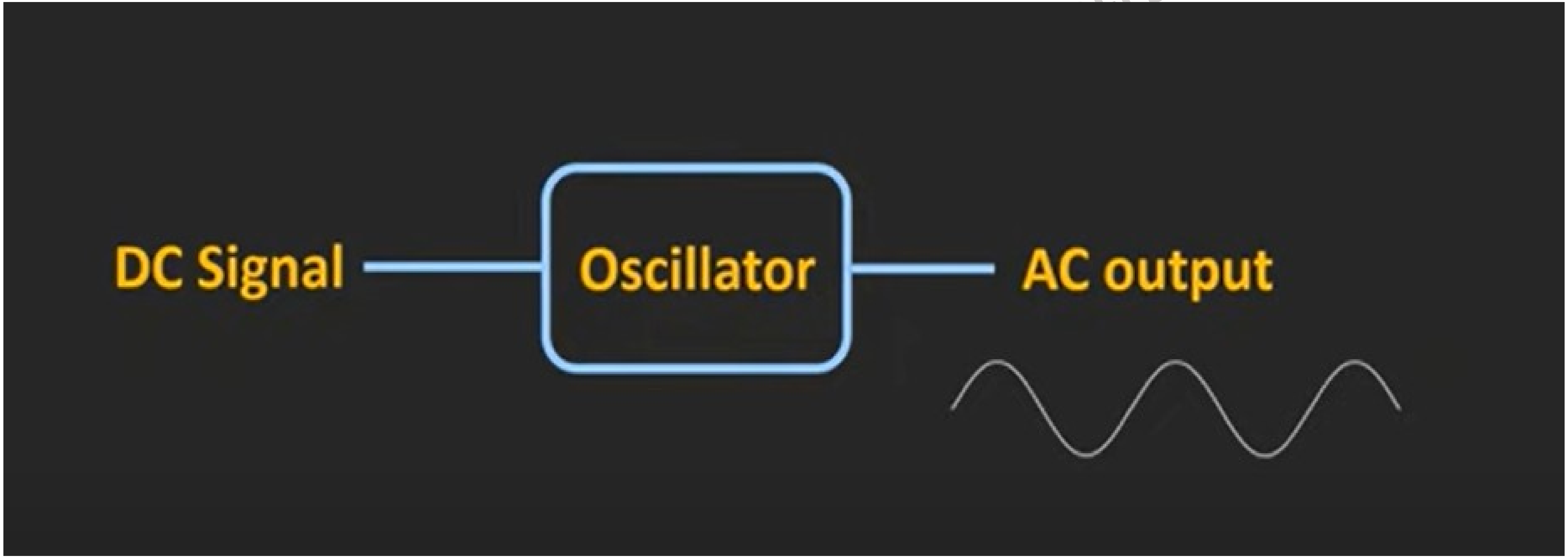
