<u>Lab</u>

Data acquisition and transport over Ethernet: *Question 91*, **completed objectives due by the end of day 6, section 3**

<u>Exam</u>

Day 6 of section 3 – only a simple calculator may be used! **Complete mastery of these objectives due by the next exam date**

Specific objectives for the "mastery" exam:
- Electricity Review: Calculate and annotate 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
- Motor/relay/3phase/PLC 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

<u>Day 1</u>

Theory session topic: Serial communication principles (continued)

Questions 1 through 20; <u>answer questions 1-9</u> in preparation for discussion (remainder for practice)

<u>Day 2</u>

Theory session topic: Transmission lines and fiber-optic cables

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

<u>Day 3</u>

Theory session topic: RS-232, 422, and 485 serial networks

Questions 41 through 60; <u>answer questions 41-47</u> in preparation for discussion (remainder for practice)

<u>Day 4</u>

Theory session topic: Ethernet networks

Questions 61 through 80; <u>answer questions 61-67</u> in preparation for discussion (remainder for practice)

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

How To . . .

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

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

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

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

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

Study for the exams: <u>Mastery exams</u> 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. <u>Proportional exams</u> feature problems you haven't seen before that are solvable using general principles learned throughout the current and previous courses, for which the only adequate preparation is independent problem-solving practice every day. Answer the "feedback questions" (practice exams) in each course section to hone your problem-solving skills, as these are similar in scope and complexity to proportional exams. Answer these feedback independently (i.e. no help from classmates) in order to most accurately assess your readiness.

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

Identify courses to register for: read the "Sequence" page found in each worksheet.

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

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

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

<u>file `howto`</u>

General Values, Expectations, and Standards

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

file expectations

Program Outcomes for Instrumentation and Control Technology (BTC)

| #1 | Communication |

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

| #2 | Time management |

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

| #3 | Safety |

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

| #4 | Analysis and Diagnosis |

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

| #5 | Design and Commissioning |

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

| #6 | System optimization |

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

| #7 | Calibration |

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

| #8 | Documentation |

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

| #9 | Independent learning |

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

| #10 | Job searching |

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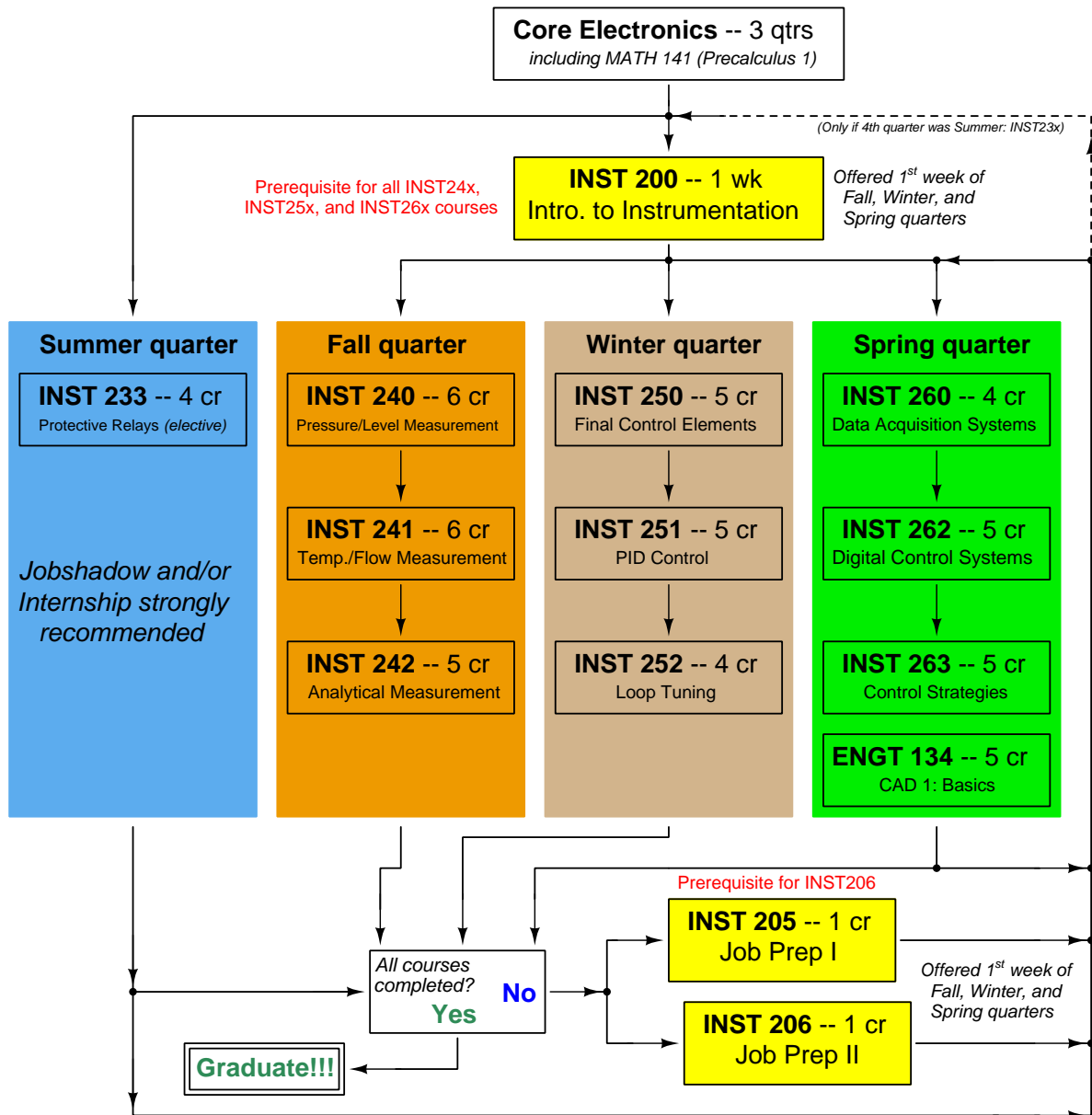
file outcomes_program

INST 260 Course Outcomes

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

- Calculate and annotate voltages and currents in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]

- Sketch proper wire connections for a data acquisition unit to measure an analog sensor signal. [Ref: Program Learning Outcome #5]

- Convert between different numeration systems (decimal, binary, hexadecimal, octal). [Ref: Program Learning Outcome #4]

- Calculate ADC (analog-digital converter) input and output values given calibrated ranges. [Ref: Program Learning Outcome #7]

- Solve for specified variables in algebraic formulae. [Ref: Program Learning Outcome #4]

- Determine the possibility of suggested faults in simple circuits given measured values (voltage, current), schematic diagrams, and reported symptoms. [Ref: Program Learning Outcome #4]

- Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems. [Ref: Program Learning Outcome #3]

- Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all labwork. [Ref: Program Learning Outcomes #1 and #2]

- 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. [Ref: Program Learning Outcome #5]

- Generate accurate schematic diagrams documenting your team's DAQ system. [Ref: Program Learning Outcome #8]

- Design and build a circuit responding to changes in either light intensity or temperature. [Ref: Program Learning Outcome #5]

- Diagnose a random fault placed in another team's DAQ 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. [Ref: Program Learning Outcome #4]

Sequence of second-year Instrumentation courses

Core Electronics -- 3 qtrs
including MATH 141 (Precalculus 1)

(Only if 4th quarter was Summer: INST23x)

INST 200 -- 1 wk
Intro. to Instrumentation

Prerequisite for all INST24x, INST25x, and INST26x courses

Offered 1st week of Fall, Winter, and Spring quarters

Summer quarter

INST 233 -- 4 cr
Protective Relays *(elective)*

Jobshadow and/or Internship strongly recommended

Fall quarter

INST 240 -- 6 cr
Pressure/Level Measurement

INST 241 -- 6 cr
Temp./Flow Measurement

INST 242 -- 5 cr
Analytical Measurement

Winter quarter

INST 250 -- 5 cr
Final Control Elements

INST 251 -- 5 cr
PID Control

INST 252 -- 4 cr
Loop Tuning

Spring quarter

INST 260 -- 4 cr
Data Acquisition Systems

INST 262 -- 5 cr
Digital Control Systems

INST 263 -- 5 cr
Control Strategies

ENGT 134 -- 5 cr
CAD 1: Basics

Prerequisite for INST206

All courses completed? **Yes** **No**

INST 205 -- 1 cr
Job Prep I

INST 206 -- 1 cr
Job Prep II

Offered 1st week of Fall, Winter, and Spring quarters

Graduate!!!

7

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

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

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

Beginning in Summer

Summer quarter (July – Aug.)
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Fall quarter (Sept. – Dec.)
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Winter quarter (Jan. – Mar.)
- INST 205 -- 1 cr — Job Prep I
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

Spring quarter (April – June)
- INST 206 -- 1 cr — Job Prep II
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

Graduation!

Beginning in Fall

Fall quarter (Sept. – Dec.)
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Winter quarter (Jan. – Mar.)
- INST 205 -- 1 cr — Job Prep I
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

Spring quarter (April – June)
- INST 206 -- 1 cr — Job Prep II
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

Summer quarter (July – Aug.)
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Graduation!

Beginning in Winter

Winter quarter (Jan. – Mar.)
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

Spring quarter (April – June)
- INST 205 -- 1 cr — Job Prep I
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

Summer quarter (July – Aug.)
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Fall quarter (Sept. – Dec.)
- INST 206 -- 1 cr — Job Prep II
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Graduation!

Beginning in Spring

Spring quarter (April – June)
- INST 200 -- 1 wk — Intro. to Instrumentation
- INST 260 -- 4 cr — Data Acquisition Systems
- INST 262 -- 5 cr — Digital Control Systems
- INST 263 -- 5 cr — Control Strategies
- ENGT 134 -- 5 cr — CAD 1: Basics

Summer quarter (July – Aug.)
- INST 233 -- 4 cr — Protective Relays (elective)
- Jobshadow and/or Internship strongly recommended

Fall quarter (Sept. – Dec.)
- INST 205 -- 1 cr — Job Prep I
- INST 240 -- 6 cr — Pressure/Level Measurement
- INST 241 -- 6 cr — Temp./Flow Measurement
- INST 242 -- 5 cr — Analytical Measurement

Winter quarter (Jan. – Mar.)
- INST 206 -- 1 cr — Job Prep II
- INST 250 -- 5 cr — Final Control Elements
- INST 251 -- 5 cr — PID Control
- INST 252 -- 4 cr — Loop Tuning

Graduation!

file sequence

General tool and supply list

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

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

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

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

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

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

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

file `tools`

Methods of instruction

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

Inverted theory sessions

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

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

Small sessions

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

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

Large sessions

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

Correspondence

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

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

Sample rubric for pre-assessments

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

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

Sample rubric for post-assessments

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

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

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

Methods of instruction (continued)

Lab sessions

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

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

Troubleshooting assessments must meet the following guidelines:

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

file `instructional`

Distance delivery methods

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

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

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

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

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

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

file distance

Metric prefixes and conversion constants

- **Metric prefixes**
- Yotta = 10^{24} Symbol: Y
- Zeta = 10^{21} Symbol: Z
- Exa = 10^{18} Symbol: E
- Peta = 10^{15} Symbol: P
- Tera = 10^{12} Symbol: T
- Giga = 10^{9} Symbol: G
- Mega = 10^{6} Symbol: M
- Kilo = 10^{3} Symbol: k
- Hecto = 10^{2} Symbol: h
- Deca = 10^{1} Symbol: da
- Deci = 10^{-1} Symbol: d
- Centi = 10^{-2} Symbol: c
- Milli = 10^{-3} Symbol: m
- Micro = 10^{-6} Symbol: 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

METRIC PREFIX SCALE

T	G	M	k		m	μ	n	p
tera	giga	mega	kilo	(none)	milli	micro	nano	pico
10^{12}	10^{9}	10^{6}	10^{3}	10^{0}	10^{-3}	10^{-6}	10^{-9}	10^{-12}

10^{2}	10^{1}	10^{-1}	10^{-2}
hecto	deca	deci	centi
h	da	d	c

- **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 $(c) = 2.9979 \times 10^8$ meters per second (m/s) = 186,281 miles per second (mi/s)

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

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

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

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

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

Properties of Water

Freezing point at sea level $= 32^o$F $= 0^o$C

Boiling point at sea level $= 212^o$F $= 100^o$C

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·^{o}C $= 1$ BTU/lb·^{o}F $= 4.1869$ Joules/g·^{o}C

Specific heat of ice ≈ 0.5 calories/g·^{o}C

Specific heat of steam ≈ 0.48 calories/g·^{o}C

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

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

pH of pure water at 25° 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) $= 1.8 \times 10^{-5}$ Pascal-seconds (Pa·s)

file conversion_constants

How to get the most out of academic reading:

- Outline, don't highlight! Identify every major idea presented in the text, and express these ideas in your own words. A suggested ratio is one sentence of your own thoughts per paragraph of text read.

- Articulate your thoughts as you read (i.e. "have a conversation" with the author). This will develop *metacognition*: active supervision of your own thoughts. Note points of agreement, disagreement, confusion, epiphanies, and connections between different concepts or applications.

- Work through all mathematical exercises shown within the text, to ensure you understand all the steps.

- Imagine explaining concepts you've just learned to someone else. Teaching forces you to distill concepts to their essence, thereby clarifying those concepts, revealing assumptions, and exposing misconceptions. Your goal is to create the simplest explanation that is still technically accurate.

- Create your own questions based on what you read, as a teacher would to challenge students.

How to effectively problem-solve and troubleshoot:

- Rely on principles, not procedures. Don't be satisfied with memorizing steps – learn *why* those steps work. Each step should make logical sense and have real-world meaning to you.

- Sketch a diagram to help visualize the problem. Sketch a graph showing how variables relate. When building a real system, always prototype it on paper and analyze its function *before* constructing it.

- Identify what it is you need to solve, identify all relevant data, identify all units of measurement, identify any general principles or formulae linking the given information to the solution, and then identify any "missing pieces" to a solution. Annotate all diagrams with this data.

- Perform "thought experiments" to explore the effects of different conditions for theoretical problems. When troubleshooting, perform *diagnostic tests* rather than just visually inspect for faults.

- Simplify the problem and solve that simplified problem to identify strategies applicable to the original problem (e.g. change quantitative to qualitative, or visa-versa; substitute easier numerical values; eliminate confusing details; add details to eliminate unknowns; consider simple limiting cases; apply an analogy). Remove components from a malfunctioning system to simplify it and better identify the nature and location of the problem.

- Check for exceptions – does your solution work for *all* conditions and criteria?

- Work "backward" from a hypothetical solution to a new set of given conditions.

How to manage your time:

- Avoid procrastination. Work now and play later, every single day.

- Consider the place you're in when deciding what to do. If there is project work to do and you have access to the lab, do that work and not something that could be done elsewhere (e.g. homework).

- Eliminate distractions. Kill your television and video games. Turn off your mobile phone, or just leave it at home. Study in places where you can concentrate, like the Library.

- Use your "in between" time productively. Don't leave campus for lunch. Arrive to school early. If you finish your assigned work early, begin working on the next assignment.

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

file `question0`

Checklist when reading an instructional text

"Reading maketh a full man; conference a ready man; and writing an exact man" – Francis Bacon

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

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

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

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

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

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

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

General challenges following a tutorial reading assignment

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

General follow-up challenges for assigned problems

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

Question 1

Read and outline the "Data Frames" subsection of the "Digital Data Communication Theory" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04402

Question 2

Read and outline the "Channel Arbitration" subsection of the "Digital Data Communication Theory" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04403

Question 3

Read and outline "The OSI Reference Model" subsection of the "Digital Data Communication Theory" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04404

Question 4

Here is an oscilloscope's view of an eight-bit data stream sent asynchronously with no parity bit and two stop bits ("8-N-2"), using *NRZ* (Non-Return to Zero) encoding. "Non-Return to Zero" is a fancy way of saying a constant "high" voltage represents consecutive *spaces* and a constant "low" voltage represents consecutive *marks* – the simplest encoding scheme possible:
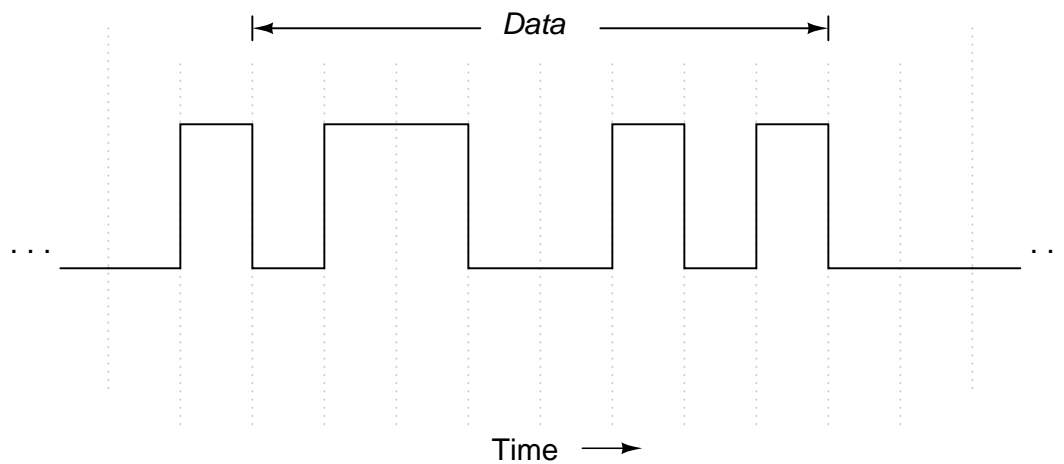
Identify the following from this waveform:

- All "Mark" and "Space" states
- The location and state of the *start bit*
- The eight-bit binary data represented by this waveform
- The location and state of the *stop bits*
- The default "idle" state between serial data packets

Suggestions for Socratic discussion

- Explain why it is critically important that we know in advance this is an *eight-bit* data frame.
- In this particular example, is the number of stop bits significant? Why or why not?
- What would be different in this waveform if the frame format were 8-E-2 rather than 8-N-2?
- What would be different in this waveform if the frame format were 8-O-2 rather than 8-N-2?

file i02365

Question 5

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

Space

Start

Stop $\longrightarrow$

Mark
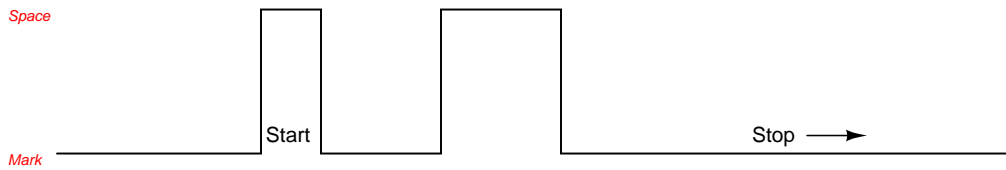
Identify the binary data represented by this waveform, and express it in hexadecimal form as well.

Suggestions for Socratic discussion

- Explain how we would (or would not) interpret this waveform differently if the parity were set for *even* rather than *none*.
- In this particular example, is the number of stop bits significant? Why or why not?

file i02367

Question 6

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:

Space

Mark
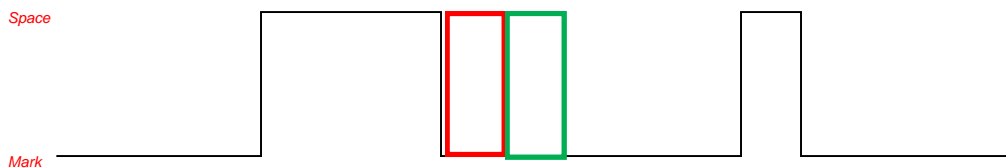
Identify the binary data represented by this waveform, and express it in hexadecimal form as well.

Suggestions for Socratic discussion

- What would be different in this waveform if the parity was set for "even"?
- What would be different in this waveform if the parity was set for "odd"?
- Explain why it is critically important that we know in advance this is an *eight-bit* data frame.
- In this particular example, is the number of stop bits significant? Why or why not?

file i02368

Question 7

Here is an oscilloscope's view of an ASCII character (7 bits) sent asynchronously with even parity and 2 stop bits ("7-E-2"), using *NRZ* (Non-Return to Zero) encoding:
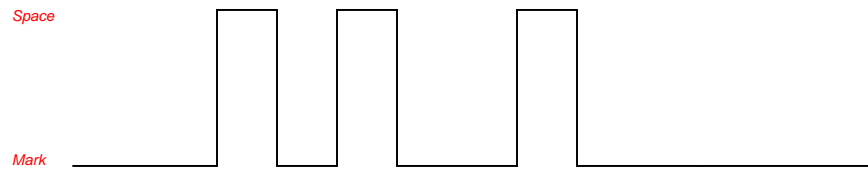
Space

Mark

Identify the specific ASCII character represented by the data in this frame, and determine whether or not the parity checks out okay.

Question 8

Data sent in *synchronous* serial networks is very efficient: each bit in the datastream's bandwidth is used to transfer data and nothing else. Data sent in *asynchronous* serial networks is less efficient, because in each data frame there are "extra" bits necessary for the *start*, *stop*, and *parity* signals.

Calculate the amount of time required to transfer 400 kilobytes of data in a synchronous serial network operating at 56 kilobits per second.

Calculate the amount of time required to transfer 400 kilobytes of data in an asynchronous serial network operating at 56 kilobits per second, with 7 data bits, 1 start bit, 2 stop bits, and 1 parity bit.

Suggestions for Socratic discussion

- Which type of serial network is more commonly used in long-haul applications, such as digital communications trunks between major cities in the United States?
- Are there any advantages to the slower type of serial network?

  file i04423

A *strain gauge* is an array constructed from thin metal film designed to increase resistance as it is stretched and decrease resistance as it is compressed. Strain gauges are typically bonded to metal specimens undergoing mechanical testing, as a means of sensing how much strain is being applied to that metal specimen. In order to translate the resistance of the strain gauge into a measurable voltage signal, the strain gauge is typically incorporated into one arm of a "bridge" circuit.

The following bridge circuit uses two strain gauges (one to measure strain, the other to compensate for temperature changes), the amount of strain indicated by the voltmeter in the center of the bridge. Unfortunately, though, it has a problem. Instead of registering a very small voltage as it normally does, the voltmeter is "pegged" (driven beyond its normal full-range measurement) by a large voltage difference, with point **B** positive and point **A** negative as shown here:
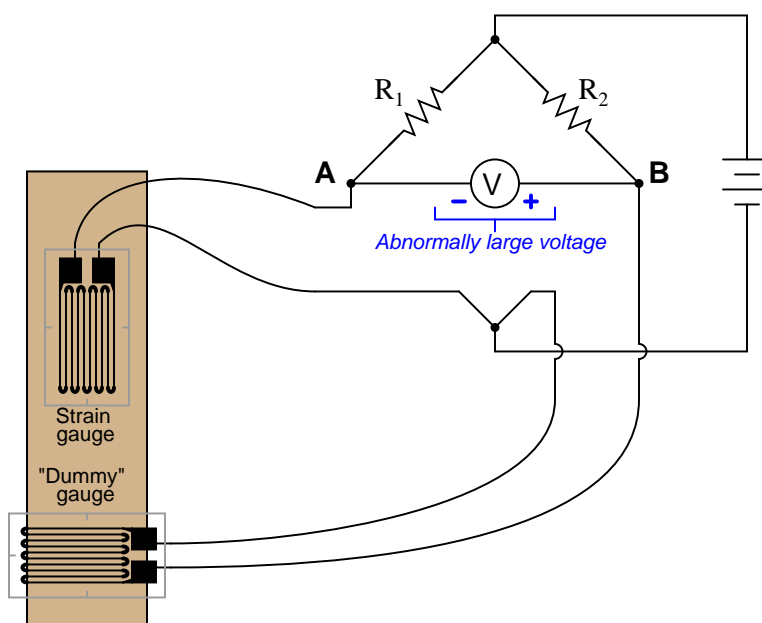
Something is wrong in the bridge circuit, because this voltage is present even when there is no physical stress on the specimen. Identify which of the following faults could cause the excessive voltage to appear across the voltmeter, and which could not. Consider only one of these faults at a time (no multiple, simultaneous faults):

Fault	Possible	Impossible
R_1 failed open	■	
R_2 failed open		■
Strain gauge failed open		■
Dummy gauge failed open	■	
R_1 failed shorted		■
R_2 failed shorted	■	
Strain gauge failed shorted	■	
Dummy gauge failed shorted		■
Voltage source dead		■

Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Explain why the two strain gauge elements are orthogonally bonded (i.e. attached 90° to each other) to the specimen.

file i00188

Question 10

A *strain gauge* is a device used to measure the strain (compression or expansion) of a solid object by producing a resistance change proportional to the amount of strain. As the gauge is strained, its electrical resistance alters slightly:
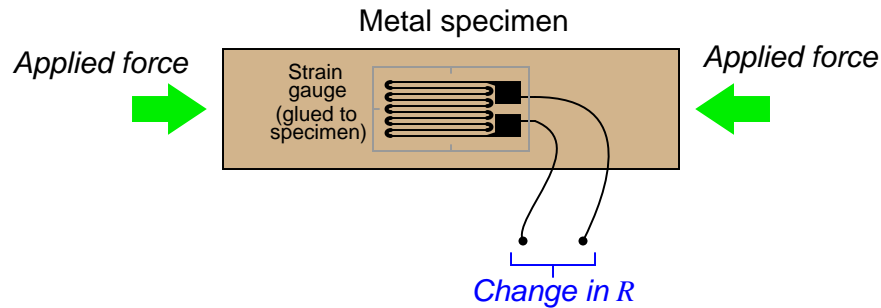
Explain *why* the electrical resistance of a strain gauge changes as it stretches and shrinks, and also correlate the direction of resistance change (more or less) with the direction of applied force.

