projects off-campus or in different areas of campus (e.g. BTC's Fish Hatchery) are encouraged. Hands-on *troubleshooting exercises* build diagnostic skills.
- **Feedback questions:** sets of *practice problems* at the end of each course section challenge your knowledge and problem-solving ability in current as as well as first year (Electronics) subjects. These are optional assignments, counting neither for nor against your grade. Their purpose is to provide you and your instructor with direct feedback on what you have learned.
- **Tours and guest speakers:** quarterly *tours* of local industry and *guest speakers* on technical topics add breadth and additional context to the learning experience.

STUDENT ASSIGNMENTS/REQUIREMENTS: All assignments for this course are thoroughly documented in the following course worksheets located at:
`http://www.ibiblio.org/kuphaldt/socratic/sinst/index.html`

- `INST260_sec1.pdf`
- `INST260_sec2.pdf`
- `INST260_sec3.pdf`

EVALUATION AND GRADING STANDARDS: (out of 100% for the course grade)

- Completion of all mastery objectives = 50%
- Mastery exam score (first attempt) = 10%
- Proportional exam score = 30%
- Lab questions = 10%
- Quiz penalty = -1% per failed quiz
- Tardiness penalty = -1% per incident (1 "free" tardy per course)
- Attendance penalty = -1% per hour (12 hours "sick time" per quarter)
- Extra credit = +5% per project

All grades are criterion-referenced (i.e. no grading on a "curve")

100% ≥ **A** ≥ 95%	95% > **A-** ≥ 90%		
90% > **B+** ≥ 86%	86% > **B** ≥ 83%	83% > **B-** ≥ 80%	
80% > **C+** ≥ 76%	76% > **C** ≥ 73%	73% > **C-** ≥ 70% (minimum passing course grade)	
70% > **D+** ≥ 66%	66% > **D** ≥ 63%	63% > **D-** ≥ 60%	60% > **F**

A graded "preparatory" quiz at the start of each classroom session gauges your independent learning prior to the session. A graded "summary" quiz at the conclusion of each classroom session gauges your comprehension of important concepts covered during that session. If absent during part or all of a classroom session, you may receive credit by passing comparable quizzes afterward or by having your preparatory work (reading outlines, work done answering questions) thoroughly reviewed prior to the absence.

Absence on a scheduled exam day will result in a 0% score for the proportional exam unless you provide documented evidence of an unavoidable emergency.

If you fail a mastery exam, you must re-take a different version of that mastery exam on a different day. Multiple re-tries are allowed, on a different version of the exam each re-try. There is no penalty levied on your course grade for re-taking mastery exams, but failure to successfully pass a mastery exam by the due date (i.e. by the date of the *next* exam in the course sequence) will result in a failing grade (F) for the course.

If any other "mastery" objectives are not completed by their specified deadlines, your overall grade for the course will be capped at 70% (C- grade), and you will have one more school day to complete the unfinished objectives. Failure to complete those mastery objectives by the end of that extra day (except in the case of documented, unavoidable emergencies) will result in a failing grade (F) for the course.

"Lab questions" are assessed by individual questioning, at any date after the respective lab objective (mastery) has been completed by your team. These questions serve to guide your completion of each lab exercise and confirm participation of each individual student. Grading is as follows: full credit for thorough, correct answers; half credit for partially correct answers; and zero credit for major conceptual errors. All lab questions must be answered by the due date of the lab exercise.

Extra credit opportunities exist for each course, and may be assigned to students upon request. The student and the instructor will first review the student's performance on feedback questions, homework, exams, and any other relevant indicators in order to identify areas of conceptual or practical weakness. Then, both will work together to select an appropriate extra credit activity focusing on those identified weaknesses, for the purpose of strengthening the student's competence. A due date will be assigned (typically two weeks following the request), which must be honored in order for any credit to be earned from the activity. Extra credit may be denied at the instructor's discretion if the student has not invested the necessary preparatory effort to perform well (e.g. lack of preparation for daily class sessions, poor attendance, no feedback questions submitted, etc.).

REQUIRED STUDENT SUPPLIES AND MATERIALS:

- Course worksheets available for download in PDF format
- *Lessons in Industrial Instrumentation* textbook, available for download in PDF format
  → Access worksheets and book at: `http://www.ibiblio.org/kuphaldt/socratic/sinst`
- Spiral-bound notebook for reading annotation, homework documentation, and note-taking.
- Laptop computer with Ethernet port (and ideally with a USB-to-serial RS-232 converter) for performing network experiments.
- Instrumentation reference CD-ROM (free, from instructor). This disk contains many tutorials and datasheets in PDF format to supplement your textbook(s).
- Tool kit (see detailed list)
- Simple scientific calculator (non-programmable, non-graphing, no unit conversions, no numeration system conversions), TI-30Xa or TI-30XIIS recommended

ADDITIONAL INSTRUCTIONAL RESOURCES:

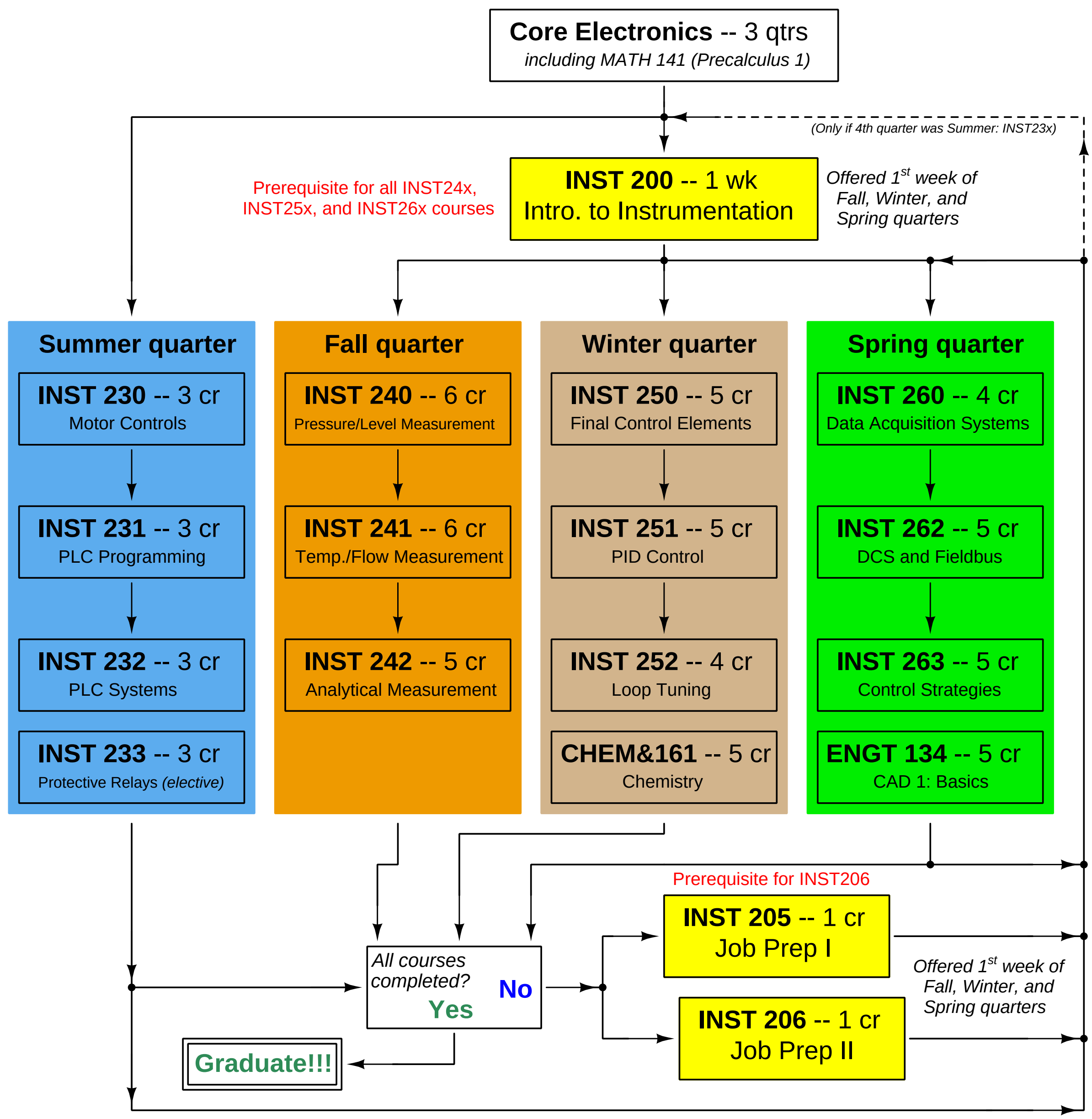
- The BTC Library hosts a substantial collection of textbooks and references on the subject of Instrumentation, as well as links in its online catalog to free Instrumentation e-book resources available on the Internet.
- "BTCInstrumentation" channel on YouTube (`http://www.youtube.com/BTCInstrumentation`), hosts a variety of short video tutorials and demonstrations on instrumentation.
- *Webster's New World Telecom Dictionary*, written by Ray Horak, published by Wiley Publishing; ISBN-13: 978-0471774570.
- *Ethernet: the definitive guide*, written by Charles E. Spurgeon, published by O'Reilly ; ISBN-10: 1565926609 ; ISBN-13: 978-1565926608.
- ISA Student Section at BTC meets regularly to set up industry tours, raise funds for scholarships, and serve as a general resource for Instrumentation students. Membership in the ISA is $10 per year, payable to the national ISA organization. Membership includes a complementary subscription to *InTech* magazine.
- ISA website (`http://www.isa.org`) provides all of its standards in electronic format, many of which are freely available to ISA members.
- *Purdy's Instrument Handbook*, by Ralph Dewey. ISBN-10: 1-880215-26-8. A pocket-sized field reference on basic measurement and control.
- *Cad Standard* (CadStd) or similar AutoCAD-like drafting software (useful for sketching loop and wiring diagrams). Cad Standard is a simplified clone of AutoCAD, and is freely available at: `http://www.cadstd.com`

CAMPUS EMERGENCIES: If an emergency arises, your instructor may inform you of actions to follow. You are responsible for knowing emergency evacuation routes from your classroom. If police or university officials order you to evacuate, do so calmly and assist those needing help. You may receive emergency information alerts via the building enunciation system, text message, email, or BTC's webpage (`http://www.btc.ctc.edu`), Facebook or Twitter. Refer to the emergency flipchart in the lab room (located on the main control panel) for more information on specific types of emergencies.

ACCOMMODATIONS: If you think you could benefit from classroom accommodations for a disability (physical, mental, emotional, or learning), please contact our Accessibility Resources office. Call (360)-752-8345, email `ar@btc.ctc.edu`, or stop by the AR Office in the Admissions and Student Resource Center (ASRC), Room 106, College Services Building

file `INST260syllabus`

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:

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: *when turning any threaded fastener, one should choose a tool engaging the maximum amount of surface area on the fastener's head in order 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
- Tongue-and-groove pliers (sometimes called "Channel-lock" 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
- Alligator-clip 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!
- Masking tape (for making temporary labels)
- Permanent marker pen
- Teflon pipe tape
- Utility knife
- Tape measure, 12 feet minimum
- Flashlight

An inexpensive source of tools is your local pawn shop. Look for tools with unlimited lifetime guarantees (e.g. *Sears* "Craftsman" brand). Check for BTC student discounts as well!

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*.

Theory

In the theory portion of each course, students independently research subjects *prior* to entering the classroom for discussion. This means working through all the day's assigned questions as completely as possible. This usually requires a fair amount of technical reading, and may also require setting up and running simple experiments. At the start of the classroom session, the instructor will check each student's preparation with a quiz. Students then spend the rest of the classroom time working in groups and directly with the instructor to *thoroughly* answer all questions assigned for that day, articulate problem-solving strategies, and to approach the questions from multiple perspectives. To put it simply: fact-gathering happens outside of class and is the individual responsibility of each student, so that class time may be devoted to the more complex tasks of critical thinking and problem solving where the instructor's attention is best applied.

Classroom theory sessions usually begin with either a brief Q&A discussion or with a "Virtual Troubleshooting" session where the instructor shows one of the day's diagnostic question diagrams while students propose diagnostic tests and the instructor tells those students what the test results would be given some imagined ("virtual") fault scenario, writing the test results on the board where all can see. The students then attempt to identify the nature and location of the fault, based on the test results.

Each student is free to leave the classroom when they have completely worked through all problems and have answered a "summary" quiz designed to gauge their learning during the theory session. If a student finishes ahead of time, they are free to leave, or may help tutor classmates who need extra help.

The express goal of this "inverted classroom" teaching methodology is to help each student cultivate critical-thinking and problem-solving skills, and to sharpen their abilities as independent learners. While this approach may be very new to you, it is more realistic and beneficial to the type of work done in instrumentation, where critical thinking, problem-solving, and independent learning are "must-have" skills.

Lab

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 eight-day period typically allotted 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)
(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.

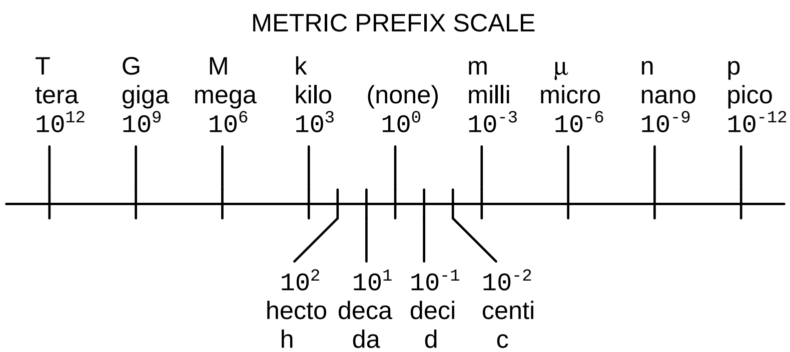
In lieu of small-group activities and class discussions, comprehension of the theory portion of each course will be ensured by completing and submitting detailed answers for *all* worksheet questions, not just passing daily quizzes as is the standard for conventional students. The instructor will discuss 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.

file `distance`

- **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: μ
- 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**
- ^{o}F = (^{o}C)(9/5) + 32
- ^{o}C = (^{o}F - 32)(5/9)
- ^{o}R = ^{o}F + 459.67
- K = ^{o}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^3) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm^3)

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^2) = 4840 square yards (yd^2) = 4046.86 square meters (m^2)

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^{10} 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^2) = 32.1740 feet per second per second (ft/s^2)

Physical constants

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

Avogadro's number (N_A) = 6.022×10^{23} per mole (mol^{-1})

Electronic charge (e) = 1.602×10^{-19} Coulomb (C)

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

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

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

Properties of Water

Freezing point at sea level = 32^oF = 0^oC

Boiling point at sea level = 212^oF = 100^oC

Density of water at 4^oC = 1000 kg/m^3 = 1 g/cm^3 = 1 kg/liter = 62.428 lb/ft^3 = 1.94 slugs/ft^3

Specific heat of water at 14^oC = 1.00002 calories/g$\cdot^o$C = 1 BTU/lb$\cdot^o$F = 4.1869 Joules/g$\cdot^o$C

Specific heat of ice $\approx$ 0.5 calories/g$\cdot^o$C

Specific heat of steam $\approx$ 0.48 calories/g$\cdot^o$C

Absolute viscosity of water at 20^oC = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa$\cdot$s)

Surface tension of water (in contact with air) at 18^oC = 73.05 dynes/cm

pH of pure water at 25^o C = 7.0 (*pH scale = 0 to 14*)

Properties of Dry Air at sea level

Density of dry air at 20^oC and 760 torr = 1.204 mg/cm^3 = 1.204 kg/m^3 = 0.075 lb/ft^3 = 0.00235 slugs/ft^3

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

How to get the most out of academic reading:

- Articulate your thoughts as you read (i.e. "have a conversation" with the author). This will develop *metacognition*: active supervision of your own thoughts. Write your thoughts as you read, noting points of agreement, disagreement, confusion, epiphanies, and connections between different concepts or applications. These notes should also document important math formulae, explaining in your own words what each formula means and the proper units of measurement used.
- Outline, don't highlight! Writing your own summary or outline is a far more effective way to comprehend a text than simply underlining and highlighting key words. A suggested ratio is one sentence of your own thoughts per paragraph of text read. Note points of disagreement or confusion to explore later.
- 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.
- Write your own questions based on what you read, as though you are a teacher preparing to test students' comprehension of the subject matter.

How to effectively problem-solve and troubleshoot:

- Study principles, not procedures. Don't be satisfied with merely knowing how to compute solutions – learn *why* those solutions work. In mathematical problem-solving this means being able to identify the practical meaning (and units of measurement) of every intermediate calculation. In other words, *every step of your solution should make logical sense.*
- Sketch a diagram to help visualize the problem. 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 real systems, perform *diagnostic tests* rather than visually inspecting 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). Often you can add or remove components in a malfunctioning system to simplify it as well and better identify the nature and location of the problem.
- Work "backward" from a hypothetical solution to a new set of given conditions.

How to create more time for study:

- Kill your television and video games. Seriously – these are incredible wastes of time. Eliminate distractions (e.g. cell phone, internet, socializing) in your place and time of study.
- Use your "in between" time productively. Don't leave campus for lunch. Arrive to school early. If you finish your assigned work early, begin studying the next day's material.

Above all, cultivate persistence. Persistent effort 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`

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file `license`

Question 1

Read and outline the introduction to the "Ethernet Networks" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04419

Question 2

When multiple digital devices "talk" together on a common network, they must have some way of arbitrating who gets to talk, and in what order. Otherwise there will be data loss as multiple devices inevitably attempt to transmit at the same time.

A variety of protocols exist to handle this problem. A few are listed here:

- Master/slave
- Token passing
- TDMA (*Time Division Multiple Access*)
- CSMA/CD (*Carrier Sense Multiple Access / Collision Detect*)
- CSMA/BA (*Carrier Sense Multiple Access / Bitwise Arbitration*)
- CSMA/CA (*Carrier Sense Multiple Access / Collision Avoidance*)

Explain how each of these protocols works, and identify which one is used in the *Ethernet* communication standard (IEEE 802.3).

Suggestions for Socratic discussion

- *Wireless* communications such as WLAN (IEEE 802.11) absolutely *cannot* use CSMA/CD protocol. Explain why this is.
- Explain what "jabbering" is, in your own words, and what effect it will have on networks using each of these five different protocols.
- Identify ways to identify a "jabbering" problem occurring in a network.

file i02200

Question 3

Read and outline the "Repeaters (Hubs)" subsection of the "Ethernet Networks" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04420

Question 4

Read and outline the "Ethernet Cabling" subsection of the "Ethernet Networks" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04421

Question 5

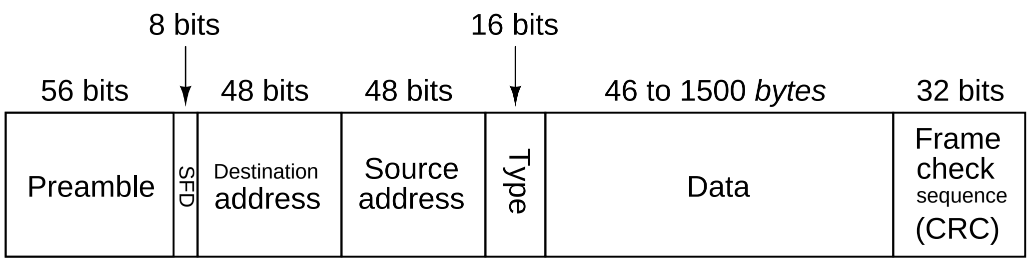
Read and outline the "Switching Hubs" subsection of the "Ethernet Networks" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

Note: a video demonstration of the difference between an Ethernet switch and an Ethernet hub (repeater) may be viewed on the BTC Instrumentation YouTube channel (search for a video named "Ethernet hubs versus switches"). In this video, we see a potential problem that can arise if you move cables from port to port on an Ethernet switch.

file i04422

Question 6

Data in an Ethernet network is transmitted in a series of bits known as a *frame*. A basic organizational illustration for an Ethernet frame is as follows (according to the IEEE 802.3 standard):



Explain the purpose of each frame section:

- Preamble:
- SFD:
- Destination address:
- Source address:
- Type (or Length):
- Data:
- Frame check sequence:

Suggestions for Socratic discussion

- The *preamble* section of an Ethernet frame is extremely important for practical reasons, although at first blush it appears to be useless (an alternating sequence of 1's and 0's?). Explain why the preamble is a necessary component of the Ethernet frame.
- Ethernet data frames do not use a "parity" bit as is the case with data frames of RS-232 and other (simpler) serial network standards. Why is a parity bit unnecessary with Ethernet? Explain why a parity bit would be far less useful (if it was used) in Ethernet than it is in an RS-232 data frame.

file i02204

Question 7

Each Ethernet device manufactured in the world today possesses a unique identifying number, known as a *MAC address* or *hardware address*. This address is 6 bytes, or octets, long (48 bits). An example of a valid Ethernet MAC address is shown here:

`D2-48-1C-30-EA-B5`

Given the number of bits in a MAC address field, how many unique identifier addresses can exist in the world?

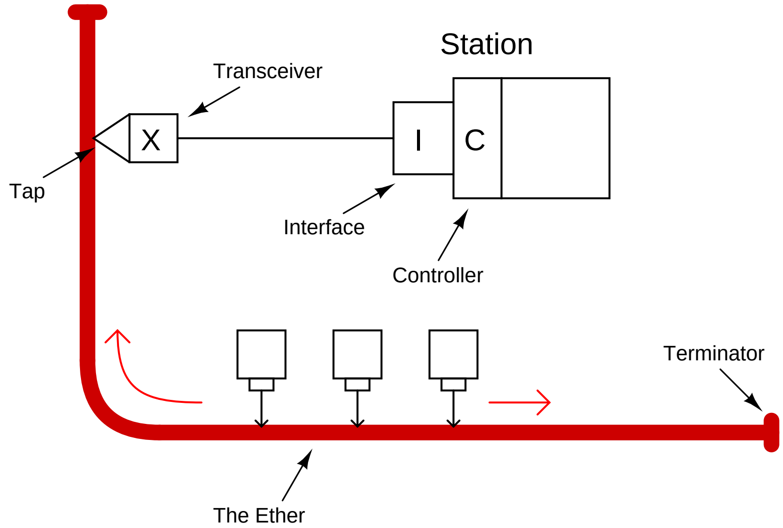
Suggestions for Socratic discussion

- Ethernet MAC addresses are very interesting, in that each one is unique to a single manufactured device. Explain why this is.
- Describe what might happen in an Ethernet network if two or more devices shared the same MAC address.
- In cyber-crime investigations, MAC addresses can be important. Explain why, and also describe how the MAC address of a cyber-criminal might be identified.
- On your personal computer, open up a command-line interface ("cmd" on Microsoft Windows operating systems) and issue the command `arp -a` to see a listing of known IP addresses and their corresponding MAC addresses on your computer's network.

file i02205

Question 8

In 1976, an engineer named Bob Metcalfe designed a new type of digital communication standard he dubbed *Ethernet*. A sketch he drew of his new system looked like this:



Explain the basic concept behind Metcalfe's Ethernet system, and why he chose the word "ether" to name it. Also, identify the bit rate (speed) at which his original Ethernet communicated at.

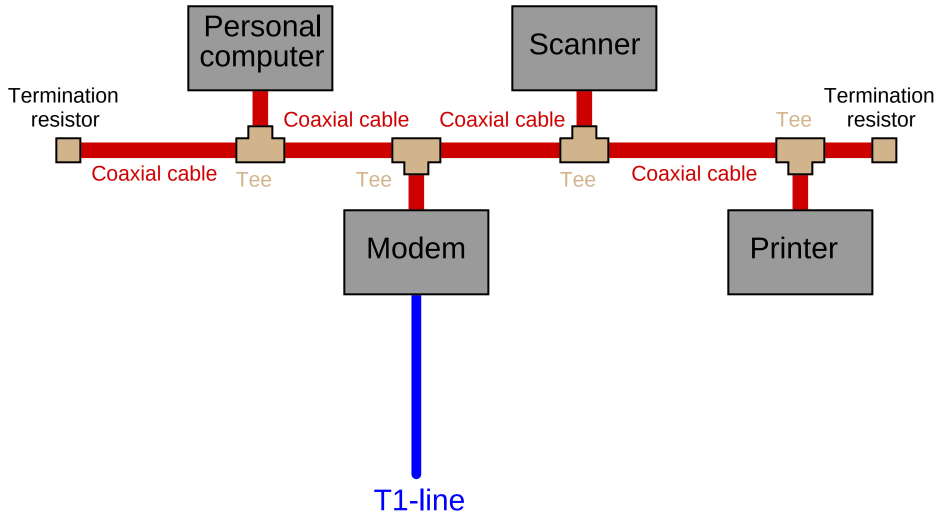
Suggestions for Socratic discussion

- Identify some disadvantages of the original coaxial-based Ethernet versus modern twisted-pair (with hubs) Ethernet networks.

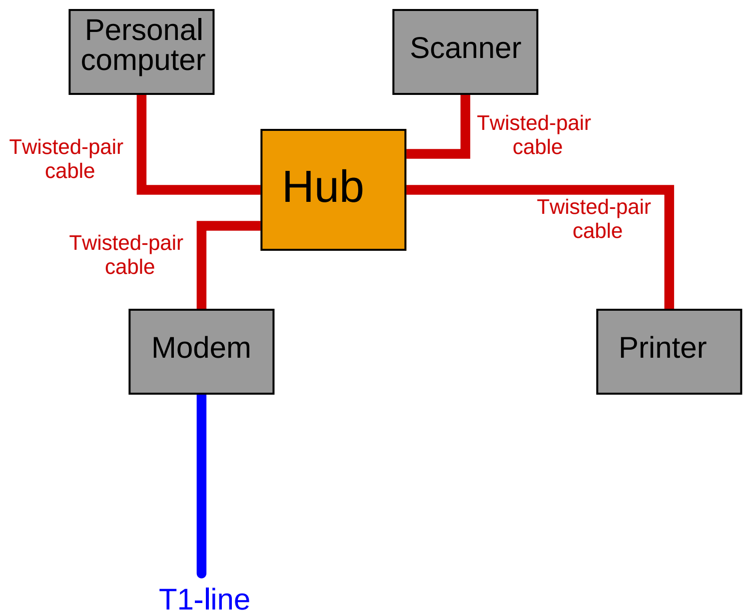
file i02201

Question 9

Bob Metcalfe's original Ethernet communication standard was based on "thick" coaxial cable. Connections to this cable were made using coaxial "Tee" fittings.



