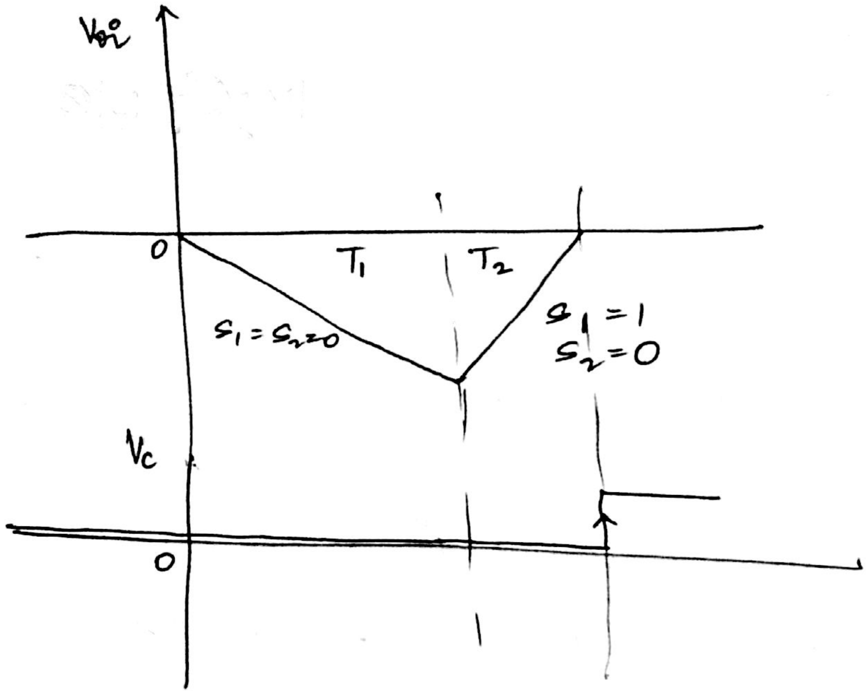
~~$kx<0$~~



$kx < 0$
$\Rightarrow R_1 < R_2$

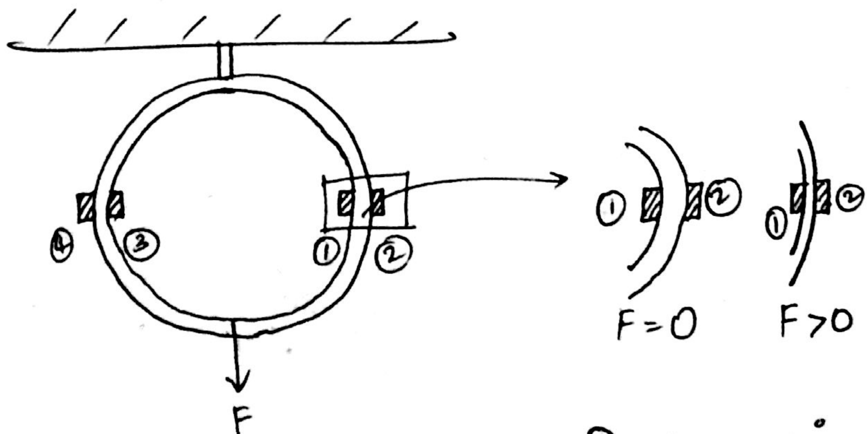
To find out sign of kx, check V_c at $t = T_1$.

If $V_c > 0 \Rightarrow kx > 0$

$V_c = 0 \Rightarrow kx < 0$

LOAD CELL

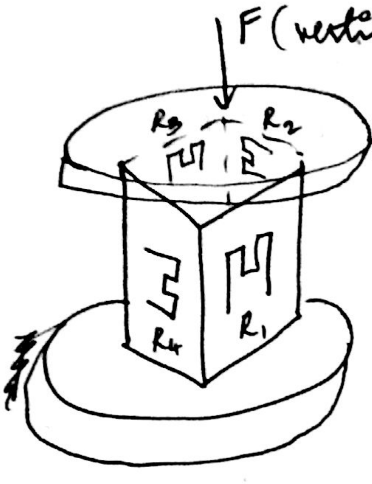
- Usage of strain gauge to measure force.
- Proving ring:



① : expansion
② : contraction

①, ③ : R ↑ces
②, ④ : R ↓ses

- Can be used until $F \sim 50kg$.
- What about $F > 50kg$?

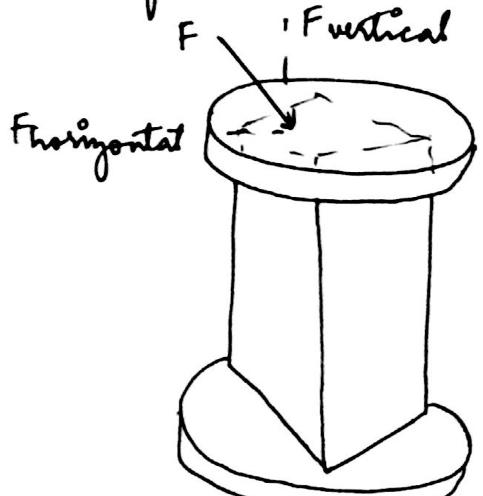


R_1	R_2	R_3	R_4
↕	↔	↕	↔

↔ : sensitivity axes

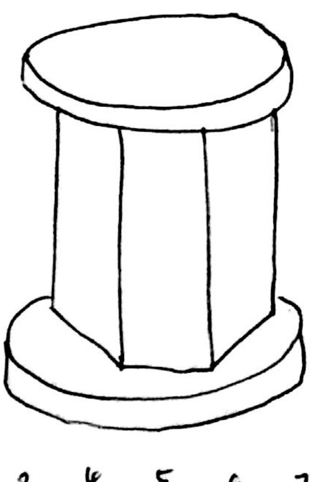
Using poisson ratio, we can use R_1, R_2, R_3, R_4 in a full bridge.

If F is at an ∠le:



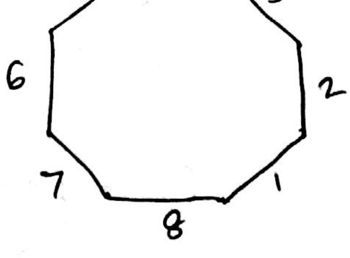
There will be strain due to horizontal comp. of F.
But, we want to see only influence of vertical comp.
(ie; it must not be sensitive to bending/shear force).

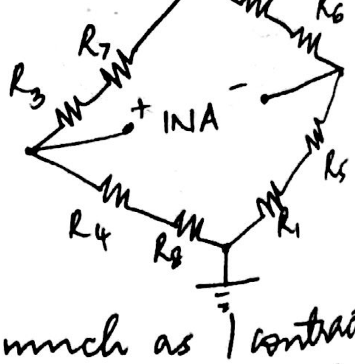
So, then use 8 sided polygon:



1	2	3	4	5	6	7	8
↕	↔	↕	↔	↕	↔	↕	↔

Cross section:





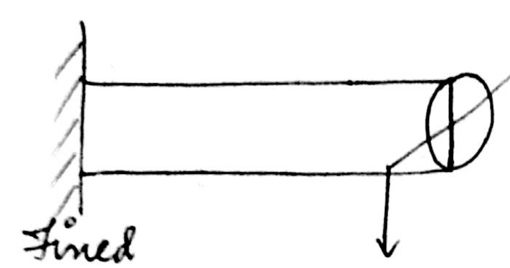
Now, 5 elongates as much as 1 contracts wrt shear force

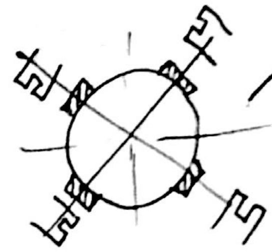
Similarly, 4, 8; 6, 2; 7, 3;

So, use these pairs in each arm of bridge.

Torque

- τ = Force × Distance
-



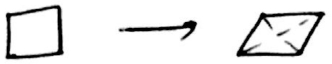


Use these in a bridge.

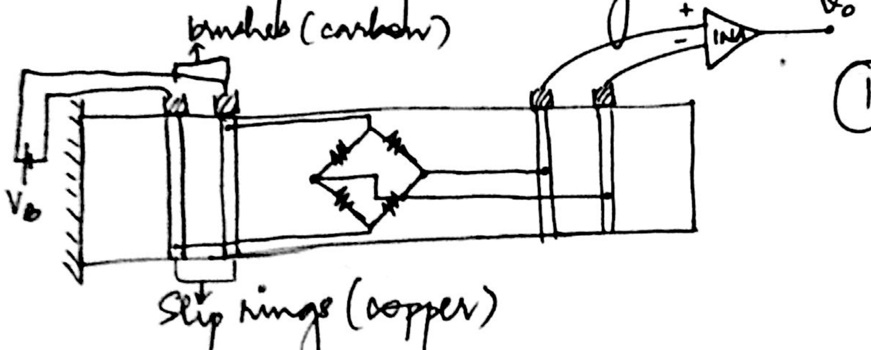
Finally aligne to 45° axis.
So, put ~~along~~ strain gauges at 45°, 135°, −45°, −135°.

If we can't have electrical connections to these gauges because of twisting, what do we do?

A differential element after twisting becomes elongated/comp along 2 directions resp.

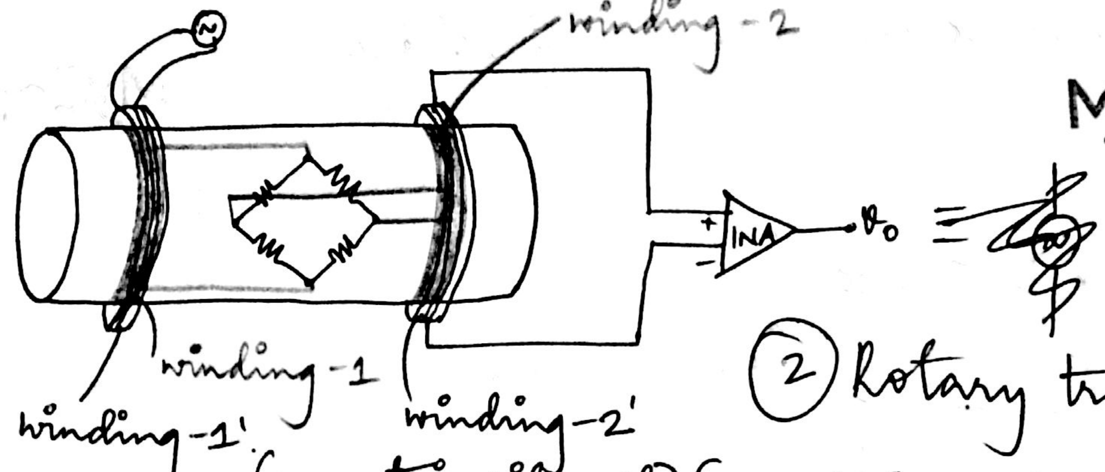


Use slip ring at arrangement



① Slip ring type

Issue is that there is friction at electrical contacts b/w rings & brushes which are subjected to wear. This could introduce some loading on the rotation.