The following strain gauge is shown connected in a "quarter-bridge" circuit (meaning only one-quarter of the bridge actively senses strain, while the other three-quarters of the bridge are fixed in resistance):
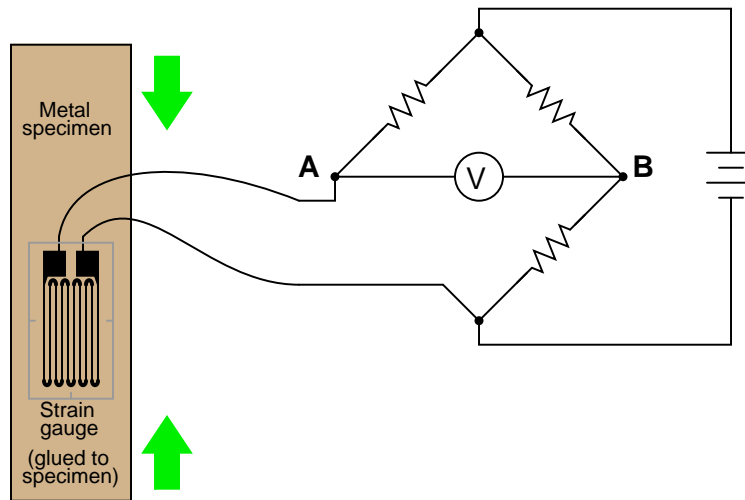
Explain what would happen to the voltage measured across this bridge circuit (V_{AB}) if the strain gauge were to be *compressed*, assuming that the bridge begins in a balanced condition with no strain on the gauge.

Suggestions for Socratic discussion

- A good problem-solving technique to apply when analyzing directions of change in a Wheatstone bridge circuit is to consider *limiting cases*. Instead of asking ourselves what would happen in the circuit if the strain gauge resistance changed slightly, we ask ourselves what would happen if the resistance changed *dramatically* (i.e. full open or full short). Explain how we could apply this problem-solving technique to this circuit.
- Strain gauges are widely used in the automotive and aerospace industries to study the strain of mechanical assemblies. Explain how a strain gauge might be used to measure the strain of something like a truck axle.

file i00181

Question 11

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

Space

Mark
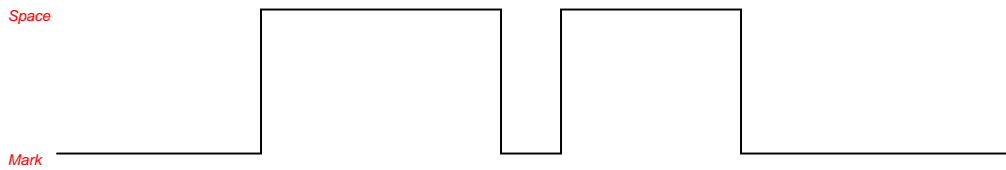
Identify the binary data represented by this waveform.

<u>file i02366</u>

Question 12

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:

Space

Mark

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.

<u>file i02369</u>

Question 13

Here is an oscilloscope's view of an ASCII character (7 bits) sent asynchronously with odd parity and 1 stop bit ("7-O-1"), using *NRZ* (Non-Return to Zero) encoding:
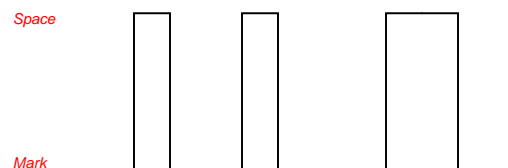
Space

Mark

Identify the specific ASCII character represented by the data in this frame, and determine whether or not the parity checks out okay.

<u>file i02913</u>

Question 14

Here is an oscilloscope's view of an ASCII character sent asynchronously with 8 data bits, even parity and 1 stop bit ("8-E-1"), using *NRZ* (Non-Return to Zero) encoding:
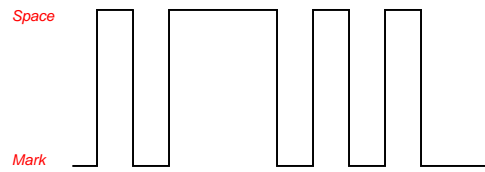
Space

Mark

Identify the specific ASCII character represented by the data in this frame, and determine whether or not the parity checks out okay.

file i02916

Question 15

Here is an oscilloscope's view of some digital data sent asynchronously with 7 data bits, no parity, and 1 stop bit ("7-N-1"), using *NRZ* (Non-Return to Zero) encoding:

Space

Mark

Identify the data sent in this transmission, expressing it in octal form.

file i02908

Question 16

Convert the following numbers from binary (base-two) to decimal (base-ten):

- $10_2 =$
- $1010_2 =$
- $10011_2 =$
- $11100_2 =$
- $10111_2 =$
- $101011_2 =$
- $11100110_2 =$
- $10001101011_2 =$

file i03613

Question 17

Calculate the amount of time required for an asynchronous serial data network to transfer a 24.5 megabyte file, assuming a data rate of 112 kilobits per second, 8 data bits, 1 start bit, 1 stop bit, and even parity.

file i02175

Question 18

Encode the following text message in ASCII format (expressing your codes in hexadecimal characters):

Zero & Span

Then, encode the exact same message with *odd parity*. Since the parity bit will be an eighth bit in the message (ASCII codes only requiring 7 bits each), include the parity bit as the MSB when you express each code in hexedecimal form.

file i02177

Question 19

A serial communication system is designed to transmit digital data in 7-bit blocks, with one parity bit added to make an 8-bit-long data "frame." Take the following 7-bit data blocks and add the necessary parity bits to the most-significant position (MSB), assuming *odd parity*. Be sure to write these 8-bit answers in *hexadecimal* form.

0111111   1111100

file i02447

Question 20

Question 21

Read and outline the "Transmission Lines" section of the "AC Electricity" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

Note: a video demonstration of a transmission line being terminated both properly and improperly may be found on the BTC Instrumentation YouTube channel (search for a video named "Reflected Waves on a Cable"). In this video, an oscillscope is used to demonstrate the reflected signal caused by improper termination of a spooled cable.

file i04409

Question 22

An instrument called a *Time-Domain Reflectometer*, or *TDR*, is used to check for opens or shorts along a cable length by generating a short voltage pulse and waiting to receive the reflected pulse "bounced" back from either the fault or from the unterminated cable end. This represents an interesting application of a *poorly-terminated* transmission line.

Shown below is the reflected voltage pulse for an open fault in a cable, as indicated by a TDR. It is assumed here that the pulse width is shorter in duration than the time it takes for the pulse to travel to the fault and back:
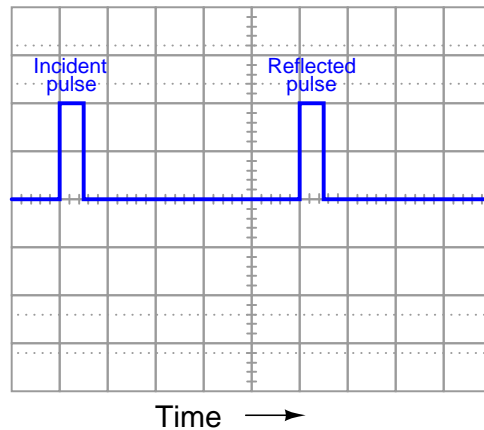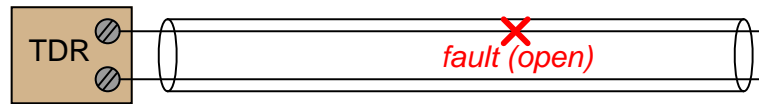
Now we see the reflected voltage pulse for an shorted fault in a cable, as indicated by a TDR. As before, it is assumed here that the pulse width is shorter in duration than the time it takes for the pulse to travel to the fault and back:
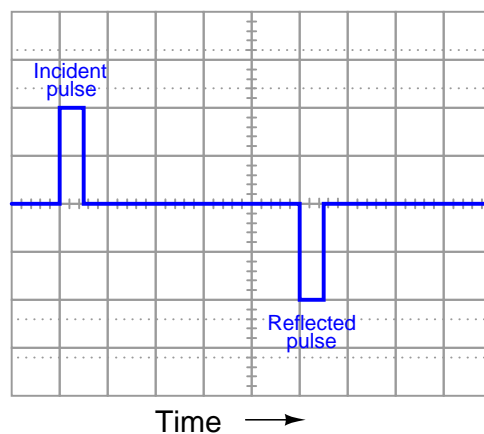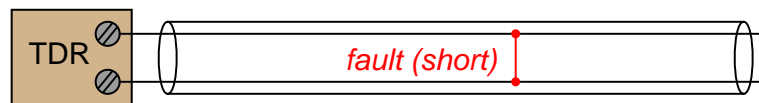
What would the technician look for in the TDR display to determine where the fault was in the cable? Also, what would the TDR display look like for a good (non-faulted) cable?

- What if another technician decides to play a trick on the one operating the TDR, and connects a resistor equal to the cable's surge impedance to the far end, so it is no longer open, but properly terminated. What would a (good) cable register as on the TDR with the resistor connected?
- How would the open-fault test oscillograph differ (if at all) if there was a termination resistor at the far end of the faulted cable?
- How would the shorted-fault test oscillograph differ (if at all) if there was a termination resistor at the far end of the faulted cable?
- Suppose the cable's temperature were to rise significantly due to changes in ambient weather conditions. How would this change in cable resistance affect the results of the TDR test?
- Design a 555 timer circuit to generate the extremely brief pulses needed to perform such a test.
- A technique for sensing the location of a fault in a long-distance electrical power transmission line is called *traveling wave fault detection*, and is based on the concept of a fault producing a sudden rise or fall in line voltage which propagates along that line at nearly the speed of light. Explain how this technique might work in a power line application: what exactly would need to be measured at either end of the line to detect and locate a fault somewhere in between?

file i02185

Question 23

It is common in some digital networks to connect paralleled devices to the network cable, like this:
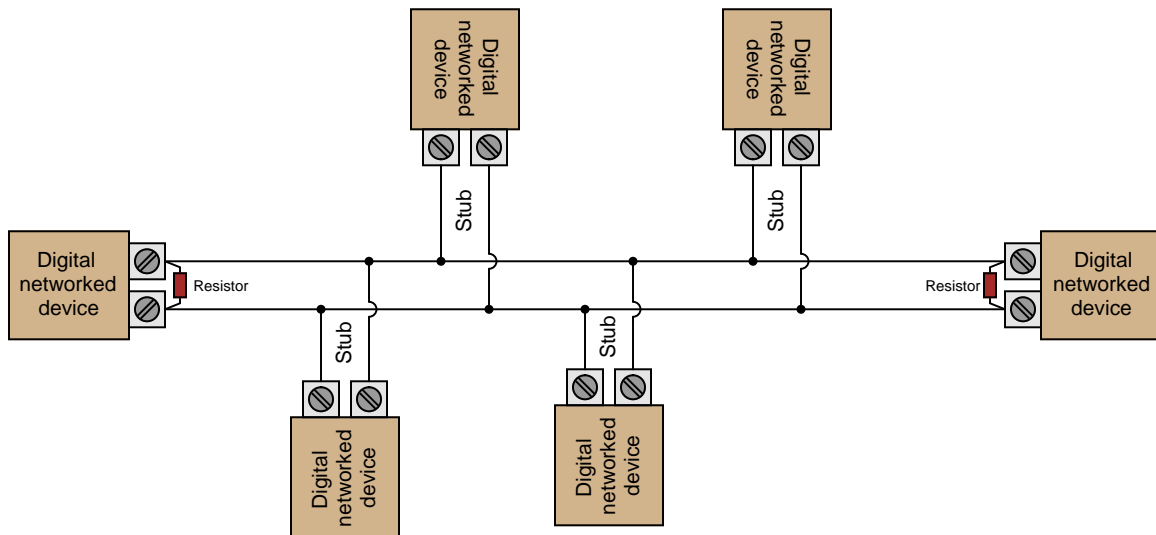
Note that the far-end devices have terminating resistors connected in parallel to the network connection terminals, while the devices at the end of the stubs do not. Does this constitute a problem? In other words, will reflected signals result from the unterminated stubs? Why or why not?

Furthermore, what would happen if each of the stub devices were terminated with the same resistance value as the end devices?

| Suggestions for Socratic discussion |

- Supposing the cable's characteristic impedance is 100 Ω, how much resistance should each of the terminating resistors in this network have?

file i02188

Question 24

Read and outline the "Fiber Optic Data Communication", "Fiber Optic Cable Construction", "Fiber Optic Cable Connectors, Routing, and Safety", and "Fiber Optic Cable Testing" sections of the "Instrument Connections" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.

(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).

(3) General principles, especially physical laws, referenced in the text.

(4) Questions of your own you would pose to another reader, to challenge their understanding.

(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

(6) Any points of confusion, and precisely why you found the text confusing.

file i02744

Question 25

Suppose a technician performs an optical power test of this optical fiber run and determines there is an excessive end-to-end power loss:
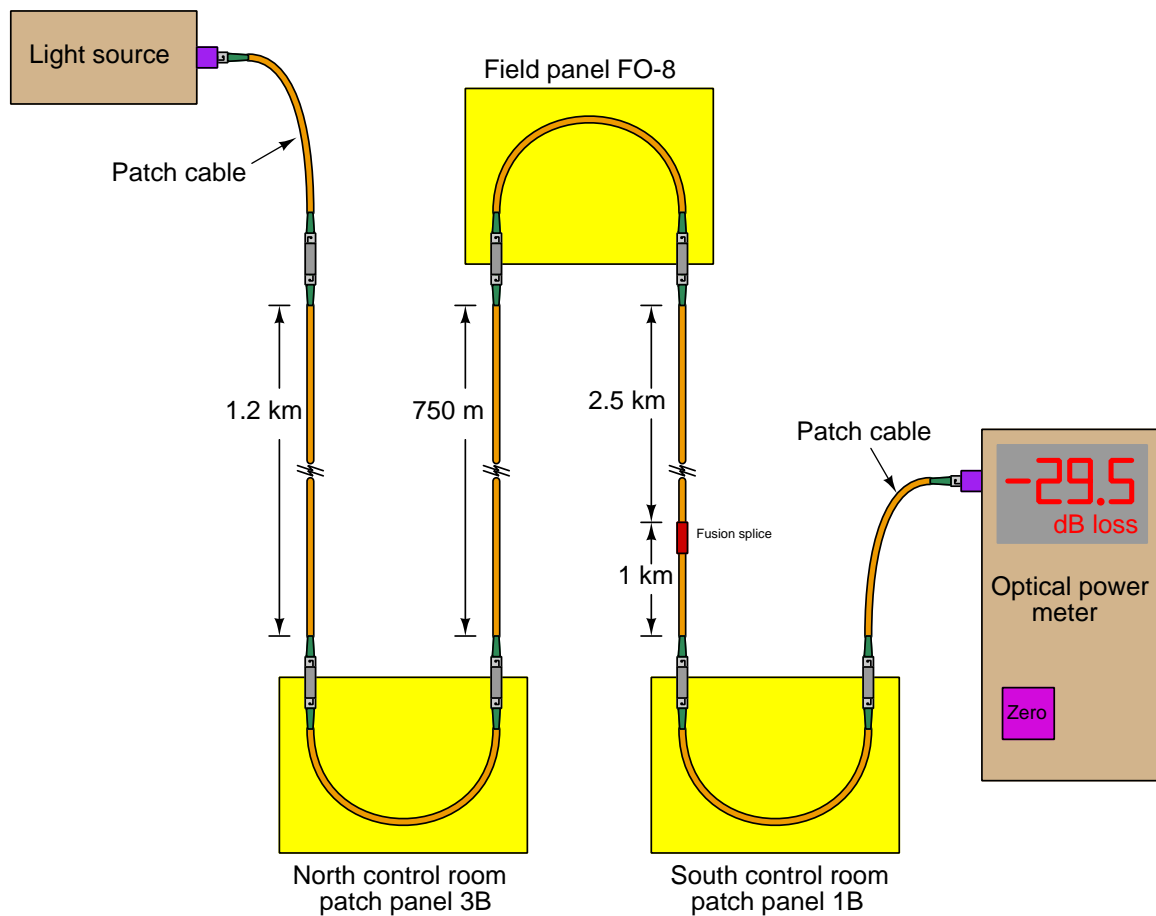
Assuming a typical cable attenuation of -1 dB per kilometer, a typical connector loss of -2 dB per cable-to-cable connection, and a typical fusion splice loss of -0.2 dB per splice, calculate the expected optical power loss for the test configuration shown.

Describe a diagnostic procedure by which you could locate which section(s) of this optical fiber run might account for the excessive power loss.

Identify an error the first technician may have committed that would have given a falsely high power loss measurement (i.e. explain how this fiber optic cable run might actually be within acceptable power loss parameters after all!).

Finally, describe how an OTDR could be used to test this fiber optic run instead of an optical power meter.

| Suggestions for Socratic discussion |

- What exactly is a "fusion splice" and how does it differ from the "butt connectors" shown elsewhere in this illustration?

- Identify the causes of optical power loss at connectors.
- Identify the causes of optical power loss at fusion splices.
- Identify the causes of optical power loss along the length of an optical fiber.
- Would the result of this test be any different if we swapped locations of the optical source and power meter? Why or why not?
- What would happen to the optical power meter's reading if we were to disconnect one of the junctions in this system?
- What would happen to the optical power meter's reading if we were to sharply bend one of the fibers in this system?

file i02760

Question 26

Read selected portions of the "SEL Fiber-Optic Products and Applications" data sheet (February 2015) and answer the following questions:

Schweitzer Engineering Laboratories (SEL) manufactures electronic equipment designed to monitor and protect high-voltage electrical power grid components, including specialized devices called *protective relays* designed to monitor voltage and current conditions in power grids and take automatic protective action to "clear" faults before they cause irreparable damage to the system and/or threaten human safety. Why do you suppose a company like SEL would offer fiber-optic components such as serial data converters and fiber optic cables? Of what use would fiber optic devices have in a high-voltage substation, generating station, or similar facility?

Page 1 of this document highlights features of the SEL-2800 series of fiber optic data *transceivers* manufactured by Schweitzer Engineering Laboratories. Based on the information found here, describe where you might find such transceivers used. Identify where you could use these in the school's lab, at least to demonstrate the concept.

Read the section of this document entitled "Reflection Issues When Running Short-Distance, Single-Mode Fiber" and describe what the potential problems are and how they are mitigated.

Find the photographs of "splice bushings" shown in this document and explain their use.

Suggestions for Socratic discussion

- Table 1 (found on page 2 of this document) provides "link budget" figures for each model of fiber optic transceiver. Explain what a "link budget" value represents, and why it might be important.
- Table 3 (found on page 5 of this document) provides typical attenuation values for different types of optical fiber. Identify which optical fiber type exhibits the least amount of loss, and explain why. Also, explain why single-mode fiber shows "N/A" (*not applicable*) for attenuation at a light wavelength of 850 nm.

file i02743

Question 27

Sketch connecting wires so that this DAQ unit will register an increasing positive measurement on channel 4 as the potentiometer shaft is turned *counter-clockwise*:
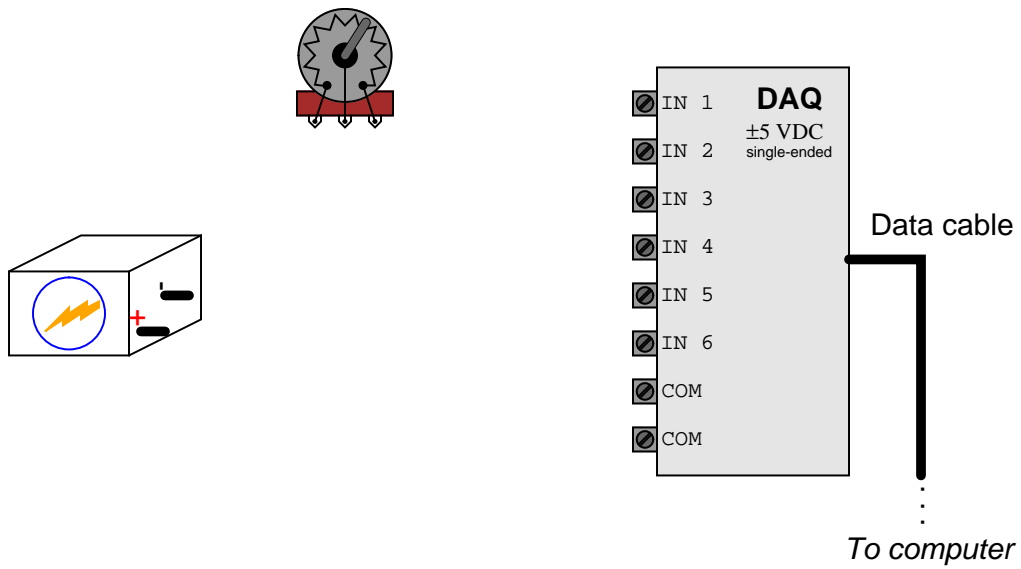
Suggestions for Socratic discussion

- An important determination for any DAQ unit is whether its inputs are *single-ended* or *differential*. How can we tell, in this instance?
- Re-sketch the circuit to yield an increasing positive measurement on channel 4 as the potentiometer shaft is turned *clockwise*.

file i02125

39

Question 28

An instrument called a *Time-Domain Reflectometer*, or *TDR*, may be used to measure the length of an unterminated cable by generating a very brief voltage pulse and waiting to receive the reflected pulse "bounced" back from the cable's end. The duration of this pulse is so brief that it is done and over before the signal has a chance to travel down the cable and back:
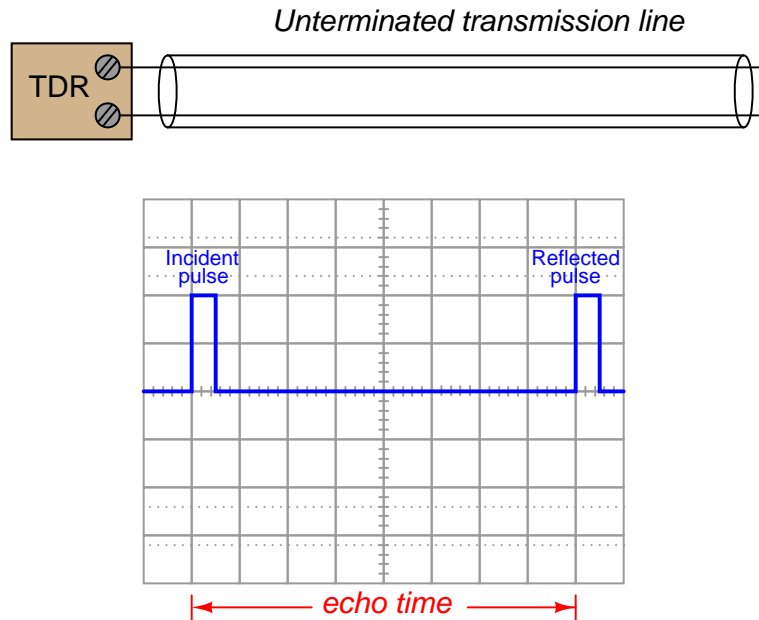
Build a computer spreadsheet to calculate cable length, given the echo time (entered in microseconds) measured by a TDR, and the velocity factor of the cable. An example spreadsheet layout is shown here (the cell fill coloring is just for looks, distinguishing the *calculated* value of cable length from the *entered* values of echo time and velocity factor):

	1	2	3	4	5
1	Echo time =		(microseconds)		
2	Velocity factor =		(unitless)		
3					
4	Cable length =		(feet)		
5					

Suggestions for Socratic discussion

- How could you *test* your spreadsheet cable-length calculator for accuracy (to verify you haven't made any mistakes) once you've entered all your equations?
- Note that there is no entry on this spreadsheet for the *frequency* of the TDR's test signal, or the width of that signal's pulse duration. Explain why these parameters are not a part of the cable length calculation.
- What would a *real* oscilloscope screenshot look like in this scenario, with a real cable?

file i02181

Question 29

Suppose a digital temperature measurement system is not functioning as it should. The ADC is outputting a count value of 002 (hex) when the sensor is known to be at a temperature of 20 degrees Celsius (room temperature). The sensor is an RTD: a variable-resistance device which is supposed to be 100 ohms at 0 ^{o}C and 138.5 ohms at 100 ^{o}C, linearly proportional to temperature. The analog input range of the ADC is 0 to 0.5 volts DC. Your first diagnostic test is to check the voltage between test points **G** and **H**, and there you measure 5.08 volts DC:

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

Fault	Possible	Impossible
RTD failed open		
RTD failed shorted		
Wire broken open between points **C** and **E**		
Wire broken open between points **C** and **A**		
Wire broken open between points **D** and **B**		
Wire broken open between points **D** and **F**		
Current 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.

Suggestions for Socratic discussion

- Calculate the ideal count value from the ADC at a sensor temperature of 100 ^{o}C.
- For those of you who have studied RTD temperature measurement, explain why we use *four* wires to connect the RTD to the measurement circuit, rather than just two wires.

file i02173

Question 30

In the study of basic electricity, we generally assume the travel speed of electrical signals to be infinite. For example, we assume the LED will energize *immediately* when the transistor turns on in this circuit:
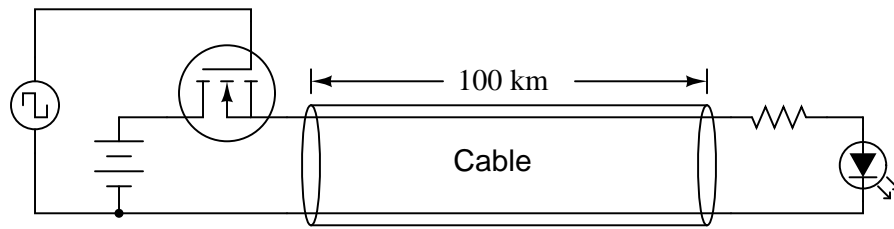
However, we know the effects of electricity cannot travel beyond a certain maximum speed: the speed of *light*. Estimate the delay in time between the transistor's turning on and the LED's lighting up, assuming the cable connecting the two is 100 km (kilometers) in length.

