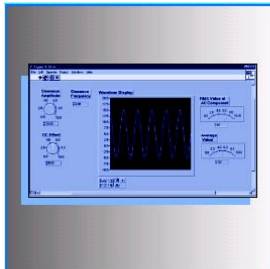
Chapter 9
Computer-Based Instrumentation Systems

1. Describe the operation of the elements of a computer-based instrumentation system.

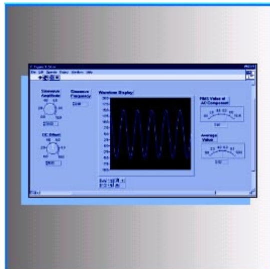
2. Identify the types of errors that may be encountered in instrumentation systems.



3. Avoid common pitfalls such as ground loops, noise coupling, and loading when using sensors.

4. Determine specifications for the elements of computer-based instrumentation systems such as data-acquisition boards.

5. Know how to use LabVIEW to create virtual instruments for computer-aided test and control systems in your field of engineering.



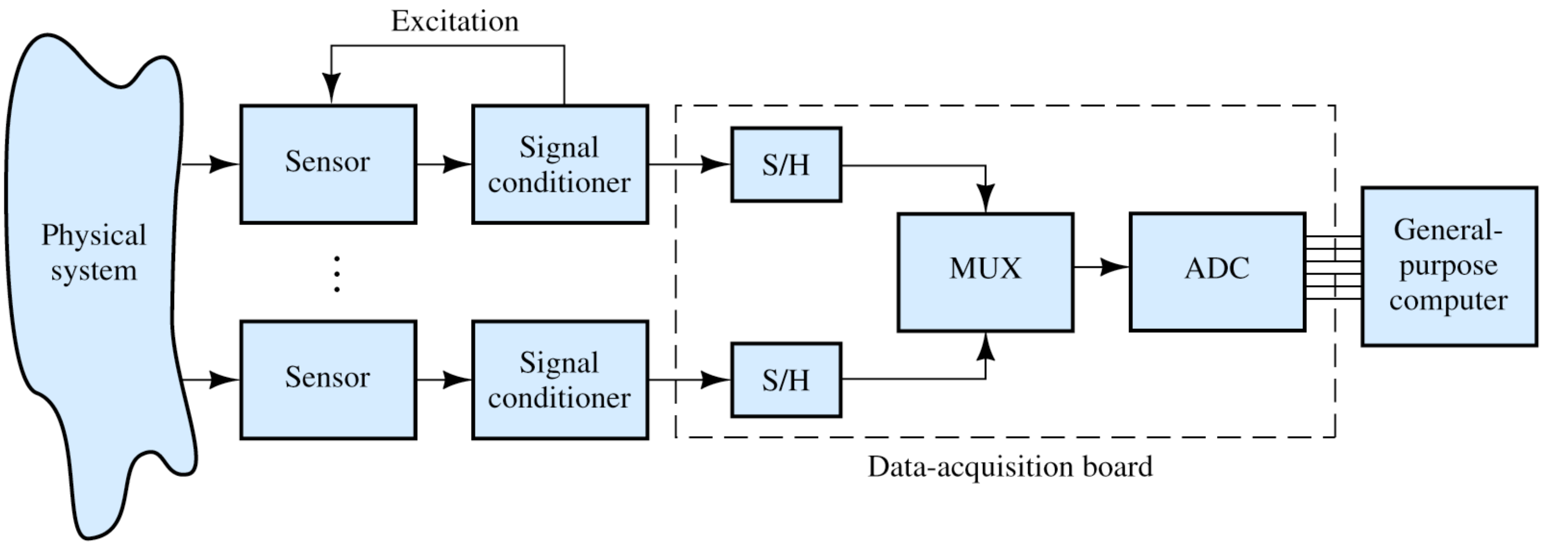
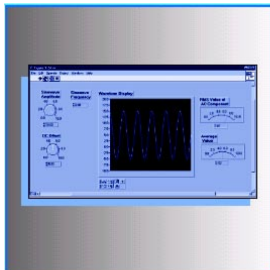
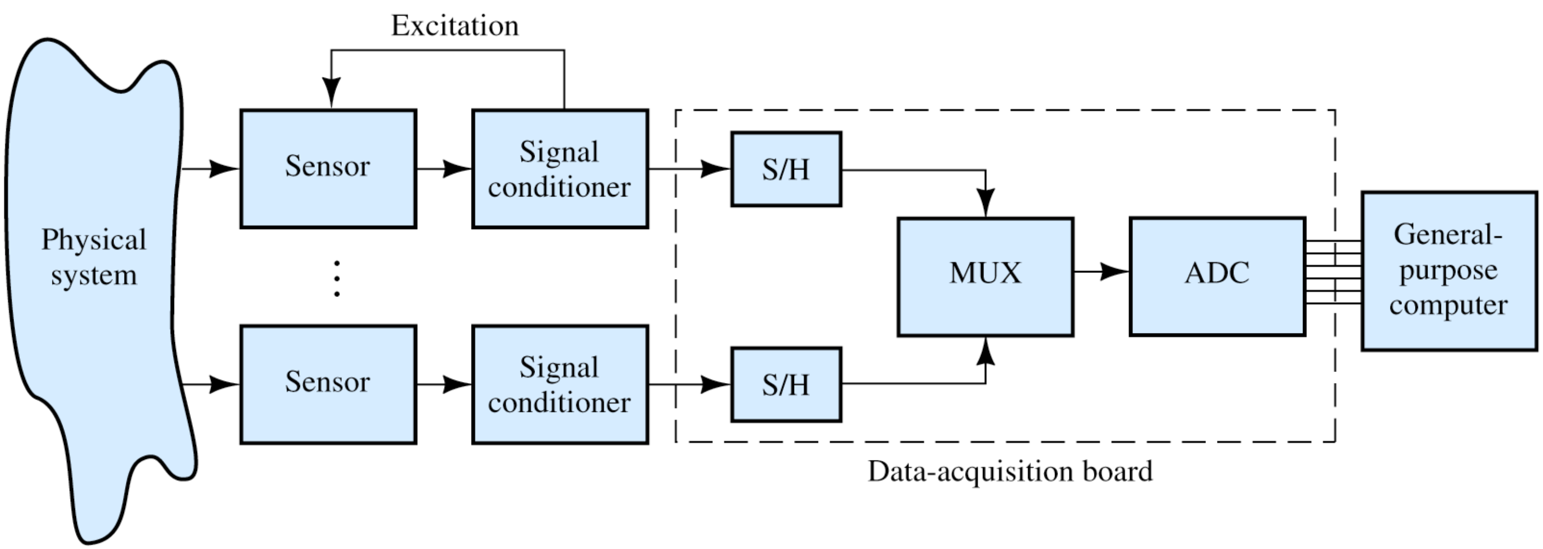
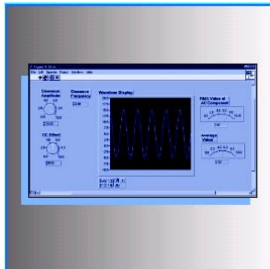


Figure 9.1 Computer-based data-acquisition system.



Overview of Computer-Based Instrumentation





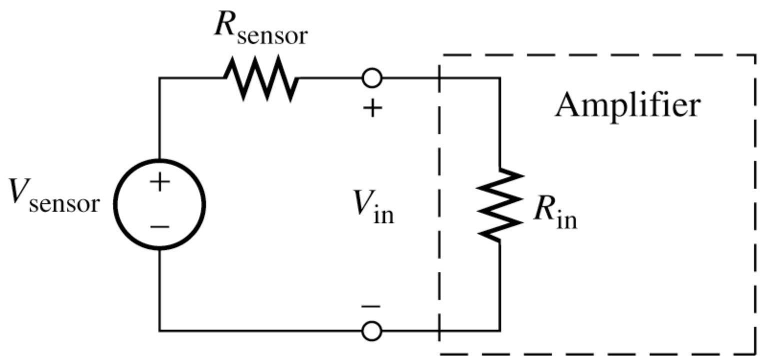
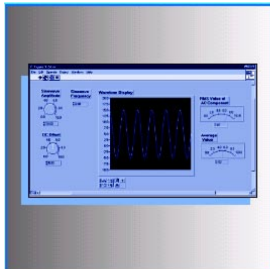
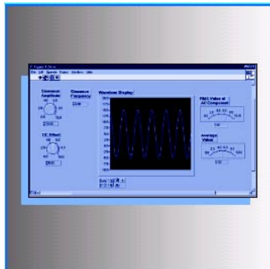
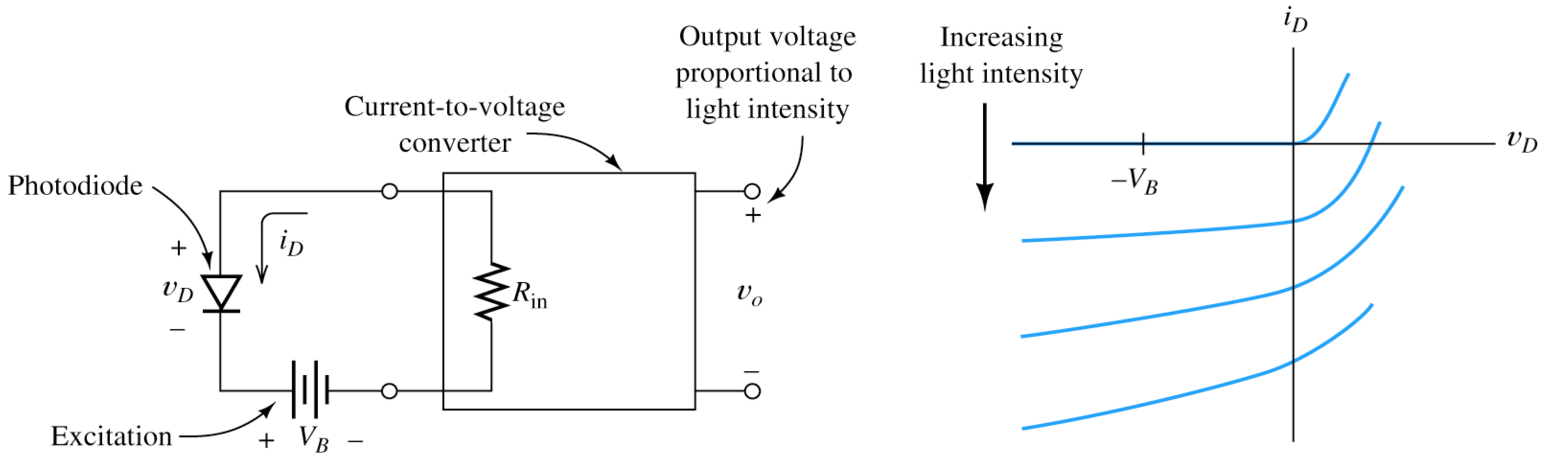


Figure 9.2 Model for a sensor connected to the input of an amplifier.



. . . when we need to measure the internal voltage of the sensor, we should specify a signal-conditioning amplifier having an input impedance that is much larger in magnitude than the Thévenin impedance of the sensor.

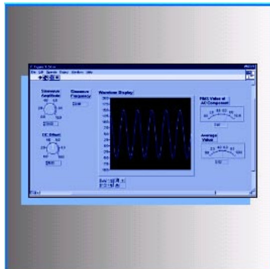




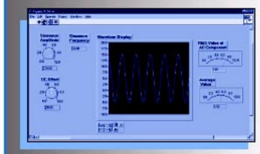
(a) Photodiode light sensor connected to a current-to-voltage converter

(b) Volt–ampere characteristic of photodiode

Figure 9.3 Photodiode light-sensing system. Because the diode voltage should be constant, R_{in} should ideally equal zero.



