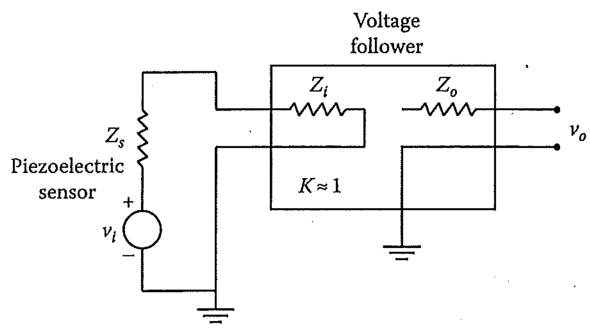
Problems

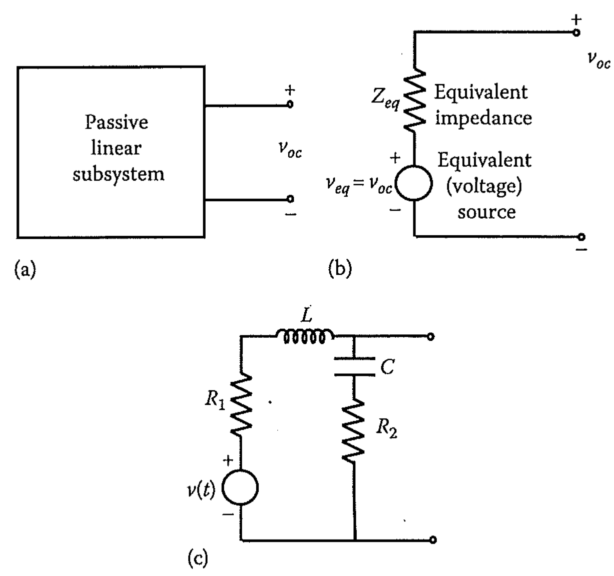
2.1 (a) Define electrical impedance and mechanical impedance. (b) Identify a defect in these definitions in relation to the force–current analogy. (c) What improvements would you suggest? (d) What roles do input impedance and output impedance play in relation to the accuracy of a measuring device?

2.2 List four reasons why impedance matching is important in component interconnection.

2.3 What is meant by loading error in a signal measurement? Also, suppose that a piezoelectric sensor of output impedance Z_s is connected to a voltage-follower amplifier of input impedance Z_i, as shown in the following figure. The sensor signal is v_i volts and the amplifier output is v_o volts. The amplifier output is connected to a device with very high input impedance. Plot to scale the signal ratio v_o/v_i against the impedance ratio Z_i/Z_s for values of the impedance ratio in the range 0.1–10.



2.4 Thevenin's theorem states that with respect to the characteristics at an output port, an unknown subsystem consisting of linear passive elements and ideal source elements may be represented by a single across variable (voltage) source v_{eq} connected in series with a single impedance Z_{eq}. This is illustrated in (a) and (b) of the following figure. Note in (b) of the following figure that, v_{eq} = open-circuit across variable v_{oc} at the output port because the current through Z_{eq} is zero. Consider the circuit shown in (c) of the following figure. Determine the equivalent source voltage v_{eq} and the equivalent series impedance Z_{eq}, in the frequency domain, for this circuit.



2.5 For the circuit with resistive source and load circuit, shown in Figure 2.2, plot the curves of: (a) Load power Efficiency and (b) ratio of (load power)/(maximum load power), against the ratio (load resistance)/(source resistance). Comment on the results.

2.6 Explain why a voltmeter should have a high resistance and an ammeter should have a very low resistance. What are some of the design implications of these general requirements for the two types of measuring instruments, particularly with respect to instrument sensitivity, speed of response, and robustness? Use a classical moving-coil galvanometer as the model for your discussion. *Note*: Galvanometers are currently not used in measuring electrical signals. Instead they are used in positioning and motion control applications.

2.7 Indicate a suitable impedance for the connected component in the following two applications:
(a) A pH sensor of output impedance 10 MΩ is connected to a conditioning amplifier.
(b) A power amplifier of output impedance 0.1 Ω is connected to a passive speaker.
In each case estimate a possible percentage error in the transmitted signal.

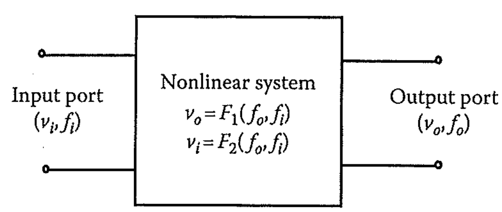
2.8 A two-port nonlinear device is shown schematically in the following figure. The transfer relations under static equilibrium (i.e., steady-state) conditions are given by

$$v_o = F_1(f_o, f_i)$$

$$v_i = F_2(f_o, f_i)$$

where
v denotes an across variable
f denotes a through variable
the *subscripts* o and i represent the output port and the input port, respectively.

Obtain expressions for the input impedance and the output impedance of the system in the neighborhood of an operating point, under static conditions, in terms of partial derivatives of the functions F_1 and F_2. Explain how these impedances could be determined experimentally.



2.9 A signal is transmitted through a cable of impedance Z_c and transmitted through an antenna of impedance Z_l (see the following figure).
(a) Show that $v_t = 2Z_l/(Z_l + Z_c)v_i$; where v_i is the voltage of the incident signal at the cable-antenna interface, v_t is the voltage of the signal that is transmitted from the cable to the antenna.
(b) What is the required relationship between Z_l and Z_c for proper impedance matching in this example?
(c) One method of impedance matching in this application is by using an impedance pad at the antenna connection. Suggest another method.