Suggestions for Socratic discussion

- Suppose the characteristic impedance (Z_0) of the cable did not match the resistance of the LED and dropping resistor. How long would it take the reflected signal to reach the source from the time the transistor turned on?
- Real cables have *velocity factors* less than unity. Explain how this realistic effect will impact your calculations of delay time for a real cable.
- Explain how an E-type MOSFET is turned on and off, identifying the necessary gate-source voltage necessary to stimulate it into saturation and cutoff.

file i02179

Question 31

When considering the propagation of high-frequency electrical signals along a pair of conductors, it is important to remember that all cables possess distributed *capacitance* and *inductance* along their length:
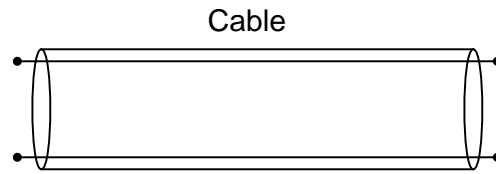
Cable

Equivalent lumped-parameter model of cable
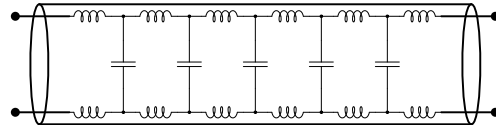
This means every electrical cable has the ability to store energy, in both an electric field (in the capacitance) and a magnetic field (in the inductance). This has profound impact on how high-frequency and transient (pulse) signals "see" the cable. No longer can we view a cable as a simple pair of wires, but it must now be considered a component in its own right.

Examining the cable model comprised of multiple capacitors and inductors in a series/parallel arrangement, try to determine voltages and currents along the cable immediately after the output of the digital logic gate goes from a "low" state to a "high" state:
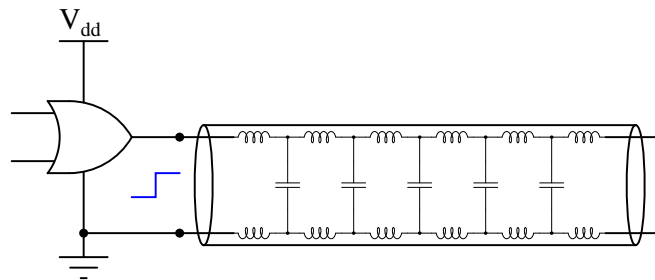
file i02180

Suppose we were to test the voltage at the source end of a long cable, driven by a 24 volt power supply and a fast-switching MOSFET transistor:
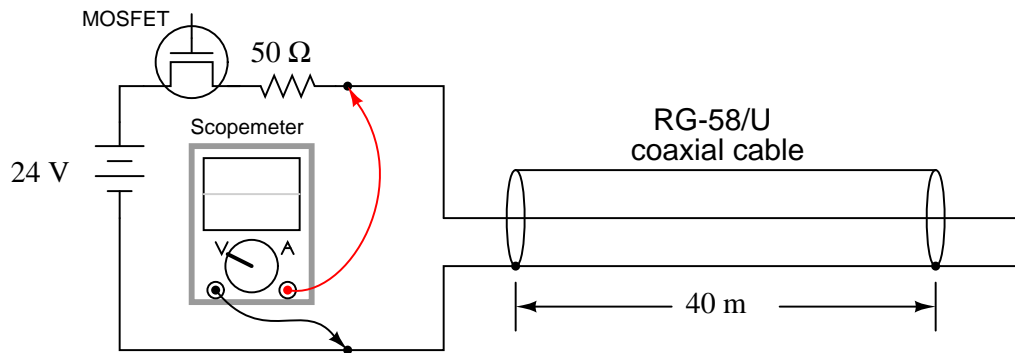
The *characteristic impedance* of an RG-58/U cable is 50 Ω (also called the "surge" impedance), and the Thévenin equivalent impedance of our power supply is 50 Ω as well. When the transistor is turned on, the scope registers an immediate step in voltage, but only to 12 volts (one-half the supply voltage). It isn't until several tenths of a microsecond later that the voltage steps up to the full 24 volts:
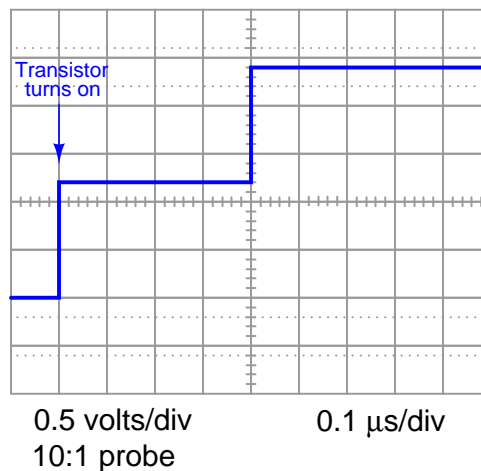
Explain why the voltage waveform steps to 12 volts, then to 24 volts as it does. Why doesn't it step all the way to 24 volts immediately, given a cable that is open at the far end?
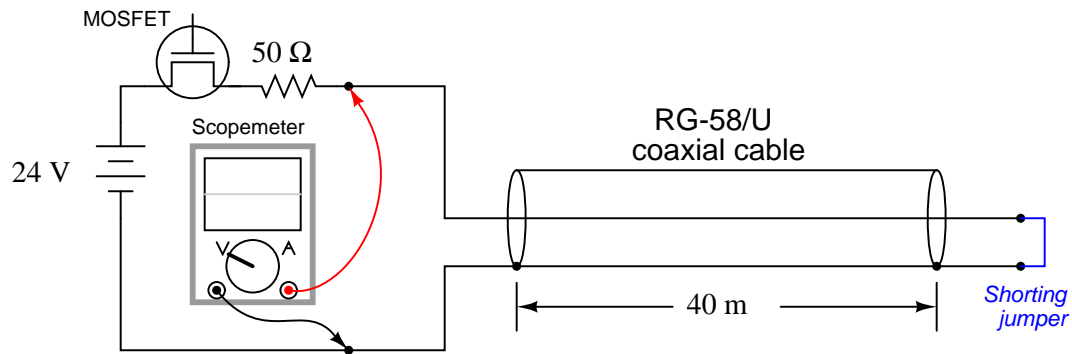
Next, suppose we were to short-circuit the end of the cable and repeat the test, once again capturing the voltage signal with the scope. This time, the voltage steps to 12 volts and then steps back down to nearly zero volts several tenths of a microsecond later:

0.5 volts/div
10:1 probe

0.1 μs/div
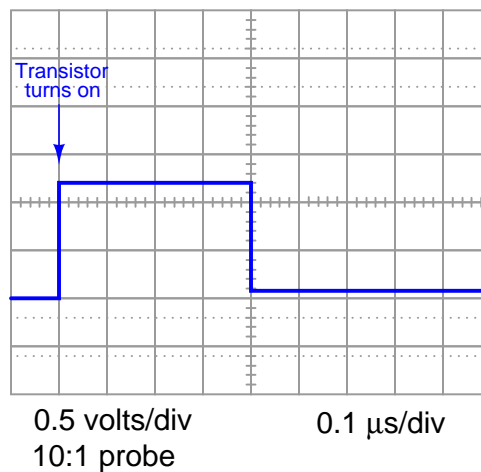
Again, explain why the voltage waveform does this. Why doesn't the voltage remain nearly zero the entire time, given a dead short at the end of the cable?

Additionally, show how the time duration of the "step" in each case is about 0.4 microseconds, given the length of the cable as 40 meters. Note: the *velocity factor* of RG-58/U cable is approximately 0.66.

file i02187

45

Question 33

Suppose we "drive" one twisted pair of a Category-5 ("Cat-5") communications cable with a signal generator having the same Thévenin equivalent impedance as the cable (100 Ω, which is standard for the unshielded, twisted wire pairs Cat-5 cable). Actually, the cable consists of two coiled sections joined together in the middle so that we may monitor voltage mid-way as well as at the front end where the signal generator connects, with a dual-trace oscilloscope:
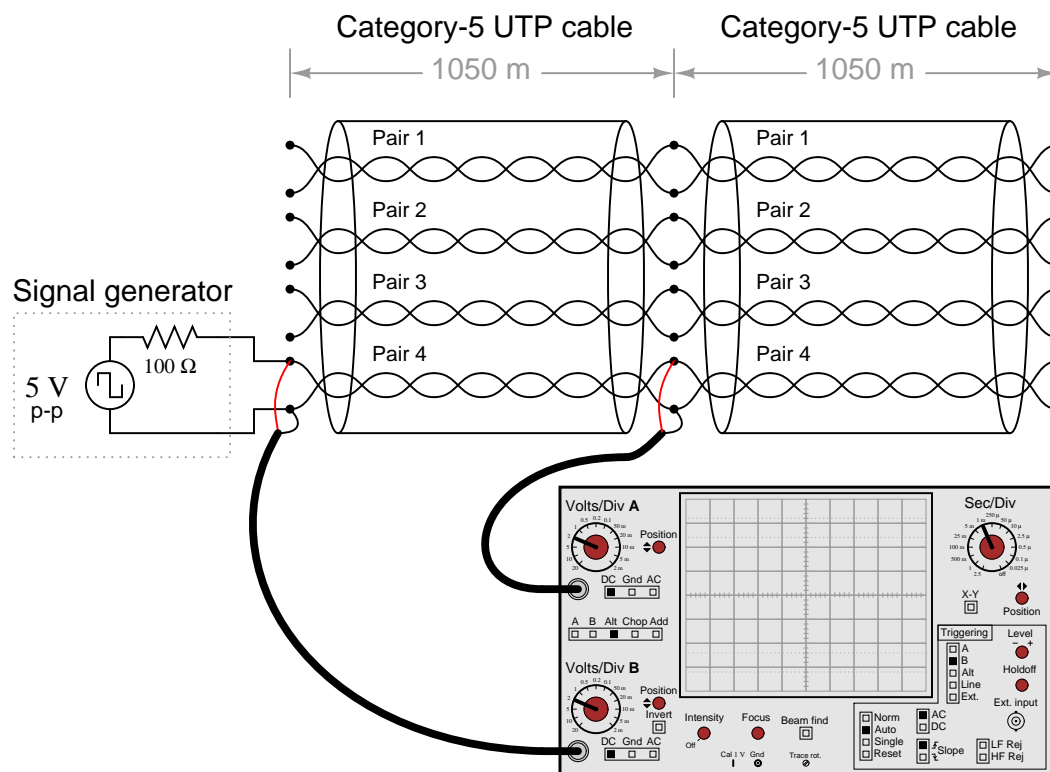
Given a typical velocity factor of 0.7, meaning that electrical signals will travel down the cable at 70% the speed of light, it should take 10 microseconds for the signal to travel from the signal generator to the far end of the cable. Given these conditions, we input a square-wave voltage signal at a frequency of 250 Hz and record the results:

Signal generator frequency = 250 Hz

Channel B
(Signal generator)

Channel A
(Mid-point junction)
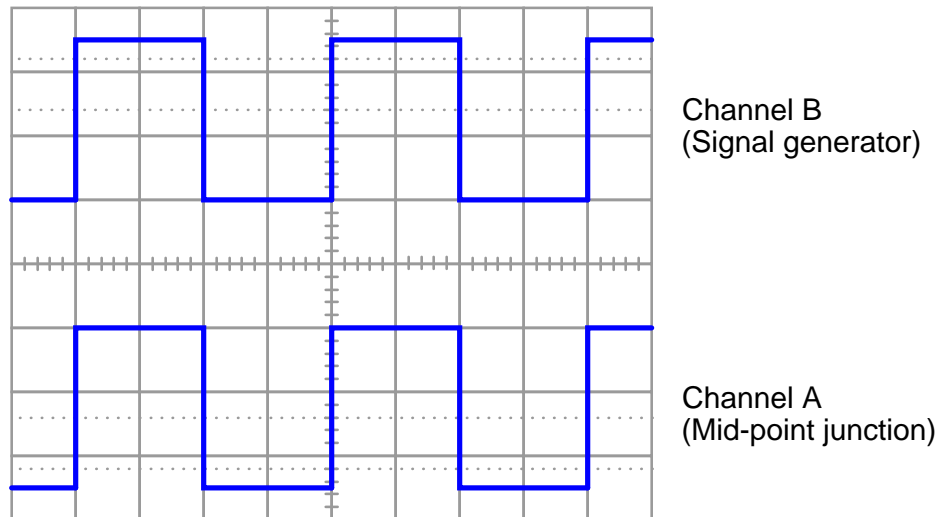
Vertical sensitivity = 2 V / div

Timebase = 1 ms / div

1:1 probe

So far, things look just fine. We are seeing the same voltage signal at the mid-point of the cable that we're injecting at the left-hand end. There is no noticeable distortion, and the time delay due to propagation time along the cable length is too short to be significant at this scale.

Now, we increase the signal generator frequency to 5 kHz and correspondingly increase the sweep speed of the oscilloscope. The waveforms we see are not so clean anymore!

Signal generator frequency = 5 kHz

Channel B
(Signal generator)

Channel A
(Mid-point junction)
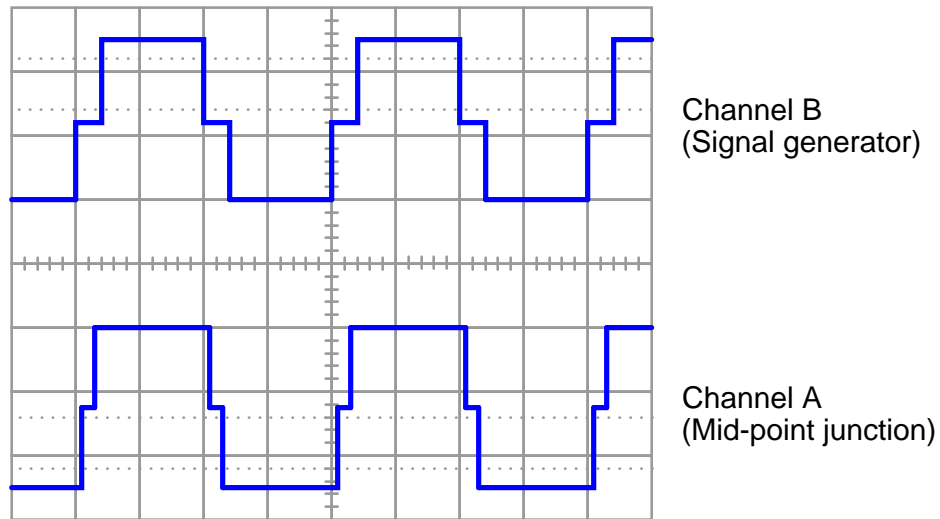
Vertical sensitivity = 2 V / div

Timebase = 50 μs / div

1:1 probe

Explain what accounts for the "stepped" shape of the square wave on its leading and trailing edges.

file i02182

Question 34

A serial communication system is designed to transmit digital data in 7-bit blocks, with one parity bit added to make an 8-bit-long data "frame." Take the following 7-bit data blocks and add the necessary parity bits to the most-significant position (MSB), assuming *even parity*. Be sure to write these 8-bit answers in *hexadecimal* form.

    1110011   1100000

file i02395

Question 35

Sketch connecting wires so that this DAQ unit will register an increasing negative voltage on channel 1 as the potentiometer shaft is turned *clockwise*:
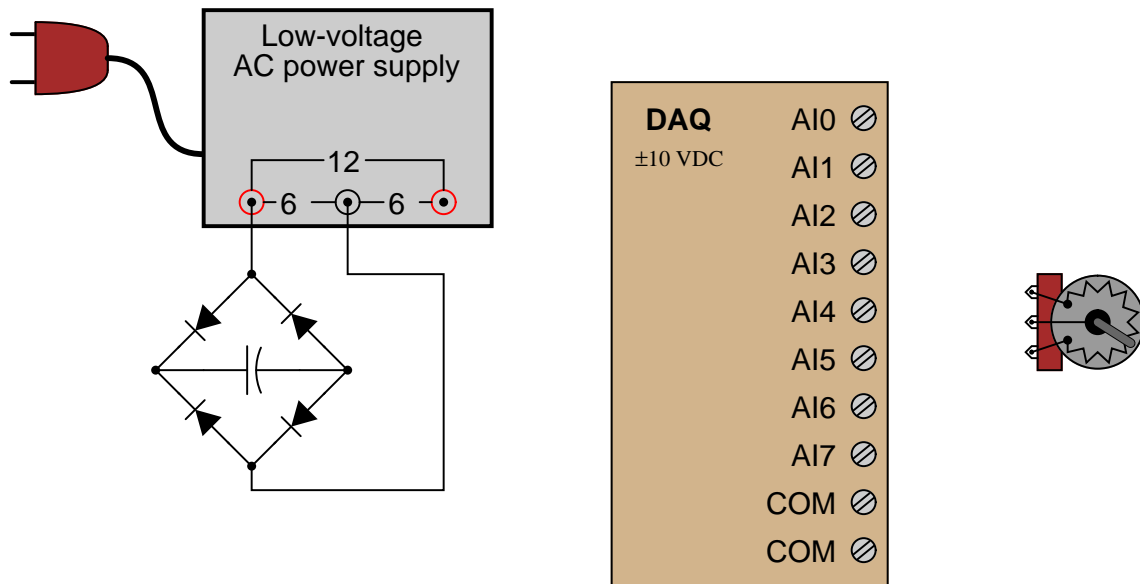
file i02127

Question 36

Sketch connecting wires to allow this data acquisition unit (DAQ) to sense strain using quarter-bridge strain gauge circuits on input channels #0 and #3, such that increasing tension on the strain gauge (increasing gauge resistance) generates a more *positive* signal voltage on each channel:

file i04585

49
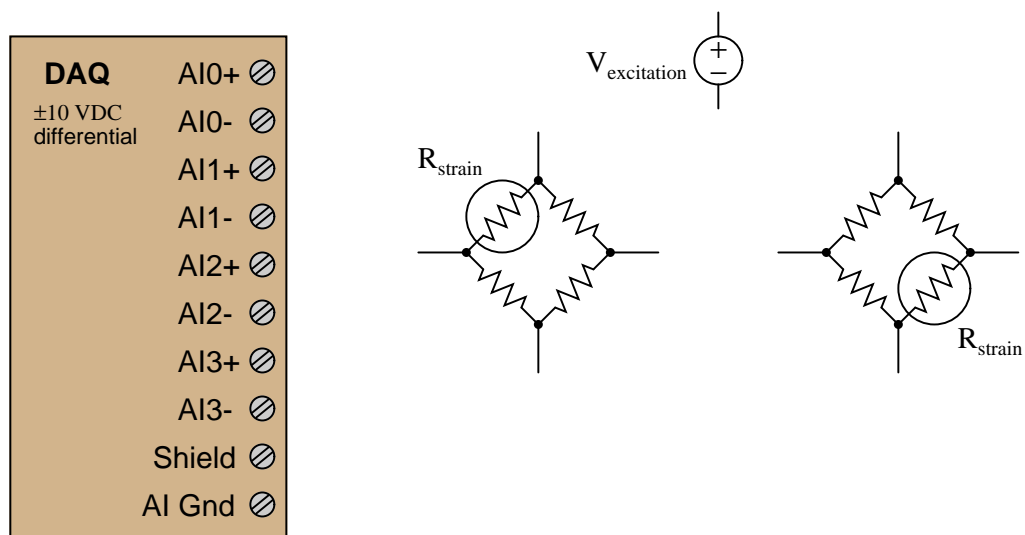
Question 37

Here, a temperature sensor called an *RTD* is used to translate ambient temperature into a proportional resistance. This in turn is converted into a proportional voltage signal by a constant current fed through the RTD by the current source:
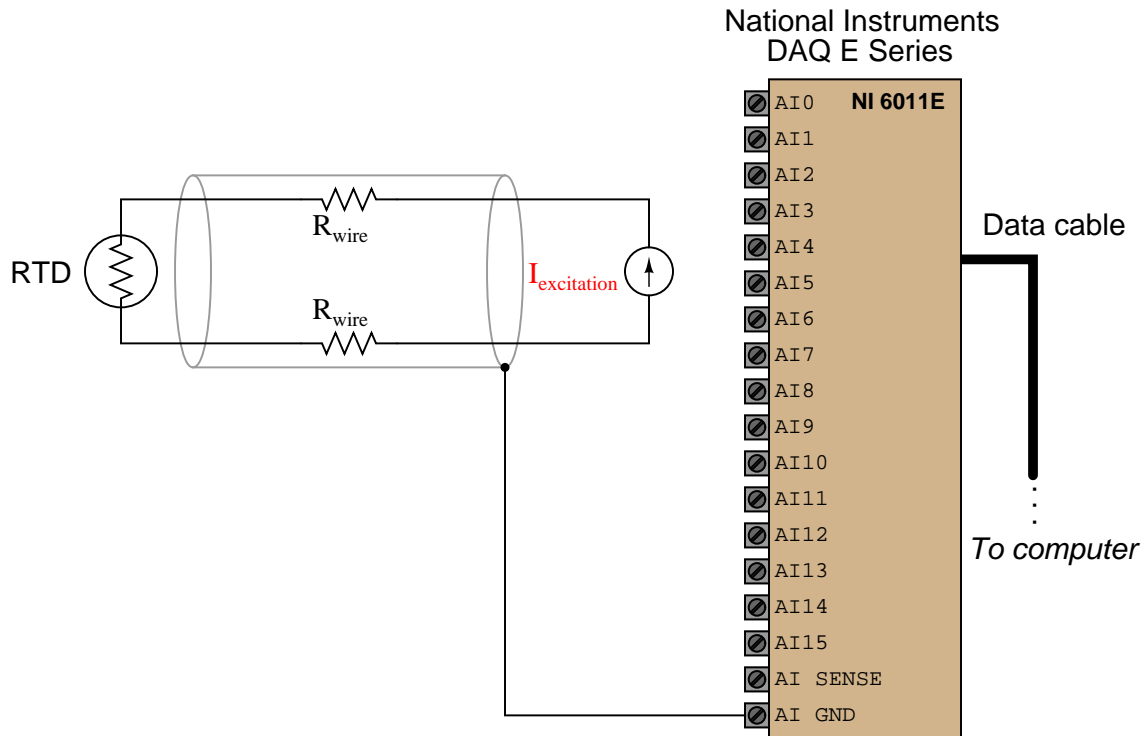
Determine how to connect the first analog input channel this DAQ to measure the RTD's voltage drop, but in such a way that voltage dropped along the cable's length will not affect the measurement. Also, determine whether this DAQ should be configured for *single-ended* or *differential* input

file i02122

50

Question 38

Work with your instructor to set up a test fixture to demonstrate reflected pulses on a transmission line. For this experiment, you will need:

- Spool of multi-conductor cable (twisted-pair preferred)
- Oscilloscope
- Signal generator with square-wave output
- Resistor (100 ohms)
- Low-value potentiometer (adjustable to near 100 ohms with ease)
- Ohmmeter

Connect these components together as shown:
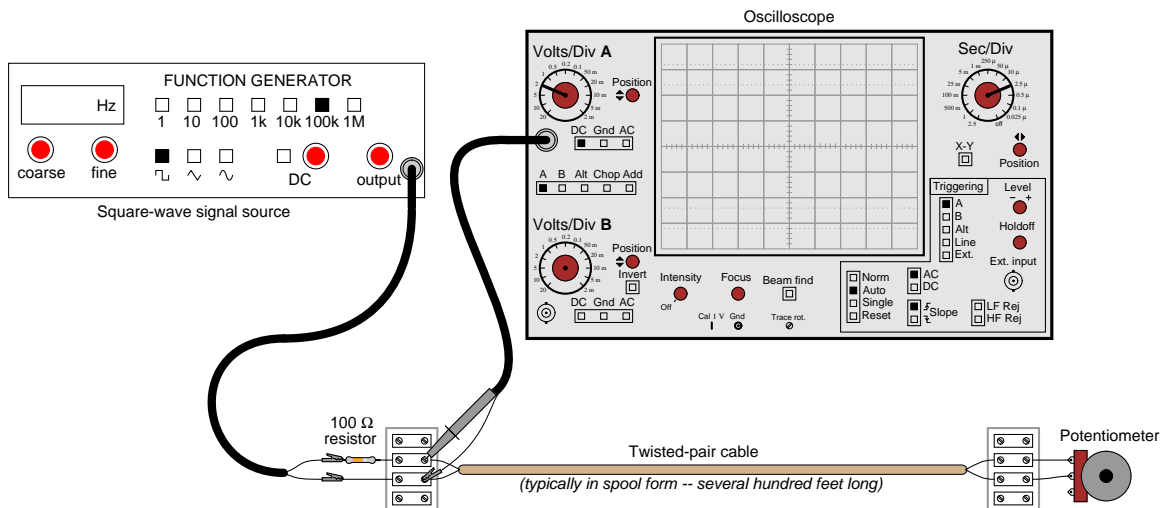
With no potentiometer connected at the cable's far end, analyze the square-wave signal showing on the oscilloscope screen. Start with low-frequency signals (e.g. 100 Hz) and then work upwards to higher and higher frequencies, until you see a "step" distortion appearing on the leading edge of each pulse. Carefully note the width of the "step" distortion as you increase and decrease signal generator frequency – does this width change with frequency? Why or why not? Measure the time-width of this step.