This approach was eventually discarded in favor of twisted-pair cabling without any mid-point taps. With twisted-pair wiring, the end of a cable always plugged in to a piece of equipment, either DTE or DCE:



Explain what the purpose of the *hub* is, and how it is more than just a connection point like a tee fitting in the old coaxial-based cable standard.

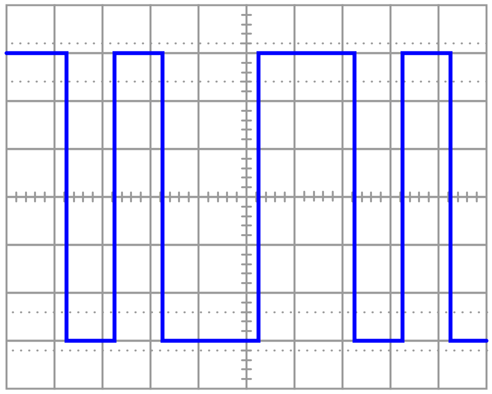
Note how the new hub-based approach does not require any termination resistors, even though the twisted-pair cables may be quite long (up to 100 meters). Explain how it is possible to go without termination resistors given such long cable lengths and high data rates (100 Mbps or more!), where they were absolutely required at the ends of the old coaxial cables.

file i02202

Question 10

Binary "1" and "0" states are not encoded using specific voltage levels in Ethernet systems as is the case with EIA/TIA-232, 422, or 485. Rather, a different scheme known as *Manchester encoding* is used for Ethernet signals. In Manchester encoding, each bit (either a 0 or a 1) is represented by a particular *transition* from low-to-high or from high-to-low. In the IEEE standard for Manchester encoding, a high-to-low transition represents a "0" bit while a low-to-high transition represents a "1" bit.

Examine this Manchester-encoded signal on an oscilloscope screen, and determine the sequence of "1" and "0" bits represented by the waveform:

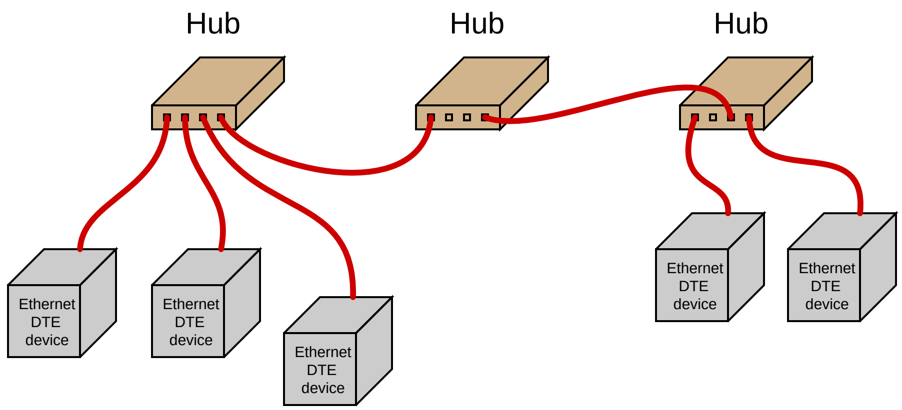


Hint: it may be easier to begin by sketching the waveform to represent a particular bit sequence. For example, try sketching the Manchester encoded waveform to represent the bit sequence `1 0 1 1 0` first, then analyze the waveform given to you in this question.

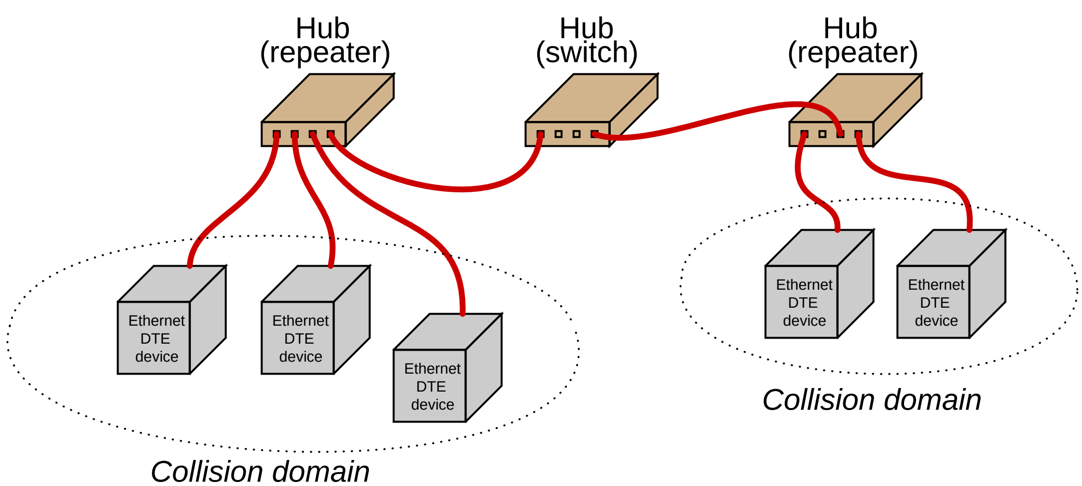
file i02203

Question 11

Twisted-pair Ethernet networks with more than two nodes must use some form of *hub* to connect everything together. Each hub has a limited number of ports, but hubs may be cascaded to form networks larger than the port limit:



All hubs are not created equal, though – they come in two varieties: *repeaters* and *switches*. If we were to use simple *repeater* hubs, all five Ethernet DTE devices would belong to the same collision domain. If we were to replace the middle repeater with a *switching* hub, however, we would have multiple collision domains instead of just one:



Explain how the operation of a switching hub (or just "switch") differs from a regular repeating hub, and how this difference results in the splitting of collision domains.

file i02206

Question 12

Twisted-pair Ethernet devices share a similar problem with EIA/TIA-232, 422, and 485 devices in that the *transmit* (TD) terminals on one device need to connect to the *receive* (RD) terminals on another. If a DTE device is connected to a DCE device, the cable wiring will be "straight" (pin 1 on one end connects to pin 1 on the other end, pin 2 with pin 2, pin 3 with pin 3, etc.). If, however, you wish to do something such as connect two computers together without a hub in between, a "straight" cable will not work, because the transmit pins on one computer will be connected through to the transmit pins on the other computer.

The fix for this problem is a special cable called a *crossover* cable. In the context of EIA/TIA-232, this is called a *null modem cable*, and it involves the same principle. Describe what that principle is.

file i02208

Question 13

Ethernet actually encompasses several similar network standards, varying by cable type and bit rate (speed). The IEEE has designated special identifier names to denote each variety of Ethernet media. Identify which type of Ethernet each of these names refers to:

- 10BASE2:
- 10BASE5:
- 10BASE-T:
- 10BASE-F:
- 100BASE-TX:
- 100BASE-FX:
- 1000BASE-T:
- 1000BASE-SX:
- 1000BASE-LX:

Suggestions for Socratic discussion

- Ethernet networks are considered "baseband" rather than "broadband." Explain the distinction between these two terms.

file i02209

Question 14

A fact of life in Ethernet networks is an event called a *collision*. While collisions are normal for an Ethernet network, too high of a collision rate will definitely slow down data transfer.

If we imagine a worst-case scenario, where every device (node) on an Ethernet network is always trying to send data, the probability of a node being delayed due to another node transmitting in the same time slot is $1 - \frac{1}{N}$, where N is the number of nodes, and the probability value lies between 0 and 1 inclusive. As you can see, the probability of collision for a 1-node Ethernet network is zero (there are no other nodes to interfere with), while the probability of delay is 1 (100% chance = absolutely guaranteed all the time) in an Ethernet network having an infinite number of nodes.

The probability that any one node is able to transmit without being delayed by any other node is equal to the probability that all the other nodes on the network are getting delayed by its success. This probability P is equal to:

$$P = \left(1 - \frac{1}{N}\right)^{N-1}$$

The average number of time slots (M) that an Ethernet node must wait before it may transmit depends on this probability:

$$M = \frac{1-P}{P}$$

Build a computer spreadsheet to calculate both the probability of no-delay transmission (P) and the average number of time slots waiting to transmit (M), then see how these numbers are affected by the number of nodes (N) on the Ethernet network. The following example layout uses yellow shading for the one cell where you enter the number of nodes, and blue shading for those cells containing calculated values (the color-shading being entirely optional):

	1	**2**	**3**	**4**	**5**
1	`# of nodes =`				
2					
3	`P (no delay) =`				
4	`Avg slots =`				
5					

Do the results surprise you? If so, how?

Suggestions for Socratic discussion

- Examining the formula $1 - \frac{1}{N}$ and imagining the cases of 1 node ($N = 1$) versus an infinite number of nodes ($N = \infty$) is an exercise mathematicians refer to as *limits*. Formally written, the limit as N approached infinity is: $\lim_{N \to \infty} \left(1 - \frac{1}{N}\right) = 1$. Even though a quantity like "infinity" cannot be handled by a calculator or a spreadsheet program, the concept of imagining what a mathematical function will do as a variable *approaches* infinity is still very useful. Identify the problem-solving technique listed in question 0 that most closely resembles this concept.

file i02207

Question 15

Question 16

Question 17

Question 18

Question 19

Question 20

Question 21

Read and outline the introduction to the "Internet Protocol (IP)" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04444

Question 22

Read and outline the "IP Addresses" subsection of the "Internet Protocol (IP)" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04445

Question 23

Read and outline the "Subnetworks and Subnet Masks" subsection of the "Internet Protocol (IP)" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04446

Question 24

Read and outline the "Command-Line Diagnostic Utilities" subsection of the "Internet Protocol (IP)" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04447

Question 25

The fourth version of the *IP* (Internet Protocol) standard, known as IPv4, specifies an address that is 32 bits wide. The address is usually expressed in the form of four "octets" translated into decimal form and separated by periods. Here is an example of an IPv4 address:

`196.252.70.183`

What are the largest and the smallest IPv4 addresses possible in this format? How many total unique addresses does this work out to be?

The next version of IP is version 6 (version 5 was experimental). IPv6 uses a 128-bit wide address. How many "octets" does it take to express an IPv6 address? How many unique addresses can be represented in the IPv6 field?

Suggestions for Socratic discussion

- Are there any special IP addresses reserved for specific purposes?
- How do the address spaces of IPv4 and IPv6 compare to that of Ethernet MAC address space?
- Why are IP addresses required in addition to Ethernet MAC addresses in a network where most devices are Ethernet-based?
- Explain what `192.168.25.7/24` means as an IP address.
- Explain what `192.168.25.7/8` means as an IP address.

file i02241

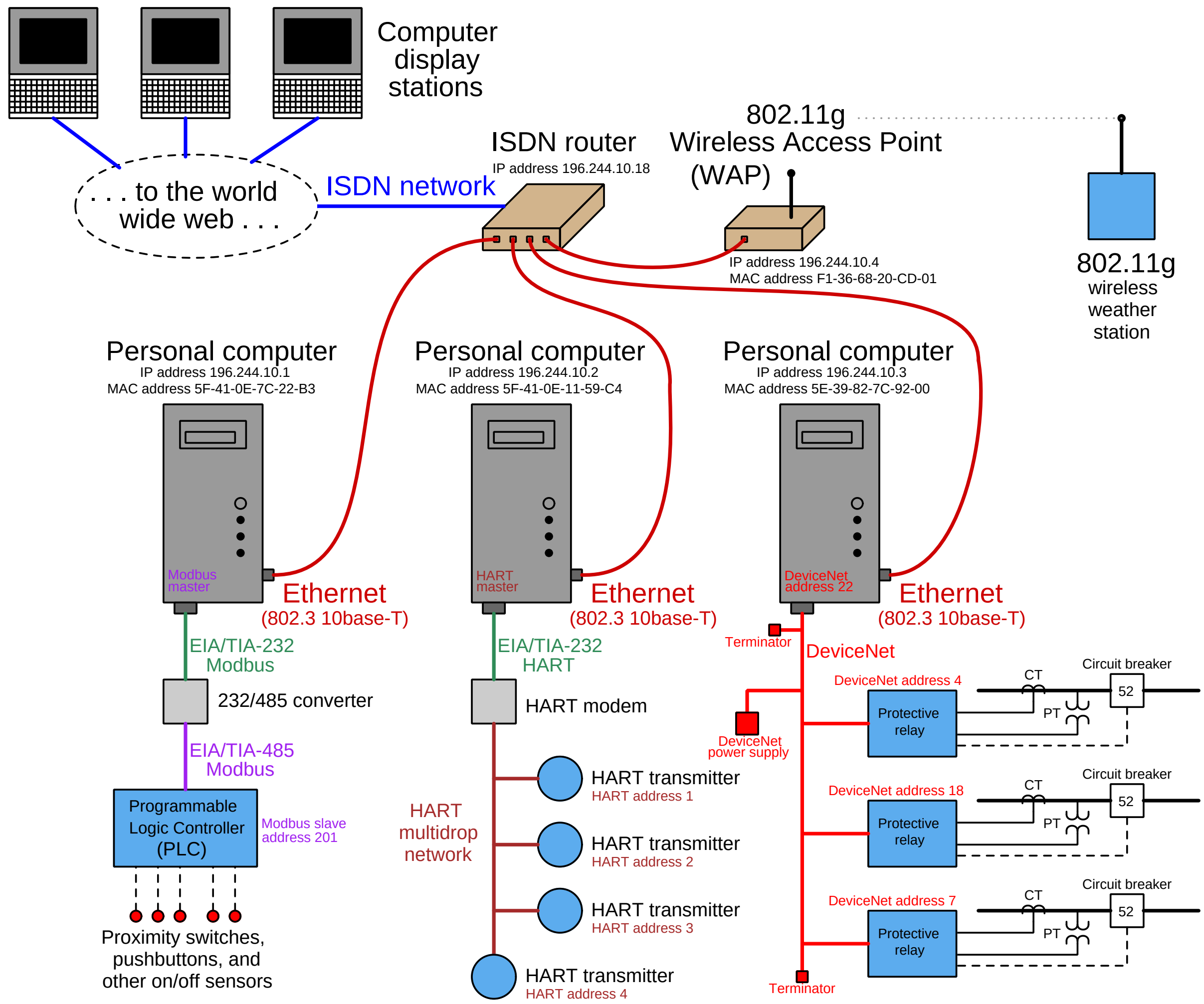
Question 26

Read and outline the "Transmission Control Protocol (TCP) and User Datagram Protocol (UDP)" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04448

Question 27

Examine this network diagram of an industrial data acquisition system, comprised of different technologies for acquiring the data, but ultimately communicating to computer display stations located somewhere on the Internet (world wide web):



Identify some of the different OSI layer 1 (physical) network standards you see in this system, as well as OSI layer 2 (data link) addressing schemes. Then, explain how all this data, in all its different forms, gets shuttled over the same ISDN cable to the Internet using TCP/IP packets.

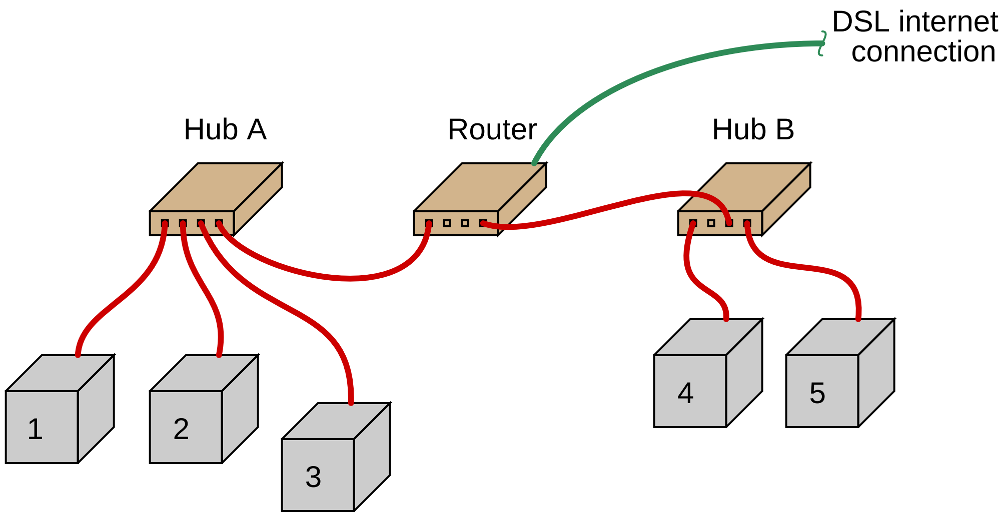
Suggestions for Socratic discussion

- Identify where the diagnostic utlility `ping` could be used to test nodes in this heterogeneous network.
- Identify where the diagnostic utlility `ping` could *not* be used to test nodes in this heterogeneous network.

file i02236

Question 28

The following Ethernet network has a problem. Someone trying to access the Internet from personal computer #4 cannot do so, and has called you to troubleshoot the problem:



Your first diagnostic test is to "ping" computer #4 from computer #5, and you find that this test is successful. Your next test is to check Internet connectivity at computer #5 by "pinging" `http://www.google.com`, and you find that test is successful as well.

Identify the likelihood of each specified fault for this network. 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 network.

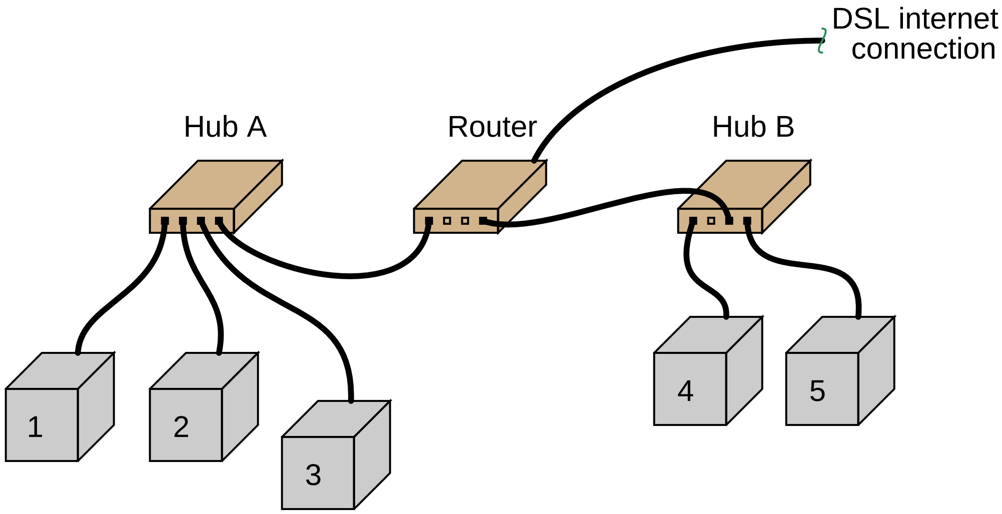
Fault	**Possible**	**Impossible**
Hub A failed		
Hub B failed		
Router failed		
Internet service provider failed		
Cable failed between computer #4 and Hub B		
Cable failed between Hub A and Router		
Cable failed between Hub B and Router		
Security settings (e.g. firewall) in computer #4		

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 i04461

Question 29

This Ethernet network has a problem in it somewhere:



- 1 can "ping" 3
- 4 can "ping" `www.google.com`
- 4 can "ping" 5
- 2 cannot "ping" `www.google.com`

An excellent diagnostic strategy is to trace paths of data flow in a complex system, looking for places of intersection. Successful paths prove all points along the pathway are functioning. Places of overlap between unsuccessful paths prove that section is suspect.

Apply this strategy to the problem at hand, and use the results to narrow the field of possible faults.

Also, identify a good "next ping" test to do.

file i02123

Question 30

One day a new instrument technician goes to connect a PLC (programmable logic controller) to an operator display panel and notices the communication ports on both the PLC and on the display panel are labeled *Modbus*, which the technician figures is some sort of networking standard. Upon inspection of the screw terminals the technician also notices the wiring is similar to RS-485 (EIA/TIA-485), with TD(+), TD(−), RD(+), and RD(−) terminals. Later on, when reading the user manuals for both devices, the technician notices the ports described as being "RS-485" as well as being "Modbus."

Asking a more experienced technician about this, the answer is that the ports are *both* EIA/TIA-485 and Modbus. These two network standards are not exclusive, but complementary.

Elsewhere in the world, a new computer network technician is going to download some software from a website, and notices it is possible to use either *HTTP* (Hyper-Text Transfer Protocol) or *FTP* (File Transfer Protocol) to do the job. Looking behind the computer, the technician notices a regular Ethernet cable (twisted-pair) plugged into the network port. Later, the technician asks someone more experienced, "Which network standard am I using when I download files, HTTP, FTP, or Ethernet?" The answer is similar to that given to the instrument technician: HTTP and FTP are alternatives to each other, both being complementary to Ethernet as parts of a complete protocol "pathway" from file to user. It is never a question of HTTP *or* Ethernet, just as it is never a question of Modbus *or* RS-485.

How would you explain either situation, using the OSI seven-layer model as a guide?

Suggestions for Socratic discussion

- A commonly-heard criticism of the OSI model is that "no communications standard fully agrees with it," i.e. no single standard has specifications in all seven layers of the model. Explain why this is not really a problem at all, and how it represents a fundamental misunderstanding of the OSI model.
- *ASCII* is a layer-6 standard for encoding alphanumeric text in digital form. Give an example where this standard works in conjunction with lower-level standards to communicate text data between two computers.
- *S-HTTP* is a layer-7 standard used for encrypting and decrypting digital data over networks. This is what you are using when you access a web page beginning with `https://`. Give an example where this standard works in conjunction with ASCII and other lower-level standards to securely communicate a credit card number between two computers during an online purchase transaction.

file i02237

Question 31

When I first heard of the "Internet," I made the mistake of thinking it was a special cable stretching across vast portions of the world, dedicated to transporting web-page digital data. To my surprise, the essential thing that makes up the Internet is not a physical object at all, but rather a *network protocol* specifying how digital data may be transparently communicated across all manner of digital networks (dedicated cables, satellite links, fiber optics, radio, etc.). This protocol permits the exchange of data across an ad-hoc collection of networks between points far and wide. Without a platform- and network-independent protocol, Internet really would have to be a dedicated cable or radio link stretching across the United States in order for people across the country to digitally communicate.

This protocol comes in two parts: *TCP* and *IP*. Sometimes it is referred to as a single standard: *TCP/IP*. Explain what "TCP" and "IP" represent, and how these network protocols are independent of specific details such as cable type, data rate, "mark" and "space" voltage levels, and other parameters associated with digital network hardware.

