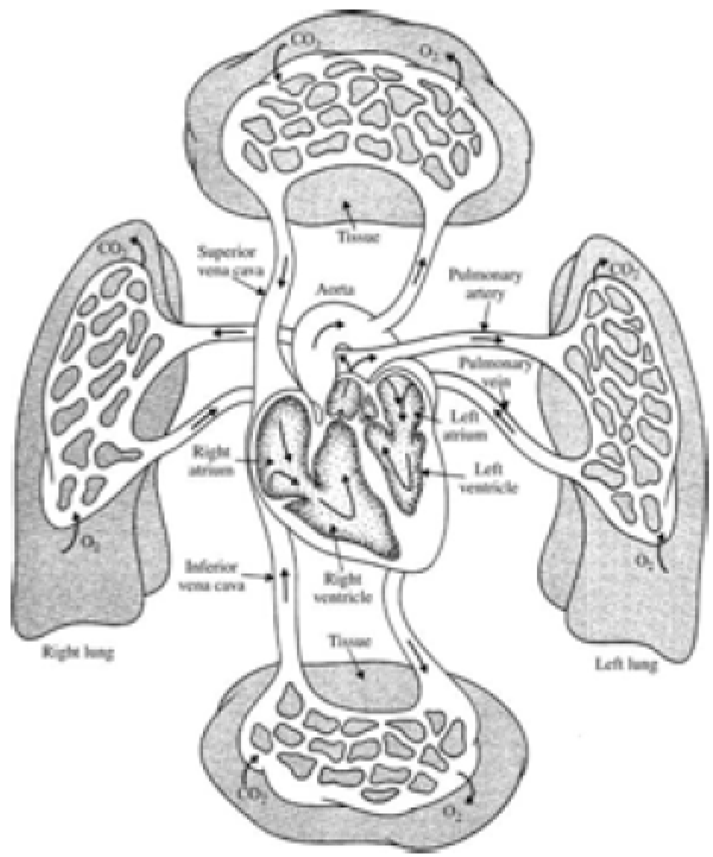
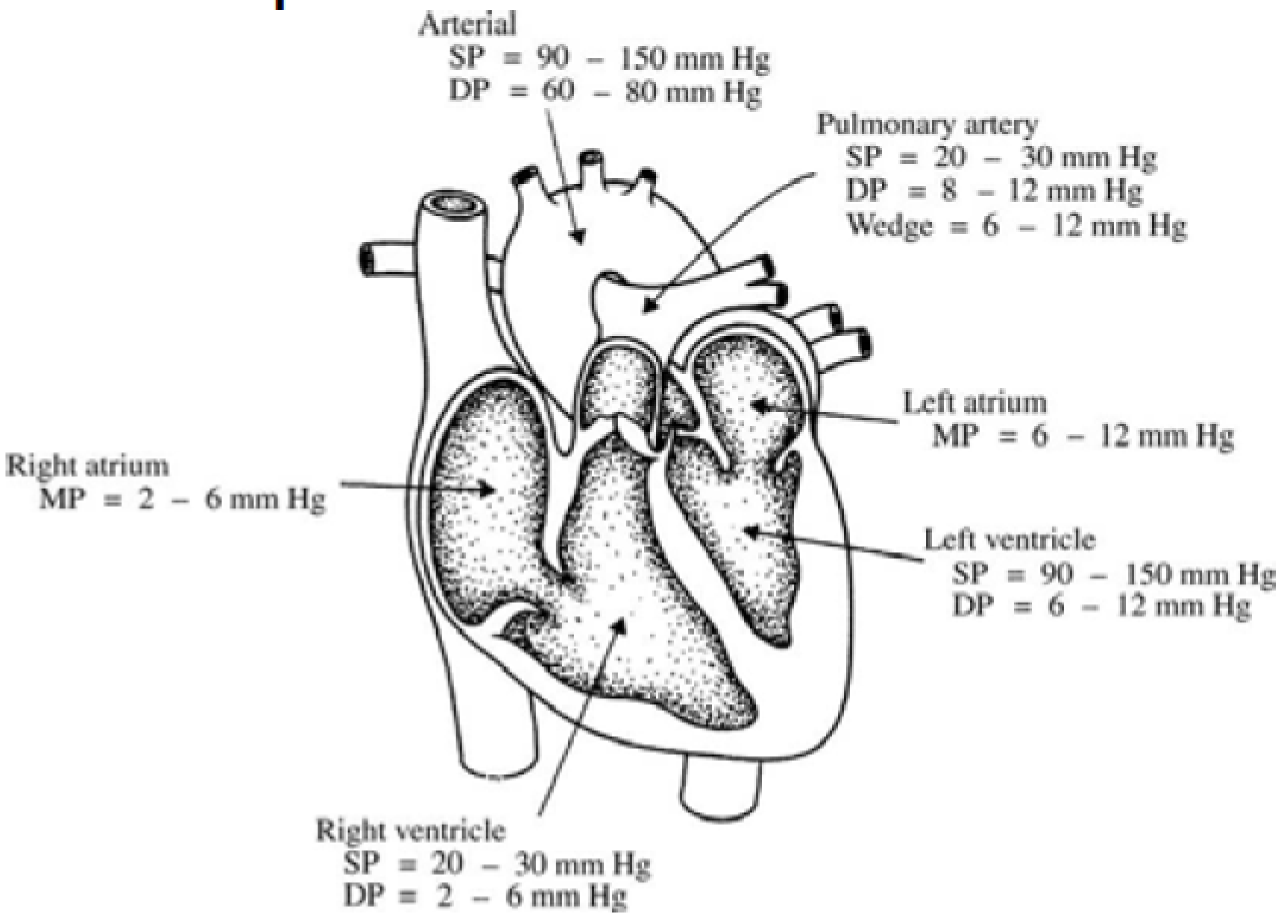
EE 4BD4 Lecture 17

