EE 4BD4 Lecture 16

Piezoelectric Transducers and Application

Piezoelectricity Theory

- Reversible system (Strain ⇆ Electrical Potential)
- Asymmetrical crystal lattice with distortion producing equal and opposite charge on each surface
- Total induced charge $q = kf$ *where* f = force in Newtons, k = piezoelectric constant Coulombs/Newton

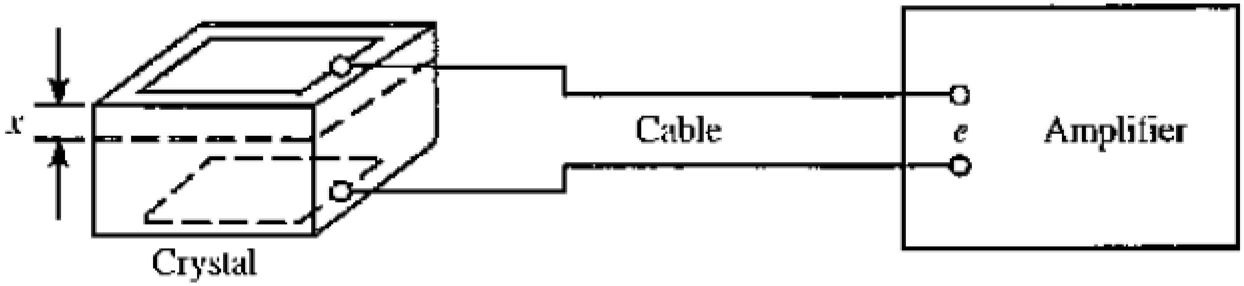
Piezoelectric Materials

- Typical values for k are 2.3 pC/n for quartz and 140 pC/n for barium titanate
- For sensor 1 cm^2 area and 1 mm thick a 10 g weight would give .23 and 14 mV respectively
- Can have different crystallographic structures to give thickness or longitudinal compression, transversal compression, thickness-shear and face shear
- Can also be had in polymeric films such as polyvinylidine flouride (PVDF) which are very thin and pliable

Piezoelectric Theory (cont’d)

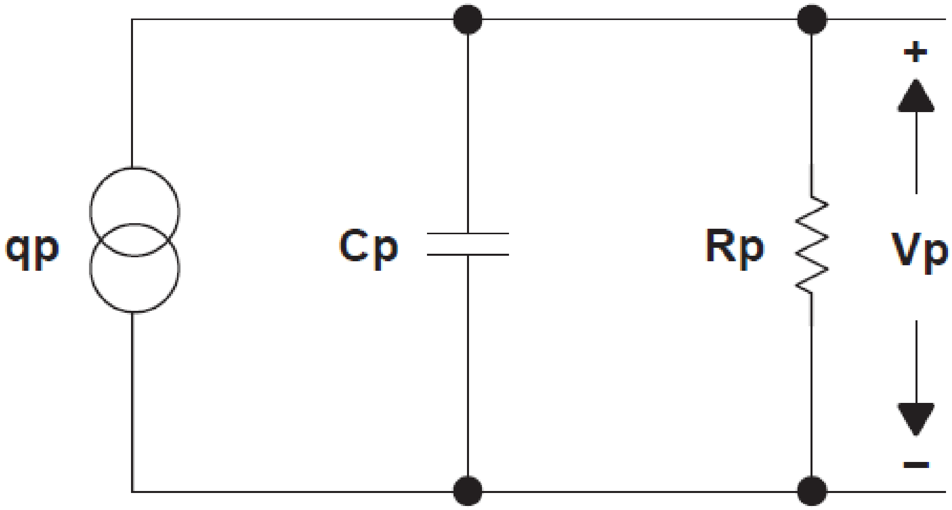
- Can be seen as a parallel plate capacitor with voltage

