CHAPTER 9

Solutions for Exercises

E9.1 The equivalent circuit for the sensor and the input resistance of the amplifier is shown in Figure 9.2 in the book. Thus the input voltage is

$$v_{in} = v_{sensor} \frac{R_{in}}{R_{sensor} + R_{in}}$$

We want the input voltage with an internal sensor resistance of 10 kΩ to be at least 0.995 times the input voltage with an internal sensor resistance of 5 kΩ. Thus with resistances in kΩ, we have

$$v_{sensor} \frac{R_{in}}{10 + R_{in}} \geq 0.995 v_{sensor} \frac{R_{in}}{5 + R_{in}}$$

Solving, we determine that R_{in} is required to be greater than 990 kΩ.

E9.2 (a) A very precise instrument can be very inaccurate because precision implies that the measurements are repeatable, however they could have large bias errors.

(b) A very accurate instrument cannot be very imprecise. If repeated measurements vary a great deal under apparently identical conditions, some of the measurements must have large errors and therefore are inaccurate.

E9.3 $v_d = v_1 - v_2 = 5.7 - 5.5 = 0.2\text{ V} \qquad v_{cm} = \frac{1}{2}(v_1 + v_2) = \frac{1}{2}(5.5 + 5.7) = 5.6\text{ V}$

E9.4 The range of input voltages is from -5 V to +5 V or 10 V in all. We have $N = 2^k = 2^8 = 256$ zones. Thus the width of each zone is $\Delta = \dfrac{10}{N} = 39.1$ mV. The quantization noise is approximately $N_{qrms} \cong \dfrac{\Delta}{2\sqrt{3}} = 11.3$ mV.

E9.5 Look at Figure 9.14 in the book. In this case, we have f_s = 30 kHz and f = 25 kHz. Thus, the alias frequency is $f_{alias} = f_s - f$ = 5 kHz.

E9.6 The file containing the vi is named Figure 9.17.vi and can be found on the CD that accompanies this book.

Answers for Selected Problems

P9.2* The equivalent circuit of a sensor is shown in Figure 9.2 in the book. Loading effects are caused by the voltage drop across R_{sensor} that occurs when the input resistance of the amplifier draws current from the sensor. Then the input voltage to the amplifier (and therefore overall sensitivity) depends on the resistances as well as the internal voltage of the sensor. To avoid loading effects, we need to have R_{in} much greater than R_{sensor}.

P9.4* $R_{in} \geq 99\ \text{k}\Omega$

P9.5* $R_{in} \leq 102\ \Omega$

P9.8* The true value lies in the range from 69.5 cm to 70.5 cm.

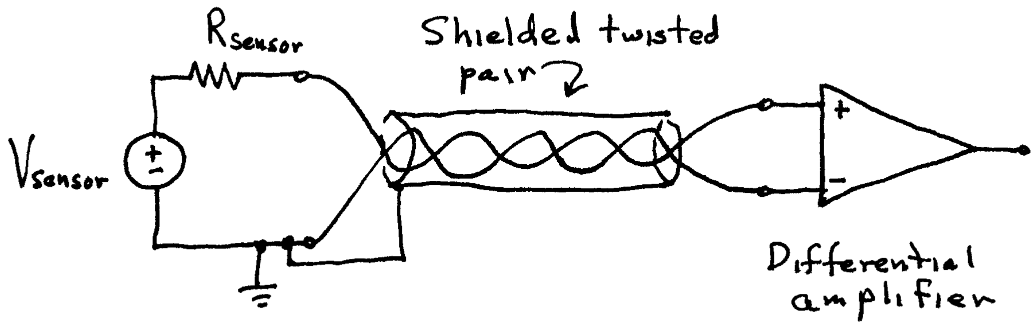
P9.10* (a) Instrument *B* is the most precise because the repeated measurements vary the least. Instrument *A* is the least precise.

(b) Instrument *C* is the most accurate because the maximum error of its measurements is least. Instrument *A* is the least accurate because it has the larges maximum error.

(c) Instrument *C* has the best resolution, and instrument *A* has the worst resolution.