Blood Pressure Measurement

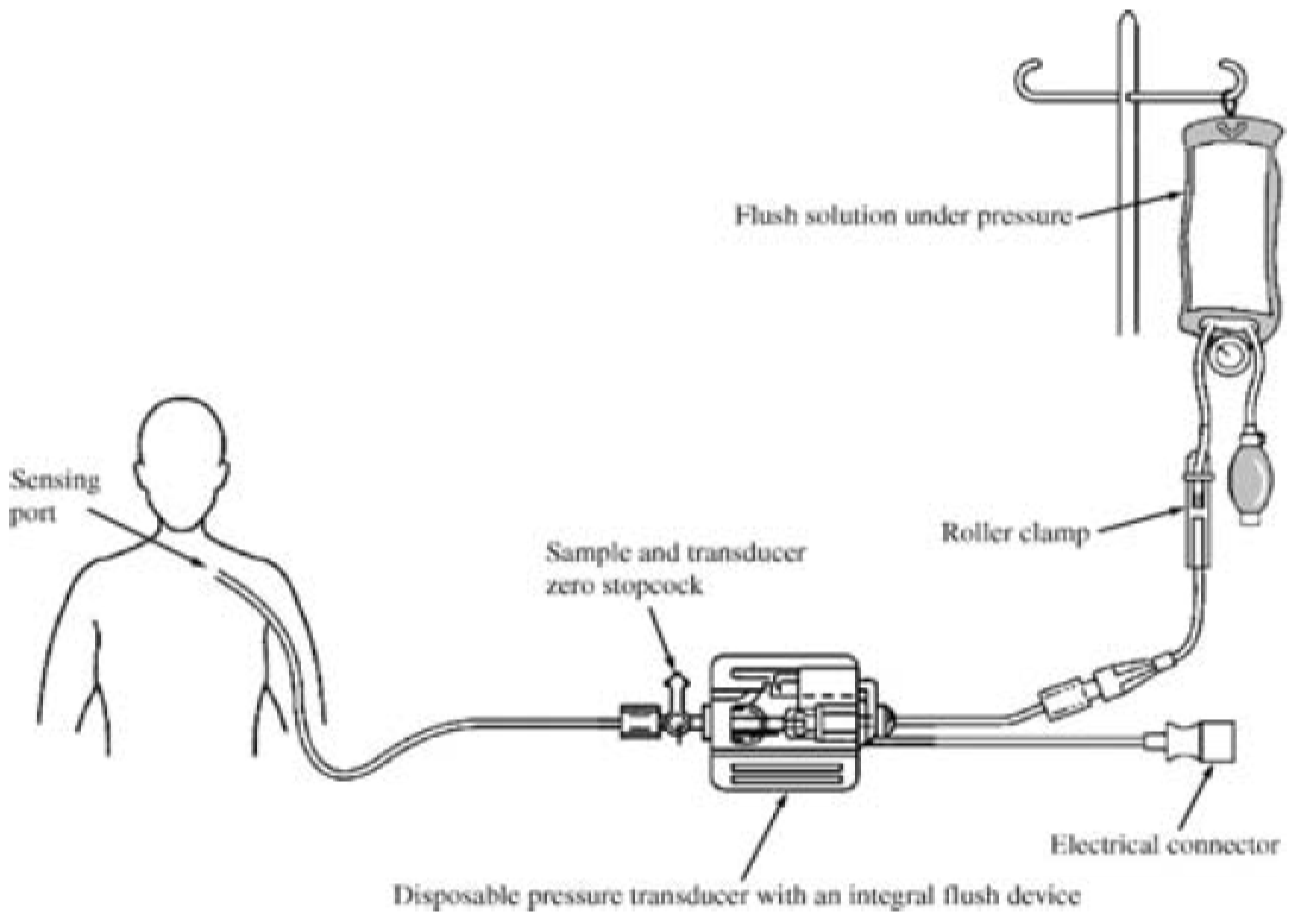
Circulatory system



Blood pressures within the heart



Direct pressure measurements - external sensor



Basic Theory

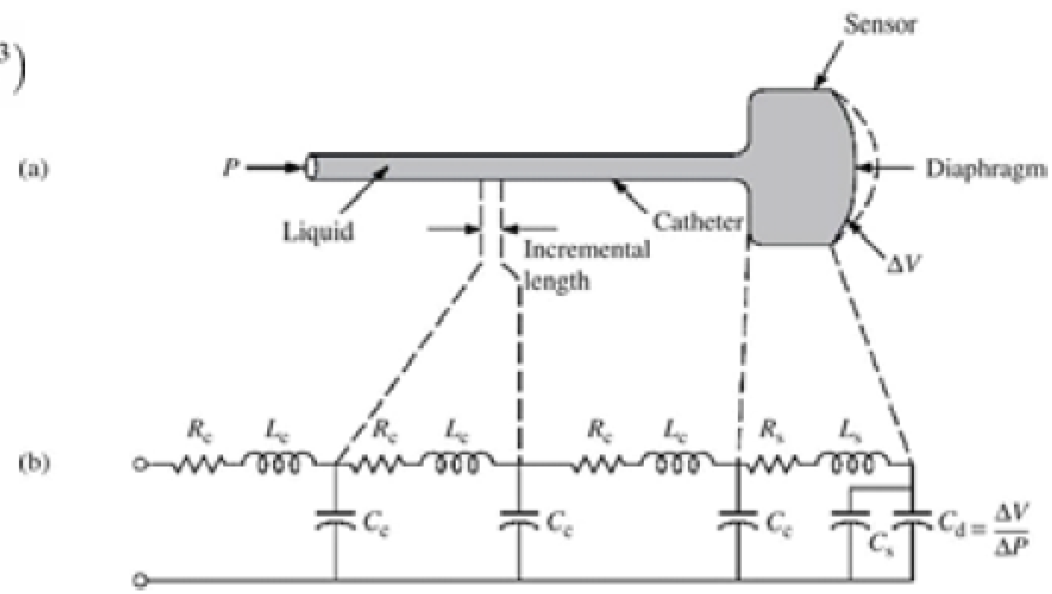
- A liquid catheter has inertial, frictional and elastic properties represented by inertance, resistance and compliance
- Diaphragm and sensor has these as well
- Electrical analogs are inductance, resistance and capacitance respectively
- In the following figure, compliance of the diaphragm is larger than that of catheter or sensor cavity if catheter is made of stiff material
- Resistance and inertance of the liquid in the sensor can be neglected compared to those of the liquid in the catheter