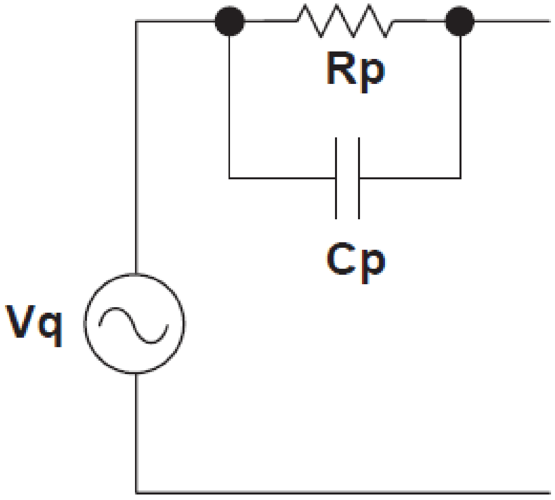
$$v = \frac{kf}{C} = \frac{kfx}{\varepsilon_0 \varepsilon_r A}$$



Sensor Models

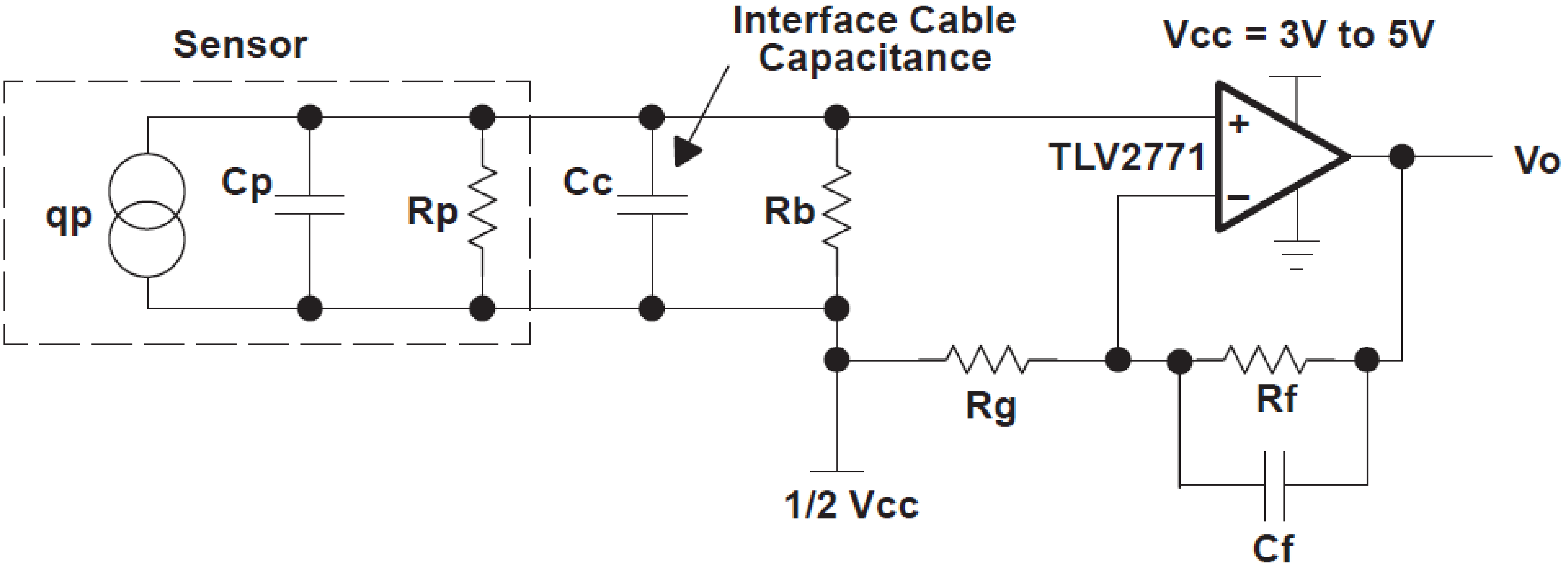
- Cp is sensor capacitance, Rp is sensor resistance