After noting the waveform with an open-ended transmission line, connect a jumper wire to the cable end to act as a dead short, noting how this affects the waveform's shape. Which part(s) of the waveform looks the same as the open-ended cable test? Which part(s) of the waveform look different from the previous test?

Finally, connect the potentiometer to the cable's end to function as a variable terminating resistor. Note the appearance of the waveform as the potentiometer's value is increased and decreased. Adjust the potentiometer until the square-wave signal appears undistorted, then disconnect the potentiometer and read its value with an ohmmeter – this is the *characteristic impedance* value of the cable!

Relate the measured width of the "step" distortion seen in both open-ended and shorted cable tests. Mathematically relate this width to the length of the cable.

file i04410

Question 39

Question 40

Question 41

Read and outline the "EIA/TIA-232" subsection of the "EIA/TIA-232, 422, and 485 Networks" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04416

Question 42

Looking at a minimalist RS-232 serial data network (now more properly known as TIA-232 or EIA-232 rather than RS-232), we see provision for data communication in two directions:
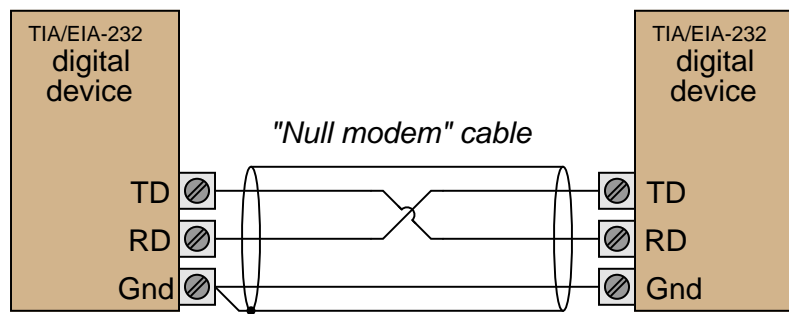
Answer the following questions about this simple serial network:

- Is this system capable of *simplex*, *half-duplex*, or *full-duplex* operation?
- Explain why the shield wire is connected to the Ground terminal only at one end, and not at both ends.
- Explain what the term "null modem" means with reference to the cable connecting these two devices together, and why it is important we use this special cable for the job

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Suggestions for Socratic discussion

- Identify a situation where we could get two serial devices to communicate with each other while using a "straight-through" cable rather than a "null modem" cable.
- Suppose we needed to verify the communication of data in this system, and the only piece of test equipment we had was a digital multimeter (DMM). Explain how we could use a DMM to sense digital data in this network.
- A special tool useful for testing EIA/TIA-232 serial data lines is called a *breakout box*. Research what a "breakout box" is and how it may be used.

file i02190

Question 43

Read and outline the "EIA/TIA-422 and EIA/TIA-485" subsection of the "EIA/TIA-232, 422, and 485 Networks" section of the "Digital Data Acquisition and Networks" chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

file i04417

Question 44

The driver (output) circuits inside of EIA/TIA-485 transceivers must be equipped with *tri-state* outputs. Explain what a "tri-state" output is, and why it is essential for multipoint transceivers to have:
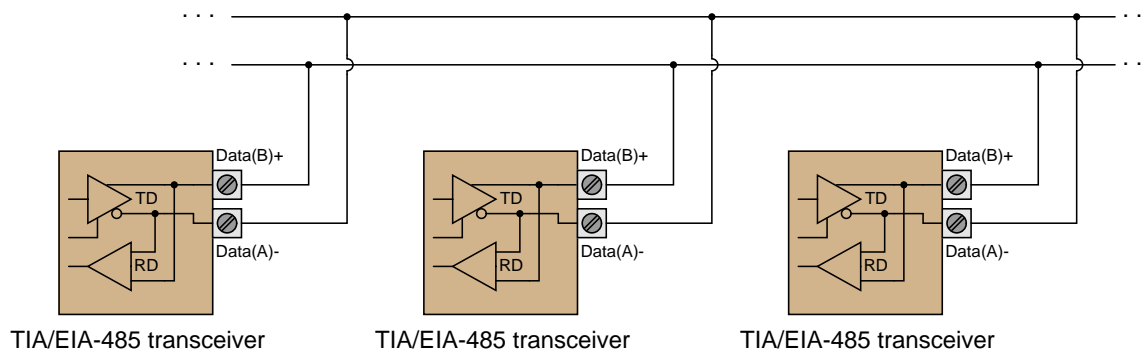
Also, would you classify the above network as a *simplex*, *half-duplex*, or *full-duplex* system? Explain why.

Suggestions for Socratic discussion

- Can you identify the channel arbitration strategy (e.g master-slave, token passing, TDMA) of this digital network from its schematic diagram? If so, which strategy do you think it uses?
- Does this digital network require termination resistors? If so, where should they be placed?

file i02199

Question 45

A data acquisition system consisting of three DAQ modules connected to a personal computer using RS-485 (multidrop) through a modem has a problem. The DAQ software running in the personal computer does not seem to "recognize" DAQ #1, although it does recognize the other two DAQ modules and is receiving data from them:
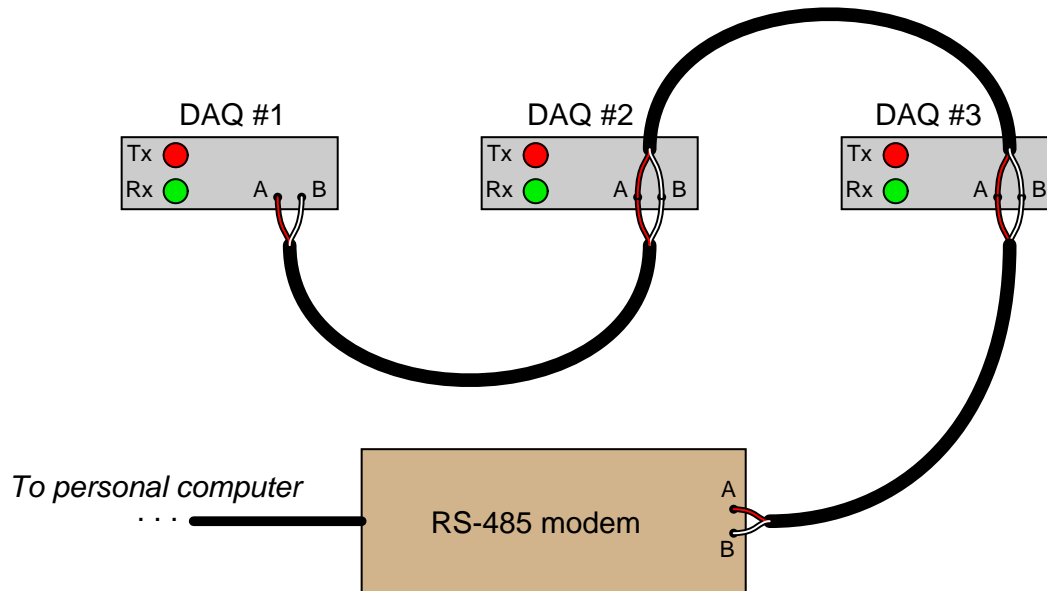
Looking at the LED indicators, you notice that the green "Rx" LEDs on all three DAQ units blink. You also notice that the red "Tx" LEDs on DAQ modules #2 and #3 are blinking as well, but that the "Tx" LED on DAQ #1 is constantly off.

Identify the likelihood of each specified fault for this system. 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
Open cable between DAQ #1 and DAQ #2		
Open cable between DAQ #2 and DAQ #3		
Open cable between DAQ #3 and modem		
Incorrect serial settings (e.g. parity, bit rate) in DAQ #1		
Incorrect serial settings (e.g. parity, bit rate) in DAQ #2		
Incorrect serial settings (e.g. parity, bit rate) in DAQ #3		
Incorrect serial settings (e.g. parity, bit rate) in computer		
Missing termination resistor		

Suggestions for Socratic discussion

• Identify how a digital multimeter (DMM) could be used to perform useful diagnostic tests in an RS-485 network such as this. What sorts of things can we measure using a DMM connected to a digital network? What sorts of things *can't* we measure using a DMM connected to a digital network?

file i00888

55

Question 46

Set up peer-to-peer EIA/TIA-232 networking between two personal computers equipped with 9-pin male serial port connectors (these are provided in the school's lab room). You will need to use a *null modem* cable (also provided by the school) to connect the two computers, and each computer will need to run a *terminal emulator* program such as `hyperterminal`, `PuTTY`, `termite`, `kermit`, or `minicom`.

An acceptable alternative to connecting a pair of personal computers together for this experiment is to connect a single personal computer to an industrial device with a serial port and *terminal server* capability. Examples of such devices include certain models of managed Ethernet switches and SEL-brand digital protective relays.

You may construct your own null modem cable using two 9-pin serial (DE-9) female connectors and cable wires connected like this:
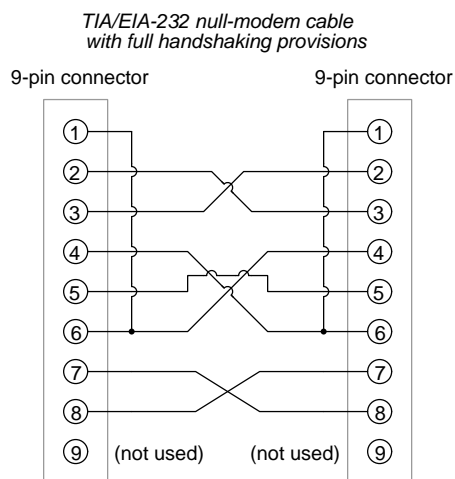
Or, of you're feeling lazy, omit all the connections shown above except for the three wires between pins 2, 3, and 5. Then, of course, you will have to set up the terminal emulator program for software instead of hardware handshaking (i.e. flow control.

After setting up both terminal emulators for the same parameters (stop and data bits, parity, baud rate, etc.) and connecting the null modem cable, you should be able to type messages in one computer and read those messages on the other!

Try experimenting with different baud rates to see how fast you can send messages without errors!

If your own personal computer lacks a serial port, you may use one of the lab's computers to exchange ASCII messages with other students.

file i02211

Question 47

ASCII (American Standard Code for Information Interchange) is a method for encoding English alphabet letters, numerals, and other symbols in the form of 7-bit data packets. EIA/TIA-232 is a protocol for encoding serial data as NRZ (Non-Return-to-Zero) voltage pulses.

Decode the following EIA/TIA-232 data "frames" captured on a digital oscilloscope, each image showing a single ASCII character. Please note that each of these examples are of serial data communicated at the exact same bit rate, with a successful partity check (i.e. no corrupted bits):

Example #1 – 8 data bits, odd parity, 1 stop bit:
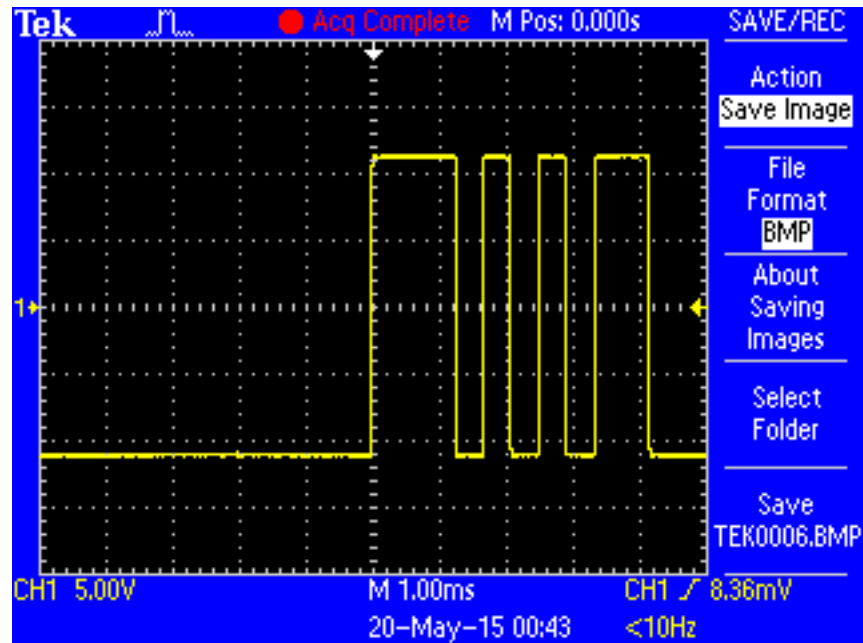
Example #2 – 8 data bits, even parity, 1 stop bit:
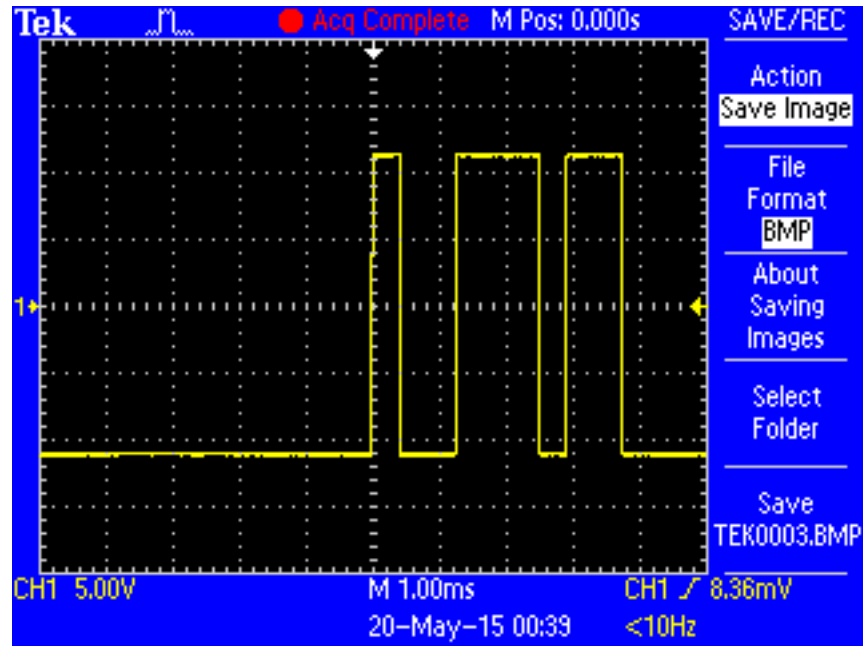
Example #3 – 8 data bits, even parity, 1 stop bit:
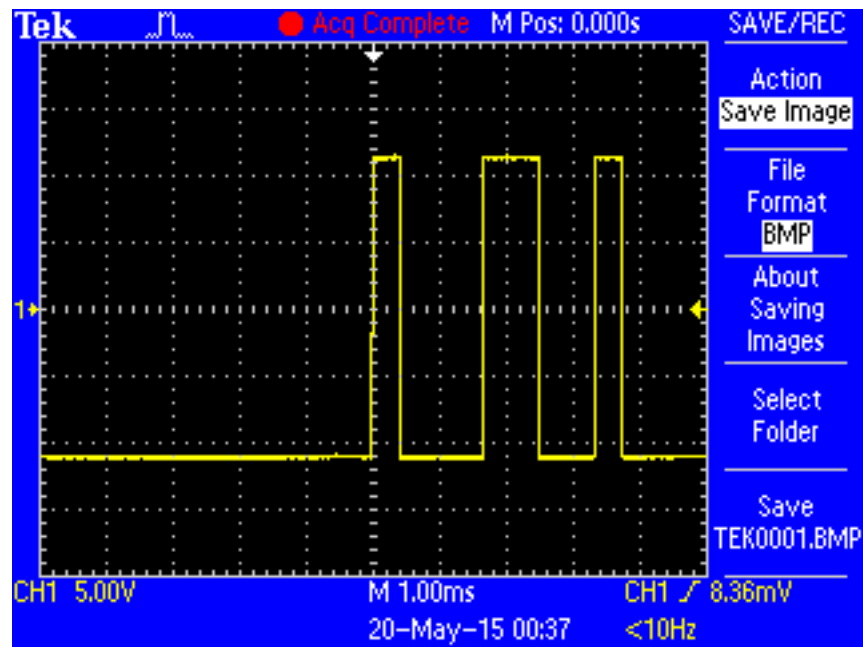
Example #4 – 8 data bits, odd parity, 1 stop bit:
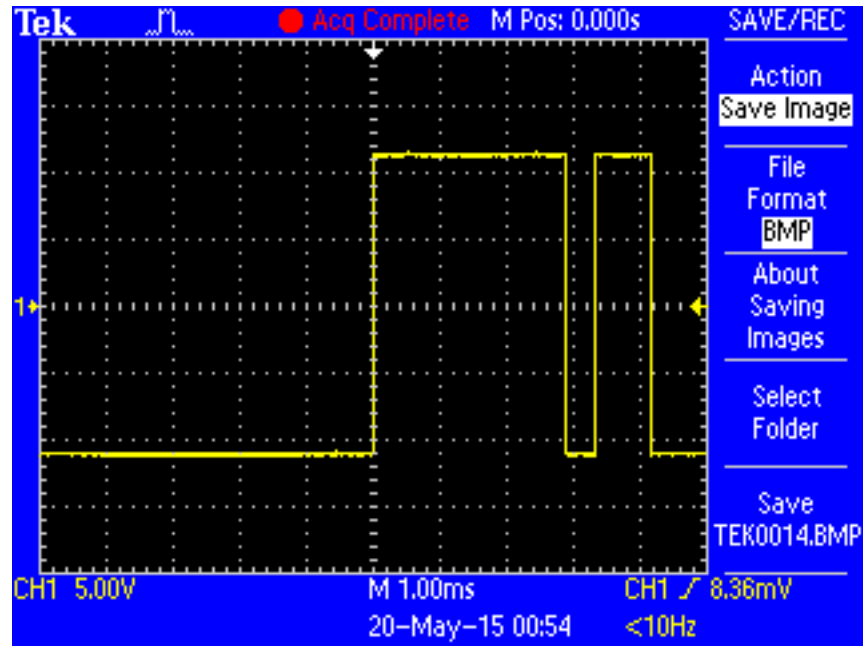
Example #5 – 8 data bits, odd parity, 1 stop bit:
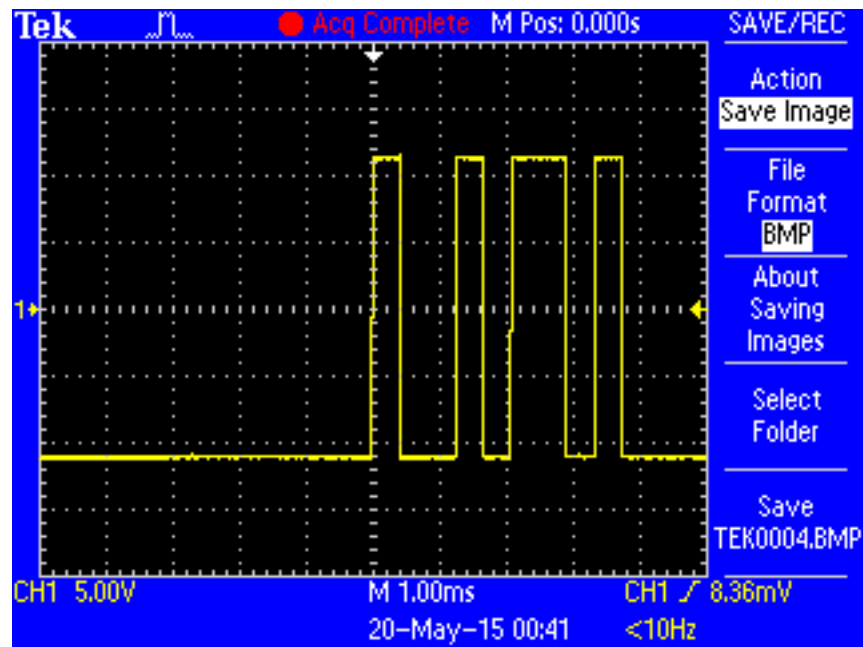
Example #6 – 7 data bits, even parity, 2 stop bits:
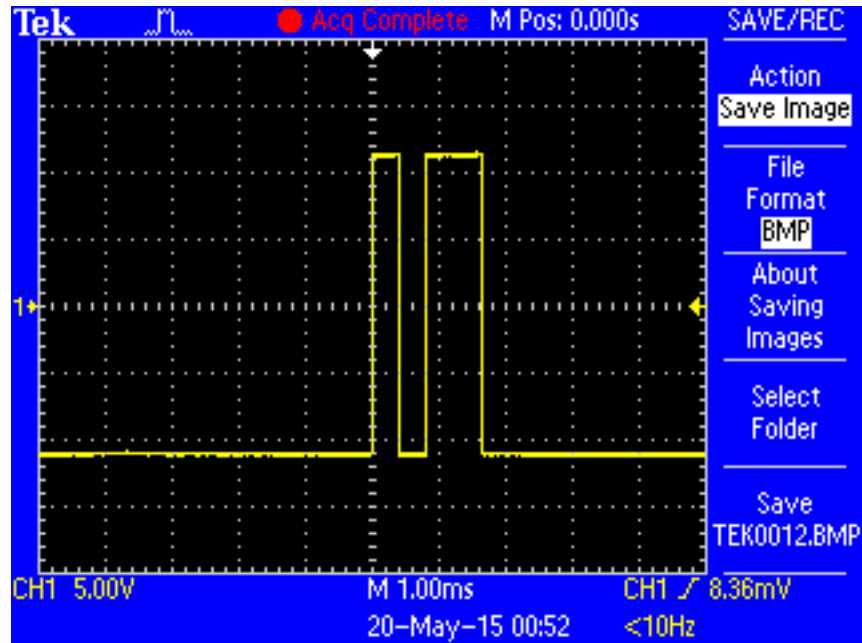
file i02189

Question 48

Locate, download, and install a *terminal emulator* program to your personal computer. This is a program that allows you to directly send ASCII characters out to a serial port on the computer, and also read ASCII characters coming in from another computer. If your computer is equipped with a 9-pin serial (RS-232) port, then you will be able to use it to communicate with similarly-equipped computers today. If not, you will still be able to learn important details of terminal emulator software by running this application and exploring its configuration options.

If using Microsoft Windows (pre-Vista), try the stock `hyperterminal` program in the Accessories folder. For Windows Vista and 7, a version of `hyperterminal` (from Hilgraeve) may be installed as an add-on. If using Linux, `minicom` is a good choice. A free option for Windows operating systems is `termite`. Another good one, available for a wide variety of operating systems, is `PuTTY`. Whatever your choice, the software needs to be installed on your computer prior to the class session.

Once the software is installed and running, examine the communication port settings and see what the allowable ranges are for each:

- Baud rate:
- Stop bits:
- Data bits:
- Parity options:

Also, identify the options provided for *flow control*, both hardware and software modes.

file i02210

Question 49

Take a working EIA/TIA-232 serial communication network and connect either a *breakout box* or a *serial data analyzer* in series with the cable to monitor all data transmitted along the network. The purpose here is to see how these data networking tools are used to monitor the states of data and flow control lines in a serial connection.

Identify how you can tell when a device transmits data to the cable.

Identify how you can tell when a device receives data from the cable.

Identify how you can tell the status of the handshaking (flow control) lines on the cable.

Suggestions for Socratic discussion

- Suppose one of the data lines in a null-modem cable connecting two personal computers together were to fail open. How would this fault be evident on one of these tools?
- Suppose a "straight" cable is used instead of a null-modem cable to connect two personal computers together. How would this error be evident on one of these tools?

file i02219

Question 50

With two computers configured to communicate with one another serially via terminal emulator software (e.g. `Hyperterminal`), the receiving computer should be able to request that the transmitting computer "halt" its transmission of data by means of a feature called *data flow control*. Typically, the serial setup parameters available for flow control include the following:

- Hardware flow control (RTS/CTS)
- Software flow control (XON/XOFF)
- No flow control

Hardware flow control uses the RTS and CTS lines of an EIA/TIA-232 port (RTS = "Request To Send" ; CTS = "Clear To Send") to request data and to be cleared to transmit data, respectively. In order for you to use hardware flow control, therefore, you must have a pair of conductors in your data cable connecting the RTS line of one device to the CTS line of the other device and vice-versa. When a device receiving data wants to stop the flow of data coming in, it "de-asserts" its RTS line, which causes the transmitting device to stop sending data when it sees its CTS line de-activate. When the receiving device is once again ready to receive data, it "re-asserts" its RTS line and the communication continues.

Software flow control does not use the RTS or CTS lines, but rather uses special control codes communicated serially over the TD and RD lines to control the flow of data. When a device receiving data wants to stop the flow of data coming in it transmits an "XOFF" code, which commands the other device to stop transmitting. When the first device is once again ready to receive data, it transmits an "XON" code and the communication continues.

With your terminal emulator software and cable properly configured for software flow control, you can experiment with this feature by making one device transmit a continuous stream of data (e.g. continuously pressing one of the lettered or numbered keys on the keyboard of a computer) while pressing the `<CTRL><S>` key combination on the receiving computer to issue an XOFF command. You can resume data transfer by pressing the `<CTRL><Q>` key combination to issue an XON command.

