Universidad de Valparaíso
CHILE

# Transductores inductivos

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Ingeniería Civil Biomédica

Dr. Alejandro Veloz

alejandro.veloz@uv.cl

# Tipos de transductores

Resistivos

Capacitivos

Piezoeléctricos

**Inductivos/magnéticos**

Térmicos

Radiación/ópticos

Electroquímicos (Cap. 4)

# Transductores de Inductancia Variable

Basados en la Ley de Inducción de Faraday

**Principio:**

- Cambio en la inductancia produce una fuerza electromotriz
- Esto se puede usar para medición y control de desplazamiento, presión y fuerza

# Tipos de Transductores de Inductancia Variable

- Autogeneradores:
  - Electromagnéticos
  - Electrodinámicos
  - De corrientes de Eddy
- Pasivos:
  - De reluctancia variable
  - De inductancia mutua
  - Transformador diferencial de variación lineal (LVDT)

# Aplicaciones

- Medición de desplazamiento lineal y angular
- Sensores de presión y fuerza
- Acelerómetros
- Medidores de flujo
- Sistemas de control industrial
- IoT
- …

# Ventajas / desventajas

- Alta sensibilidad y precisión
- Robustez y durabilidad
- Salida lineal en un amplio rango
- Miniaturización para aplicaciones MEMS
- Integración con sistemas digitales y IoT

- Sensibilidad a campos magnéticos externos
- Necesidad de excitación (en tipos pasivos)
- Limitaciones en frecuencia de operación

# Sensores inductivos

$$L = n^2 G \mu$$

n: número de vueltas de la bobina.
G: factor de forma.
μ: permeabilidad.