; System Instrumentation

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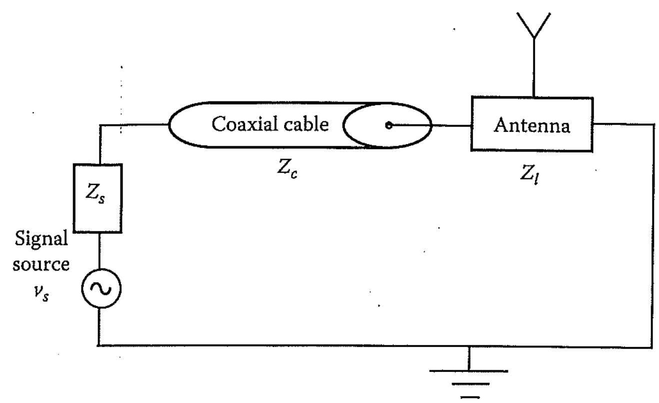
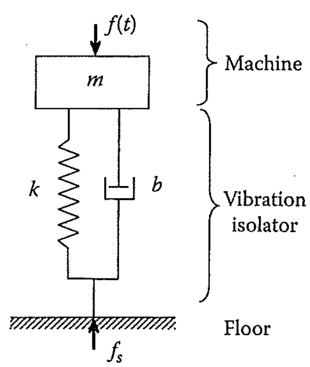


2.10 A machine of mass m has a rotating device, which generates a harmonic forcing excitation $f(t)$ in the vertical direction. The machine is mounted on the factory floor using a vibration isolator of stiffness k and damping constant b. The harmonic component of the force that is transmitted to the floor, due to the forcing excitation, is $f_s(t)$. A simplified model of the system is shown in the following figure. The corresponding force transmissibility magnitude $|T_f|$ from f to f_s is given by $|T_f| = \sqrt{(1+4\zeta^2 r^2)/((1-r^2)^2+4\zeta^2 r^2)}$, where $r = \omega/\omega_n$, ζ is the damping ratio, ω_n is the undamped natural frequency of the system, and ω is the excitation frequency (of $f(t)$).

Suppose that $m = 100$ kg and $k = 1.0 \times 10^6$ N/m. Also, the frequency of the excitation force $f(t)$ in the operating range of the machine is known to be 200 rad/s or higher. Determine the damping constant b of the vibration isolator so that the force transmissibility magnitude is not more than 0.5.

Using MATLAB, plot the resulting transmissibility function and verify that the design requirements are met.

Note: 2.0 = 6 dB; $\sqrt{2}$ = 3 dB; $1/\sqrt{2}$ = −3 dB; 0.5 = −6 dB..



2.11 Define the terms:
(a) Mechanical loading
(b) Electrical loading

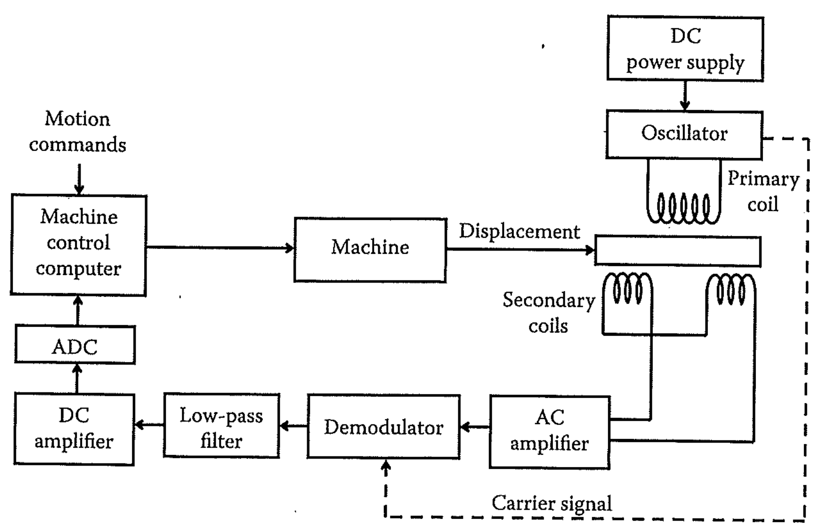
in the context of motion sensing. Explain how these loading effects can be reduced. The following table gives ideal values for some parameters of an op-amp. Give typical, practical values for these parameters (e.g., output impedance of 50 Ω).

Parameter	Ideal Value	Typical Value
Input impedance	Infinity	?
Output impedance	Zero	50 Ω
Gain	Infinity	?
Bandwidth	Infinity	?

Note: Under ideal conditions, inverting-lead voltage = noninverting-lead voltage (i.e., offset voltage is zero).

2.12 LVDT is a displacement sensor, which is commonly used in control systems. Consider a digital control loop that uses an LVDT measurement for position control of a machine. Typically, the LVDT is energized by a dc power supply. An oscillator provides an excitation signal in the kilohertz range to the primary windings of the LVDT. The secondary winding segments are connected in series opposition. An ac amplifier, demodulator, low-pass filter, amplifier, and ADC are used in the monitoring path. The following figure shows the various hardware components in the control loop. Indicate the functions of these components.

At null position of the LVDT stroke, there was a residual voltage. A compensating resistor is used to eliminate this voltage. Indicate the connections for this compensating resistor.