Suggestions for Socratic discussion

- An alternative to TCP is UDP, often used in industrial Ethernet networks. Explain why UDP is more popular within industry, and how it differs from TCP.
- SCADA systems used for the monitoring and control of such things as pipelines and electric power transmission networks typically rely on their own dedicated communication channels rather than the "internet" to communicate digital data over long distances. Explain why.
- Suppose an instrument technician got bored and decided to build a SCADA system for her home. Using a PLC to acquire data from sensors installed throughout the house and also to control lights and valves, the technician is able to monitor her home from a "smart" phone with internet access. Identify some of the network standards that might be employed in this system to transfer data between the PLC and her phone.

file i02232

Question 32

Question 33

Question 34

Question 35

Question 36

Question 37

Question 38

Question 39

Question 40

Question 41

Read and outline the "Basic Concept of HART" subsection of the "HART Digital/Analog Hybrid Standard" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04462

Question 42

Read and outline the "HART physical layer" subsection of the "HART Digital/Analog Hybrid Standard" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04463

Question 43

Read and outline the "HART Multidrop Mode" subsection of the "HART Digital/Analog Hybrid Standard" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04464

Question 44

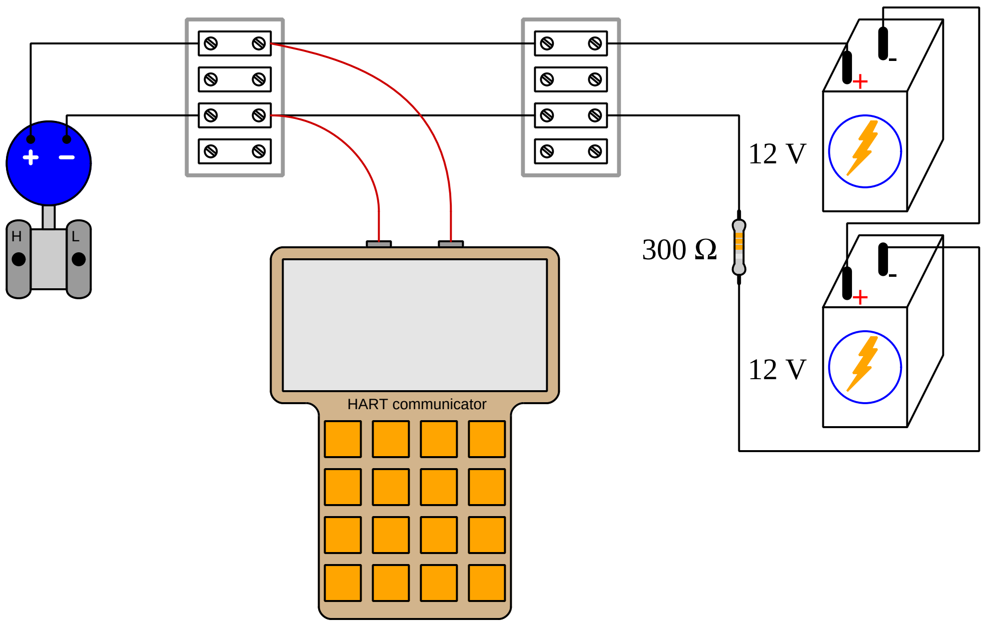
Read and outline the "HART Multi-Variable Transmitters and Burst Mode" subsection of the "HART Digital/Analog Hybrid Standard" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04465

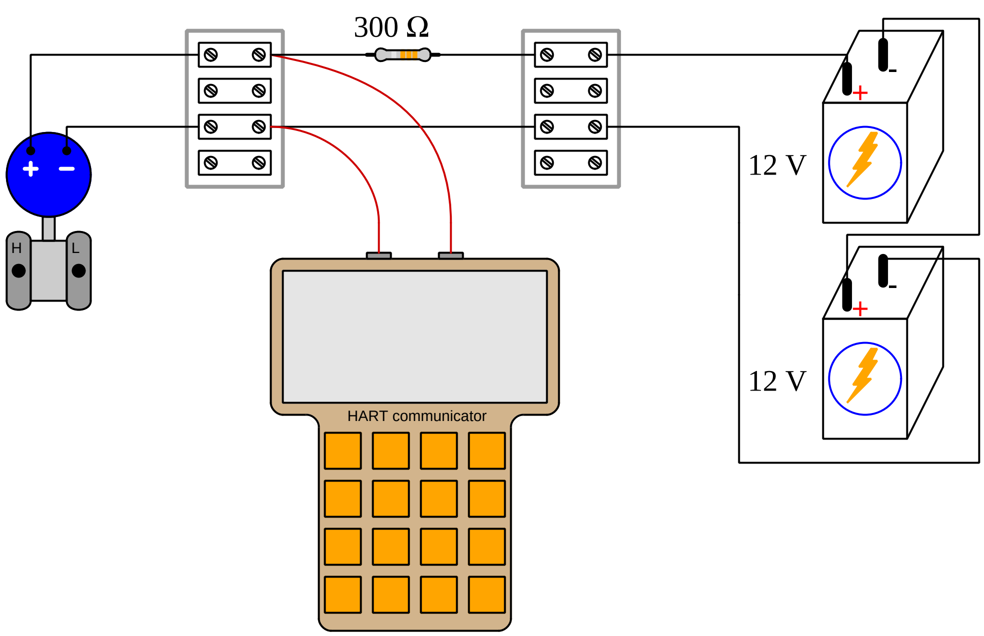
Question 45

Identify whether or not the HART communicator will be able to communicate with the HART transmitter in each of these circuits, explaining why or why not for each case:

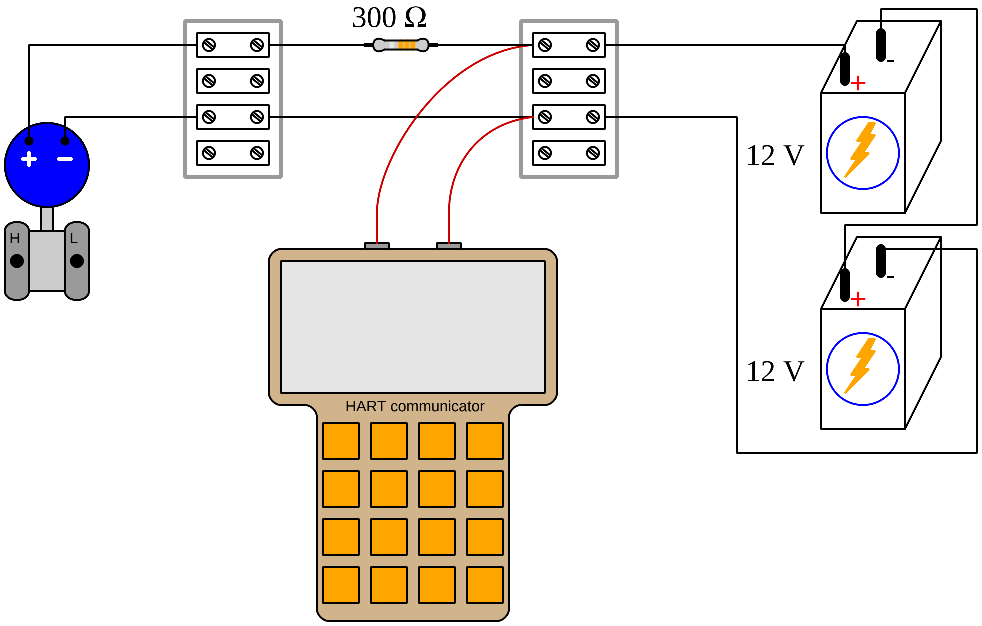
Circuit #1:



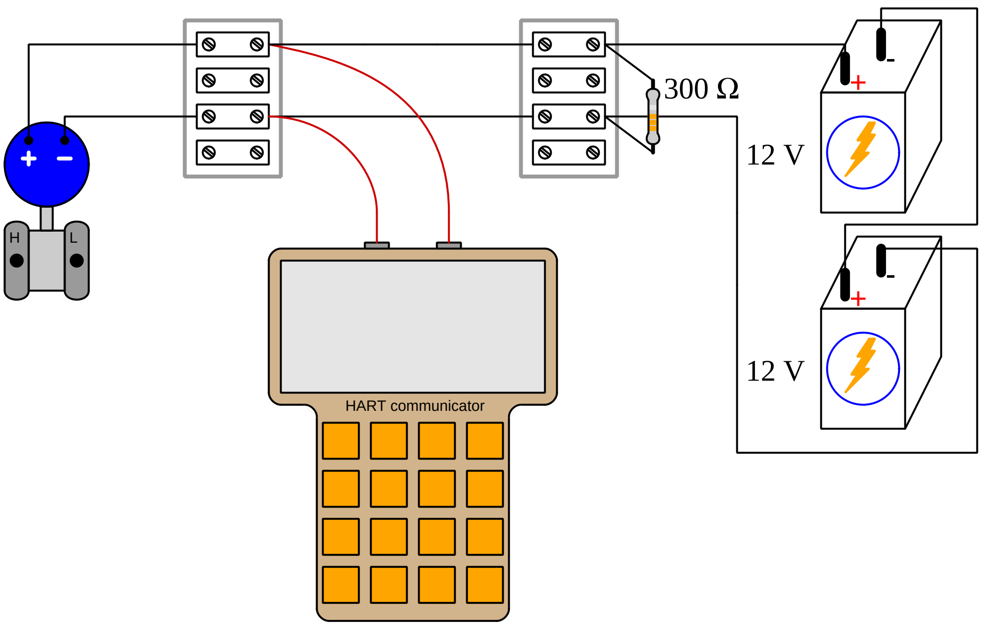
Circuit #2:



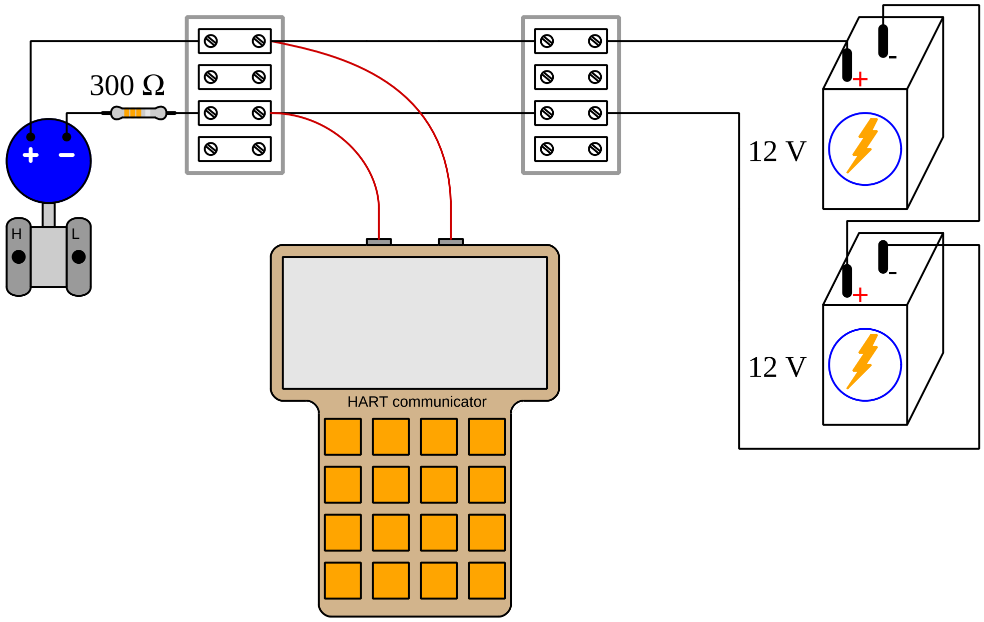
Circuit #3:



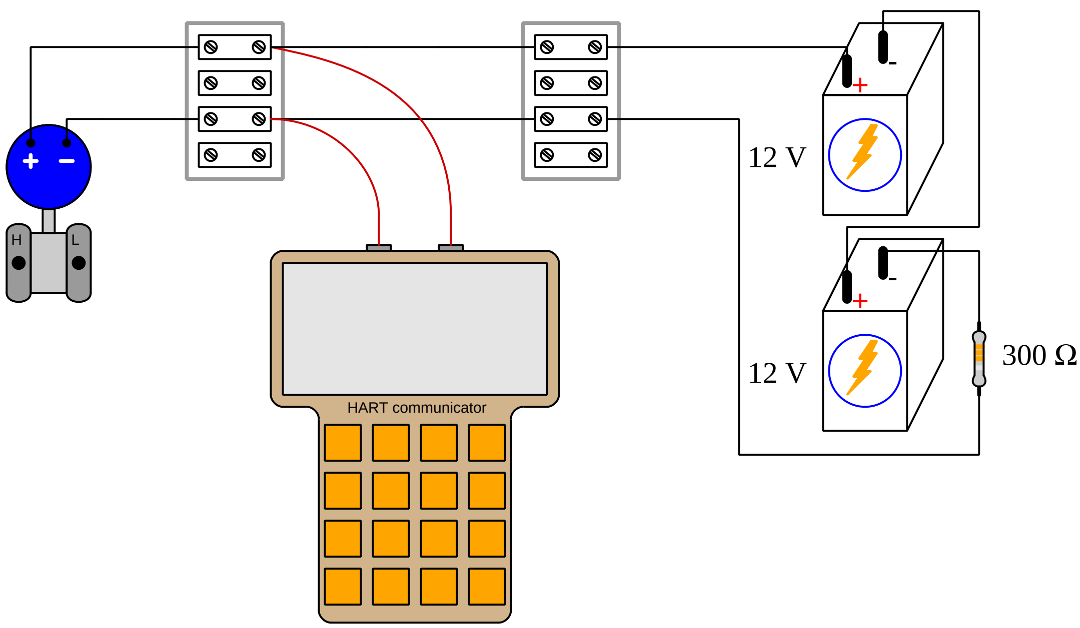
Circuit #4:



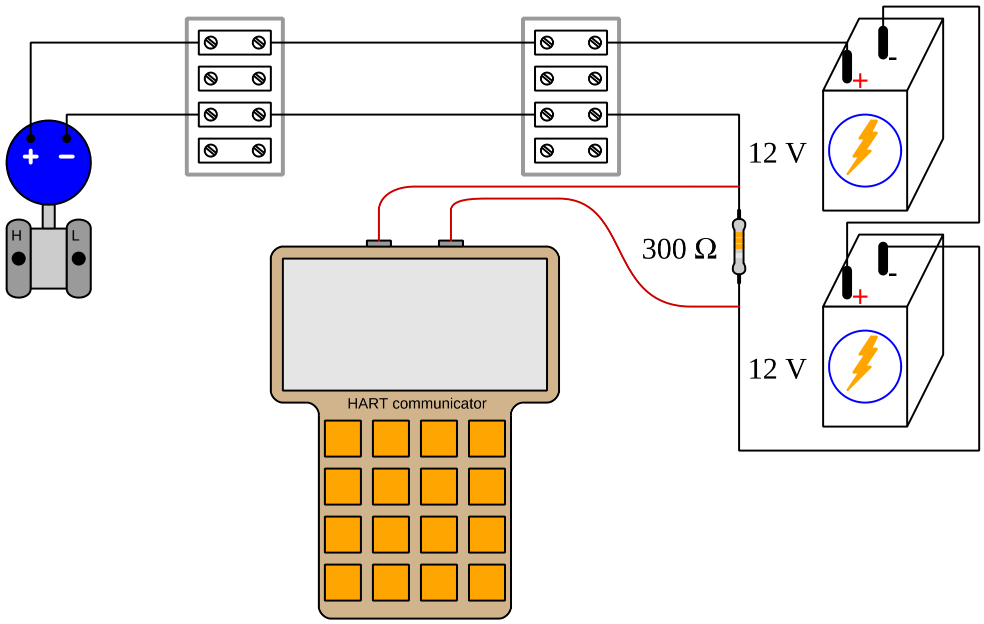
Circuit #5:



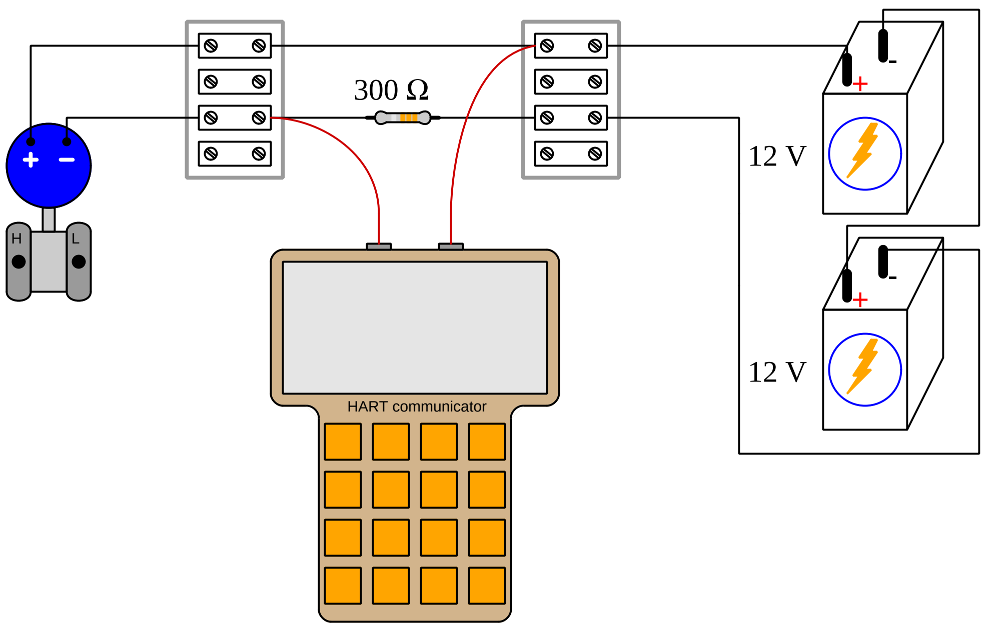
Circuit #6:



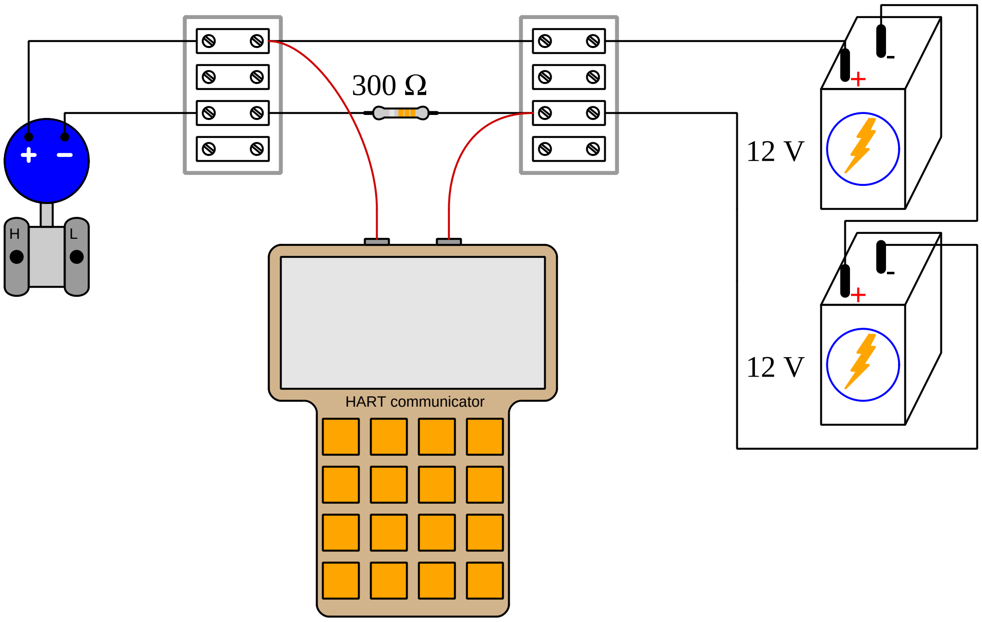
Circuit #7:



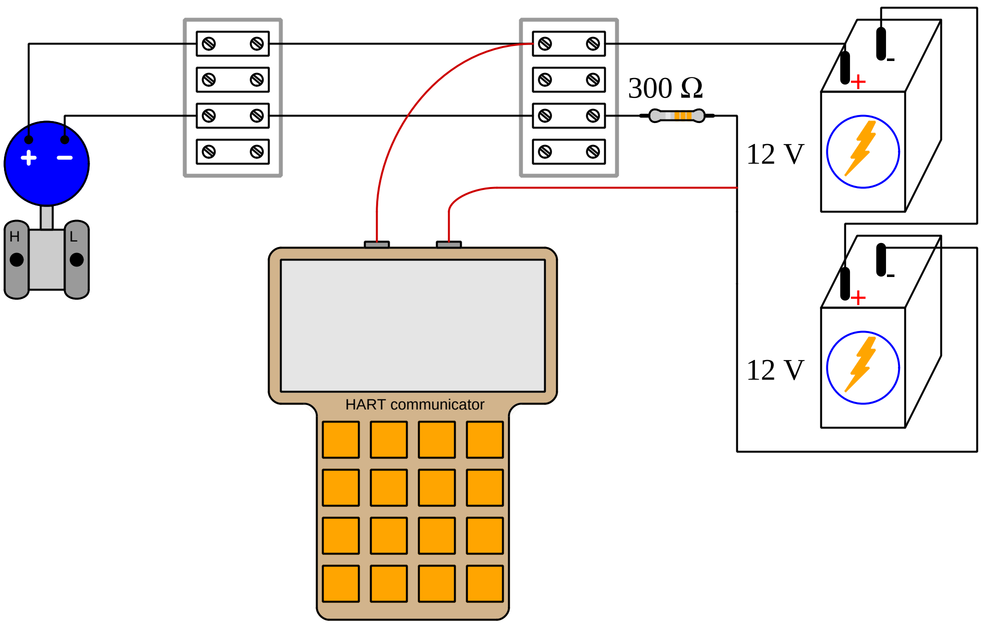
Circuit #8:



Circuit #9:



Circuit #10:



file i03332

Question 46

Read and outline the introduction and the "Modbus Data Frames" subsection of the "Modbus" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04467

Question 47

Read the "Modbus Function Codes and Addresses" subsection of the "Modbus" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04468

Question 48

Read Appendix C of the Allen-Bradley "PowerFlex 4 Adjustable Frequency AC Drive user manual" (document FRN 5.xx), and answer the following questions:

Describe what a VFD (Variable Frequency Drive) is useful for. What, exactly, does it do in a control system?

What does this section have to say about the "+" and "−" wires for Modbus RS-485 devices?

Identify some of the commands for the AC motor drive accessible as individual bits in register 8192.

Identify the register within the AC motor drive holding the frequency "reference" (command) value. This is the numerical value commanding the motor how fast to spin. Is this numerical value specified in integer, fixed-point, or floating-point format?

Does this AC drive accept Modbus commands in RTU format, ASCII format, or either?

Suggestions for Socratic discussion

- Based on your reading of this manual, is there any danger in accidently reversing the Modbus (RS-485) wire connections?
- The wiring diagram on page C-1 shows a 120 ohm termination resistor installed at the cable end. Can you think of any application where you might wish to use a different-value termination resistor on this network cable (i.e. something other than 120 Ω)?
- Page 1-9 of this manual describes a "reflected wave problem" that may manifest on long lengths of motor cable between the drive and the motor. Based on the description and the table of figures shown on that page, what does this problem consist of?
- Identify some of the error codes generated by this VFD which may be read via Modbus (held in register 8449).
- The network wiring diagram shown in figure C.1 shows an interesting method of grounding the shield conductor in each cable. Interpret this diagram, and then elaborate on alternative methods of shield grounding which would also work.

file i04469

Question 49

Read pages 4-46 through 5-8 of the Automation Direct "GS1 Series Drives user manual" (document GS1-M), and answer the following questions:

Describe what a VFD (Variable Frequency Drive) is useful for. What, exactly, does it do in a control system?

Identify the purpose of the "FA-ISONET" device referenced on pages 5-6 and 5-7.

Identify some of the status bits readable in register 48450 (2001 hex).

Identify the register within the AC motor drive holding the speed "reference" (command) value. This is the numerical value commanding the motor how fast to spin. Is this numerical value specified in integer, fixed-point, or floating-point format?

Does this AC drive accept Modbus commands in RTU format, ASCII format, or either?

Suggestions for Socratic discussion

- Identify which layer of the OSI model the FA-ISONET device operates on.
- Can the Modbus bit rate of this VFD be arbitrarily set, or is it fixed at one communication speed?
- Which variant of Modbus is more efficient from the standpoint of maximum data transfer in minimum time: ASCII or RTU?
- Identify which register(s) within the VFD you would have to write data into via Modbus in order to command the drive to "Run" and to "Stop".
- Explain the significance of the speed reference value residing in a register address beginning with "4" within the Modbus addressing scheme.

file i04470

Question 50

The `grades_template` spreadsheet provided for you on the Y: network drive allows you to calculate your grade for any course (by entering exam scores, attendance data, etc.) as well as project to the future for courses you have not yet taken. Download the spreadsheet file (if you have not done so yet) and enter all the data you can for grade calculation at this point in the quarter.

Also, locate the pages in your course worksheet entitled "Sequence of Second-Year Instrumentation Courses" to identify which courses you will need to register for next quarter.

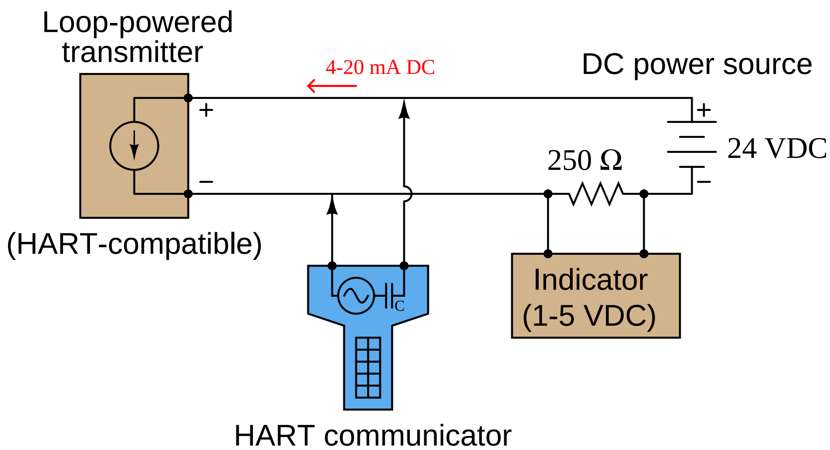
Suggestions for Socratic discussion

- If you do not yet have enough data to calculate a final grade for a course (using the spreadsheet), experiment with plugging scores into the spreadsheet to obtain the grade you would like to earn. How might this be a useful strategy for you in the future?
- Why do you suppose this spreadsheet is provided to you, rather than the instructor simply posting your grades or notifying you of your progress in the program courses?
- Identify any courses that are *elective* rather than required for your 2-year AAS degree.

file i02659

Question 51

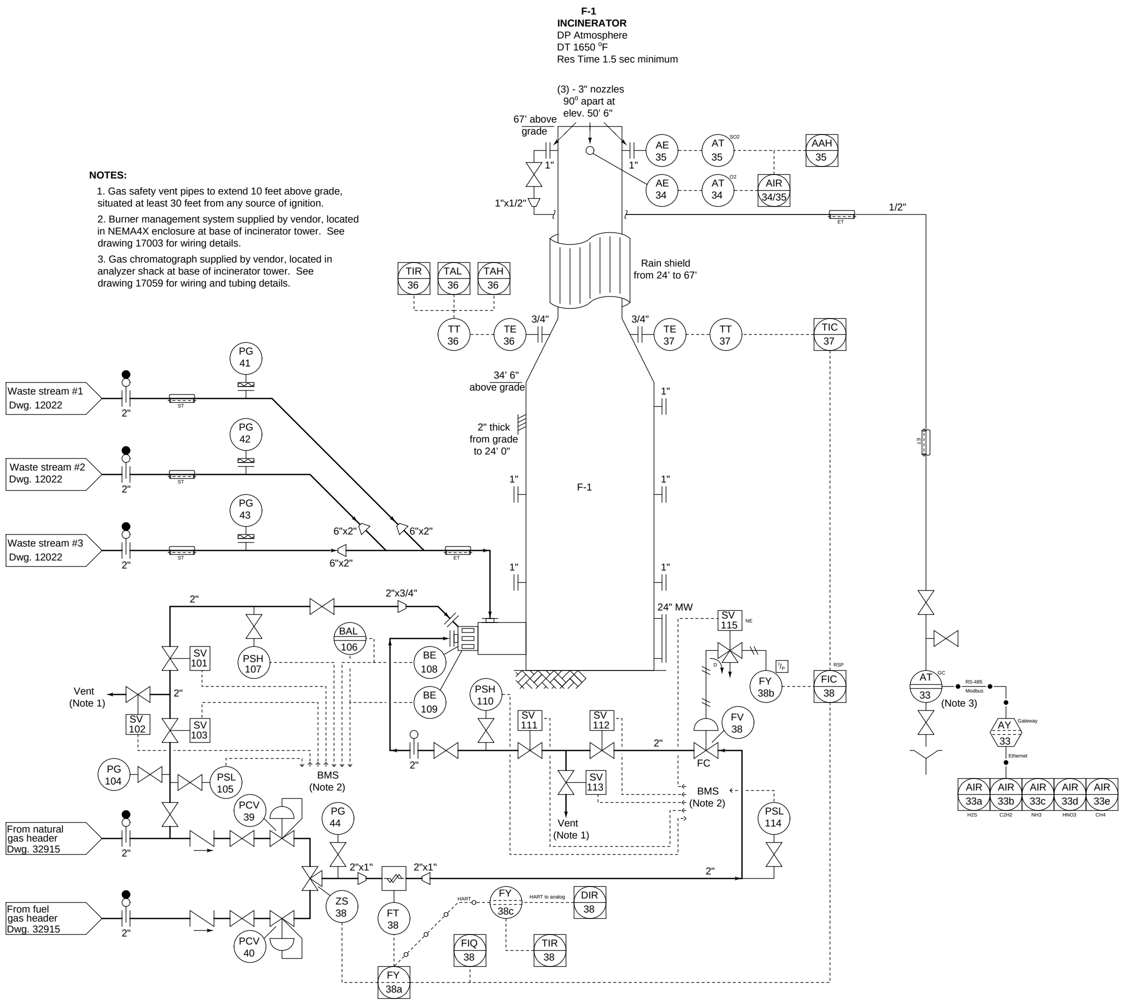
Suppose you were connecting a HART-compliant transmitter to an indicator that was intolerant of the high-frequency HART communication signals. Show where you would place a HART *filter* circuit in this 4-20 mA loop circuit to prevent those high-frequency signals from getting to the indicator, and also what that filter circuit would consist of:



file i01398

Question 52

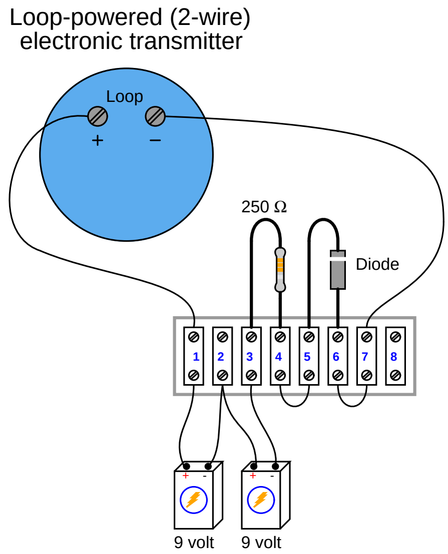
Identify where a HART multivariable transmitter is used in this incinerator process, and how the multiple variables are extracted from it to report on various indicating instruments:



file i01215

Question 53

Connect a "smart" (HART protocol) loop-powered to a DC voltage source, a 250 ohm resistor, and a diode as shown, using parts supplied by the instructor. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, or "alligator" clips permitted):



After building your circuit, answer the following questions:

- Connect a HART communicator device in parallel with the transmitter, turn it on, and use it to access the transmitter's programmable parameters.