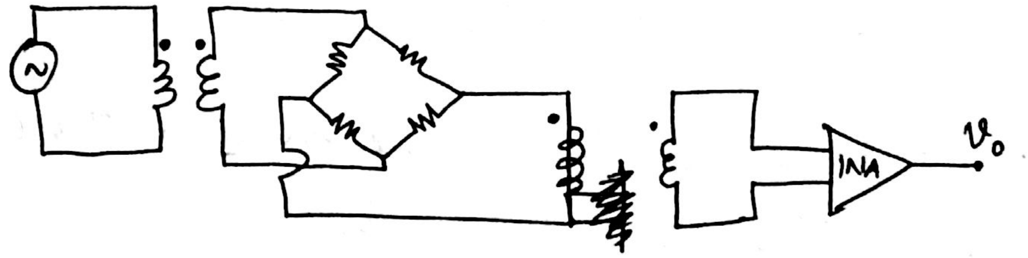


② Rotary transformer

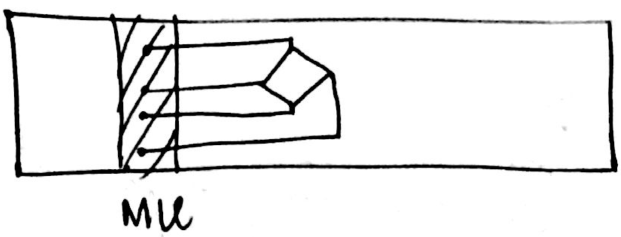
(concentric coils used) (no self induced emf)

like introducing two transformers to remove friction & wear

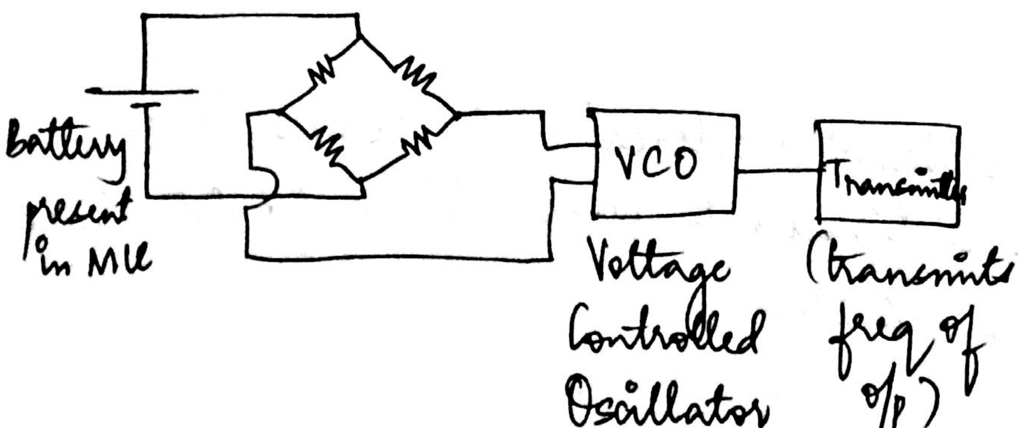
(Outer windings are for isolation)

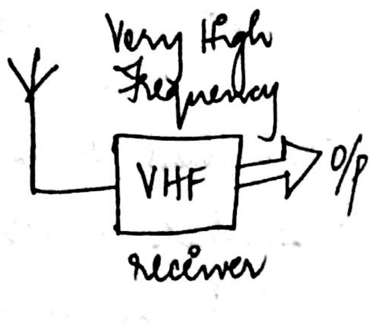


③ Telemeter : To reduce size



MU : Measurement Unit (some electronics)





Characteristics of sensors

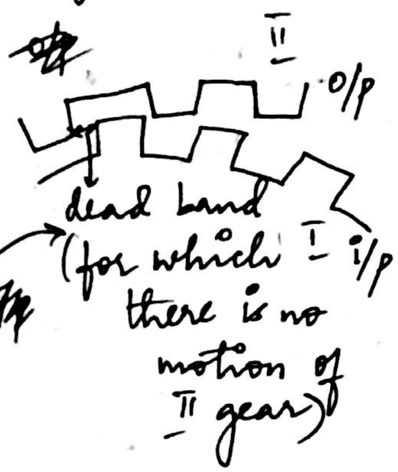
1. Range : For i/p & o/p
2. Accuracy
3. Sensitivity $= \frac{\Delta o/p}{\Delta i/p}$ (Eg:- Gauge factor $= \frac{\Delta R/R}{\Delta l/l}$) ; more sensitive ⇒ ↑ er sen
4. Linearity : Non-linearity $= \frac{\text{Largest deviation from linearity}}{\text{Full scale}}$
5. Threshold : Min. i/p to have non-zero o/p
6. Resolution : Smallest quantity that can be measured.
7. Dead-band ; 8. Precision :

Sensors have steady state and dynamic performance.

Eg:- Proving ring

i/p : 0 — 50 Kg ≡ 50 Kg range
o/p : −5V — 5V ≡ 10V range
} Range is always [0, Range]

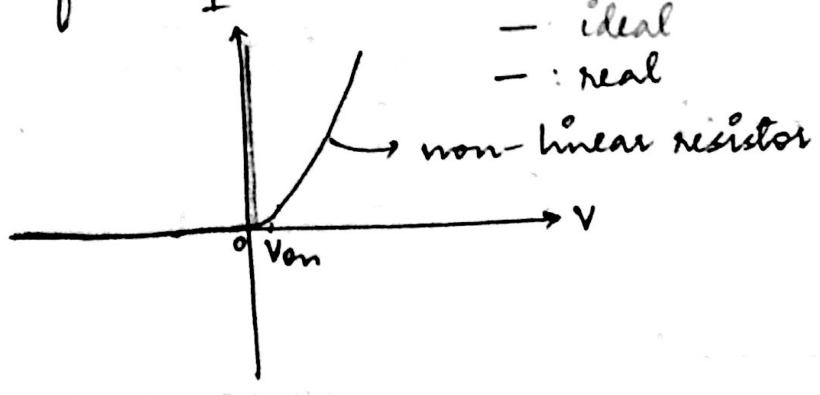
— Dead band :



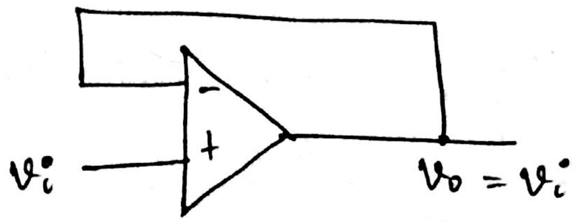
Order of system = No. of distinct storage elements

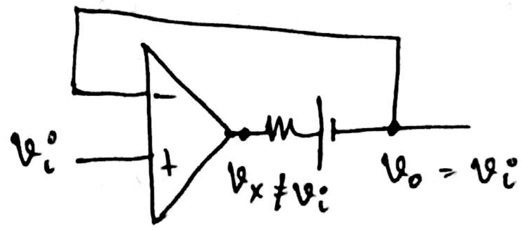
Lab experiment 4

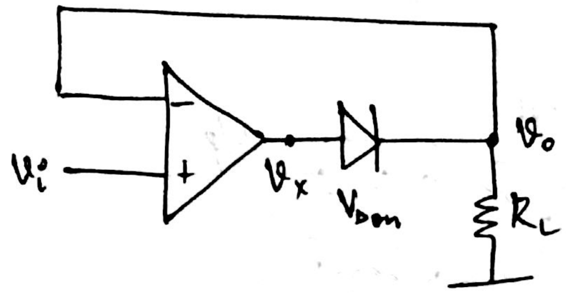
Rectifier circuit is not ideal



Precision rectifier - Diode which is made ideal using additional electronics.





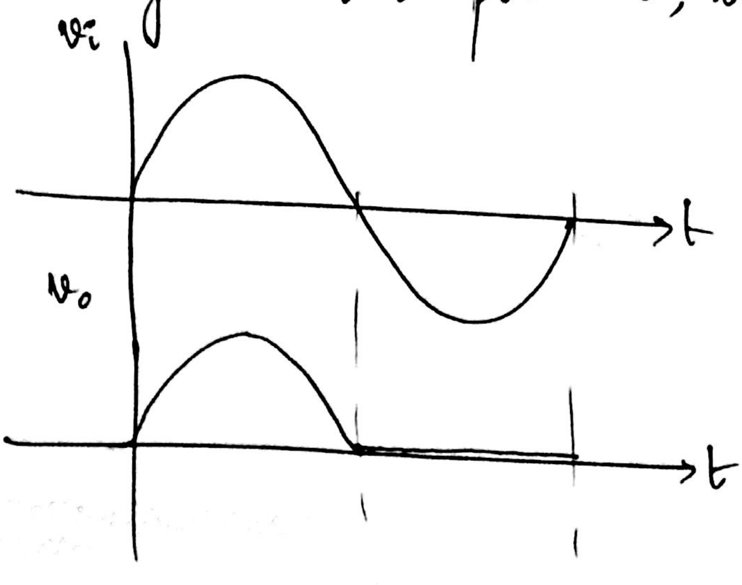


Suppose diode is off, $v_o = 0$ [$\because i_- = 0$]

$\Rightarrow v_x = v_{sat}$

$\Rightarrow$ Diode turns on.

As long as v_i is positive, diode is on and $v_o = v_i$.



So, non-idealities of diode are removed

→ Super diode.