. . . when we want to sense the current produced by a sensor, we need a current-to-voltage converter having a very small (ideally zero) input impedance magnitude.



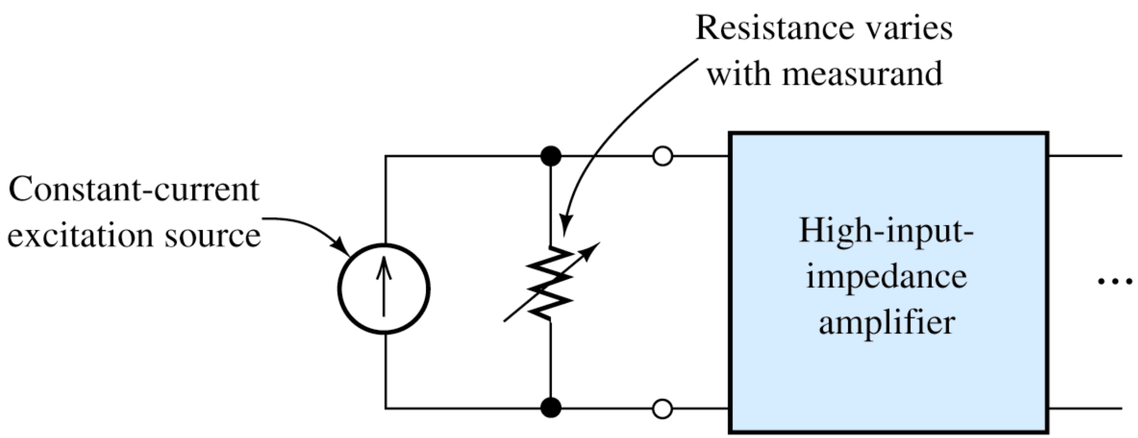
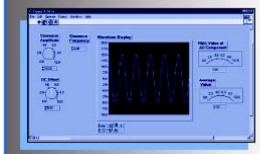


Figure 9.4 Variable-resistance sensor.

Errors in Measurement Systems

$$\text{Error} = x_m - x_{\text{true}}$$

$$\text{Percentage error} = \frac{x_m - x_{\text{true}}}{x_{\text{full}}} \times 100\%$$



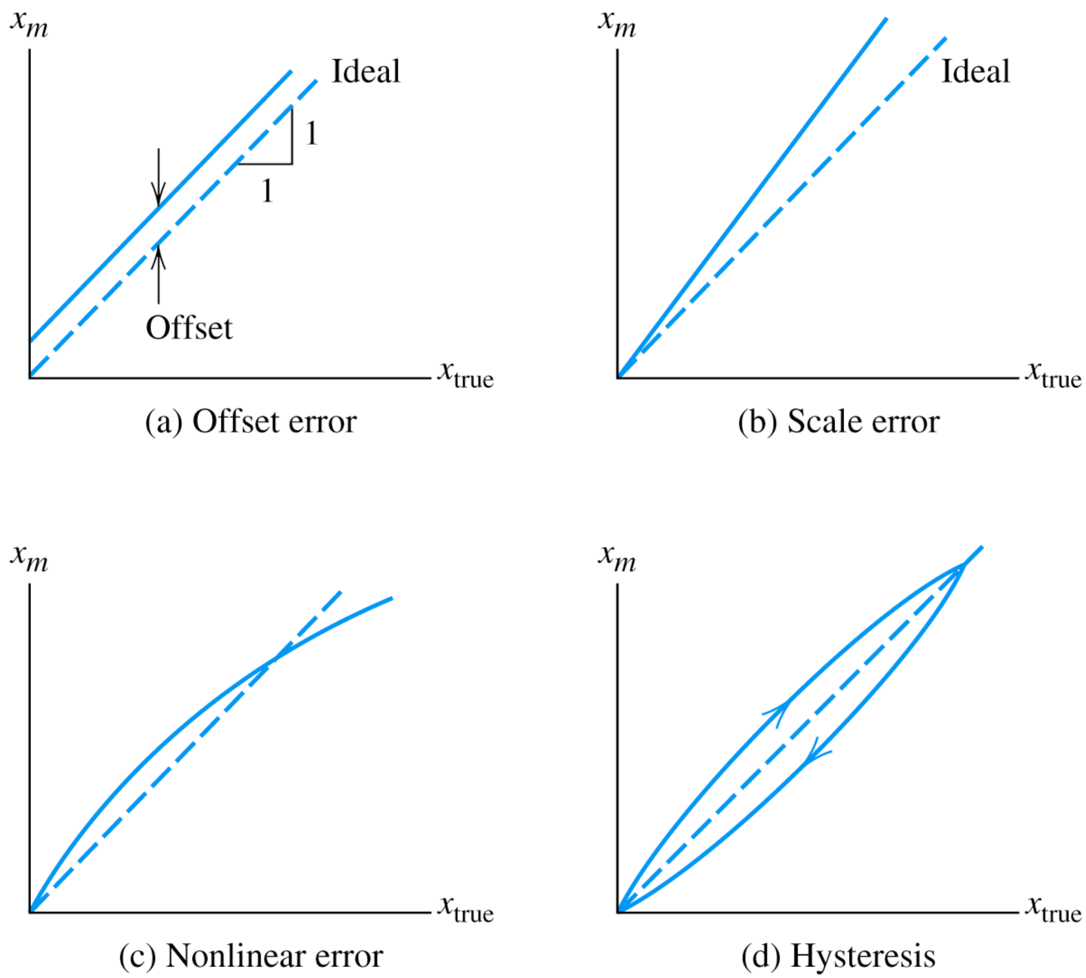
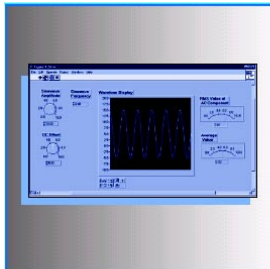
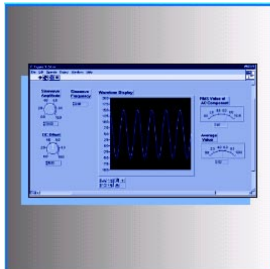


Figure 9.5 Illustration of some types of instrumentation error. x_m represents the value of the measurand reported by the measurement system, and x_{true} represents the true value.

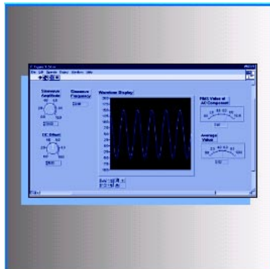


1. **Accuracy:** The maximum expected difference in magnitude between measured and true values (often expressed as a percentage of the full-scale value).

2. **Precision:** The ability of the instrument to repeat the measurement of a constant measurand. More precise measurements have less random error.



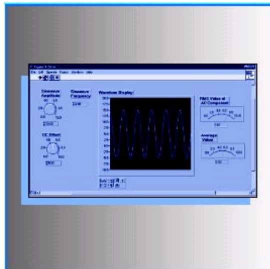
3. Resolution: The smallest possible increment discernible between measured values. As the term is used, higher resolution means smaller increments. Thus, an instrument with a five-digit display (say, 0.0000 to 9.9999) is said to have higher resolution than an otherwise identical instrument with a three-digit display (say, 0.00 to 9.99).

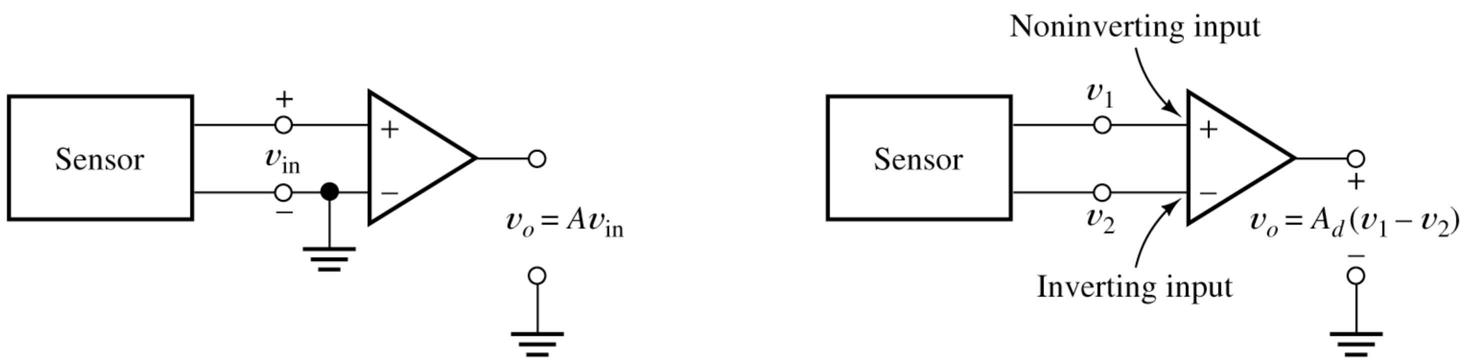


SIGNAL CONDITIONING

Some functions of signal conditioners are:

1. amplification of the sensor signals
2. conversion of currents to voltages
3. supply of (ac or dc) excitations to the sensors so changes in resistance, inductance, or capacitance are converted to changes in voltage
4. filtering to eliminate noise or other unwanted signal components

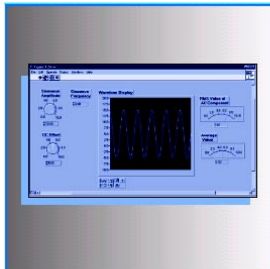




(a) Single-ended input: one amplifier input terminal is grounded

(b) Differential input: neither amplifier input is grounded and the output is gain A_d times the difference between the input voltages

Figure 9.6 Amplifiers with single-ended and differential input terminals.



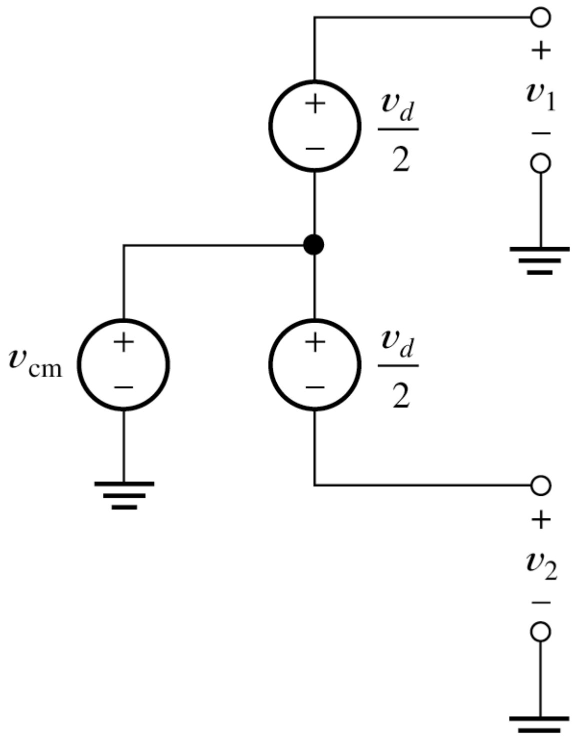
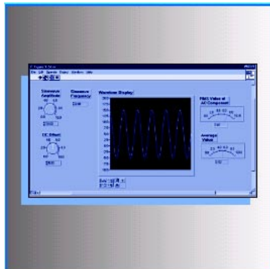
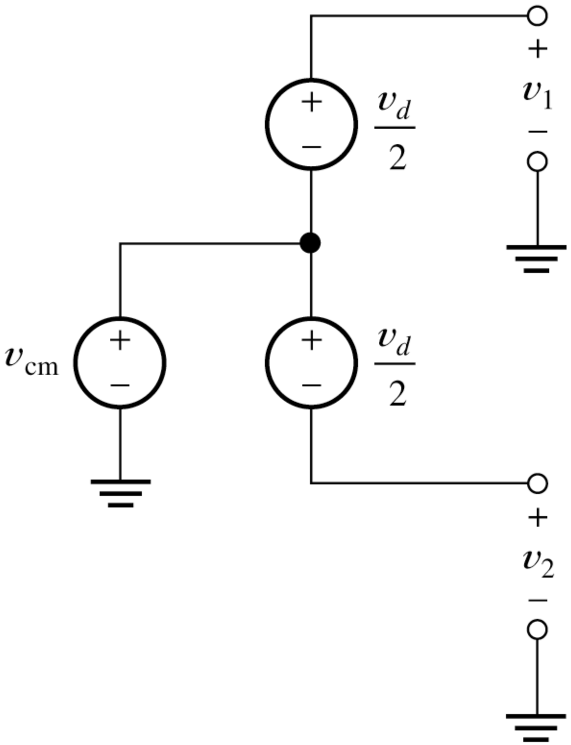


Figure 9.7 Model for a sensor with differential and common-mode components.