External pressure sensor model

$$R_c = \frac{\Delta P}{F}\,(\mathrm{Pa\cdot s/m^3})$$

$$R_c = \frac{\Delta P}{\bar{u}A}$$

$$R_c = \frac{8\eta L}{\pi r^4}$$



$$L_c = \frac{\Delta P}{dF/dt}\,(\mathrm{Pa\cdot s^2/m^3})$$ $$L_c = \frac{\Delta P}{aA}$$ $$L_c = \frac{m}{A^2}$$ $$L_c = \frac{\rho L}{\pi r^2}$$

Theory (continued)

- R_c is liquid resistance in catheter (friction) for laminar flow
- ΔP is pressure difference across segment in pascals (N/m^2)
- F is flow rate in m^3/s
- $\bar{u}$ is average velocity in m/s
- A is Cross-section area in m^2
- L is catheter length in m
- r is radius in m; η is liquid viscosity in pascal-seconds
- L_c is liquid inertance; a is acceleration in m/s^2
- m is mass of liquid in kg; ρ is density of liquid in kg/m^3
- E_d is volume modulus of elasticity

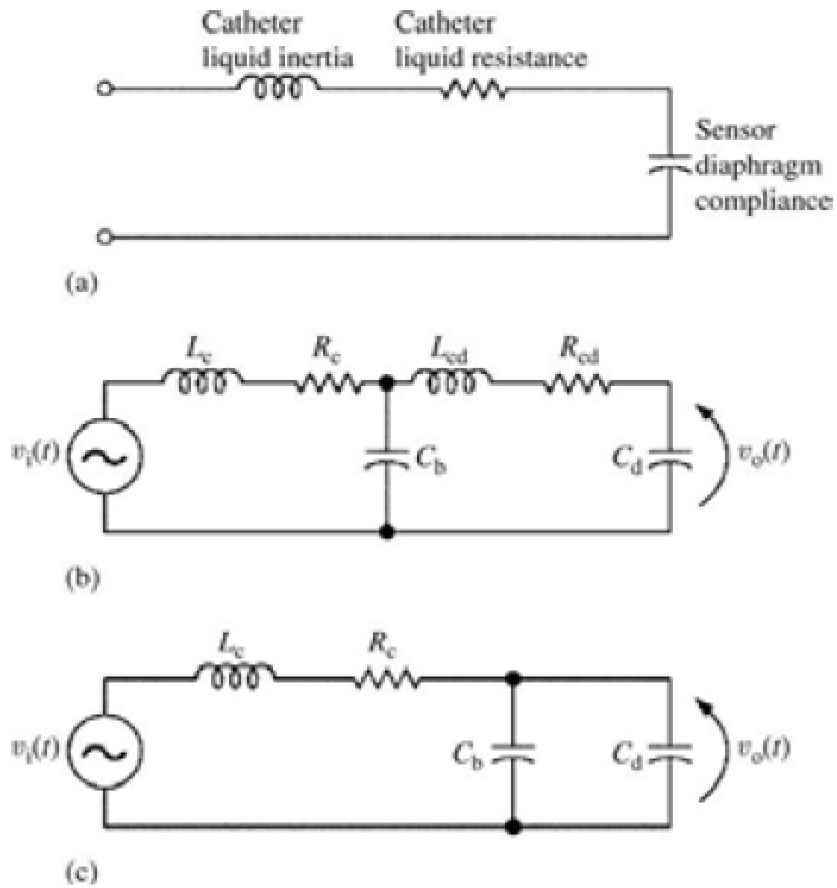
Parameters variability

Table 7.1 Mechanical Characteristics of Fluids

Parameter	Substance	Temperature	Value
η	Water	20 °C	0.001 Pa·s
η	Water	37 °C	0.0007 Pa·s
η	Air	20 °C	0.000018 Pa·s
ρ	Air	20 °C	1.21 kg/m^3
$\Delta V/\Delta P$	Water	20 °C	$0.53 \times 10^{-15} m^5/N$ per ml volume
η	Blood	All	$\cong 4 \times \eta$ for water

