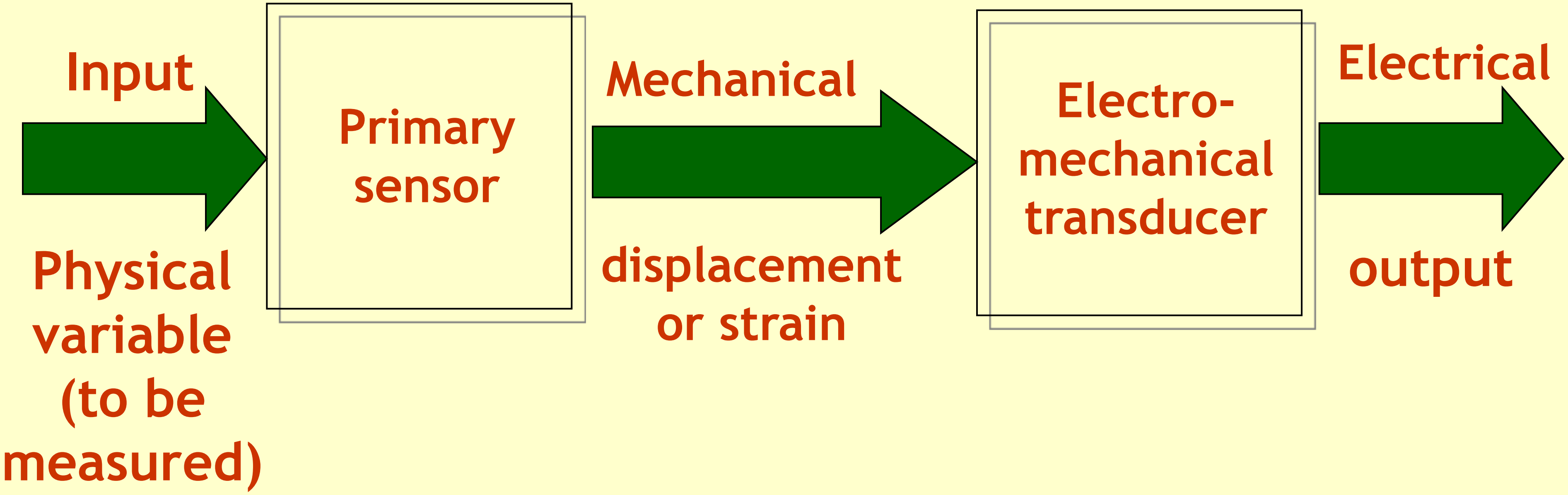
Displacement Transducers

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Motion Transducers

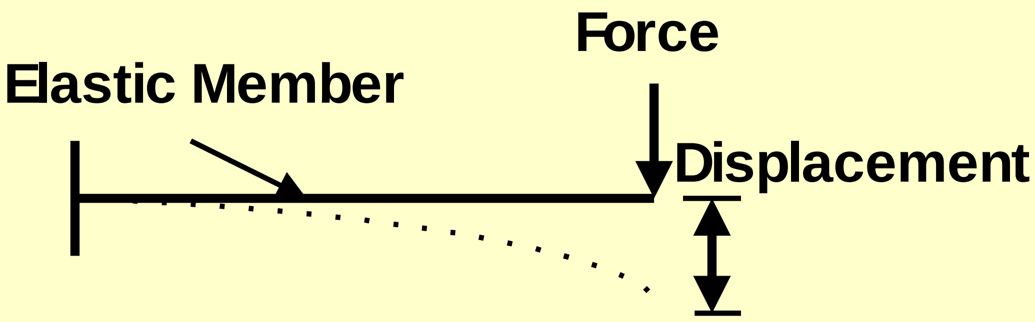
✓ **Electromechanical transducers produce an electrical output in response to an input of mechanical displacement or strain produced by physical variables like pressure, flow etc.**



Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Primary Sensors

Example 1

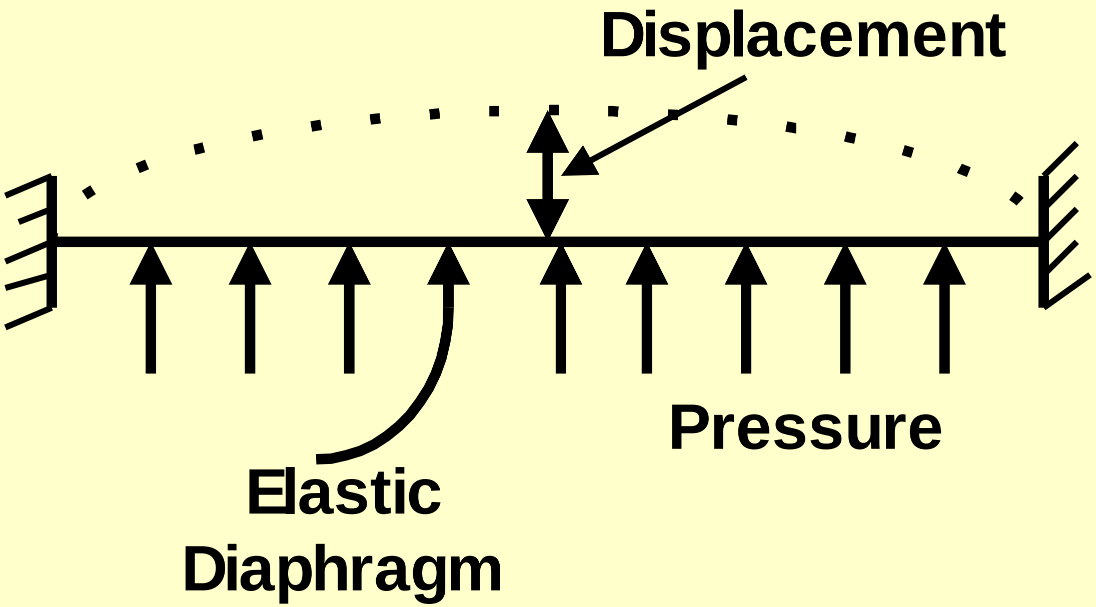


Primary Sensor for Force Input

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Primary Sensors

Example 2

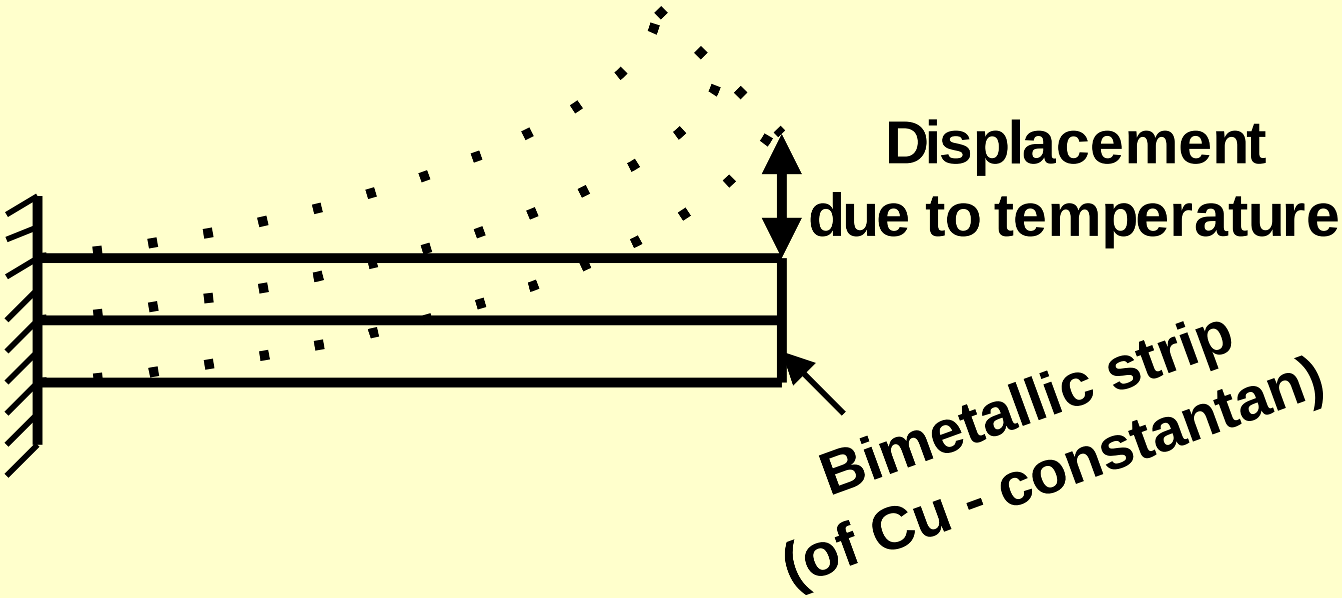


Primary Sensor for Pressure Input

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Primary Sensors

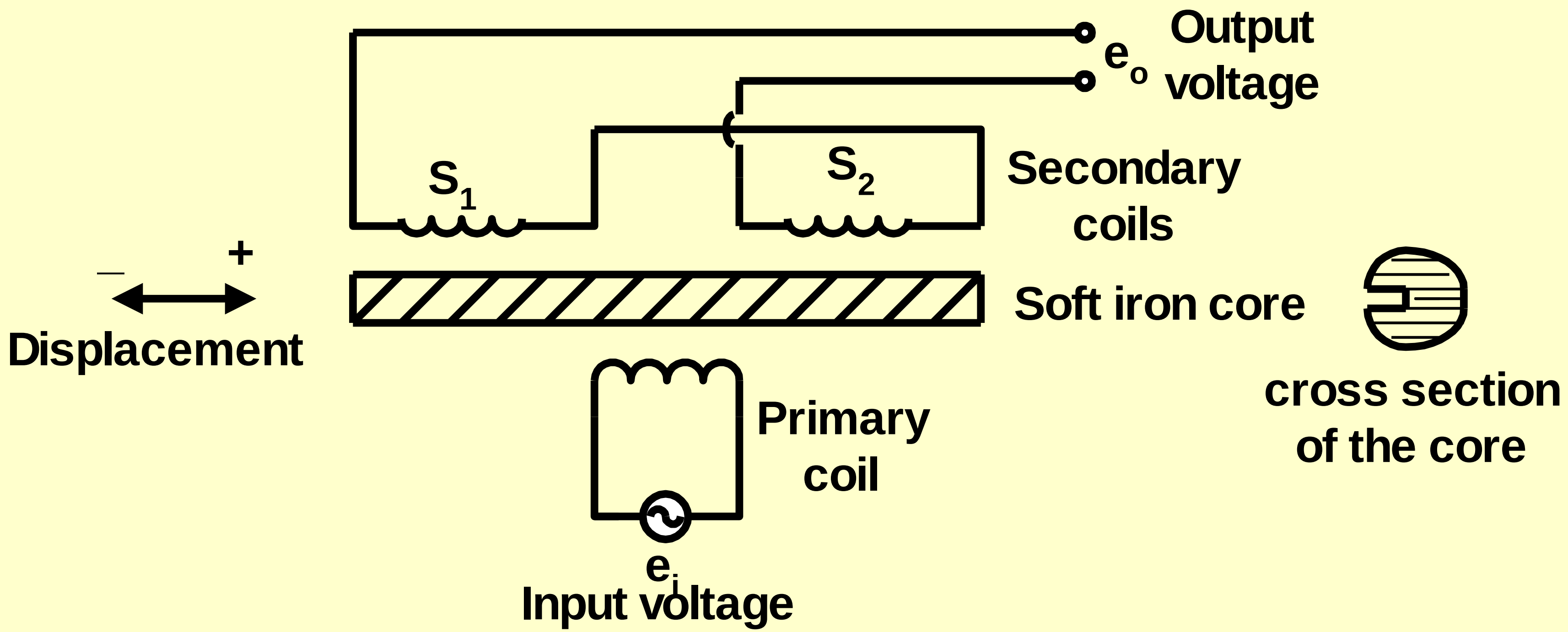
Example 3



Primary Sensor for Temperature Input

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

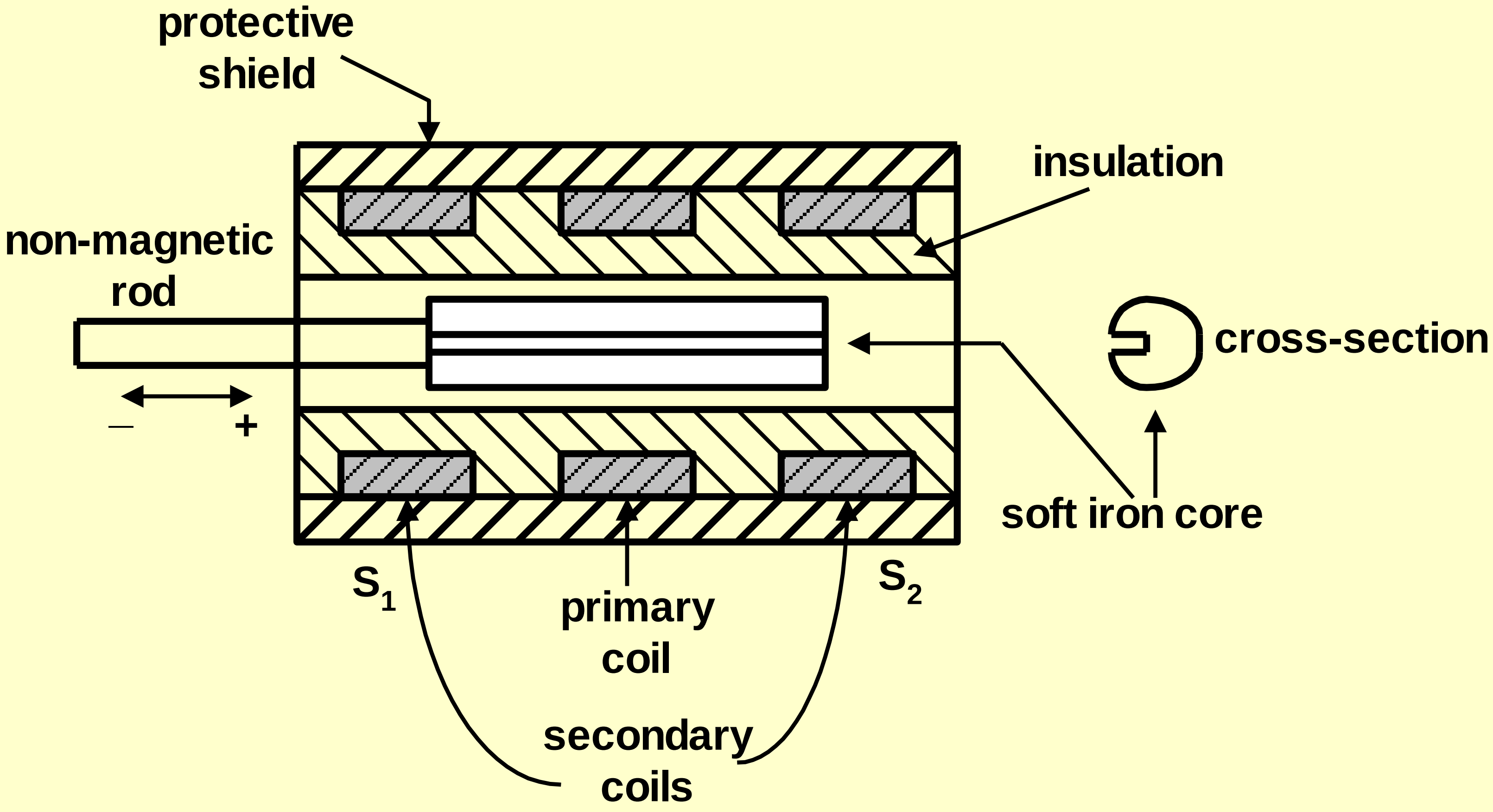
Linear Variable Differential Transformer (LVDT)



Schematic diagram of LVDT

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

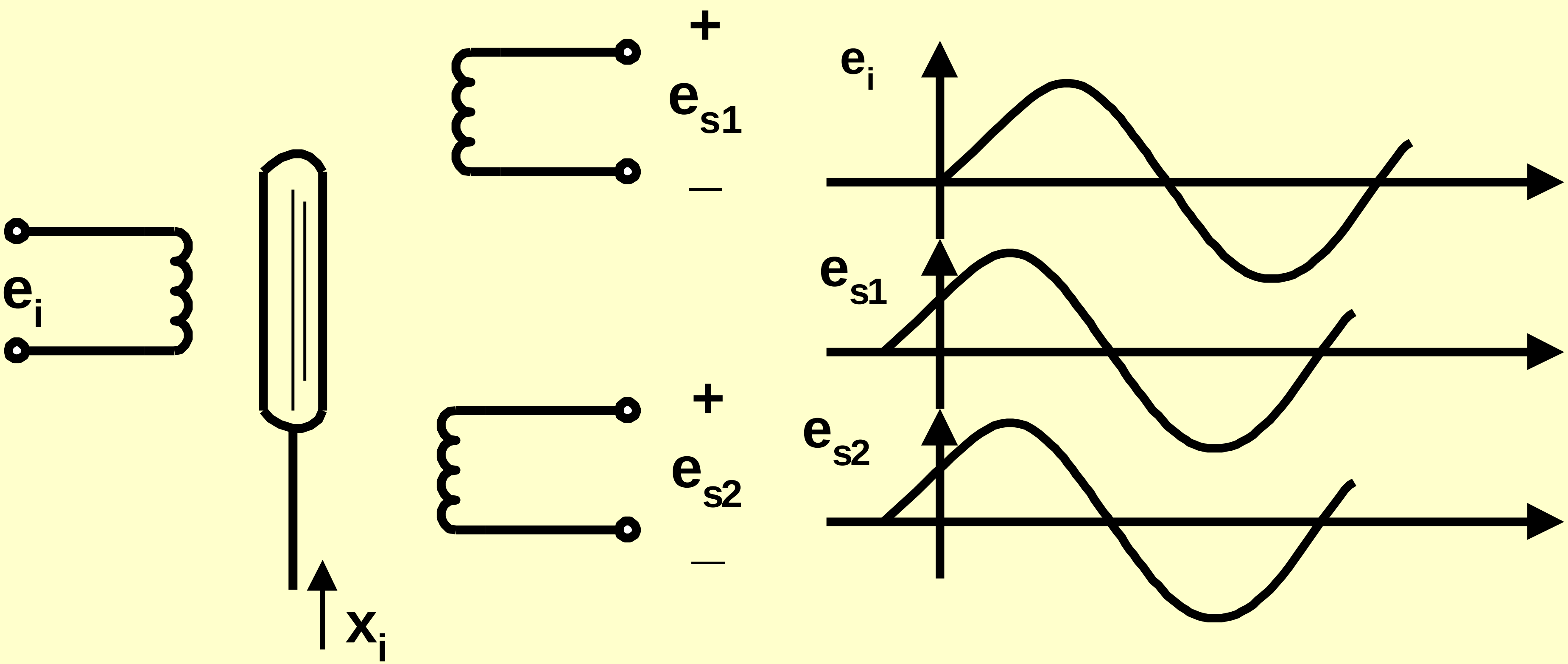
LVDT (contd….)



Construction of a commercial LVDT

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

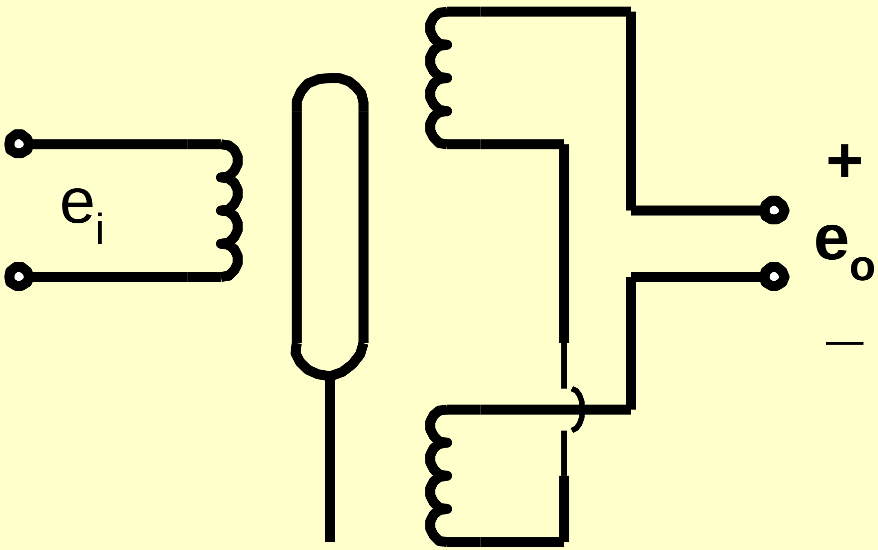
LVDT (contd….)



Core in null position

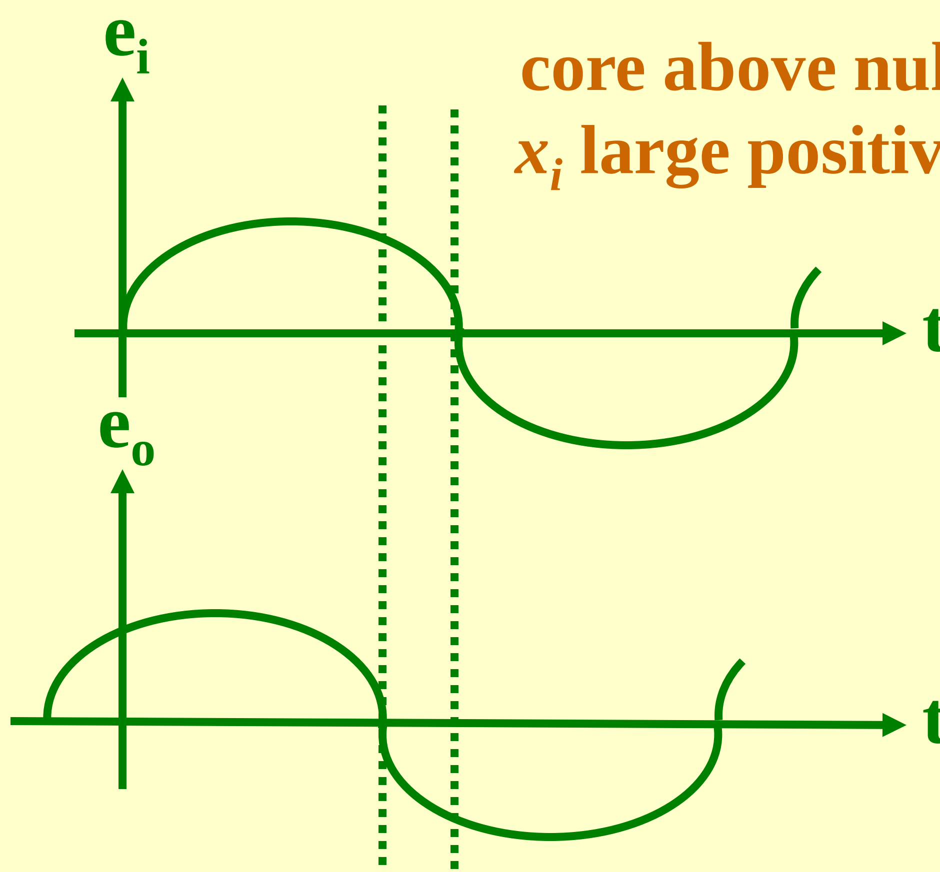
Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT (contd….)



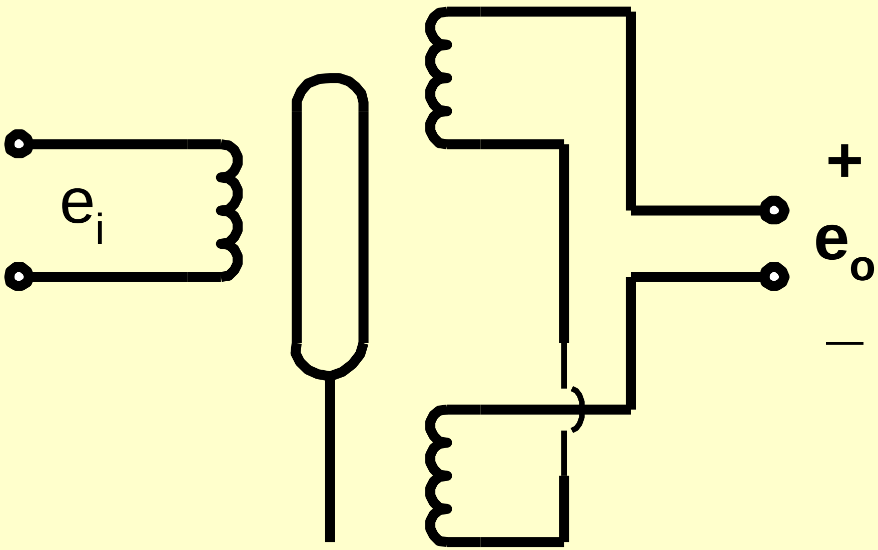
Series opposing secondaries

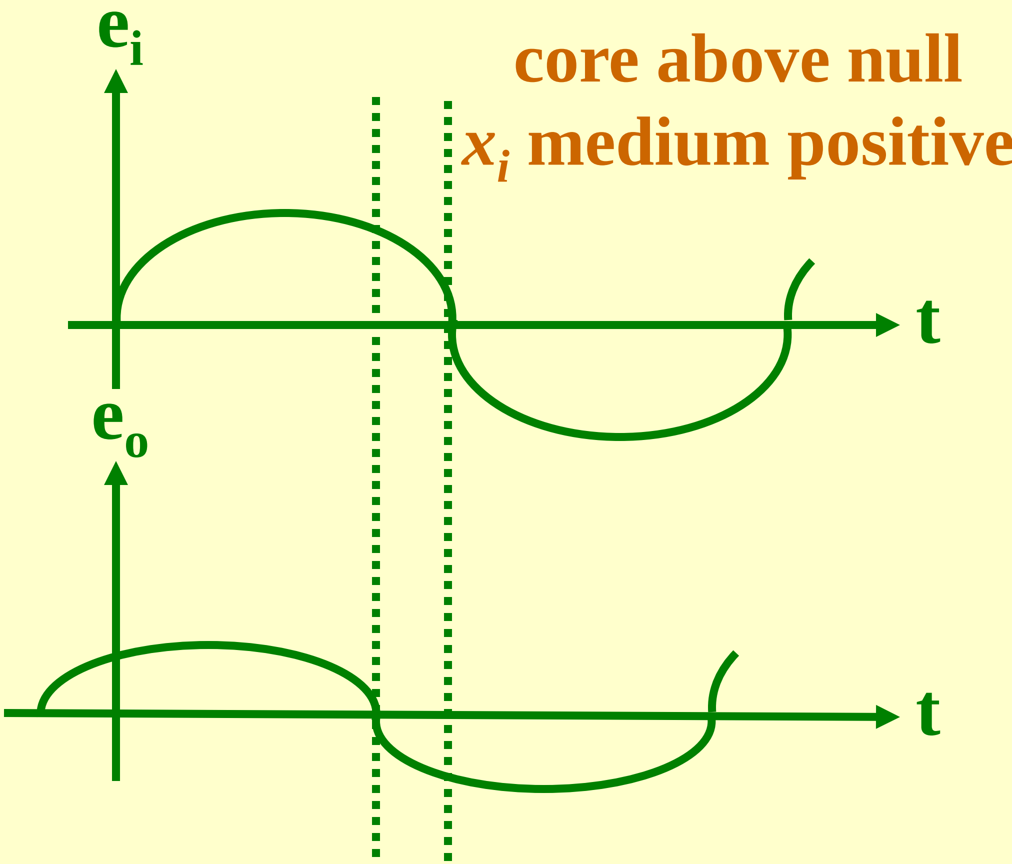
core above null
***x_i* large positive**



Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT (contd….)