Single-Ended Versus Differential Amplifiers



$$v_d = v_1 - v_2$$

$$v_{cm} = \frac{1}{2}(v_1 + v_2)$$

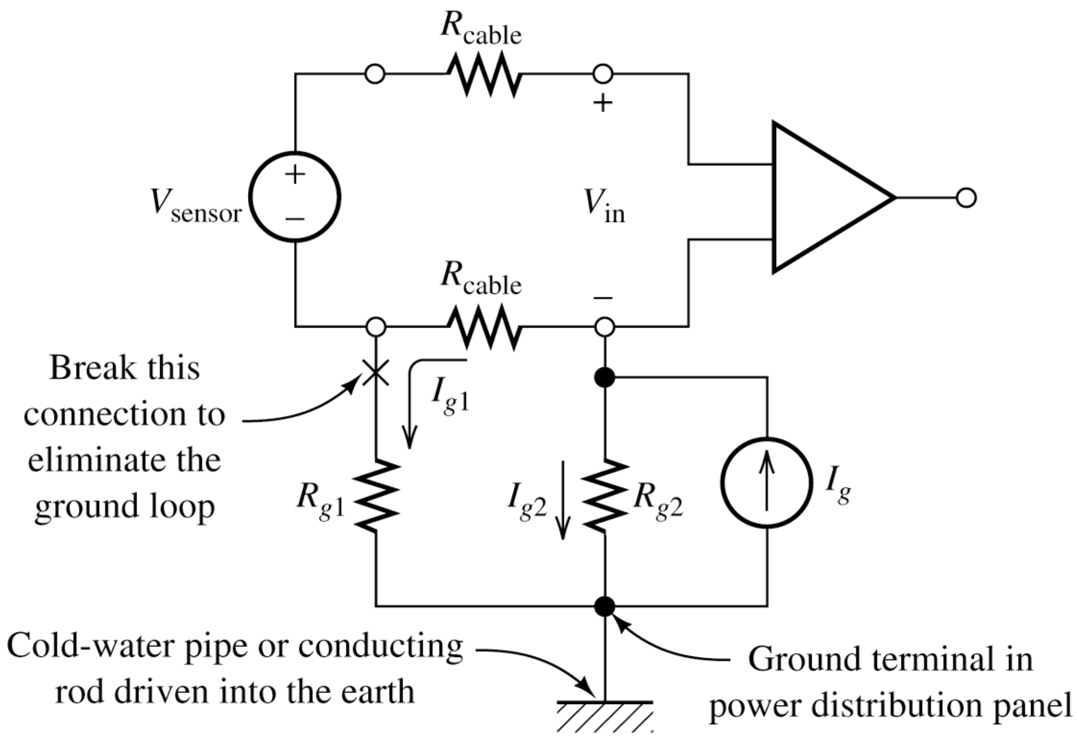
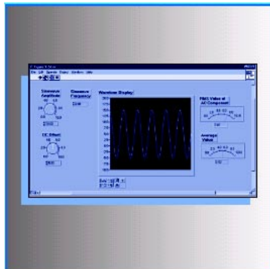
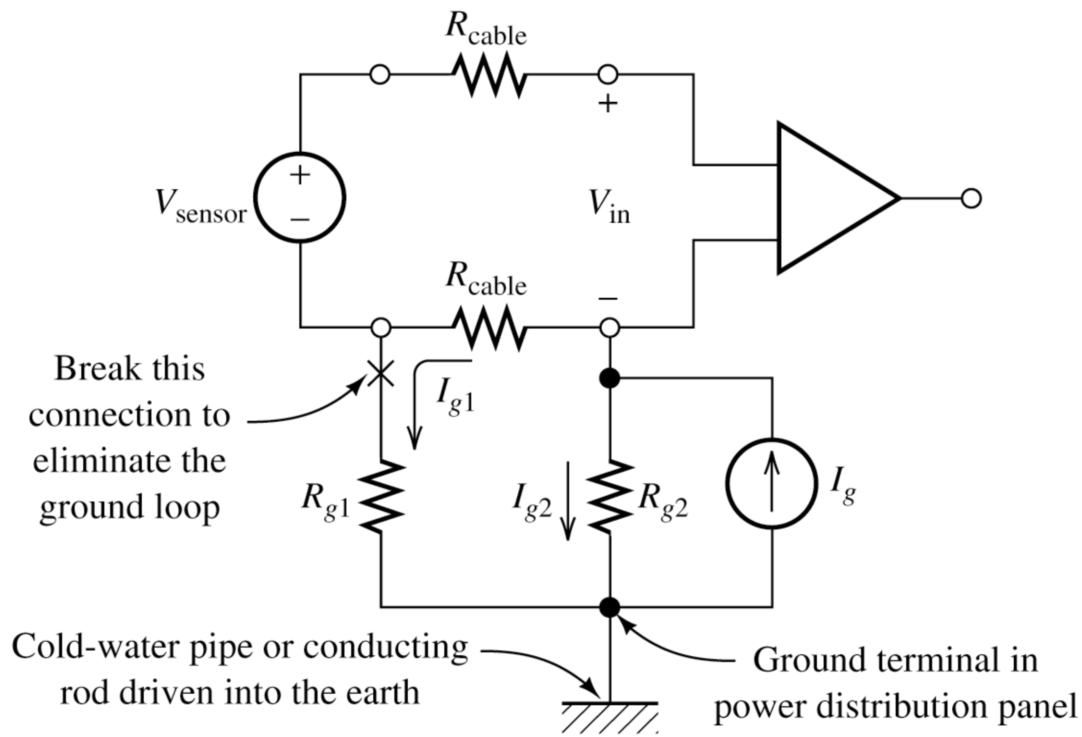


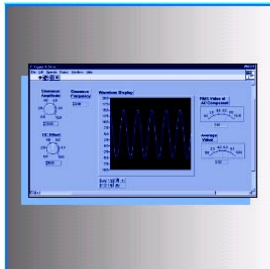
Figure 9.8 Ground loops are created when the system is grounded at several points.

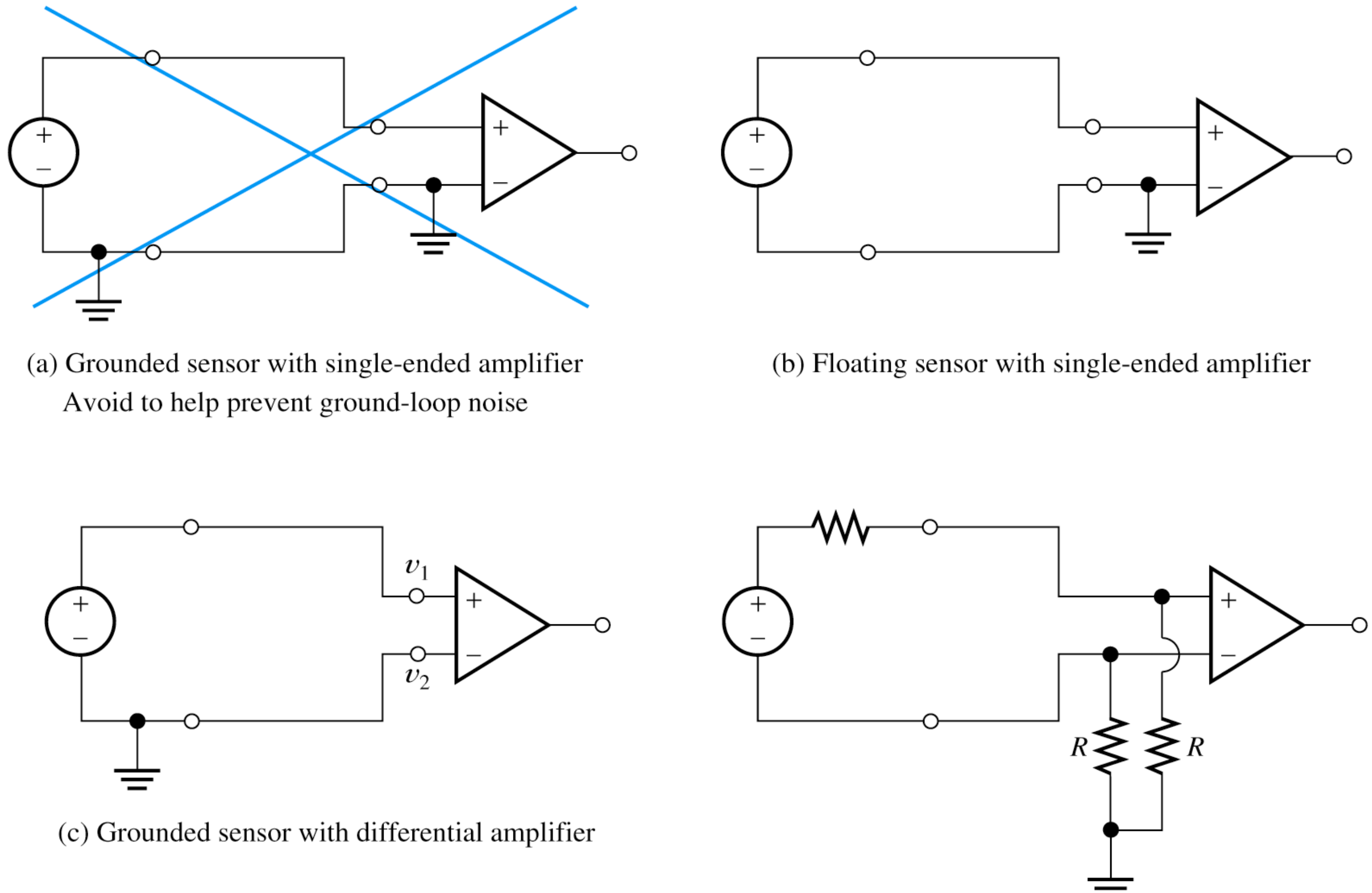


Ground Loops

. . . in connecting a sensor to an amplifier with a single-ended input, we should select a floating sensor.







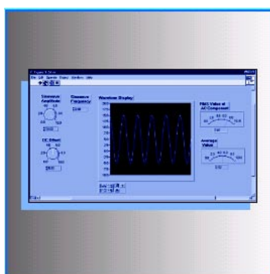
(a) Grounded sensor with single-ended amplifier
Avoid to help prevent ground-loop noise

(b) Floating sensor with single-ended amplifier

(c) Grounded sensor with differential amplifier

(d) Floating sensor with differential amplifier including resistors to provide a path for the input bias current

Figure 9.9 Four sensor–amplifier combinations.