External sensor simplified model

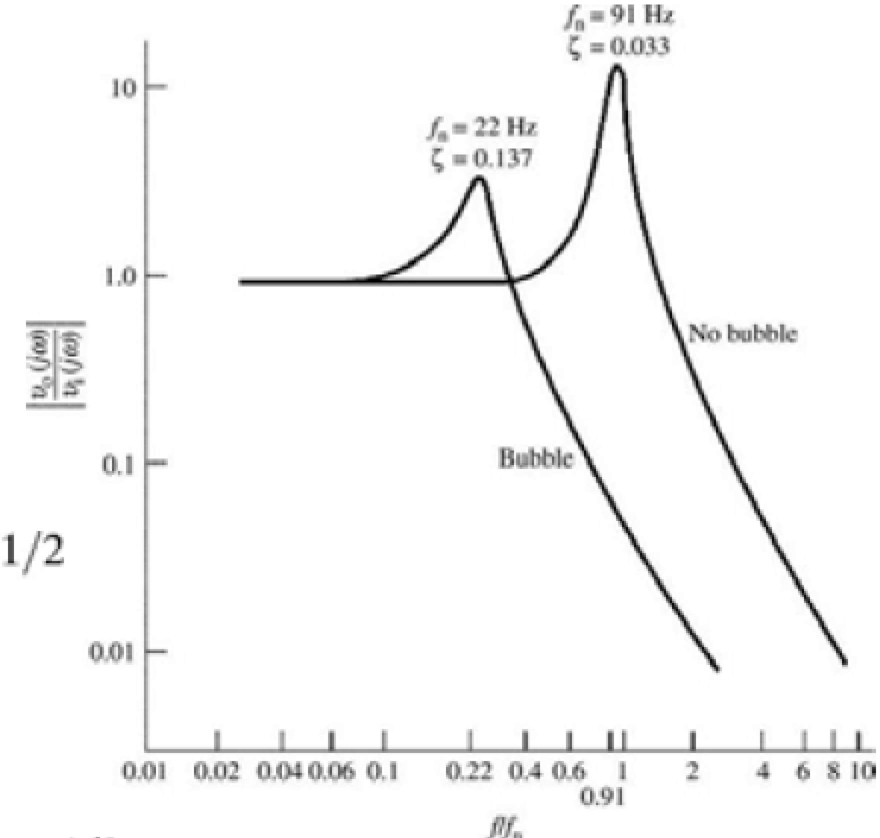
Figure 7.8 (a) Simplified analogous circuit. Compliance of the sensor diaphragm is larger than compliance of catheter or sensor cavity for a bubble-free, noncompliant catheter. The resistance and inertance of the catheter are larger than those of the sensor, because the catheter has longer length and smaller diameter, (b) Analogous circuit for catheter–sensor system with a bubble in the catheter. Catheter properties proximal to the bubble are inertance *Lc* and resistance *Rc*. Catheter properties distal to the bubble are *Lcd* and *Rtf*. Compliance of the diaphragm is *Cd*; compliance of the bubble is *Cb*. (c) Simplified analogous circuit for catheter–sensor system with a bubble in the catheter, assuming that *Lcd* and *Rcd* are negligible with respect to *Rc* and *Lc*.



$$C_d = \frac{\Delta V}{\Delta P} = \frac{1}{E_d} \qquad C_t = \frac{\Delta V}{\Delta P_d} + \frac{\Delta V}{\Delta P_b}$$

Simplified model characteristics

Figure 7.9 Frequency-response curves for catheter–sensor system with and without bubbles. Natural frequency decreases from 91 Hz to 22 Hz and damping ratio increases from 0.033 to 0.137 with the bubble present.