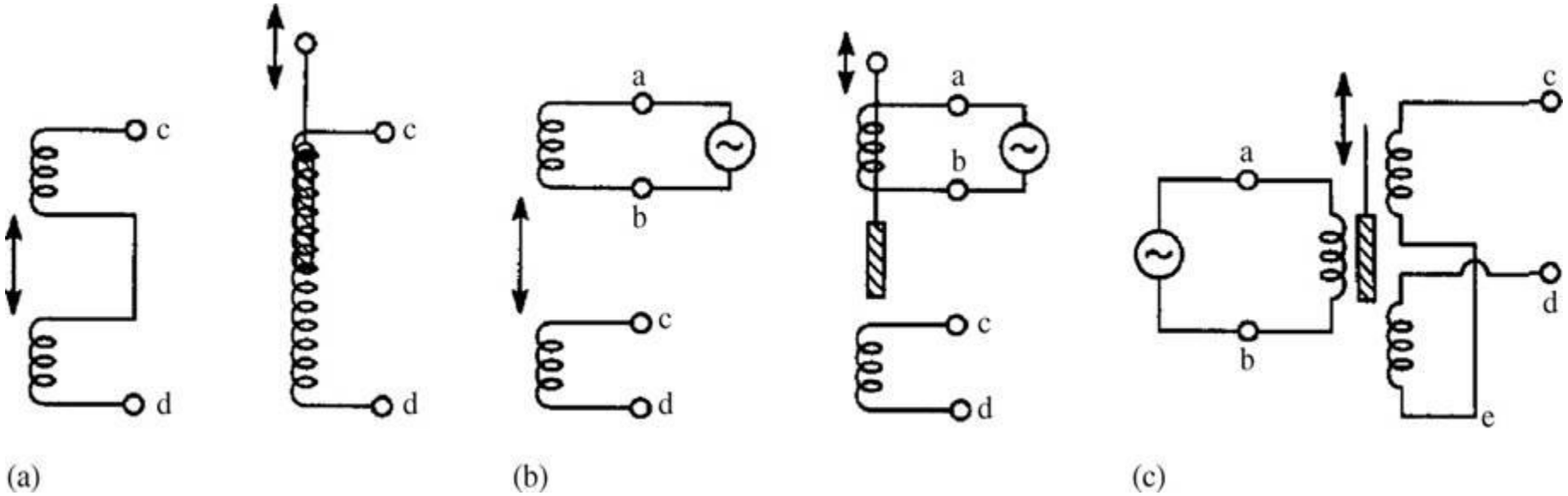



**Figure 2.7 Inductive displacement sensors (a) Self-inductance, (b) Mutual inductance, (c) Differential transformer.**

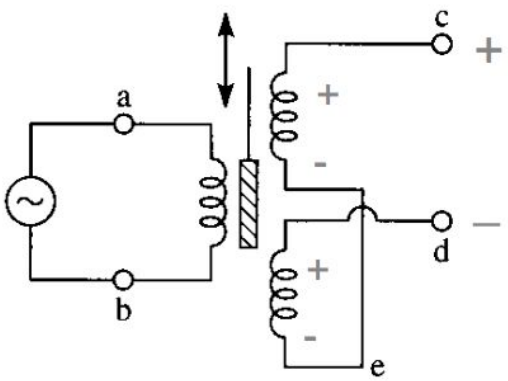
# Sensores inductivos

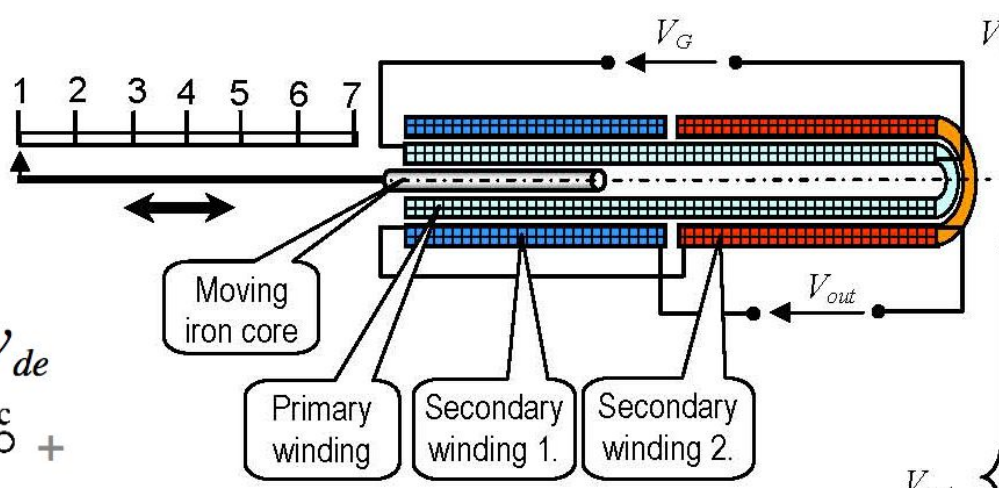
- Desplazamientos en el rango 0.1-250 mm
- 0.5-2 mV para un desplazamiento de 0.01mm
- sensibilidad mayor en relación a las GE

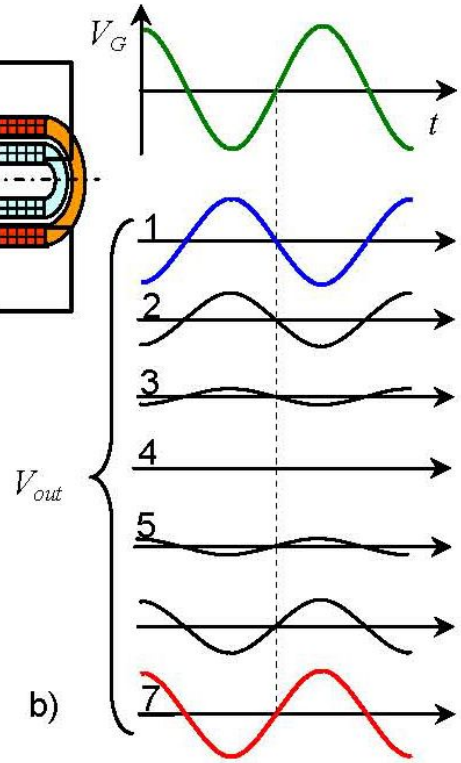
Desventaja: requiere procesamiento de señal más complejo.