2.13 Today, digital image sensors are used in many industrial tasks including process monitoring and control and product quality assessment. There are two main types of image sensors: charge-coupled-device (CCD) and CMOS, depending on the sensing element. Both devices receive light from a monitored object and generate electrical charges, which are amplified and converted into voltages for subsequent ADC (in the case of digital image sensor as opposed to an analog image sensor, which provides an analog *video* signal) and image processing. The steps of doing this are different in the two cases, but the end result of object image is essentially the same. The image sensor provides image frames, which are acquired by a frame grabber in a computer (with the necessary software). The results from image processing in the computer are used to determine the necessary information for subsequent actions. This is the software approach of image processing. The need for very large data-handling rates is a limitation on a real-time controller that uses software-based image processing.

A CCD camera has an image plate consisting of a matrix of MOSFET elements. The electrical charge that is held by each MOSFET element is proportional to the intensity of light falling on the element. The output circuit of the camera has a charge-amplifier–like device (capacitive-coupled), which is supplied by each MOSFET element. The MOSFET element that is to be connected to the output circuit at a given instant is determined by the control logic, which systematically scans the matrix of MOSFET elements. The capacitor circuit provides a voltage that is proportional to the charge in each MOSFET element.

An image may be divided into pixels (or picture elements) for representation and subsequent processing. A pixel has a well-defined coordinate location in the picture frame, relative to some reference coordinate frame. In a CCD sensor, the number of pixels per image frame is equal to the number of CCD elements in the image plate. The information carried by a pixel (in addition to its location) is the photointensity (or gray level) at the image location. This number has to be expressed in the digital form (using a certain number of bits) for digital image processing.

(a) Draw a schematic diagram for an industrial process that uses a CCD sensor and a computer to monitor an object and based on that carry out mechanical actions (e.g., object movement). Indicate the necessary signal modification operations at various stages in the monitoring and action loop, showing filters, amplifiers, ADC, and DAC as necessary. *Note*: There are many ways to link a digital image sensor to a computer. Details of such hardware and associated software are not needed here.

(b) Consider an image frame of the size 488 × 380 pixels. The refresh rate of the picture frame is 30 frames/s. If 8 bits are needed to represent the gray level of each pixel, what is the associated data (bits/s or baud) rate?

(c) Discuss whether you prefer hardware-based image processing or programmable-software–based image processing in this application.

2.14 Usually, an op-amp circuit is analyzed by making use of the following two assumptions:

1. The potential at the positive input lead is equal to the potential at the negative input lead.
2. The current through each of the two input leads is zero.

Explain why these assumptions are valid under unsaturated conditions of an op-amp.

(a) An amateur electronics enthusiast connects to a circuit an op-amp without a feedback element. Even when there is no signal applied to the op-amp, the output was found to oscillate between +12 and −12 V once the power supply is turned on. Give a reason for this behavior.

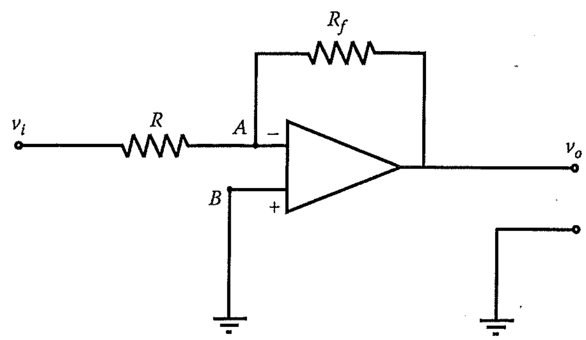
(b) An op-amp has an open-loop gain of 5×10^5 and a saturated output of ±14 V. If the noninverting input is −1 μV and the inverting input is +0.5 μV, what is the output? If the inverting input is 5 μV and the noninverting input is grounded, what is the output?

2.15 Define the following terms in connection with an op-amp:

(a) Offset current
(b) Offset voltage (at input and output)
(c) Unequal gains
(d) Slew rate

Give typical values for these parameters. The open-loop gain and the input impedance of an op-amp are known to vary with frequency and are known to drift (with time) as well. Still, the op-amp circuits are known to behave very accurately. What is the main reason for this?

2.16 (a) What is a voltage follower? Give a practical use of a voltage follower. (b) Consider the amplifier circuit shown in the following figure. Determine an expression for the voltage gain K_v of the amplifier in terms of the resistances R and R_f. Is this an inverting amplifier or a noninverting amplifier?



2.17 The speed of response of an amplifier may be represented using the three parameters: bandwidth, rise time, and slew rate. For an idealized linear model (transfer function), it can be verified that the rise time and the bandwidth are independent of the size of the input and the dc gain of the system. Since the size of the output (under steady conditions) may be expressed as the product of the input size and the dc gain, it is seen that rise time and the bandwidth are independent of the amplitude of the output, for a linear model.

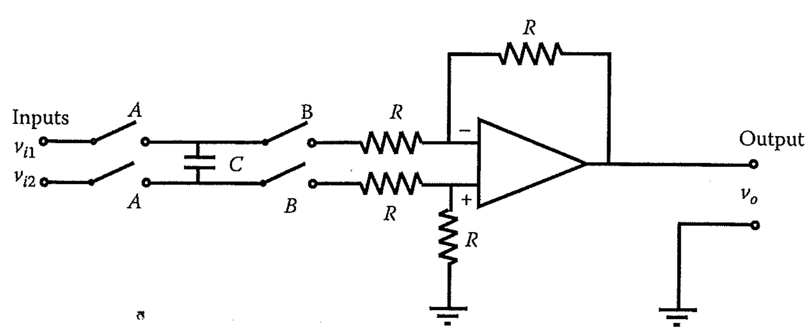
Discuss how slew rate is related to bandwidth and rise time of a practical amplifier. Usually, amplifiers have a limiting slew rate value. Show that the bandwidth decreases with the output amplitude in this case.