Note the effects seen at *both* computers!
file i03548

Question 51

In data communications terminology, a binary "1" state is called a *mark* while a binary "0" state is called a *space*. Research the minimum allowable voltage levels constituting a "mark" and a "space" in each of the following serial communication standards, and then explain why the standards differ so much in this respect:

Standard	Mark (1) voltage transmitted	Space (0) voltage transmitted
EIA/TIA-232		
EIA/TIA-422		
EIA/TIA-485		

Standard	Mark (1) voltage received	Space (0) voltage received
EIA/TIA-232		
EIA/TIA-422		
EIA/TIA-485		

Note that in digital communications, the following terms are synonymous:

0 = Space = "on"

1 = Mark = "off" = "idle" (line state in a condition of no communication)

Explain how *noise margin* relates to the minimum voltage signal levels specified in these standards. Which of these serial communication standards enjoys the greatest immunity to electrical noise, based on the figures you research?

| Suggestions for Socratic discussion |

- Identify the difference between an EIA/TIA-422 device and an EIA/TIA-485 device.
- Explain how the terms "mark" and "space" relate historically to *Morse Code*, an early serial communication standard.
- Some cheap USB-to-serial converters you can buy for your personal computer do not fully comply with the EIA/TIA-232 standard, in that they only output +5 V and 0 V, not +5 V and −5 V. Explain why this might be a problem.

file i02193

Question 52

Both EIA/TIA-422 and EIA/TIA-485 networks have the ability to operate in *multidrop mode*, where devices are connected together like this:
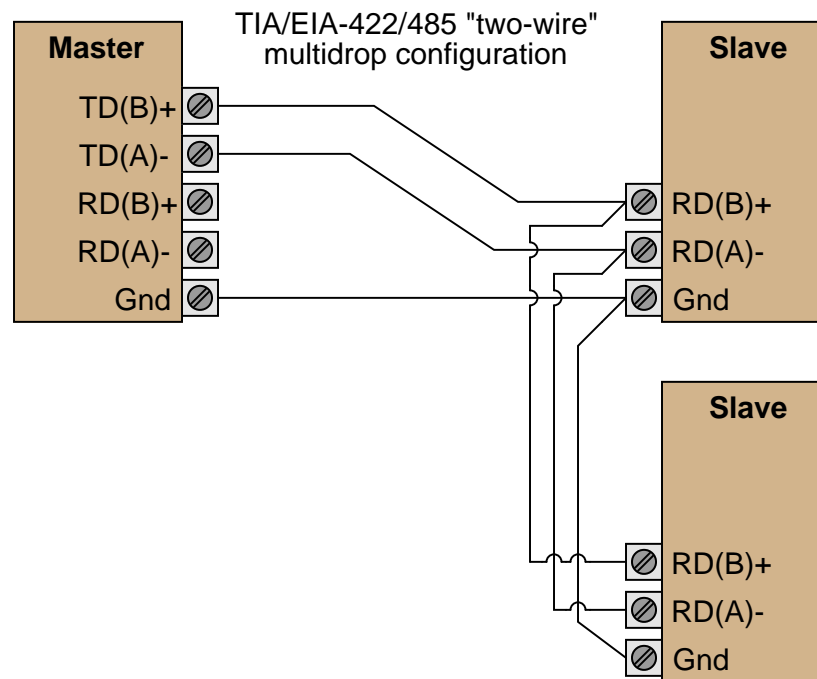
However, only EIA/TIA-485 networks are able to operate in *multipoint mode*, where devices are connected together a bit differently:
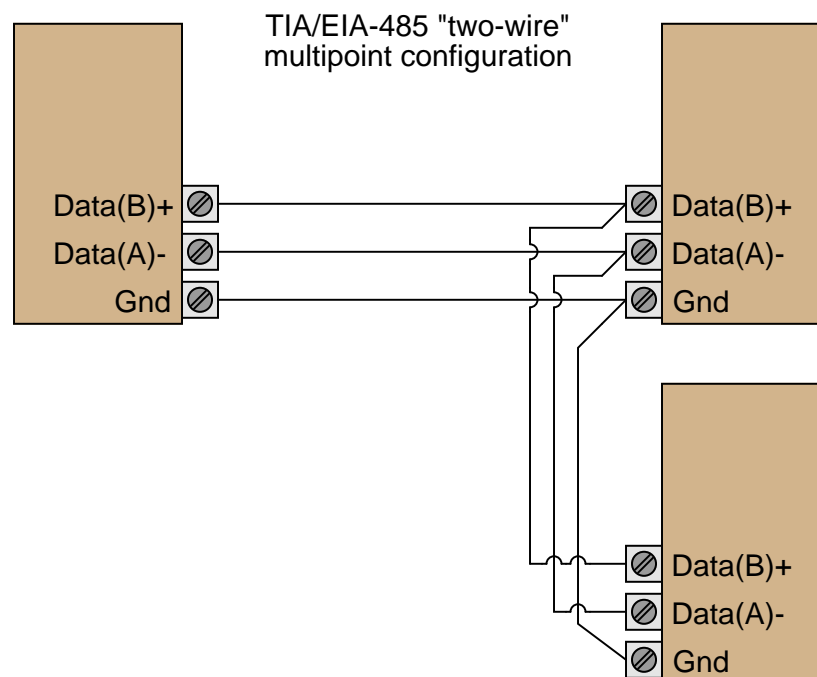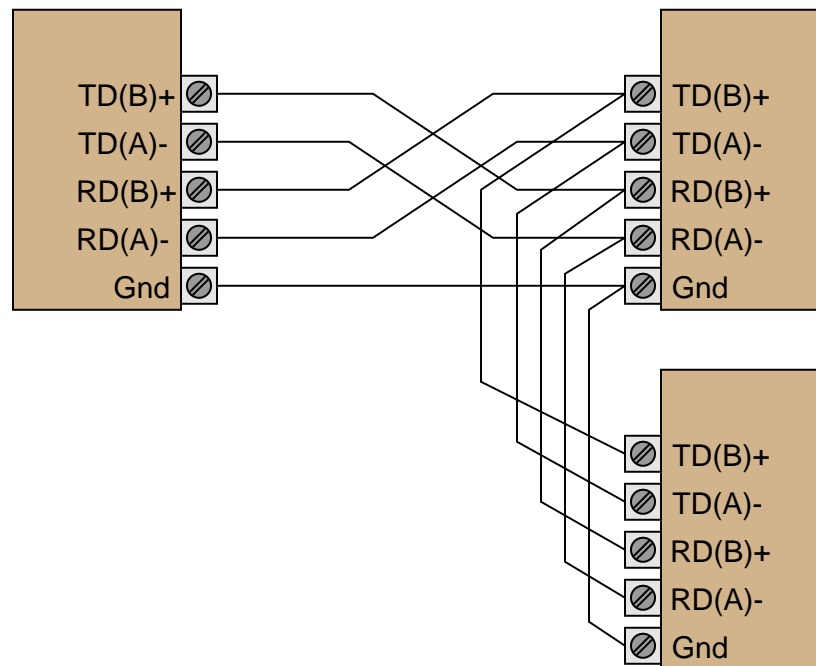

Explain the significance of the "Master/Slave" labels in the multidrop network, and also how the

multipoint (EIA/TIA-485 only) network is fundamentally different.

Question 53

Is this network a EIA/TIA-422 or a EIA/TIA-485? Is it possible to tell from this diagram, and if so, how?

64

Question 54

You should be well aware of the need to separate power and signal wires in control cabinets and other electrical enclosures. Failure to do so may result in power-line "noise" coupled to the signal circuitry, causing spurious signals.

However, this hazard varies according to the types of signals placed near power conductors, and the type of power placed near signal conductors. Rank the following signal types in order from most susceptible to noise (1) to most tolerant of noise (4):

- ____ 4-20 milliamp DC, loop resistance = 250 Ω

- ____ 24 VDC switch circuit to PLC input

- ____ 1-5 volt DC signal to loop indicator instrument

- ____ 4-20 milliamp DC, loop resistance = 100 Ω

Next, rank the following power types in order of most able to couple noise on to signal wires (1) to least able to corrupt signals (5):

- ____ 60 Hz, 120 VAC, powering an incandescent lamp

- ____ Output of variable-frequency drive to motor (approx. 480 volts)

- ____ 250 VDC, powering an incandescent lamp

- ____ 60 Hz, 120 VAC, powering a personal computer with a switching power supply.

- ____ 60 Hz, 480 VAC, input to power a variable-frequency drive

file i02515

65

Question 55

Draw connecting wires between the 4-20 mA *self-powered* (4-wire) level transmitter, the 24 VDC power supply, and "Analog input #1" of the Honeywell UDC2500 controller so that the controller registers the measured level as its process variable (PV). Assume the 4-wire transmitter's analog output is the *sourcing* type:

Honeywell model UDC2500 controller

120 VAC power

L1

L2/N

Output relay #1

Alarm relay #2

Analog + input #2 −

250 Ω

Alarm relay #1

Analog + input #1 −

250 Ω

Non-contact radar level transmitter

24 VDC power supply

L1

L2

120 VAC power

file i01119

66
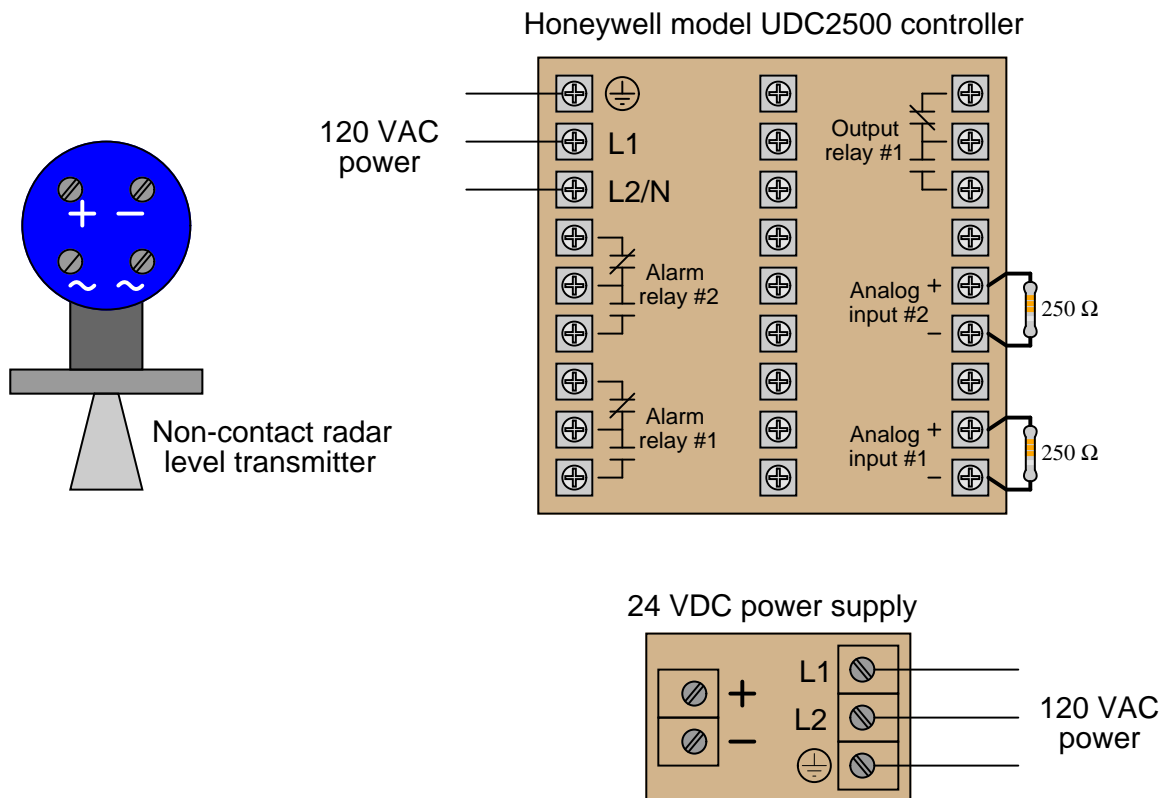
Question 56

Sketch connecting wires so that this DAQ unit will register an increasing positive voltage on channel 2 as the potentiometer shaft is turned *clockwise*:
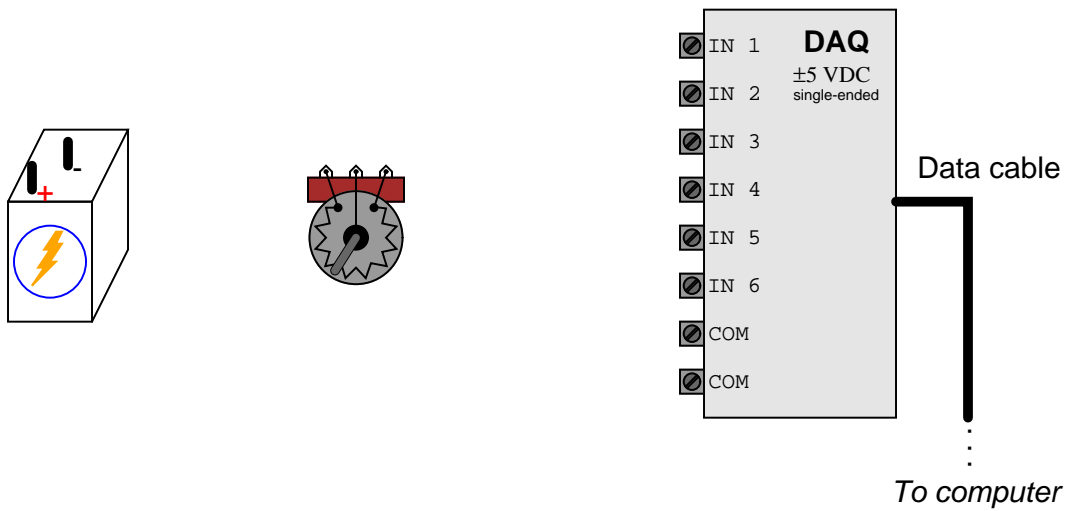
Question 57

Sketch connecting wires so that this DAQ unit will register an increasing positive voltage on channel 5 as the potentiometer wiper moves to the *left*:
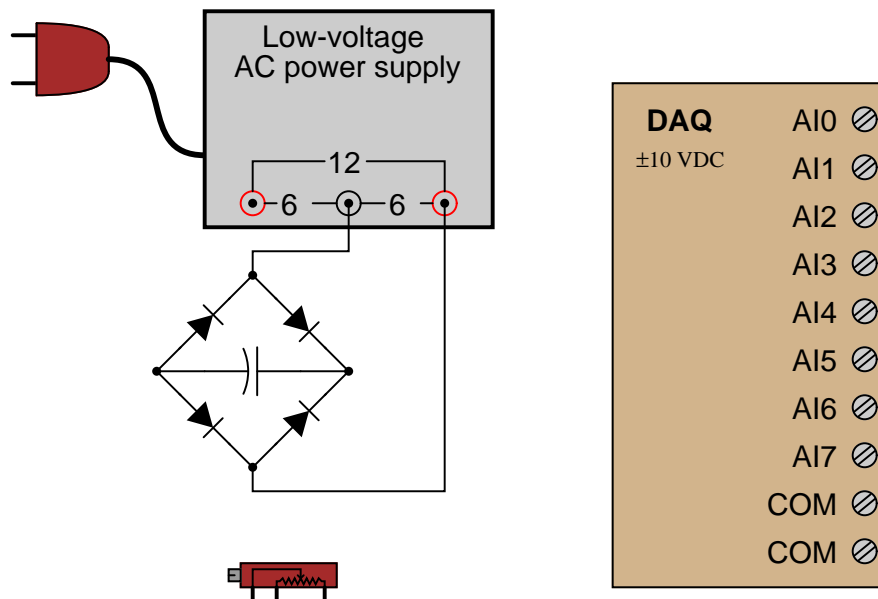
Question 58

Determine how to connect this DAQ unit to measure the output voltage of the Wheatstone bridge in such a way that an increasing compression on the strain gauge causes a *positive* indication at channel 3 of the DAQ, and that the same DAQ channel will register zero when the strain gauge is at rest:
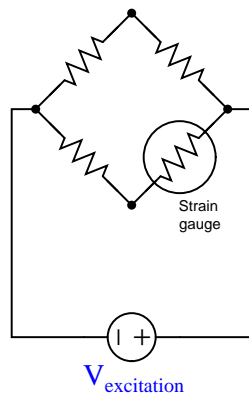
file i02121

Question 59

Suppose we wished to use this DAQ unit to measure the *peak inverse voltage* across diode D_3 during operation of the power supply circuit. Identify how we should connect channel 1 of the DAQ to do this, assuming we want the DAQ to register a *positive* value at the moment in time of the diode's peak inverse voltage:
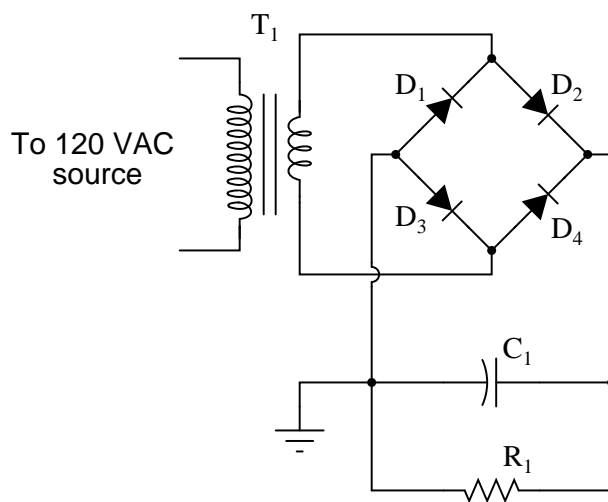
file i02120

Question 60

EIA/TIA-485 networks require *biasing resistors* to provide a definite "idle" (mark) state when the drivers are all in high-impedance mode. Otherwise, the lines would be left to float, and the logic state would be indeterminate.

Show how two resistors are connected to the A and B lines inside each EIA/TIA-485 device to provide a definite idle state. Note that these resistors are usually internal to the device, and do not have to be externally added:
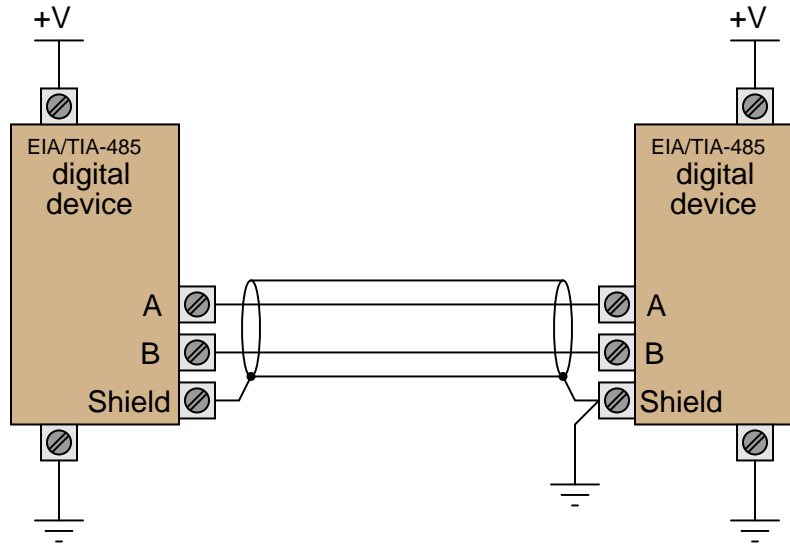
Suggestions for Socratic discussion

- How would the presence of *termination* resistors affect this biasing?

file i02195

Question 61

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.

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

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

file i04419

Question 62

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 63

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.

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

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

file i04420

Question 64

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.

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

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

file i04421

Question 65

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.

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

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

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 66

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):
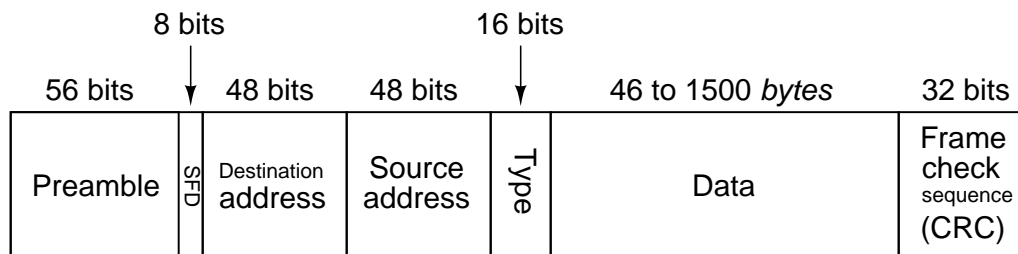
Explain the purpose of each frame section:

- Preamble:

- SFD:

- Destination address:

- Source address:

- Type (or Length):

- Data:

- Frame check sequence:

Also, calculate the distance the first bit of the preamble will travel along a copper Ethernet cable during the preamble period, assuming a transmission speed of 10 million bits per second, a cable velocity factor of 0.7 and a cable temperature of 65 degrees Fahrenheit.

Question 67

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?
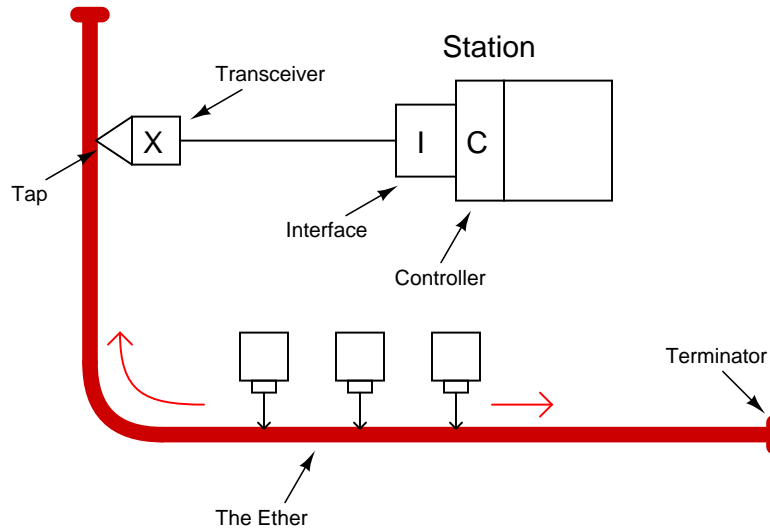
Suggestions for Socratic discussion

- 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 68

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.
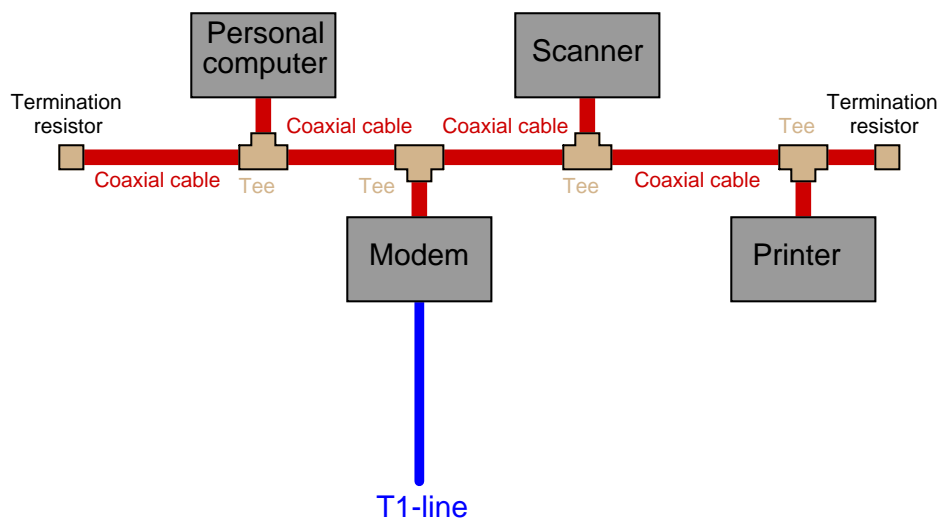
Suggestions for Socratic discussion

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

  file i02201

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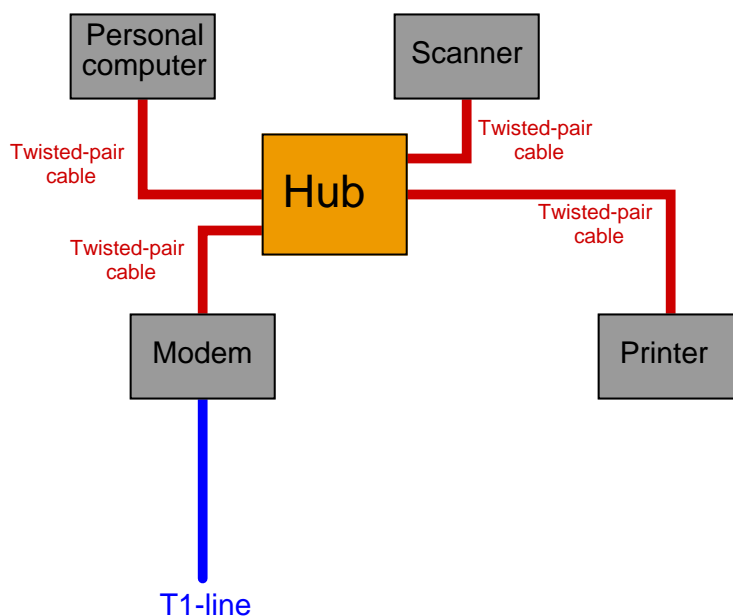
Explain what the purpose of the *hub* is, and how it is more than just a connection point like a tee fitting in the old coaxial-based cable standard.