http://www.macrosensors.com/lvdt_macro_sensors/lvdt_tutorial/lvdt_primer.pdf

$$v_o = v_{cd} = v_{ce} - v_{de}$$



# Sensores inductivos

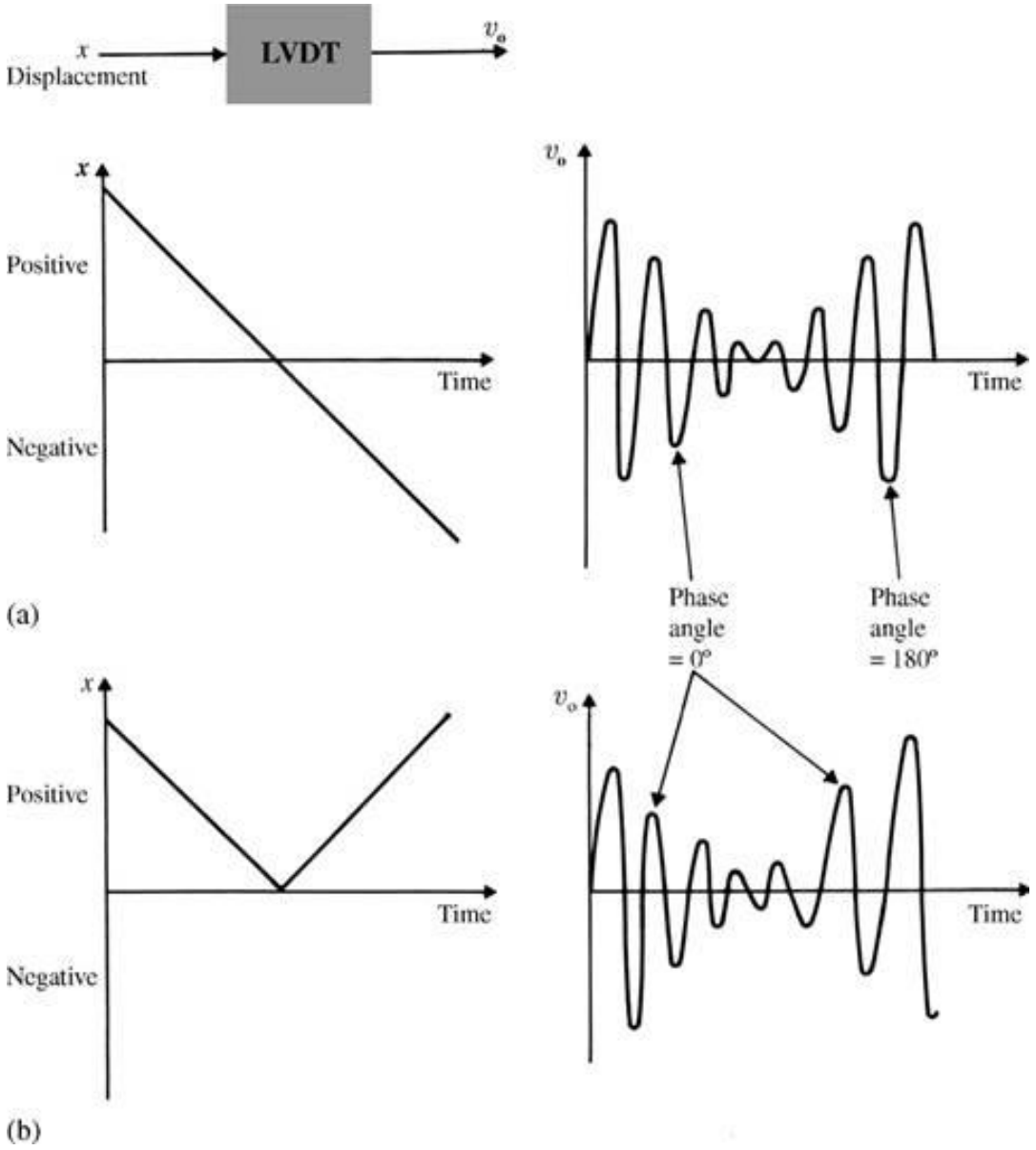
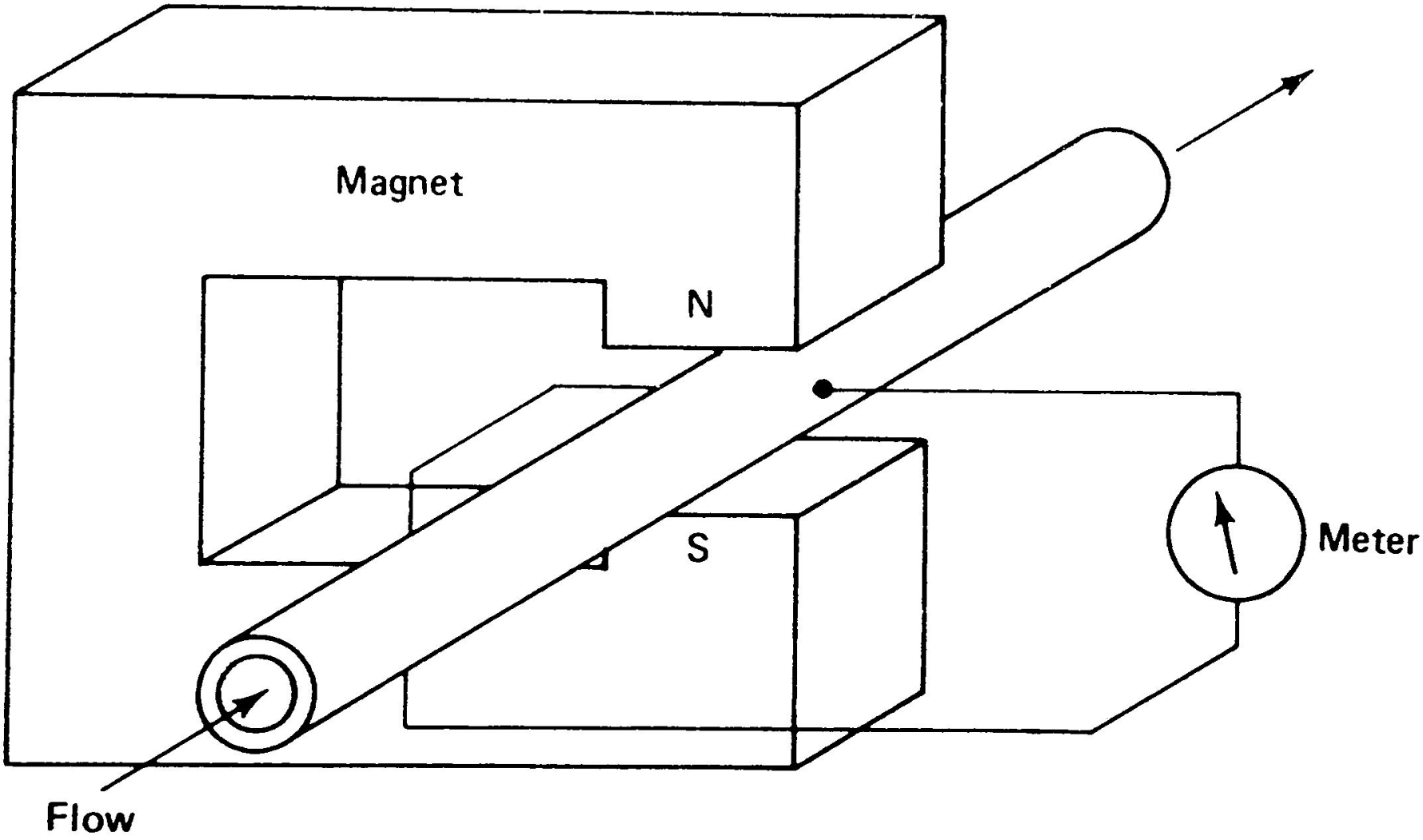