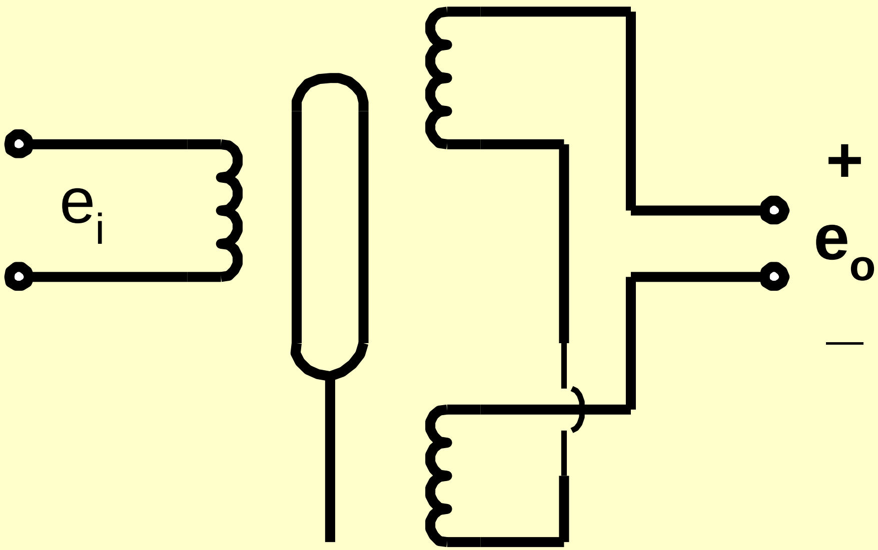




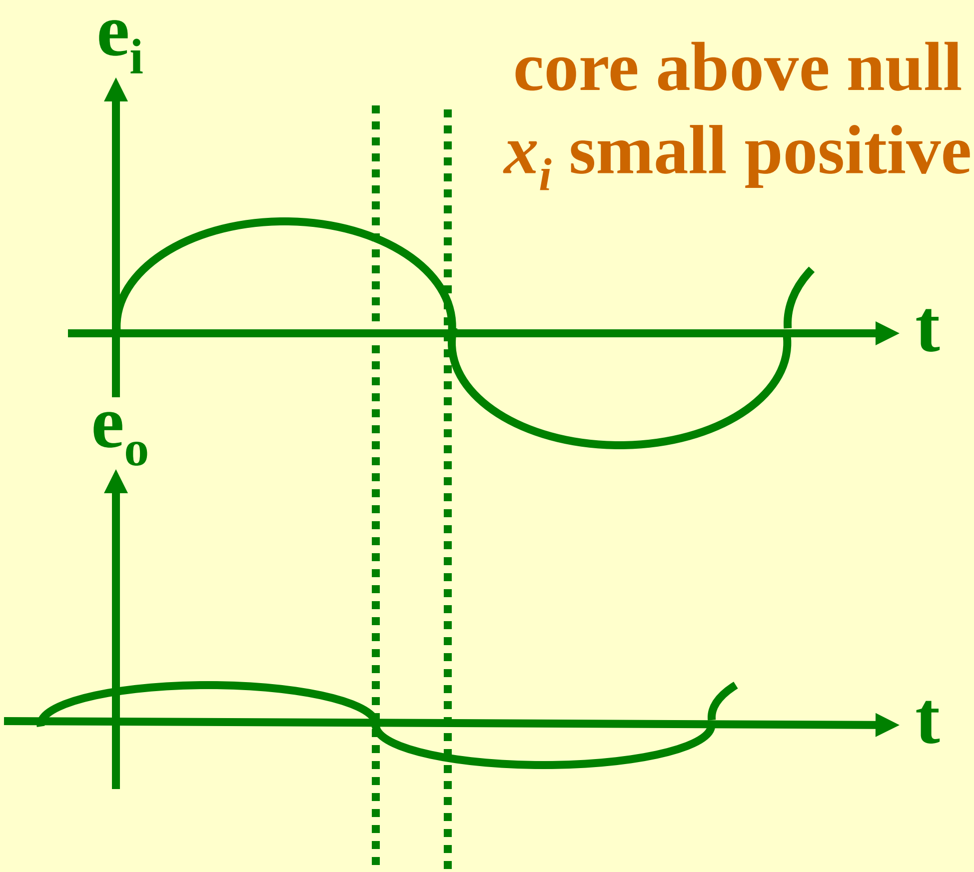
Series opposing secondaries

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT (contd….)



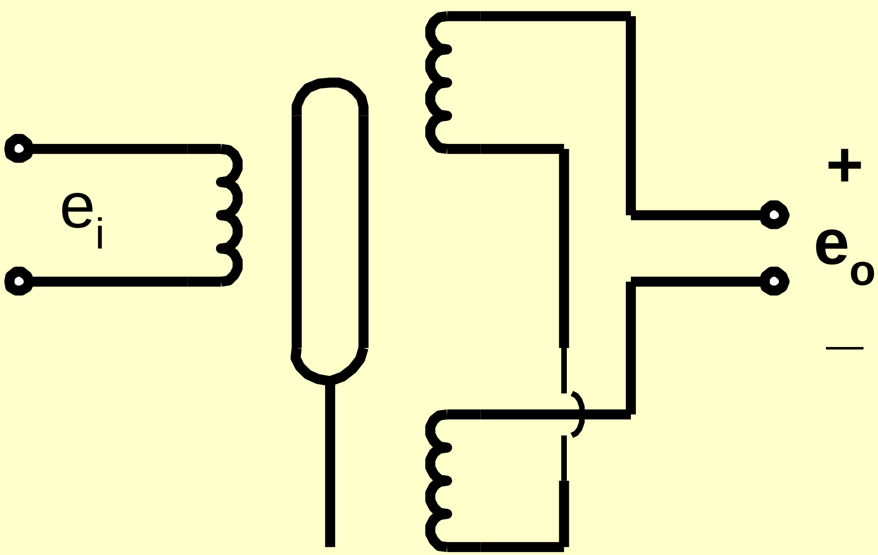
Series opposing secondaries

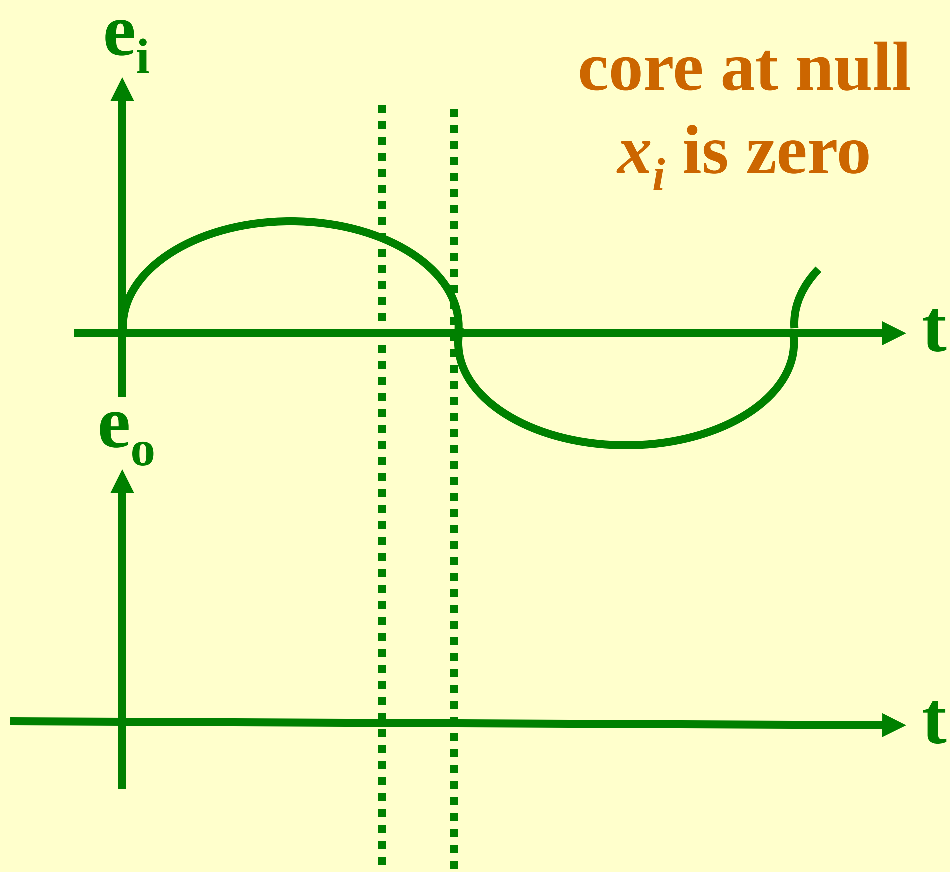


Amitava Chatterjee

Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT (contd….)

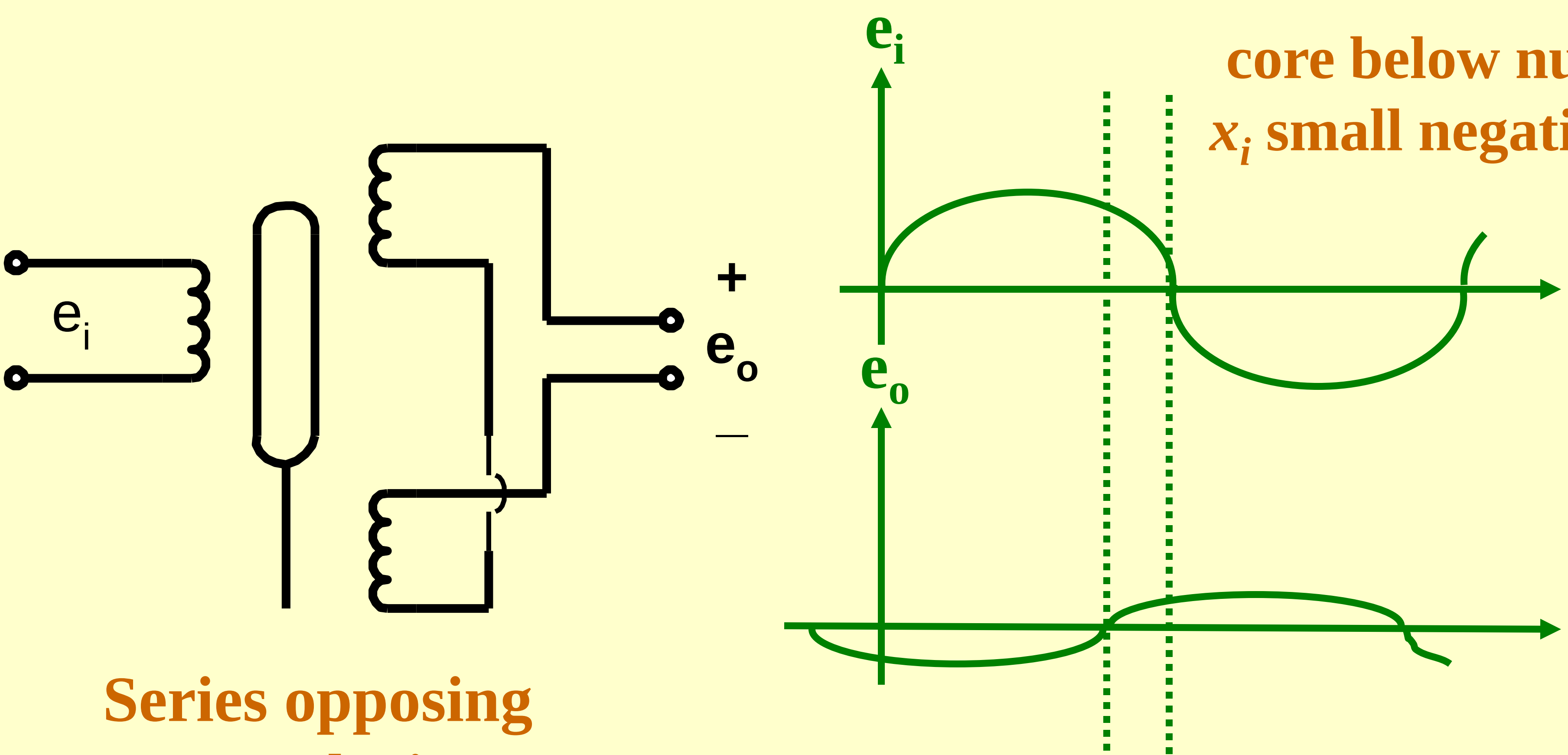




Series opposing secondaries

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT (contd....)