A voltage follower has a slew rate of 0.5 V/μs. If a sinusoidal voltage of amplitude 2.5 V is applied to this amplifier, estimate the operating bandwidth. If, instead, a step input of magnitude 5 V is applied, estimate the time required for the output to reach 5 V.

2.18 Define the terms:

(a) Common-mode voltage
(b) Common-mode gain
(c) CMRR

What is a typical value for the CMRR of an op-amp? The following figure shows a differential amplifier circuit with a flying capacitor. The switch pairs *A* and *B* are turned on and off alternately during operation. For example, first the switches denoted by *A* are turned on (closed) with the switches *B* off (open). Next, the switches *A* are opened and the switches *B* are closed. Explain why this arrangement provides good common-mode rejection characteristics.

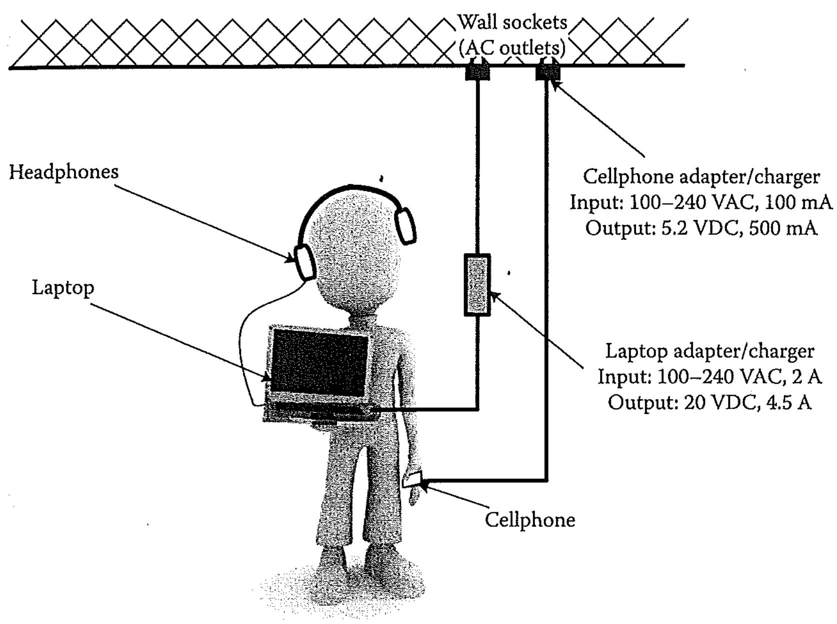


2.19 Compare the conventional (textbook) meaning of system stability and the practical interpretation of instrument stability.

An amplifier is known to have a temperature drift of 1 mV/°C and a long-term drift of 25 μV/month. Define the terms temperature drift and long-term drift. Suggest ways to reduce drift in an instrument.

2.20 Electrical isolation of a device (or circuit) from another device (or circuit) is very useful in the engineering practice. An isolation amplifier may be used to achieve this. It provides a transmission link, which is almost one way and avoids loading problems. In this manner, damage in one component due to increase in signal levels in the other components (perhaps due to short-circuits, malfunctions, noise, high common-mode signals, etc.) could be reduced. An isolation amplifier can be constructed from a transformer and a demodulator with other auxiliary components such as filters and amplifiers. Draw a suitable schematic diagram for an isolation amplifier and explain the operation of this device.

2.21 A newspaper report has described a death by electrocution of a person while using a cellphone and a laptop computer. According to the report, the person was using both devices while they were being charged (see the following figure). In particular, the person was wearing headphones, which were connected to the laptop. Burns were found on the ears and the chest of the person. While it was alleged that the cause was the faulty cellphone charger sending a high-voltage electrical pulse into the body, this cannot be conclusive, which should be clear from the following figure. Discuss possible causes of this electrocution.



2.22 What are passive filters? List several advantages and disadvantages of passive (analog) filters in comparison to active filters.

A simple way to construct an active filter is to start with a passive filter of the same type and add a voltage follower to the output. What is the purpose of such a voltage follower?

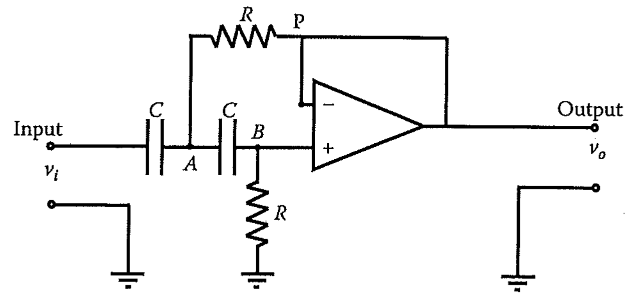
2.23 Give one application each for the following types of analog filters:

(a) Low-pass filter
(b) High-pass filter
(c) Band-pass filter
(d) Notch filter

Suppose that several single-pole active filter stages are cascaded. Is it possible for the overall (cascaded) filter to possess a resonant peak? Explain.

2.24 Butterworth filter is said to have a maximally flat magnitude. Explain what is meant by this. Give another characteristic that is desired from a practical filter.

2.25 An active filter circuit is given in the following figure.
(a) Obtain the filter transfer function. What is the order of the filter?
(b) Sketch the magnitude of the frequency transfer function. What type of filter does it represent?
(c) Estimate the cutoff frequency and the roll-off slope of the filter.