P9.14*
$$v_d = v_1 - v_2 = 0.004\ \text{V}$$
$$v_{cm} = \tfrac{1}{2}(v_1 + v_2) = 5\cos(\omega t)\ \text{V}$$
$$v_o = A_d v_d = 4\ \text{V}$$

P9.16* To avoid ground loops, we must not have grounds at both ends of the 5-m cable. Because the sensor is grounded, we need to use a differential amplifier. To reduce interference from magnetic fields, we should use a twisted pair or coaxial cable. To reduce interference from electric fields we should choose a shielded cable and connect the shield to ground at the sensor. A schematic diagram of the sensor, cable and amplifier is:



P9.18* 60-Hz interference can be caused by magnetic fields linked with the sensor circuit. We could try a coaxial or twisted pair cable and/or move the sensor cable away from sources of 60-Hz magnetic fields such as transformers.

Another possibility is that the interference could be caused by a ground loop which we should eliminate.
Also electric field coupling is a possibility, in which case we should use a shielded cable with the shield grounded.

P9.22* Use a 10-bit converter.

P9.23* (a) $\Delta = 10/2^{12} = 2.44\text{ mV}$

(b) $P_q = 4.967 \times 10^{-7} / R$ watts

(c) $P_s = 2/R$ watts

(d) $\text{SNR}_{\text{dB}} = 10\log\left(\frac{P_s}{P_q}\right) = 66.0\text{ dB}$