$v_i < 0$: Diode off $\Rightarrow v_x = -V_{sat}$

Diode off

$\Rightarrow v_o = 0$

Slew rate ! $= \frac{dv_o}{dt}$

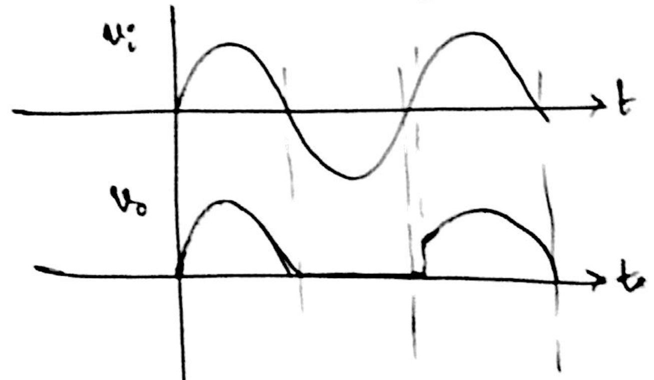
But, in the next +ve cycle, v_x must go from $-V_{sat}$ to 0

In LF341, slew rate = 13V/μs

If V_{sat} = 13V, we require 1μs for v_x to come back to 0

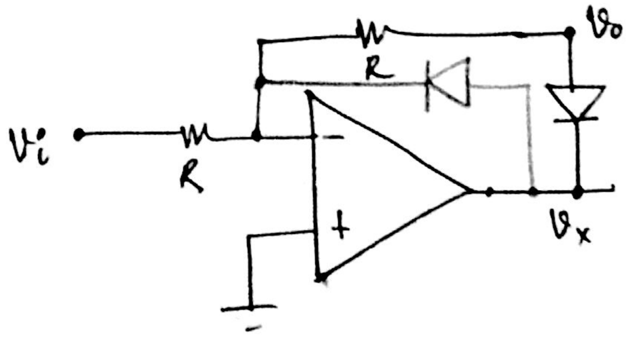
For $v_i \sim \frac{1}{2}$MHz, you lose like $\frac{1}{2}$ a cycle!

$v_i \sim$ 1Hz, you lose ~ a few μs → Not an issue!



Opamp has many poles → Dominant pole / frequency compensation

Slew rate determined by capacitor used above



Half wave rectifier

$v_i > 0$: (assume diode off)

$\Rightarrow v_x = -V_{sat}$

Diode on & Feedback on!

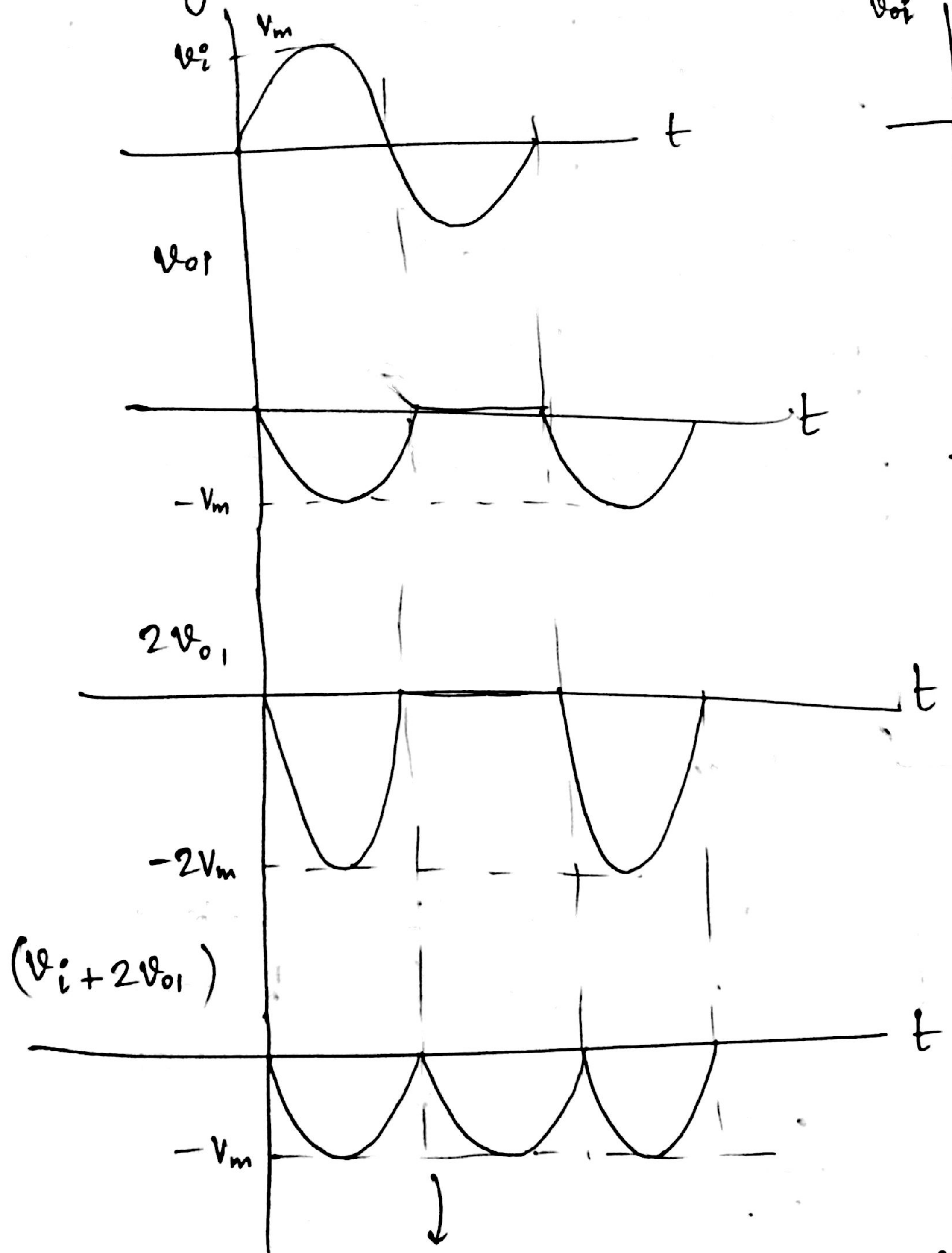
$v_i < 0$: Issue!

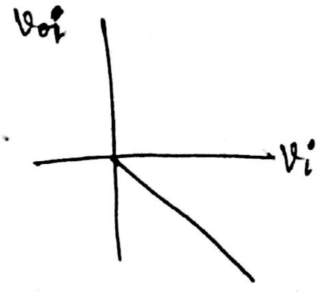
Introduce — : So that swing is b/w $-V_{Don}$ to $+V_{Don}$ → lower slew rate req.

Can use at higher frequencies!

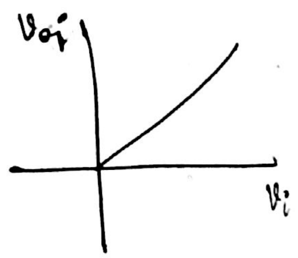
But, this is still only a $\frac{1}{2}$ wave rectifier!

Above gives:



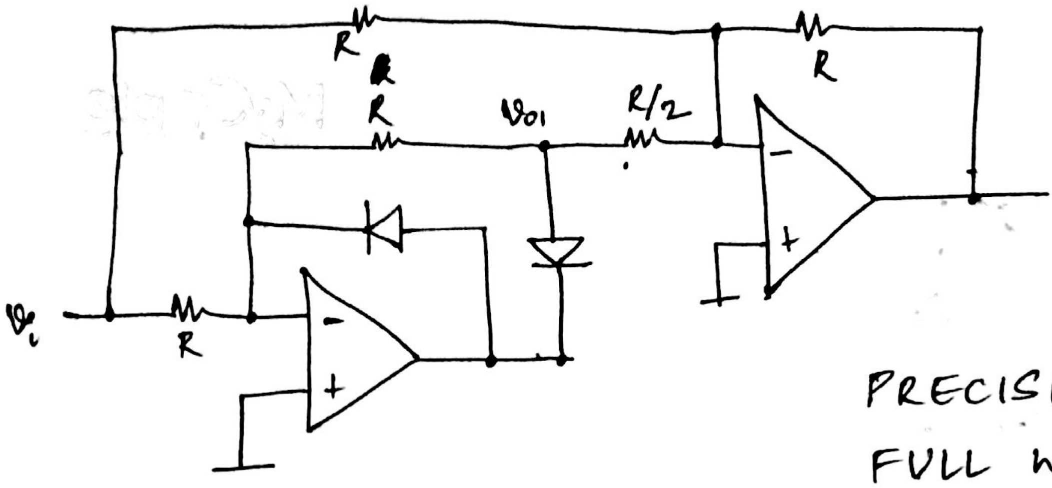


If we want



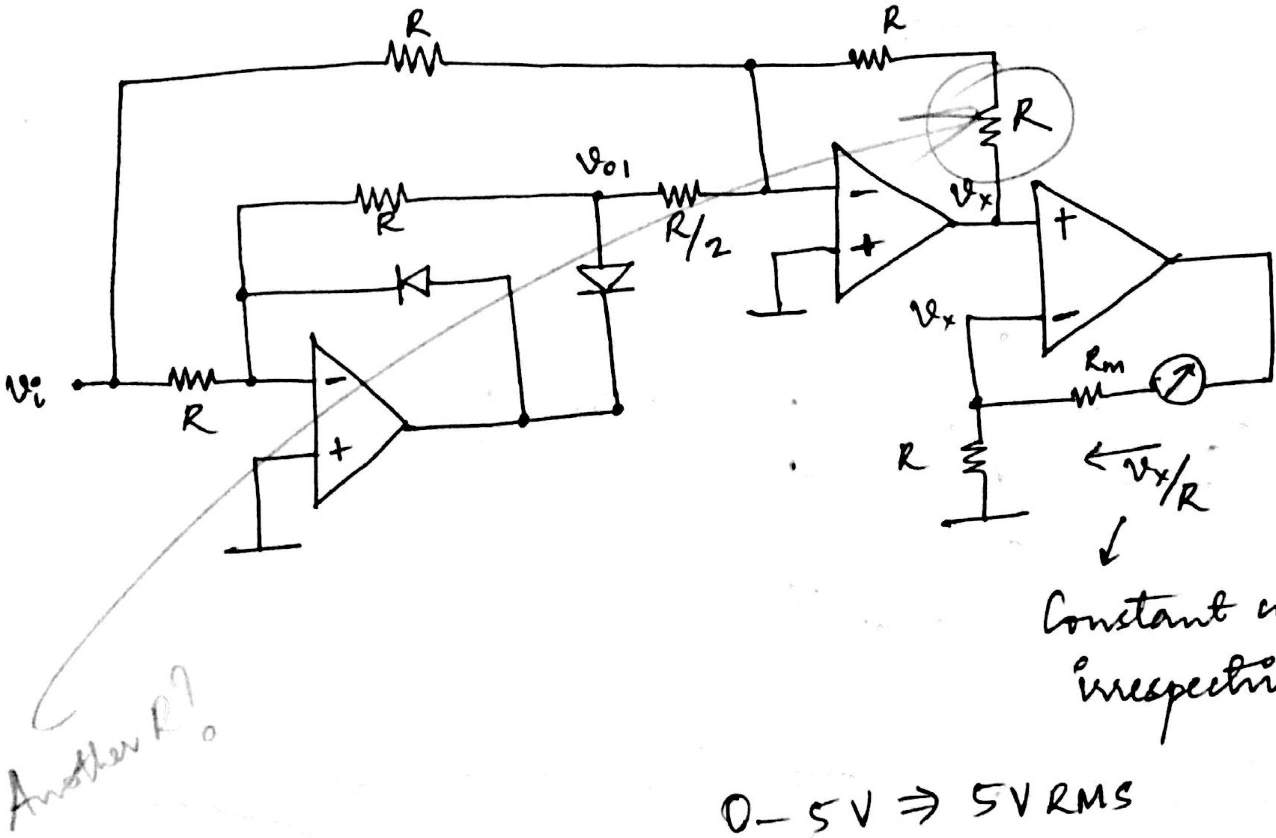
This needs to be inverted.