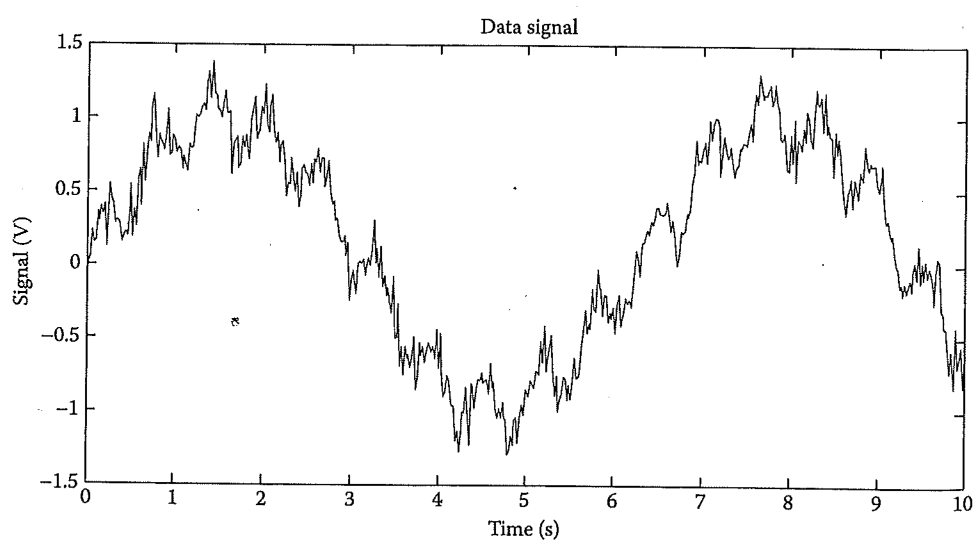


2.26 Select a set of sensors and identify the type of noise that may be present in the measurement of those sensors. Indicate what type of filtering may be used for filtering out that noise.

2.27 Generate a noisy signal (501 points sampled at sampling periods of 0.02 s), as shown in the following figure, using the MATLAB script:

```
% Filter input data
t=0:0.02:10.0;
u=sin(t)+0.2*sin(10*t);
for i=1:501
u(i)=u(i)+normrnd(0.0,0.1); % normal random noise
end
% plot the results
plot(t,u,'-')
```

(a) Identify some characteristics of this signal (assuming that you did not generate the signal and it was given to you without any description).
(b) Use a four-pole Butterworth low-pass filter with cutoff frequency at 2.0 rad/s and obtain the filtered signal. Describe the nature of this signal.
(c) Use a four-pole Butterworth band-pass filter with the pass-band: (9.9, 10.1), (9.0, 11.0), and (8.0, 12.0) rad/s and obtain the filtered signals. Discuss these results.



2.28 What is meant by each of the following terms: modulation, modulating signal, carrier signal, modulated signal, and demodulation? Explain the following types of signal modulation giving an application for each case:

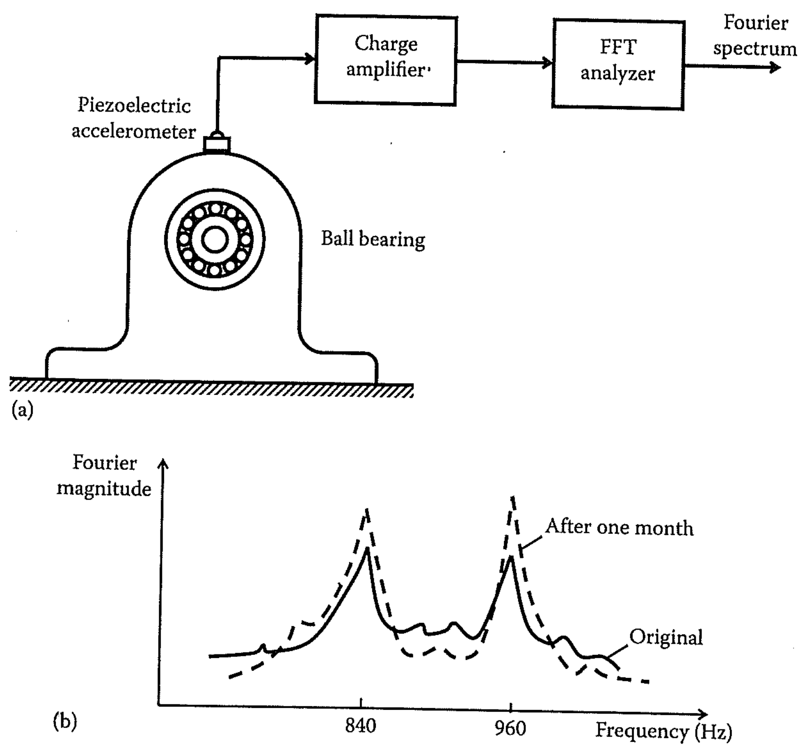
(a) AM, (b) FM, (c) PM, (d) PWM, (e) PFM, (f) PCM.

How could the sign of the modulating signal be accounted for during demodulation in each of these types of modulation?

2.29 Give two situations where AM is intentionally introduced, and in each situation explain how AM is beneficial. Also, describe two devices where AM might be naturally present. Could the fact that AM is present be exploited to our advantage in these two natural situations as well? Explain.