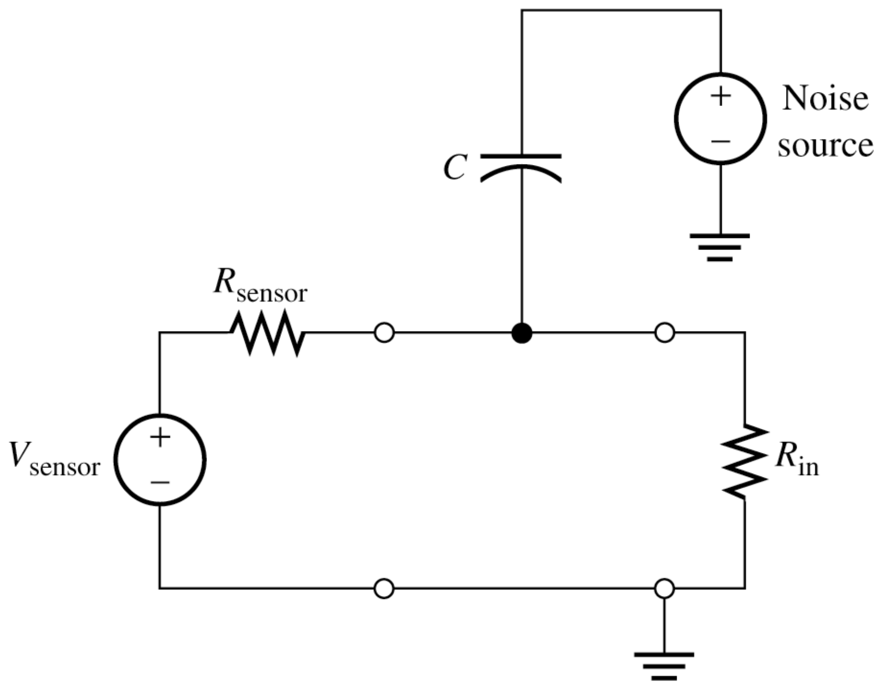
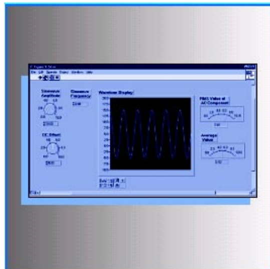


Figure 9.10 Noise can be coupled into the sensor circuit by electric fields. This effect is modeled by small capacitances between the noise source and the sensor cable.



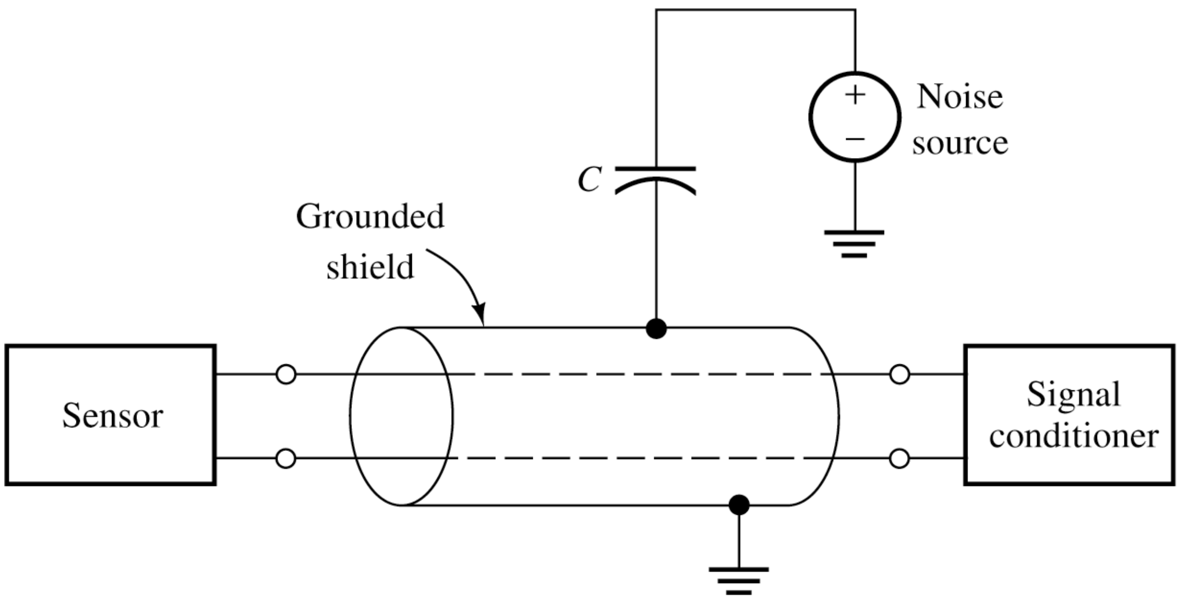
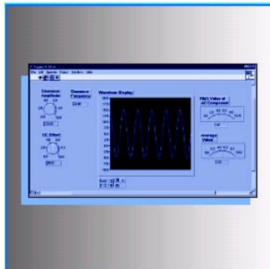
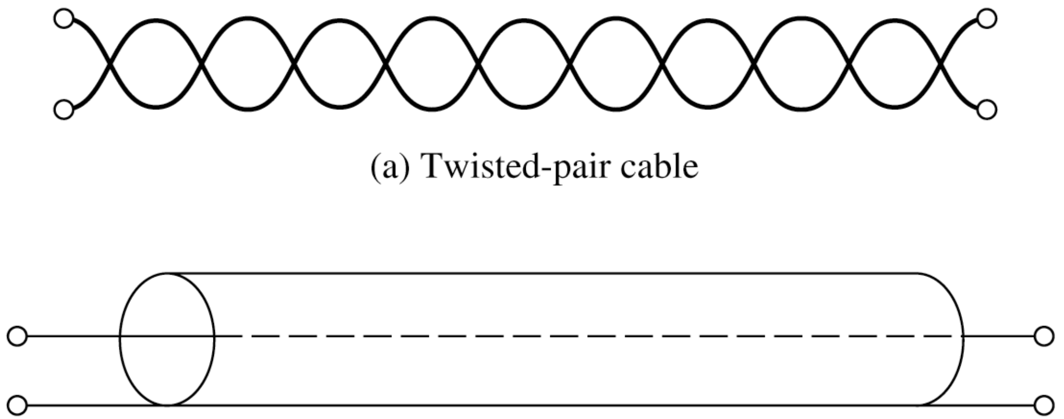


Figure 9.11 Electric field coupling can be greatly reduced by using shielded cables.

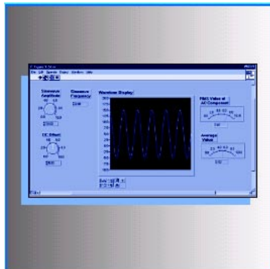




(a) Twisted-pair cable

(b) Coaxial cable

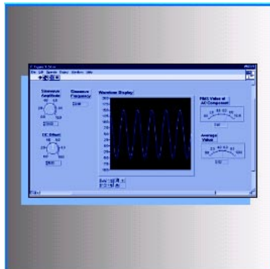
Figure 9.12 Magnetic field coupling can be greatly reduced by using twisted-pair or coaxial cables.



Noise

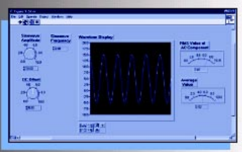
Electric field coupling of noise can be reduced by using shielded cables.

Magnetically coupled noise is reduced by using coaxial or twisted-pair cables.

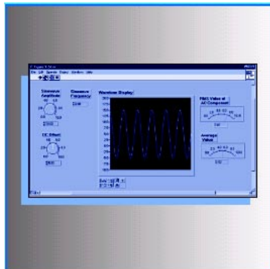


ANALOG-TO-DIGITAL CONVERSION

If a signal contains no components with frequencies higher than f_H , all of the information contained in the signal is present in its samples, provided that the sampling rate is selected to be more than twice f_H .



Analog-to-digital conversion is a two-step process. First, the signal is sampled at uniformly spaced points in time. Second, the sample values are quantized so they can be represented by words of finite length.



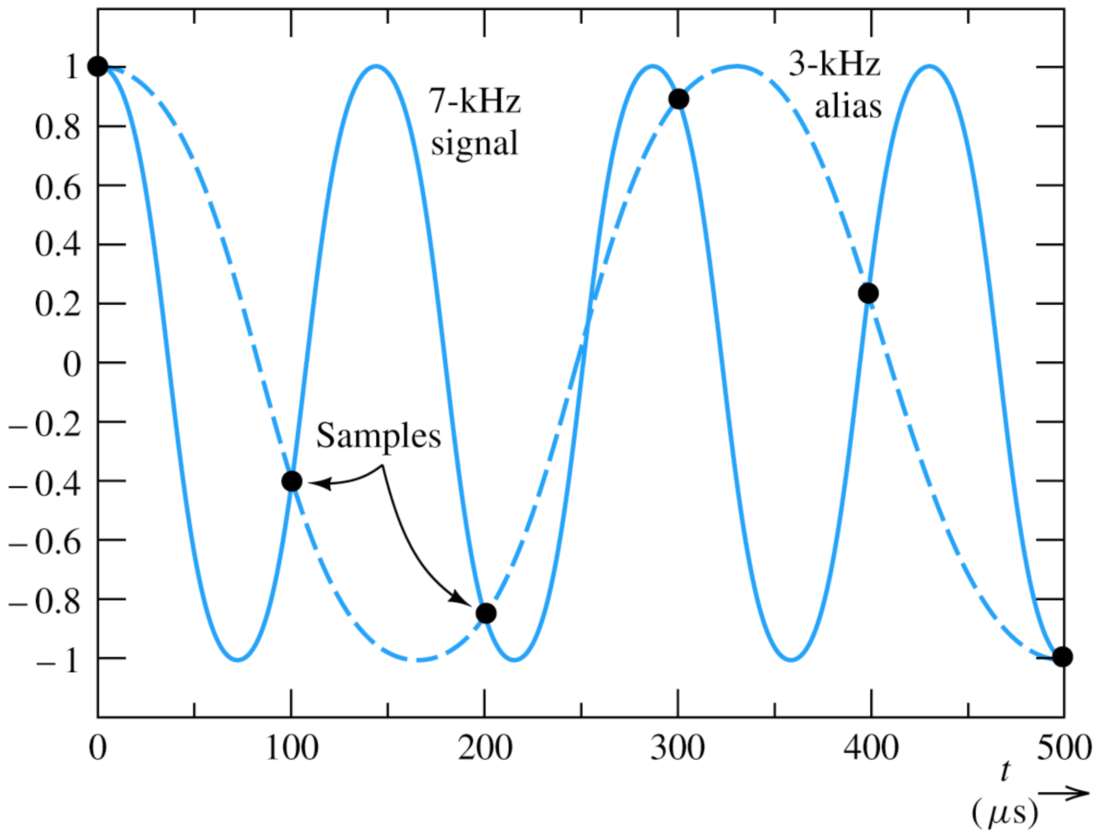
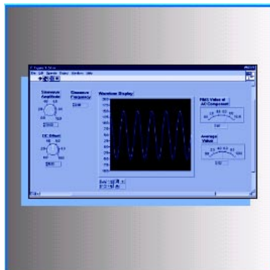
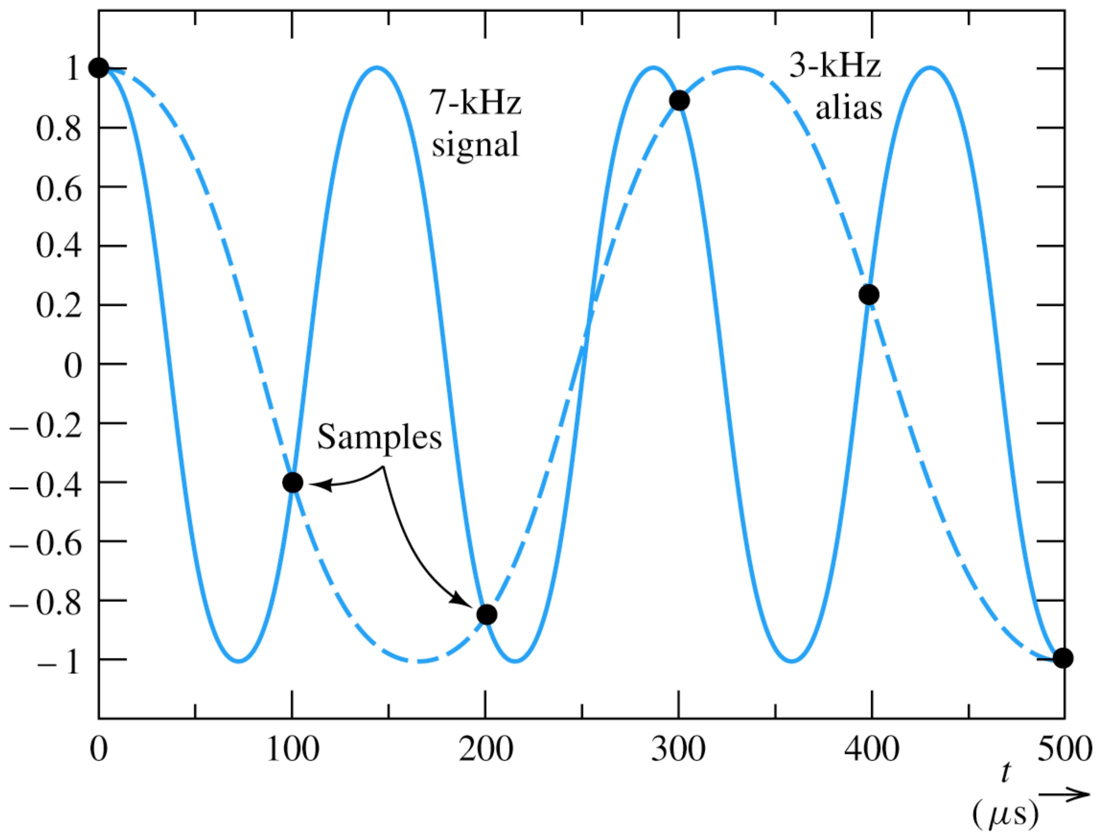


