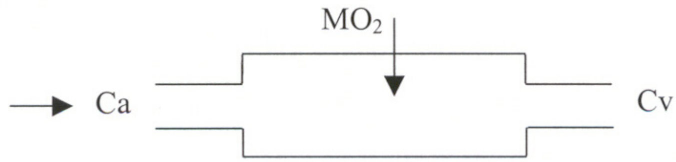
Chapter 16-Flow Measurement

Biomedical Engineering Measurements

Cardiac Output
Indicator-Dilution Techniques

Fick Technique



Ca = concentration of O_2 at a
Cv = concentration of O_2 at v
MO_2 = amount of O_2 added
F = flow

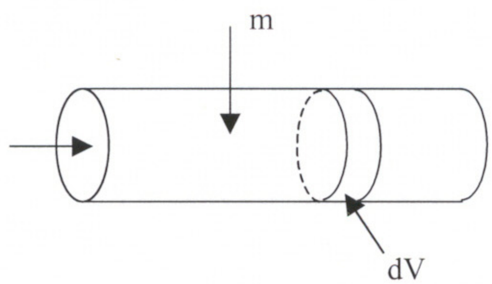
$$CaF + \frac{dMO_2}{dt} = CvF$$

measure mass flow rate of O_2

$$F = \frac{\frac{dMO_2}{dt}}{Cv - Ca}$$

measure blood concentrations of O_2

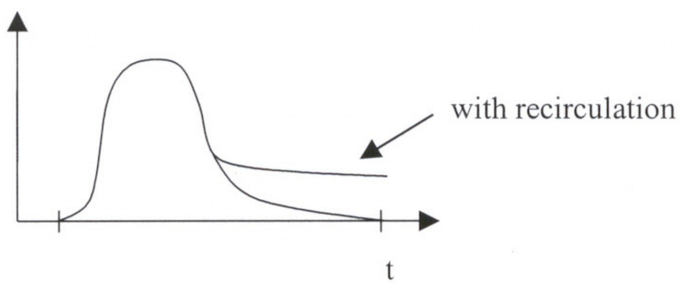
Rapid Injection



$$dm = C(t)dV$$

$$\frac{dm}{dt} = C(t)\frac{dV}{dt} \qquad \frac{dV}{dt} = F_i$$

$$dm = F_i C(t)dt$$



$m = \int_0^{t_1} F_i C(t)dt$, assuming $F_i = constant$

injected dye

$$\overline{F} = \frac{m}{\int_0^{t_1} C(t)dt}$$

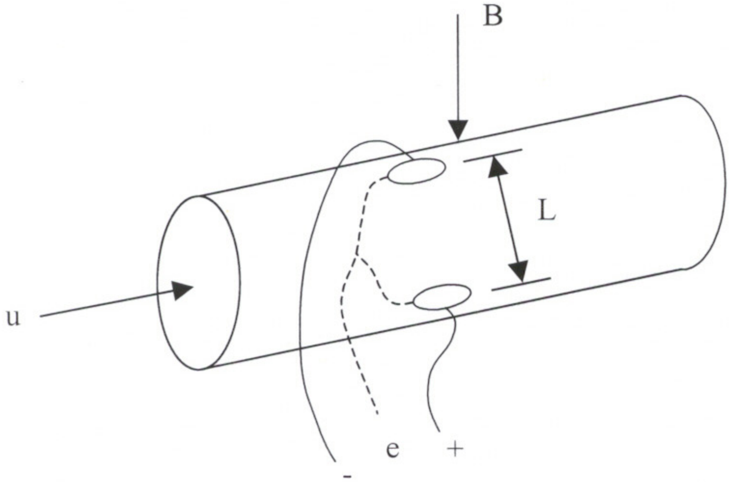
Thermodilution

$$\overline{F} = \frac{Q}{e_f C_f \int_0^{t_1} \Delta T_f dt}$$

Injectable

$$Q = V_i \Delta T_i e_i C_i$$

Electromagnetic Flow Meters – Conductive Fluid



$e = \int_0^{L_1} u \times B \bullet dL$

$e = BLu$ (if orthogonal)
B = magnetic density, T
L = distance between electrodes, m
u = instantaneous velocity of blood, m/s