- Use a multimeter set to measure *AC* volts to detect HART communications in the circuit. What happens to the AC voltage measurement when the HART communicator is turned off? Is there any way to capture the peak HART signal values using your multimeter?

- Temporarily short past the resistor with a jumper wire and note whether or not this has any effect on the 4-20 mA analog current signal. Also note whether this elimination of the resistor has any effect on the ability of the transmitter to communicate using HART (digital) signals.

Suggestions for Socratic discussion

- It is possible to properly connect a HART communicator to a HART instrument and still not have it "talk." The communicator must also be programmed with a *Device Description* (DD) for the HART instrument in order to communicate and access all its parameters. Explain they purpose and rationale for Device Descriptions.

  file i03878

Question 54

Question 55

Question 56

Question 57

Question 58

Question 59

Question 60

Question 61

Read the "LabVIEW exercise #1" tutorial document in preparation for implementing it in the computer lab, in conjunction with a USB-based data acquisition unit. Here, you will learn how to configure a simple "virtual instrument" in National Instruments LabVIEW software to display an analog signal value on the computer screen.

Note: the tutorial you need to do this exercise is found on your "Instrumentation Reference" (a set of digital document files) your instructor has prepared for you.

file i00705

Question 62

Read the "LabVIEW exercise #2" tutorial document in preparation for implementing it in the computer lab, in conjunction with a USB-based data acquisition unit. Here, you will learn how to scale an analog input and also implement a comparison function to create an alarm function for a simulated water-level measurement system.

Note: the tutorial you need to do this exercise is found on your "Instrumentation Reference" (a set of digital document files) your instructor has prepared for you.

file i01615

Question 63

Read the "LabVIEW exercise #3" tutorial document in preparation for implementing it in the computer lab, in conjunction with a USB-based data acquisition unit. Here, you will learn how to configure a digital output function on a DAQ so that your VI has the ability to control a real-world device (in this case, an LED).

Note: the tutorial you need to do this exercise is found on your "Instrumentation Reference" (a set of digital document files) your instructor has prepared for you.

file i01619

Question 64

Read the "LabVIEW exercise #4" tutorial document in preparation for implementing it in the computer lab, in conjunction with a USB-based data acquisition unit. Here, you will learn how to add a trend graph to a VI in order to plot an analog signal value over time.

Note: the tutorial you need to do this exercise is found on your "Instrumentation Reference" (a set of digital document files) your instructor has prepared for you.

file i01684

Question 65

Calculate the resistance between points **A** and **B** (R_{AB}) for the following resistor networks:

Figure 1

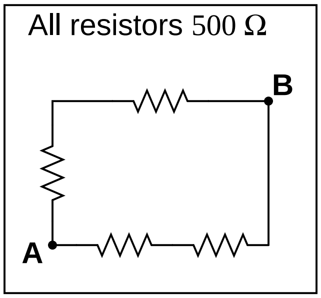


Figure 2

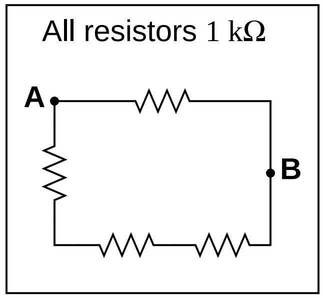


Figure 3

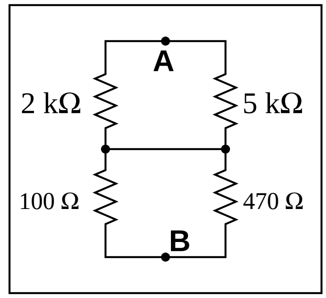


Figure 4

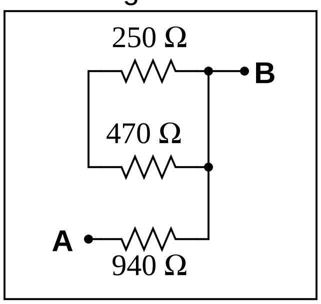


Figure 5

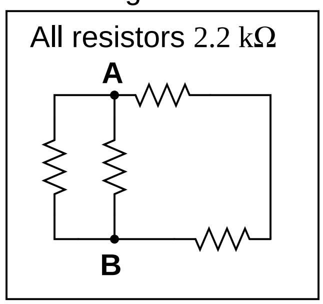
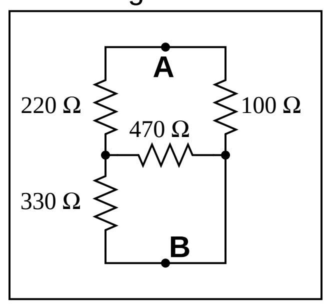


Figure 6



file i00597

Question 66

Question 67

Question 68

Question 69

Question 70

Question 71

Question 72

Question 73

Question 74

Question 75

Question 76

Question 77

Question 78

Question 79

Question 80

Question 81

Identify any area(s) of your study in which you would like to become stronger. Examples include technical reading, electrical circuit analysis, solving particular types of problems, time management, and/or skills applied in the lab. Cite specific examples if possible, and bring these to your instructor's attention so that together you may target them for improvement. As a starting point, try consulting the list of topics on the first page of the worksheet for the upcoming mastery exam, as well as the "General Values and Expectations" list near the beginning of the worksheet identifying the habits and qualities necessary for success in this career.

Next, identify practical strategies you will use to strengthen these areas. Examples include focusing on specific types of problem-solving whenever those types appear in the homework, working through practice problems for a particular subject, and/or coordinating with your lab team to give you more practice on specific skills.

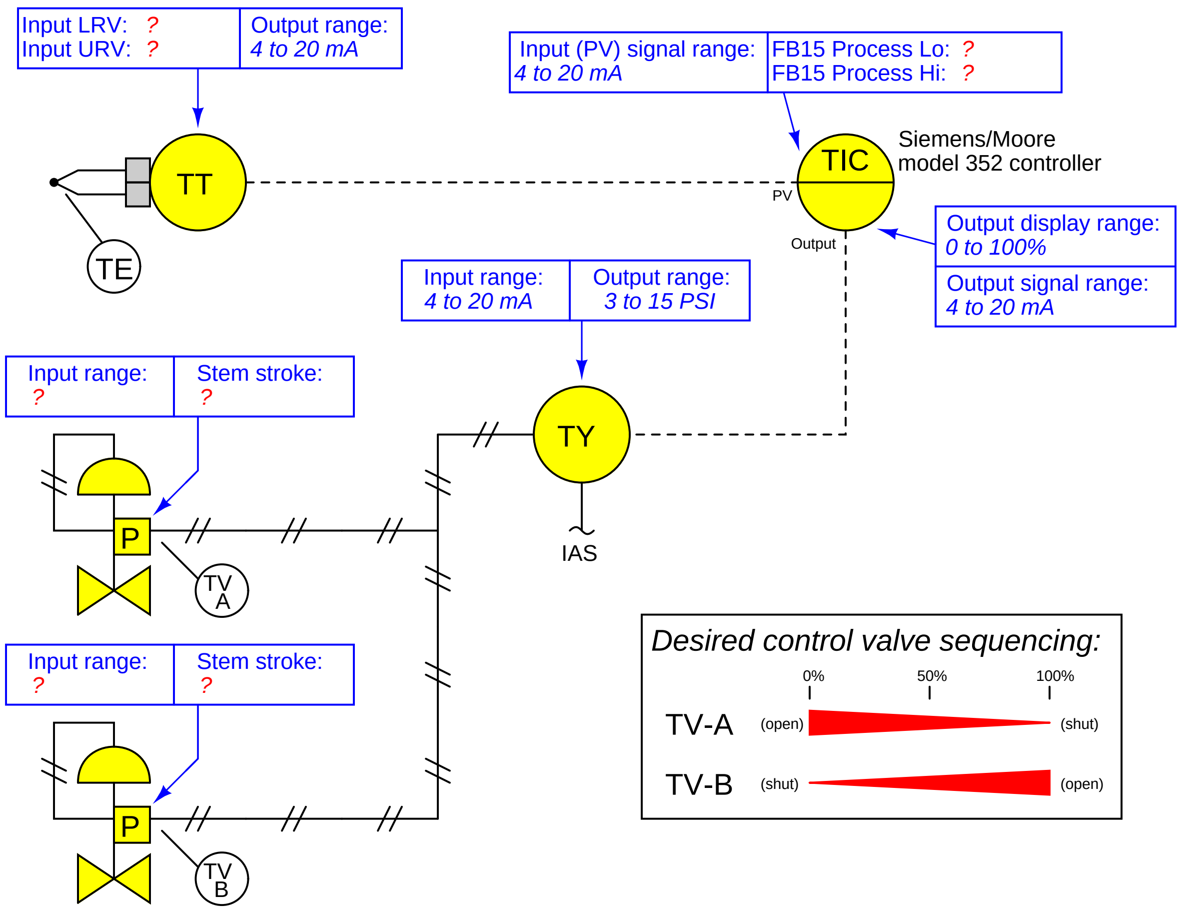
Suggestions for Socratic discussion

- One useful strategy is to maintain a *journal* of all you've learned in a course of study. Explore ways you could take the work you're already doing to prepare for homework (daily discussions with your instructor) and turn this into a journal or even a weblog ("blog") for your own reflection and eventual use as a portfolio to showcase your capabilities to employers.
- Where exactly are the practice problem worksheets located on the *Socratic Instrumentation* website?

file i00999

Question 82

Suppose you are asked to configure the instruments in this temperature control loop to sense and display process temperature over a range of 200 to 1800 degrees Celsius, with the loop controller actuating two split-ranged control valves in a complementary sequence:



Write the proper range values inside the boxes near each instrument, showing the proper configuration for each instrument needed to achieve the desired result.

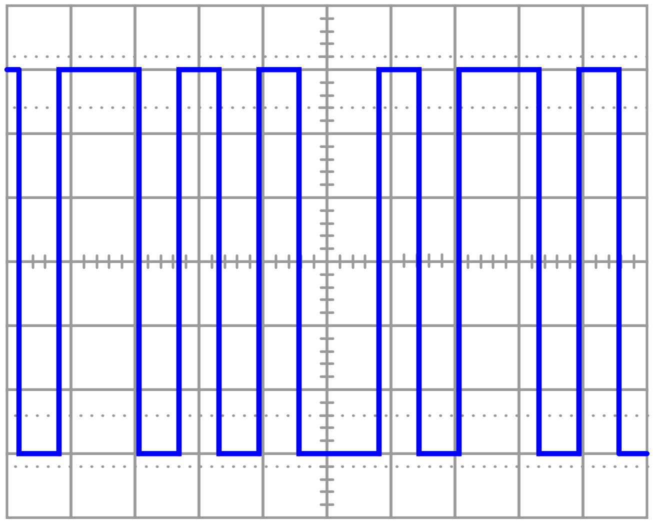
Suggestions for Socratic discussion

- Suppose the controller displayed a temperature of 1246 when the actual process temperature was 1265 ^{o}C. First, identify *two* possible locations in this loop for a calibration error that would account for this discrepancy. Then, assuming only one fault, explain how you could positively determine the location of this calibration error with a single diagnostic test.
- Suppose valve TV-A was 44% open and TV-B was 56% open when the controller output displayed 52%. First, identify *two* possible locations in this loop for a calibration error that would account for this discrepancy. Then, assuming only one fault, explain how you could positively determine the location of this calibration error with a single diagnostic test.

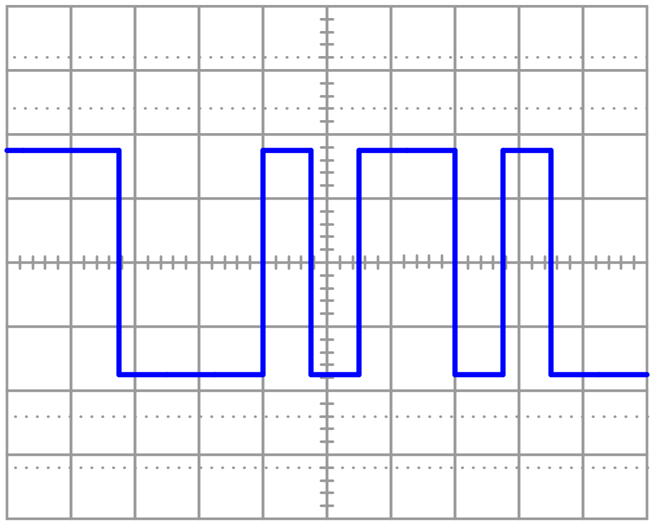
file i02078

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

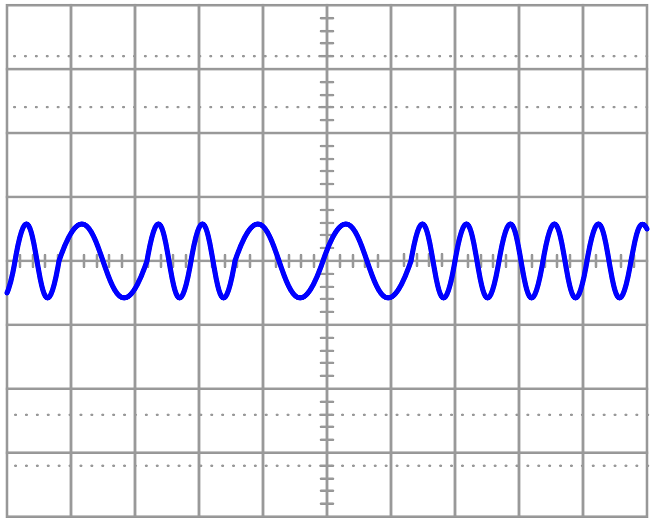
(Manchester encoding)



(NRZ encoding)



(FSK encoding)



Suggestions for Socratic discussion

- Students often experience confusion interpreting data streams when viewed like this, especially Manchester-encoded data. One problem-solving strategy that works well to help interpret waveform patterns is to *work the problem backwards*. Start with a known data stream (binary 1's and 0's) and then sketch a waveform representing that data stream. Do this for several different data streams, experimenting with different pattern combinations of 1's and 0's (repeating bits versus alternating bits, etc.), and then examine the waveforms you sketched to see what general principles you might apply to reliably interpret any data stream encoded in that manner.
- A necessity for proper interpretation of NRZ datastreams is proper measurement of pulse width. Suggest a way to do this when the pulse don't evenly line up with divisions on the oscilloscope screen.
- Explain how these three different encoding methods provide an excellent contrast between *bit rate* and *baud*. Which form of encoding has the greatest bits/second to baud ratio? Which form of encoding has the least bits/second to baud ratio?

file i00883

Question 84

Here is an oscilloscope's view of an eight-bit data stream sent asynchronously with no parity bit, using *NRZ* (Non-Return to Zero) encoding:

Identify the binary data represented by this waveform.

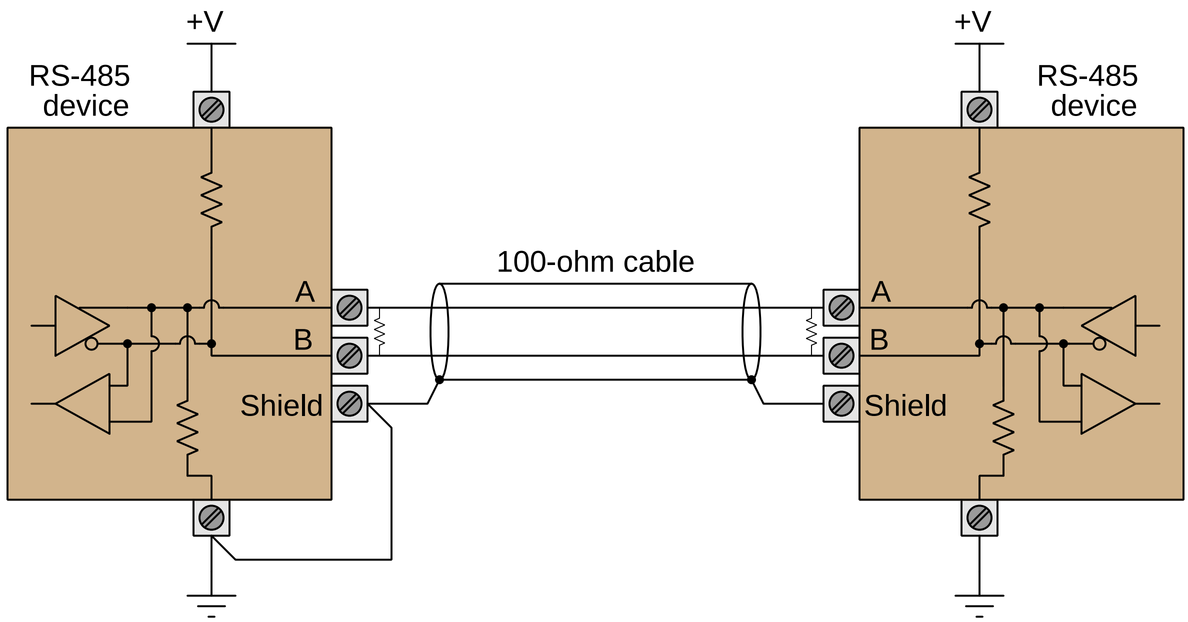
Suggestions for Socratic discussion

- Explain why it is absolutely vital to know the data frame contains eight data bits and no parity, when interpreting this waveform.
- Describe a practical method for determining the width of each bit in this waveform.
- Re-draw this NRZ waveform assuming it was sent with an "odd" parity bit.
- Re-draw this NRZ waveform assuming it was sent with an "even" parity bit.

file i02369

Question 85

Terminating resistors are not always necessary in EIA/TIA-485 networks, but when they are it is important to ensure their presence does not compromise biasing. Explain how termination resistors may adversely affect the biasing of a EIA/TIA-485 network, based on what you see in this schematic:



Calculate the "idle" voltage for this data network, assuming termination resistors of 100 Ω each, bias resistors of 1k Ω each, and a 15 volt power supply at each end. Does this meet the standard for a EIA/TIA-485 network?

Suggestions for Socratic discussion

- Are terminating resistors always needed in an EIA/TIA-485 network? If not, what applications can do without them?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- Based on the information given in this problem, can we ascertain the characteristic impedance of the cable used in this system? Why or why not?
- If the cable used in this system is replaced by one having significantly greater length but possessing the same characteristic impedance rating as before, will the terminating resistor values need to be altered? Why or why not? If the resistor values do need to be changed, will they need to be larger (more ohms) or smaller (less ohms) than they are now?

file i02198

Question 86

An analog-to-digital converter (ADC) has a calibrated input range of 0 to 5 volts, and a 12-bit output. Complete the following table of values for this converter, assuming perfect calibration (no error):

Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
1.6			
		3022	
	40		
			A2F

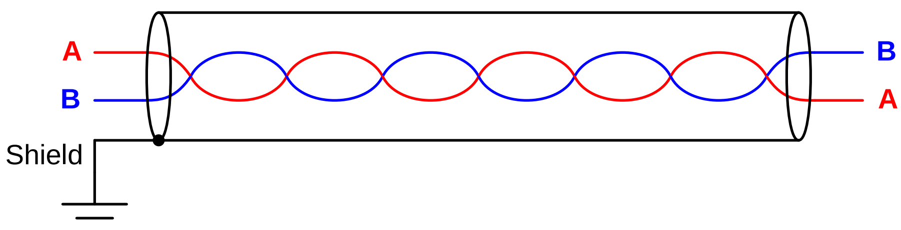
Suggestions for Socratic discussion

- Calculate the resolution of this ADC in *percent* of full-scale range. In other words, what is the smallest percentage of input signal change it is able to resolve?

file i03822

Question 87

Industrial signal cables are often comprised of *twisted, shielded wire pairs*. Both the twisting of the wire pairs and the shielding encapsulating the pairs works to protect the signals from corruption due to external noise. One of these techniques guards against interference from stray electrical fields while the other guards against interference from stray magnetic fields. Identify which does which, and explain why.



Furthermore, explain how a multimeter set to measure AC voltage (ideally, AC millivolts) could be used to detect the presence of *electric* field-induced noise anywhere along the cable's length. Also, explain how a multimeter set to measure AC millivoltage could be used to detect the presence of *magnetic* field-induced noise anywhere along the cable's length.

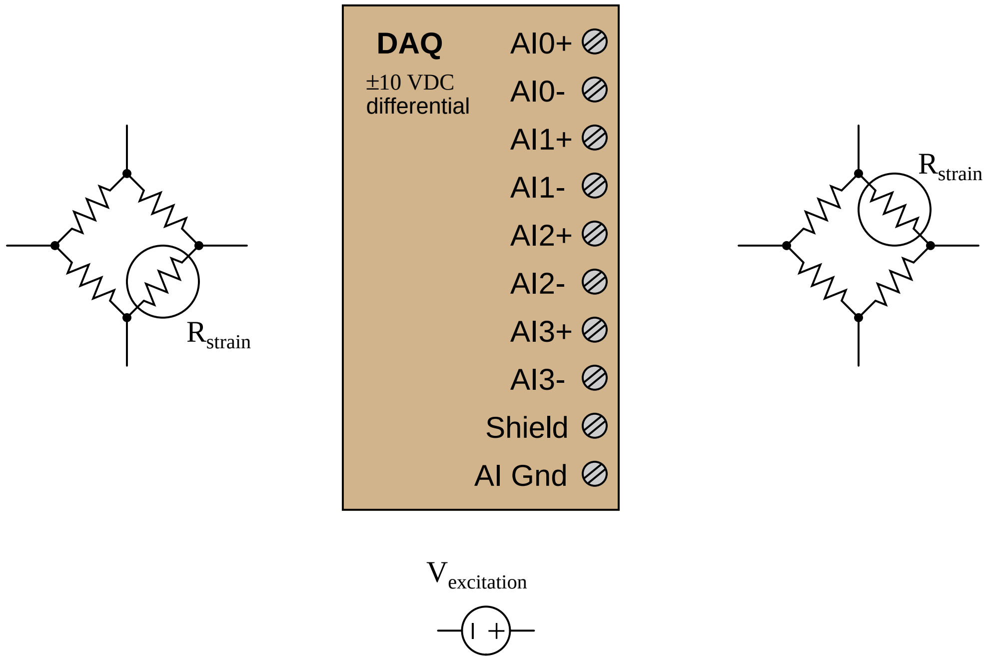
Suggestions for Socratic discussion

- Identify what would cause a *ground loop* to form in this cable, why that would be a bad thing, and how we may avoid it.
- Is the *rate of twist* of the wire pair relevant to noise immunity? If so, which would be better – a cable with a "slow" twist or a cable with a tightly-twisted wire pair?

file i02192

Question 88

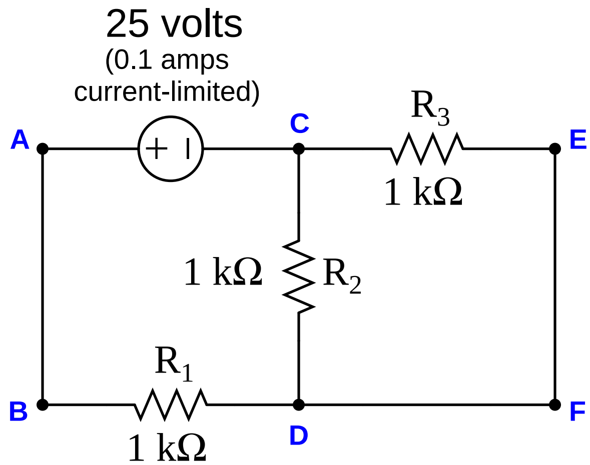
Sketch connecting wires to allow this data acquisition unit (DAQ) to sense strain using quarter-bridge strain gauge circuits on input channels #2 and #3, such that increasing tension on the strain gauge (increasing gauge resistance) generates a more *positive* signal voltage on each channel:



file i04586

Question 89

Suppose an ammeter inserted between test point **D** and the nearest lead of resistor R_1 registers 25 mA 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_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Voltage source dead		

This question is typical of those in the "Fault Analysis of Simple Circuits" worksheet found in the *Socratic Instrumentation* practice worksheet collection, except that all answers are provided for those questions. Feel free to use this practice worksheet to supplement your studies on this very important topic.