$$f_n = \frac{r}{2}\left(\frac{1}{\pi\rho L}\frac{\Delta P}{\Delta V}\right)^{1/2}$$

$$\zeta = \frac{4\eta}{r^3}\left(\frac{L(\Delta V/\Delta P)}{\pi\rho}\right)^{1/2}$$

Effects of Bad Catheter/Sensor Design

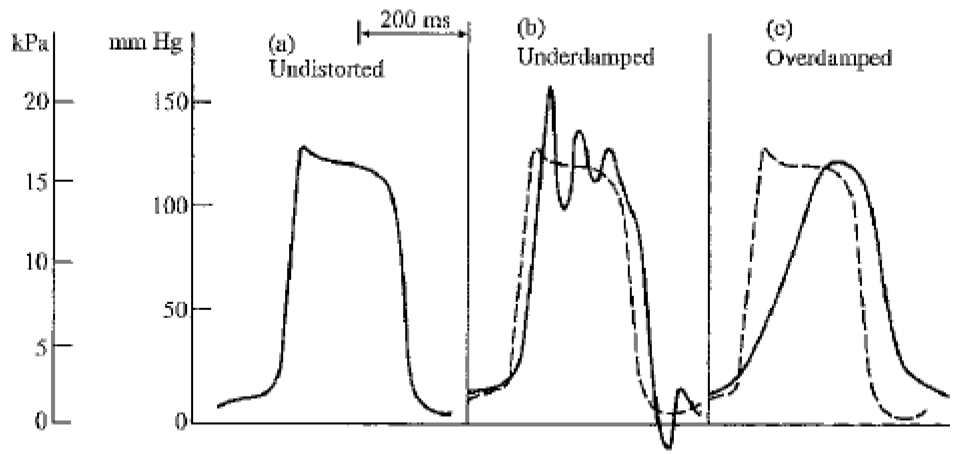


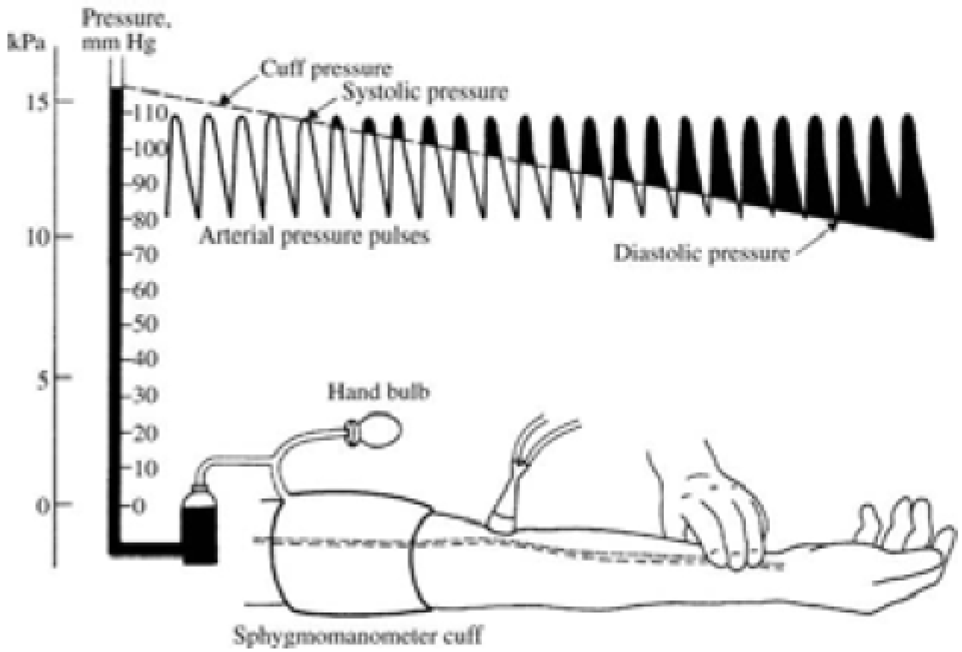
Figure 7.13 Pressure-waveform distortion (a) Recording of an undistorted left-ventricular pressure waveform via a pressure sensor with bandwidth dc to 100 Hz. (b) Underdamped response, where peak value is increased. A time delay is also evident in this recording. (c) Overdamped response that shows a significant time delay and an attenuated amplitude response.