Charge Model


Voltage Model

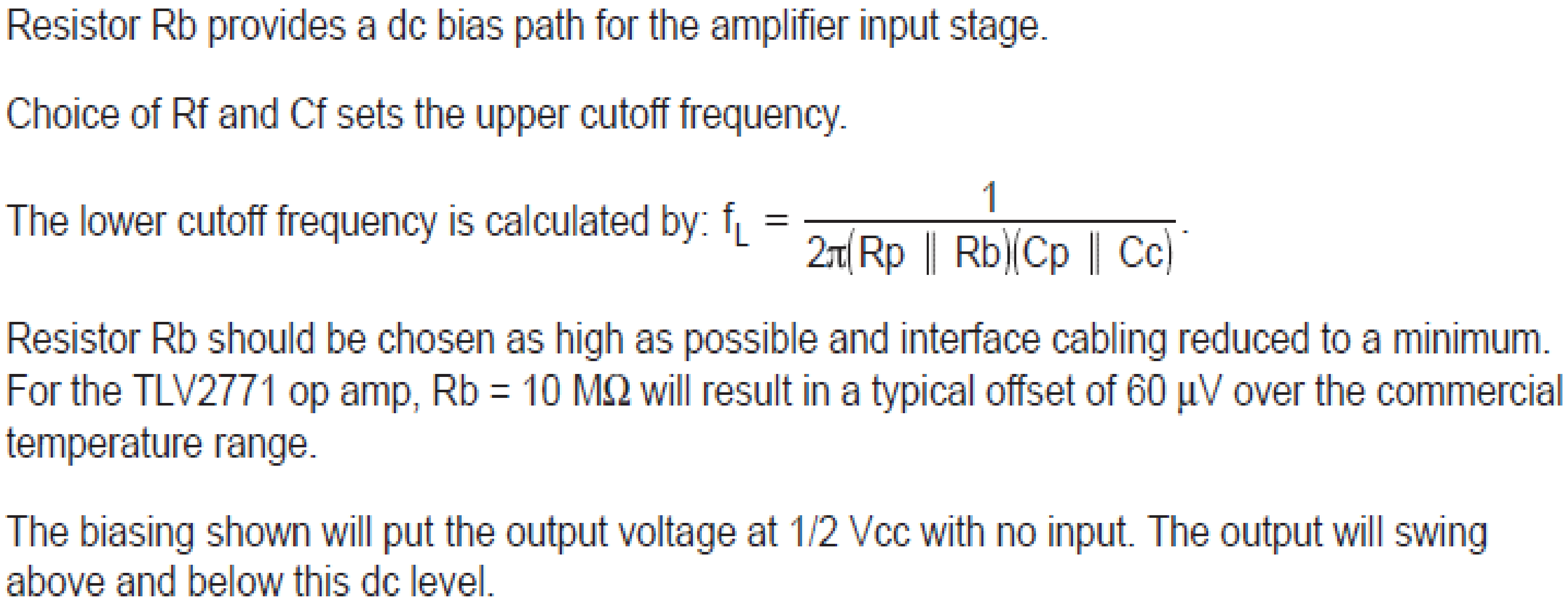
Signal Conditioning

Voltage Mode Amplifier



$$V_o = \frac{q_p}{(C_p + C_c)} \times \left[1 + \frac{R_f}{R_g}\right] + \frac{V_{cc}}{2}$$

Signal Conditioning (cont’d)



Resistor Rb provides a dc bias path for the amplifier input stage.

Choice of Rf and Cf sets the upper cutoff frequency.

The lower cutoff frequency is calculated by: $f_L = \dfrac{1}{2\pi(Rp \parallel Rb)(Cp \parallel Cc)}$.

Resistor Rb should be chosen as high as possible and interface cabling reduced to a minimum. For the TLV2771 op amp, Rb = 10 MΩ will result in a typical offset of 60 µV over the commercial temperature range.

The biasing shown will put the output voltage at 1/2 Vcc with no input. The output will swing above and below this dc level.