Suggestions for Socratic discussion

- Identify a good diagnostic "next step" to narrow the scope of the problem and ultimately locate the one fault in this circuit.

file i04490

Question 90

A numeration system often used as a "shorthand" way of writing large binary numbers is the *octal*, or base-eight, system. Based on what you know of place-weighted numeration systems, describe how many valid ciphers exist in the octal system, and the respective "weights" of each place in an octal number.

Also, perform the following conversions:

- 35_8 into decimal:
- 16_{10} into octal:
- 110010_2 into octal:
- 51_8 into binary:

Suggestions for Socratic discussion

- If binary is the "natural language" of digital electronic circuits, why do we even bother with other numeration systems such as hex and octal?
- Why is octal considered a "shorthand" notation for binary numbers?

file i02166

Question 91

A numeration system often used as a "shorthand" way of writing large binary numbers is the *hexadecimal*, or base-sixteen, system.

Based on what you know of place-weighted numeration systems, describe how many valid ciphers exist in the hexadecimal system, and the respective "weights" of each place in a hexadecimal number.

Also, perform the following conversions:

- 35_{16} into decimal:
- 34_{10} into hexadecimal:
- 11100010_2 into hexadecimal:
- 93_{16} into binary:

file i02167

Question 92

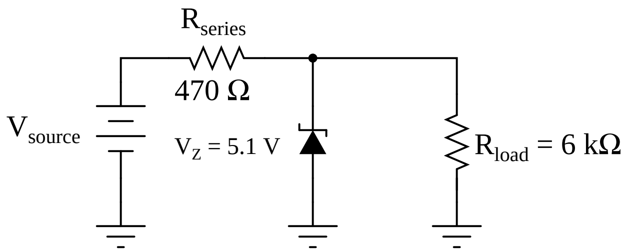
Identify the practical purpose of each of these diagnostic utility programs, all accessible through the "command line" environment of a personal computer:

- `ping`
- `ipconfig` or `ifconfig`
- `netstat`
- `tracert` or `traceroute`
- `nslookup`

Be sure to bring your portable computer to class and experiment with each of these commands!
file i04466

Question 93

Calculate the current through the zener diode for the given values of input (source) voltage in this circuit:



- $V_{source} = 25$ V ; $I_{zener} =$
- $V_{source} = 20$ V ; $I_{zener} =$
- $V_{source} = 15$ V ; $I_{zener} =$
- $V_{source} = 10$ V ; $I_{zener} =$
- $V_{source} = 5$ V ; $I_{zener} =$

Do you see any relationship between source voltage and zener diode current? If so, explain what that relationship is.

file i00757

Question 94

Suppose the analog-to-digital converter in an instrument has 12 bits of resolution to represent an analog voltage input range of 0 to 5 volts DC. Determine the digital "count" value of this ADC (expressed in binary form) given a 3.6 volt input signal.

Count = __________

file i03795

Question 95

Suppose the analog-to-digital converter in an instrument has 12 bits of resolution to represent an analog voltage input range of 0 to 5 volts DC. Determine the digital "count" value of this ADC (expressed in binary form) given a 2.1 volt input signal.

Count = __________

file i03796

Question 96

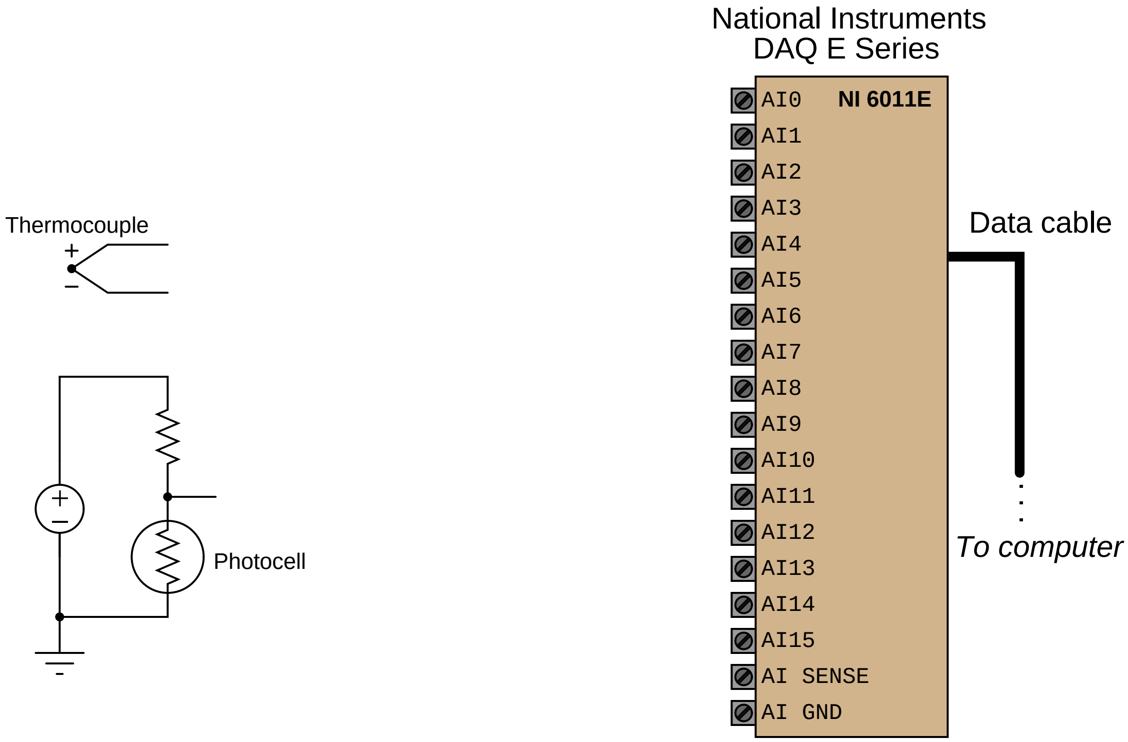
Suppose the analog-to-digital converter in an instrument has 12 bits of resolution to represent an analog voltage input range of 0 to 5 volts DC. Determine the digital "count" value of this ADC (expressed in binary form) given a 1.4 volt input signal.

Count = __________

file i03797

Question 97

Identify suitable input terminals, proper modes, and necessary connecting wires to allow this National Instruments E-series data acquisition unit (DAQ) to sense the two voltage sources shown:



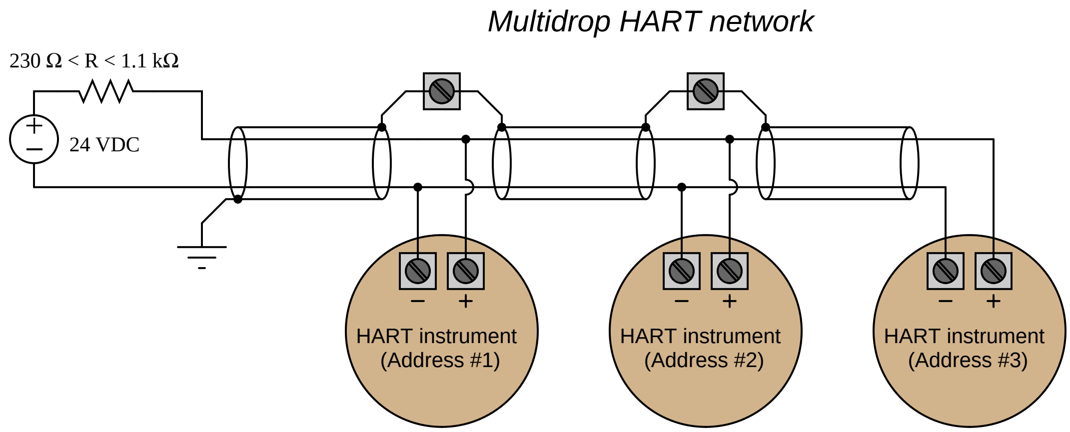
The available modes for the input channels are RSE, NRSE, and DIFF:

Channel	Mode	First terminal	Second terminal
0			
1			

file i01686

Question 98

HART instruments have the capability of operating as purely digital devices, with no analog current signal output. When multiple HART devices are operated like this, paralleled on a common network cable, it is called *multidrop mode*:



Answer the following questions about "multidropped" HART instruments:

- Explain why multidrop HART mode precludes the use of 4-20 mA as a signaling standard. In other words, explain why the option of "multidropping" HART instruments is an *all-or-nothing* choice, rendering the loop current signal meaningless with regard to process measurements.
- Explain why each HART instrument in multidrop mode requires a unique "address" number assigned to it, and identify how many (maximum) different addresses may exist in a HART multidrop network.
- Explain why "burst mode" cannot be used with multidrop HART instruments, and then identify applications where burst mode *would* be useful.
- Finally, identify at least three different places in this network where a HART modem or handheld communicator could be connected to establish communication with the devices.

Suggestions for Socratic discussion

- How much total current would you expect to measure in a multidrop HART network?
- What is the maximum number of HART devices that may be multi-dropped?

file i02229

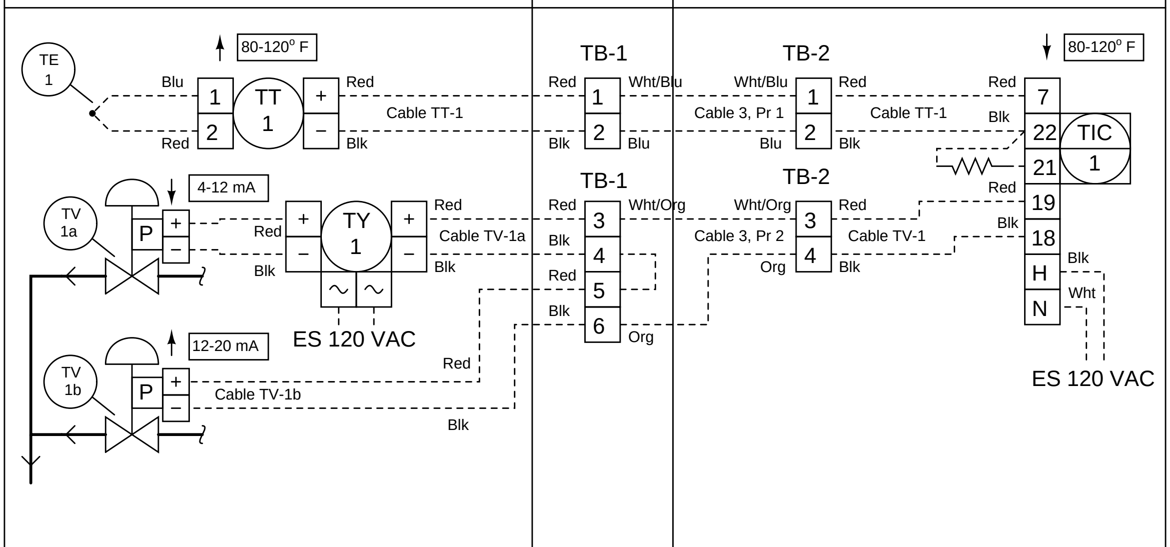
Question 99

"Smart" control valve positioners are devices that take a 4-20 mA DC analog current signal and very precisely position the valve stem according to that signal. Since smart positioners contain microprocessors, they are more than capable of communicating via a digital network standard such as HART.

A problem may arise, though, if we try to connect more than one HART-capable valve positioner in the same 4-20 mA current loop, such as when we wish to *split-range* two or more control valves. This is where multiple control valves actuate over different portions of the 4-20 mA range, for example a heating valve that operates from 4 to 12 mA and a cooling valve that operates from 12 to 20 mA. In a traditional (analog) split-range control valve system, the I/P transducers would simply be connected in series so that the same current flowed through both I/P coils, driving both control valves. With HART-capable positioners, though, we might not want the devices to be connected directly in series, because then there may be a conflict of HART signals when we just wish to "talk" with one of the devices.

Explain how this problem is overcome in the following split-range control valve system:

Loop Diagram: Bio-reactor temp control	**Revised by:** C. Hart	**Date:** April 1, 2006
Process area	Field panel JB-1	Control panel



Tag number	Description	Manufacturer	Model	Calibration	Notes
TE-1	Thermocouple	Omega		Type T	Ungrounded tip
TT-1	Temperature transmitter	Rosemount	3144	80-120°F 4-20 mA	
TIC-1	Controller	Siemens	PAC 353	1-5 V 80-120°F	Reverse-acting control
TY-1	HART isolator	Action Instruments	AP4830-2000	n/a	
TV-1a	Control valve	Fisher	Easy-E	4-12 mA	DVC6000 smart positioner
TV-1b	Control valve	Fisher	Easy-E	12-20 mA	DVC6000 smart positioner

Suggestions for Socratic discussion

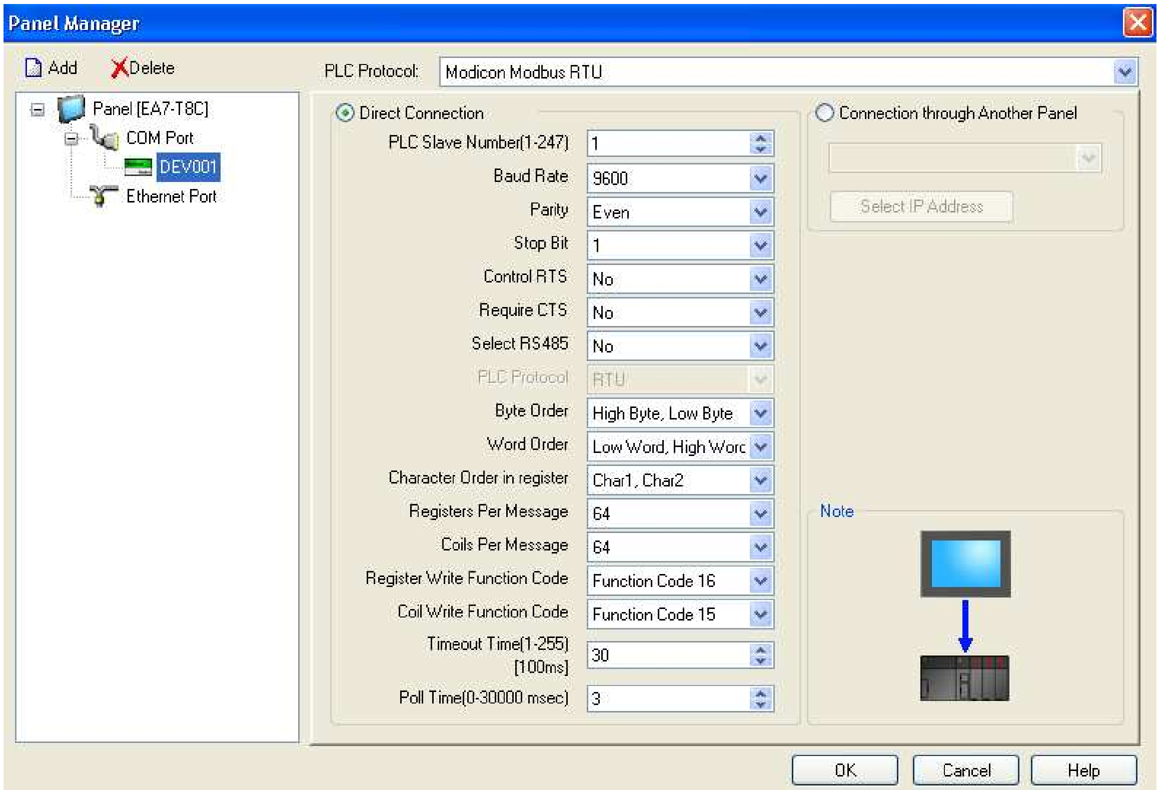
- If we were to connect a HART communicator device to terminals 3 and 4 of TB-1, which control valve would we be communicating with?
- Which valve carries the cooling fluid and which valve carries the heating fluid in this temperature control system?

file i02230

Question 100

Question 101

The following screen capture shows the configuration window for an HMI panel, providing serial communication parameters for it to exchange data with a Modbus device:



Identify the purpose for the "Control RTS" and "Require CTS" parameters, both of which happen to be de-activated (set to "No").

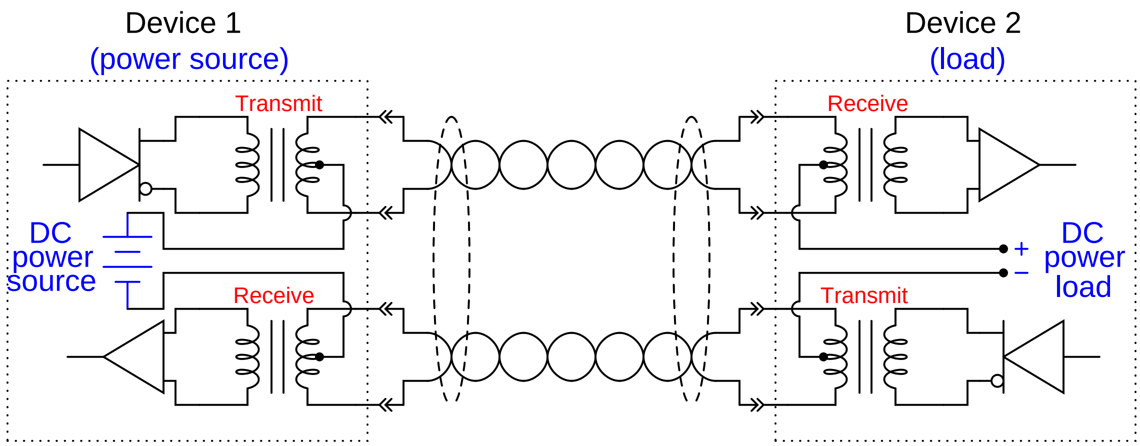
Two options exist for Modbus Register Write function codes: 06 and 16. Likewise, two options exist for Modbus Coil Write function codes: 05 and 15. Explain the difference between each option, and why one setting might be more useful than the other.

file i00718

Question 102

Ethernet is a popular communications standard for many digital devices, personal computers included. Originally, Ethernet was intended to be a network standard for conveying digital data only, without power. In later years, however, upgrades to the standard allowed DC power to be conveyed over the same wire pairs. The IEEE standard `802.3af` is one example of a power-over-Ethernet standard.

Shown here is a schematic showing how two Ethernet devices connect together over a Category 5 ("Cat 5") twisted-pair cable, with DC power conveyed over the same wire pair:

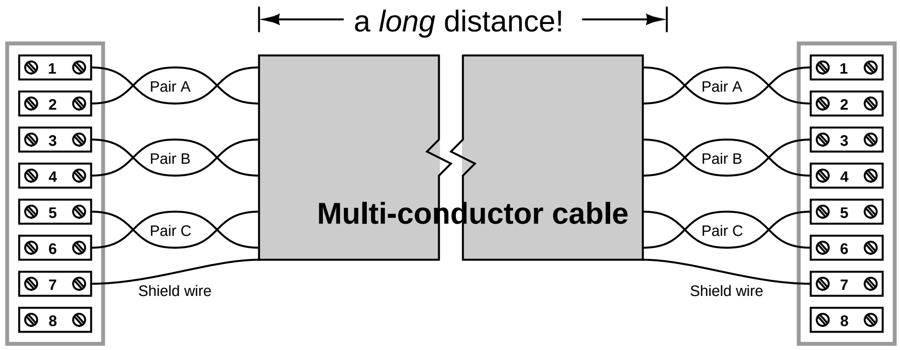


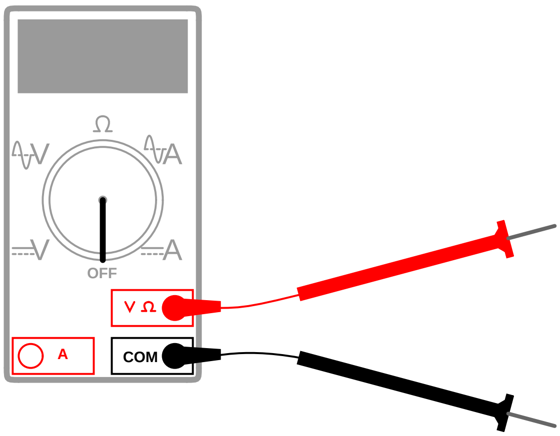
Explain what function(s) the transformers provide in this system, and how they allow DC power to travel through the wire pairs from source to load without interfering with the Ethernet data signals, which are AC.

file i02289

Question 103

Suppose you are asked to check the integrity of a multi-conductor signal cable run between two locations. The cable has six signal conductors in it plus a shield, each one terminated at a terminal block at each end:



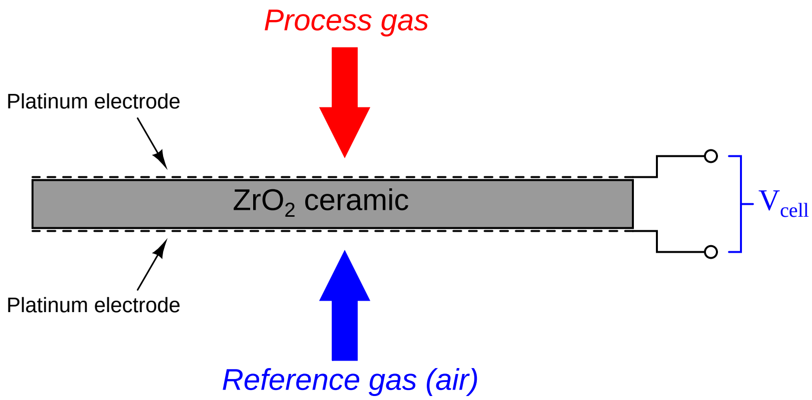


Faults you are looking for include *open* conductors, as well as *shorts* between conductors and/or shorts to ground. Devise a series of tests you could perform with nothing but a multimeter to comprehensively check the electrical integrity of this cable.

file i00734

Question 104

The *Nernst equation* finds application in many different chemical analyzer technologies. One of these analytical technologies is *oxygen concentration* in mixed gas streams, such as the exhaust from a combustion process where oxygen content is usually maintained at about 2% (instead of the normal 20.9% oxygen concentration of Earth's atmosphere). A common oxygen sensor is made of a "sandwich" of platinum electrodes on either side of a solid zirconium oxide membrane. One side of this electrochemical cell is exposed to the exhaust gas (process), while the other side is exposed to heated air which serves as a reference:



Voltage output by the cell is predicted by the Nernst equation:

$$V = \frac{RT}{nF} \ln \left(\frac{C_1}{C_2} \right)$$

Where,

V = Voltage produced across membrane due to ion exchange, in volts (V)
R = Universal gas constant (8.315 J/mol·K)
T = Absolute temperature, in Kelvin (K)
n = Number of electrons transferred per ion exchanged (2, for oxygen atoms)
F = Faraday constant, in coulombs per mole (96,485 C/mol e^-)
C_1 = Concentration of oxygen in ambient air (20.9%)
C_2 = Concentration of oxygen in exhaust gas

Suppose a DAQ module were connected to one of these oxygen-sensing cells, and you needed to enter a formula into the DAQ software to translate voltage into oxygen concentration. Manipulate the Nernst equation to solve for the concentration of oxygen in the exhaust gas from the measured voltage:

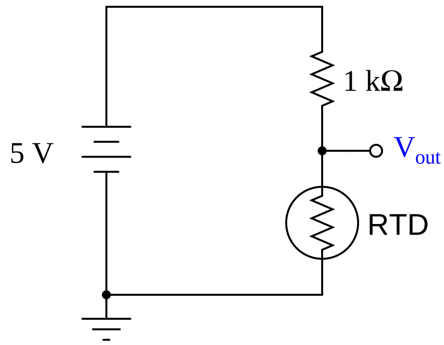
$C_2 =$

file i00929

Question 105

Write an equation describing the output voltage as a function of temperature, assuming the RTD (Resistive Temperature Detector) has a resistance predicted by the following formula:

$$R_{RTD} = 100(1 + 0.00392T)$$

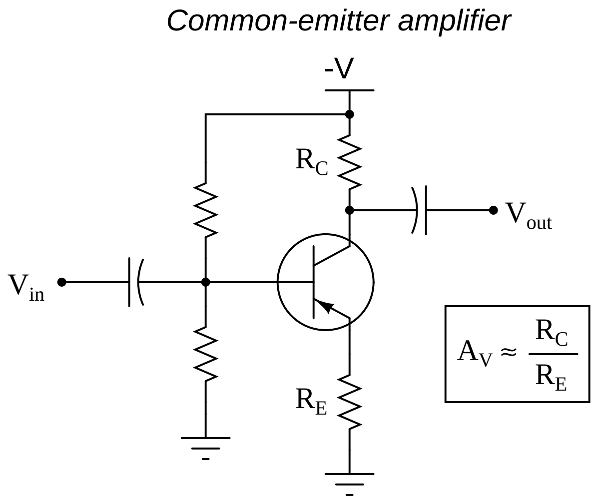


$V_{out} = f(T) =$

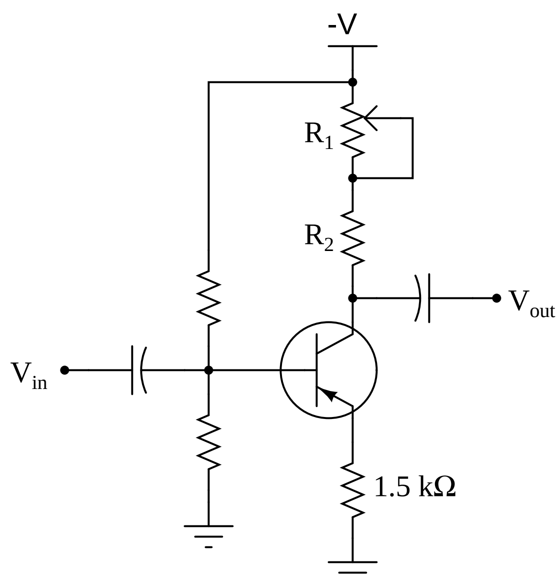
file i00536

Question 106

The voltage gain of a common-emitter transistor amplifier is approximately equal to the collector resistance divided by the emitter resistance:



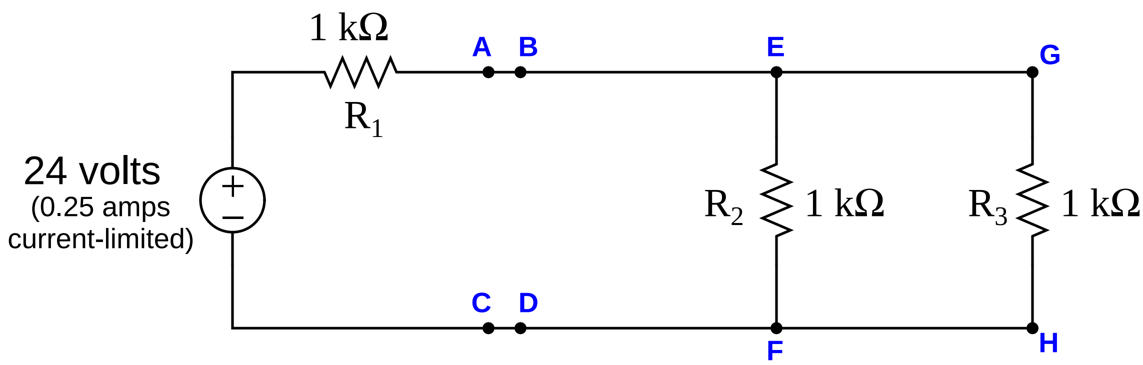
Knowing this, calculate the necessary resistance values for the following fixed-value resistor (R_2) and potentiometer (R_1) to give this common-emitter amplifier an adjustable voltage gain range of 2 to 8:



file i03519

Question 107

Suppose a voltmeter registers 0 volts between test points **A** and **C**, but measures 24 volts between those same two test points after the connection has been broken between points **C** and **D**:



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.