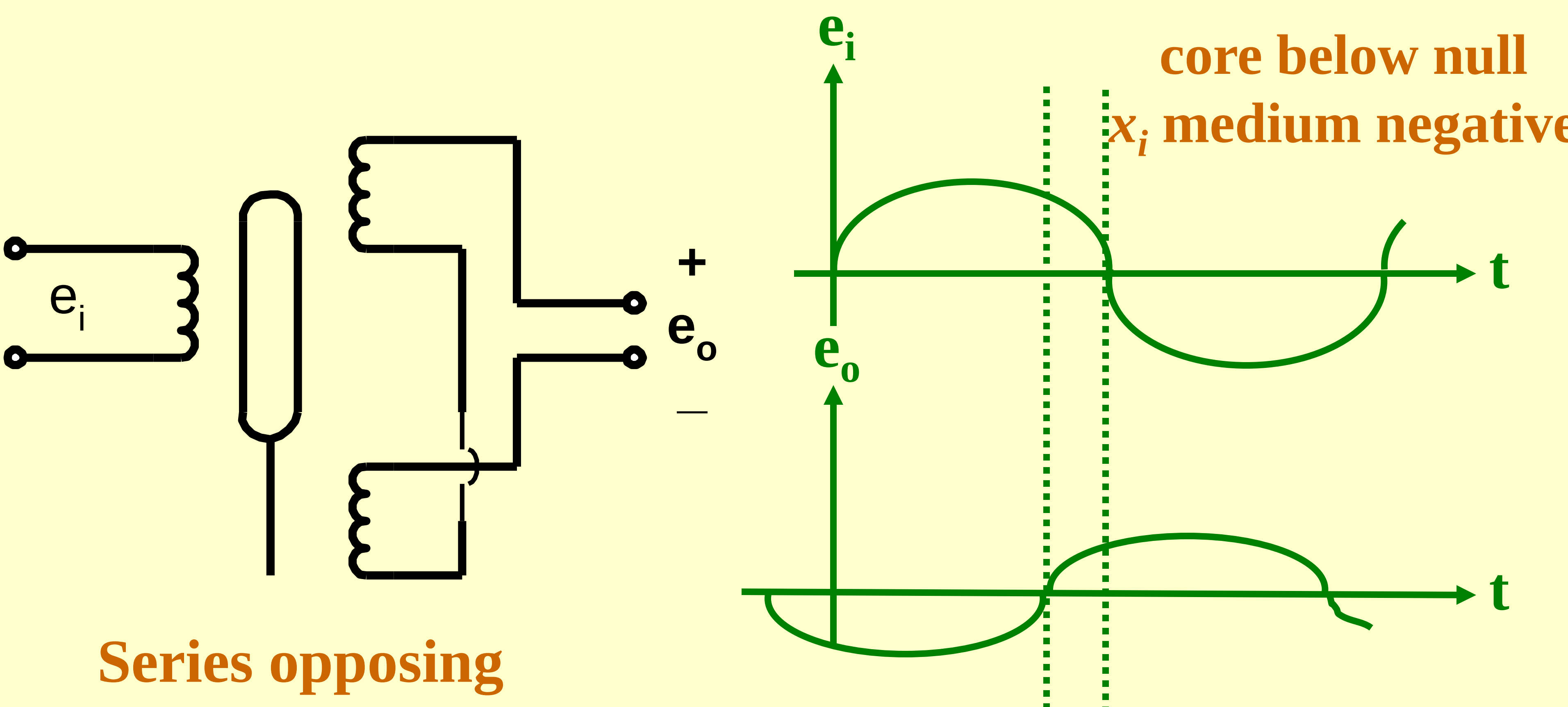


core below null
x_i small negative

Series opposing secondaries

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

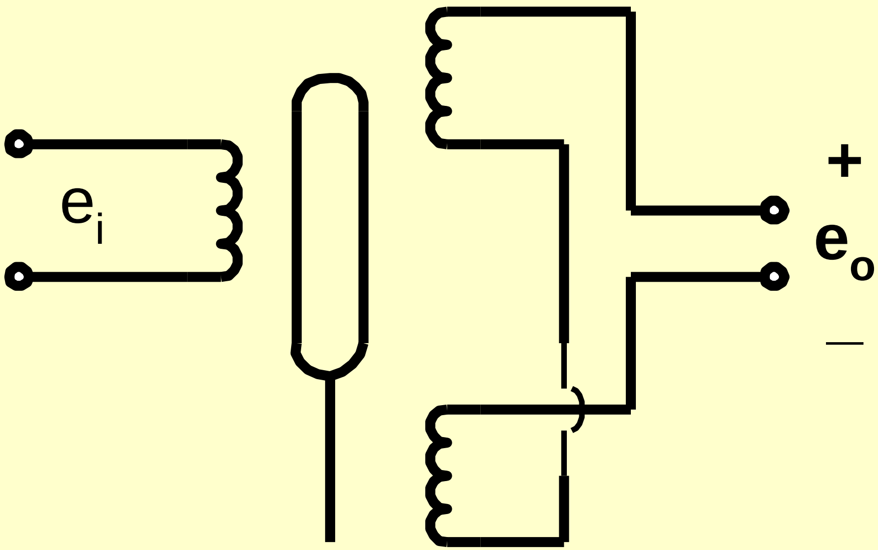
LVDT (contd….)

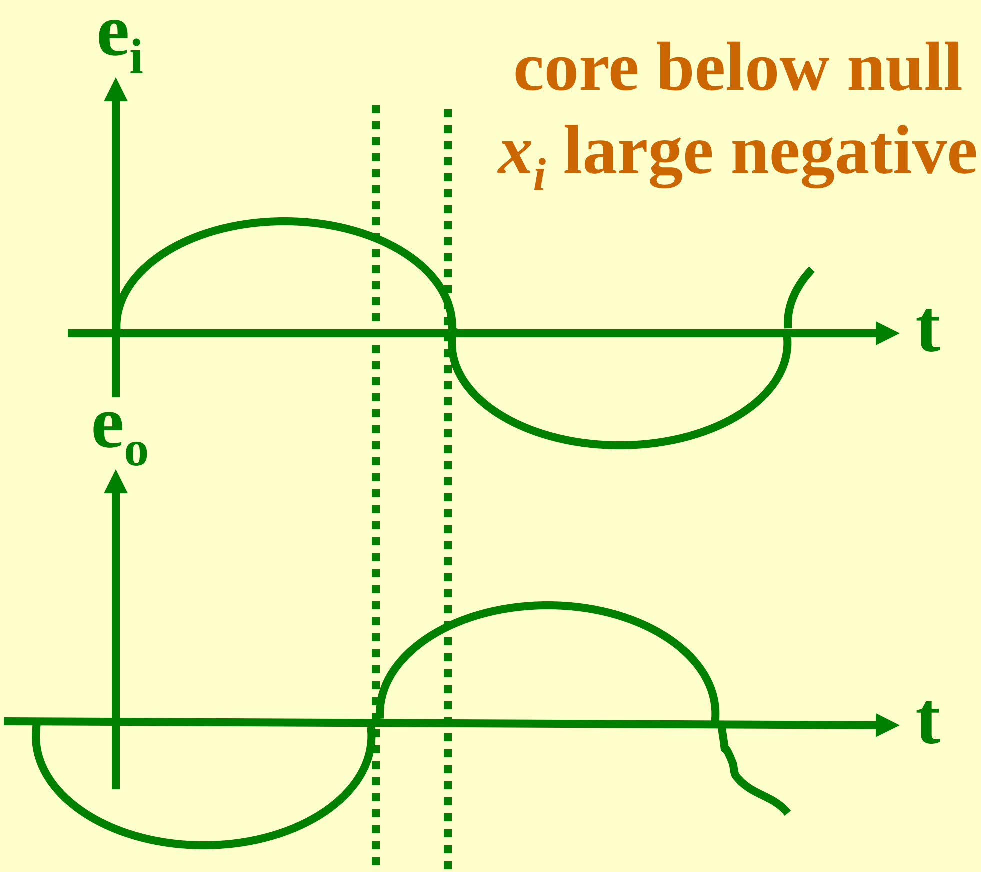


Series opposing secondaries

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT (contd....)

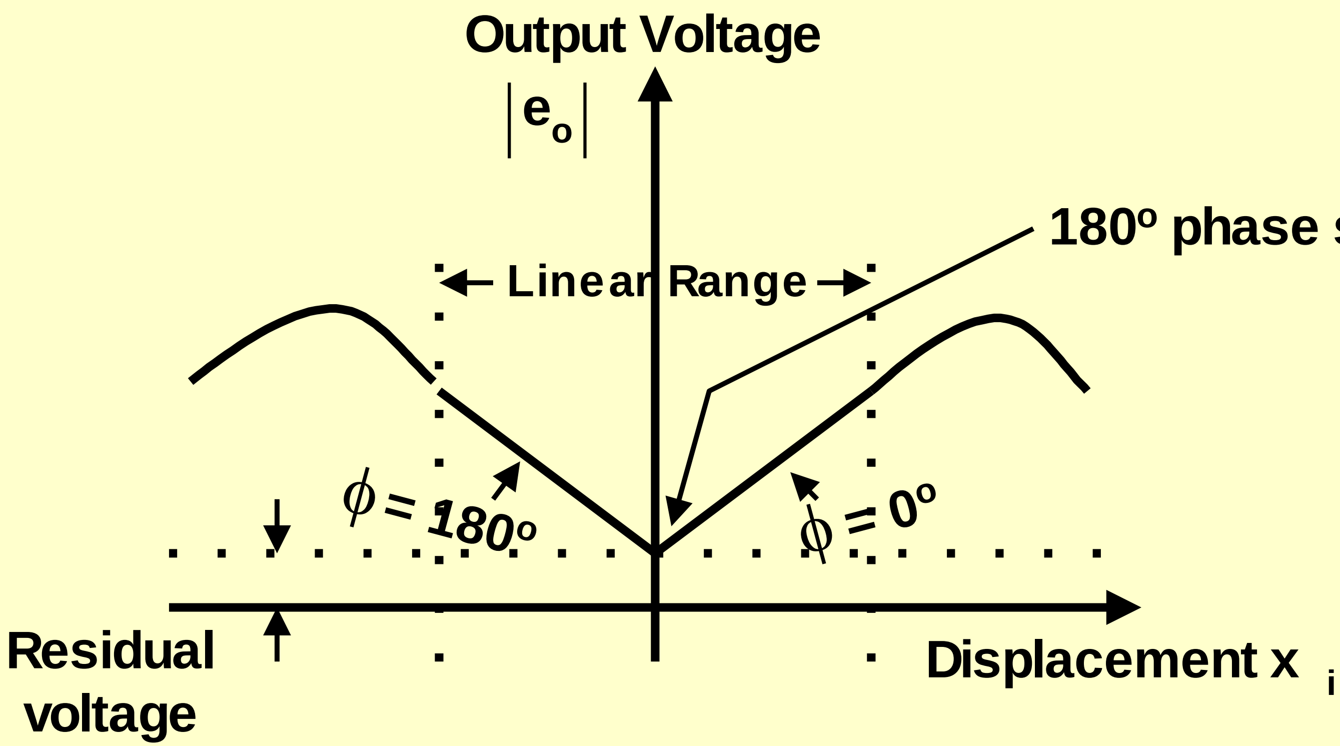




Series opposing secondaries

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT (contd….)