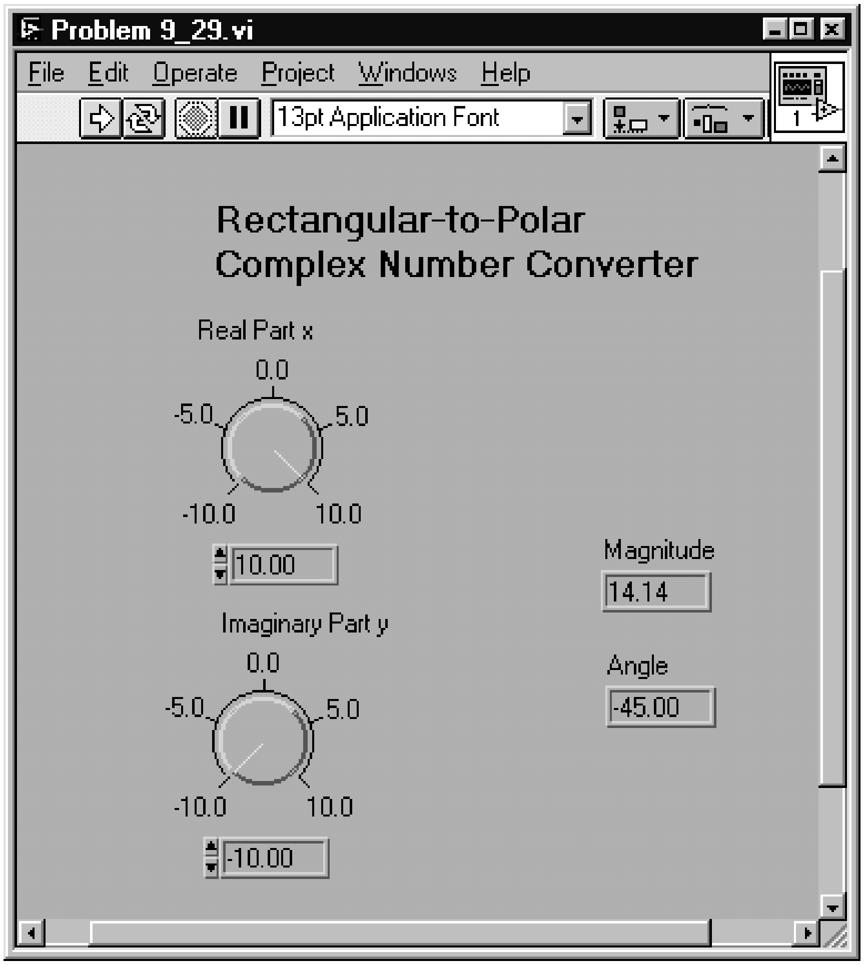
P9.24* $k = 8$

P9.25* (a) 1 kHz

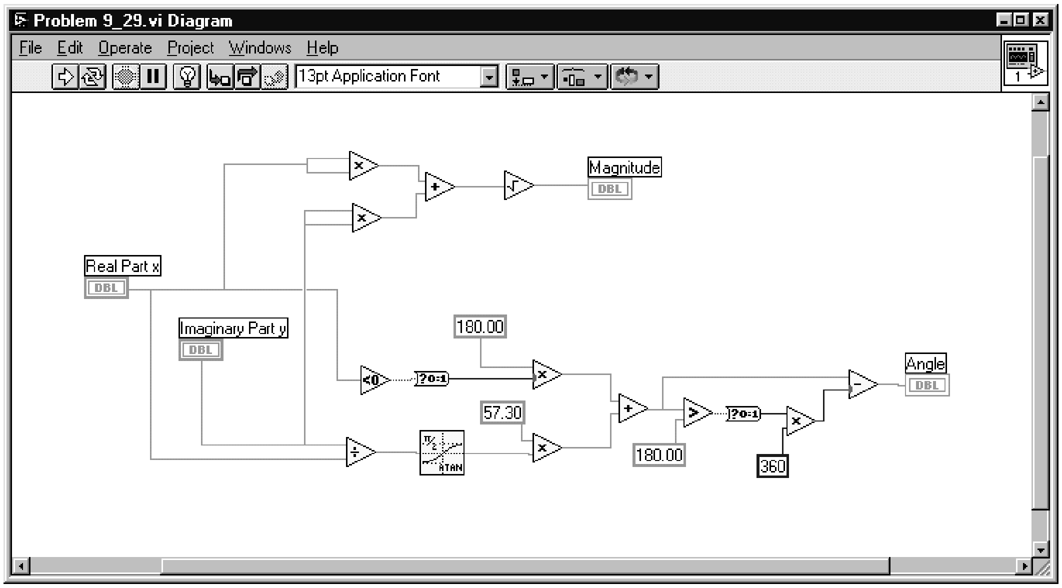
(b) 2 kHz

(c) 10 kHz

P9.29* The front panel is:



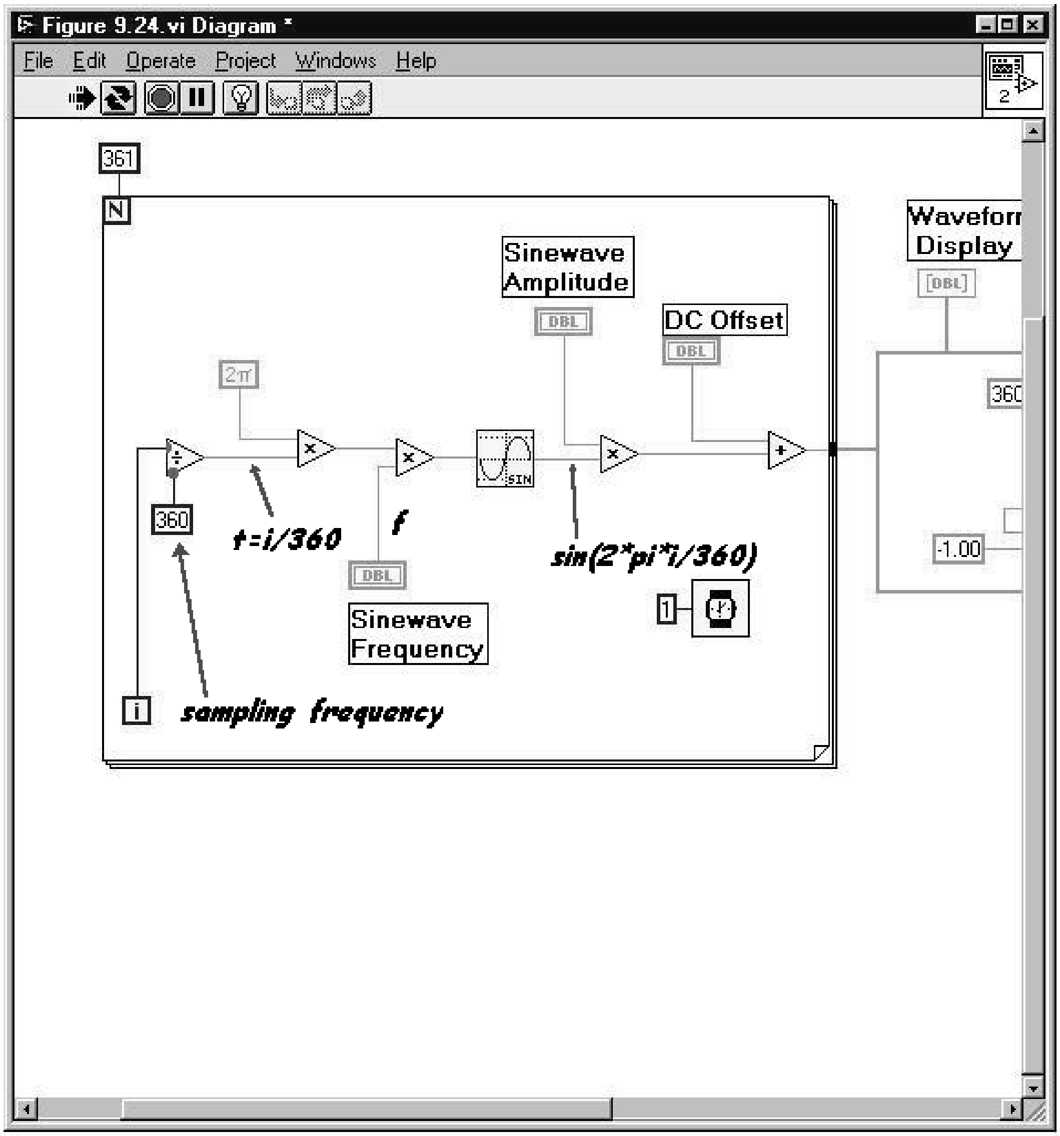
The magnitude of the complex number is computed as $A = \sqrt{x^2 + y^2}$. To find the angle, first we compute $\arctan(y / x)$ and convert the result to degrees by multiplying by 57.30. Then if x is negative, we add 180° which gives the correct angle. However we want the angle to fall between -180° and $+180^\circ$. Thus if the angle is greater than 180°, we subtract 360°. The block diagram is:



P9.31* We must keep in mind that G-programs deal with sampled signals even though they may appear to be continuous in time on the displays. In the virtual instrument Figure 9.24.vi, the sampling frequency for the sinewave is 360 samples per second. Thus we can expect aliasing if the frequency is greater than 180 Hz. Referring to Figure 9.14 in the book, we see that for each frequency f, the alias frequency is

f	f_{alias}
355	5
356	4
357	3
358	2
359	1
360	0
361	1
362	2
363	3
364	4

Thus as the frequency f increases, the apparent frequency decreases as we observe on the front panel. The partial block diagram and the quantities at various points are shown below:



Practice Test

T9.1. The four main elements are sensors, a DAQ board, software, and a general-purpose computer.

T9.2. The four types of systematic (bias) errors are offset, scale error, nonlinearity, and hysteresis.

T9.3. Bias errors are the same for measurements repeated under identical conditions, while random errors are different for each measurement.

T9.4. Ground loops occur when the sensor and the input of the amplifier are connected to ground by separate connections. The effect is to add noise (often with frequencies equal to that of the power line and its harmonics) to the desired signal.

T9.5. If we are using a sensor that has one end grounded, we should choose an amplifier with a differential input to avoid a ground loop.

T9.6. Coaxial cable or shielded twisted pair cable.

T9.7. If we need to sense the open-circuit voltage, the input impedance of the amplifier should be very large compared to the internal impedance of the sensor.

T9.8. The sampling rate should be more than twice the highest frequency of the components in the signal. Otherwise, higher frequency components can appear as lower frequency components known as aliases.