Gain Characteristics

- In voltage mode cable capacitance plays a part and motion artifact altering cable capacitance could be a problem

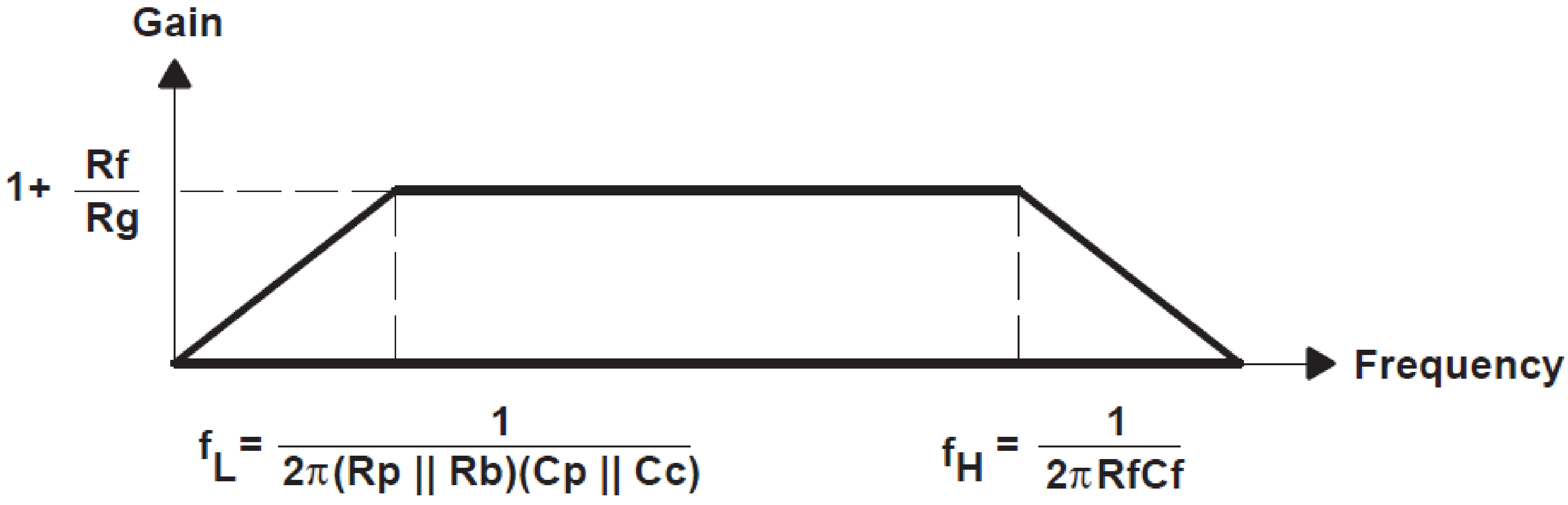
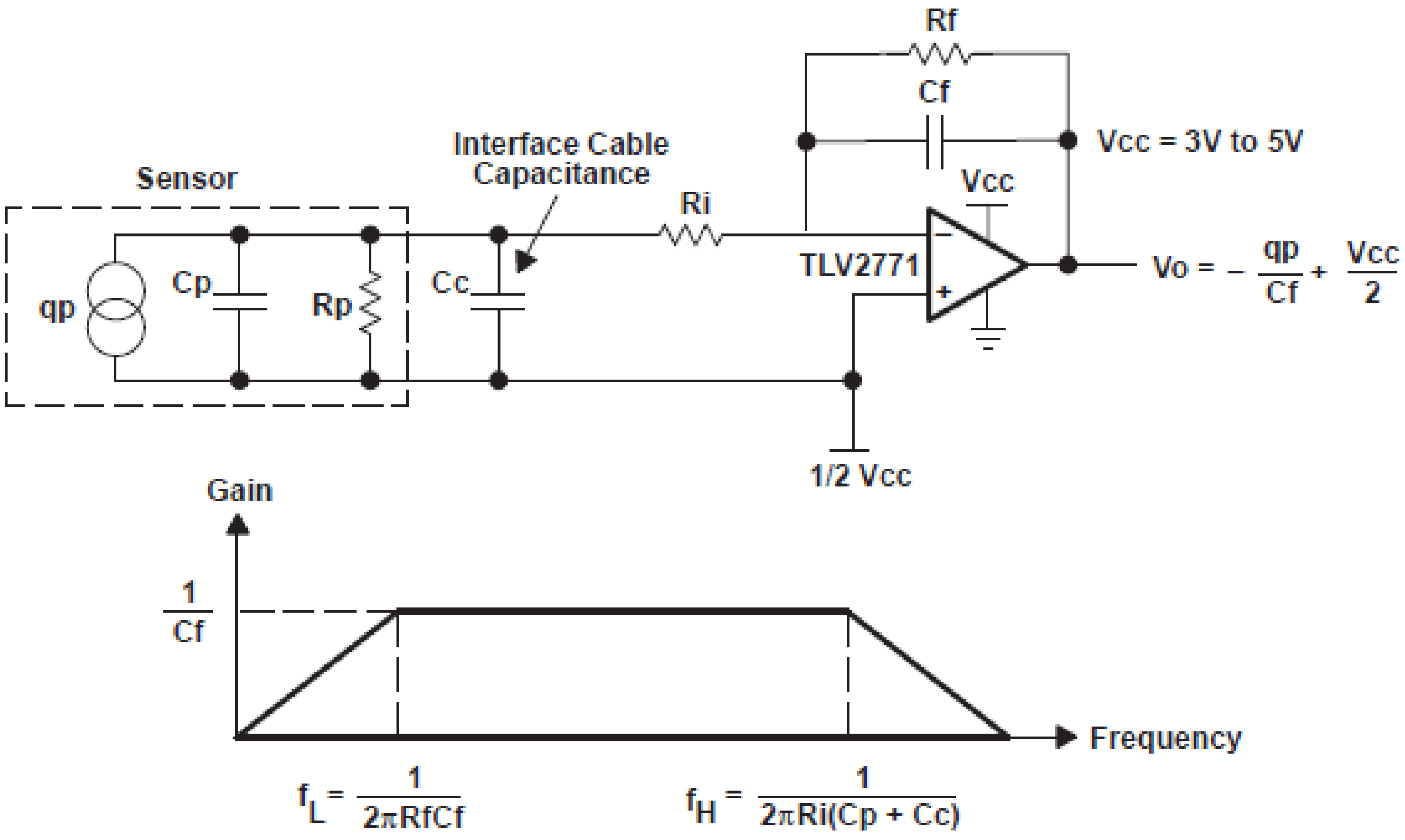