Output characteristic of an LVDT

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Residual voltage exists in null position

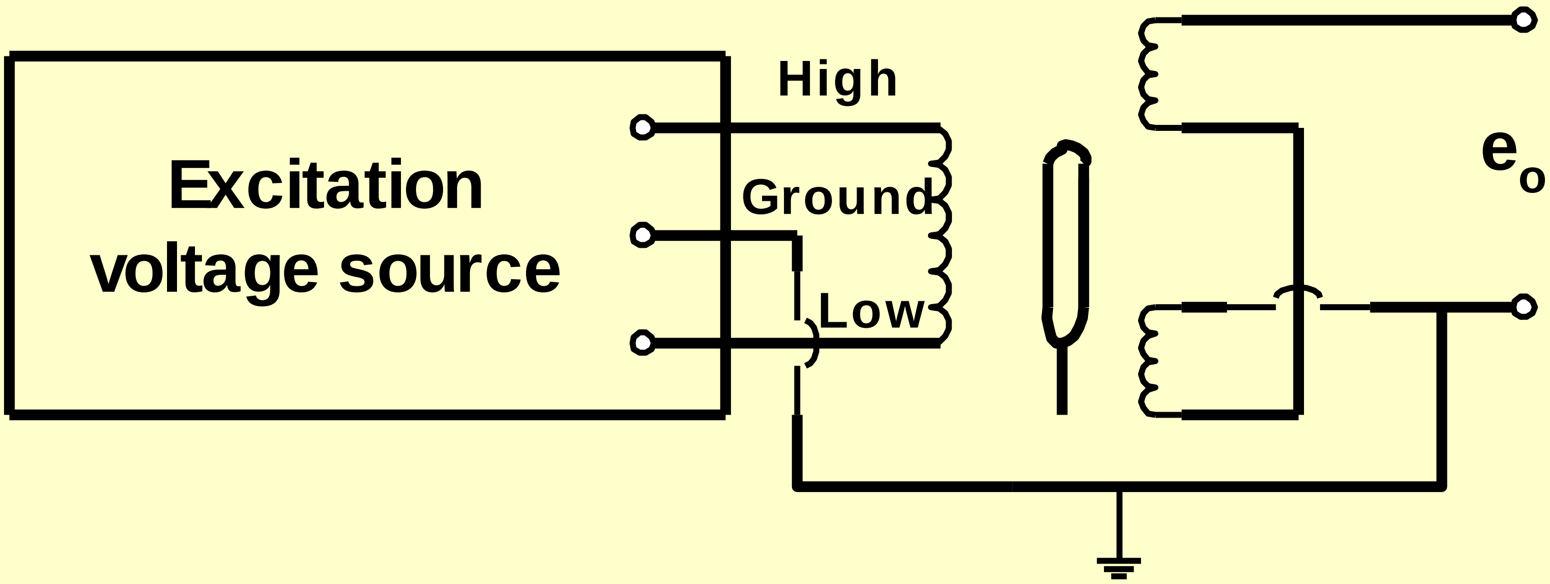
Why ?

- ✓ **May be on account of harmonics present in the input supply voltage**
- ✓ **Due to stray capacitance coupling between primary and secondary**
- ✓ **Due to harmonics produced in the output supply voltage**
- ✓ **Due to stray magnetic fields**
- ✓ **Due to temperature effect …**

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Methods for Null Reduction

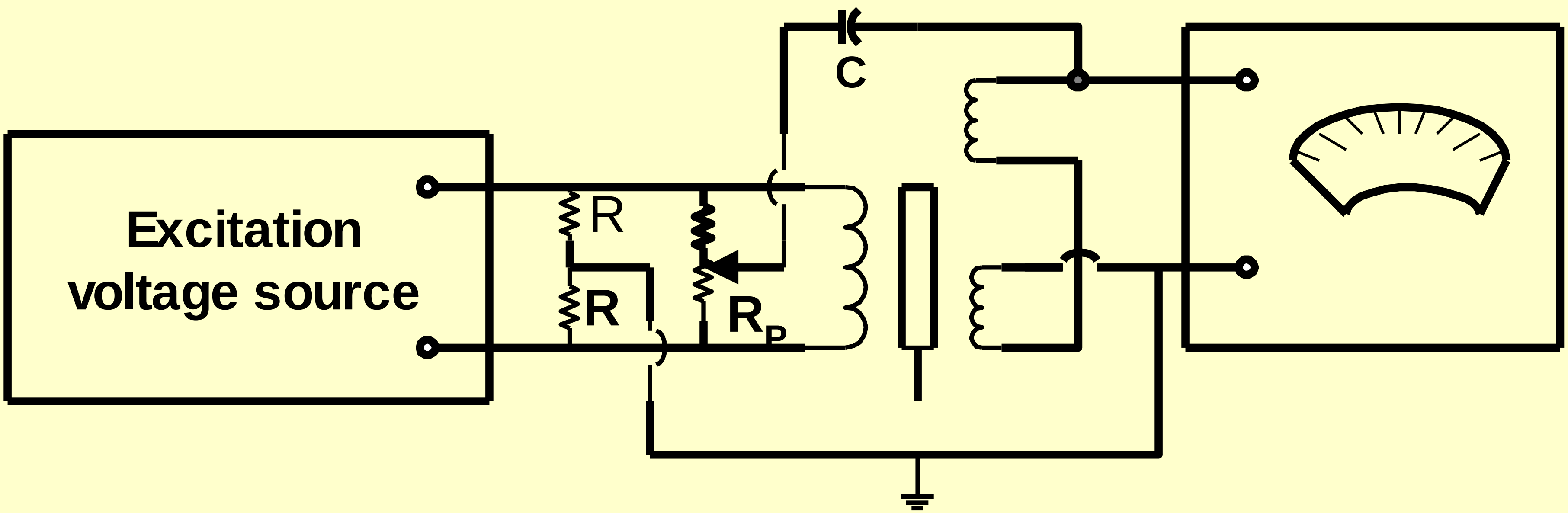
Method – 1:



✓ **The method can be used if a centre-tapped excitation voltage source is available.**

Methods for Null Reduction (contd…)

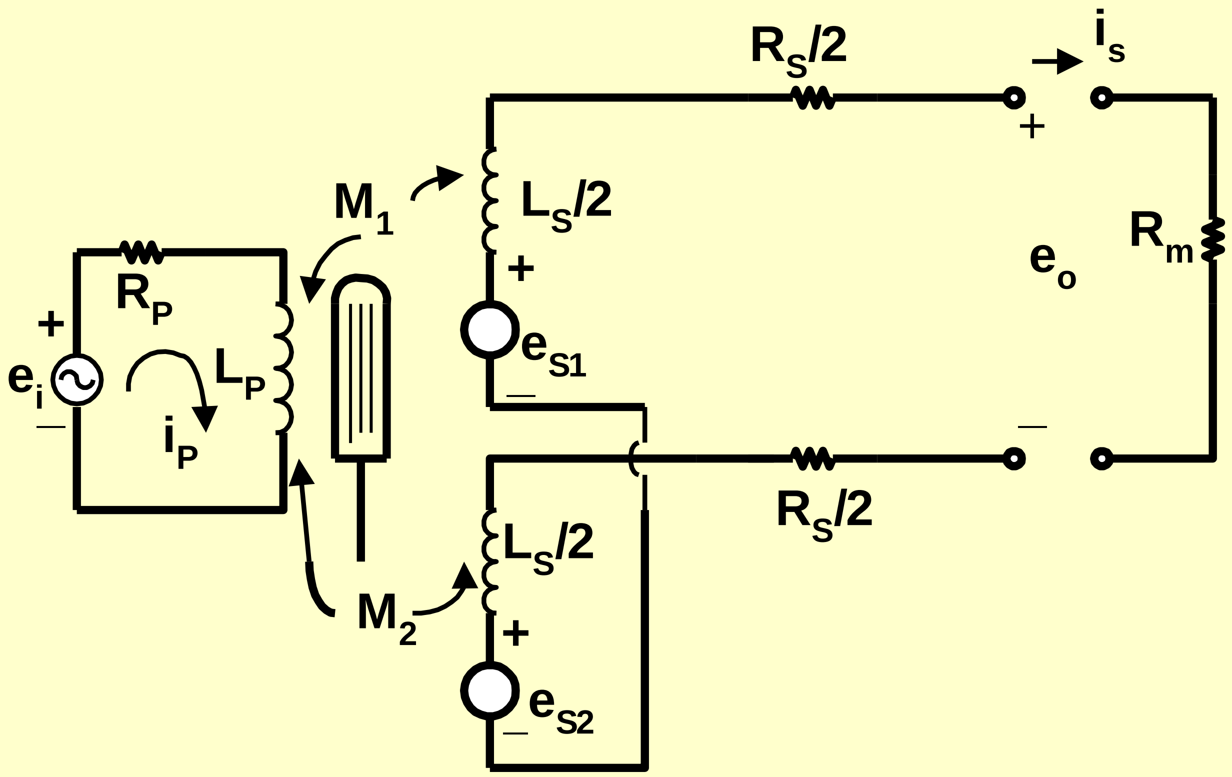
Method – 2:



- ✓ This method is used when a centre-tapped excitation voltage source is not available.

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Analysis of the Equivalent Circuit



Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Analysis of the Equivalent Circuit (contd…)

Case I: A voltage measuring device with infinite R_m

Governing equations:

$$i_p R_p + L_p \frac{di_p}{dt} - e_i = 0$$

$$e_{s1} = -M_1 \frac{di_p}{dt}$$

$$e_{s2} = -M_2 \frac{di_p}{dt}$$

$$e_o = e_{s1} - e_{s2} = (M_2 - M_1)\frac{di_p}{dt}$$

Input-output relation:

For a given core position

$$\frac{E_o(s)}{E_i(s)} = \frac{\left[(M_2 - M_1)/R_p \right] s}{\tau_p s + 1} \quad \text{where } \tau_p = \frac{L_p}{R_p}$$

Frequency response

$$\frac{E_o}{E_i}(j\omega) = \frac{\omega (M_2 - M_1)/R_p}{\sqrt{(\omega \tau_p)^2 + 1}} \angle \phi \quad \text{where,}$$

$$\phi = 90^o - \tan^{-1}(\omega \tau_p).$$

✓ **This demonstrates the phase shift between e_o and e_i.**

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Analysis of the Equivalent Circuit (contd…)

Case II: A voltage measuring device with finite R_m

Governing equations:

$$e_i - \left[-\left(M_1 - M_2\right)\frac{di_s}{dt} \right] = i_p R_p + L_p \frac{di_p}{dt}; \qquad -\left(M_1 - M_2\right)\frac{di_p}{dt} = i_s\left(R_s + R_m\right) + L_s \frac{di_s}{dt}$$

Input-output relation:

For a given core position

$$\frac{E_o(s)}{E_i(s)} = \frac{sR_m\left(M_2 - M_1\right)}{s^2\left[\left(M_1 - M_2\right)^2 + L_p L_s\right] + s\left[L_p\left(R_s + R_m\right) + L_s R_p\right] + R_p\left(R_s + R_m\right)}$$

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Analysis of the Equivalent Circuit (contd…)

Case II: A voltage measuring device with finite R_m (contd.)

Frequency response

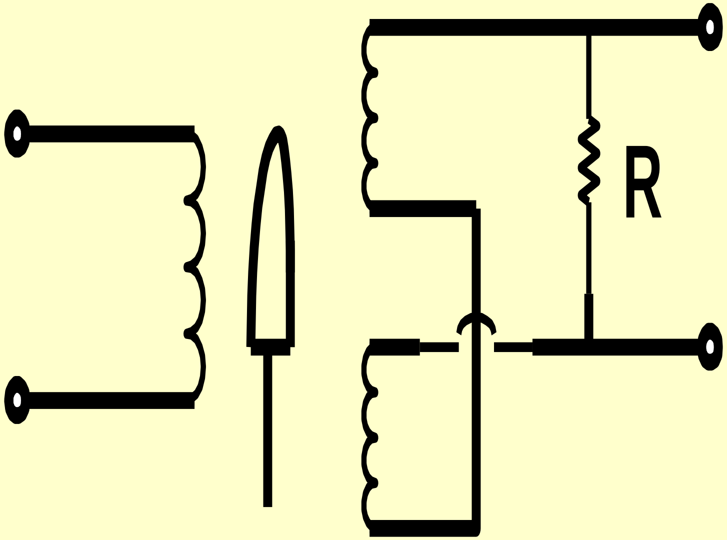
$$\frac{E_o}{E_i}(j\omega)=\frac{\omega R_m\left(M_2-M_1\right)}{\sqrt{\left\{R_p\left(R_s+R_m\right)-\omega^2\left[\left(M_1-M_2\right)^2+L_pL_s\right]\right\}^2+\omega^2\left[L_p\left(R_s+R_m\right)+L_sR_p\right]^2}}\angle\phi$$

where phase response:

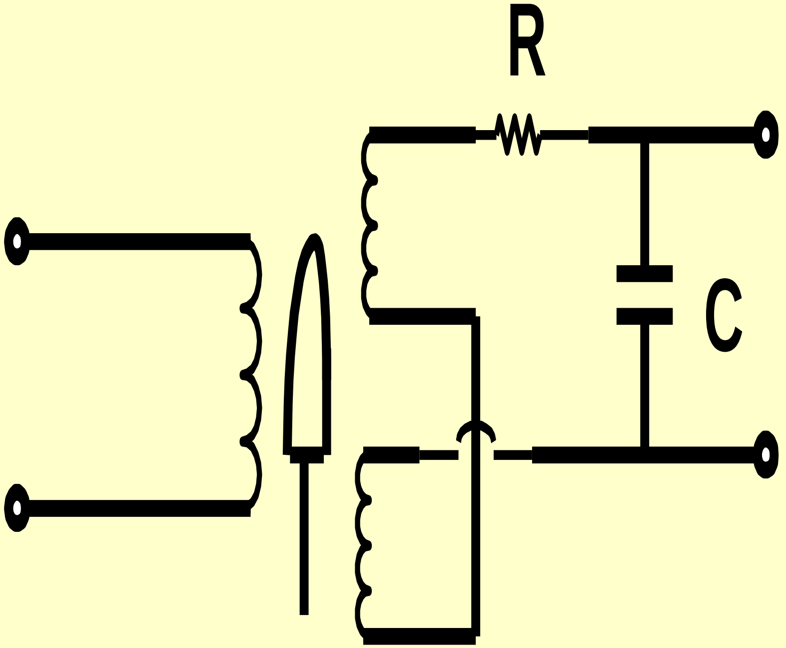
$$\phi = 90^o - tan^{-1}\left(\frac{\omega\left[L_P+\frac{L_SR_P}{R_S+R_m}\right]}{R_P-\frac{\omega^2}{R_S+R_m}\left[\left(M_1-M_2\right)^2+L_PL_S\right]}\right)$$