Use an inverting summing amplifier :)



PRECISION
FULL WAVE RECTIFIER

But, meter has resistance.



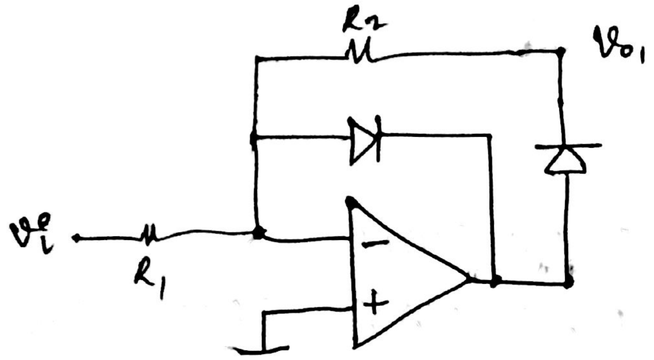
Constant current irrespective of variation in R_m

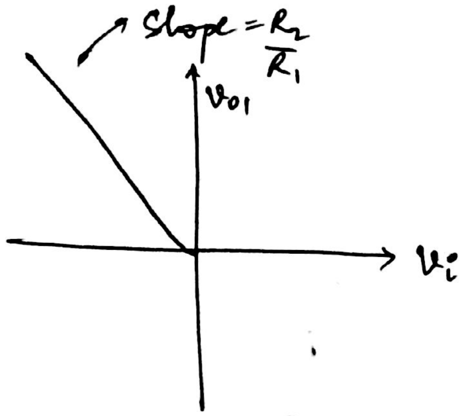
0 – 5 V ⇒ 5 V RMS

Find V_x avg value.

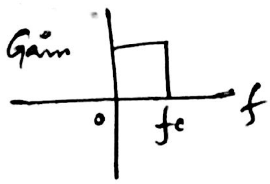
$$V_{avg} = 5\sqrt{2} \times \frac{2}{\pi}$$

$$I_{full\,scale} = \frac{1}{R} \times \frac{10\sqrt{2}}{\pi}$$

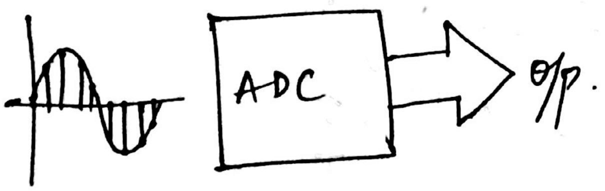




25/2/16

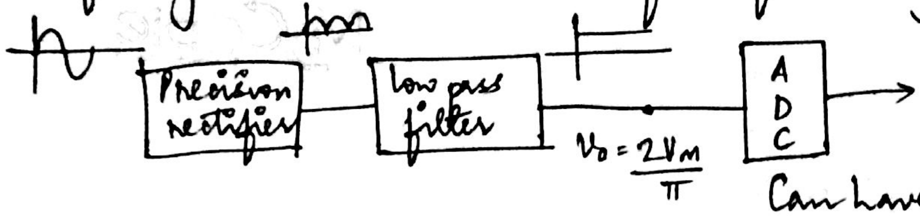


We can do this in ~~analog~~ digital domain too:



Sampling rate must be sufficient to sample the i/p sinusoid $f_{sampling} > f_{input}$

If digitization is done after filtering,



Can have low sampling rate since nearly constant signal is the i/p.

Noise and Interference

Noise: Inherent from a device.

Interference: Unwanted signals coming from external sources.

- Thermal noise (in resistors, ..): Random motion of e^-s / holes

  Thermal noise power $E_t^2 = 4kTRB$ (R: resistance, B: bandwidth)

- Shot noise: Charge carrier crossing potential barrier.
- Flicker noise: Charge traveling semiconductor encounters traps.

Due to noise, resolution gets affected.

Eg:- Temp. sensor: $10\mu V/°C$

Resolution $1\mu V$

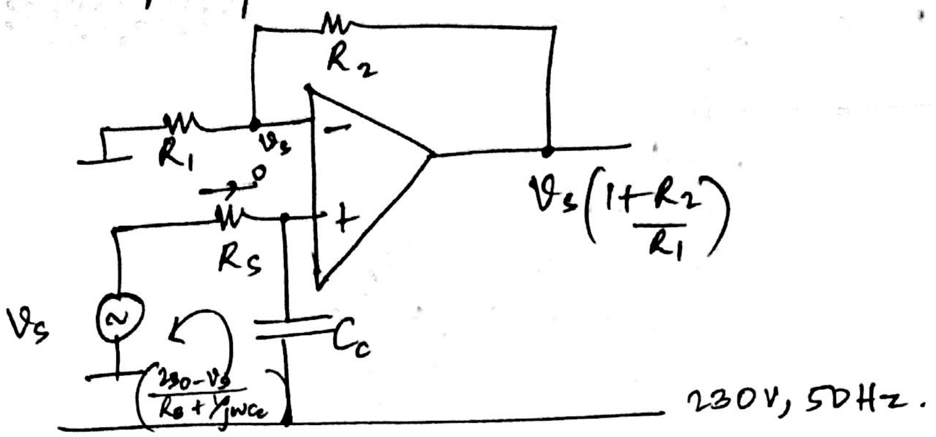
$\Rightarrow$ Can measure $0.1°C$.

If noise: $2\mu V \Rightarrow$ resolution $\geq 0.2°C$. Anything less than $0.2°C$, you can't ~~resvo~~ resolve.

To measure a source V_s:

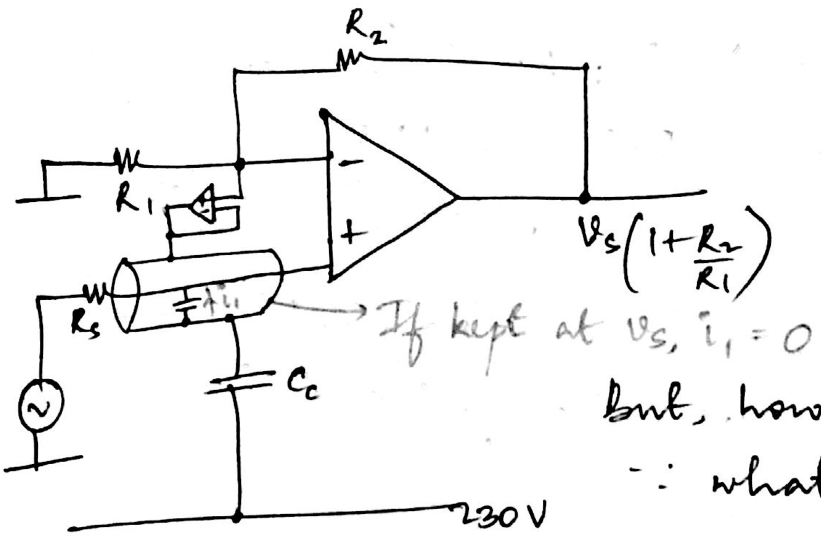
Can't be used since there is loading

Use an opamp :



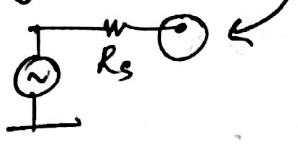
Suppose there is a 230V supply nearby. There is capacitive coupling → Current drawn.

Insert a metallic tool surrounding R_s wire.

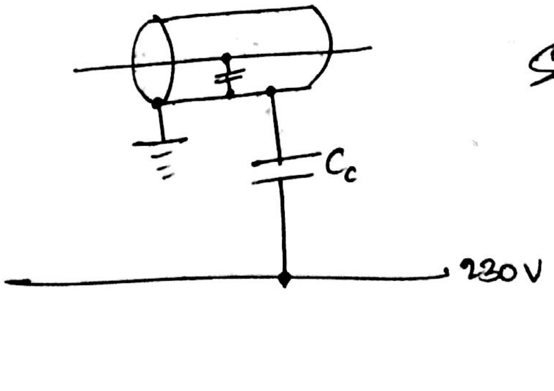


But, how will you keep it at V_s!

∴ what you have is



Use a buffer!



Shielding

If buffer is used, power is used. It is driven. Called guarding

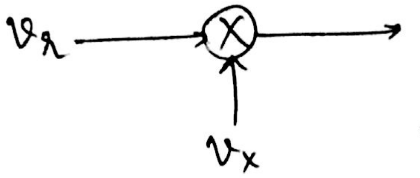
So far, bridge was excited by DC.

If you excite it at f_B, take its o/p only at f_B using a filter. → Interference doesn't come into picture.

If bridge is excited using $v_R = \sqrt{2}\, V_R \sin \omega t$, ($V_R$ = RMS)

At filter o/p, we get $v_x = \sqrt{2}\, V_x \sin(\omega t + \theta)$

We are interested in V_x & θ.