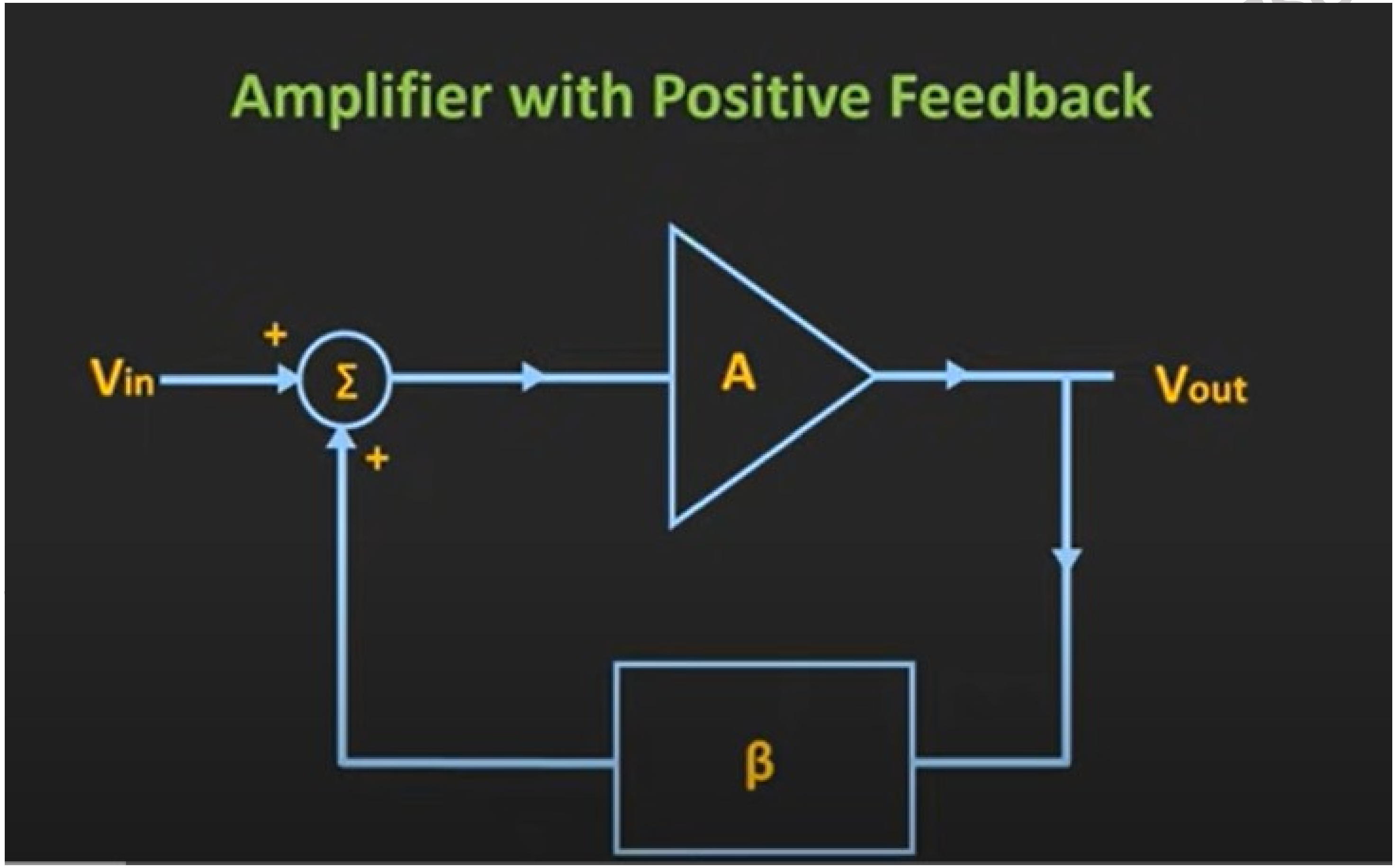
OP-AMP OSCILLATORS AND MULTIVIBRATORS