(a) Undistorted pressure waveform

(b) Air bubble in catheter

(c) Catheter whip distortion

Indirect blood-pressure measurements



Oscillatory method for detecting blood pressure

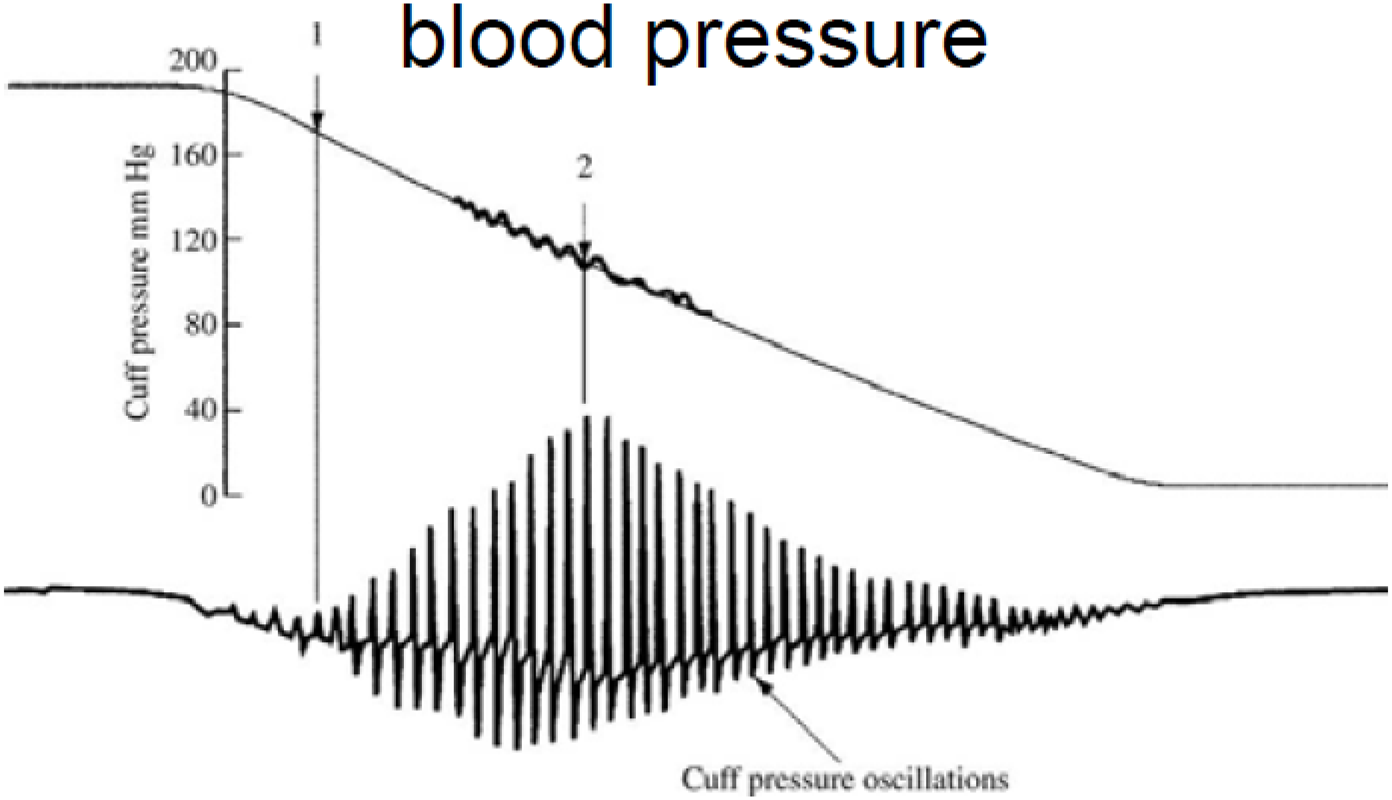


Figure 7.22 The oscillometric method A compression cuff is inflated above systolic pressure and slowly deflated. Systolic pressure is detected (Point 1) where there is a transition from small amplitude oscillations (above systolic pressure) to increasing cuff-pressure amplitude. The cuff-pressure oscillations increase to a maximum (Point 2) at the mean arterial pressure.