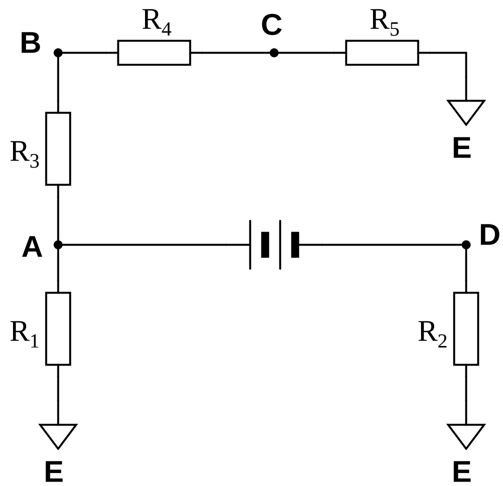
Fault	**Possible**	**Impossible**
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Voltage source dead		

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.

file i00171

Question 108

Determine what will happen to the following voltage drops (between specified test points in the circuit) if the resistance of resistor R_3 happens to decrease:

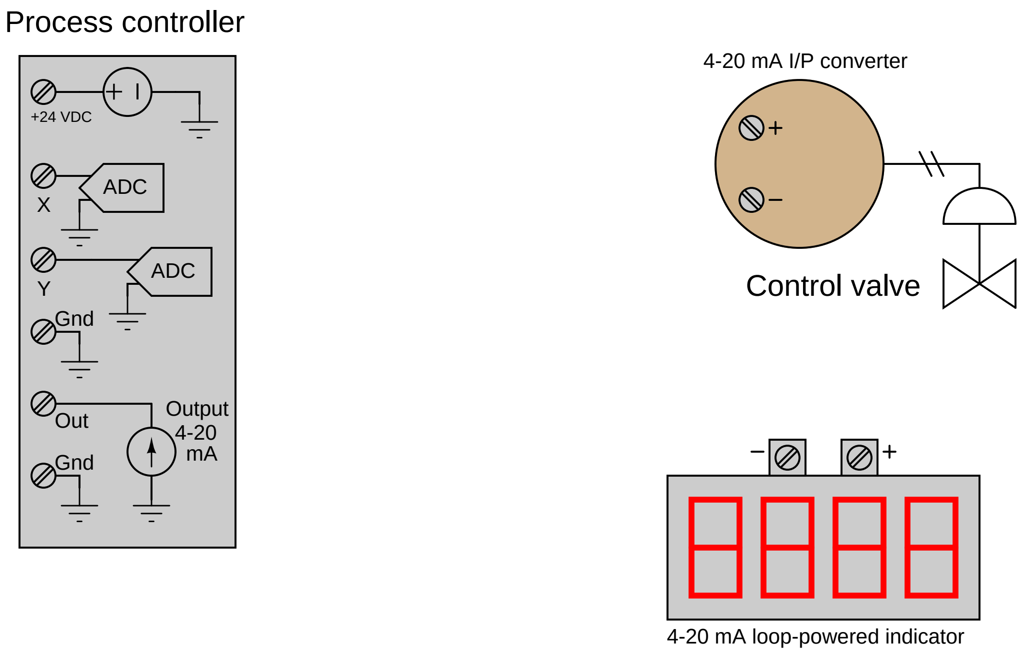


- V_{AC} = (*increase*, *decrease*, or *stay the same*)
- V_{BE} = (*increase*, *decrease*, or *stay the same*)
- V_{AD} = (*increase*, *decrease*, or *stay the same*)
- V_{CD} = (*increase*, *decrease*, or *stay the same*)

file i02914

Question 109

Shown here is a process controller, an I/P transducer, and a loop-powered indicator:

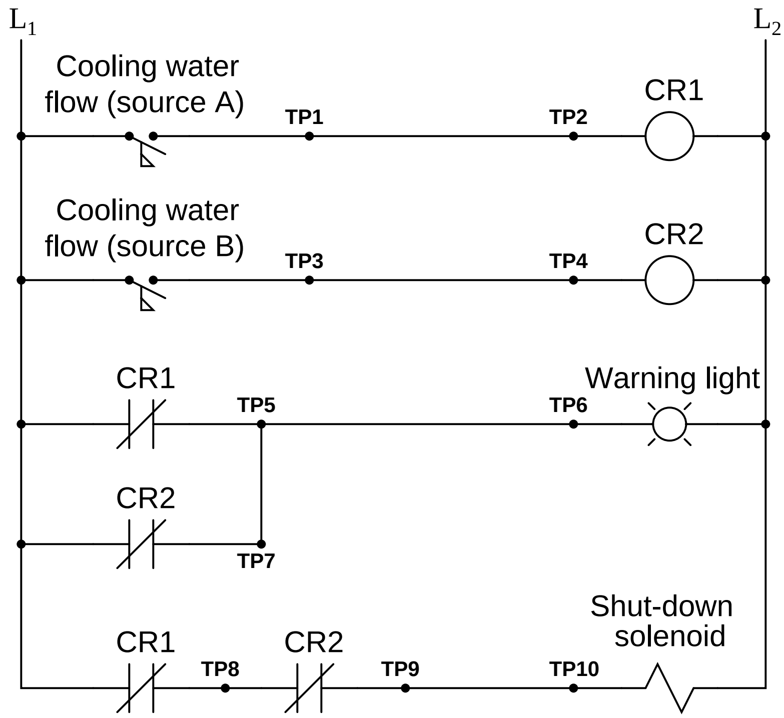


Show how the controller would connect to drive the I/P transducer and also provide a 4-20 mA DC input signal to the loop-powered indicator such that the indicator will show the percentage signal output to the I/P transducer (i.e. the approximate valve position).

file i02529

Question 110

A water-cooled generator at a power plant has two sources of cooling water flow, each source equipped with a flow switch that returns to its normally-open status if the water flow through the pipe stops. If either water source ceases supplying cooling water to the generator (for whatever reason), that flow switch will de-actuate and turn the warning light on. This is all that is required, as the generator will still receive adequate cooling from only one source. If both water sources cease supplying water, however, a "trip" solenoid will energize to shut down the generator before it overheats:



One day the warning light comes on, but there is still cooling water flowing to the generator so it does not shut down. You are asked to determine what the problem is, while maintaining the system in an operating condition (i.e. you are not allowed to shut off control power or do anything else that might shut down the generator).

First, assess whether or not the following diagnostic test would provide any useful information about the fault: *suppose a technician connects an AC voltmeter between terminals TP6 and L2*. Will this test provide information to help us diagnose the nature and/or location of the fault? Why or why not?

Next, propose a diagnostic test that would definitely provide useful information about either the location or the nature of the fault in this system. Your proposal must identify the meaning of at least one possible result of the test (e.g. *"If I jumper terminals X and Y together and I measure a decrease in source voltage, it means the fault must be a short somewhere in branch A-B-C of the circuit"*). Remember that the best diagnostic test is one that yields definitive answers no matter what its result might be. Directly checking a suspected component is *not* a good diagnostic test, unless there are simply no other options!

file i03199

Question 111

Lab Exercise – introduction

Your task is to build, document, and troubleshoot a telemetry system consisting of an analog sensor connected to a data acquisition (DAQ) module, which then sends the data over Ethernet to a personal computer. Temperature and pressure are suggested process variables to measure. Electric current (measured using a shunt resistor or a current transformer) is another excellent process variable to measure, and this works well to introduce the specialized topic of electric power metering and protection. In fact, setting up an electronic protective relay to sense AC current and initiate a breaker "trip" signal is an excellent alternative to using a generic DAQ. Other process variables are open for consideration, though.

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:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Team meeting and prototype sketch (do *first!*)	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final documentation and system inspection	mastery					– – – –
Demonstrate IP "ping" utility	mastery	–	–	–	–	
Demonstrate use of a "knockout punch" tool	mastery	–	–	–	–	
Accurate measurement of variable (± 1% of span)	mastery	–	–	–	–	
Data communicated via Ethernet	mastery	–	–	–	–	
Troubleshooting	mastery					– – – –
Lab question: Instrument connections	proportional					– – – –
Lab question: Commissioning	proportional					– – – –
Lab question: Mental math	proportional					– – – –
Lab question: Diagnostics	proportional					– – – –
Decommission and lab clean-up	mastery	–	–	–	–	

The only "proportional" scoring in this activity are the lab questions, which are answered by each student individually. A listing of potential lab questions are shown at the end of this worksheet question. The lab questions are intended to guide your labwork as much as they are intended to measure your comprehension, and as such the instructor may ask these questions of your team day by day, rather than all at once (on a single day).

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 – team meeting, prototype sketch, and instrument selection

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.

An absolutely essential step in completing this lab exercise is to work together as a team to **sketch a prototype diagram** showing what you intend to build. This usually takes the form of a simple electrical schematic and/or loop diagram showing all electrical connections between components, as well as any tubing or piping for fluids. This prototype sketch need not be exhaustive in detail, but it does need to show enough detail for the instructor to determine if all components will be correctly connected for their safe function.

For example, if you intend to connect field devices to a PLC (Programmable Logic Controller), your prototype sketch must show how those devices will connect to typical input/output terminals on the PLC, where electrical power will be supplied, etc. Prototype sketches need not show all intermediary connections between components, such as terminal blocks in junction boxes between the field device and the controller.

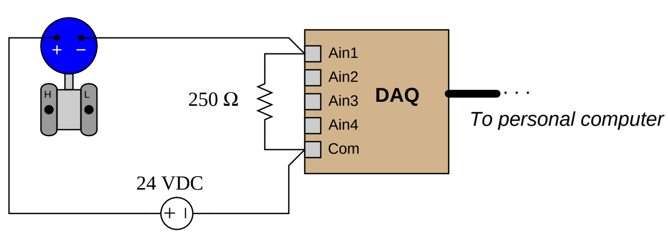
You should practice good problem-solving techniques when creating your prototype sketch, such as consulting equipment manuals for information on component functions and marking directions of electric current, voltage polarities, and identifying electrical sources/loads. Use this task as an opportunity to strengthen your analytical skills! Remember that you will be challenged in this program to do all of this on your own (during "capstone" assessments), so do not make the mistake of relying on your teammates to figure this out for you – instead, treat this as a problem *you* must solve and compare your results with those of your teammates.

Your team's prototype sketch is so important that the instructor will demand you provide this plan before any construction on your team's working system begins. *Any team found constructing their system without a verified plan will be ordered to cease construction and not resume until a prototype plan has been drafted and approved!* Similarly, you should not deviate from the prototype design without instructor approval, to ensure nothing will be done to harm equipment by way of incorrect connections. Each member on the team should have ready access to this plan (ideally possessing their own copy of the plan) throughout the construction process. Prototype design sketching is a skill and a habit you should cultivate in school and take with you in your new career.

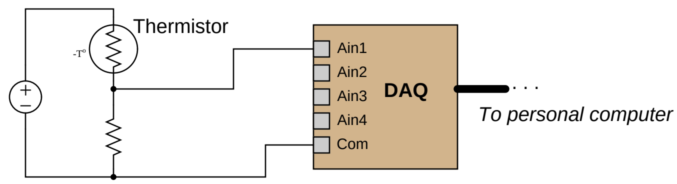
Each lab team locker has its own data acquisition unit (DAQ), and other DAQ units are available from the instructor. You will need to install software on a personal computer in order for that computer to gather analog data from the DAQ unit.

It is recommended that you test your DAQ before connecting it to any external circuitry. For a simple test of an analog input, set your multimeter to "Diode Test" so that it outputs a small voltage, then connect your meter leads to one of the analog input channels on the DAQ: the software should register a small voltage on that channel, letting you know the DAQ is functioning.

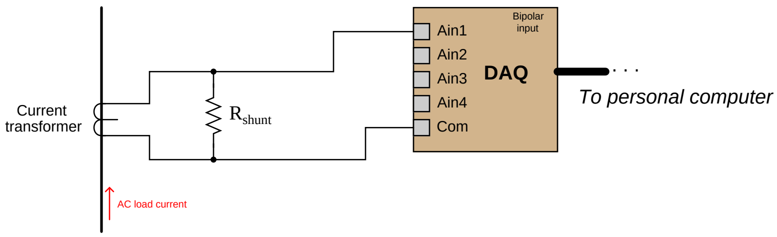
You will need to choose a suitable sensor to connect to one of the DAQ analog inputs. For greatest accuracy, I recommend using a standard 4-20 mA loop-powered pressure or temperature transmitter, with a 250 ohm resistor connected to the DAQ so it can read a 1-5 volt signal:



You are also welcome to be more creative and build yourself a simpler analog sensing circuit such as this:



The challenge with a circuit such as this is that it will *not* output a signal that is linearly proportional to temperature like the loop-powered transmitter will. In order to make this work, you will have to program a formula into the DAQ software to "linearize" the voltage signal into a proportional temperature value. This will require extra work on your part to characterize the sensor, then develop a formula describing the signal voltage value as a function of the measured variable. You may find a computer spreadsheet program to be helpful, plotting a curve of voltage versus sensor stimulus (e.g. temperature), then using the curve-fitting utility in the spreadsheet to develop an equation relating voltage to the measurement.



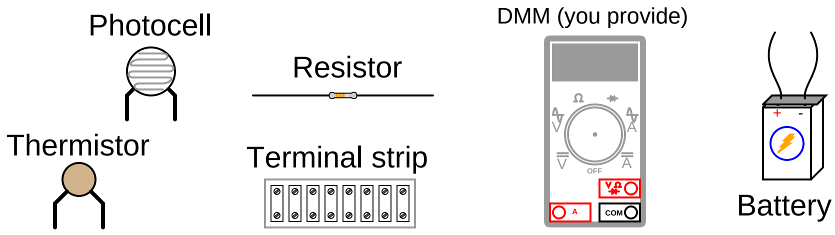
If you choose to build a system to measure AC current using a current transformer (CT, shown above), you will need to select a suitable shunt resistor to drop voltage generated by current output by the CT. This is done by researching the "burden" rating of the CT, which will tell you how large that load resistor may be. CTs act as current sources, and so "want" to drive a low-resistance load (e.g. an ammeter to measure the CT secondary current). However, the DAQ needs to see a strong enough voltage drop across the shunt resistor to use a reasonable percentage of its range, in order to make good use of its resolution. *If you build this circuit, you must be sure to do so in a way that the CT's secondary winding will never become open-circuited when load current goes through it! Open-circuited current transformers are capable of generating dangerously high voltages!!!*

Planning a functioning system should take no more than an hour if the team is working efficiently, and will save you hours of frustration (and possible component destruction!).

Lab Exercise – circuit design challenge

Build a simple circuit using either a light sensor (photocell) or a temperature sensor (thermistor) connected to a fixed-value resistor and a battery such that a variable output voltage will be generated as the sensor is stimulated. Your circuit must either make the voltmeter indication increase with increasing sensor stimulus (more voltage for more light or heat – direct action), or do the exact opposite (reverse action), as specified by the instructor. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, or "alligator" clips permitted). You will also need to demonstrate how to record and display the lowest and highest voltages output by this circuit using your digital multimeter's "min/max" recording function function.

This exercise tests your ability to properly identify the operating characteristics of a light or temperature sensor, properly size a resistor to form a voltage divider circuit with the sensor, properly connect a voltmeter into the circuit to achieve the specified response direction, properly use a DMM to capture minimum and maximum voltage values, and use a terminal strip to organize all electrical connections.



The following components and materials will be available to you: assorted CdS **photocells** and **thermistors** ; an assortment of **resistors** ; **terminal strips** ; lengths of **hook-up wire** ; **battery clips** (holders).

You will be expected to supply your own screwdrivers and digital multimeter (DMM) for assembling and testing the circuit at your desk. The instructor will supply the battery(ies) to power your circuit when you are ready to see if it works. Until that time, your circuit will remain unpowered.

Meter response (instructor chooses): ____ Direct ____ Reverse

Captured value (instructor chooses): ____ $V_{minimum}$ ____ $V_{maximum}$

Sensor type (instructor chooses): ____ Photocell ____ Thermistor

Lab Exercise – building the system

The Instrumentation lab is set up to facilitate the construction of working instrument "loops," with over a dozen junction boxes, pre-pulled signal cables, and "racks" set up with 2-inch vertical pipes for mounting instruments. The only wires you should need to install to build a working system are those connecting the field instrument to the nearest junction box, and then small "jumper" cables connecting different pre-installed cables together within intermediate junction boxes.

After getting your prototype sketch approved by the instructor, you are cleared to begin building your system. All wire connections should be made using terminal blocks. No twisted or taped wire connections will be allowed.

You will need to configure the DAQ software to "scale" the 1-5 VDC signal into an actual measurement of your process variable (e.g. temperature, pressure). A requirement of this lab is that the DAQ software accurately register the process variable you are measuring, rather than merely displaying a voltage value from the sensor.

The personal computer attached to the DAQ may be your own laptop, or one of the lab's computers. Regardless of which computer you use, it needs to be connected to the lab's Ethernet network so that another computer in the lab may acquire the data from it.

Your chosen system may require its own electrical enclosure to house the DAQ and/or other components, not already a part of the lab's permanently-installed loop system. If you need to punch a hole in the side of a custom enclosure as part of your system, you must use a special tool called a *knockout punch* to make these holes (rather than use a hole saw on a drill). The Greenlee company manufactures a line of knockout punches called the *Slug Buster*, which you may wish to research in preparing to use this tool.

Common mistakes:

- Starting to build the circuit before planning its construction on paper with a proposed circuit sketch.
- Failing to heed signal voltage limits for the DAQ analog input channels. *Be careful not to over-power the DAQ with signal voltages exceeding its measurement limits!*
- Failing to tug on each and every wire where it terminates to ensure a mechanically sound connection.
- Students working on portions of the system in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!

Building a functioning system should take no more than one full lab session (3 hours) if all components are readily available and the team is working efficiently!

Lab Exercise – advanced multimeter usage

Part of this lab exercise is learning how to use an incredibly powerful feature of your digital multimeter: its ability to capture and record minimum and maximum measurements. On Fluke-brand multimeters, this mode is engaged by pressing a button labeled "Min/Max". Once engaged, the meter will store in its memory the lowest, highest, and average values of that measurement from the time the mode is engaged until the time you read those captured values.

Some digital multimeters (DMMs) have even more advanced functionality, whereby they record multiple data points over time, more like a data recorder. Additionally, other advanced features such as *high-speed Min/Max*, *high-resolution measurement*, and *low-pass filtering* are provided by Fluke-brand multimeters. Take the time to try all of these measurement features while using your multimeter in this lab exercise.

These functions are important when diagnosing intermittent faults in a system. The multimeter's ability to capture and remember measurement values over long spans of time gives the technician the flexibility to set the multimeter as a recording device, leave to do other tasks, then return to see what the meter recorded during that span of time.

It should be noted that your multimeter may not retain its automatic ranging capability when set to record data. If your meter is like this and you engage this mode while the measurement value is low, the meter may respond with an "overload" indication should the measurement value exceed the range locked in at the time the record mode was engaged. In this case, the you are advised to manually set the meter's measurement range before engaging the recording mode.

It should also be noted that some DMMs provide multiple sampling times for their record function. In other words, your meter might provide a "slow" recording mode plus a "fast" recording mode. The trade-off for faster sampling time is – as always for DAQ hardware – less measurement resolution. In other words, you might not be able to record data as precisely as you would like in the fast speed. Conversely, if you desire maximum resolution, you may have to settle for a slower sampling rate.

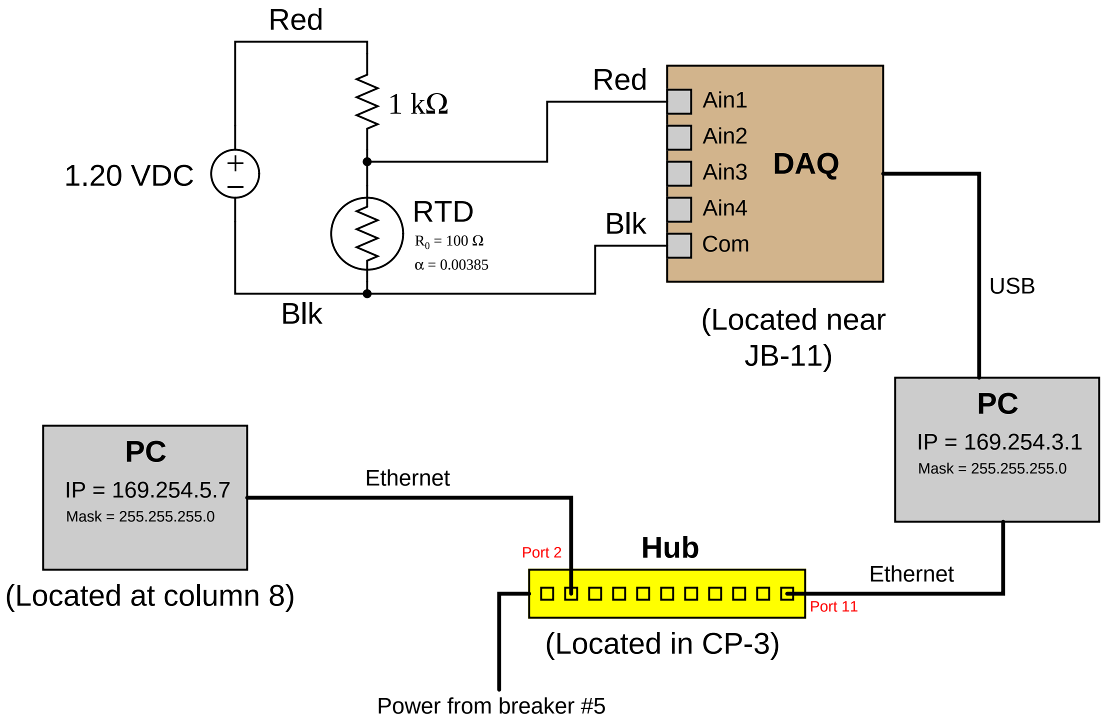
Common mistakes:

- Failing to consult the multimeter's instruction manual.
- Failing to consult the multimeter's instruction manual.
- Failing to consult the multimeter's instruction manual.
- Note: *this repetition is not a typographical error. I* **really** *want you to consult the instruction manual that came with your multimeter!*

Lab Exercise – documenting the system

Each student must sketch their own *system diagram* for their team's data acquisition system. This will not be an ISA-standard loop diagram, but rather a combination of schematic diagram (showing the sensor and DAQ connections) and block diagram (showing the computer Ethernet network complete with IP addresses). Your diagram must be *comprehensive* and *detailed*, showing every wire connection, every cable, every terminal block, range points, network addresses, etc.

An example system diagram is shown here:



When your entire team is finished drafting your individual diagrams, call the instructor to do an inspection of the system. Here, the instructor will have students take turns going through the entire system, with the other students checking their diagrams for errors and omissions along the way. During this time the instructor will also inspect the quality of the installation, identifying problems such as frayed wires, improperly crimped terminals, poor cable routing, missing labels, lack of wire duct covers, etc. The team must correct all identified errors in order to receive credit for their system.