Oscillators uses:

- Used in laptop and smartphone processors for generating the clock signals.
- Used in radio & mobile receivers for generating the local carrier frequency.
- Used in signal generators used in lab.

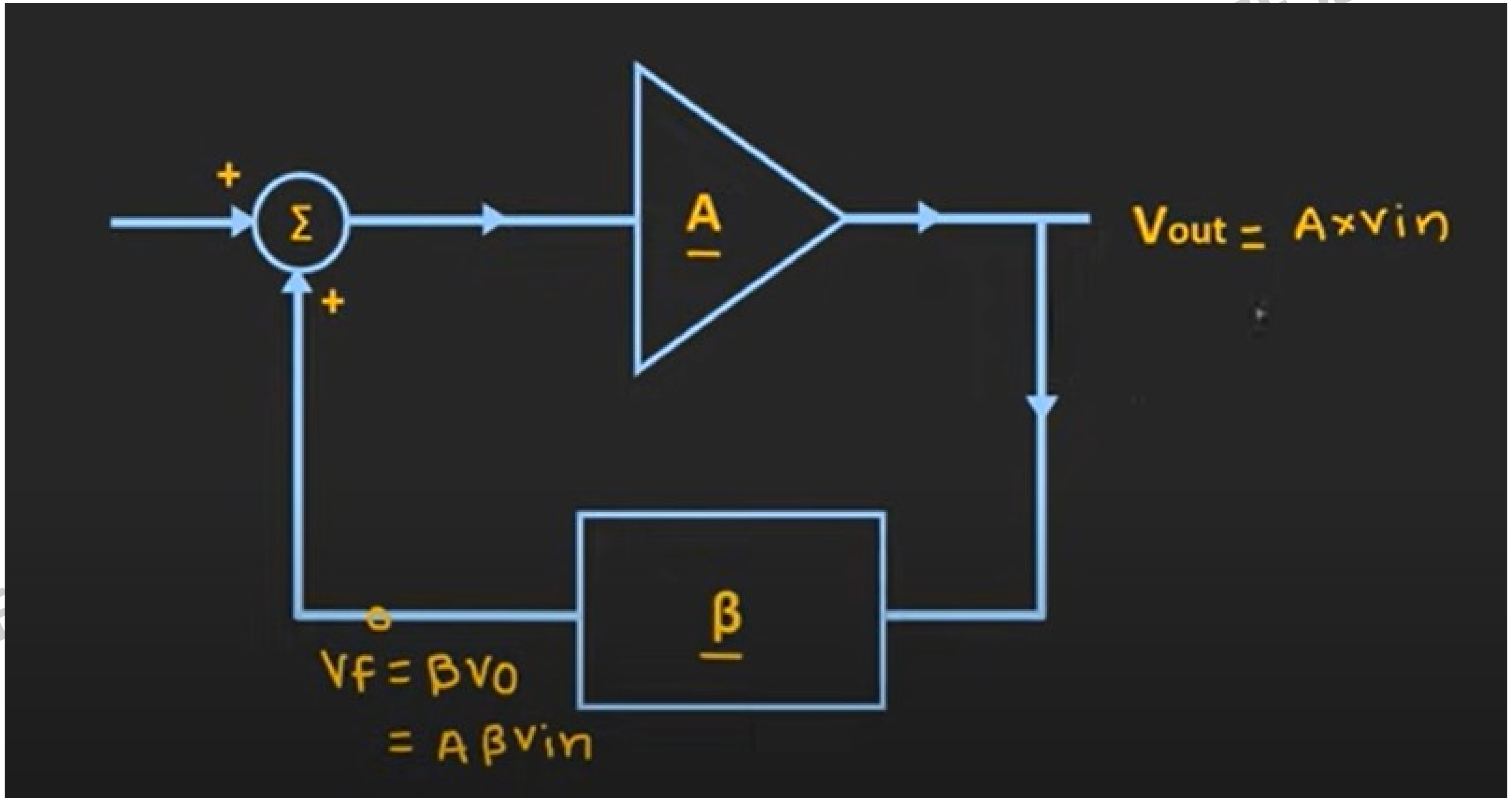
OSCILLATOR




Amplifier with Positive Feedback
+
Vin
Σ
+
A
Vout
β

- Accepts DC voltage and it generates periodic AC s/g of the desired freq.
- Can generate freqs from few Hz to even GHz.
- o/p of oscr can be sinusoidal or non sinusoidal s/gs (like square and triangular wave)
- **Oscr – amplifier with a positive feedback.**