2.30 The monitoring system for a ball bearing of a rotating machine is schematically shown in (a) of the following figure. It consists of an accelerometer to measure the bearing vibration and an FFT analyzer to compute the Fourier spectrum of the response signal. This spectrum is examined over a period of 1 month after installation of the rotating machine to detect any degradation in the bearing performance. An interested segment of the Fourier spectrum can be examined at high resolution by using the zoom analysis capability of the FFT analyzer. The magnitude of the original spectrum and that of the current spectrum (determined 1 month later), in the same zoom region, are shown in (b) of the following figure.

(a) Estimate the operating speed of the rotating machine and the number of balls in the bearing.
(b) Do you suspect any bearing problems?



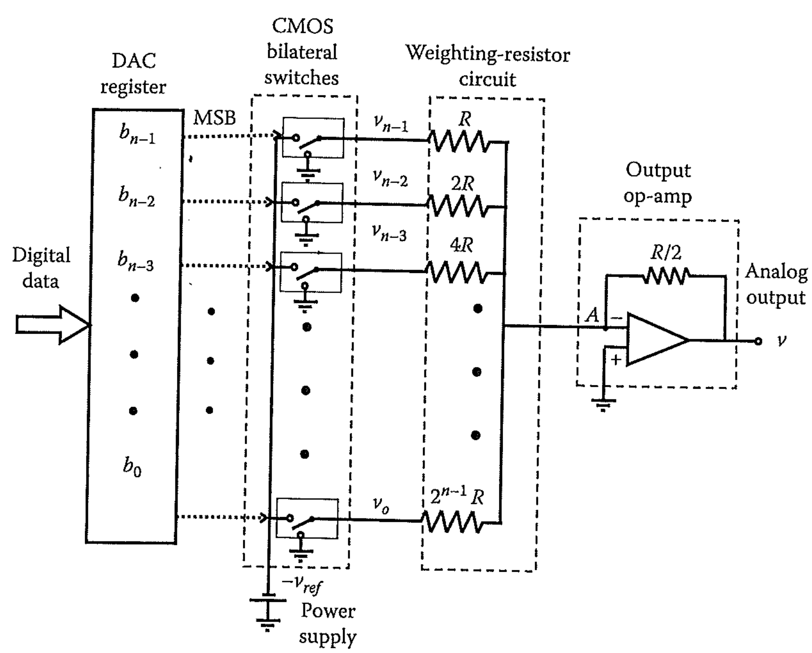
2.31 Explain the following terms:
(a) Phase-sensitive demodulation
(b) Half-wave demodulation
(c) Full-wave demodulation

When vibrations in rotating machinery such as gearboxes, bearings, turbines, and compressors are monitored, it is observed that a peak of the spectral magnitude curve does not usually occur at the frequency corresponding to the forcing function (e.g., tooth meshing, ball or roller hammer, blade passing). Instead, two peaks occur on the two sides of this frequency. Explain the reason for this fact.

2.32 An 8-bit ADC has a maximum analog input (FSV) of 10 V. What is the resolution and what is the quantization error of the ADC?

2.33 A schematic representation of a weighted-resistor DAC (or summer DAC or adder DAC) is shown in the following figure. This is a general n-bit DAC and n is the number of bits in the output register. The binary word in the register is $w = [b_{n-1}b_{n-1}b_{n-3}\ldots b_1b_0]$, where b_i is the bit in the ith position and it can take the value 0 or 1, depending on the value of the digital output.

(a) Obtain an equation for the analog output in terms of the digital input.
(b) What is the FSV?
(c) Give a drawback of this DAC over the ladder DAC.



2.34 Define the following terms in relation to an ADC.

(a) Resolution
(b) Dynamic range
(c) FSV
(d) Quantization error

2.35 Describe the operation of the following types of ADC.

(a) Dual-Slope ADC (integrating ADC)
(b) Counter ADC

2.36 Estimate the conversion times for an n-bit dual-slope (integrating) ADC and counter ADC. Compare these estimates with that for a successive approximation ADC.

2.37 Briefly describe the operation of the following types of ADCs:
(a) Direct-conversion ADC (flash ADC)
(b) Ramp-compare ADC
(c) Wilkinson ADC
(d) Delta-encoded ADC (counter-ramp ADC)
(e) Pipeline ADC (subranging quantizer)
(f) ADC with intermediate FM stage

2.38 Single-chip amplifiers with built-in compensation and filtering circuits are becoming popular for signal-conditioning tasks in engineering applications, particularly those associated with data acquisition, machine health monitoring, and control. Signal processing such as integration that would be needed to convert, say, an accelerometer into a velocity sensor could also be accomplished in the analog form using an IC chip. What are the advantages of such signal-modification chips in comparison with the conventional analog signal-conditioning hardware that employs discrete circuit elements and separate components to accomplish various signal-conditioning tasks?

2.39 Compare the three types of bridge circuits: constant-voltage bridge, constant-current bridge, and half bridge, in terms of nonlinearity, effect of change in temperature, and cost.

Obtain an expression for the percentage error in a half-bridge circuit output due to an error δv_{ref} in the voltage supply v_{ref}. Compute the percentage error in the output if voltage supply has a 1% error.

2.40 Suppose that in the constant-voltage (Wheatstone) bridge circuit shown in Figure 2.43a we have, $R_1 = R_2 = R_3 = R_4 = R$. Let R_1 represent a strain gauge mounted on the tensile side of a bending beam element and R_3 represent another strain gauge mounted on the compressive side of the bending beam. Due to bending, R_1 increases by δR and R_3 decreases by δR. Derive an expression for the bridge output in this case, and show that it is nonlinear. What would be the result if instead R_2 represents the tensile strain gauge and R_4 represents the compressive strain gauge?