**Figure 2.8 (a) As x moves through the null position, the phase changes 180°, while the magnitude of $v_o$ is proportional to the magnitude of x. (b) An ordinary rectifier-demodulator cannot distinguish between (a) and (b), so a phase-sensitive demodulator is required.**

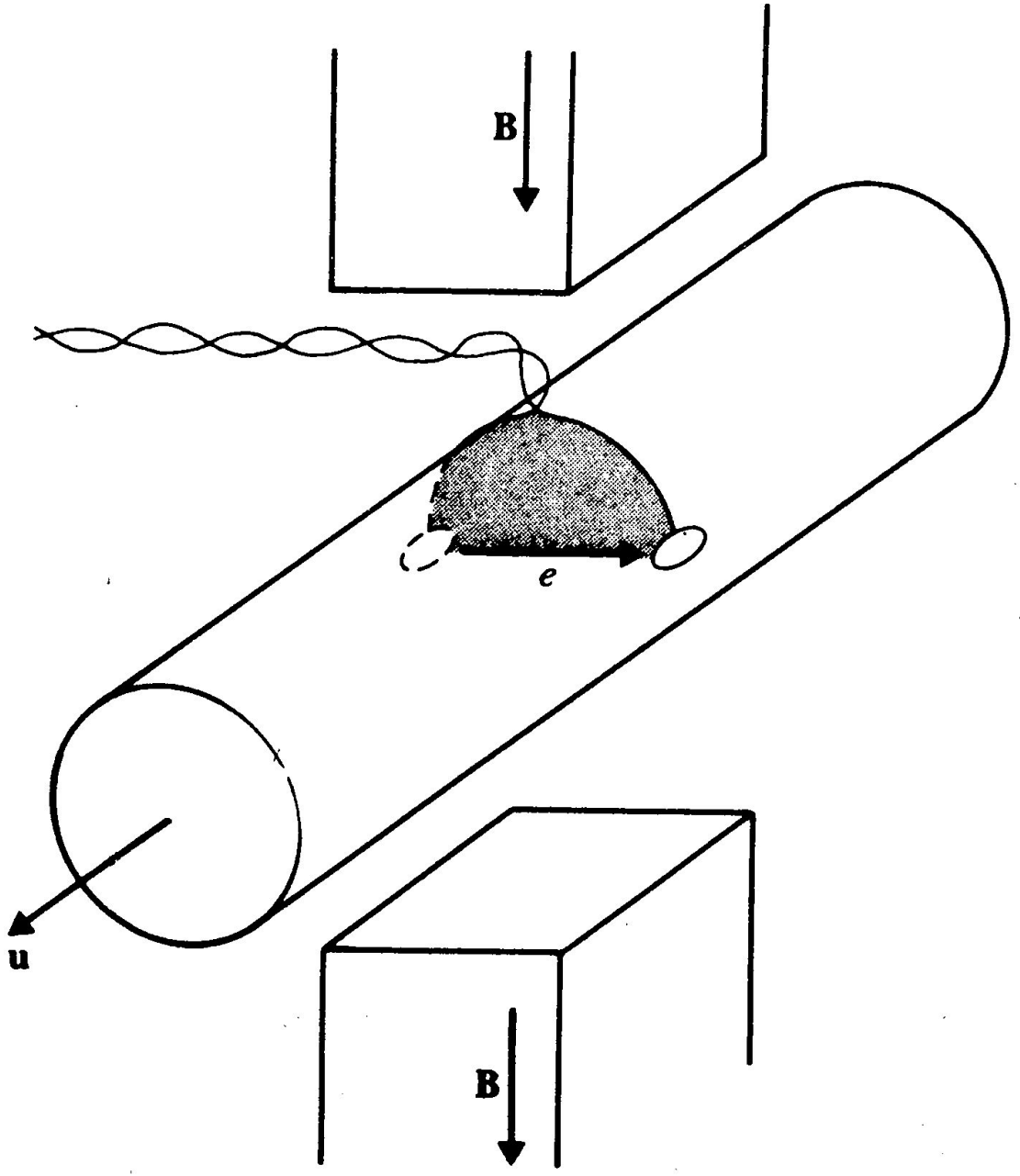
# Electromagnetic Blood Flow Meters

- Measures **instantaneous pulsatile flow of blood**