BASIC PRINCIPLE OF SINE WAVE OSCILLATORS

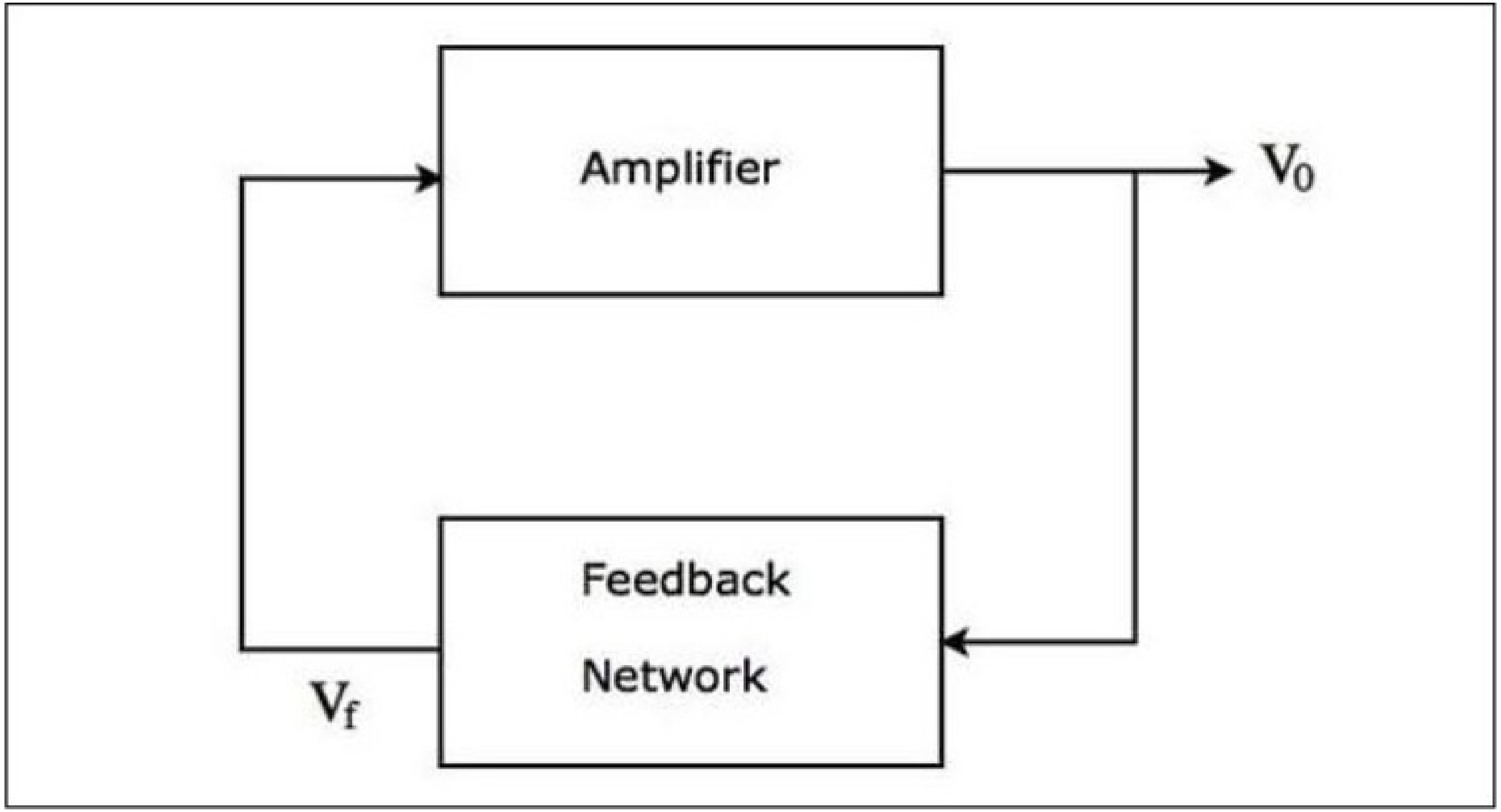


- If the oscillator produces sinusoidal oscillations, it is called as a **sinusoidal oscillator**.
- Let's say some input sinusoidal s/g is applied to this amplifier.
- At o/p, we get i/p multiplied by gain of this ampr.