DC – Operation – Not Used

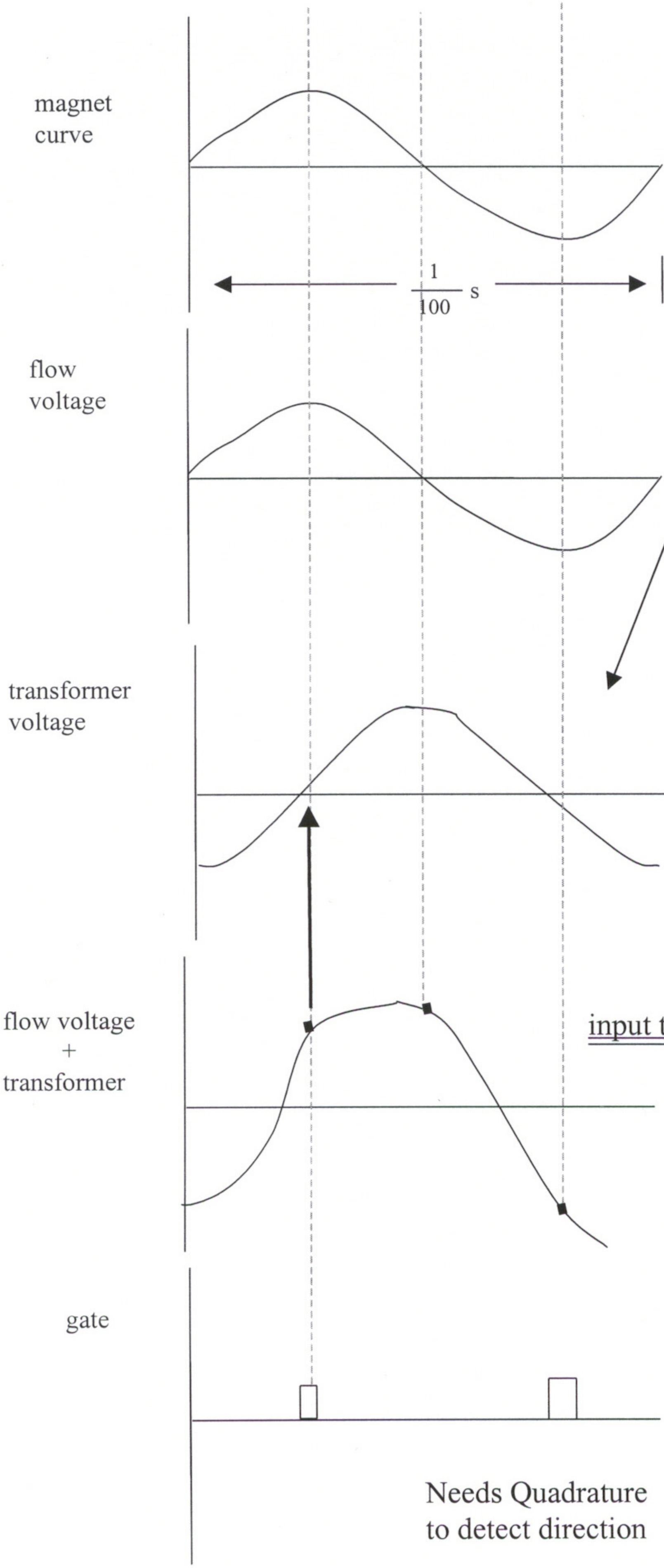
1) Electrode-to-solution interface produces voltages in series with flow voltage e. Changes in this voltage causes drift problems to occur in DC.

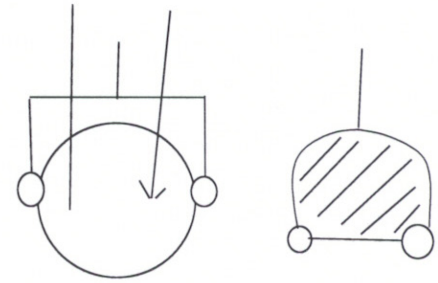
AC – Operation

1) Reduces problems with DC systems
2) Now introduces another problem – transfer voltage

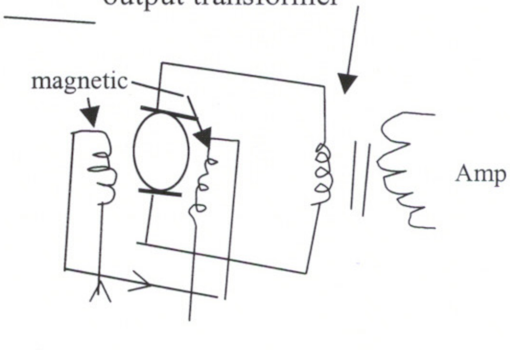
If loop produced by wires and electrodes is not exactly parallel to the B field, a voltage is induced in loop.

$E = -K\frac{dB}{dt}$ 90° out of phase with magnet current and flow voltages



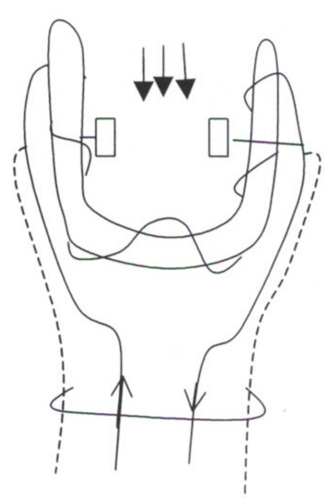


if electrode “plane” is not “exactly” parallel to B field, a voltage is induced on the output transformer