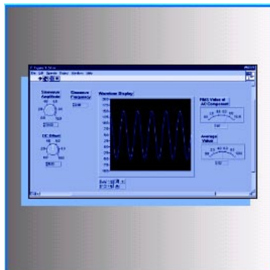
Figure 9.13 When a 7-kHz sinusoid is sampled at 10 kHz, the sample values appear to be those of a 3-kHz sinusoid.



Aliasing



1
0.8
0.6
0.4
0.2
0
– 0.2
– 0.4
– 0.6
– 0.8
– 1
0
100
200
300
400
500
7-kHz signal
3-kHz alias
Samples
t (μs)



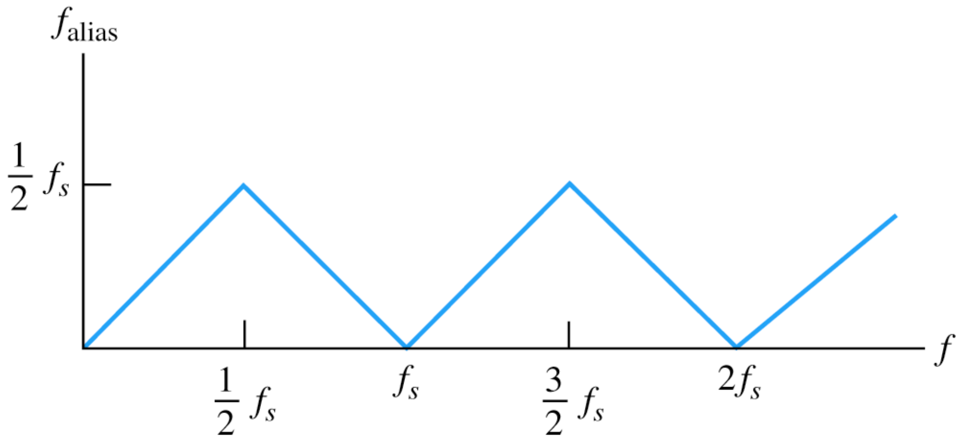
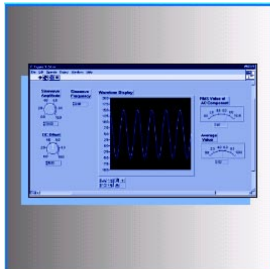


Figure 9.14 Alias or apparent frequency versus true signal frequency.

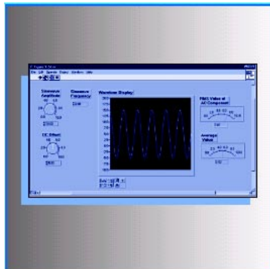


Quantization Noise

The effect of finite word length can be modeled as adding quantization noise to the reconstructed signal.

$$N = 2^k$$

$$N_{qrms} = \frac{\Delta}{2\sqrt{3}}$$



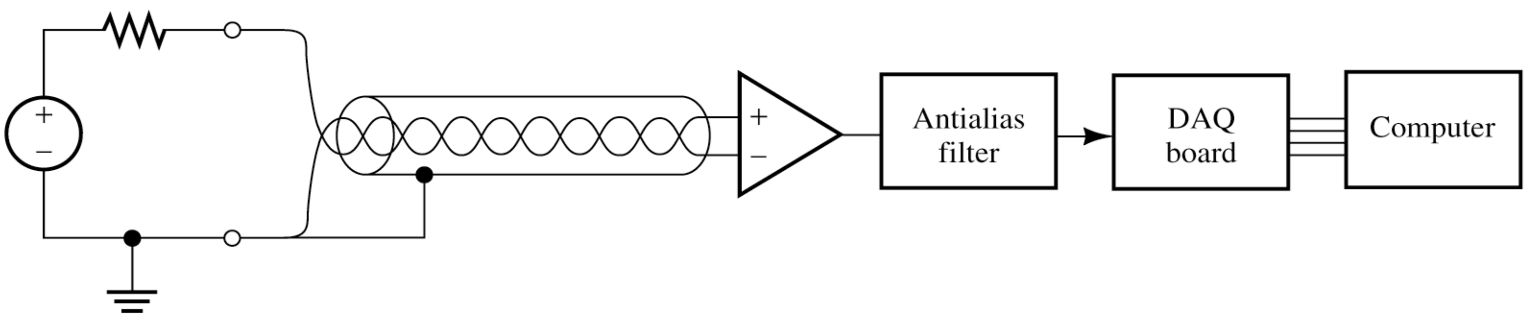
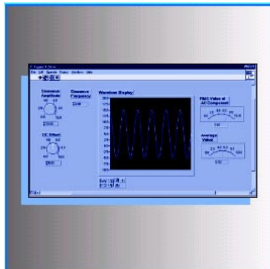
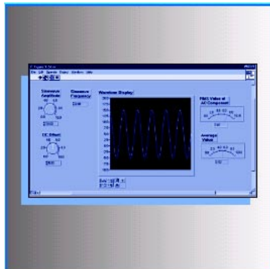


Figure 9.15 See Example 9.1.



LabVIEW

LabVIEW, a product of National Instruments, is an industry-standard program used by all types of engineers and scientists for developing sophisticated instrumentation systems such as the time–frequency vibration analyzer. LabVIEW is an acronym for *Lab*oratory *V*irtual *I*nstrument *E*ngineering *W*orkbench.



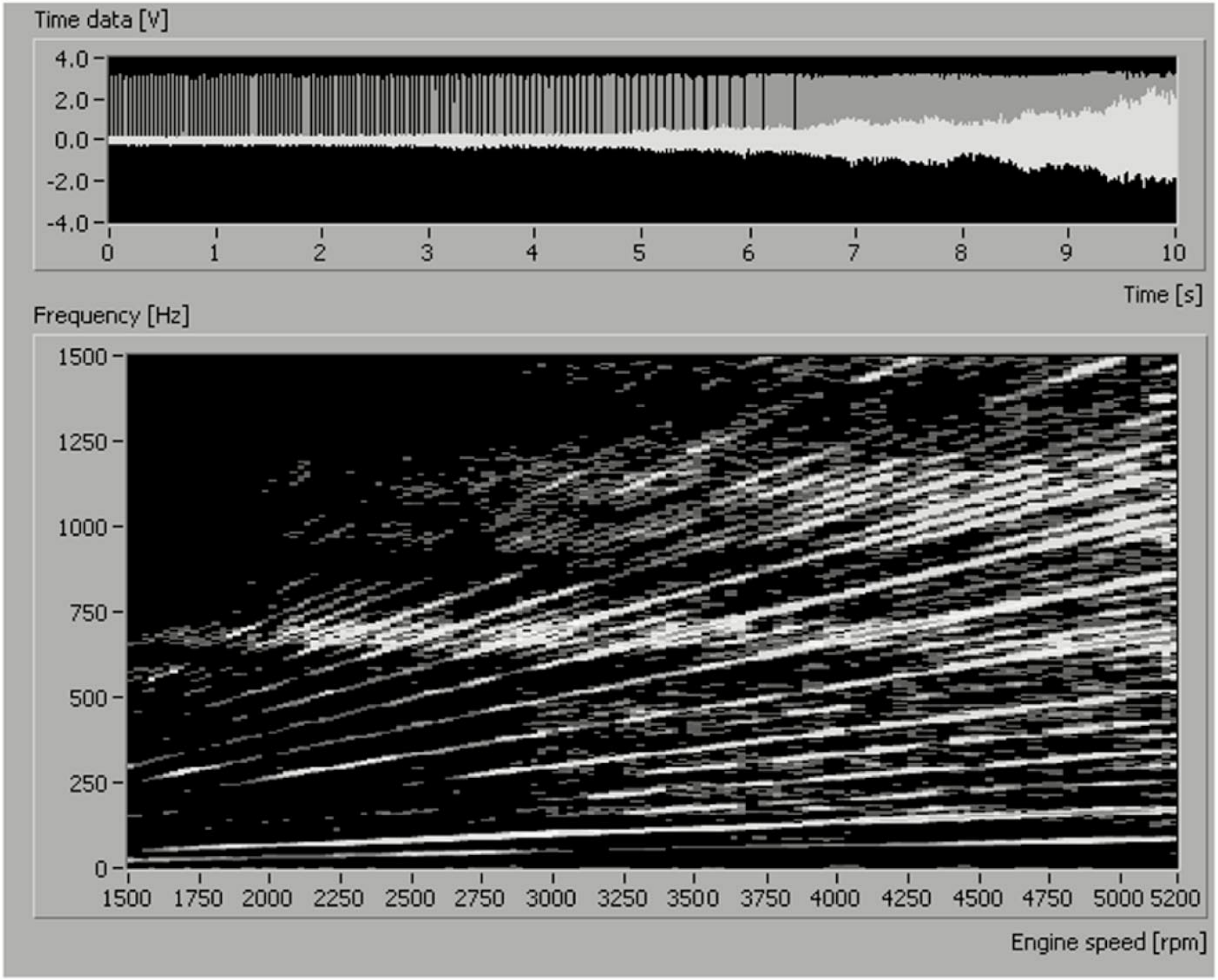
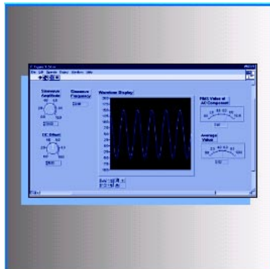
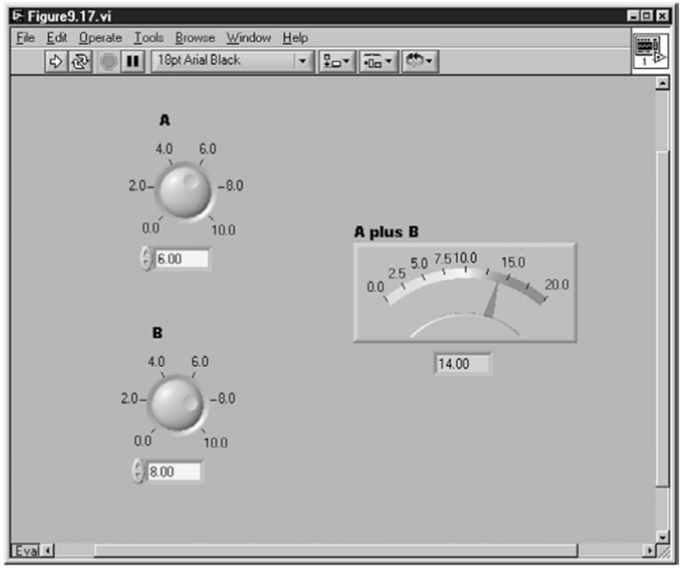
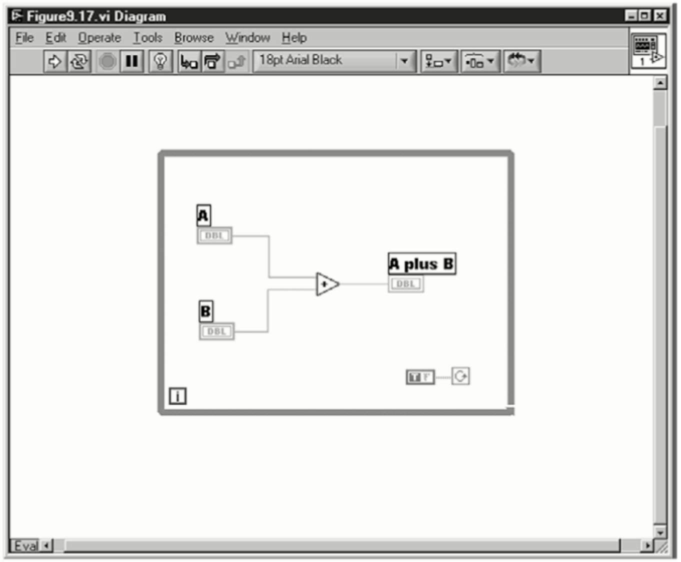