$$V_{out} = AV_{in}$$

- This o/p s/g is given as i/p to f/b ckt with gain β.
- A freq selective f/b n/w (having inductive or capacitive components) with transfer ratio β.
- o/p of f/b ckt $V_f = \beta V_{out} = A\beta V_{in}$
- Aβ is known as loop gain

- If the values of A and β are adjusted so that $A\beta = 1$, then $V_f = V_{in}$.
- Now if the original external s/g V_{in} is removed and only this f/b is connected, then the ckt will continue to provide o/p as the ampr cannot distinguish whether input V_{in} is coming from ext source or f/b ckt.
- Thus o/p can be continuously obtained w/o any i/p s/g if we can satisfy the condition on the loop gain $A\beta = 1$.
- This is called as Barkhausen criterion for oscillations.
- The condition $A\beta = 1$ can be satisfied only at one specific freq f_0 for the given component values.

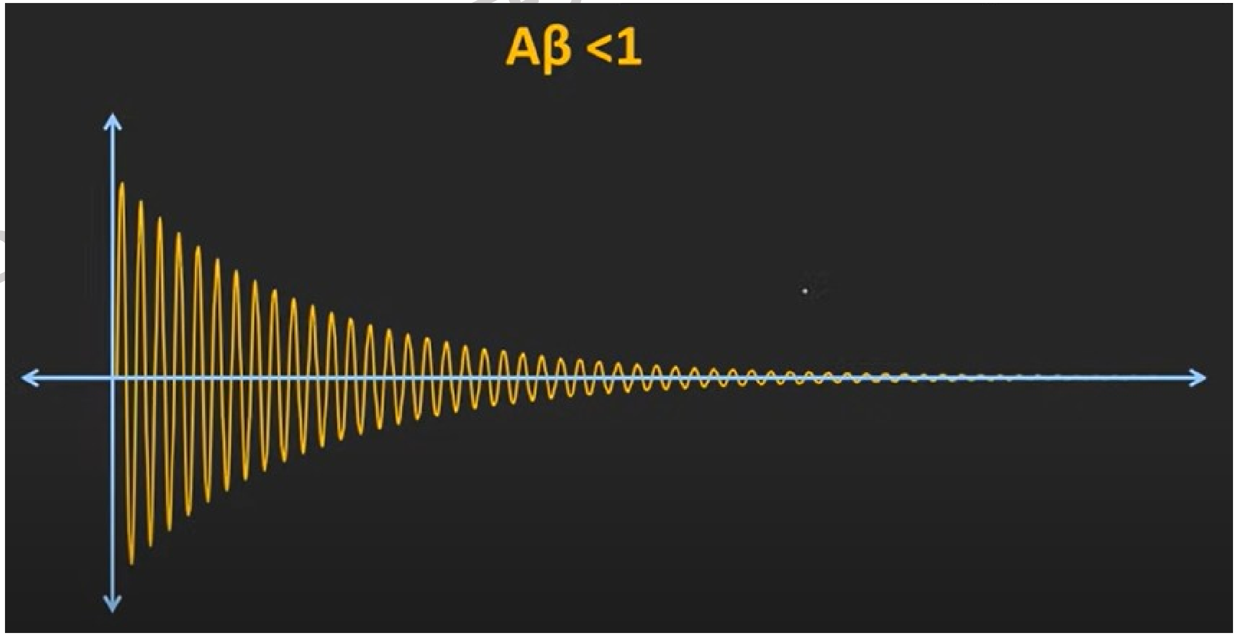

Amplifier
V_0
Feedback
Network
V_f

- Ckt thus provides o/p at freq f_0 where the ckt components meets the condition $A\beta = 1$.
- We can rewrite eqn as $A(j\omega_0)\ \beta(j\omega_0) = 1^{o}$
- There are 2 conditions (one on phase and other on magnitude) of the loop gain which needs to be satisfied simultaneously to achieve oscillations.
- Total phase shift of the loop gain should be 0 or multiples of 2π
- The magnitude of the loop gain should be equal to unity.