- Works based on the principle of electromagnetic induction
  - The voltage induced in a conductor moving in a magnetic field is proportional to the velocity of the conductor
- The **conductive blood is the moving conductor**

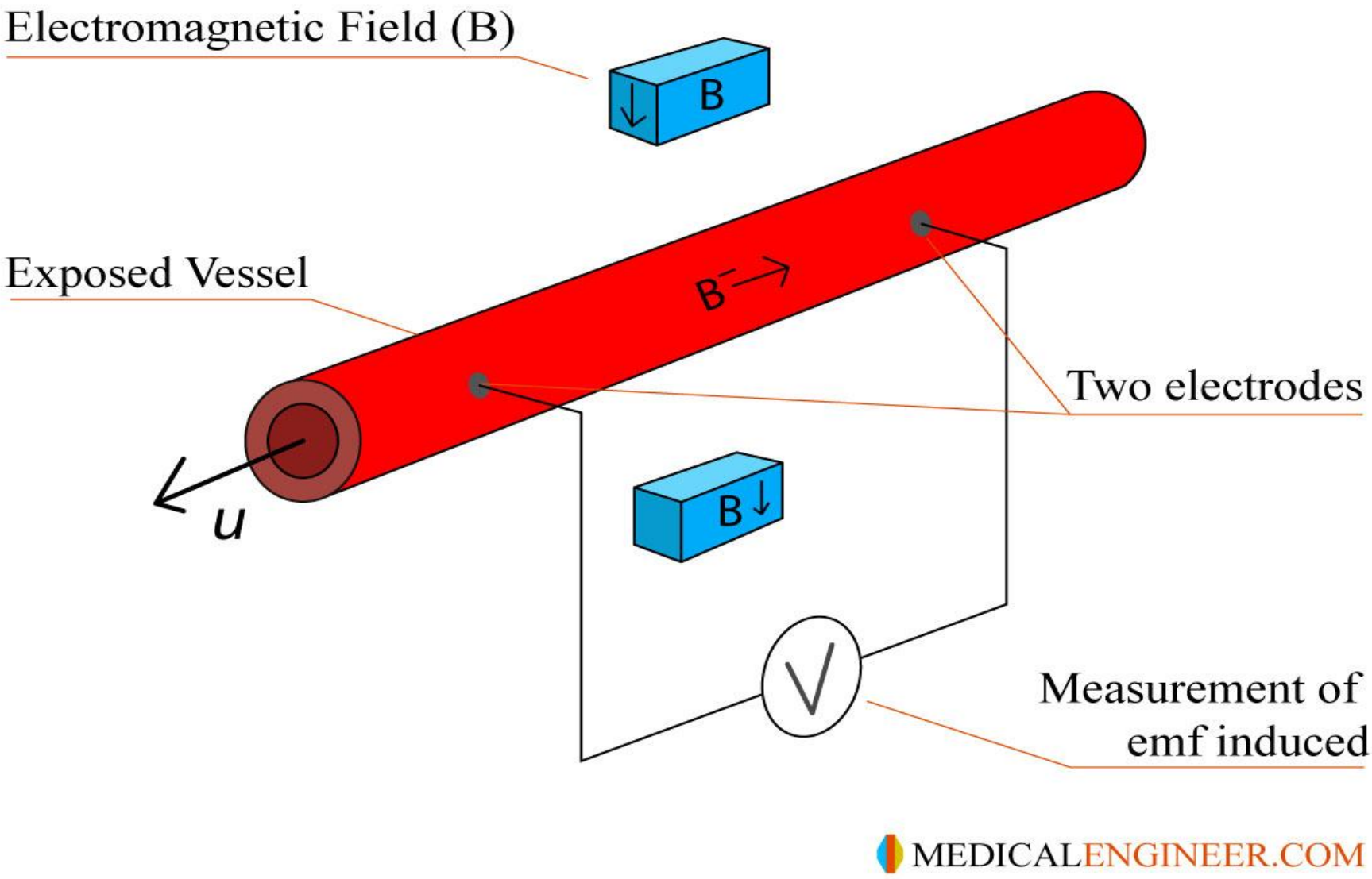
# Principle of Electromagnetic Blood Flow Meters