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 70

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:
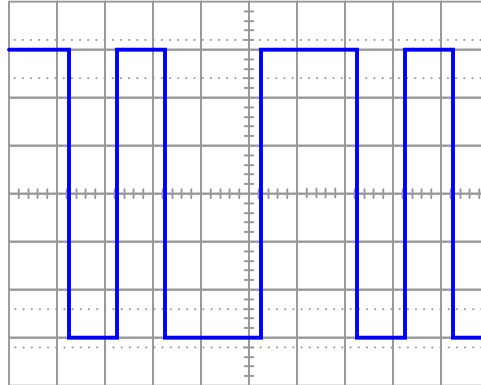

Hint: it may be easier to begin by sketching the waveform to represent a particular bit sequence. For example, try sketching the Manchester encoded waveform to represent the bit sequence 1 0 1 1 0 first, then analyze the waveform given to you in this question.
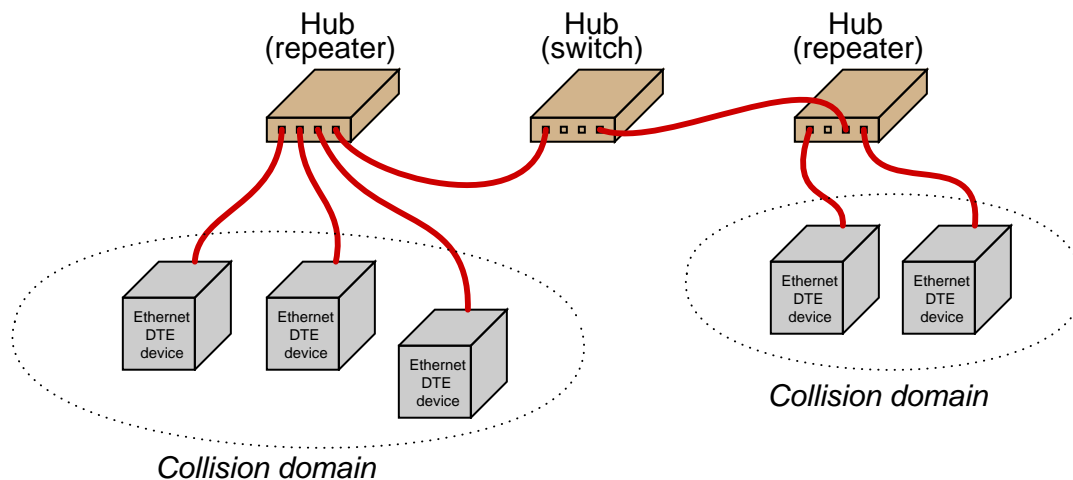
file i02203

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:
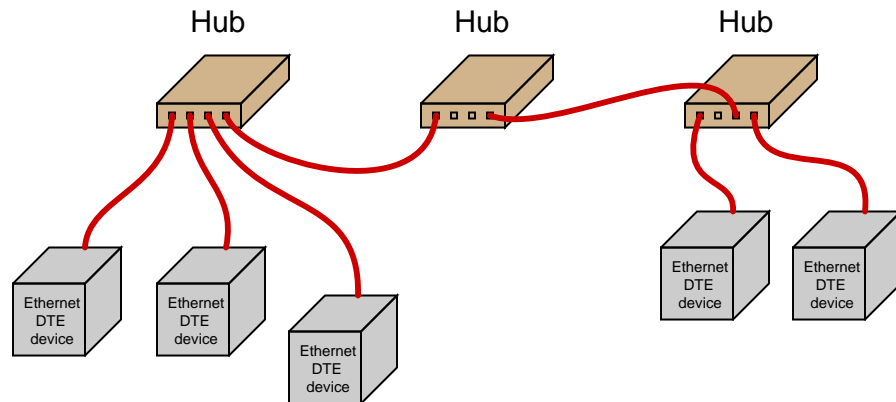
All hubs are not created equal, though – they come in two varieties: *repeaters* and *switches*. If we were to use simple *repeater* hubs, all five Ethernet DTE devices would belong to the same collision domain. If we were to replace the middle repeater with a *switching* hub, however, we would have 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 72

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 73

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 74

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 75

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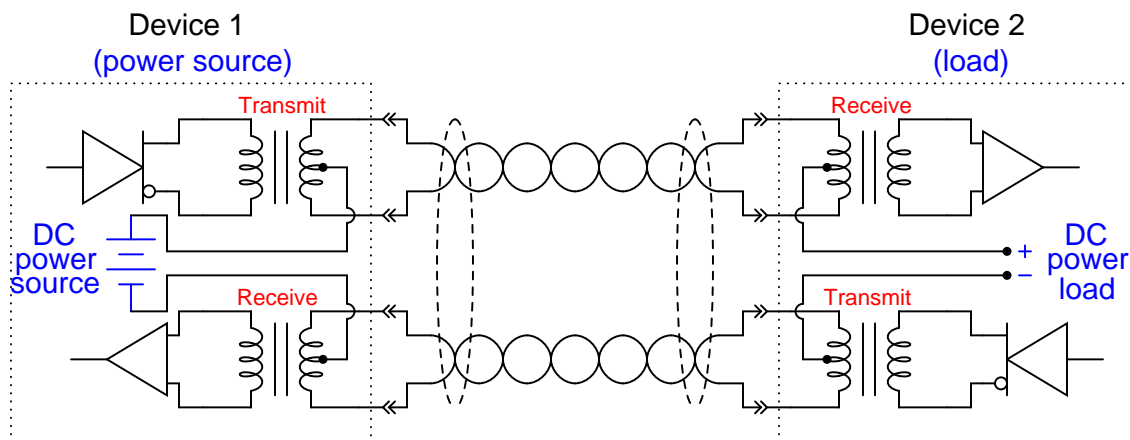
Explain what function(s) the transformers provide in this system, and how they allow DC power to travel through the wire pairs from source to load without interfering with the Ethernet data signals, which are AC.

file i02289

Question 76

Question 77

Question 78

Question 79

Question 80

Question 81

Add the necessary parity bits to each of these one-byte (eight-bit) data words. The data is shown in hexadecimal format, and your answers should be in hexadecimal format as well, making the parity bit a ninth (most-significant) bit for each word:

- `A7`   Even parity = _____   Odd parity = _____
- `58`   Even parity = _____   Odd parity = _____
- `20`   Even parity = _____   Odd parity = _____
- `CA`   Even parity = _____   Odd parity = _____

Be sure to show your work in converting these hex numbers into binary so as to count the bits!

file i02220

Question 82

A data acquisition unit is needed to sample vibration data on a large steam turbine. The turbine's shaft speed is 1800 RPM, and the intent is to measure vibrations as high as the 11th harmonic frequency of the shaft speed.

Determine the minimum sampling rate for the DAQ module to avoid *aliasing*. Also, determine a practical sampling rate so that even the highest-frequency component of interest will be well-digitized.

Question 83

Suppose two computer devices are networked together using RS-232 serial data ports. The cable connecting the devices' two 9-pin ports together has three wires: *transmit*, *receive*, and *ground*. The problem is, the devices refuse to "talk" with one another over this network: no data sent by the first device is received by the second, or vice-versa.

This is a brand-new system, and the technician who built it has just finished checking the continuity of the data cable's three conductors (from one end to the other) using an ohmmeter. Furthermore, the technician verified that the proper communication software has been installed and is running in both computer devices. What else other than the cable might be set up incorrectly to prevent these two devices from "talking" via RS-232? Identify *five* different potential problems that could prevent communication between these two devices.

(1)

(2)

(3)

(4)

(5)

file i02290

82

Question 84

Sketch a waveform showing the hexadecimal value 5C sent in NRZ-encoded serial form, complete with start bit, stop bit, an "odd" parity bit, and all eight bits of the data sent in proper order.

file i02224

Suppose a technician is troubleshooting this network of digital devices, and suspects an electrical fault somewhere in the network preventing communication. It seems *none* of the devices is able to communicate with any other device on the network:
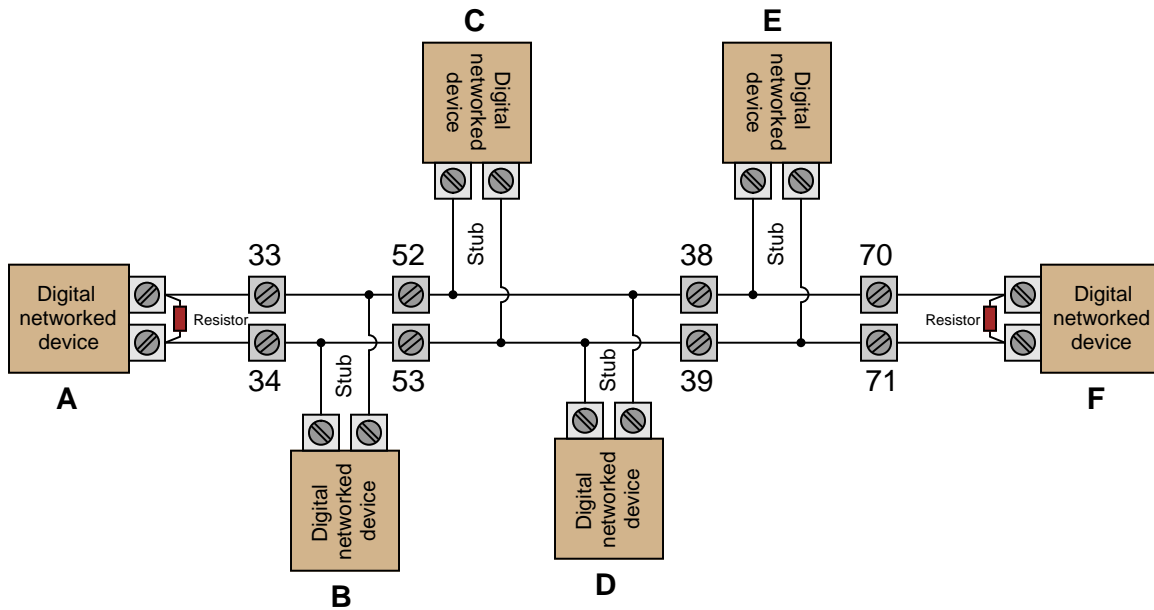

The technician decides to loosen terminal number 38 and remove the wire entering its left-hand side. Then, she uses her ohmmeter to measure resistance between terminals 52 and 53. The ohmmeter registers 152 ohms.

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 the ohmmeter measurement as well as the total lack of communication in this network.

Fault	Possible	Impossible
Device **A** failed shorted		
Device **B** failed open		
Broken wire between terminals 38 and 70		
Right-hand terminating resistor shorted		
Device **E** failed shorted		
Short between terminals 33 and 34		

file i02223

Question 86

Suppose you needed to choose a fixed resistor value (R) to make a voltage divider circuit, given a known potentiometer resistance value, the source voltage value, and the desired range of adjustment:
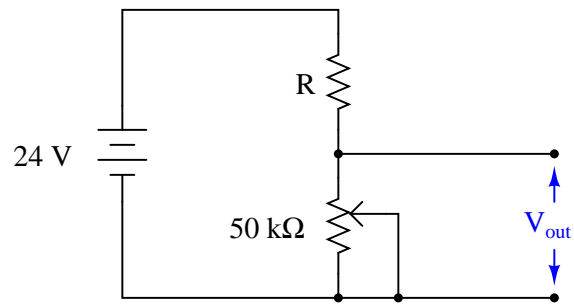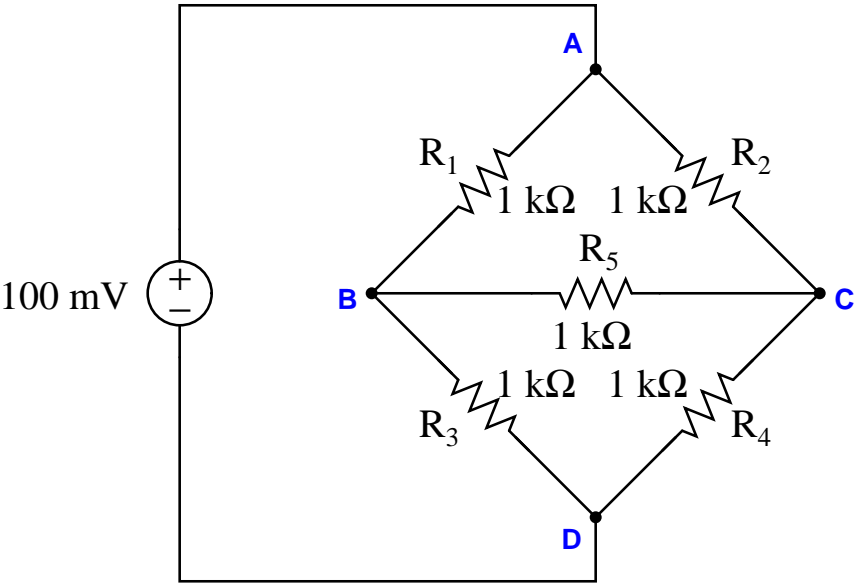

Desired range for V_{out} = *0 to 17 volts*

Solve for R, and show the equation you set up in order to do it. Also, determine the respective potentiometer wiper positions at 0 volts and at 17 volts.

Question 87

Suppose a voltmeter registers substantially greater than 50 millivolts between test points **C** and **D** in this circuit:


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

Fault	Possible	Impossible
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_4 failed open		
R_5 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
R_4 failed shorted		
R_5 failed shorted		

<u>file i03139</u>

Question 88

Determine the voltages registered by a voltmeter between the following points in this circuit. Be sure to note whether the voltmeter's indication will be a positive value or a negative value in each case:
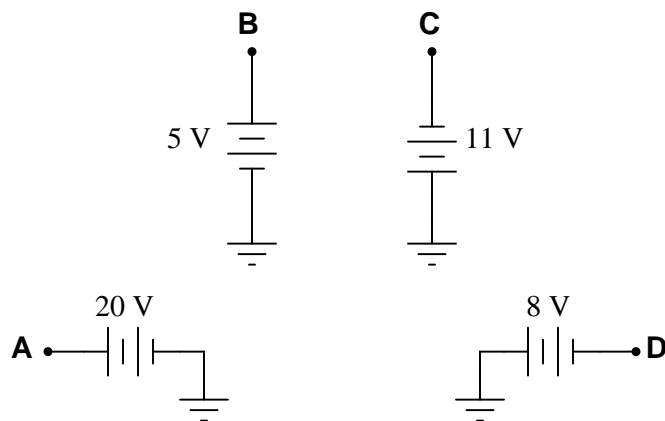
$V_A =$ _____ (red lead on **A**, black lead on ground)

$V_B =$ _____ (red lead on **B**, black lead on ground)

$V_C =$ _____ (red lead on **C**, black lead on ground)

$V_D =$ _____ (red lead on **D**, black lead on ground)

$V_{AC} =$ _____ (red lead on **A**, black lead on **C**)

$V_{DB} =$ _____ (red lead on **D**, black lead on **B**)

$V_{BA} =$ _____ (red lead on **B**, black lead on **A**)

$V_{BC} =$ _____ (red lead on **B**, black lead on **C**)

$V_{CD} =$ _____ (red lead on **C**, black lead on **D**)

<u>file i02522</u>

Question 89

Sketch connecting wires to allow this data acquisition unit (DAQ) to sense current (using the "shunt" resistor as a primary sensing element) on input channel #2 and also generator output voltage on input channel #3:
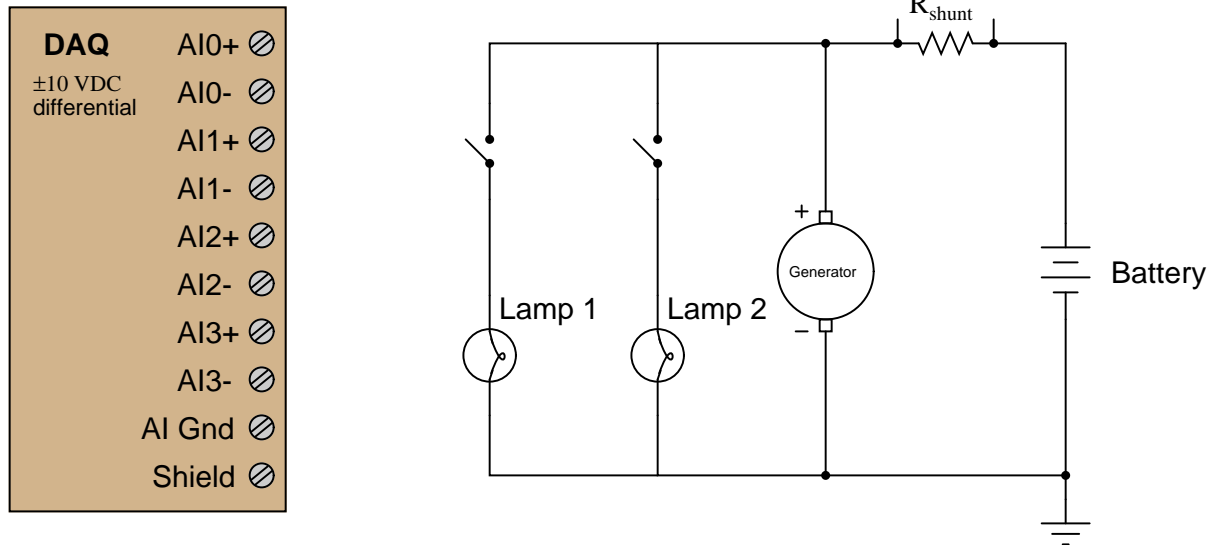
Your circuit should be wired in such a way that a *discharging* battery produces a *negative* signal at channel #2, and a *charging* battery produces a *positive* signal at channel #2. Draw an arrow in the circuit diagram showing the direction of current through the battery (conventional flow notation) while it is charging.

file i04583

The following electric heater seems to have a problem: it heats up slower than usual with all three switches turned "on."
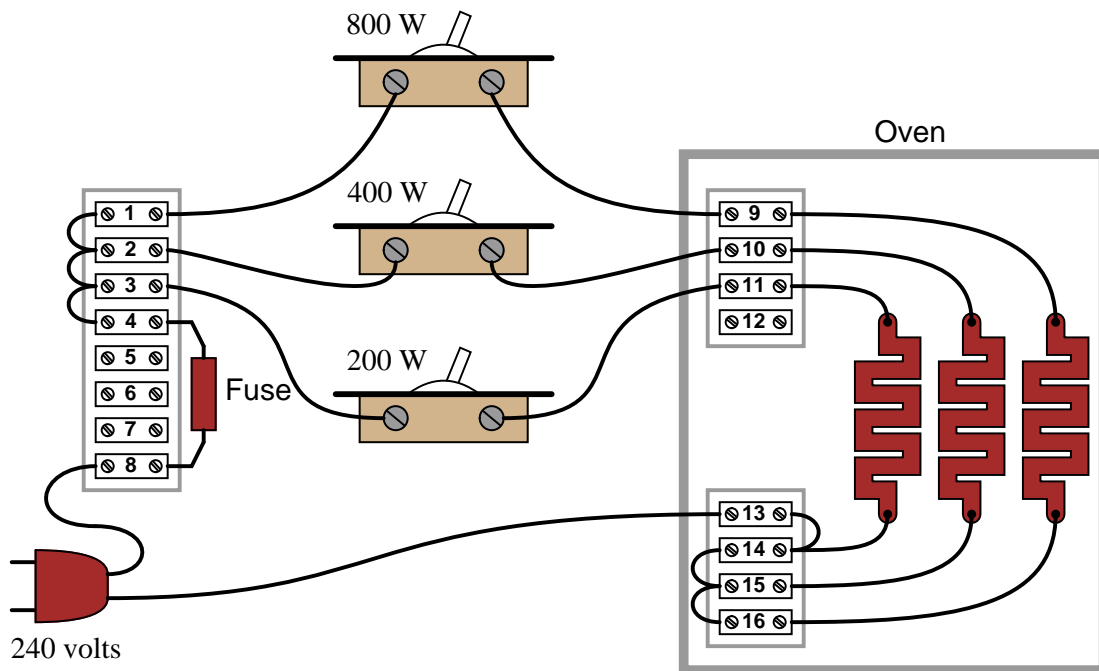
With three differently-sized heating elements (200 watt, 400 watt, and 800 watt), the oven operator can set the power in seven discrete steps by turning on specific combinations of switches: 200 watts, 400 watts, 600 watts, 800 watts, 1000 watts, 1200 watts, and 1400 watts.

You are summoned to diagnose this oven's problem *without turning it off*. You are allowed to turn off any single switch for a few seconds at most, but otherwise you need to leave all three heaters on because the oven needs to heat up as fast as it can! The idea is to figure out where the problem might be, then gather together any parts necessary for repairs while the oven is still being used, and fix the oven as fast as possible when you finally get the chance to turn it off completely.

Using a magnetic "clamp-on" ammeter to measure current without breaking the circuit, you read 2.6 amps through the wire between the power plug and terminal 13 with all three switches in the "on" position. Then, you momentarily turn the "800 watt" switch off and on, noticing that the current remains unchanged at 2.6 amps.

Based on this data, identify two things:

- <u>Two</u> components or wires in the oven circuit that you know must be in good working condition.

- <u>Two</u> independent components or wires in the oven circuit that could possibly be bad (and thus cause the slow heating problem), including the type of fault (open or short) you suspect for each.

<u>file i03164</u>

Question 91

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 some form of digital display console (e.g. a personal computer running appropriate software, an HMI panel, etc.). 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. 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 ($\pm$ 1% of span)	mastery	–	–	–	–	
Data communicated via Ethernet	mastery	–	–	–	–	
Troubleshooting	mastery					– – – –
Safety and professionalism	deduction					
Lab percentage score	proportional					– – – –
Decommission and lab clean-up	(ungraded)	–	–	–	–	

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

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

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

Lab Exercise – objectives and expectations

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

Team meeting and prototype sketch

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

Circuit design challenge

Design and build either a light-sensing or temperature-sensing circuit from components meeting criteria randomly specified by the instructor, using a digital multimeter (DMM) to record either minimum or maximum signal levels.

Final loop diagram and system inspection

Create a complete loop diagram of your team's completed system according to the ISA 5.1 standard, then show that the constructed system meets or exceed all standards described in the lab exercise documentation.

Demonstration of IP "ping" utility

Correctly use the `ping` command-line utility to test connectivity between two or more IP-networked devices.

Demonstrate use of a "knockout punch" tool

Safely use a "knockout punch" tool to punch a hole in sheet metal suitable for connection to an electrical conduit fitting.

Accurate measurement of variable

Demonstrate that your data acquisition system accurately registers the process variable to within $\pm 1\%$ of span over the entire measurement range. This will require you to enter a mathematical formula into the DAQ polling software to convert the "raw" voltage signal into a value representing the real process variable value.

Data communicated via Ethernet

Demonstrate that your data acquisition system communicates data over an Ethernet network.

Troubleshooting

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

Lab Exercise – objectives and expectations (continued)

Lab percentage score

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

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

Safety and professionalism (deduction)

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

General format and philosophy

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

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

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

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

Lab Exercise – team meeting, 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.

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:
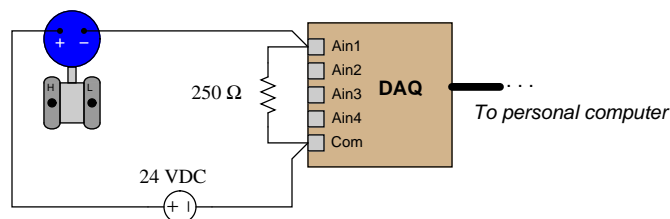
You are also welcome to be more creative and build yourself a simpler analog sensing circuit such as this:
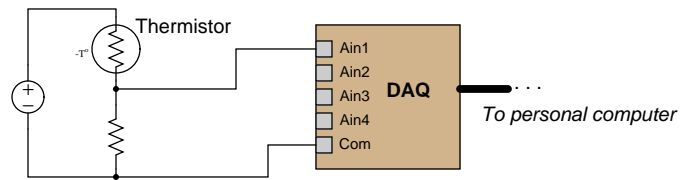
The challenge with a circuit such as this is that it will *not* output a signal that is linearly proportional to temperature like the loop-powered transmitter will. In order to make this work, you will have to program a formula into the DAQ software to "linearize" the voltage signal into a proportional 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.
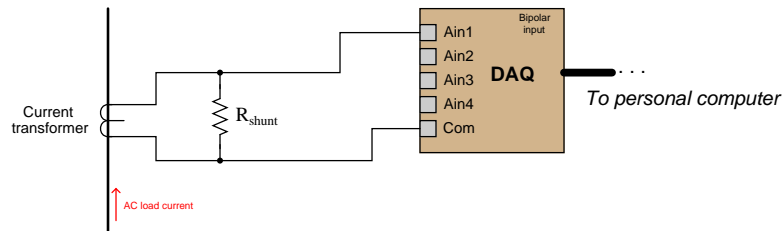
If you choose to build a system to measure AC current using a current transformer (CT, shown above), you will need to select a suitable shunt resistor to drop voltage generated by current output by the CT. This is done by researching the "burden" rating of the CT, which will tell you how large that load 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!!!*

For any application, it is extremely important to check the input ratings of your DAQ unit to ensure they are appropriate for the measurement task, and also check to see that the *absolute maximum* ratings are such that the DAQ will not become damaged in the event of any single-component failure. For example, if your DAQ happens to have an absolute maximum input voltage rating of 20 volts and your circuit could potentially apply 24 volts to the DAQ input in the event of a particular component fault, it means you must re-design your circuit to prevent this ever from happening.

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. 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. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, etc.) "Alligator" clips are permitted for making connections to battery terminals only.

This exercise tests your ability to 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.
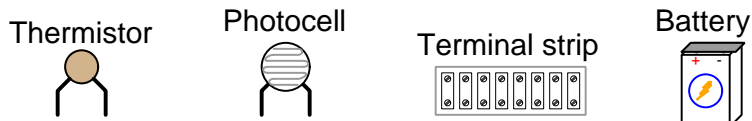
The following components and materials will be available to you: assorted CdS **photocells** and **thermistors** ; **terminal strips** ; lengths of **hook-up wire** ; **battery**. You must provide resistor(s), your own tools, and digital multimeter (DMM) as well as a copy of this page for your instructor to mark objectives.