$$|A\beta| = 1$$

$$< A\beta = 0^{o} \text{ or multiples of } 2\pi$$

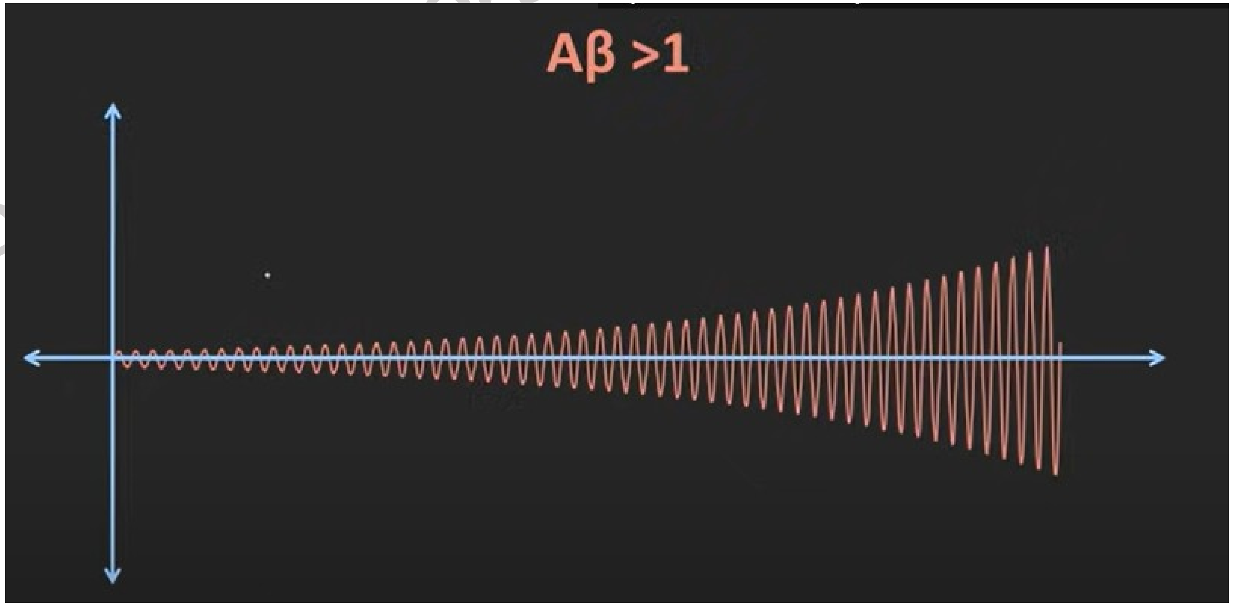
- The condition **|Aβ|=1** is usually difficult to maintain in the ckt as the values of A and β vary due to temp variations, aging of components, change of supply voltage, etc.



- if **|Aβ|<1**, f/b s/g V_f goes on reducing in each f/b cycle and the oscns will die down eventually.