# Principle of Electromagnetic Blood flow Measurement



# ELECTROMAGNETIC FLOWMETER



# Principle of Electromagnetic Blood Flow Meters

- A **permanent magnet or electromagnet** positioned **around the blood vessel** generates a magnetic field perpendicular to the direction of the flow of the blood.
- **Voltage induced** in the moving blood column is **measured with stationary electrodes** located on opposite sides of the blood vessel and perpendicular to the direction of the magnetic field.

# Principle of Electromagnetic Blood Flow Meters

The Induced ***emf***

$$e = \int_0^{L_1} \mathbf{u} \times \mathbf{B} \cdot d\mathbf{L}$$

where:

**B** is the magnetic flux density, T

**L** is the length between electrodes, m

**u** is the instantaneous velocity of the conductor (blood) moving through the magnetic field, m/s

# Ejemplo

Considere un vaso sanguíneo expuesto a un campo magnético para la medición del flujo y los siguientes parámetros:

- Velocidad del flujo sanguíneo (u): 0.1 m/s
- Intensidad del campo magnético aplicado (B): 0.005 Tesla
- Longitud de los electrodos de detección (L): 0.2 m

Asumiendo un **campo magnético uniforme** perpendicular a la dirección del flujo sanguíneo y un **flujo uniforme** la expresión de la Ley de Faraday

$$e = \int_0^{L_1} \mathbf{u} \times \mathbf{B} \cdot d\mathbf{L}$$

equivale a:

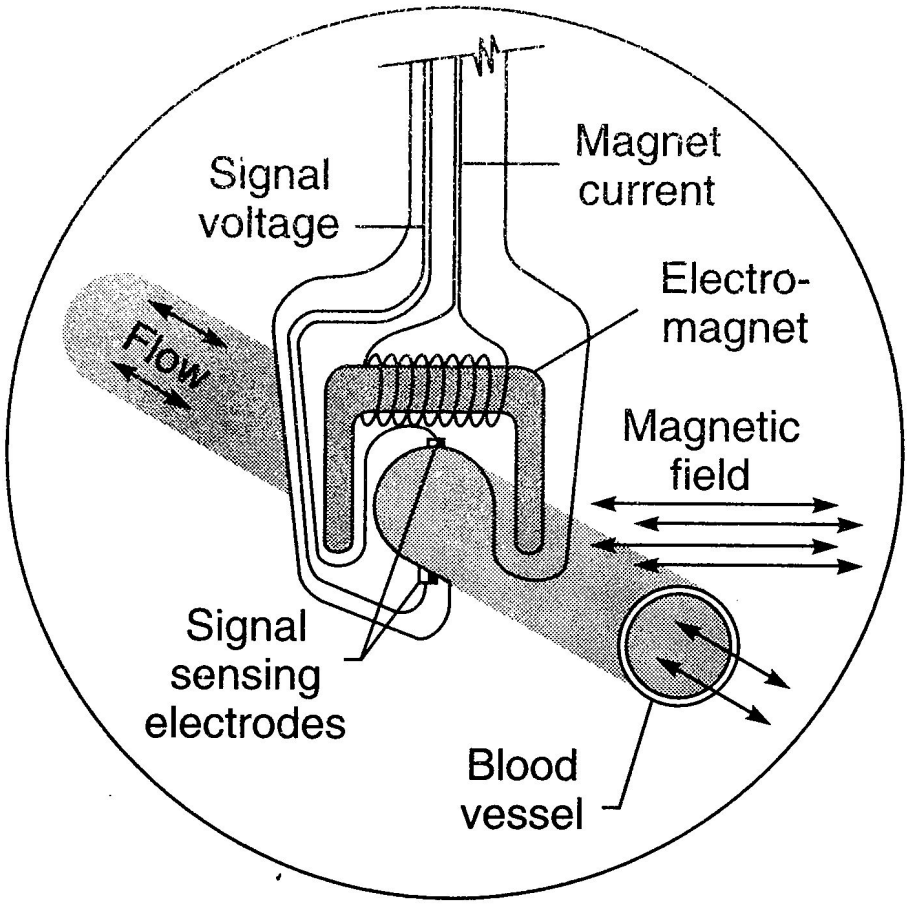
**e = u*B*L**

**Resolviendo se tiene:**

**e = 0.1 m/s** * **0.005 Tesla** * **0.2 m** = 0.0001 V

# Principle of Electromagnetic Blood Flow Meters

This method **requires that the blood vessel be exposed** so that the flow head or the measuring probe can be put across it.



# Design of Flow Transducers

- The electromagnetic flow-transducer **is a tube of non-magnetic material** to ensure that the magnetic flux does not bypass the flowing liquid and go into the walls of the tube.

- The tube is made of a **conducting material** and generally has an insulating lining to prevent short circuiting of induced emf.

- The induced emf is picked up by point **electrodes made from stainless steel or platinum.**

# Design of Flow Transducers

- The flow head contains a slot through which the intact blood vessel can be inserted to make a snug fit.

- Several probes of different sizes must therefore accompany the flowmeter to match the full range of sizes of the blood vessels which have various diameters.

- Flow heads having as small as 1mm are available.

# Types of Electromagnetic Blood Flow Meters

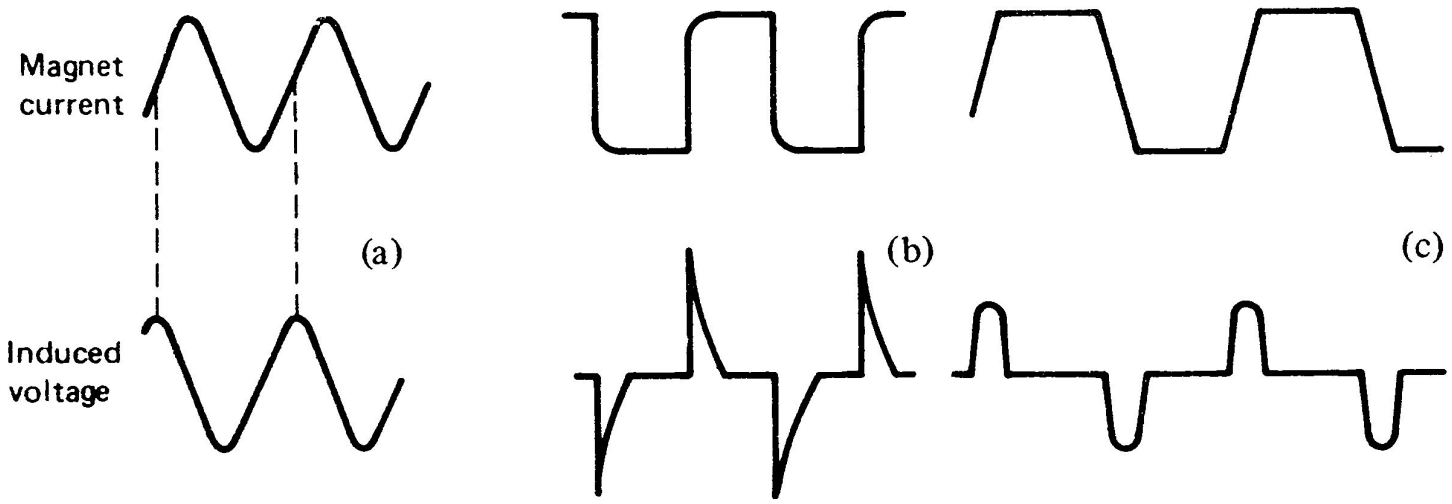
- **DC Flow meters**
  - Use DC Magnetic field.
  - Cause electrode polarization and amplifier drift.

- **AC Flow meters**
  - Electromagnets are driven by alternating currents.
  - The transducer acts like a Transformer and **induces error voltages** that often exceed the signal levels by several orders of magnitude.

# Electromagnetic AC flow meters

- Error recovery is achieved by using several different waveforms for magnet current

**Sine, Square, Trapezoidal**




- Suitable balancing circuits are used to balance out the error voltage.