Figure 9.16 Time–frequency analyzer display of an engine-vibration signal.



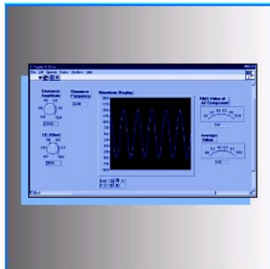


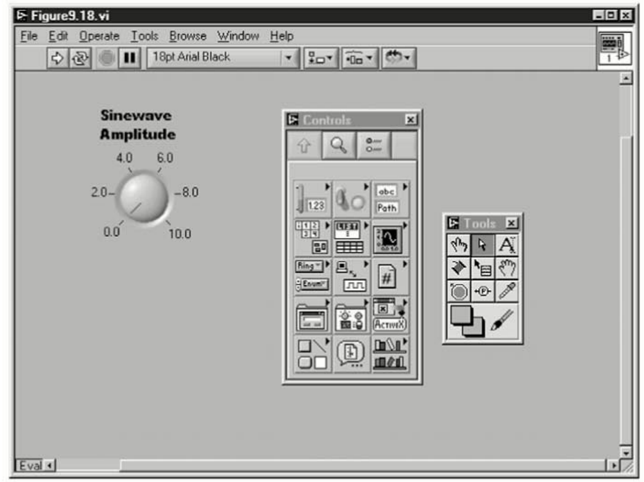
(a) Front panel



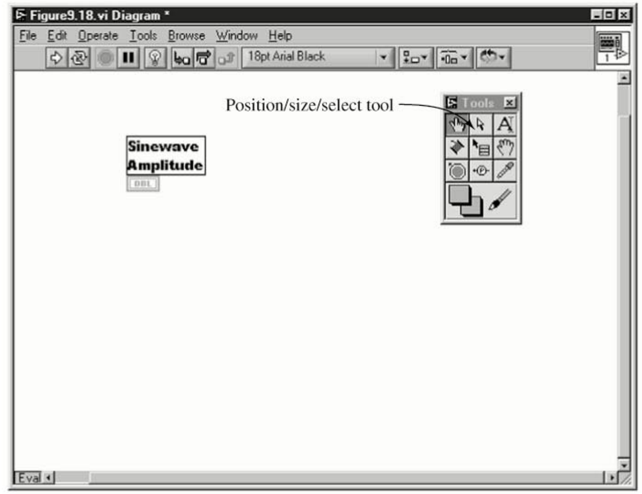
(b) Diagram

Figure 9.17 A simple LabVIEW virtual instrument.



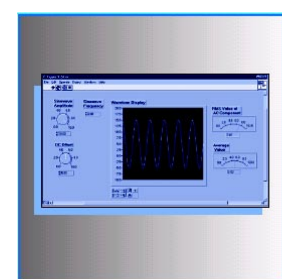


(a) Front panel



(b) Diagram

Figure 9.18 Front panel and diagram after selecting and labeling the dial control for the sinewave amplitude.



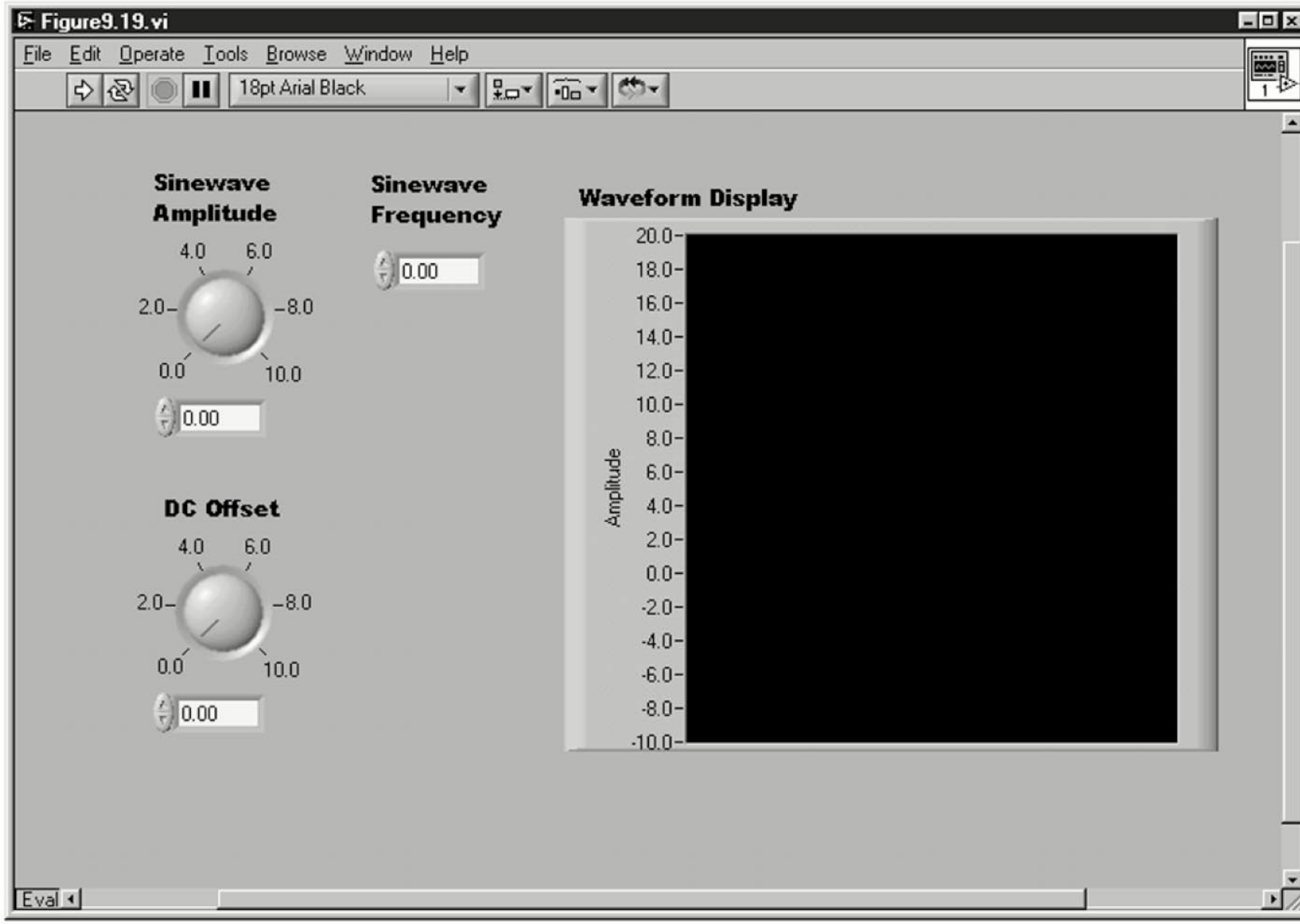
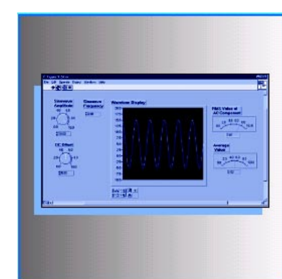


Figure 9.19 Front panel with controls and waveform display.