2.41 Suppose that in the constant-current bridge circuit shown in Figure 2.43b we have, $R_1 = R_2 = R_3 = R_4 = R$. Assume that R_1 and R_2 represent strain gauges mounted on a rotating shaft, at right angles and symmetrically about the axis of rotation. Also, in this configuration and in a particular direction of rotation of the shaft, suppose that R_1 increases by δR and R_2 decreases by δR. Derive an expression for the bridge output (normalized) in this case, and show that it is linear. What would be the result if R_4 and R_3 were to represent the active strain gauges in this example, with the former element in tension and the latter in compression?

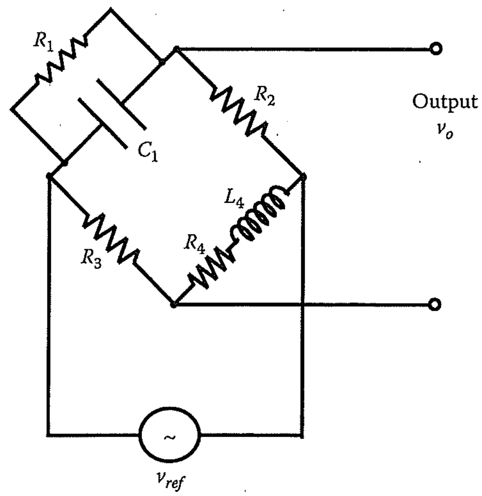
2.42 Consider the constant-voltage bridge shown in Figure 2.43a. The output Equation 2.91 can be expressed as $v_o = (R_1/R_2 - R_3/R_4)/((R_1/R_2 + 1)(R_3/R_4 + 1))v_{ref}$. Now suppose that the bridge is balanced, with the resistors set according to $R_1/R_2 = R_3/R_4 = p$. Then, if the active element R_1 increases by δR_1, show that the resulting output of the bridge is given by

$$\delta v_o = \frac{p\delta r}{[p(1+\delta r)+1](p+1)} v_{ref}$$

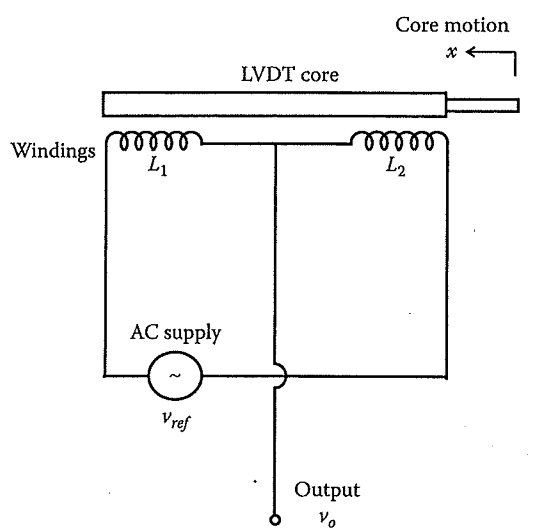
where $\delta r = \delta R_1/R_1$, which is the fractional change in resistance in the active element.

For a given δr, it should be clear that δv_o represents the sensitivity of the bridge. For what value of the resistance ratio p, would the bridge sensitivity be a maximum? Show that this ratio is almost equal to 1.

2.43 The Maxwell bridge circuit is shown in the following figure. Obtain the conditions for a balanced Maxwell bridge in terms of the circuit parameters R_1, R_2, R_3, R_4, C_1, and L_4. Explain how this circuit could be used to measure variations in C_1 or L_4.



2.44 The standard LVDT arrangement has one primary coil and two secondary coil segments connected in series opposition. Alternatively, some LVDTs use a bridge circuit to produce their output. An example of a half-bridge circuit for an LVDT is shown in the following figure. Explain the operation of this arrangement. Extend this idea to a full impedance bridge, for LVDT measurement.



2.45 The output of a Wheatstone bridge is nonlinear with respect to the variations in a bridge resistance. This nonlinearity is negligible for small changes in resistance. For large variations in resistance, however, some method of calibration or linearization should be employed. One way to linearize the bridge output is to use positive feedback of the output voltage signal into the bridge supply using a feedback op-amp. Consider the Wheatstone bridge circuit shown in Figure 2.43a. Initially, the bridge is balanced with $R_1 = R_2 = R_3 = R_4 = R$. Then, the resistor R_1 is varied to $R + \delta R$. Suppose that the bridge output δv_o is fed back (positive) with a gain of 2 into the bridge supply v_{ref}. Show that this will linearize the bridge equation.

2.46 Compare the potentiometer (ballast) circuit with the Wheatstone bridge circuit for strain-gauge measurements, with respect to the following considerations:
(a) Sensitivity to the measured strain
(b) Error due to ambient effects (e.g., temperature changes)
(c) SNR of the output voltage
(d) Circuit complexity and cost
(e) Linearity

2.47 In the strain-gauge bridge shown in Figure 2.43a, suppose that the load current i is not negligible. Derive an expression for the output voltage v_o in terms of R_1, R_2, R_3, R_4, R_L, and v_{ref}. Initially, the bridge was balanced, with equal resistances in the four arms. Then one of the resistances (say R_1) was increased by 1%. Plot to scale the ratio (actual output from the bridge)/(output under open-circuit, or infinite-load-impedance, conditions) as a function of the nondimensionalized load resistance R_L/R in the range 0.1–10.0, where R is the initial resistance in each arm of the bridge.