Methods for retarding a leading phase angle

Method – 1



Method – 2



Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Method Analysis

Method – 1

$$\frac{E_o(s)}{E_i(s)} = \frac{R(M_2 - M_1)s}{\left\{\left[(M_1 - M_2)^2 + L_pL_s\right]s^2 + \left[L_p(R_s + R) + L_sR_p\right]s + (R_s + R)R_p\right\}}$$

Frequency response

$$\frac{E_o}{E_i}(j\omega) = \frac{\omega R(M_2 - M_1)}{\sqrt{\left\{(R_s + R)R_p - \omega^2\left[(M_1 - M_2)^2 + L_pL_s\right]\right\}^2 + \left\{\omega\left[L_p(R_s + R) + L_sR_p\right]\right\}^2}} \angle\phi$$

$$\phi = 90^o - \tan^{-1}\left(\frac{\omega\left[L_p(R_s + R) + L_sR_p\right]}{(R_s + R)R_p - \omega^2\left[(M_1 - M_2)^2 + L_pL_s\right]}\right)$$

when phase angle is zero

$$R = \frac{\omega^2\left[(M_1 - M_2)^2 + L_PL_S\right]}{R_P} - R_S$$

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Method Analysis (contd…)

Method – 2

$$\frac{E_o(s)}{E_i(s)} = \frac{\left[\frac{(M_2 - M_1)}{R_p}\right]s}{\tau_p s + 1} \cdot \frac{1}{1 + sRC} = \frac{(M_2 - M_1)s}{(R_p + sL_p)(1 + sRC)}$$

Frequency response

$$\frac{E_o}{E_i}(j\omega) = \frac{\omega(M_2 - M_1)}{\sqrt{(R_p - \omega^2 L_p RC)^2 + \{\omega(L_p + R_p RC)\}^2}} \angle\phi$$

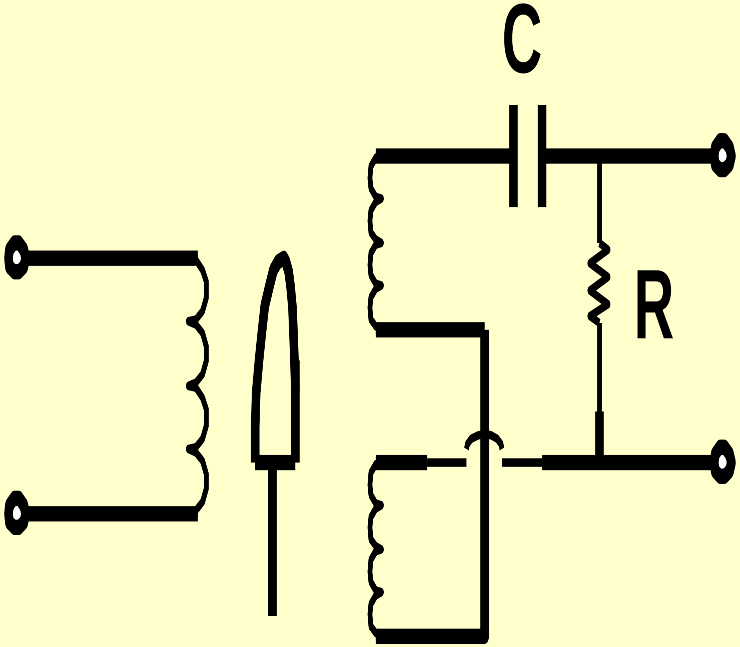
$$\phi = 90^o - \tan^{-1}\left(\frac{\omega(L_p + R_p RC)}{(R_p - \omega^2 L_p RC)}\right)$$

when phase angle is zero → $RC = \dfrac{R_p}{\omega^2 L_p}$

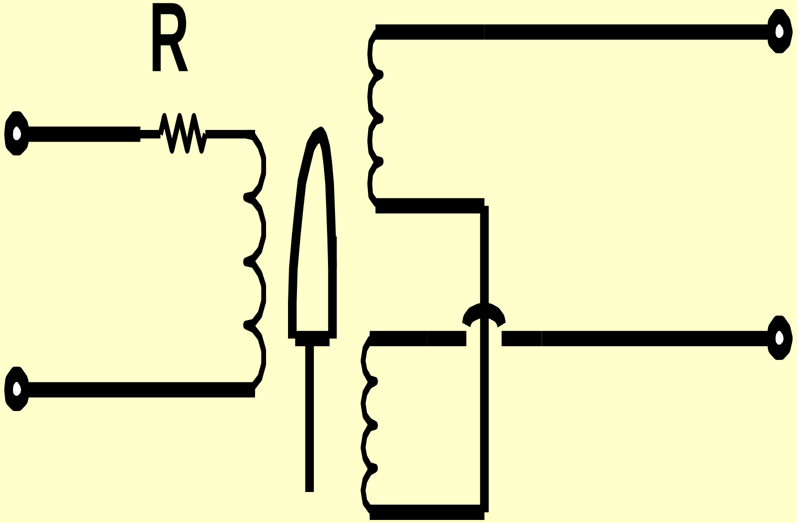
Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Methods for advancing a lagging phase angle

Method – 3



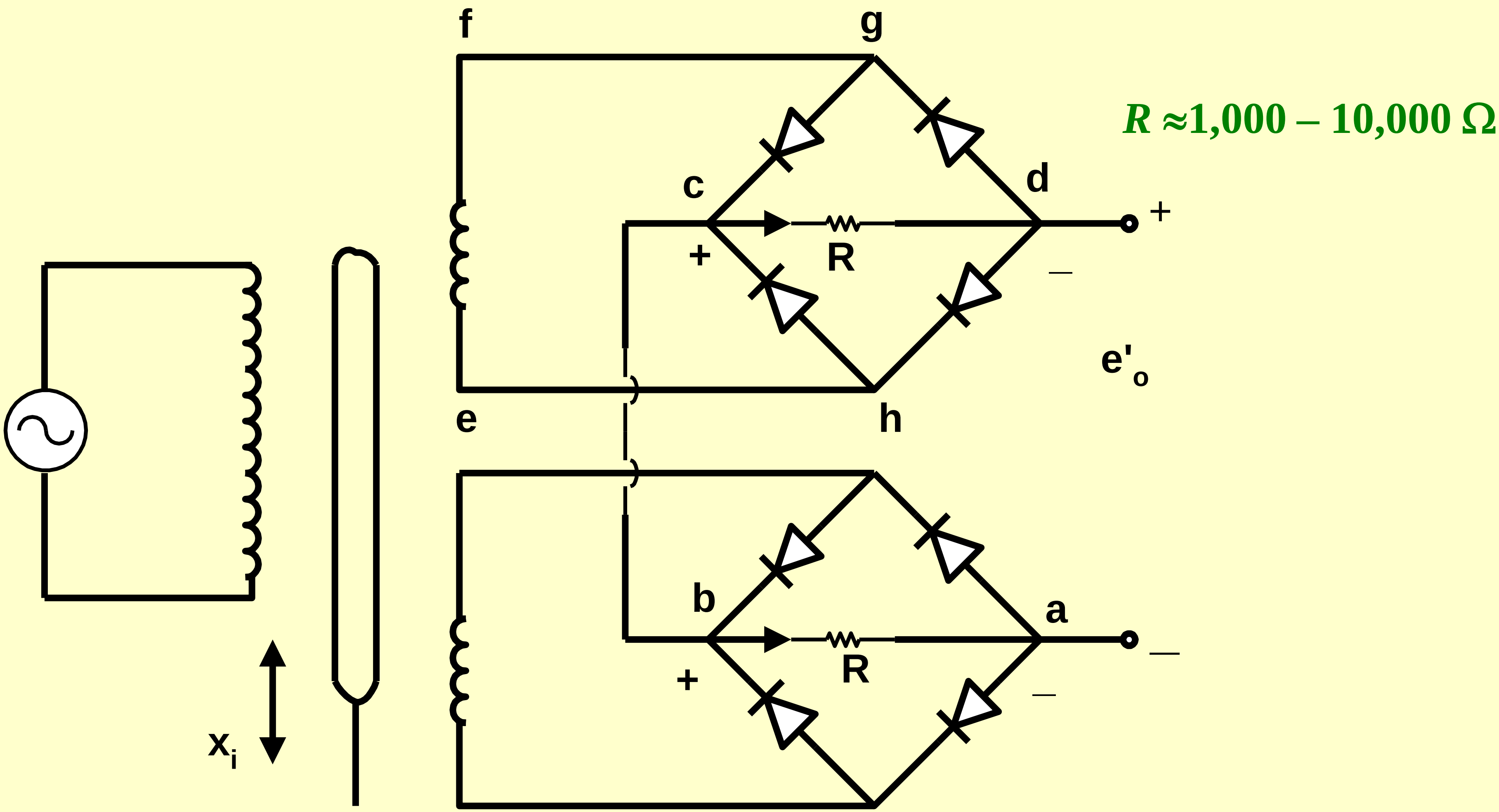
Method – 4



Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Phase Sensitive Demodulation and Filtering

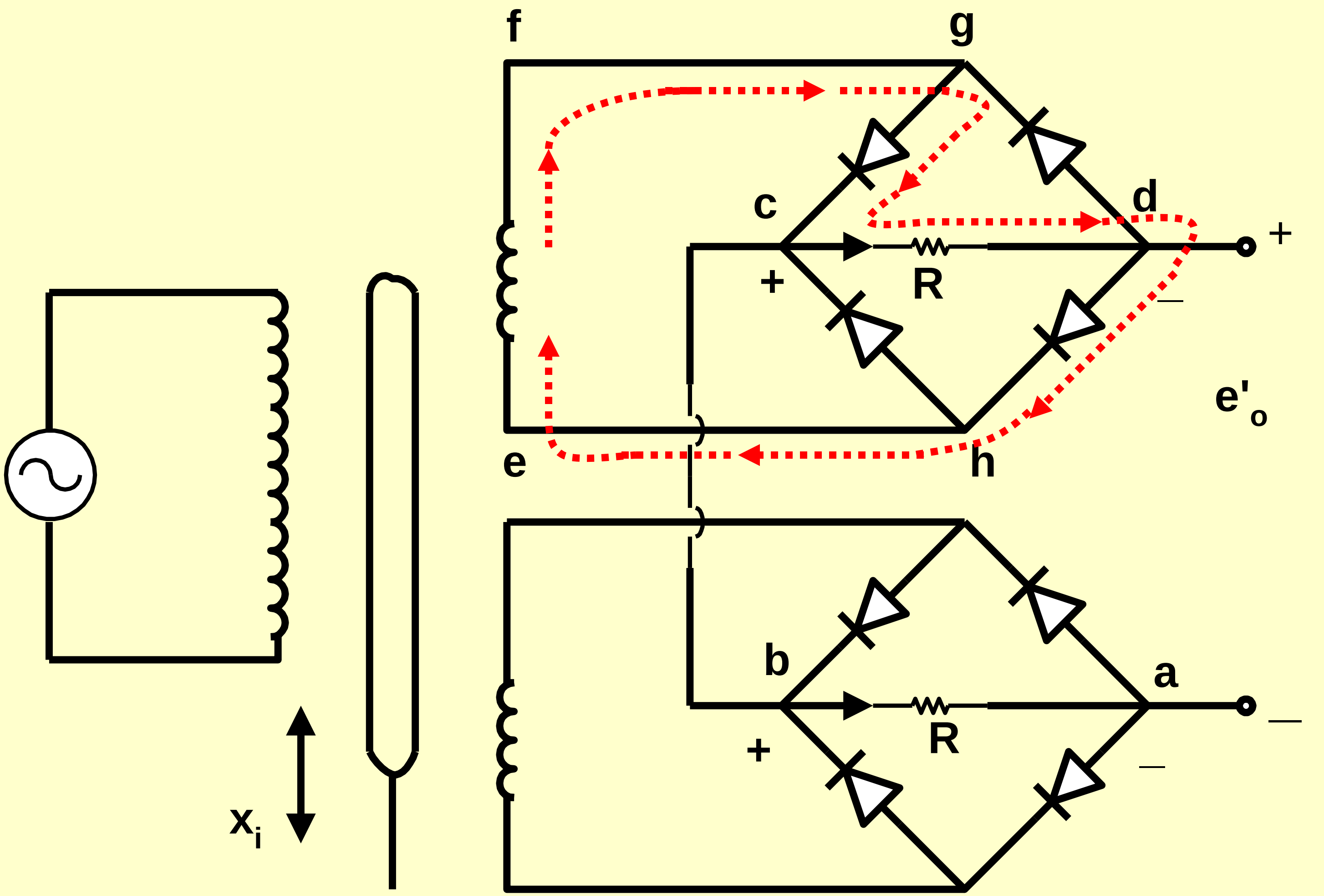
Circuit Arrangement



Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Phase Sensitive Demodulation and Filtering