SEQUENCE: (1) Instructor chooses criteria; (2) You build and test circuit without any power sources at all; (3) Instructor provides battery and observes you energizing the circuit for the very first time; (4) You demonstrate to the instructor that the circuit fulfills its intended function. (5) You demonstrate how to capture the minimum or maximum value using your DMM.

Sensor type (instructor chooses): ____ Photocell   ____ Thermistor

Meter response (instructor chooses): ____ Direct   ____ Reverse

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

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 DAQ provided in your team's tool locker is equipped with its own Ethernet port, which means you may use any Ethernet-equipped personal computer to run the DAQ software and poll data from the DAQ unit over the lab's Ethernet network. For those teams interested in learning Modbus programming and familiar with programming the lab's caSCADA system(s), I recommend writing C-language code to poll data from a Modbus-compliant DAQ and executing that code in any computer with a C compiler. Examples of Modbus programming using the `libmodbus` library are shown in the Modbus section of the *Lessons In Industrial Instrumentation* textbook.

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 – 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:
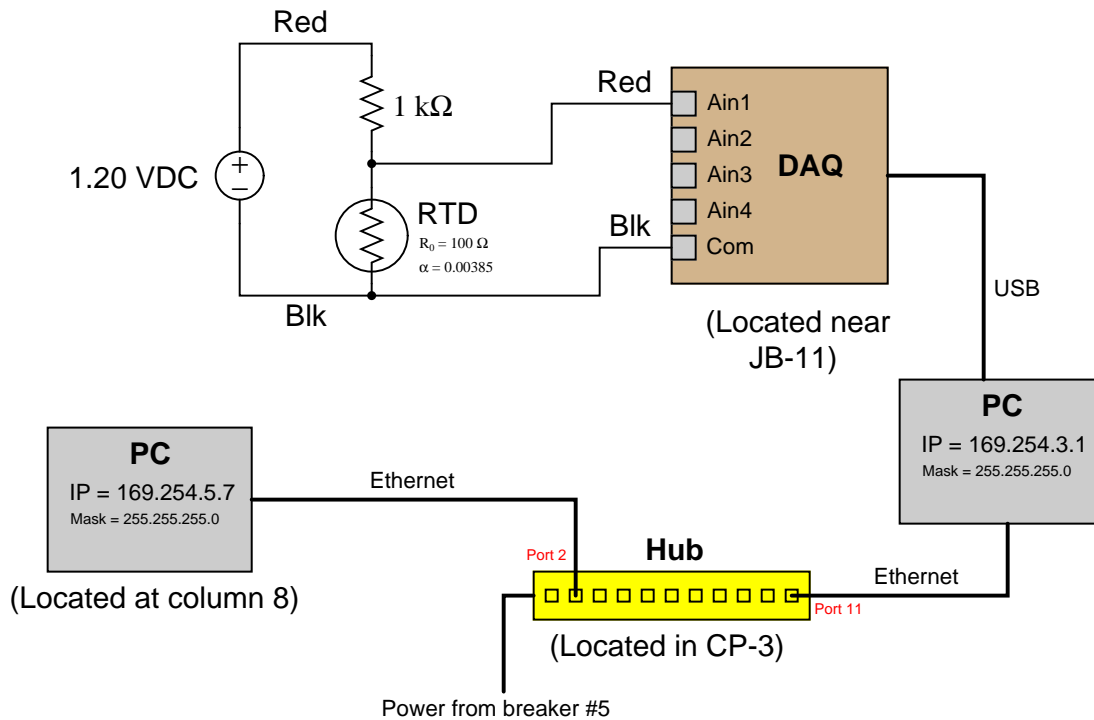
Note that if using an Ethernet-equipped DAQ unit, the DAQ will be able to plug directly into the Ethernet hub without need for an intermediary computer (e.g. 169.254.3.1 shown in this diagram.)

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).

Notes on DAQ signal scaling/linearization

Each team must configure their DAQ system to accurately report the measured variable in appropriate units of measurement. 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). DAQ polling software contains a provision for entering your own mathematical scaling formula to perform this function.

If your system uses a loop-powered 4-20 mA 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:
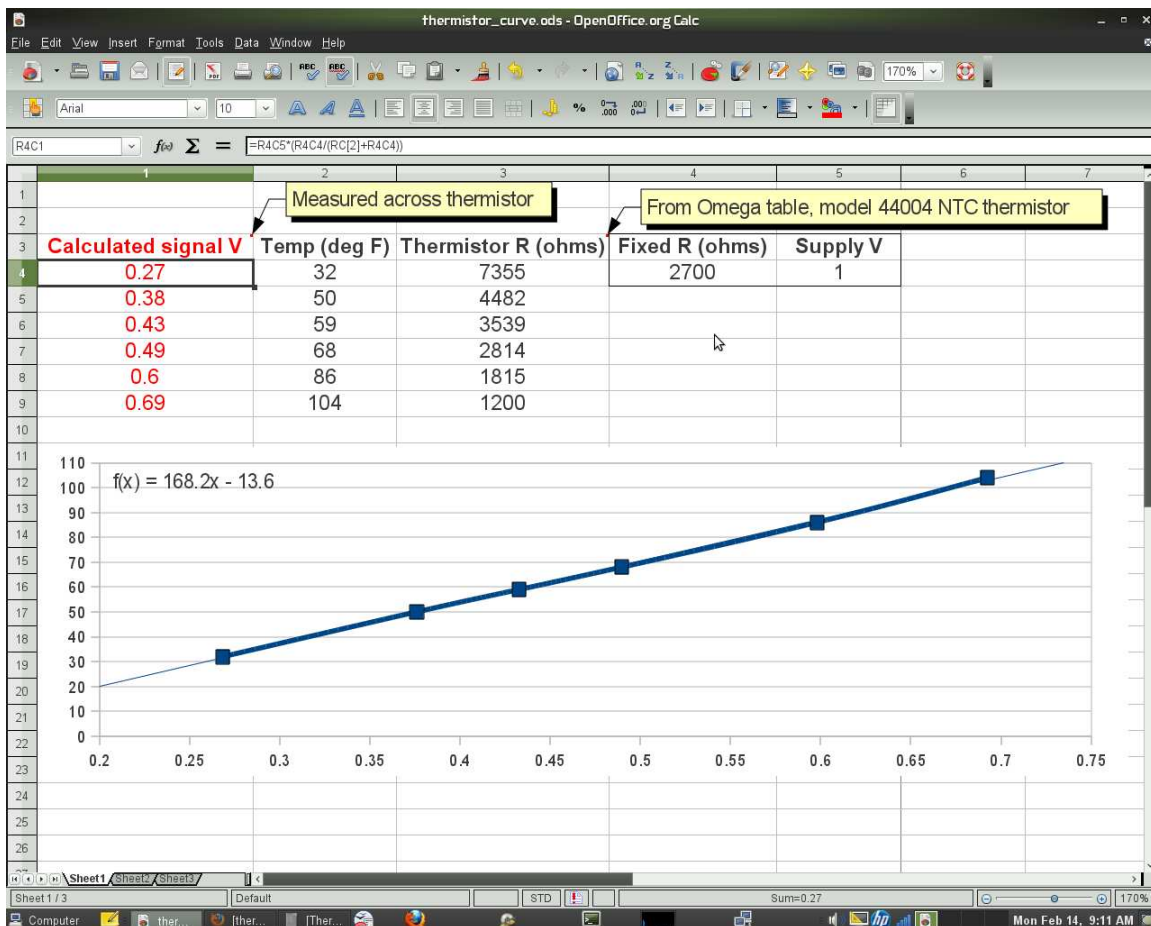
In this particular example, the sensor is a negative temperature coefficient (NTC) thermistor, model 44004, manufactured by Omega. The formula entered into cells R4C1 through R9C1 calculates the voltage dropped across a fixed resistor (2700 Ω) connected in series with the thermistor and powered by a 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. Each team's tool locker DAQ is equipped with an Ethernet port, and software is freely available for polling data over Ethernet using any personal computer. You are encouraged to install this free software on your own laptop PC and experiment with it independent of your teammates. Part of the capstone challenge at the end of every quarter (for those students who have completed this course) will include use of a DAQ on your own personal computer.

If you are familiar with C-language programming, there is a free C library called `libmodbus` which may be used to write your own data polling software to acquire data from any Modbus-compliant DAQ unit. Examples of Modbus programming using the `libmodbus` library are shown in the Modbus section of the *Lessons In Industrial Instrumentation* textbook. Writing your own polling code is fairly advanced DAQ usage, but is certainly within the capabilities of any student who has programmed any of the lab's caSCADA systems. A convenient computing platform to use for this code-writing is a Raspberry Pi, a single-board computer running the Linux operating system that is available for very modest cost.

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. The ping query and response is part of the ICMP (Internet Control Message Protocol) specified in RFC 792. 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. For example, a firewall configured with a rule to drop or reject any ICMP communications will block all "ping" queries. 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 important aspect of this lab exercise is *troubleshooting*, where you demonstrate your ability to logically isolate a problem in the system. All troubleshooting must be done on a system you did not help build, so that you must rely on others' documentation 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 location and nature of the fault. All troubleshooting activities must be proctored by the instructor to assess proper diagnostic reasoning and technique.

The standard procedure involves a group of no more than four students troubleshooting the same faulted system, with the builders of that system playing the role of operators. All troubleshooters are given a two-minute period to individually identify a plausible fault based on observable symptoms and submit it in writing to the instructor for assessment. Those students whose faults are indeed plausible advance to the next round, where each one takes turns making diagostic tests on the system. One minute is given to each student for devising this test, but no time limit is placed on the execution of that test. Whenever someone decides enough data has been collected to pinpoint the location and nature of the fault, they declare to have reached a conclusion and submit to the instructor in writing for assessment.

Individual troubleshooting with a five-minute time limit is also an acceptable format, but this generally only works with small class sizes.

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.

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:

- Attempting to *visually* locate the fault.
- Neglecting to take measurements with your multimeter.
- Neglecting to check other measurements in the system (e.g. pressure gauge readings).
- Incorrectly interpreting the loop 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!

The purpose of every 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 no demonstration of skill. Competence is only revealed by 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. Budget 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.

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.
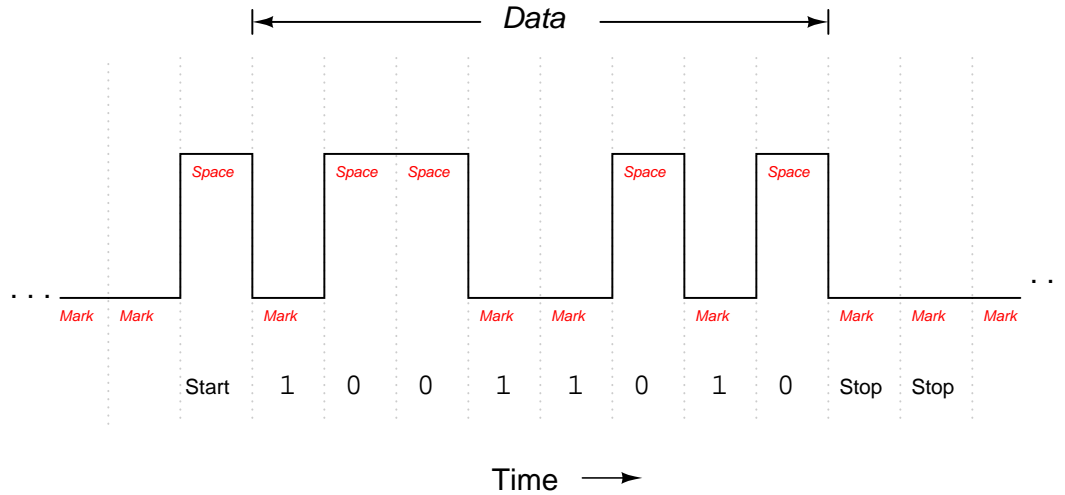
file i00350

Answer 1

Answer 2

Answer 3

Answer 4

It is common in NRZ encoding schemes to transmit the LSB first and the MSB last, so the binary value represented by this waveform is `01011001`.

Answer 5

Partial answer:

Hex = 73

Answer 6

Partial answer:

Hex = 7C

Answer 7

This is the ASCII character for a lower-case "m", and the parity checks out okay.

Answer 8

Partial answer:

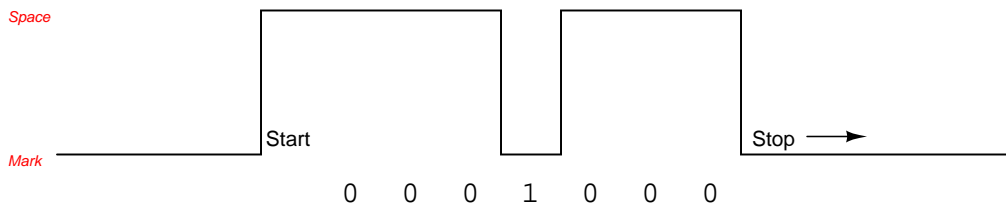57.1 seconds of time required for the synchronous network.

Answer 9

Partial answer:

Fault	Possible	Impossible
R_1 failed open	✓	
R_2 failed open		
Strain gauge failed open		✓
Dummy gauge failed open		
R_1 failed shorted		
R_2 failed shorted		
Strain gauge failed shorted		
Dummy gauge failed shorted		
Voltage source dead		✓

Answer 10

As a strain gauge is stretched, its conductors become longer and thinner, thus increasing resistance. As a strain gauge is compressed, its conductors become shorter and fatter, thus decreasing resistance. The bridge circuit becomes more unbalanced as the strain gauge's resistance changes from the neutral (resting) value.

In this circuit, voltage drop across the strain gauge decreases as it is compressed. This causes the potential at point A to become more negative, resulting in V_{AB} developing with A negative and B positive.

Answer 11

Space ... Start ... Stop →

Mark

0   0   0   1   0   0   0

Answer 12

Space ... Start ... Stop →

Mark

0   1   1   1   1   0   0   0
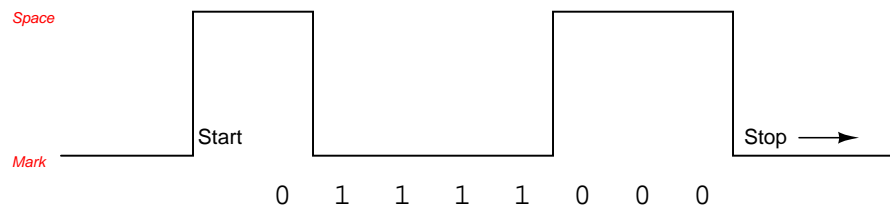
Answer 13

This is the ASCII character for a semicolon (;), and the parity checks out okay.

Answer 14

This is the ASCII character for an upper-case "Q", and the parity checks out okay.

Answer 15

The data (expressed in octal numeration) is 036.

Answer 16

- $10_2 = 2_{10}$
- $1010_2 = 10_{10}$
- $10011_2 = 19_{10}$
- $11100_2 = 28_{10}$
- $10111_2 = 23_{10}$
- $101011_2 = 43_{10}$
- $11100110_2 = 230_{10}$
- $10001101011_2 = 1131_{10}$

Answer 17

2406.25 seconds, or 40 minutes and 6.25 seconds.

Answer 18

ASCII codes (no parity):

5A 65 72 6F 20 26 20 53 70 61 6E

ASCII codes (with odd parity as the MSB):

DA E5 F2 EF 20 26 20 D3 70 61 6E

Answer 19

10111111 = $BF   **0**1111100 = $7C

Answer 20

Answer 21

Answer 22

Distance to fault is indicated by the *time gap* between incident and reflected pulses.

Answer 23

Lack of termination is not a problem so long as the stubs are short enough. The same principle applies to the network as a whole: if the total cable length is short enough, no termination resistors are needed anywhere!

Terminating all devices in the network could be problematic due to signal loading. With each additional termination resistor, the signal "sees" a heavier load. Too much loading and the signal voltage could sag below compliance.

Follow-up question #1: how do we define "short enough" in this context? How do we know if a cable (or stub) is long enough to require termination?

Follow-up question #2: how do we define "compliance" voltage levels for digital signals in this context? How do we know if we will load down the signal too much with too many termination resistors in parallel?

Answer 24

Answer 25

Answer 26

Answer 27

Answer 28

- **Cell R1C1:** `Echo time =`
- **Cell R1C3:** `(microseconds)`
- **Cell R2C1:** `Velocity factor =`
- **Cell R2C3:** `(unitless)`
- **Cell R4C1:** `Cable length =`
- **Cell R4C2:** `= 983.571056 * R1C2 * R2C2 / 2`
- **Cell R4C3:** `(feet)`

Answer 29

Partial answer:

Fault	Possible	Impossible
RTD failed open		
RTD failed shorted	√	
Wire broken open between points **C** and **E**		√
Wire broken open between points **C** and **A**		
Wire broken open between points **D** and **B**		
Wire broken open between points **D** and **F**		
Current source dead	√	

Answer 30

Distance is equal to velocity multiplied by time:

$$x = vt \qquad t = \frac{x}{v}$$

We know that the length of the cable in this circuit is 100 km (100×10^3 m). Assuming a velocity factor of 1:

$$t = \frac{100 \times 10^3 \text{ m}}{3 \times 10^8 \text{ m/s}}$$

$$t = 333.3 \mu s$$

Any reflected signals will take twice as long as this to travel down the cable and back.

Answer 31

The cable will draw current from the gate output as the capacitances and inductances "charge," then the current will stop and the cable will act as an open. This charging time primarily depends on the length of the cable.

Challenge question: what factor or factors determine the amount of current drawn from the gate as it "powers" the cable?

Answer 32

For the first 0.4 microseconds, before the leading edge of the pulse has had time to reach the end of the cable and reflect back, the source only "sees" the 50 Ω surge impedance of the cable. It isn't until after the reflected signal returns that the end-impedance of the cable manifests itself at the source terminals.

Here is the work showing the time delay between the incident pulse and the reflected pulse:

$$x = \frac{vt}{2}$$

$$t = \frac{2x}{v}$$

$$t = \frac{(2)(40)}{(2.9979 \times 10^8)(0.66)}$$

$$t = 404.32 \; \mu s$$

Answer 33

During the time period where the wave front has yet to reach the cable end and "reflect" back, the signal will be mid-way between the source's old voltage and the source's new voltage because the characteristic impedance of the cable manifests itself as a 100 Ω resistance between the cable's source voltage and end voltage.

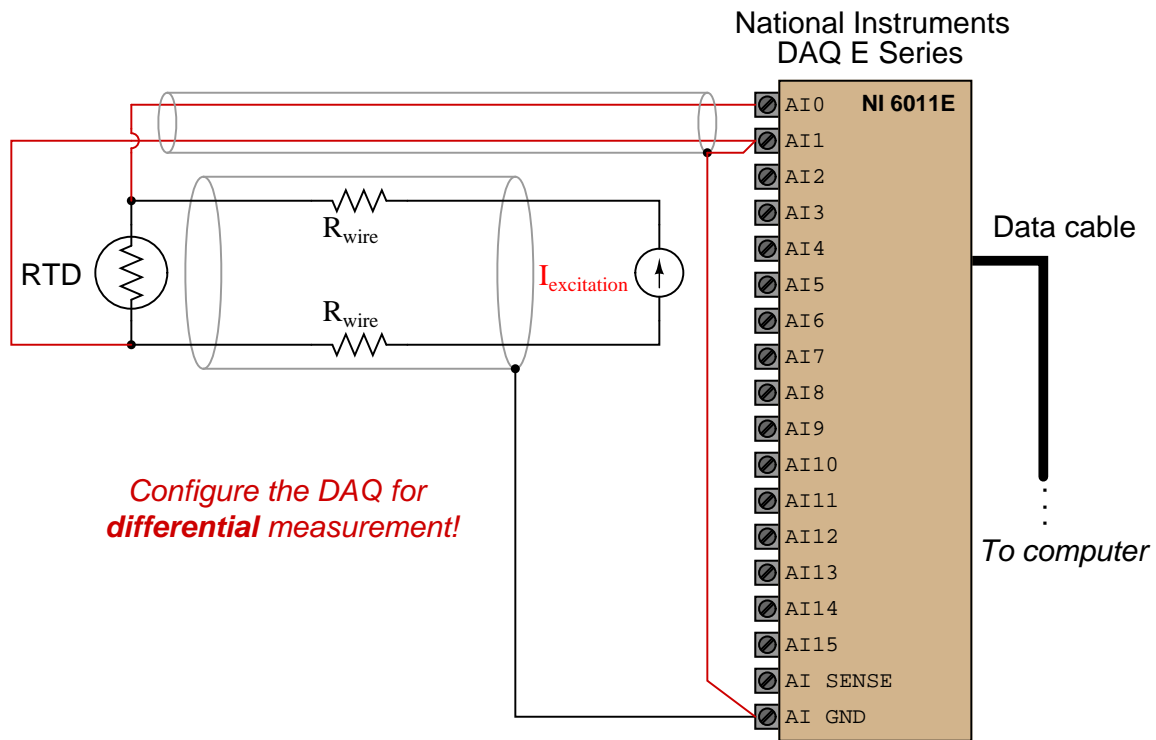Challenge question: what do you think the signal will look like at the far-right end of the cable?

Answer 34

11110011 = $F3   01100000 = $60

*This connection necessary to provide
a path for input bias currents on the DAQ*
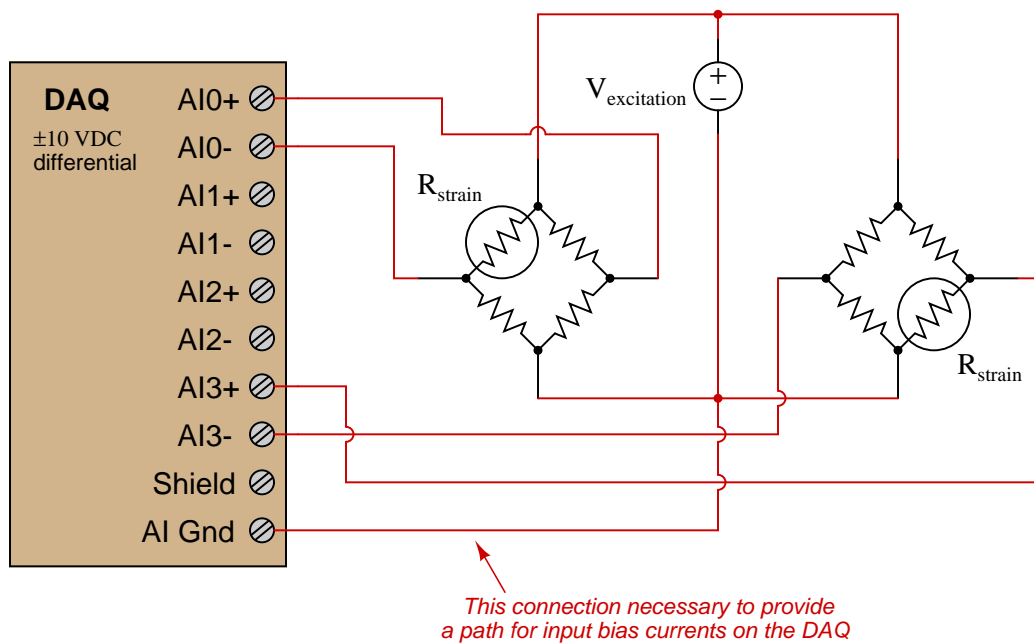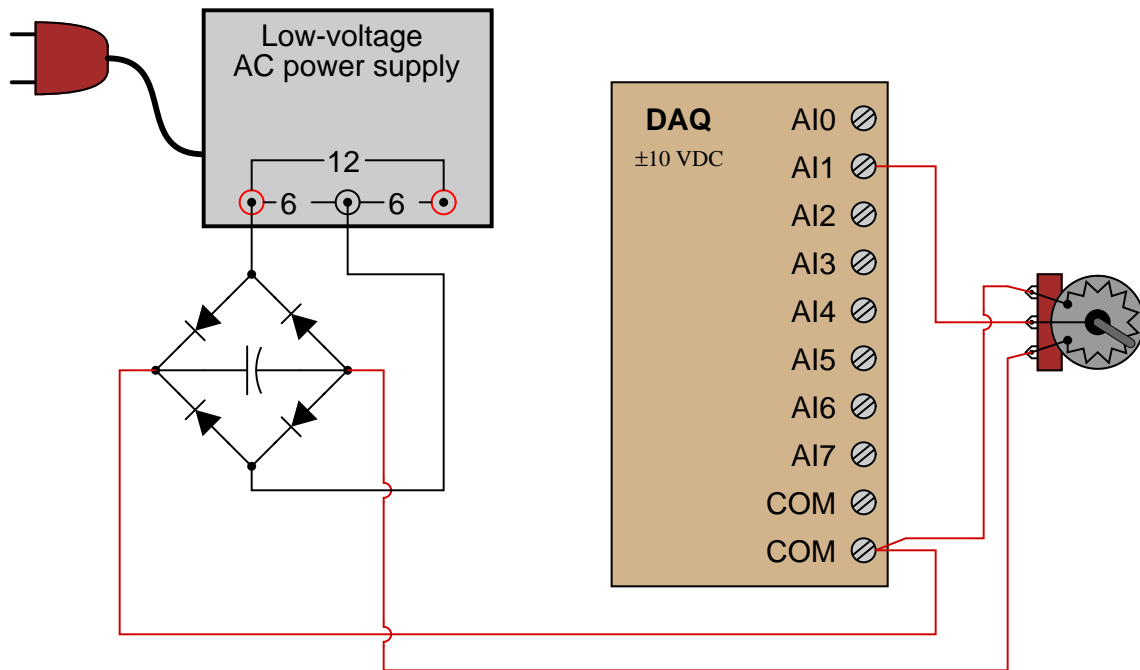
Challenge yourself by designing a different circuit to meet the same criteria!