Figure 2. Voltage Mode Amplifier Circuit

Alternate Signal Conditioning

Charge Mode Amplifier



The charge mode amplifier will balance the charge injected into the negative input by charging feedback capacitor Cf. Resistor Rf bleeds the charge off capacitor Cf at a low rate to prevent the amplifier from drifting into saturation. Resistor Rf also provides a dc bias path for the negative input. The value of Rf and Cf set the low cutoff frequency of the amplifier.

The action of the amplifier maintains 0 V across its input terminals so that the stray capacitance associated with interface cabling does not present a problem. Resistor Ri provides ESD protection. Resistor Ri and capacitors Cp and Cc combine to produce roll off at higher frequency.

The biasing shown will put the output voltage at 1/2 Vcc with no input. The output will swing around this dc level.

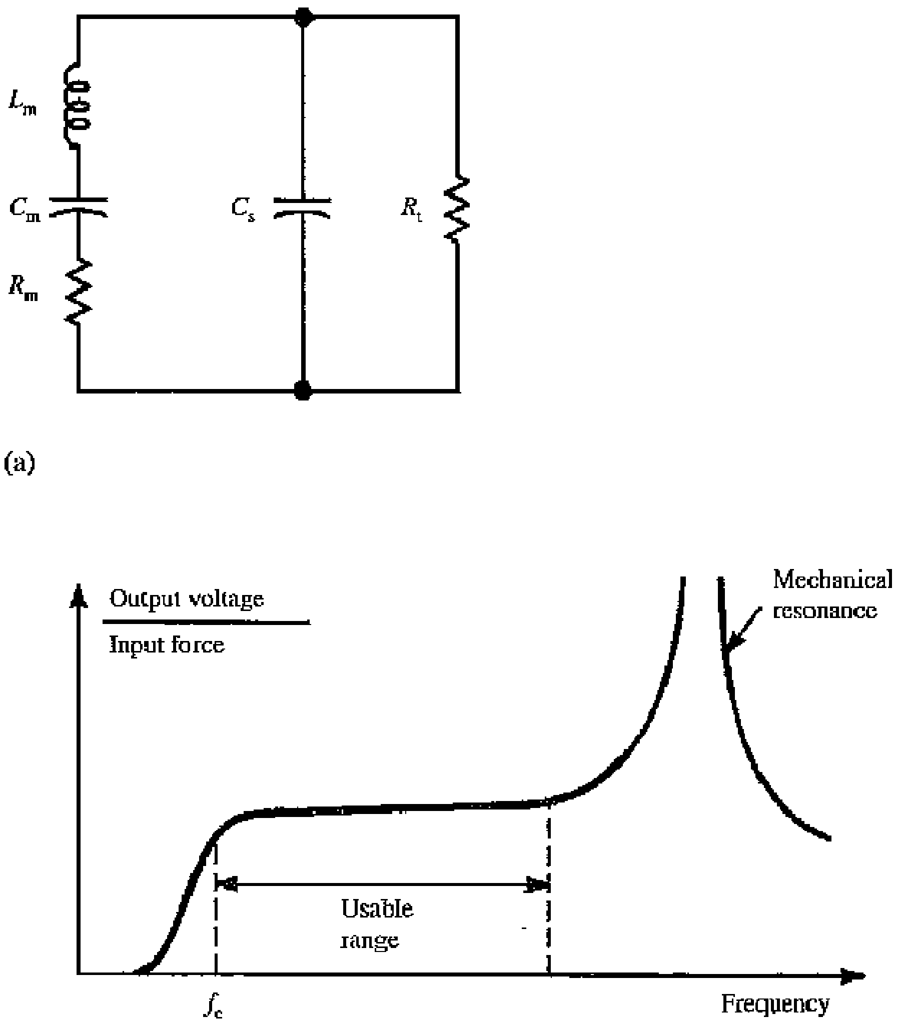
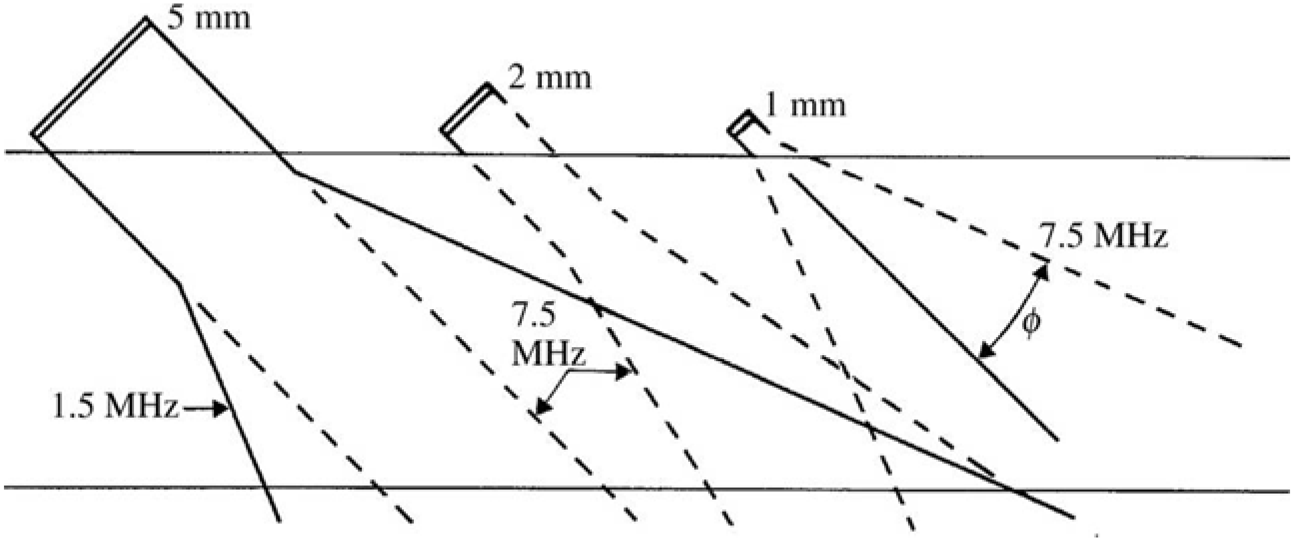


