# Higher-Order System Response

- Most measurement systems involve more than one instrument.
- Many instruments in a measurement system are linear.
- For linear systems comprised of more than one instrument, the overall system response can be determined as follows:

1. The static sensitivity is the of all static sensitivities.
2. The magnitude ratio is the of all magnitude ratios.
3. The phase lag is the of all phase lags.

# Example 5.5 in Text

*Statement*: A pressure transducer is connected through flexible tubing to a static pressure port on the surface of a cylinder that is mounted inside a wind tunnel. The structure of the flow local to the port is such that the static pressure, $p(t)$, varies as

$$p(t) = 15\sin 2t,$$

in which t is time. Both the tubing and the pressure transducer behave as second-order systems. The natural frequencies of the transducer, $\omega_{n,trans}$, and the tubing, $\omega_{n,tube}$, are 2000 rad/s and 4 rad/s, respectively. Their damping ratios are $\zeta_{trans} = 0.7$ and $\zeta_{tube} = 0.2$, respectively. Find the magnitude attenuation and phase lag of the pressure signal, as determined from the output of the pressure transducer, and then write the expression for this signal.

*Solution*: Because this measurement system is linear, the system's magnitude ratio, $M_s(\omega)$, is the product of the components' magnitude ratios and the phase lag, $\phi_s(\omega)$, is the sum of the components' phase lags, where $\omega$ the circular frequency of the pressure. Thus,

$$\boxed{M_s(\omega) = M_{tube}(\omega) \cdot M_{trans}(\omega)}$$

and

$$\boxed{\phi_s(\omega) = \phi_{tube}(\omega) + \phi_{trans}(\omega).}$$

Also, $\omega/\omega_{tube} = 2/4 = 0.5$ and $\omega/\omega_{trans} = 2/2000 = 0.001$. Application of Equations 5.62 and 5.64, noting $\zeta_{trans} = 0.7$ and $\zeta_{tube} = 0.2$, yields $\phi_{tube}$ = -21.8 °, $\phi_{trans}$ = -0.1 °, $M_{tube} = 1.86$ and $M_{trans} = 1.00$. Thus, $\phi_s(2)$ = -21.8 ° + -0.1 ° = -21.9 ° and $M_s(2) = (1.86)(1.00) = 1.86$. The pressure signal, as determined from the output of the transducer is $p_s(t) = (15)(1.86)\sin[2t - (21.9)(\pi/180)] = 27.9\sin(2t - 0.38)$. Thus, the magnitude of the pressure signal at the output of the measurement system will appear 186 % greater than the actual pressure signal and be delayed in time by 0.19 s [(0.38 s)/(2 rad/s)].