2.48 Consider the strain-gauge bridge shown in Figure 2.43a. Initially, the bridge is balanced, with $R_1 = R_2 = R$. (*Note*: R_3 may not be equal to R_1.) Then R_1 is changed by δR. Assuming that the load current is negligible, derive an expression for the percentage error as a result of neglecting the second-order and higher-order terms in δR. If $\delta R/R = 0.05$, estimate this nonlinearity error.

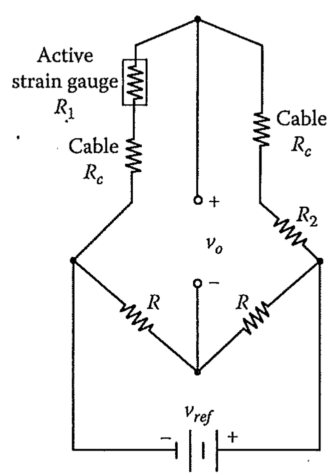
2.49 What is meant by the term bridge sensitivity? Describe methods of increasing bridge sensitivity. Assuming that the load resistance is very high in comparison with the arm resistances in the strain-gauge bridge shown in Figure 2.43a, obtain an expression for the power dissipation p in terms of the bridge resistances and the supply voltage. Discuss how the limitation on power dissipation can affect the bridge sensitivity.

2.50 Consider a standard bridge circuit (Figure 2.43a) where R_1 is the only active gauge and $R_3 = R_4$. Obtain an expression for R_1 in terms of R_2, v_o, and v_{ref}. Show that when $R_1 = R_2$, we get $v_o = 0$—a balanced bridge—as required. Note that the equation for R_1, assuming that v_o is measured using a high-impedance sensor, can be used to detect large resistance changes in R_1. Now suppose that the active gauge R_1 is connected to the bridge using a long, twisted wire pair, with each wire having a resistance of R_c. The bridge circuit has to be modified as in the following figure in this case.

Show that the equation of the modified bridge is given by

$$R_1 = R_2\left[\frac{v_{ref} + 2v_o}{v_{ref} - 2v_o}\right] + 4R_c\frac{v_o}{[v_{ref} - 2v_o]}$$

Obtain an expression for the fractional error in the R_1 measurement due to cable resistance R_c. Show that this error can be decreased by increasing R_2 and v_{ref}.



2.51 A furnace used in a chemical process is controlled in the following manner. The furnace is turned on in the beginning of the process. When the temperature within the furnace reaches a certain threshold value T_o, the (temperature) × (time) product is measured in the units of Celsius minutes. When this product reaches a specified value, the furnace is turned off. The available hardware includes an RTD—a temperature sensor using change in resistance, a differential amplifier, a diode circuit, which does not conduct when the input voltage is negative and conducts with a current proportional to the input voltage when the input is positive, a current-to-voltage converter circuit, a VFC, a counter, and an on/off control unit. Draw a block diagram for this control system and explain its operation. Clearly identify the signal-modification operations in this control system, indicating the purpose of each operation.

2.52 Typically, when a digital transducer is employed to generate the feedback signal for an analog controller, a DAC would be needed to convert the digital output from the transducer into a continuous (analog) signal. Similarly, when a digital controller is used to drive an analog process, a DAC has to be used to convert the digital output from the controller into the analog drive signal. There exist ways, however, to eliminate the need for a DAC in these two types of situations.

(a) Show how a shaft encoder and an FVC can replace an analog tachometer in an analog speed-control loop.

(b) Show how a digital controller with PWM can be employed to drive a DC motor without the use of a DAC.

2.53 The noise in an electrical circuit can depend on the nature of the coupling mechanism. In particular, the following types of coupling are available:

(a) Conductive coupling
(b) Inductive coupling
(c) Capacitive coupling
(d) Optical coupling

Compare these four types of coupling with respect to the nature and level of noise that is fed through or eliminated in each case. Discuss ways to reduce noise that is fed through in each type of coupling.

The noise due to variations in ambient light can be a major problem in optically coupled systems. Briefly discuss a method that could be used in an optically coupled device to make the device immune to variations in the ambient light level.

2.54 What are the advantages of using optical coupling in electrical circuits? For optical coupling, diodes that emit infrared radiation are often preferred over light-emitting diodes that emit visible light. What are the reasons behind this? Discuss why pulse-modulated light (or pulse-modulated radiation) is used in many types of optical systems. List several advantages and disadvantages of laser-based optical systems.

The Young's modulus of a material of known density can be determined by measuring the frequency of the fundamental mode of transverse vibration of a uniform cantilever beam specimen of the material. A photosensor and a timer can be used for this measurement. Describe an experimental setup for this method of determining the modulus of elasticity.

2.55 For an engineering application of your choice, complete the following table. *Note*: You may use an online search to obtain the necessary information.

Item	Information
What parameters or variables have to be measured in your application?	
Nature of the information (parameters and variables) needed in the particular application (analog, digital, modulated, demodulated, power level, bandwidth, accuracy, etc.).	
List of sensors needed for the application.	
Signal provided by each sensor (type—analog, digital, modulated, etc.; power level; frequency range, etc.).	
Errors present in the sensor output (SNR, etc.).	
Type of signal conditioning or conversion needed for the sensors (filtering, amplification, modulation, demodulation, ADC, DAC, voltage-frequency conversion, frequency–voltage conversion, etc.)	
Any other comments	