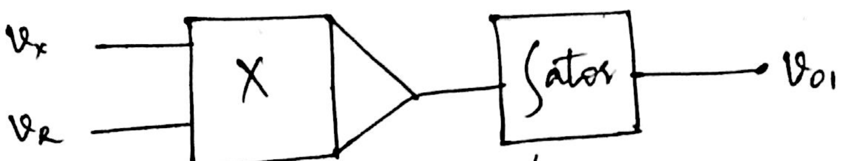


$$2 V_R V_x \sin(\omega t + \theta) \sin \omega t$$

$$= V_R V_x \left[\cos(\theta) - \cos(2\omega t + \theta)\right]$$

Avg value of this $= \frac{1}{T}\int_0^T V_R V_x (\cos\theta - \cos(2\omega t + \theta))\, dt$

$$v_{01} = V_R V_x \cos\theta$$



Can be realised using a LPF

SYNCHRONOUS DEMODULATION

(Even if there are ↑er harmonics in v_x, v_{01} = only DC component)

If $v_R = \sqrt{2}\, V_R \sin(\omega t + 90°)$,

$$v_{02} = V_R V_x \sin\theta$$

$$v_0 = \sqrt{v_{01}^2 + v_{02}^2} = V_R V_x$$

$$V_x = \frac{v_0}{V_R}$$

$$\cos\theta = \frac{v_{01}}{V_R \cancel{\cos\theta} V_x} = \frac{v_{01}}{v_0}$$

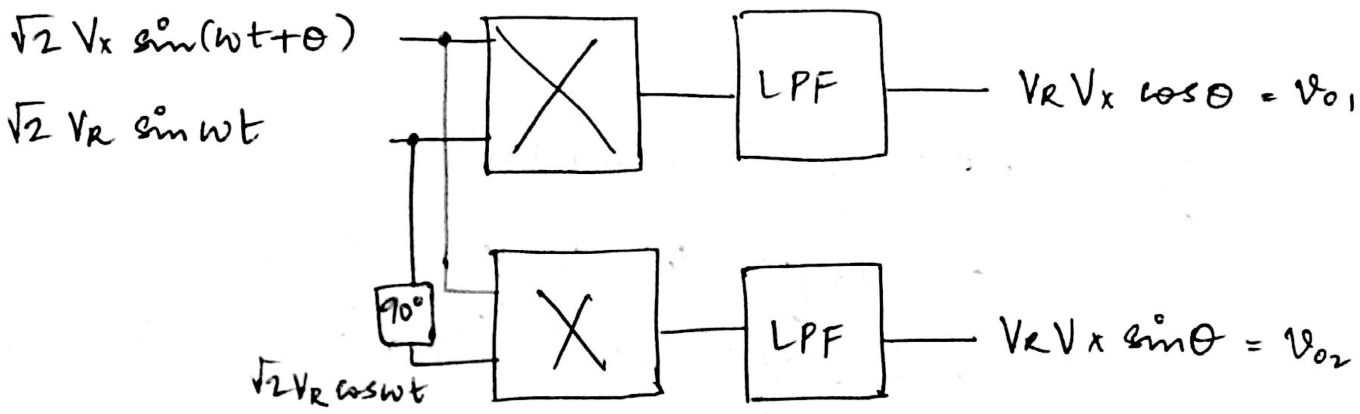
Last Class

- Noise & interference — Capacitively coupled — Shielding — Guarding; Conductively coupled
- Multiplier type Synchronous Demodulator

  ↕ same

  or

  Multiplier type PSD — Detector (Phase Sensitive)



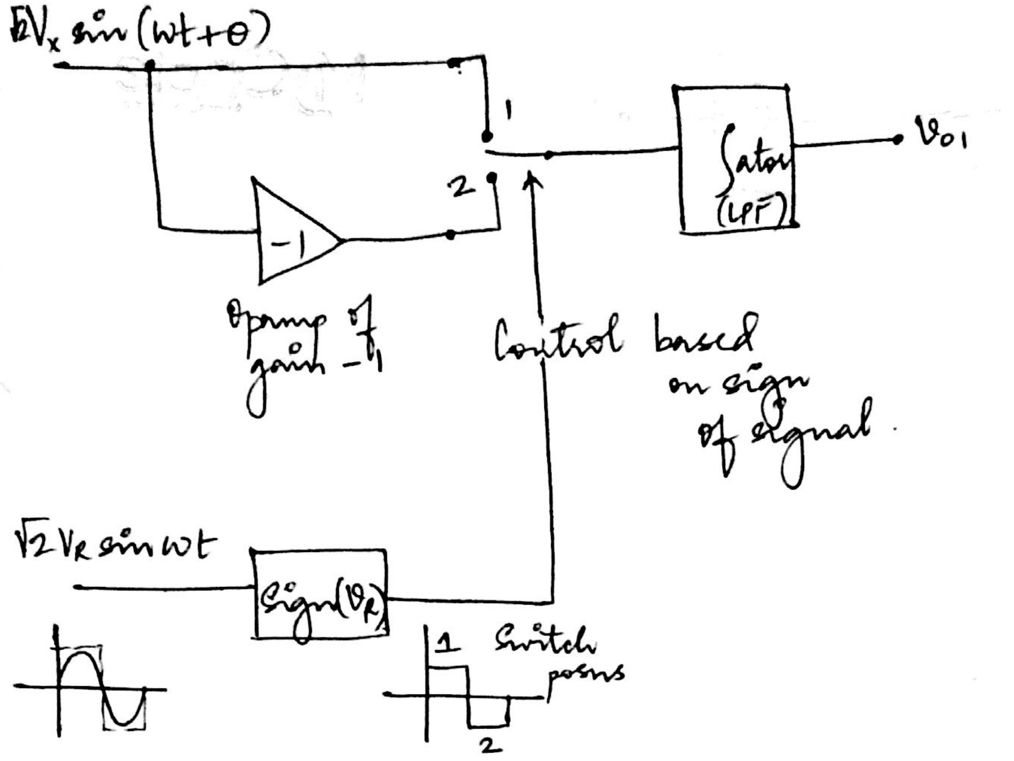
LOCK-IN AMPLIFIER
($\because$ o/p locked to freq ω, no other freq present)

$$V_o = \sqrt{V_{o1}^2 + V_{o2}^2} = V_R V_x.$$

We know $V_R \Rightarrow V_x = \dfrac{V_o}{V_R}$

$$\theta = \tan^{-1}\left(\frac{V_{o2}}{V_{o1}}\right)$$

This is useful as long as noise is at different frequency than signal (here, ω).
If noise is @ ω, we can't do much!
But, multipliers are expensive! Cheap ones are inaccurate!
Use something else apart from multipliers.



SWITCHING TYPE PSD or SYNCHRONOUS DEMODULATOR

$$v_{o1} = \frac{1}{T_0}\left(\int_0^{T_0/2} \sqrt{2}V_x \sin(\omega t+\theta)\,dt - \int_{T_0/2}^{T_0} \sqrt{2}V_x \sin(\omega t+\theta)\,dt\right)$$

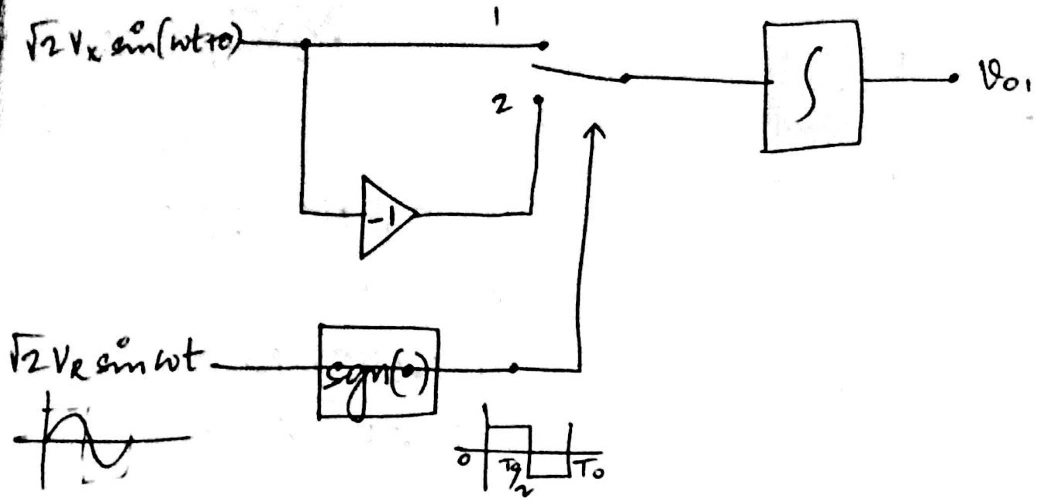
$$= \frac{\sqrt{2}V_x}{T_0}\left[\frac{T_0}{2\pi}\left(\cos\theta \; \cos(\theta+\pi) + \cos(\theta+2\pi) - \cos(\theta+\pi)\right)\right]$$

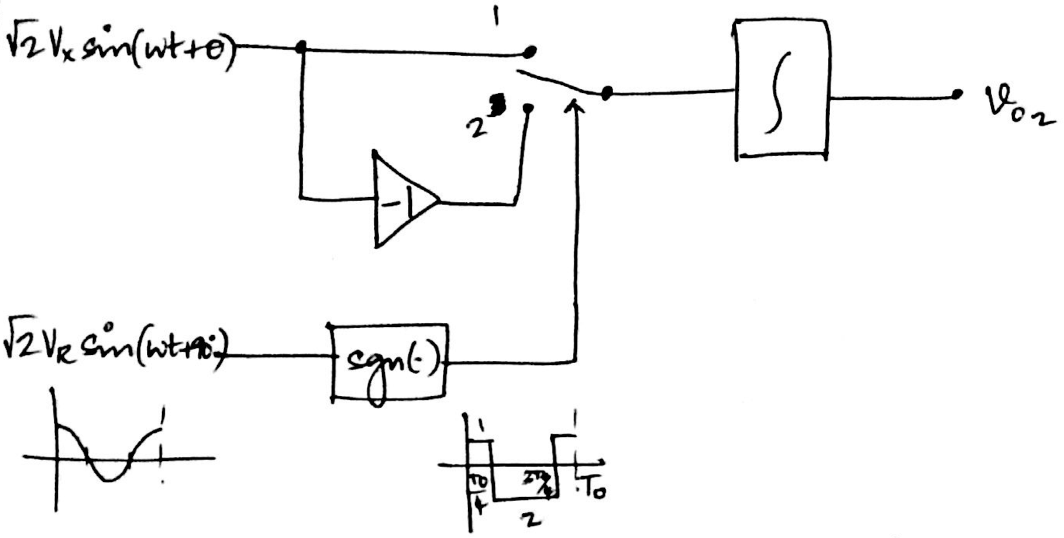
$$= \frac{V_x}{\sqrt{2}\pi}\left(\cos\theta + 2\cos\theta + \cos\theta\right)$$

$$\cancel{= \frac{V_x}{\sqrt{2}\pi}\left(1-\cos\theta\right)}$$

$$v_{o1} = \frac{2\sqrt{2}V_x}{\pi}\cos\theta$$

Precision rectifier realises the same for $\theta = 0$.