Circuit Arrangement

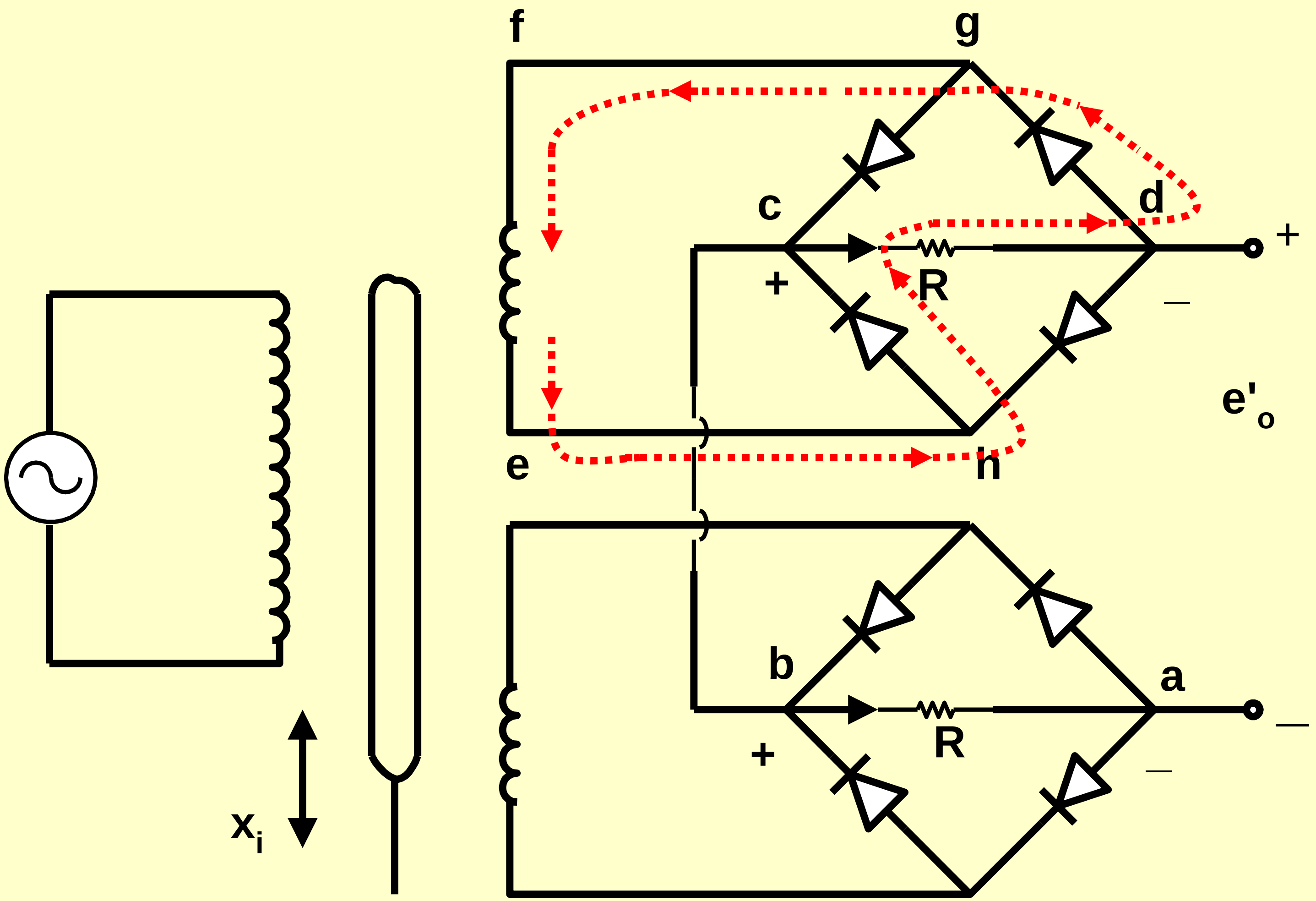


when *f* +ve
and *e* -ve

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Phase Sensitive Demodulation and Filtering

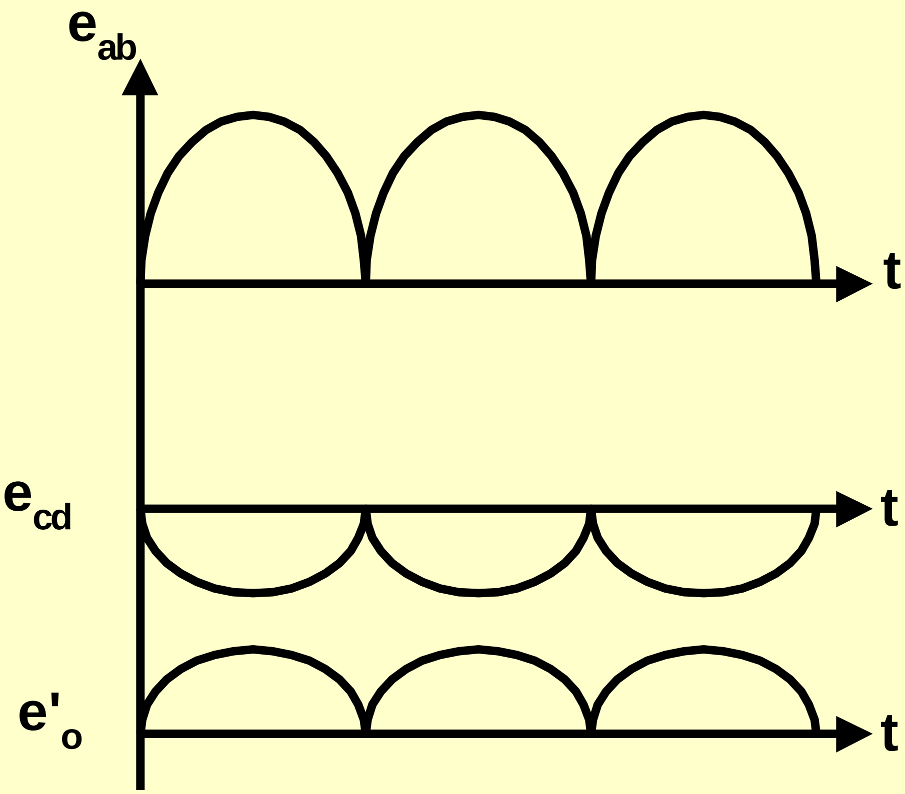
Circuit Arrangement



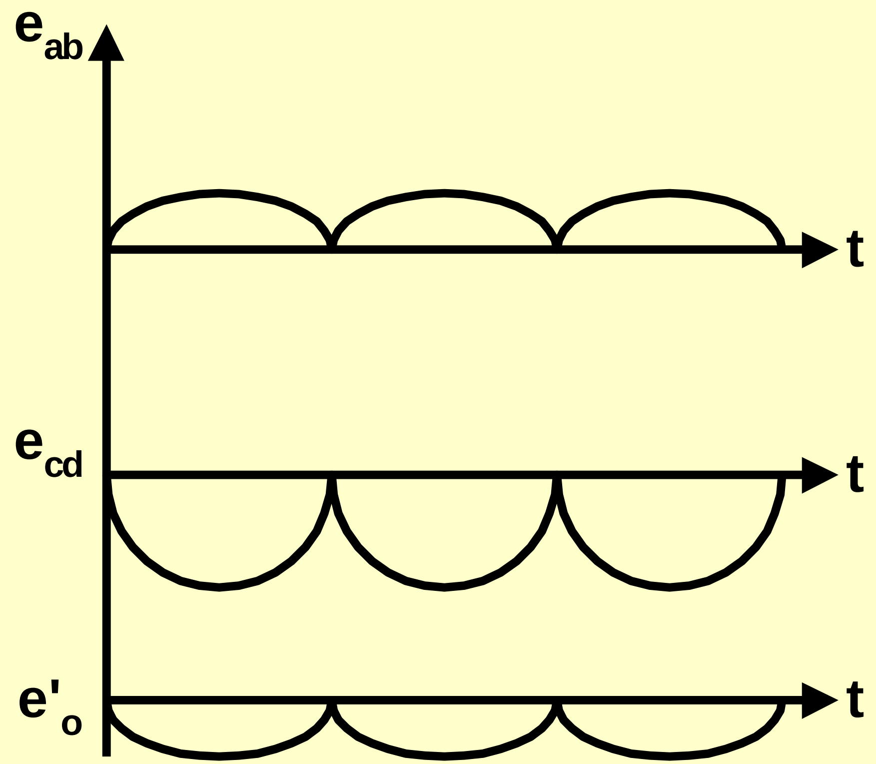
when *f* -ve and *e* +ve

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

PSD and Filtering (contd...)



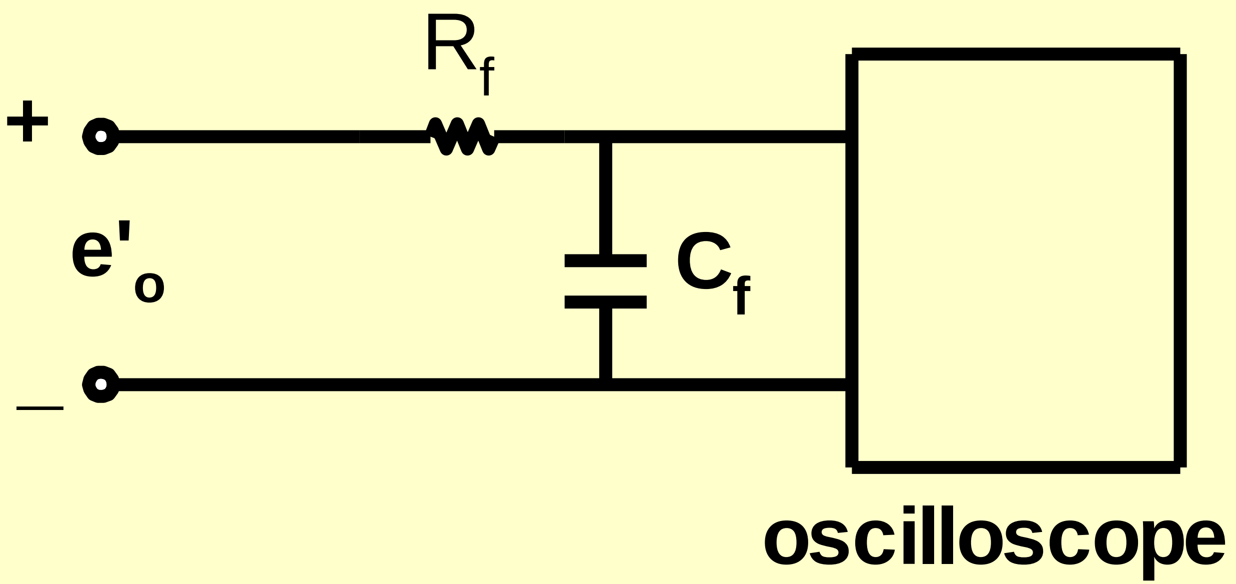
Core below null



Core above null

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

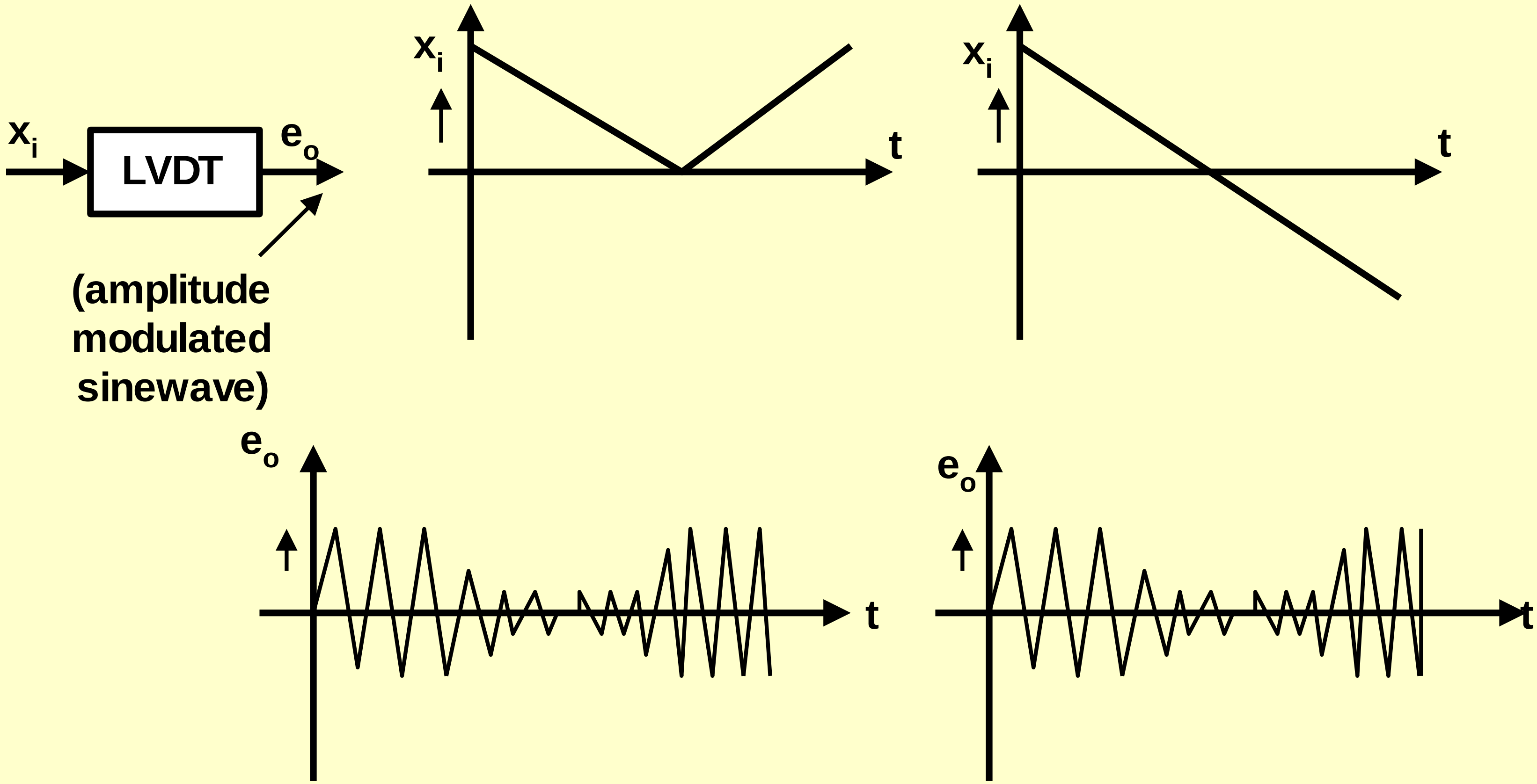
PSD and Filtering (contd...)