Figure 2.12 (a) High-frequency circuit model for piezoelectric sensor. R_s is the sensor leakage resistance and C_s is the capacitance. L_m, C_m, and R_m represent the mechanical system, (b) Piezoelectric sensor frequency response. (From *Transducers for Biomedical Measurements: Principles and Applications*, by R. S. C. Cobbold. Copyright (c) 1974, John Wiley and Sons, Inc. Reprinted by permission of John Wiley and Sons, Inc.)

Ultrasonic Flowmeters

- Measure blood flow transcutaneously by injecting and receiving ultrasound signals
- Material can be lead zirconate titanate that has a very high energy conversion efficiency
- Crystal is one-half wavelength thick for maximum efficiency
- Produces a diffraction pattern just as an aperture does in optics
- Beam pattern has near field with concentrated energy and little spreading and depth d_{nf} and spread an angle ϕ as shown



$$d_{\text{nf}} = \frac{D^2}{4\lambda}$$

$$\sin\phi = \frac{1.2\lambda}{D}$$

D = transducer diameter
λ = wavelength

Continuous-Wave Doppler Flowmeter

- When a target recedes from a fixed source that transmits sound, the frequency of the received sound is lowered because of the Doppler effect
- For small changes, fractional change in frequency = fractional change in velocity

$$\frac{f_d}{f_0} = \frac{u}{c}$$

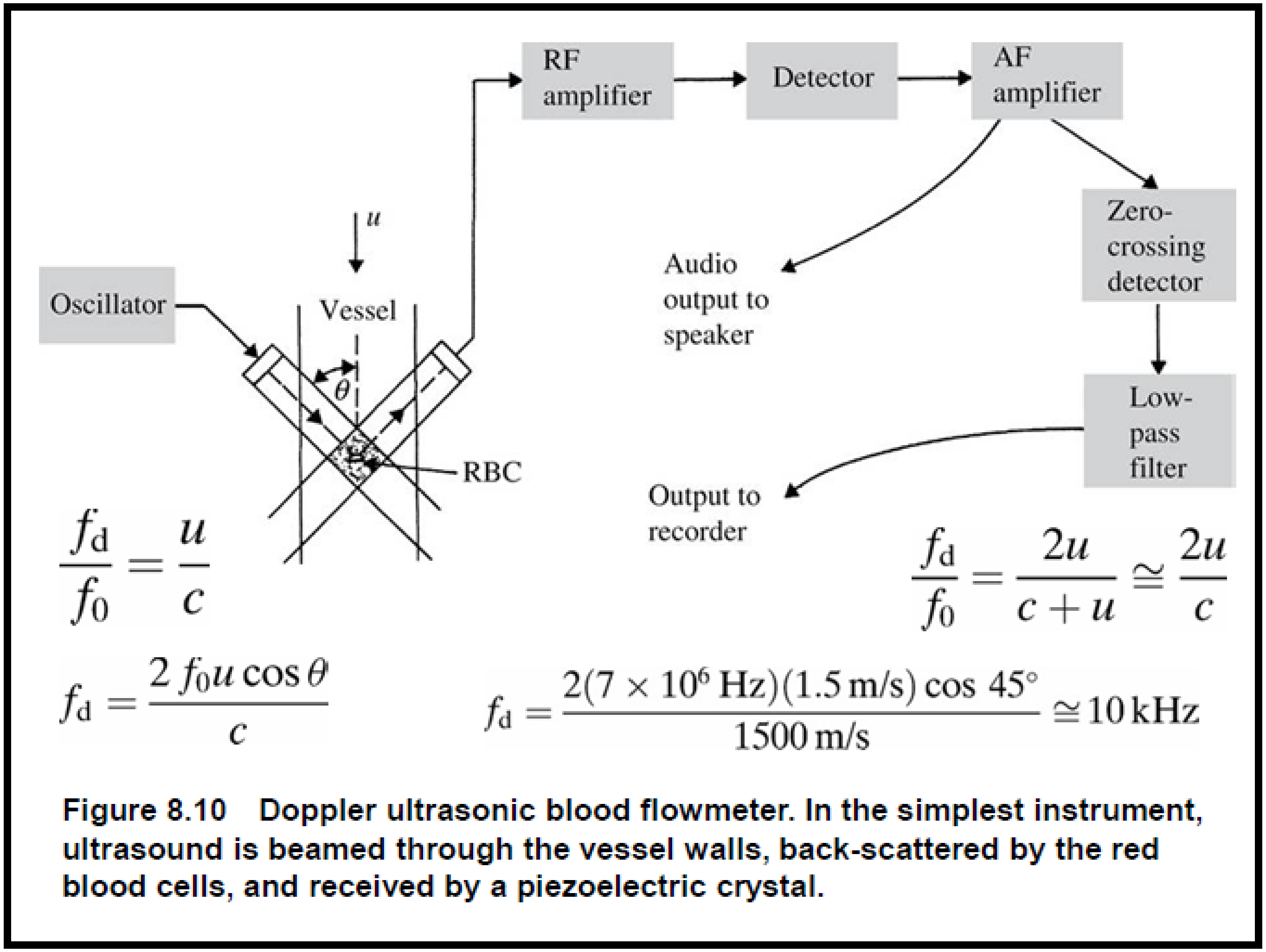
where

f_d = Doppler frequency shift

f_0 = source frequency

u = target velocity