$$v_{o2} = \frac{1}{T_0}\left[\int_0^{T_0/4} \sqrt{2}\,V_x \sin(\omega t+\theta)\,dt - \int_{T_0/4}^{3T_0/4} \sqrt{2}\,V_x \sin(\omega t+\theta)\,dt + \int_{3T_0/4}^{T_0} \sqrt{2}\,V_x \sin(\omega t+\theta)\,dt\right]$$

$$= \frac{\sqrt{2}V_x}{\cancel{T_0}} \cdot \frac{\cancel{T_0}}{2\pi}\left[\cancel{\cos}\theta + \sin\theta + \sin\theta + \sin\theta + \sin\theta - \cancel{\cos}\theta\right]$$

$$v_{o2} = \frac{2\sqrt{2}V_x}{\pi}\sin\theta$$

$$v_{o1} = \frac{2\sqrt{2}V_x}{\pi}\cos\theta$$

$$v_o = \sqrt{v_{o1}^2 + v_{o2}^2} = \frac{2\sqrt{2}V_x}{\pi}$$

$$V_x = \frac{\pi v_o}{2\sqrt{2}}$$

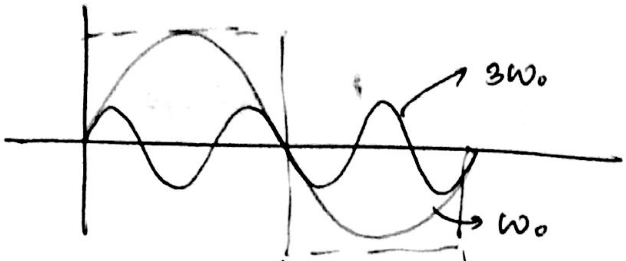
$$\theta = \tan^{-1}\left(\frac{v_{o2}}{v_{o1}}\right)$$

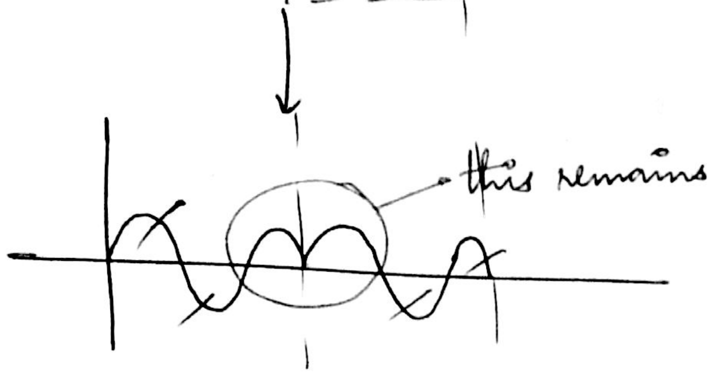
Issues!

- Switch can have delay

AD630 – switching type PSD.

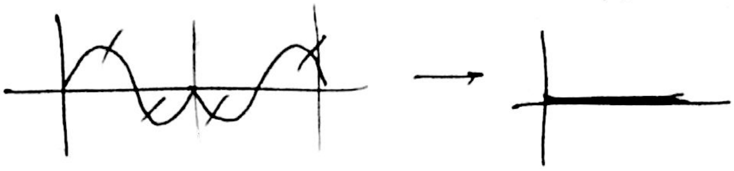
- If ~~the~~ V_x has other harmonics :



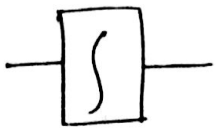


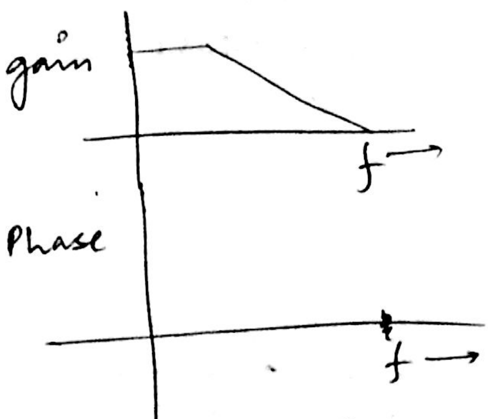
So, odd harmonics don't give o/p.

Even harmonics have ~~of~~ 0 o/p as 



Lab:

① Realise LPF 



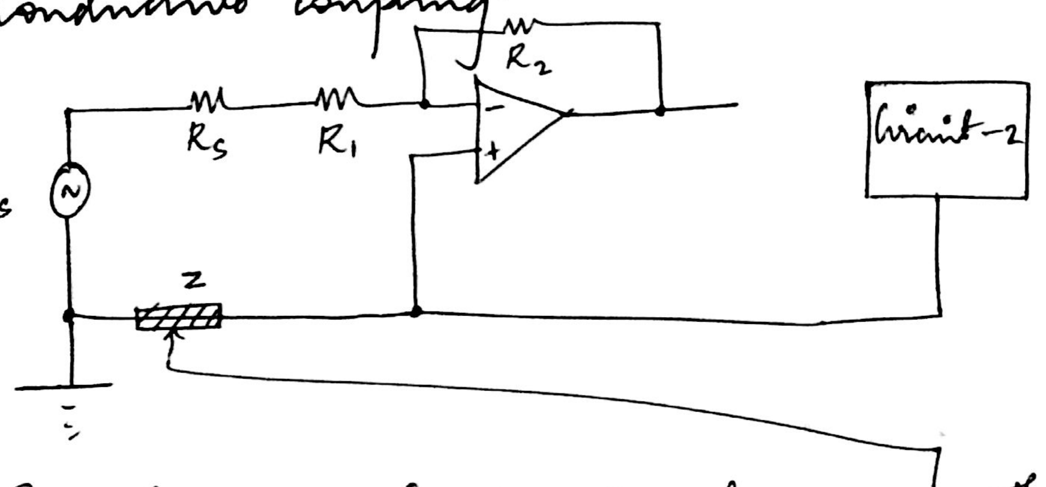
II order LPF ⇒ Apply step input, find $t_{settling}$

Interference

1. Conductive coupling
2. Capacitive coupling
3. Magnetic coupling

Though we can obtain clean o/p from noisy signal using PSD, we require ways to reducing interference 'cause this noise could saturate opamps! (?∵)

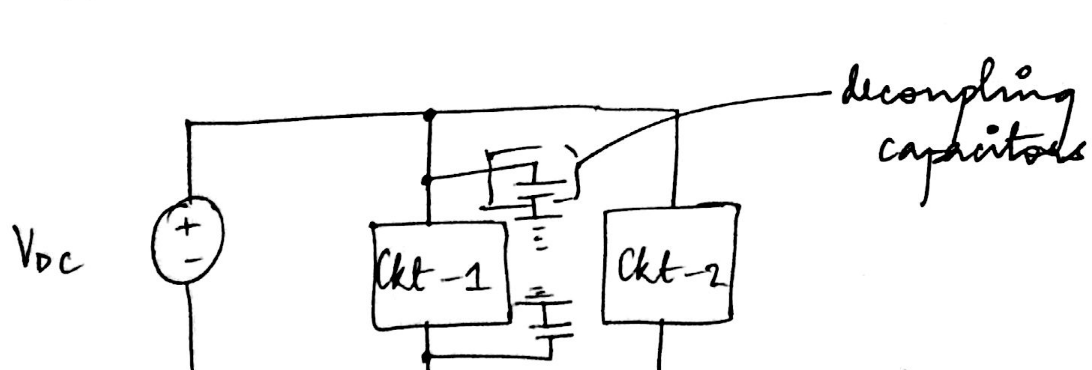
① Conductive coupling:



① ↑se cross-sectional area

Supposing your wire has impedance. Then, there is voltage drop across it depending on frequency of operation. This gives ~~noise~~ wrong o/p at opamp o/p.

~~So~~, reduce z by ↑sing cross-sectional area of ground track.

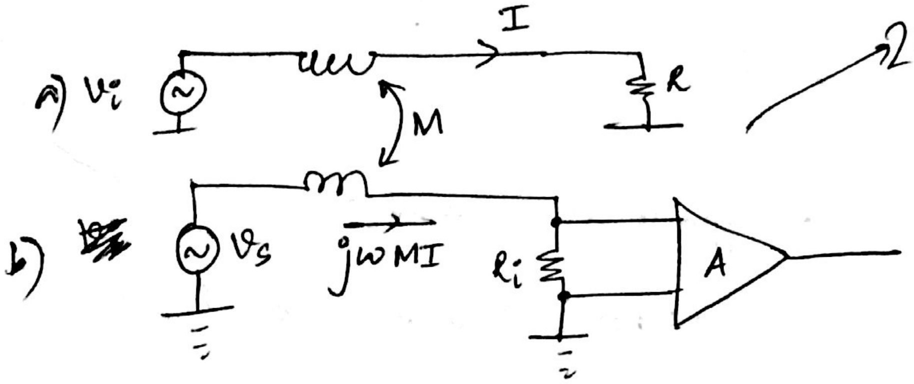


② Decoupling capacitors

Add capacitors so as to be able to give any high frequency current reqd by ckt & prevent this ↑ freq ckt from ~~so~~ flowing back thro V_{DC}.