- ✓ **For rapid core motions, a low-pass (RC) filter is connected between $e_o^{/}$ and the oscilloscope.**

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

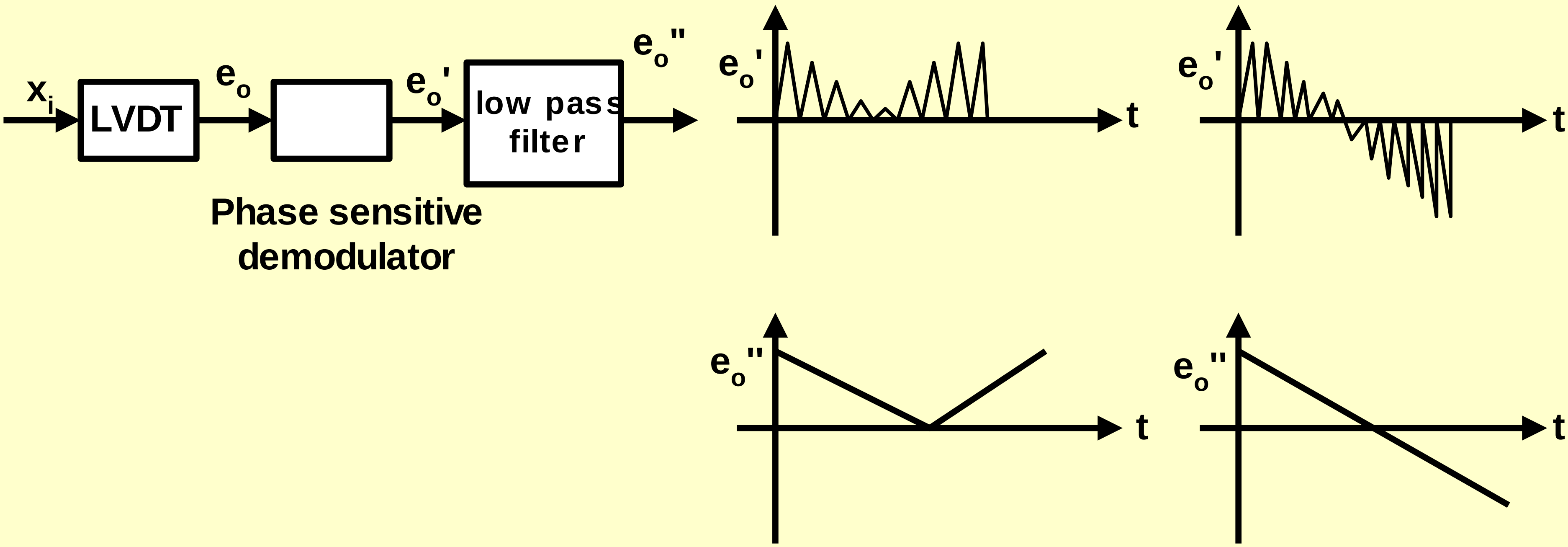
LVDT without PSD and Filtering



✓ e_o visually looks the same for two very different variations of x_i, if seen in an oscilloscope.

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

LVDT with PSD and Filtering



✓ now $e_o^{//}$ can visually capture the two very different variations of x_i, if seen in an oscilloscope.

PSD and Filtering

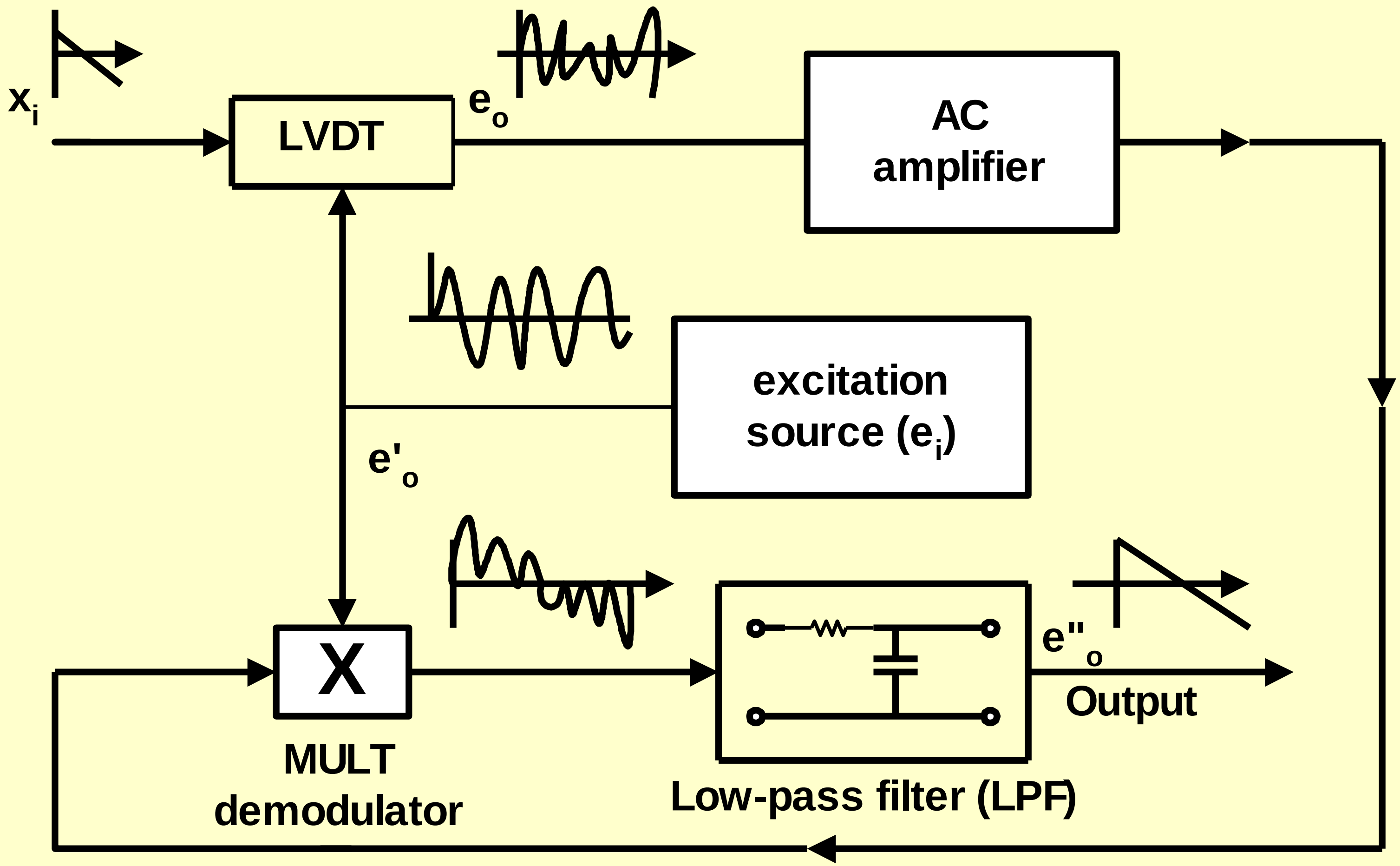
Where applicable ?

- ✓ **The PSD circuit with semiconductor diodes can only be applied for those LVDTs where all four terminals are accessible at the output.**

Alternate solution ?

- ✓ **For those LVDTs where only two terminals are accessible at the output, *synchronous demodulation technique* is employed.**

Synchronous Demodulation Technique



✓ ***Constraint:***

This scheme requires that e_i and e_o should be in phase.

Amitava Chatterjee

Department of Electrical Engg., Jadavpur University, Kolkata, India

Advantages and Disadvantages of LVDT

Advantages:

- ✓The output voltage of this transducer is practically *linear* for displacements upto 5 mm. A linearity of 0.5% is available in commercial LVDTs.
- ✓*Infinitesimal resolution:* the change in output voltage is stepless, since the variation in coupling due to core motion is continuous in nature. It is possible to build a transducer with a resolution as fine as 1×10^{-3} mm.
- ✓*High output:* therefore many a times there is no need for amplification. The full range stroke of commercially available LVDTs ranges from ± 0.005 to about ± 3 inch.

Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Advantages and Disadvantages of LVDT

Advantages (contd…):

- ✓ ***Sensitivity:*** **0.6 to 30 mV per 0.001 inch for normal excitation voltage 3 to 6 V, depending on frequency of excitation and stroke. A higher frequency gives more sensitivity and smaller strokes usually have higher sensitivity.**
- ✓ ***Low hysteresis:*** **hence repeatability is excellent.**
- ✓ ***Low Power consumption:*** **usually less than 1 W.**

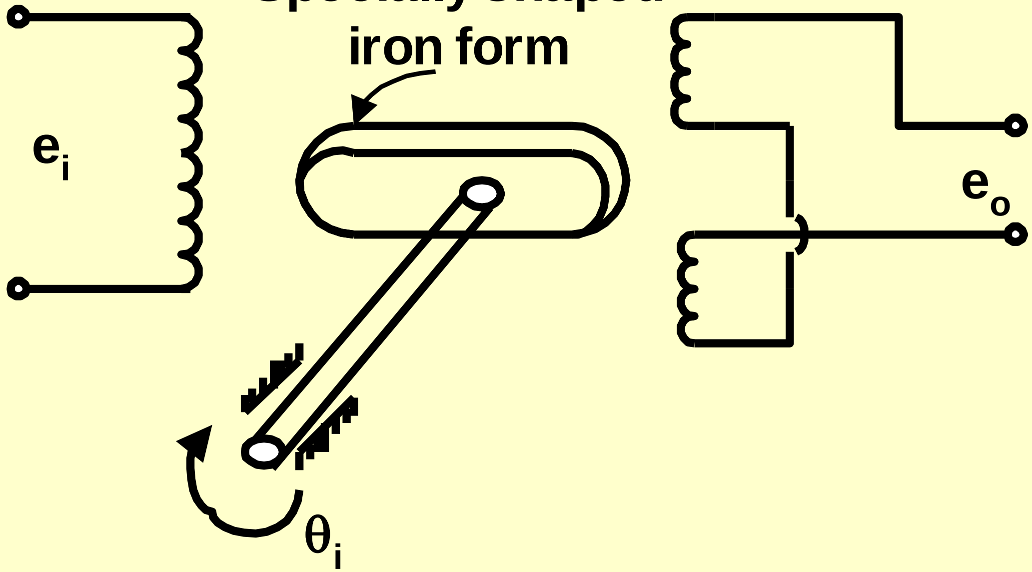
Amitava Chatterjee
Department of Electrical Engg., Jadavpur University, Kolkata, India

Advantages and Disadvantages of LVDT

Disadvantages:

- ✓ Affected by temperature variations and stray magnetic fields.
- ✓ The receiving instrument must be a.c. or a demodulation network must be used, if a d.c. output is required.
- ✓ The dynamic response of LVDTs is limited mainly by the excitation frequency, since it must be much higher than the core motion frequencies, so as to be able to distinguish between them in the amplitude modulated output signal.

LVDT for Rotary Motion



Rotational differential transformer

- ✓ **Linear for limited rotation, – 40º < θ_i < + 40º**
- ✓ **Sensitivity 10 to 20 mV/degree.**
- ✓ **Linearity ± 1% of full scale for travel of ± 40º and ± 3% for travel of ± 60º.**

Amitava Chatterjee

Department of Electrical Engg., Jadavpur University, Kolkata, India

Thank You