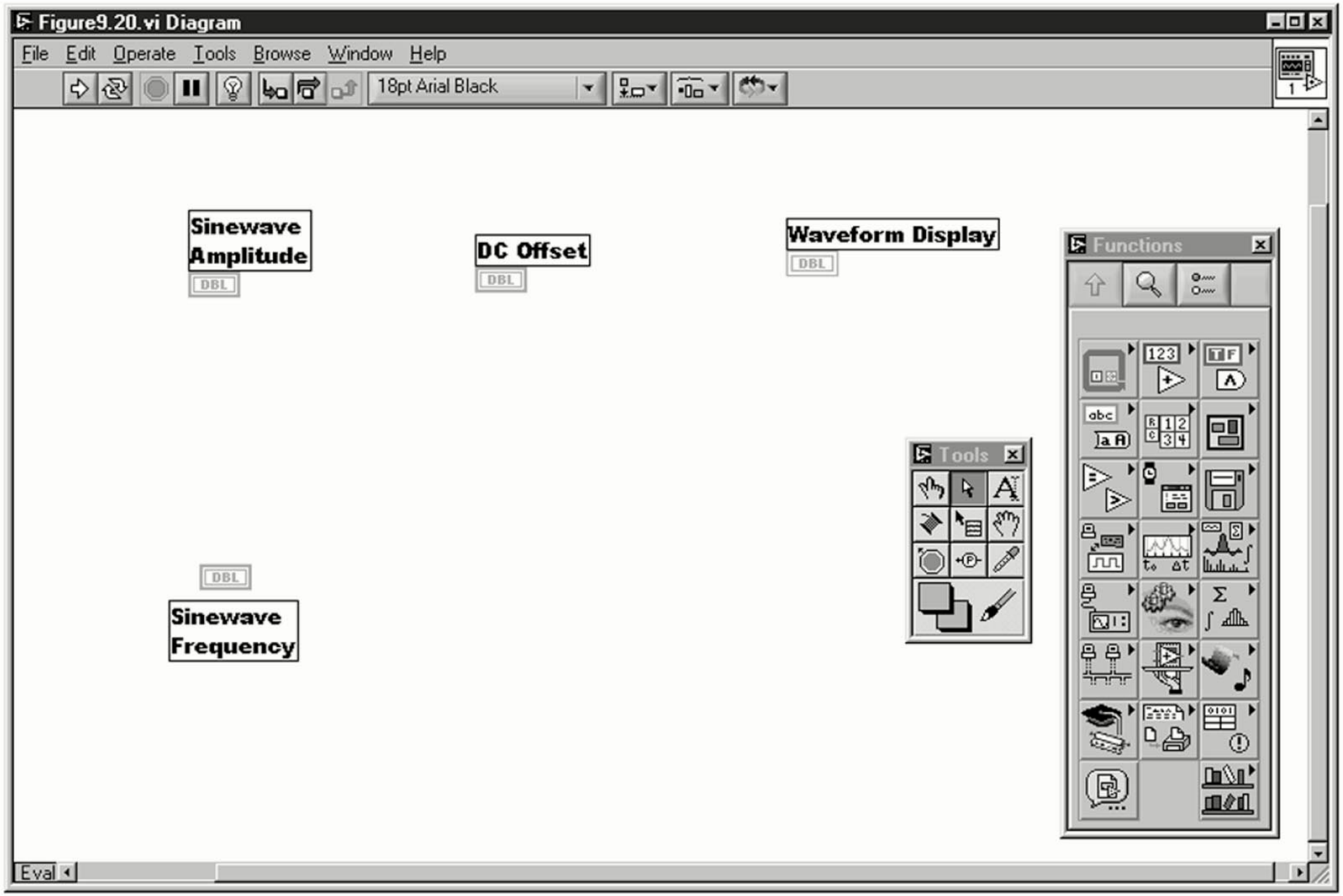
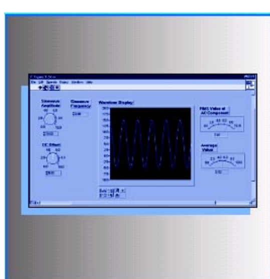


Figure 9.20 Diagram after repositioning terminals and labels.



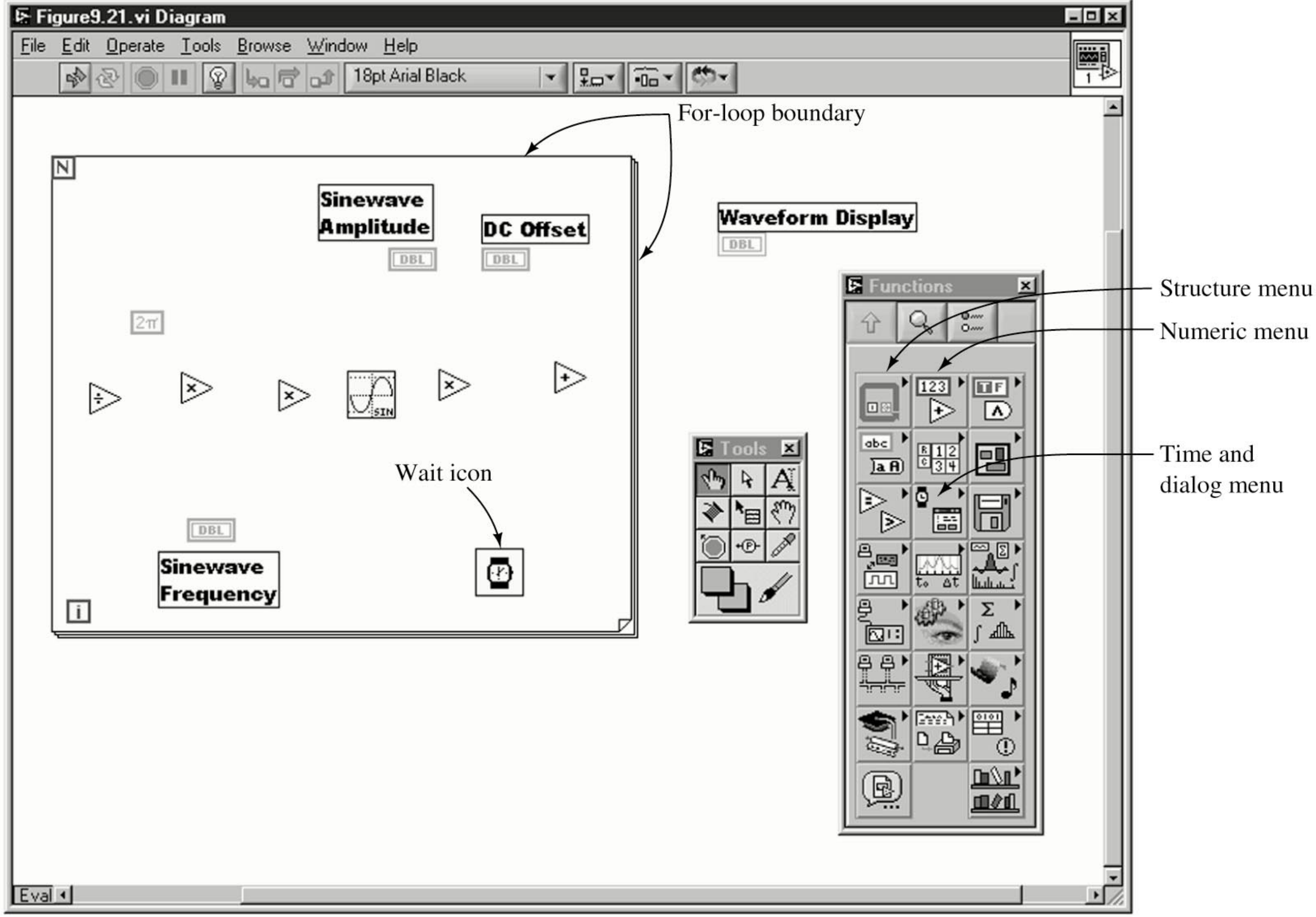
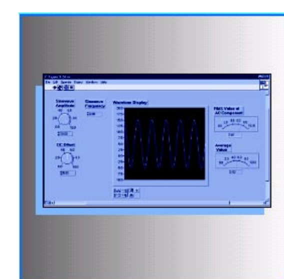


Figure 9.21 Diagram after adding function blocks.



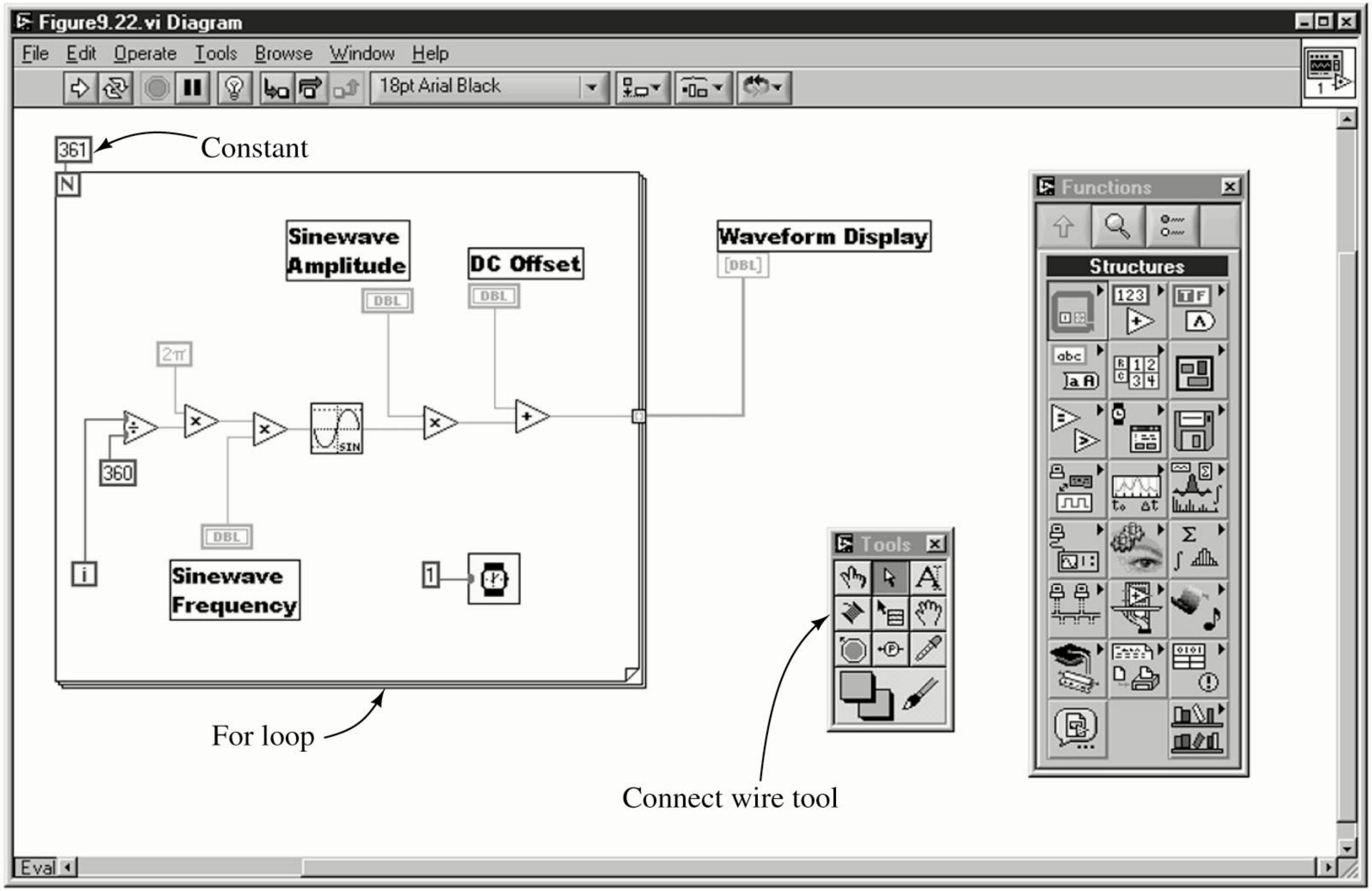
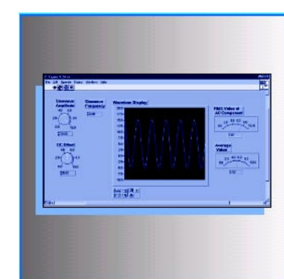


Figure 9.22 Diagram after adding constants and wires.