# Sine wave Flowmeters

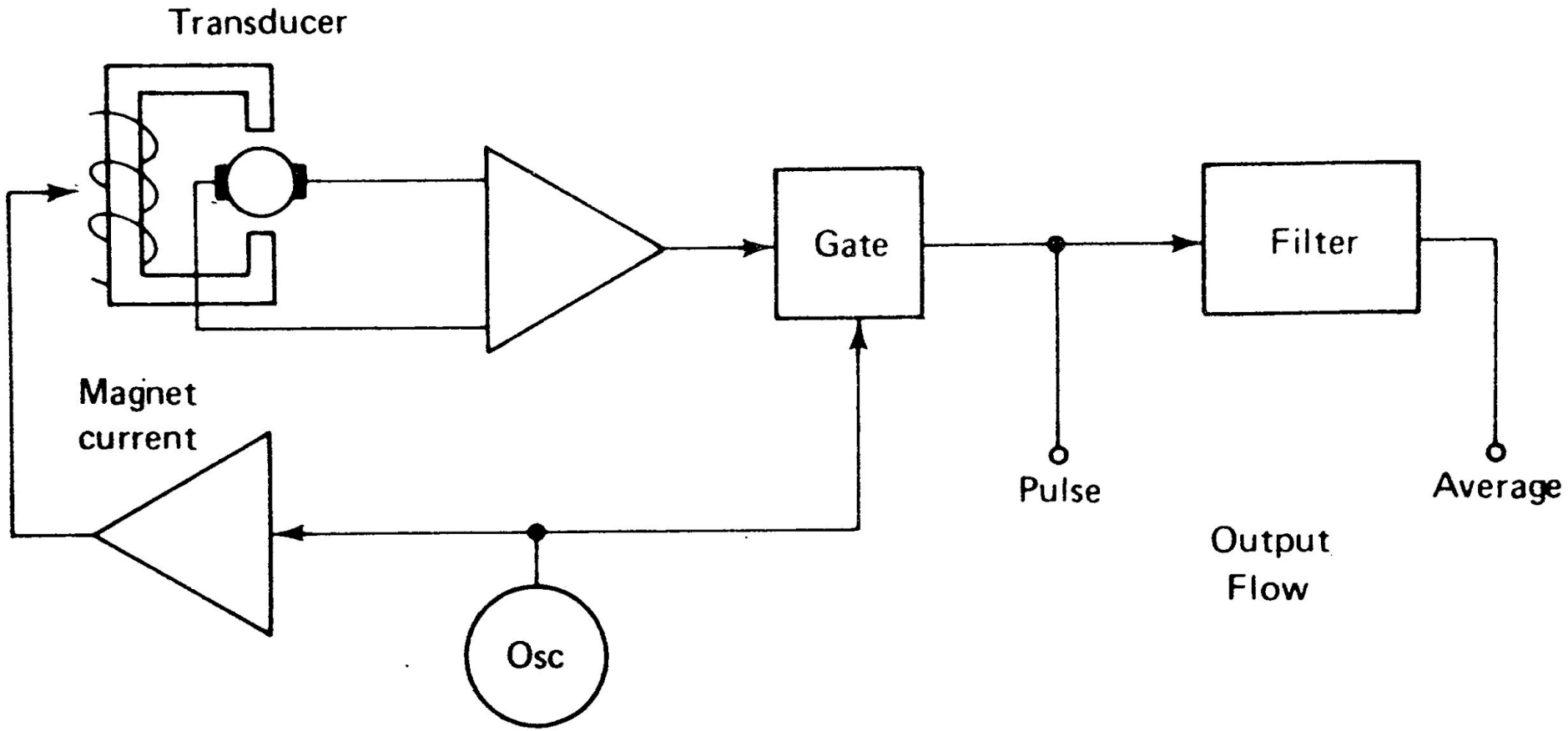
The transformer induced voltage is 90˚ out of phase and is eliminated by

- Injecting a voltage of equal strength and opposite phase into the signal.
- Using a gated amplifier.
  - Permit the amplification of the signal only during the flow induced voltages are maximum and the transformer induced voltages are minimum.

# Square wave Flowmeters

- The transformer induced voltage is only a spike.
- Separation is easier as the amplifier can be gated only for a very short period.
- Blanking is required only when the current in the magnet is reversing its direction and the amplifier works during the flat portion of the square wave.

# Magnetic Flowmeter Block Diagram



# Magnetic Flowmeter Block Diagram

- The oscillator, which drives the magnet provides a control signal for the gate, operates at a frequency of between 60 and 400 Hz.
- The frequency response is high enough to allow the recording of the flow pulses.
- The mean or average flow can be derived by use of a low-pass filter.