After successfully passing the inspection, each team member needs to place their system diagram in the diagram holder located in the middle of the lab behind the main control panel. When it comes time to troubleshoot another team's system, this is where you will go to find a diagram for that system!

Common mistakes:

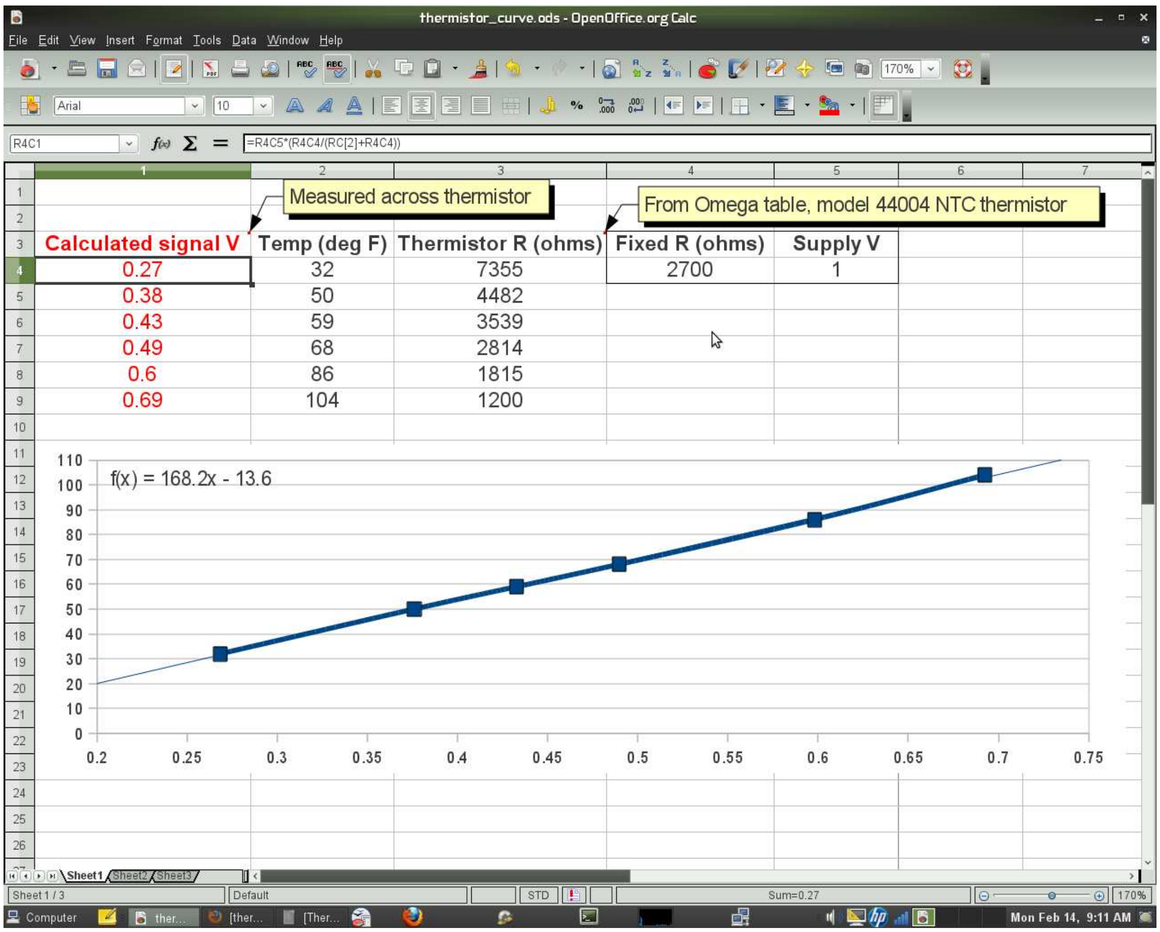
- Forgetting to label all signal wires.
- Forgetting to note all wire colors.
- Forgetting to put your name on the diagram!
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Not placing instruments in the correct orientation (field instruments on the left, control room instruments on the right).

Lab Exercise – DAQ signal scaling/linearization

Each team must configure the DAQ system to ensure it accurately measures and reports the measured variable. The measurement accuracy will be checked by the instructor by applying random stimuli to the sensor while the team verifies the remote indication (on a computer connected through the network to the DAQ module).

If your system uses a loop-powered 4-20mA transmitter, the only DAQ configuration you will need to do is "scale" the DAQ so that it converts the linear 1-5 VDC signal into a linear representation of the measured variable. However, you will need to rely on those teammates who have taken the INST24X courses to calibrate the transmitter so that it accurately outputs the 4-20 mA signal.

If your system reads a raw voltage signal from a resistive sensor in a bridge or other voltage-divider network, you will need to program the DAQ software to "linearize" the signal so that it will register the actual process variable and not just a plain signal voltage. The following screenshot shows how a computer spreadsheet may be used to generate a linearizing equation from published sensor data:



In this particular example, the sensor is a negative temperature coefficient (NTC) thermistor, model 44004, manufactured by Omega. The formula entered into cells R4C1 through R9C1 calculates the voltage dropped across a fixed resistor (2700 Ω) connected in series with the thermistor and powered by a 1 volt DC source, using the voltage divider equation ($V_R = V_{source} \frac{R}{R_{total}}$). The thermistor resistance values seen in column 3 were taken from an Omega-published table for the model 44004 thermistor. A "scatter" plot graphs temperature as a function of voltage, and a "trendline" plotted by the spreadsheet program attempts to match the data points to a mathematical formula. In this particular case, the fitted formula happens to be Temp = 168.2 * (Voltage) − 13.6. It is this formula you must enter into the DAQ software, so it knows how to translate the measured voltage signal into a temperature value.

If the sensor you choose does not have a data table describing its characteristics, you may generate your own by subjecting it to known stimuli and measuring its resistance at those known values. Then, you may use a spreadsheet to plot the voltage response and derive an equation to fit the data.

Another huge advantage of using a computer spreadsheet to model the signal voltage as a function of temperature is that it allows you to "experiment" with different values of fixed resistance, to see the effect it has on linearity. By entering a new fixed-resistor value into the spreadsheet, you may immediately see the effect that value change has on the curvature of the scatter plot, as well as the effect it has on the signal voltage strength.

Common mistakes:

- Choosing a poor-accuracy calibration standard (e.g. trying to calibrate your $1500 precision Rosemount pressure transmitter to ± 0.1 PSI using a $30 pressure gauge that only reads to the nearest 5 PSI!).
- Improperly configuring the spreadsheet scatter plot to generate a fitted equation (e.g. having variables on wrong axes)

Characterizing your sensor and scaling the DAQ software should take no more than one full lab session (3 hours) if the team is working efficiently!

Lab Exercise – Ethernet data transfer

An essential part of this lab exercise is to have the acquired data transported over an Ethernet network. Unless the DAQ software is quite sophisticated, this feature is not likely to be directly supported. A suitable alternative is to have one computer acquiring data from the DAQ module, and use another computer to remotely view the display of the first computer. This remote viewing may be done using "Remote Desktop" in Microsoft Windows operating systems, or by installing free remote-administration software such as `RealVNC`.

Not only will remote access allow you to view the live DAQ data from another computer over the Ethernet network, but it also allows you do *operate* the DAQ computer remotely. Knowing how to use remote-viewing software, therefore, is a very useful skill.

Another Ethernet-related objective in this lab exercise is using the `ping` utility to test for network connections. When two personal computers have been successfully connected to a common Ethernet network, you should be able to "ping" one computer from the other by invoking the `ping` utility with the IP address of the destination computer as an argument to the `ping` command. You may run the `ping` command from a command-line window on a Microsoft Windows operating system. More detailed instructions on the use of `ping` may be found in your *Lessons In Industrial Instrumentation* textbook.

A successful "ping" from one computer to another is a *necessary* condition for remote viewing of that computer's display, but it is not a *sufficient* condition. That is to say, although a computer that refuses to "ping" is definitely not ready to be logged into remotely, a computer that does "ping" without trouble may not necessarily be ready for remote login. Getting a successful "ping" from a computer is merely the first step in establishing full communication with it.

If a "ping" attempt proves unsuccessful, it means something is inhibiting communication between that device and the computer you're using to issue the ping. A good test to do in this circumstance is try "pinging" other devices on that same network. Any successful ping attempts will definitively prove OSI layers 1, 2, and 3 are all functional between those two points, since "ping" requires those three layers to function. Once you know which portion(s) of the network are functional, you may narrow the field of fault possibilities.

Network functions above OSI layer 3 (e.g. "firewall" software running on personal computers) are capable of inhibiting communication between devices on the lab's Ethernet network, including "ping" messages. If you decide to connect your own personal computer (laptop) to the lab's Ethernet network, you may find it easier to temporarily disable all security features on your personal computer to enable free and open communication between your computer and all other devices on the network. Just be sure to re-enable the security features when you are done, so your computer will not be unprotected the next time you connect to the Internet!

Lab Exercise – troubleshooting

The most challenging aspect of this lab exercise is *troubleshooting*, where you demonstrate your ability to logically isolate a problem in the system. All troubleshooting is done on an individual basis (no team credit!), and must be done *on a system you did not help build*, so that you must rely on loop diagrams to find your way around the system instead of from your own memory of building it.

Each student is given a limited amount of time to identify both the general location and nature of the fault, logically justifying all diagnostic steps taken. All troubleshooting activities will take place under direct instructor supervision to ensure students are working independently and efficiently.

Failure to correctly identify both the general location and nature of the fault within the allotted time, and/or failing to demonstrate rational diagnostic procedure to the supervising instructor will disqualify the effort, in which case the student must re-try with a different fault. Multiple re-tries are permitted with no reduction in grade.

A standard multimeter is the only test equipment allowed during the time limit. No diagnostic circuit breaks are allowed except by instructor permission, and then only after correctly explaining what trouble this could cause in a real system.

The instructor will review each troubleshooting effort after completion, highlighting good and bad points for the purpose of learning. Troubleshooting is a skill born of practice and failure, so do not be disappointed in yourself if you must make multiple attempts to pass! One of the important life-lessons embedded in this activity is how to deal with failure, because it *will* eventually happen to you on the job! There is no dishonor in failing to properly diagnose a fault after doing your level best. The only dishonor is in taking shortcuts or in giving up.

Common mistakes:

- Neglecting to take measurements with your multimeter.
- Neglecting to check other measurements in the system (e.g. pressure gauge readings).
- Incorrectly interpreting the diagram (e.g. thinking you're at the wrong place in the system when taking measurements).
- Incorrect multimeter usage (e.g. AC rather than DC, wrong range, wrong test lead placement). This is especially true when a student comes to lab unprepared and must borrow someone else's meter that is different from theirs!

Remember that the purpose of the troubleshooting exercise is to foster and assess your ability to intelligently diagnose a complex system. Finding the fault by luck, or by trial-and-error inspection, is not a successful demonstration of skill. The only thing that counts as competence is your demonstrated ability to logically analyze and isolate the problem, correctly explaining all your steps!

Troubleshooting takes a lot of lab time, usually at least two 3-hour lab sessions for everyone in a full class to successfully pass. Be sure your team budgets for this amount of time as you plan your work, and also be sure to take advantage of your freedom to observe others as they troubleshoot, to better learn this art.

Lab questions

- **Instrument connections**
- Determine correct wire connections between a DAQ module and an electrical sensor, based on diagrams of instruments with terminals labeled
- Correctly determine all electrical sources and loads, as well as all voltage polarities and current directions in a DAQ/sensor circuit, based on diagrams of instruments with terminals labeled

- **Commissioning and Documentation**
- Explain the operating principle of the sensor used in your system
- Explain the difference between a *single-ended* input channel and a *differential* input channel on an analog DAQ module
- Describe the use of some of the advanced functions of your multimeter *besides* record ("Min/Max") mode
- Explain why power and signal wiring should not be run together in conduit or in a panel
- Explain why it is necessary to use a *bushing* to protect electrical wires that enter and exit an electrical enclosure through a hole in the side of that enclosure

- **Mental math** (no calculator allowed!)
- Determine allowable calibration error of instrument (e.g. +/- 0.5% for an instrument ranged 200 to 500 degrees)
- Convert 1-5 V signal into a percentage of span (e.g. 3.5 V = ____%)
- Convert percentage of span into a 1-5 V signal value (e.g. 70% = ____ V)
- Calculate resolution of ADC given number of bits and input signal range

- **Diagnostics**
- Explain how to distinguish an "open" cable fault from a "shorted" cable fault using only a voltmeter (no current or resistance measurement, but assuming you are able to break the circuit to perform the test)
- Determine whether or not a given diagnostic test will provide useful information, given a set of symptoms exhibited by a failed system
- Identify at least two plausible faults given the results of a diagnostic test and a set of symptoms exhibited by a failed system
- Propose a diagnostic test for troubleshooting a failed system and then explain the meanings of two different test results

Lab Exercise – decommissioning and clean-up

The final step of this lab exercise is to decommission your team's entire system and re-stock certain components back to their proper storage locations, the purpose of which being to prepare the lab for the next lab exercise. Remove your system documentation (e.g. loop diagram) from the common holding area, either discarding it or keeping it for your own records. Also, remove instrument tag labels (e.g. FT-101) from instruments and from cables. 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

Return the following components to their proper storage locations:

- Sensing elements (e.g. thermocouples, pH probes, etc.)
- Process transmitters
- "Jumper" cables used to connect terminal blocks within a single junction box
- Plastic tubing and tube fittings (disconnect compression-style tube fittings)
- Power cables and extension cords
- Adjustment (loading station) air pressure regulators

Finally, you shall return any control system components to their original (factory default) configurations. This includes controller PID settings, function block programs, input signal ranges, etc.

file i00350

Answer 1

Answer 2

I'll let you research the answers here!

Answer 3

Answer 4

Answer 5

Answer 6

Partial answer:

- Preamble:
- SFD: *Start-of-Frame Delimiter, to signal the end of the preamble bitstream.*
- Destination address: *the MAC address of the intended recipient.*
- Source address: *the MAC address of the transmitting station.*
- Type (or Length): *contains a code to specify the purpose of the data bits, or a code specifying the number of data bytes contained in the Data field. This can be either, depending on the value of the code. If 1500 or less, it represents the Data field length; if 1536 or more, it represents data type (assumed Data field length of 46 bytes).*
- Data:
- Frame check sequence:

Answer 7

I'll let you figure out the answer to this question, as well as explain how you got it!

Answer 8

The basic idea of Ethernet is that there is an electrically passive medium (a coaxial cable) serving as a conduit for signals transmitted by any station connected to that medium. The transparency and passivity of the network cabling was supposed to be analogous to the "luminiferous ether" that was once thought of as filling all space, serving as a medium for electromagnetic waves to exist.

The data rate for the original Ethernet specification was 2.94 Mbps (2.94 million bits per second).

It should be noted that Metcalfe's original Ethernet was an example of a *multipoint*, broadcast network. All stations are allowed to initiate communication, and that communication gets broadcast to all stations connected to that line. Now, with switching hubs, the "broadcast" portion of the description is a bit more limited, but it is still a true multipoint network.

Answer 9

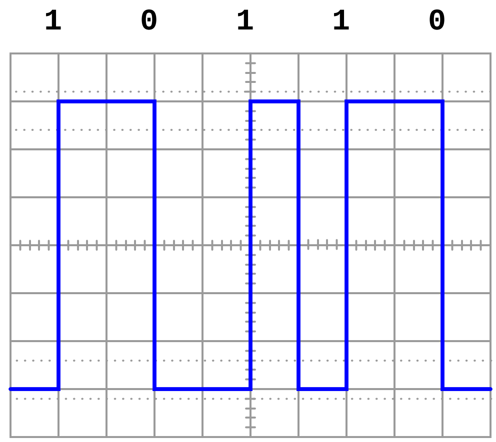
An Ethernet *hub* is an active piece of communications equipment: an actual DCE, and not just a passive connector. Inside, it contains transceiver circuits to amplify received signals and re-transmit them to the other "ports" on the hub.

Termination resistors are not required with twisted-pair Ethernet networks because all Ethernet devices (DTE and DCE) are engineered with the proper termination impedance built in to the transceivers.

Answer 10

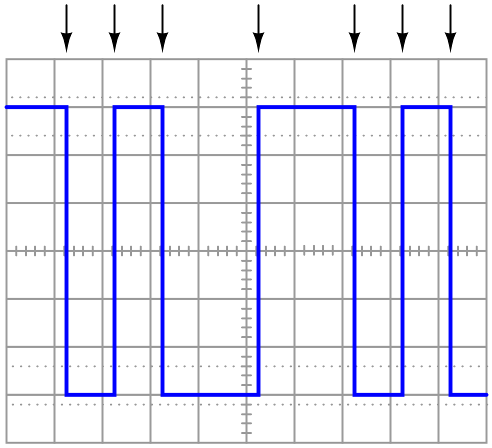
The data stream represented by the given waveform is `0 0 1 0 0`.

Here is the waveform answer to the "hint," where we encode the bitstream `1 0 1 1 0`:

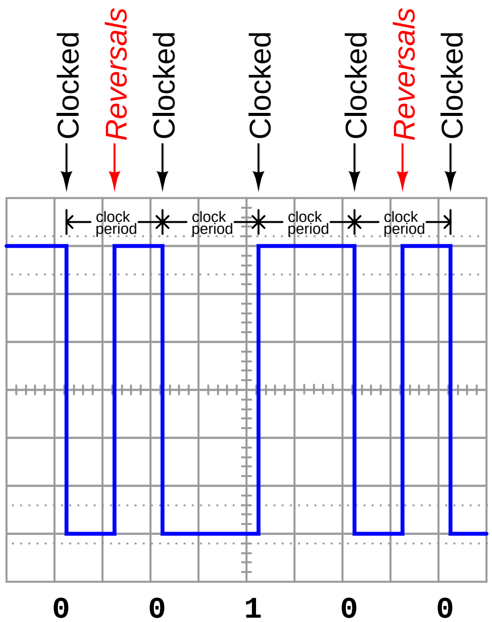


Note how one of the transitions does *not* represent a bit, but merely "sets up" the voltage level in preparation for another low-to-high ("1") transition. The key to deciphering a Manchester-encoded data stream is being able to identify which transitions represent real data bits and which do not. Do you see the pattern, and how to distinguish one type of transition from the other?

Here's a clue to decoding a Manchester-encoded signal. First, identify *all* signal transitions, as such:



Next, knowing that all **data bits** are timed to a clock, and that these clock pulses are always equally spaced in time, you can see which transitions constitute data, and which are merely state reversals to set up the next bit.



An advantage of Manchester encoding is that it encodes the clock signal directly into the data stream. This helps devices synchronize each other without the need for a separate wire to carry a clock signal. Auto-sensing 10/100 Mbit Ethernet hubs rely on this to tell what speed the incoming signals are going.

A disadvantage of Manchester encoding is that the baud rate may be as high as twice the value of the bit rate. For example, a Manchester-encoded 10 Mbps bitstream of all ones or all zeros would require a baud rate of 20 Mbaud, since each identical bit would require *two* voltage-level transitions.

Answer 11

A switch does not blindly broadcast all incoming data to all outgoing ports. Instead, it learns what MAC address(es) reside on each port, and directs data frames only to their intended destination ports.

Answer 12

The cable is built so that the transmit and receive lines "cross over" to the opposite terminals between one plug and the other.

Answer 13

- 10BASE2: 10 Mbps, thin coaxial cable, 185 meters length maximum
- 10BASE5: 10 Mbps, thick coaxial cable, 500 meters length maximum
- 10BASE-T: 10 Mbps, two twisted wire pairs, Category 3 cable or better
- 10BASE-F: 10 Mbps, two optical fibers (includes 10BASE-FB, 10BASE-FP, and 10BASE-FL)
- 100BASE-TX: 100 Mbps, two twisted wire pairs, Category 5 cable or better
- 100BASE-FX: 100 Mbps, two optical fibers, multimode
- 1000BASE-T: 1 Gbps, four twisted wire pairs, Category 5 cable or better
- 1000BASE-SX: 1 Gbps, two optical fibers, short-wavelength
- 1000BASE-LX: 1 Gbps, two optical fibers, long-wavelength

Answer 14

- **Cell R1C1:** `# of nodes =`
- **Cell R3C1:** `P (no delay) =`
- **Cell R3C2:** `= (1 - (1 / R1C2)) ^ (R1C2 - 1)`
- **Cell R4C1:** `Avg slots =`
- **Cell R4C2:** `= (1 - R3C2) / R3C2`

Collisions tend to increase as data packet size decreases, because this means each node on the network must initiate communications (to begin a new packet) more often, and this is when collisions occur. What you might find surprising is just how tolerant an Ethernet network is to lots of nodes:

N	P	M
1	100%	0
2	50%	1
3	44.44%	1.25
4	42.19%	1.3704
5	40.96%	1.4414
10	38.74%	1.5812
100	36.97%	1.7047
1000	36.81%	1.7169

These formulae came from pages 308-309 of the book *Practical Data Communications for Instrumentation and Control*, by John Park, Steve Mackay, and Edwin Wright (2003).

Answer 15

Answer 16

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Answer 25

Partial answer:

Largest IPv4 address: `255.255.255.255`

Smallest IPv4 address: `0.0.0.0`

IPv4 gives almost 4.3 *billion* unique addresses, but believe it or not we have already run out of IPv4 addresses (i.e. there are more IP-capable devices in existence than there are IPv4 addresses)!

Answer 26

Answer 27

Some of the different OSI layer 1 formats seen here:

- EIA/TIA-232
- EIA/TIA-485
- Bell 202 (HART FSK signals)
- DeviceNet
- Ethernet 10BASE-T (IEEE 802.3)
- IEEE 802.11g (wireless)

Some of the OSI layer 2 addressing schemes seen here:

- HART field device addresses
- MAC addresses for each personal computer

The personal computers are responsible for "wrapping" the disparate data streams into TCP/IP packets, which are then forwarded to the router over Ethernet, then transmitted over ISDN. Once in packetized form, they become portable over any network standard, requiring only a computer with an "understanding" of TCP/IP protocol to reassemble and "unwrap" at the receiving end(s).

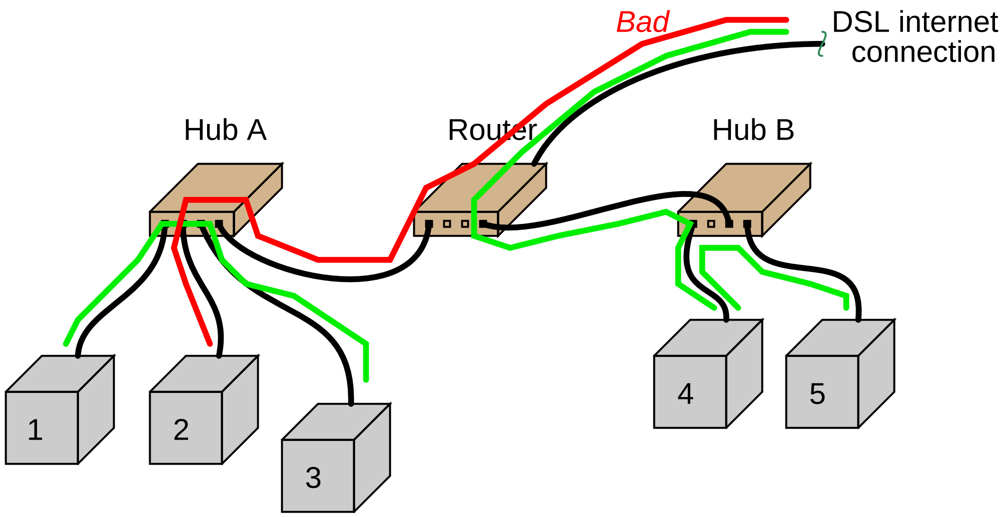
Answer 28

Partial answer:

Fault	**Possible**	**Impossible**
Hub A failed		
Hub B failed		
Router failed		$\surd$
Internet service provider failed		$\surd$
Cable failed between computer #4 and Hub B		
Cable failed between Hub A and Router		$\surd$
Cable failed between Hub B and Router		
Security settings (e.g. firewall) in computer #4		

Answer 29

"Good" paths shown in bright green, "bad" paths shown in bright red:



Suspect components include 2, cable between 2 and hub A, cable between hub A and router.

A good "next ping" test to do is to try pinging 1 or 3 from 2: that would test 2 as well as the cable between 2 and hub A. An alternative test would be to ping 4 or 5 from 1 or 3: that would test the cable between hub A and the router.

Answer 30

The different networking standards listed describe different layers of the OSI model. EIA/TIA-485 describes layer 1; Ethernet describes layers 1 and 2; Modbus, HTTP, and FTP all describe layer 7.

The OSI model is fundamentally a *framework* for defining the potential purposes of a network standard. No existing standard occupies all seven layers because no existing standard is absolutely comprehensive from physical layer all the way up to application layer, exhibiting all possible functions and features in between. Such a standard would be completely stand-alone. Most networks are a conglomeration of different standards, working together to achieve a practical end.

Answer 31

IP stands for *Internet Protocol*, and it specifies how long blocks of data may be divided into smaller chunks called *packets*, how those packets may be re-assembled at the receiving end, and also how devices connected to a large network may be addressed both individually and by group.

TCP stands for *Transmission Control Protocol*, and it specifies (among other things) how to ensure integrity of communication in a network where data has been broken down into individual packets. In essence, TCP guarantees deliver of all data packets even when network connections are less than perfectly reliable, by acknowledging correct receipt of each packet and requesting re-transmission in the event of corrupted or lost packets.

Answer 32

Answer 33

Answer 34

Answer 35

Answer 36

Answer 37

Answer 38

Answer 39

Answer 40

Answer 41

Answer 42

Answer 43

Answer 44

Answer 45

Partial answer:

- Circuit #2: **Yes**
- Circuit #3: **No**
- Circuit #6: **Yes**
- Circuit #9: **No**

Hint: apply the Superposition Theorem to each circuit example, where the HART communicator is the only active signal source in the circuit, and see if the communicator's signal is able to reach the transmitter.