input to amplifiers

Probe Design

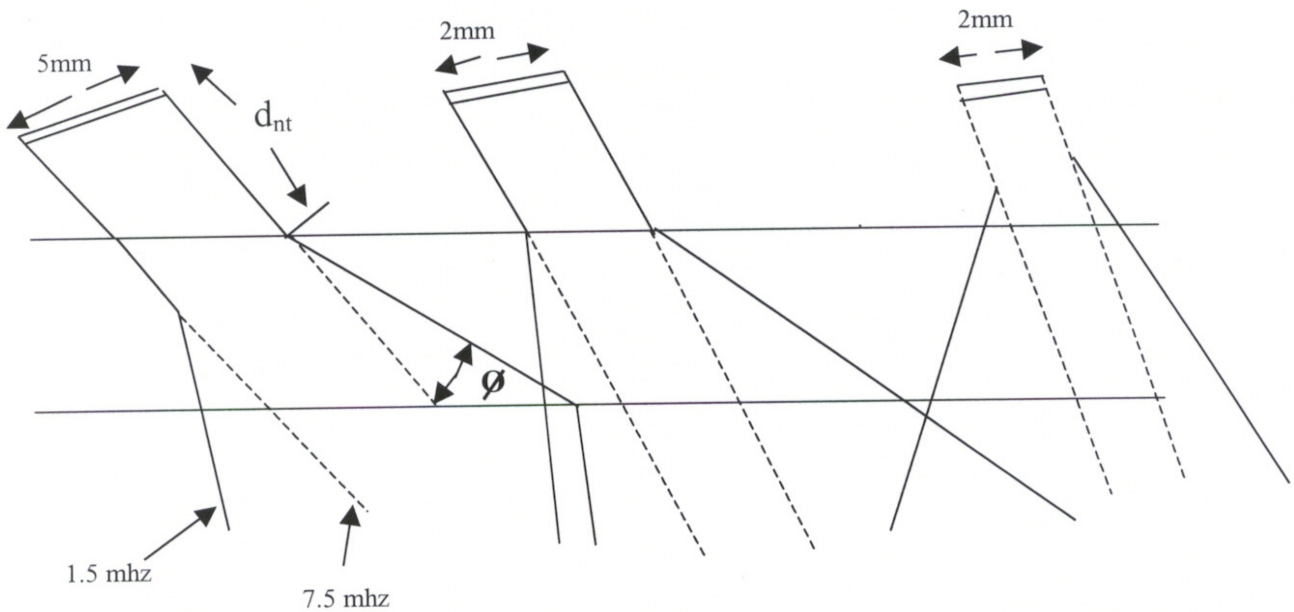


Needs Quadrature to detect direction

Ultrasound

Transducers-

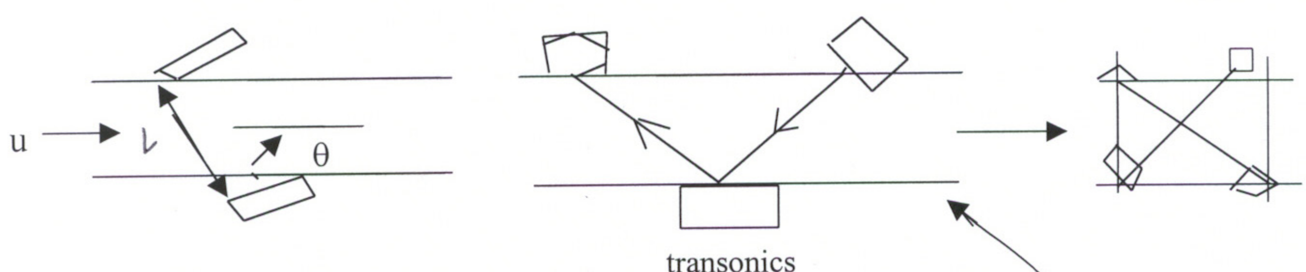
Lead zirconate tatanate



$$d_{nf} = \frac{D^2}{4\lambda} \qquad \sin\phi = \frac{1.2\lambda}{D}$$

want large D small λ

Transit time: - <u>Art</u>^{2} -Triton



$$t = \frac{\text{Distance}}{\text{Velocity}} = \frac{L}{C \pm u\cos\theta} \qquad \frac{L}{C + u\cos\theta} - \frac{L}{C - u\cos w}$$

upstream - downstream

+ downstream
- upstream

$$\overline{C^2 - u^2\cos^2\theta}$$

$$\Delta t = \frac{2Lu\cos\theta}{C^2 - u^2\cos^2\theta} \approx \frac{2Lu\cos\theta}{C^2}$$

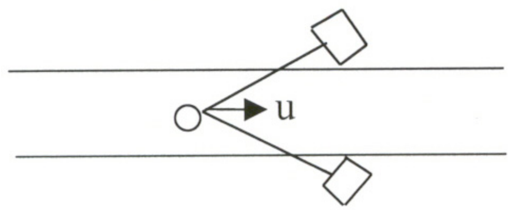
$\Delta t \longrightarrow$ nanoseconds

Doppler

In General,

$$\frac{fd}{fo} = \frac{u}{c}$$

fd = doppler shift
fo = source frequency
u = target velocity
c = velocity of sound



$$\frac{fd}{fo} = \frac{2u}{C+u} \approx \frac{2u}{C}$$

for flow not along axis

$$\frac{fd}{fu} = \frac{2u\cos\theta}{C}$$