Answer 37

National Instruments
DAQ E Series

Answer 38

The relationship between "step" distortion width and cable length is as follows:

$$t = \frac{2x}{v}$$

Where,

t = Width of "step" in seconds
x = Cable length in feet or meters
v = Velocity of propagation in feet per second or meters per second

Answer 39

Answer 40

Answer 41

Answer 42

Answer 43

Answer 44

A tri-state digital device has three output modes: *high*, *low*, and *high-Z*, the latter state being where the output transistors all go into cutoff and "disconnect" themselves so they neither source nor sink current.

Does this symbol jog some memories of your previous electronics studies?
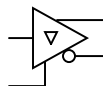
Answer 45

Answer 46

No answers provided here. You'll have to try it yourself on a real computer!

Answer 47

Example #1 = *capital letter "T"*

Example #2 = *pound symbol (#)*

Example #3 = *lowercase letter "g"*

Example #4 = *"at" symbol (@)*

Example #5 = *capital letter "K"*

Example #6 = *lowercase letter "y"*

Answer 48

No answers provided here. You'll have to try it yourself on a real computer!

Answer 49

No answers provided here. You'll have to try it yourself on a real computer!

Answer 50

No answers provided here. You'll have to try it yourself on a real computer!

Answer 51

Standard	Mark (1) voltage transmitted	Space (0) voltage transmitted
EIA/TIA-232	−5 V	+5 V
EIA/TIA-422	−2 V	+2 V
EIA/TIA-485	−1.5 V	+1.5 V

Standard	Mark (1) voltage received	Space (0) voltage received
EIA/TIA-232	−3 V	+3 V
EIA/TIA-422	−200 mV	+200 mV
EIA/TIA-485	−200 mV	+200 mV

Note that the latter two communications standards, being differential rather than single-ended (ground-referenced), can operate with much less signal amplitude due to the relative immunity to external noise.

Answer 52

In the multi*drop* network, only one device talks (the Master), while the other devices merely listen (the Slaves). In the multi*point* network, multiple devices have the ability to talk in such a way that they have the potential to "collide" with each other.

Follow-up question: what challenge does this raise for the programming of the devices in a multipoint network, which simply does not exist in a multidrop network?

Answer 53

This must be a EIA/TIA-485 network, because there is more than one driver connected to the same pair of lines. In other words, this is a multi*point* system, rather than a multi*drop* system where there is only one driver (transmitter) and multiple listeners (receivers).

Answer 54

- **[2]** 4-20 milliamp DC, loop resistance = 250 Ω
- **[4]** 24 VDC switch circuit to PLC input
- **[1]** 1-5 volt DC signal to loop indicator instrument
- **[3]** 4-20 milliamp DC, loop resistance = 100 Ω

- **[4]** 60 Hz, 120 VAC, powering an incandescent lamp
- **[1]** Output of variable-frequency drive to motor (approx. 480 volts)
- **[5]** 250 VDC, powering an incandescent lamp
- **[3]** 60 Hz, 120 VAC, powering a personal computer with a switching power supply.
- **[2]** 60 Hz, 480 VAC, input to power a variable-frequency drive

Answer 55

This is a bit of a "trick" question, because there is no need for the 24 VDC power supply. The self-powered (4-wire) level transmitter functions as a current *source* rather than a current *regulator* as would be the case if it were loop-powered (2-wire)L

Answer 56

Answer 57

Answer 58
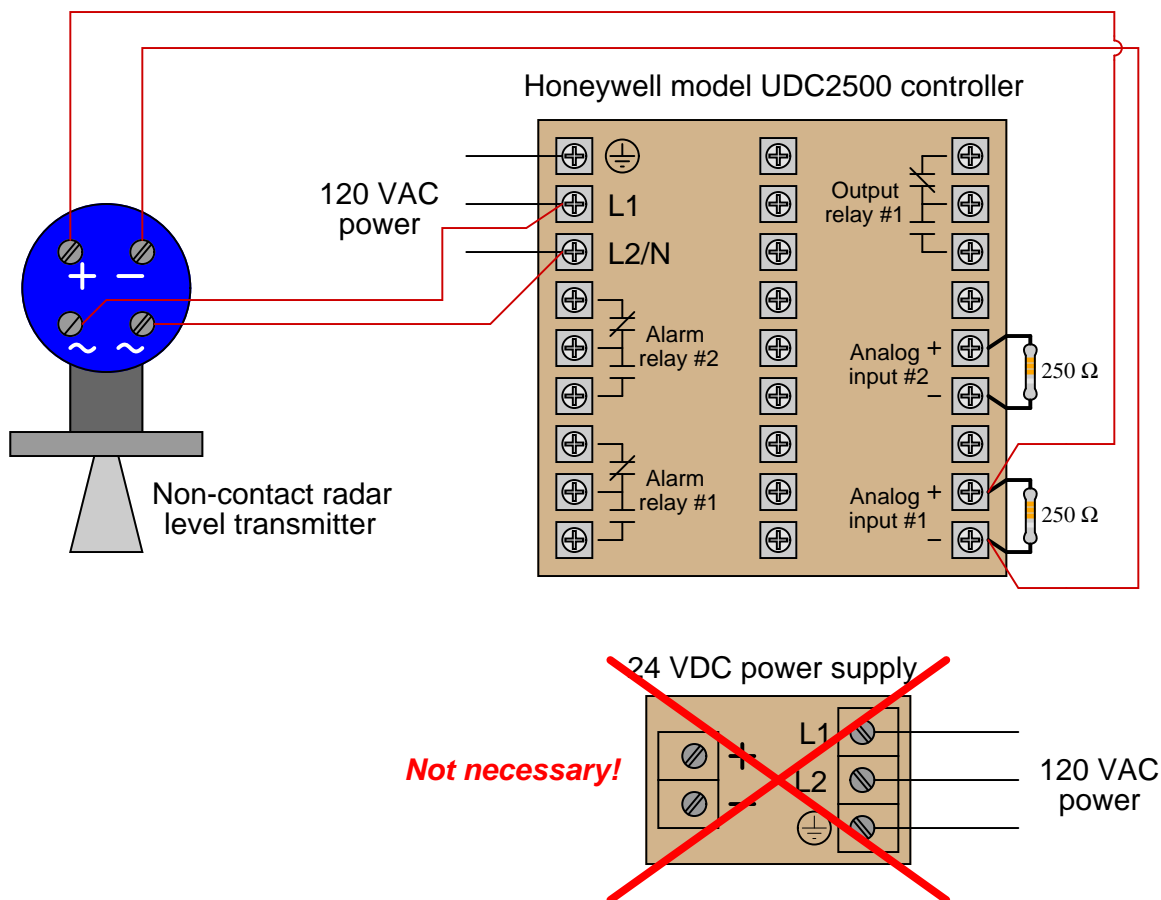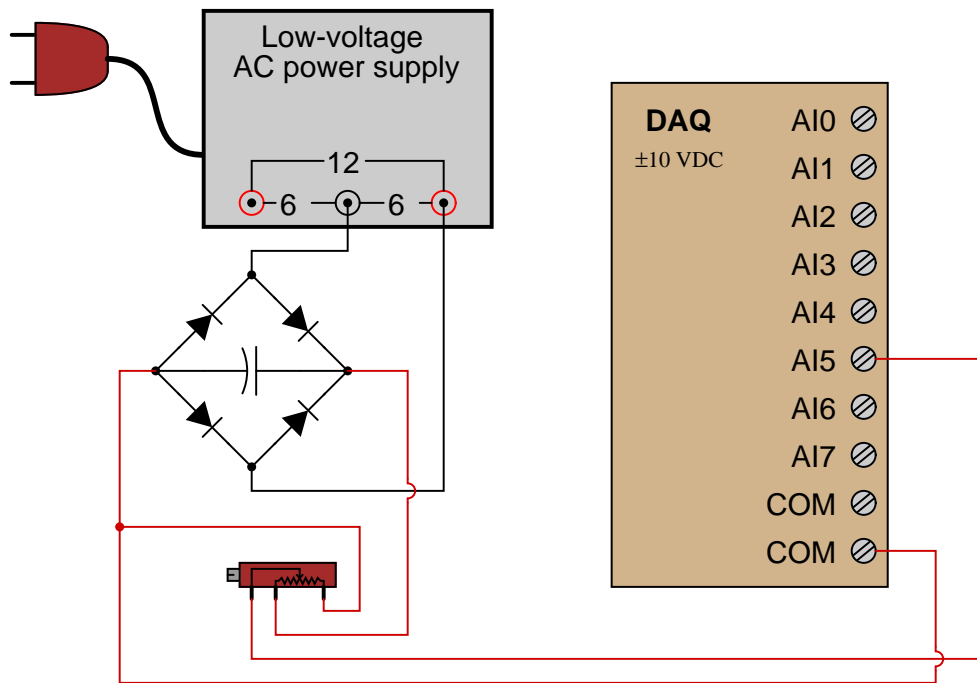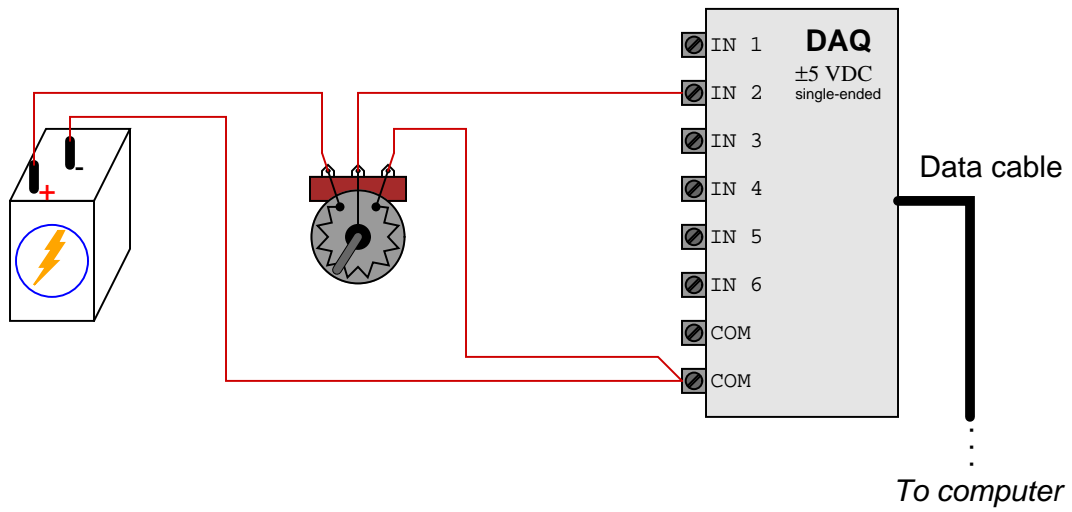
Remember that *stretching* a strain gauge causes its resistance to increase, while *compressing* a strain gauge causes its resistance to decrease:
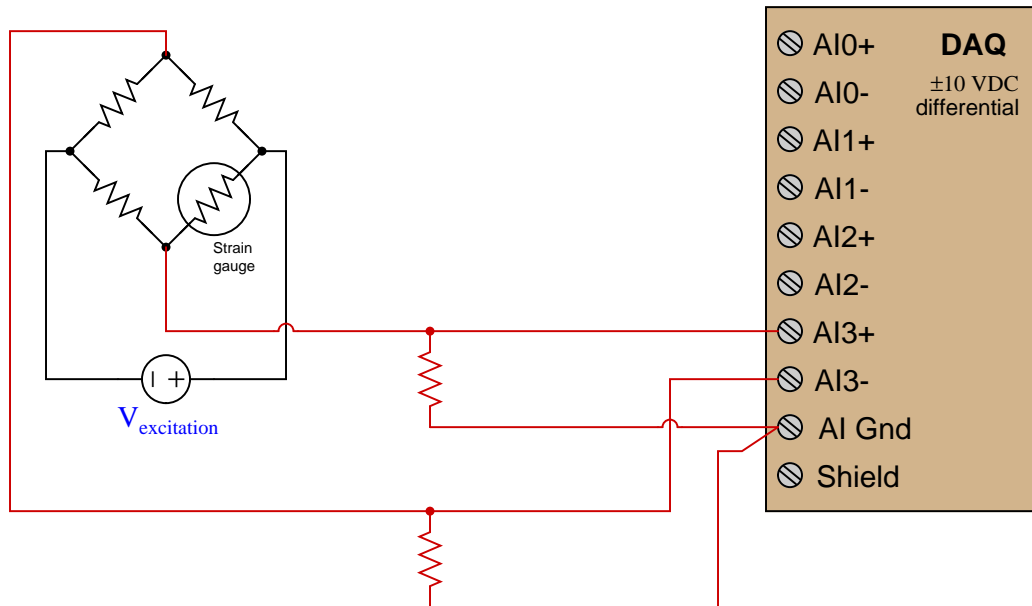

The two resistors (typically high-value, in the hundreds of kilo-ohms or even mega-ohms) provide a path for the DAQ's input bias currents, which is essential for a differential-input amplifier such as the instrumentation amplifier circuits inside the DAQ.

Answer 59

The phrase "peak inverse voltage" refers to the maximum instantaneous voltage impressed across a diode in the diode's reverse-bias (blocking) direction. Thus, the peak we wish to capture will be positive on the cathode and negative on the anode:
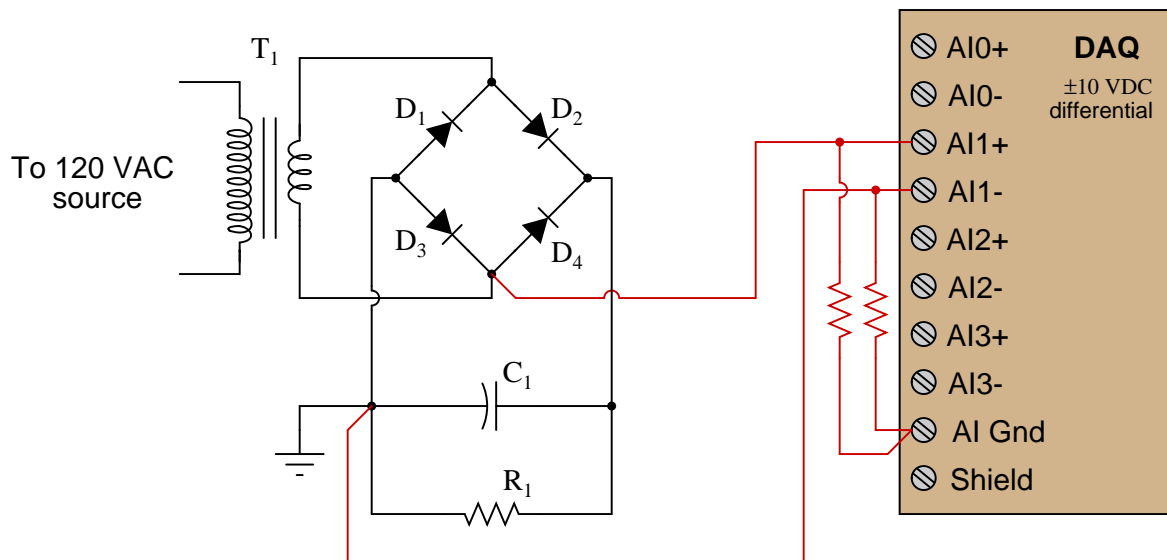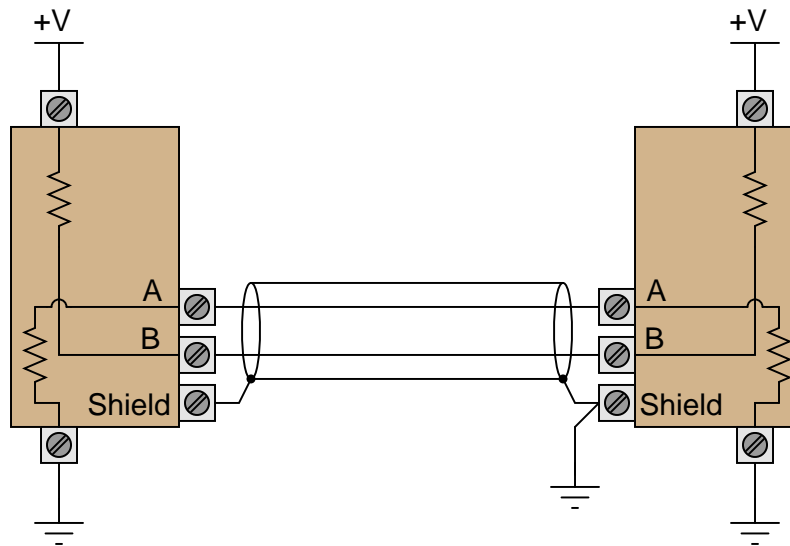

A simpler way to manage input bias currents on the DAQ is to simply connect one of the input terminals to the DAQ ground terminal like this (although doing so may yield results a bit less precise give the unequal bias current paths to ground):
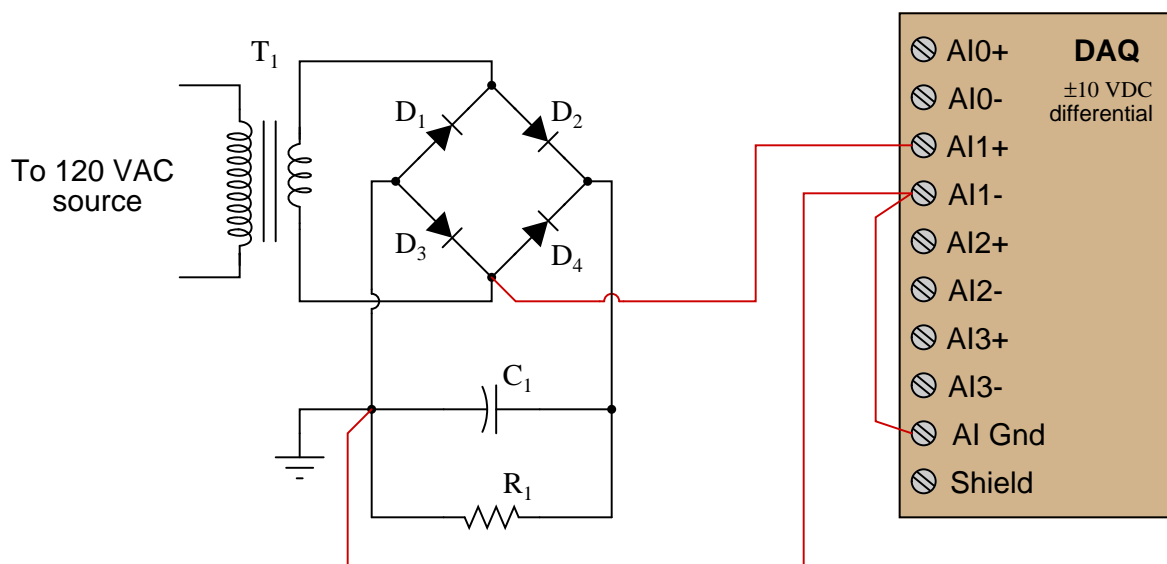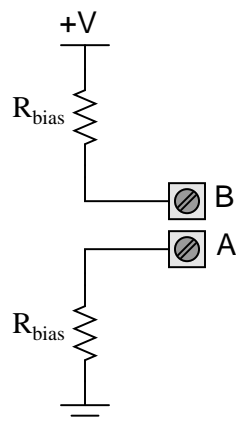
Answer 60

Pulling B high and A low places an otherwise floating differential line into the idle (1, off, or mark) state.
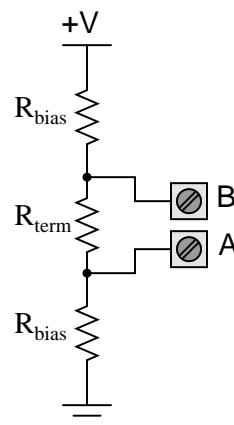

With a (low-valued) termination resistor at either (or both) end of the cable, the bias resistor network would be greatly affected! Here is a comparative circuit to illustrate:

The impact is especially pronounced because $R_{term} << R_{bias}$.

On an entirely different note, the location of the shield ground is entirely arbitrary: I could have just as well placed it on the left-hand shield terminal. So long as I terminate only one end of the cable's shield, it will work properly.

Answer 61

Answer 62

I'll let you research the answers here!

Answer 63

Answer 64

Answer 65

Answer 66
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 67
I'll let you figure out the answer to this question, as well as explain how you got it!

Answer 68
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 69
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 70

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`:
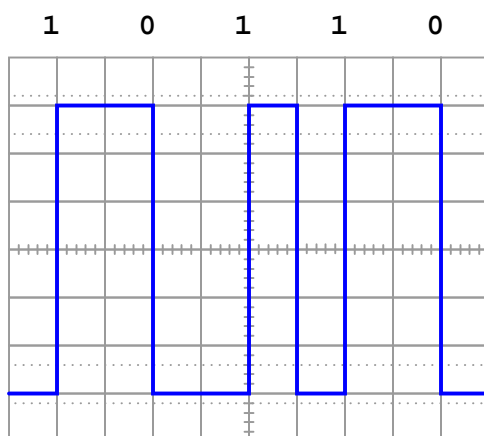
Note how one of the transitions does *not* represent a bit, but merely "sets up" the voltage level in preparation for another low-to-high ("1") transition. The key to deciphering a Manchester-encoded data stream is being able to identify which transitions represent real data bits and which do not. Do 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:
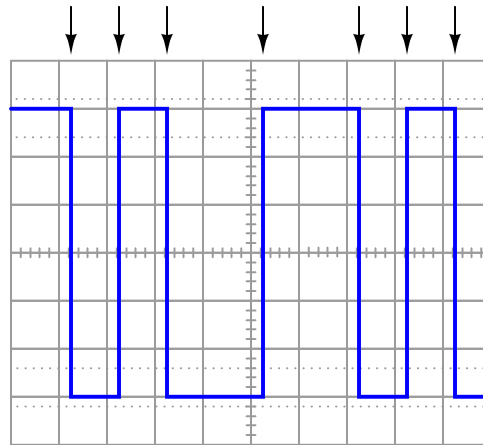
Next, knowing that all **data bits** are timed to a clock, and that these clock pulses are always equally spaced in time, you can see which transitions constitute data, and which are merely state reversals to set up the next bit.
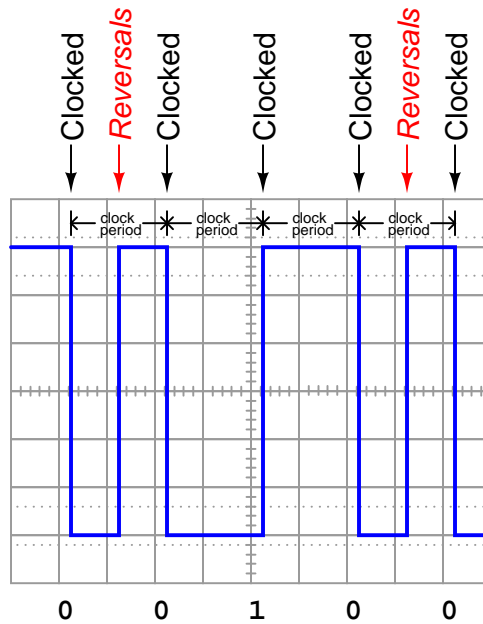
An advantage of Manchester encoding is that it encodes the clock signal directly into the data stream. This helps devices synchronize each other without the need for a separate wire to carry a clock signal. Auto-sensing 10/100 Mbit Ethernet hubs rely on this to tell what speed the incoming signals are 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 71

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 72

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

Answer 73

- 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 74

- **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 75

The transformers allow the AC (data) signals to be coupled from transmitter to receiver without interference from the DC power source. Just how it accomplishes this feat is worthy of note.

AC signals are coupled between primary and secondary windings at each transformers, so that the transmitters and receivers may send Manchester-encoded data to one another easily. The DC power, however, passes in "split" fashion through one winding of each transformer so as to provide an unbroken copper path for DC current from source to load. Trace the DC current from source to load and you will see that there is zero net magnetic flux in the transformer cores resulting from the DC, meaning that the transformers do not "see" the DC current for all practical purposes.

What this means is that the DC power cannot interfere with the AC Ethernet signals, even if the DC power happens to pulse or surge. Most students, looking at the transformers and remembering that only AC can pass through a transformer (and not DC), think this is the principle of design exploited here. Actually, it's a lot more clever than that! The fundamental principle of operation here is that the power is routed through the center-tapped winding of each transformer so as to cancel any magnetism it might otherwise produce in each transformer core. The fact that the power here is DC rather than AC is actually irrelevant! For the sake of discussion, we could route AC power the same way and it would have no impact on the Ethernet signals.

Answer 76

Answer 77

Answer 78

Answer 79

Answer 80

Answer 81

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

Answer 82

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

Answer 83

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

Answer 84

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

Answer 85

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

Answer 86

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

Answer 87

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

Answer 88

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

Answer 89

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

Answer 90

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

Answer 91

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.

In order to meet the project standard of data communication via Ethernet with a non-Ethernet DAQ module, you will have to use an intermediary personal computer to poll the DAQ over its serial cable connection, and then use "Remote Desktop" software on another personal computer to view the display of that intermediary personal computer (the remote access taking place over an Ethernet network). `RealVNC` is an example of a very powerful third-party remote access application which may be used for this purpose.