Digital ckts usually have lot of tranceients ~~during~~ due to switching. So, have separate grounds for analog & digital ckts. (3) Separate gnd for A, D

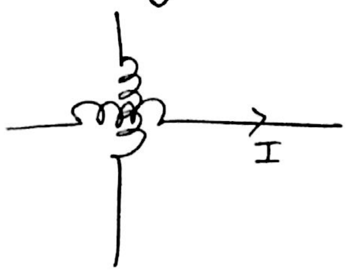
(3) Magnetic coupling:



2 Closeby ckts.

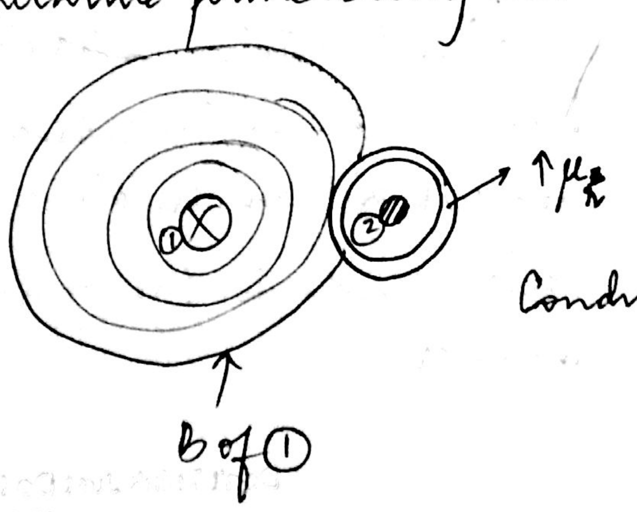
So, there will be o/p in b) due to current in a). due to magnetic coupling.

If they are arranged as



, M's effect is low!

So, what you do is introduce a tube of low reluctance ↑ relative permeability ~~mat~~ → Magnetic shielding.



Conductors (1) & (2).

" Don't Think Just Do It "
— MyCopie

LVDT

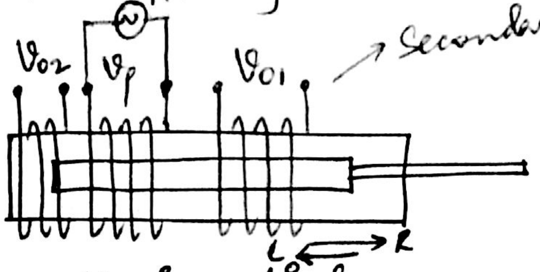
Linear

Variable

Differentiation

Transformer

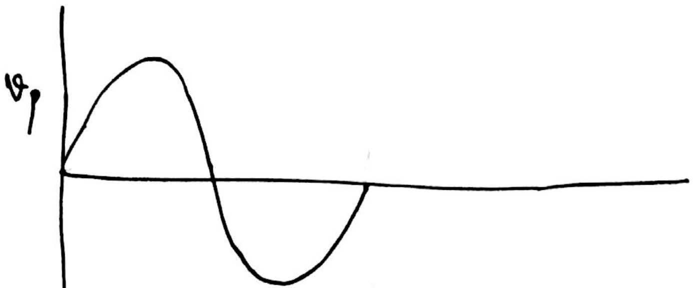
Demerits of resistive sensors - power loss due to friction.

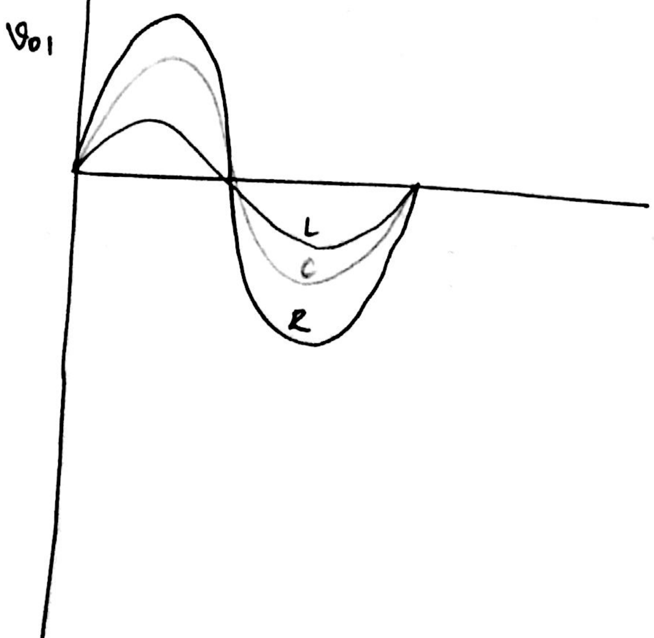


V_p is applied.

V_{01} is obtained.

→ : move core in this direction



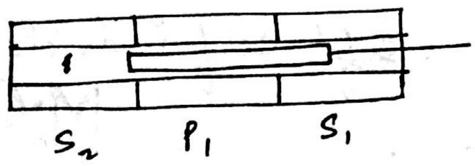


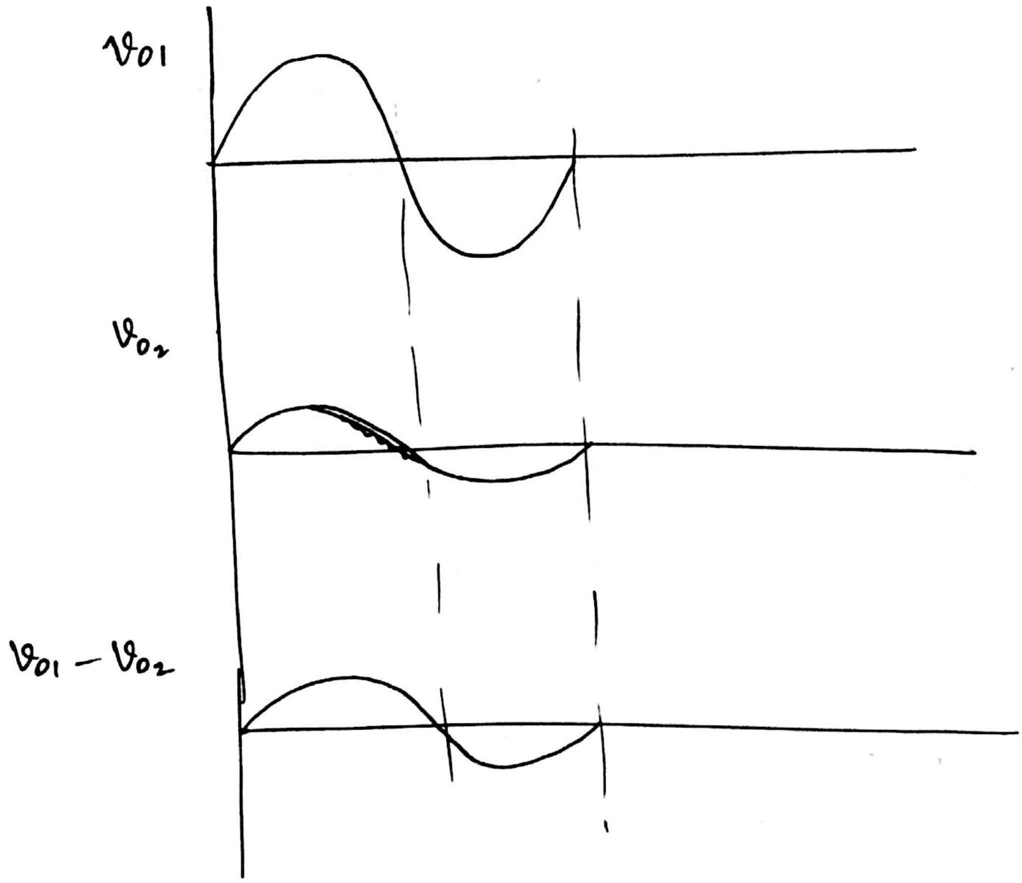
L: left

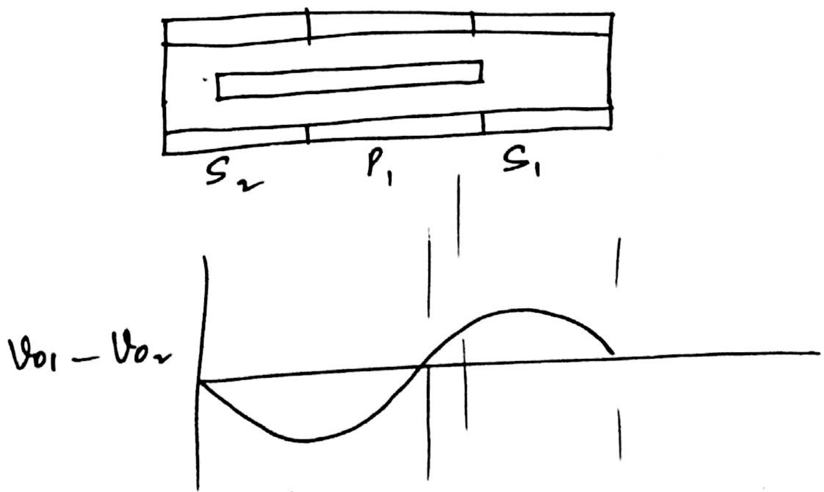
C: Center

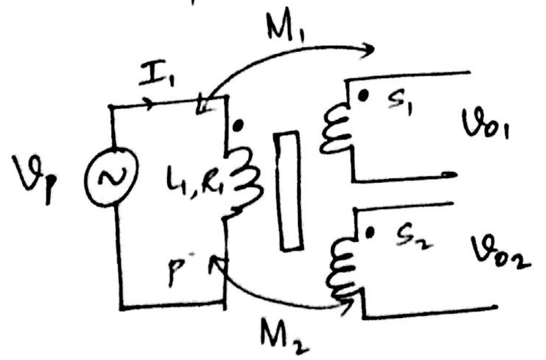
R: Right

We wish to obtain difference b/w L & R. So, introduce another coil on the other side which reacts in the opposite manner.









$$I_1 = \frac{V_p}{R_1 + j\omega L_1}$$

$$v_{o1} = j\omega I_1 M_1$$

$$= j\omega \frac{V_p}{R_1 + j\omega L_1} \cdot M_1$$

$$v_{o2} = j\omega \frac{V_p}{R_1 + j\omega L_1} \cdot M_2$$

$V_0 = V_{01} - V_{02}$

L_1 : ~~seft~~ self inductance of Primary

$$V_0 = j \frac{V_p}{R_1 + j\omega L_1} \omega (M_1 - M_2)$$

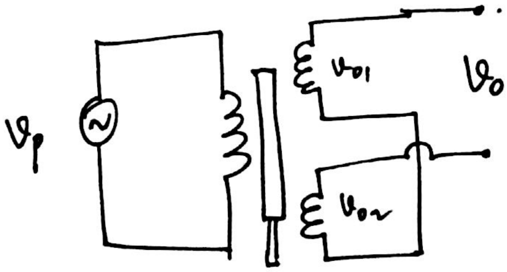
M_1, M_2 : mutual inductance of S_1, S_2 wrt P

Here, we don't consider self inductances of S_1, S_2 since there is no current drawn from S_1 or S_2. V_{01}, V_{02} are induced.