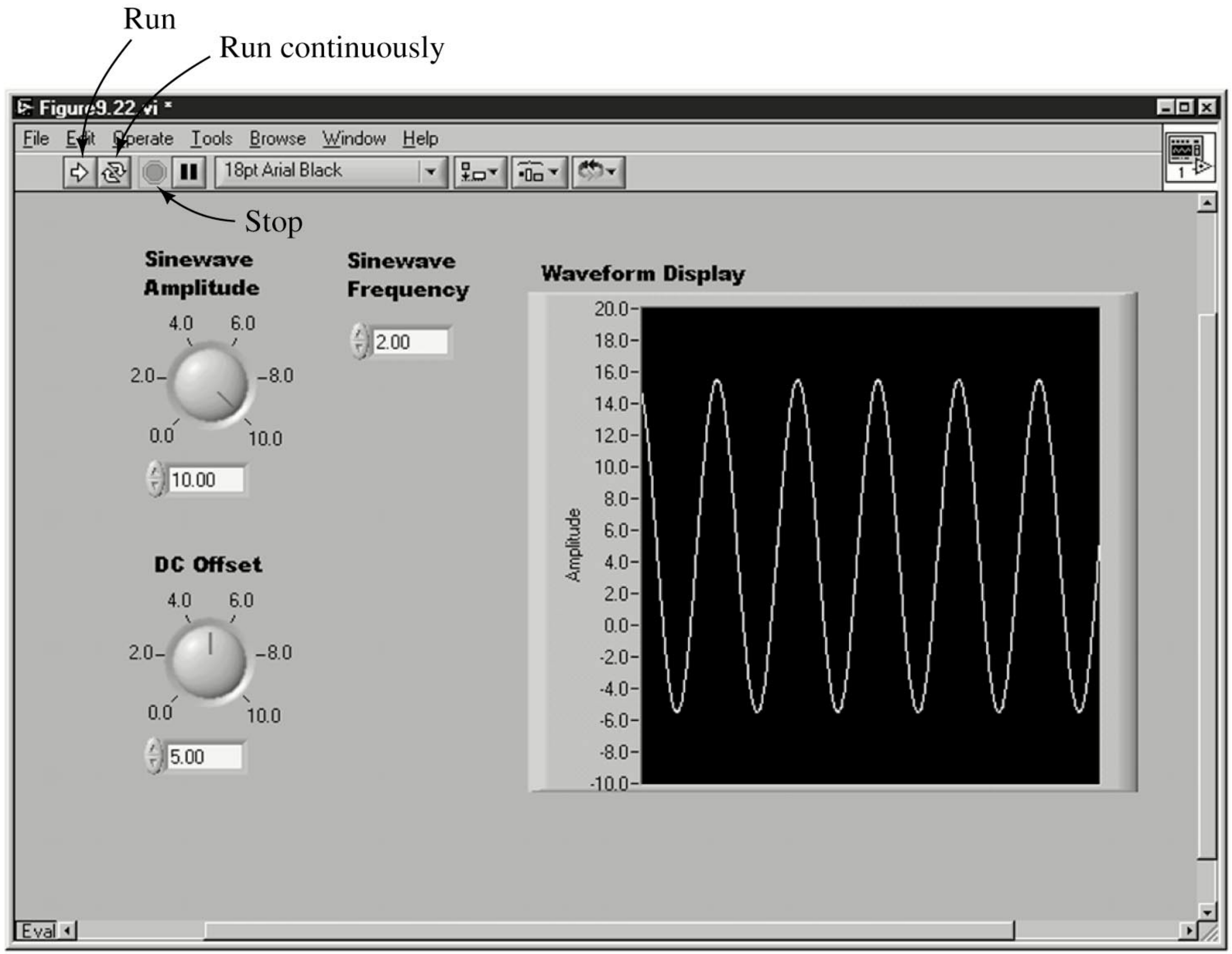
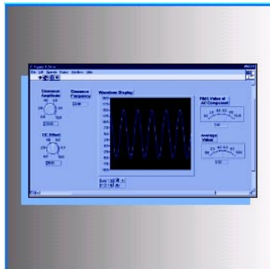


Figure 9.23 Front panel showing simulated data.



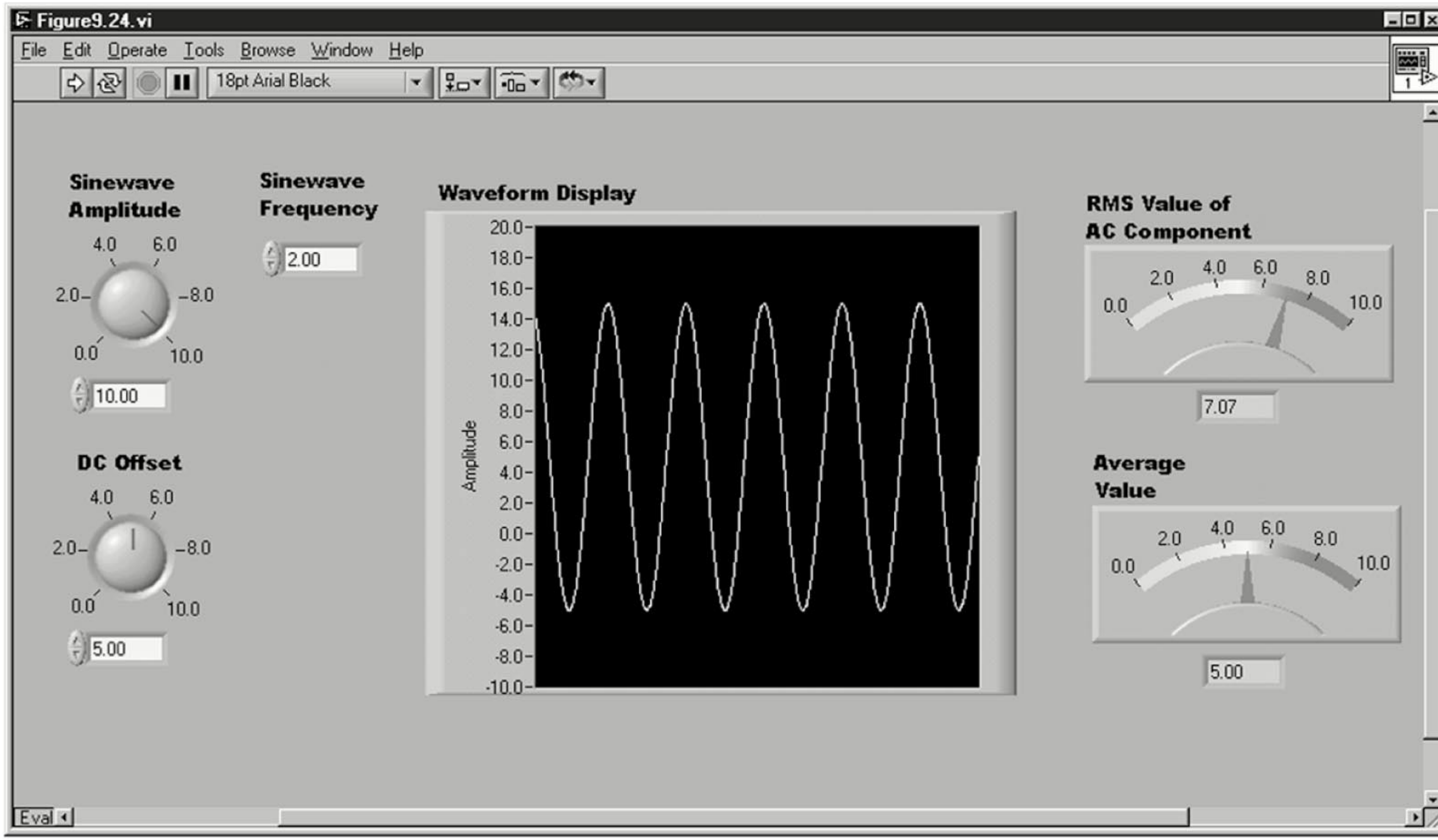
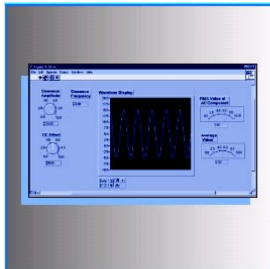


Figure 9.24 Completed front panel.



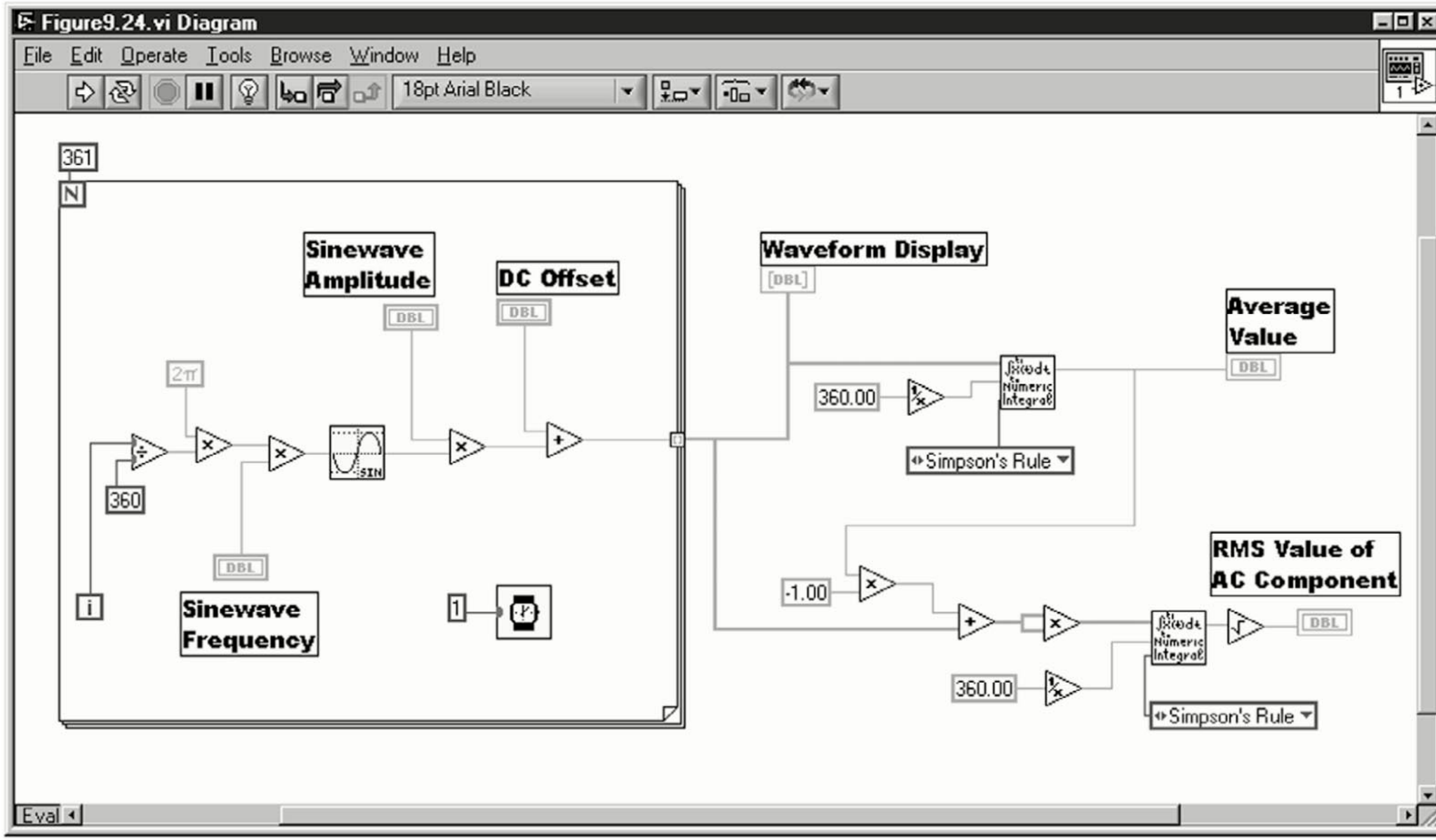


Figure 9.25 Completed diagram.