c = velocity of sound



$$\frac{f_d}{f_0} = \frac{u}{c}$$

$$\frac{f_d}{f_0} = \frac{2u}{c+u} \cong \frac{2u}{c}$$

$$f_d = \frac{2\,f_0 u \cos\theta}{c}$$

$$f_d = \frac{2(7 \times 10^6\ \text{Hz})(1.5\ \text{m/s}) \cos 45^\circ}{1500\ \text{m/s}} \cong 10\ \text{kHz}$$

Figure 8.10 Doppler ultrasonic blood flowmeter. In the simplest instrument, ultrasound is beamed through the vessel walls, back-scattered by the red blood cells, and received by a piezoelectric crystal.

Technical Considerations

- Oscillator must have low output impedance to drive the crystal because it operates in resonance with an input impedance of about 100 Ω.

The Doppler-shifted signal is not at a single frequency, as implied by (8.15), for several reasons.

1. Velocity profiles are rarely blunt, with all cells moving at the same velocity. Rather, cells move at different velocities, producing different shifts of the Doppler frequency.
2. A given cell remains within the beam-intersection volume for a short time. Thus the signal received from one cell is a pure frequency multiplied by some time-gate function, yielding a band of frequencies.
3. Acoustic energy traveling within the main beam, but at angles to the beam axis, plus energy in the side lobes, causes different Doppler-frequency shifts due to an effective change in θ.
4. Tumbling of cells and local velocities resulting from turbulence cause different Doppler-frequency shifts.