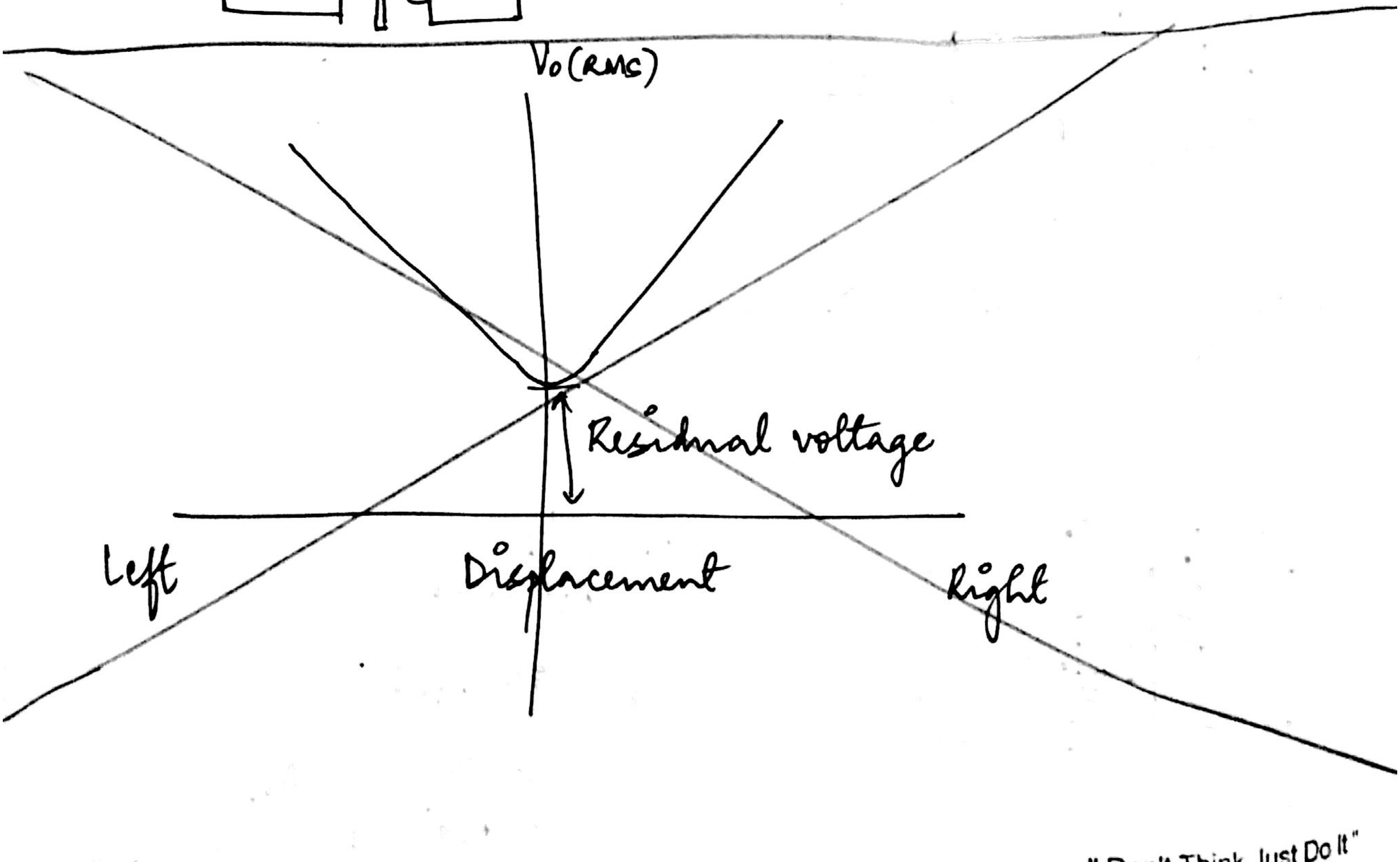
$$\Rightarrow V_0 \propto \underbrace{(M_1 - M_2)}_{\text{due to movement of core.}}$$

There is negligible ~~E~~ energy loss (if R_1 is small).

Also, core can ~~most~~ move freely w/o friction.

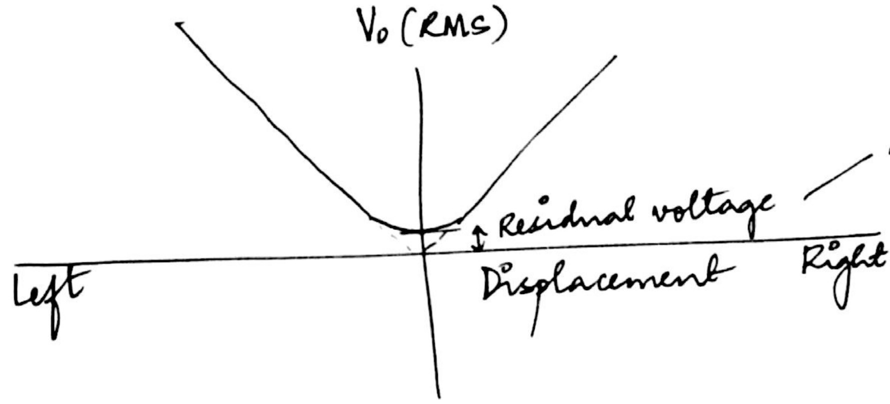


$V_0 = V_{01} - V_{02}$.

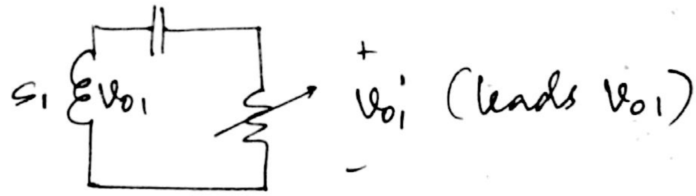


Synchronous Machine

- Can be used in
  1. Standalone operation
  2. Grid connected operation.
- A grid is a large electrical network consisting of various sources & loads. Interconnection b/w them consists of transmission & distribution systems.
- Sources: Alternators. Renewable sources include wind, solar.



You can make this zero by having a lag-lead network



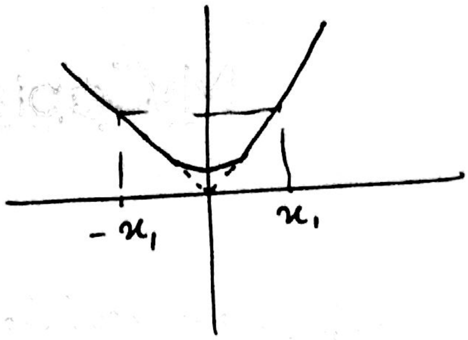
But, this balancing is for one particular frequency. There will be other harmonics for current thro S_1, S_2.

Core can be laminated to reduce core loss.

The primary winding attracts core due to current thro it } Require extra force to be applied to move core.

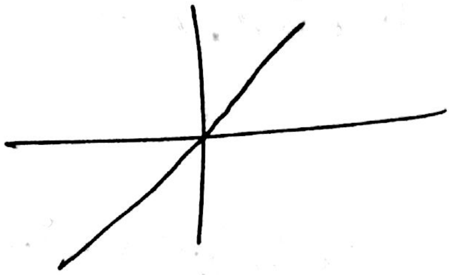
Air - damping

Eddy current

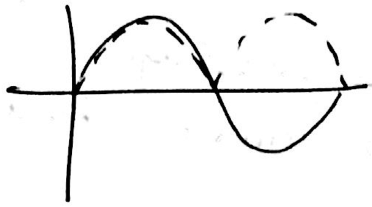


At x_1 & $-x_1$, we get same output. How do we distinguish?

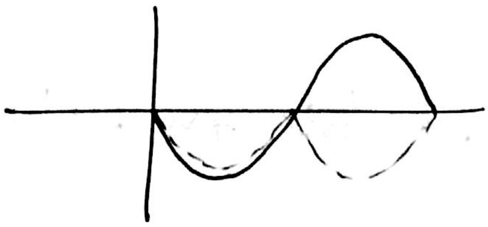
ie; how do we get characteristics of the form

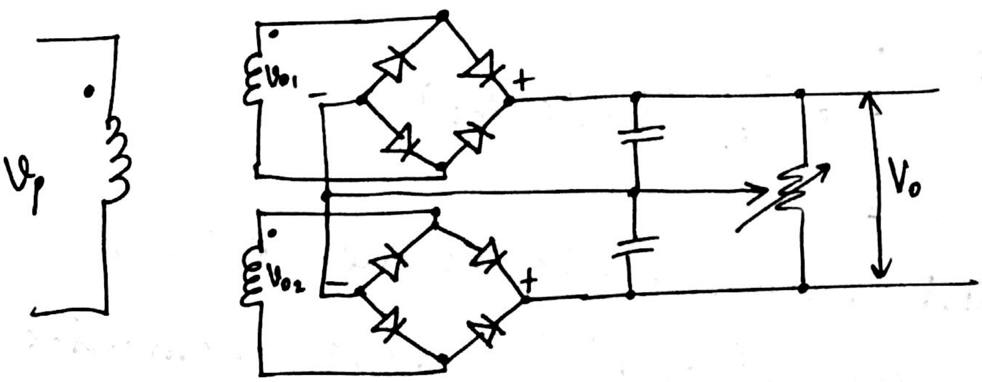


Rectify V_{o1} as :

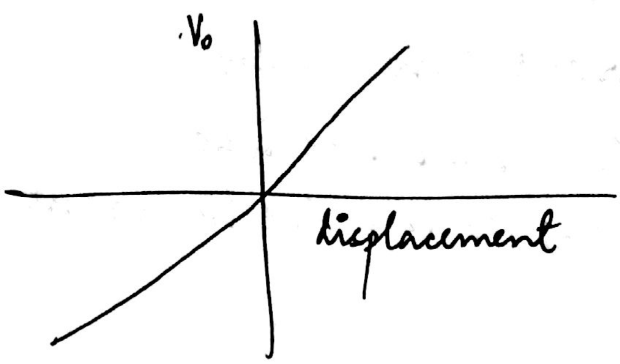


and V_{o2} as :





So, whatever you're doing for S_1, do the opposite for S_2!



But, diodes require turning on voltage. As long as ~~mag~~ amplitude of $V_{o1}, V_{o2} > 0.7V$, its fine!