NIBP Monitor

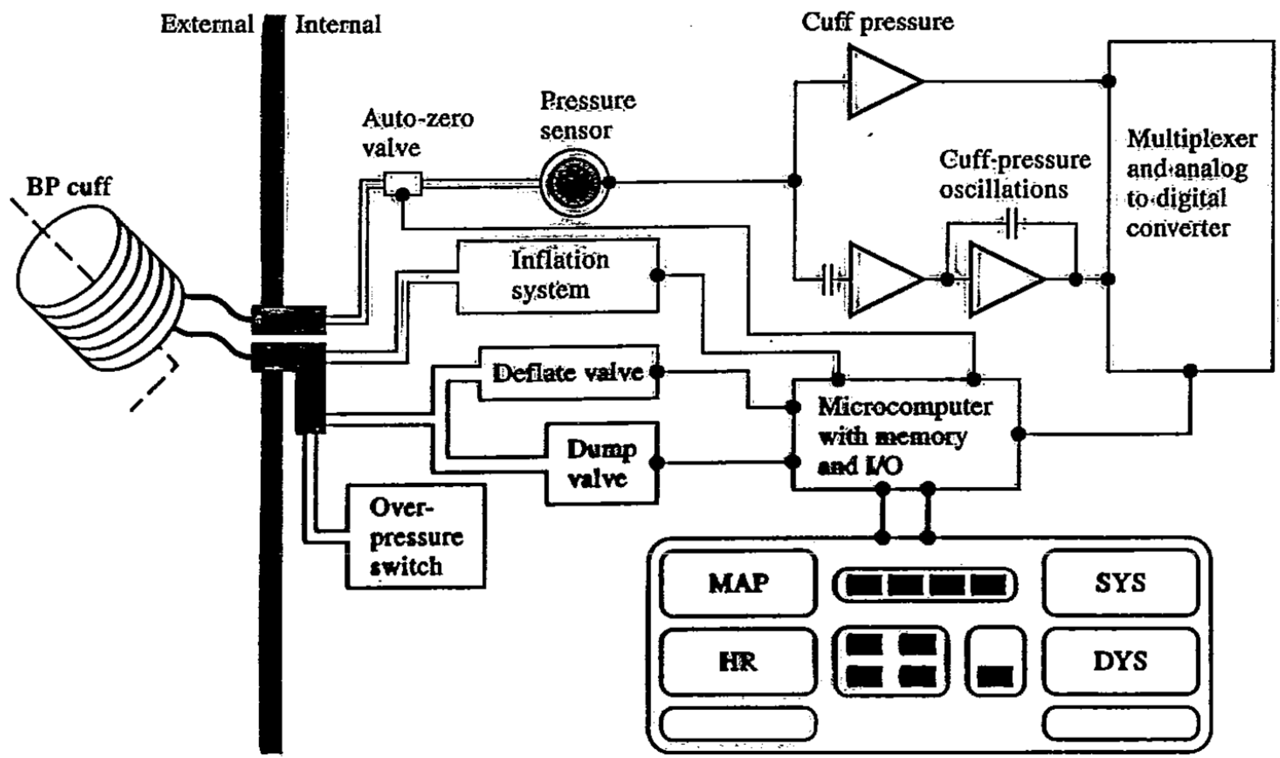


Figure 7.23 Block diagram of the major components and subsystems of an oscillometric blood-pressure monitoring device, based on the Dinamap unit, I/O = input/output; MAP = mean arterial pressure; HR = heart rate; SYS = systolic pressure; DYS = diastolic pressure. From Ramsey M III. Blood pressure monitoring: automated oscillometric devices, *J. Clin. Monit.* 1991, 7, 56–67.