Answer 46

Answer 47

Answer 48

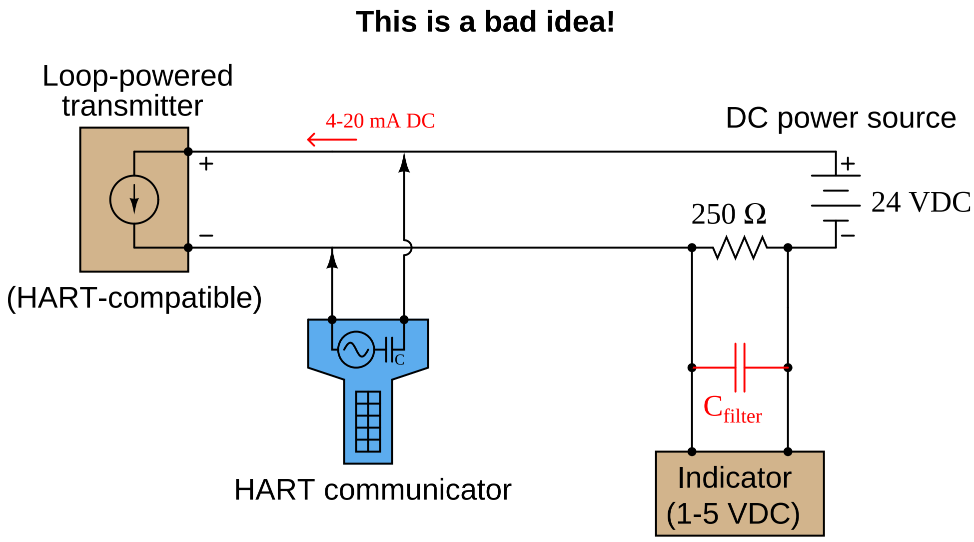
Answer 49

Answer 50

You may locate the `grades_template` on the `Y:` network drive at BTC, provided you log in to the computer system using your individual student ID and password (not a generic login such as "btc"). It is also available for download at the *Socratic Instrumentation* website.

Answer 51

However you plan to filter the HART signals, resist the temptation to do this:



While placing a capacitor across the terminals of the indicator will bypass high-frequency AC HART signals around the indicator, it will also completely short out the HART data so the transmitter and communicator can't talk with one another!

I'll let you figure out a better method of HART signal filtering – one that blocks HART frequencies from getting to the indicator without killing the HART signals throughout the network.

Answer 52

Flow transmitter FT-38 is a Coriolis mass flow transmitter, simultaneously measuring mass flow rate, density, and temperature. Mass flow is the primary variable reported by this transmitter in 4-20 mA form, while the secondary and tertiary variables of density and temperature are extracted by FY-38c (a HART-to-analog converter) and reported to indicating recorders DIR-38 and TIR-38 in 4-20 mA form.

Answer 53

Answer 54

Answer 55

Answer 56

Answer 57

Answer 58

Answer 59

Answer 60

Answer 61

Answer 62

Answer 63

Answer 64

Answer 65

Partial answer:

Figure 1:
$R_{AB} = 500\ \Omega$

Figure 3:
$R_{AB} = 1.511\ \mathrm{k}\Omega$

Figure 4:
$R_{AB} = 940\ \Omega$

Figure 6:
$R_{AB} = 80.54\ \Omega$

Answer 66

Answer 67

Answer 68

Answer 69

Answer 70

Answer 71

Answer 72

Answer 73

Answer 74

Answer 75

Answer 76

Answer 77

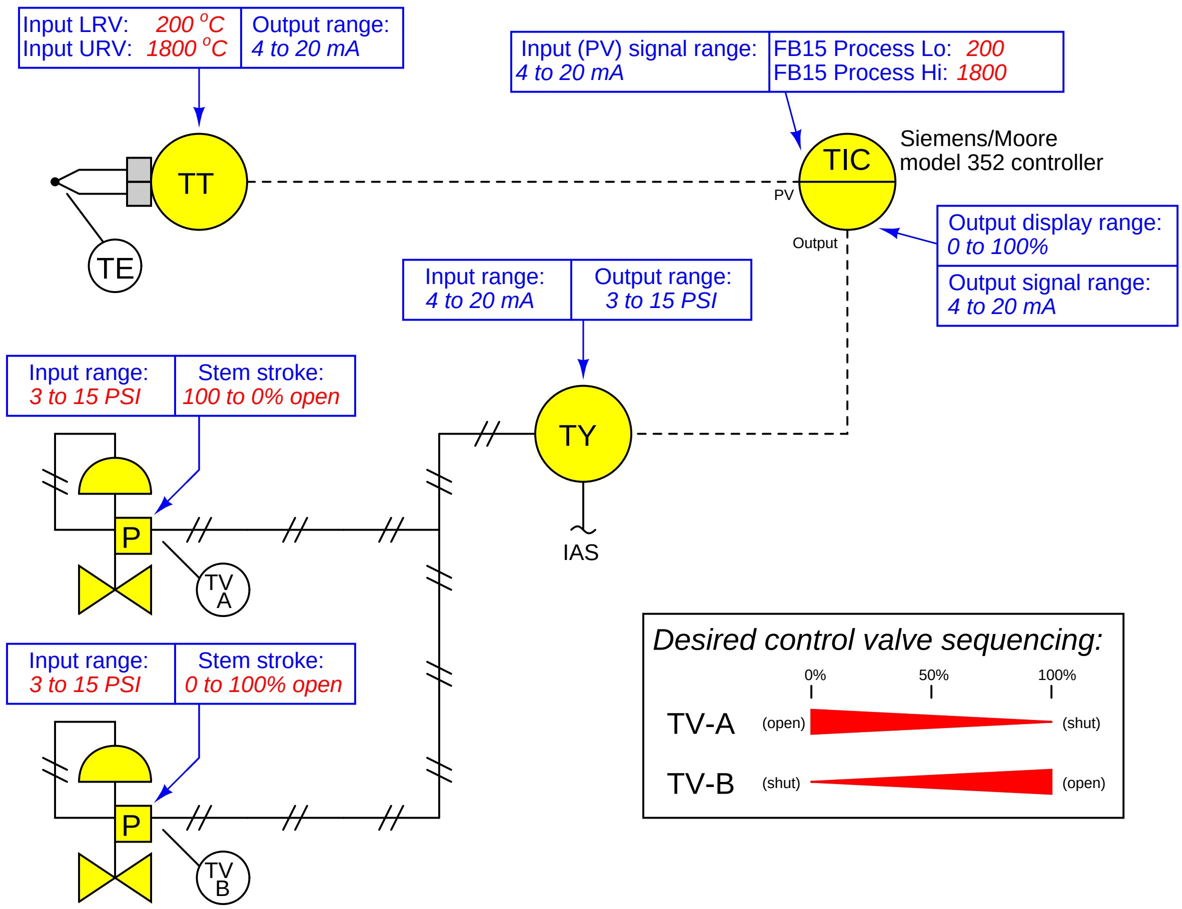
Answer 78

Answer 79

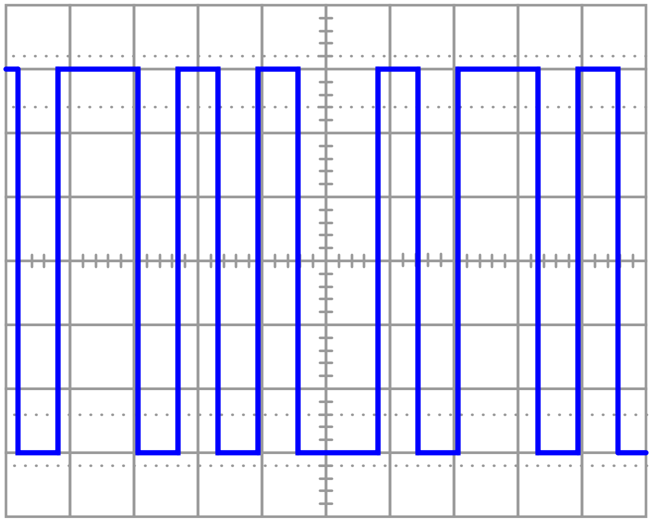
Answer 80

Answer 81

Answer 82

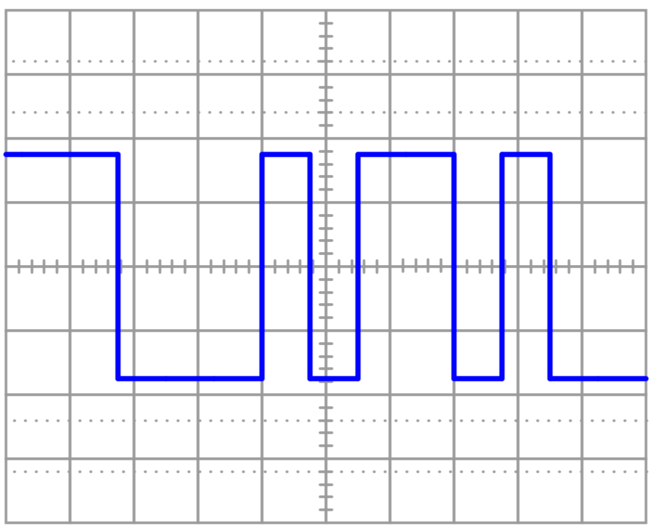


(Manchester encoding)



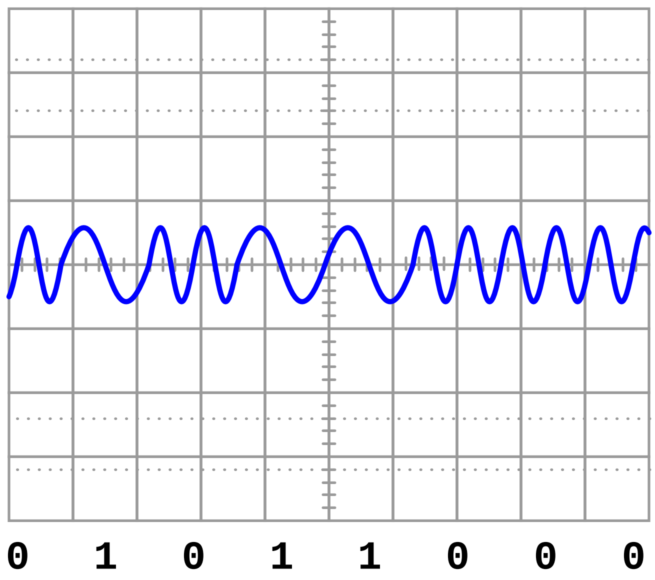
1 0 0 0 1 1 0 0

(NRZ encoding)

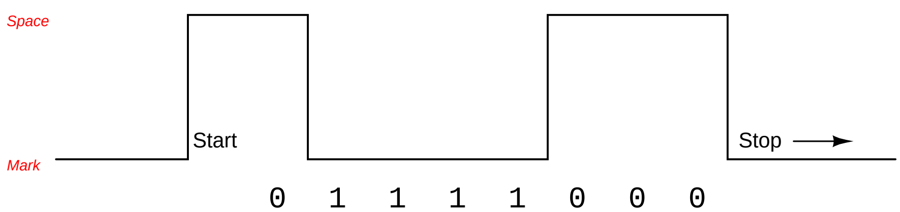


0 0 1 1 1 0 1 0 0 1 0 1 1

(FSK encoding)



Answer 84



Answer 85

The bias voltage provided by these resistor values will meet the EIA/TIA-485 standard for voltage at a receiver device (−200 mV), but not for voltage at a transmitter device (−1.5 V). Thus, the noise margin is compromised, and the system may not perform to the standard in a noisy environment.

Answer 86

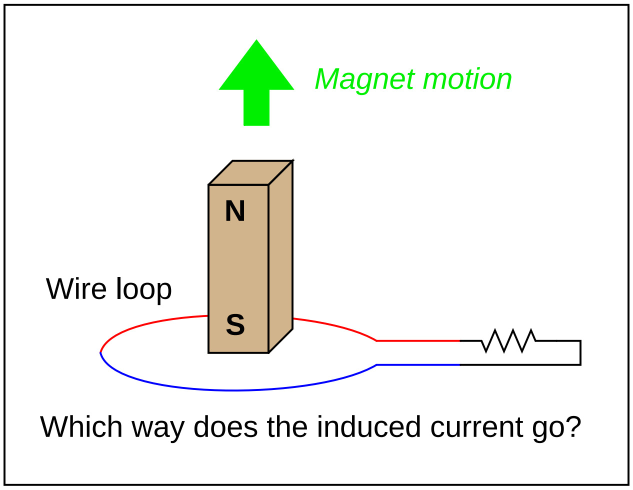
Partial answer:

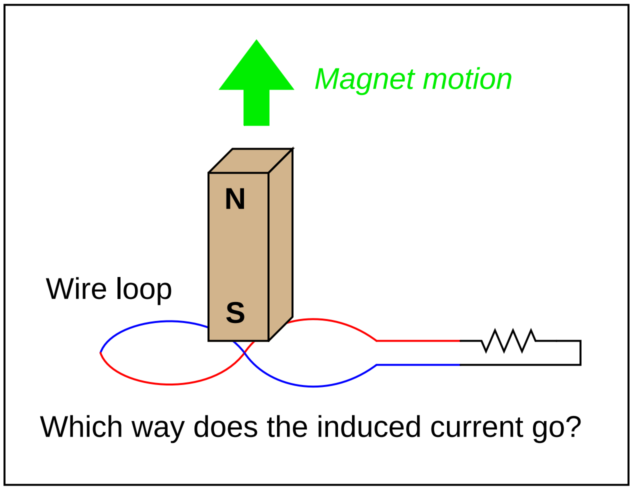
Input voltage (volts)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
1.6	32	1310 or 1311	
	73.8	3022	
	40		666
3.18			A2F

Answer 87

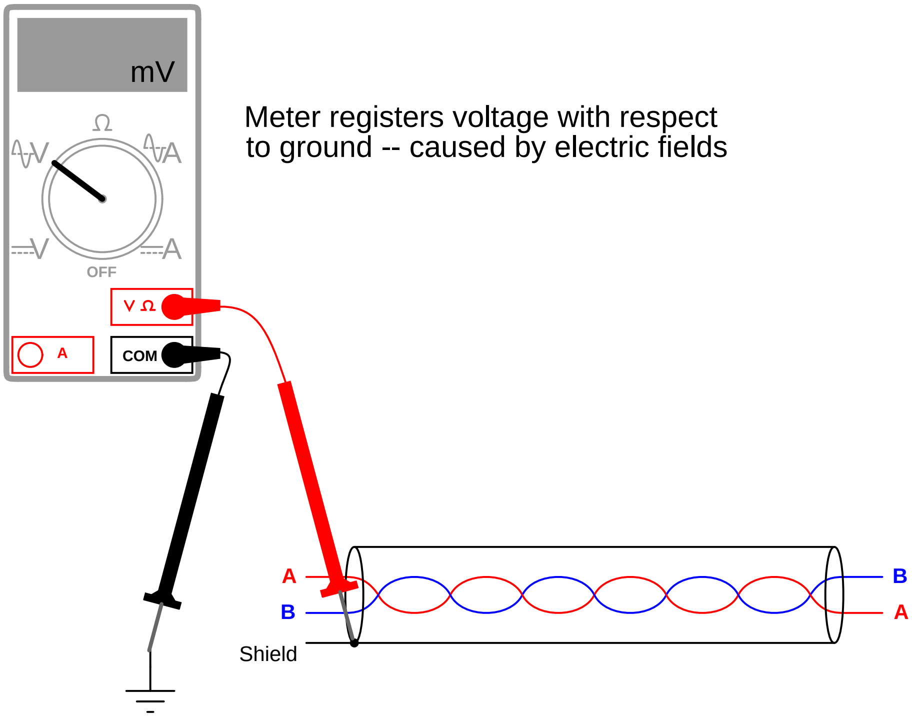
Shielding guards against electric fields by creating a zero-potential surface around the wires to act as a terminal point for any external electric fields. Thus, the space inside the cable is free from external electric fields by virtue of the shield.

Twisting the wires ensures that a current loop will never be formed to allow electromagnetic induction from external (changing) magnetic fields. The following "thought experiment" comparing two scenarios proves this conclusively:





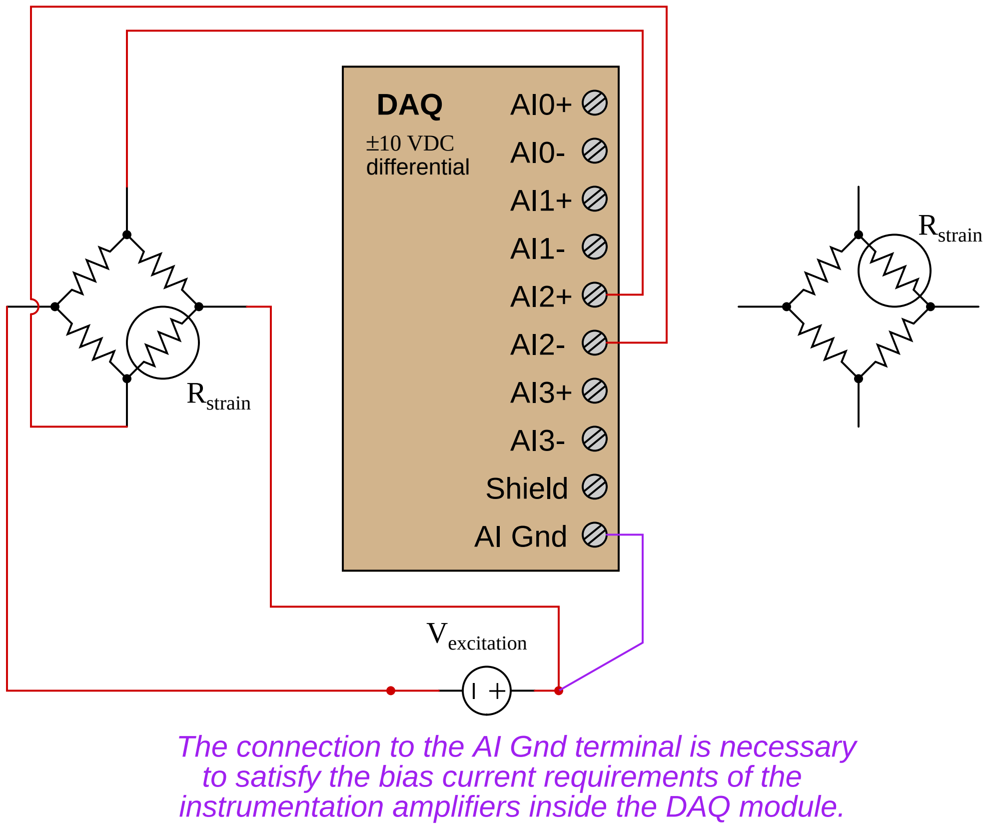
Demonstration of how to measure electric field noise voltage:



Answer 88

Partial answer:

Note that this is not the only valid solution:



Answer 89

Answer 90

There are only eight valid ciphers in the octal system (0, 1, 2, 3, 4, 5, 6, and 7), with each successive place carrying eight times the "weight" of the place before it.

- 35_8 into decimal: 29_{10}
- 16_{10} into octal: 20_8
- 110010_2 into octal: 62_8
- 51_8 into binary: 101001_2

Answer 91

There are sixteen valid ciphers in the hexadecimal system (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F), with each successive place carrying sixteen times the "weight" of the place before it.

- 35_{16} into decimal: 53_{10}
- 34_{10} into hexadecimal: 22_{16}
- 11100010_2 into hexadecimal: $E2_{16}$
- 93_{16} into binary: 10010011_2

Follow-up question: why is hexadecimal considered a "shorthand" notation for binary numbers?

Answer 92

- `ping` tests for the presence of an IP-enabled device on a network
- `ipconfig` or `ifconfig` shows the IP configuration data for a computer (IP address, subnet mask, etc.)
- `netstat` displays the TCP and UDP port connection statuses for a computer
- `tracert` or `traceroute` traces the route taken by a data packet over the Internet from source to destination
- `nslookup` shows the DNS "name" for a computer on the Internet

Answer 93

As the source voltage decreases, zener diode current also decreases:

- $V_{source} = 25$ V ; $I_{zener} = 41.49$ mA
- $V_{source} = 20$ V ; $I_{zener} = 30.85$ mA
- $V_{source} = 15$ V ; $I_{zener} = 20.21$ mA
- $V_{source} = 10$ V ; $I_{zener} = 9.58$ mA
- $V_{source} = 5$ V ; $I_{zener} = 0$ mA

It should be noted that the calculated answers shown here will *not* precisely match a real zener diode circuit, due to the fact that zener diodes tend to gradually taper off in current as the applied voltage nears the zener voltage rating rather than current sharply dropping to zero as a simpler model would predict.

Answer 94

`1011 1000 0100` or `1011 1000 0101`

Answer 95

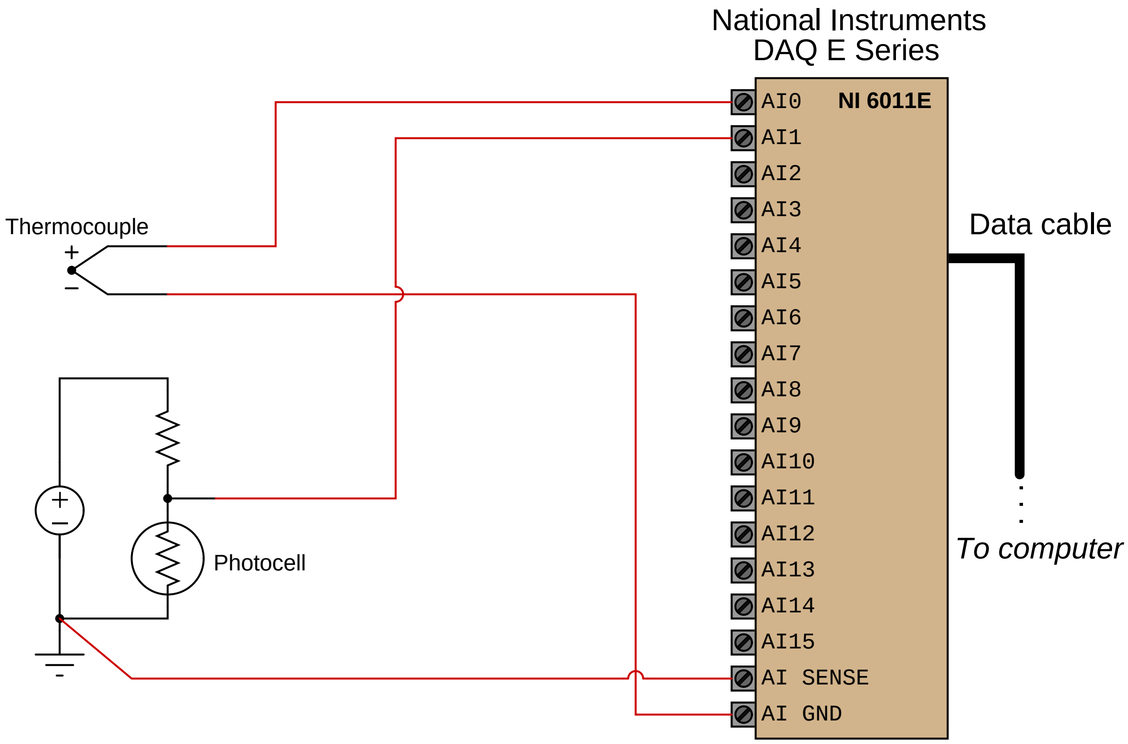
`0110 1011 0111` or `0110 1011 1000`

Answer 96

`0100 0111 1010` or `0100 0111 1011`

Answer 97

This is one possible solution:



Channel	Mode	First terminal	Second terminal
0	RSE	AI0	AI Gnd
1	NRSE	AI1	AI Sense

Answer 98

The reason why we must abandon 4-20 mA signaling in a multidrop HART network should be obvious if you understand the characteristics of parallel DC circuits: the total current is the *sum* of all branch currents.

Unique HART addresses are necessary to ensure the ability to communicate to and from specific transmitters, one at a time.

In burst mode, the field instrument does not wait to be polled by a master device; instead, it continually broadcasts data to the HART network.

You may connect a HART modem or communicator in the following locations in a multidrop network:

- In parallel with the two wires, anywhere along the cable length
- In parallel with the connection terminals of instrument #1
- In parallel with the connection terminals of instrument #2
- In parallel with the connection terminals of instrument #3
- In parallel with the resistor

Unique addressing is required because this "bus" network is *broadcast* by nature.

Answer 99

The HART isolator filters out HART signals to or from one positioner from getting to the other positioner.

We *might* communicate with control valve TV-1b, depending on the high-frequency AC characteristics of the controller output. Certainly, the isolator prevents us from communicating with TV-1a, so we know we can't talk to it. However, the only way we can talk to the other valve from these connection points is if the HART signals are able to "pass through" the controller output. If the controller output acts as an ideal current source, it should block the HART signals completely, and our communicator will talk to no valve at all.

Control valve TV-1a carries the cooling fluid while control valve TV-1b carries the heating fluid. As process temperature rises, the reverse-acting controller decreases its output signal. This will drive TV-1a further open and TV-1b further shut.

Answer 100

Answer 101

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

Answer 102

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

Answer 103

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

Answer 104

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

Answer 105

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

Answer 106

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

Answer 107

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

Answer 108

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

Answer 109

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

Answer 110

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

Answer 111

There exist some inexpensive data acquisition modules on the market for personal computers, including some with USB interfaces (and most with RS-232 serial interfaces). If all you have is a serial-interface module and a USB-only computer (as most laptop computers are!), you may use a USB-to-serial adapter to connect the serial DAQ device to the personal computer. Within Microsoft Windows, you may force the operating system to recognize the USB adapter as an old-style COM 1 or COM 2 RS-232 serial device, at which time the DAQ software should "talk" through the adapter to the DAQ module seamlessly.