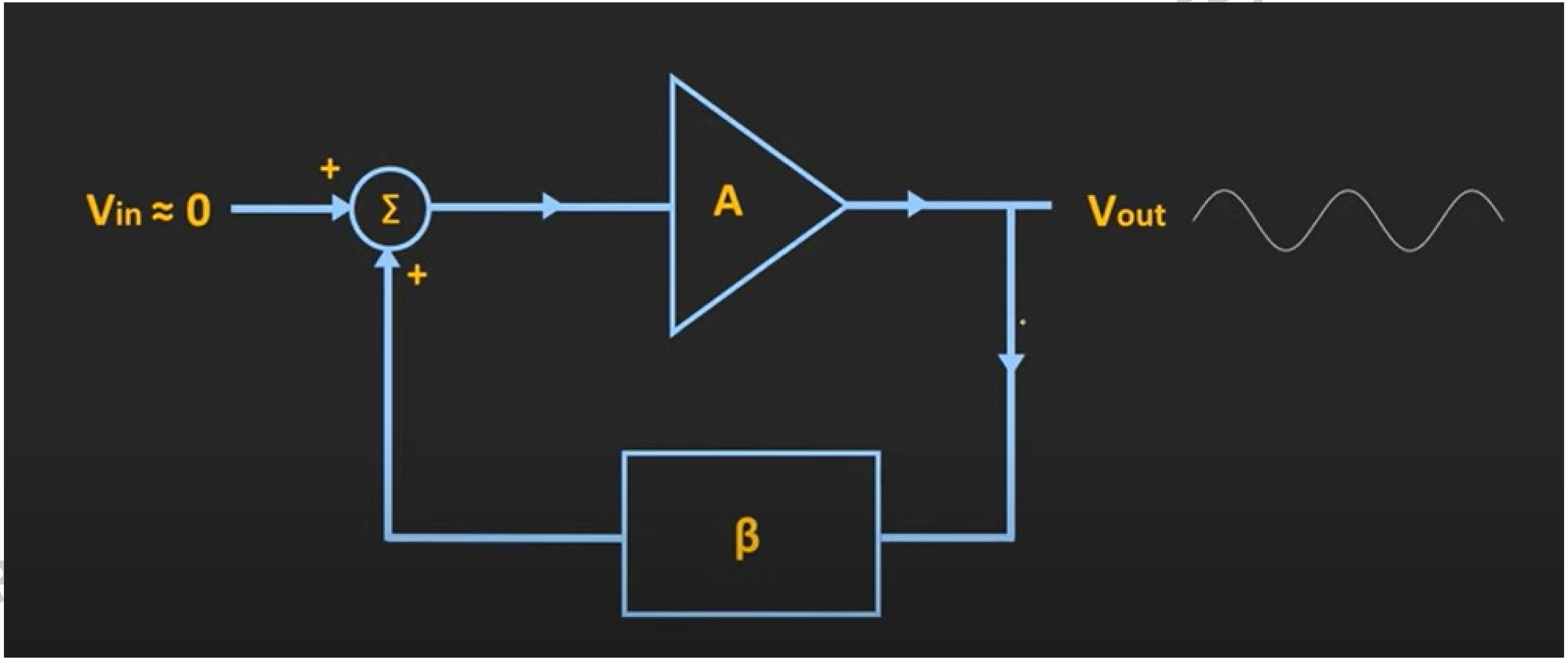
- When $|A\beta|$ >1, oscn in the ckt will build up.

- So in both cases we are not getting sustained oscns.



- In order to ensure sustained oscns inspite of variations, the ckt is designed so that **|Aβ|** is slightly >1.
- Now the o/p amp will go on increasing with every f/b cycle.

- The s/g however cannot go on increasing & gets limited due to the non linearity of the device (ie, as transistor enters into saturation).
- It is the non linearity of the transistor bcoz of which the sustained oscns can be achieved.
- The value of **|Aβ|** is usually kept greater by abt 1 to 5% to ensure that **|Aβ|** does not fall below unity.
- Till now, we had assumed that we first connect a s/g source to start the oscn and later remove it.
- In practical oscr, it is not done so.



+
Vin ≈ 0
Σ
+
A
Vout
β

- o/p waveform is obtained as soon as power is turned ON.
- Actually there is noise signal always present at input (ie, base) of the transistor due to temp (called Johnson's noise) or variation in the carrier conc(Schottky noise).
- Thermal noise contains all freqs(few Hz to even hundreds of GHz).
- So initially when this oscr is turned on, all the freq components of this noise will get amplified by the ampr.
- The noise s/g at the freq at which the ckt satisfies the condition **$|A\beta|=1$** is picked up and amplified.

SINE WAVE OSCILLATORS

1. RC phase shift oscillator
2. Wein Bridge oscillator

Both are audio frequency oscillators.

RC PHASE SHIFT OSCILLATOR

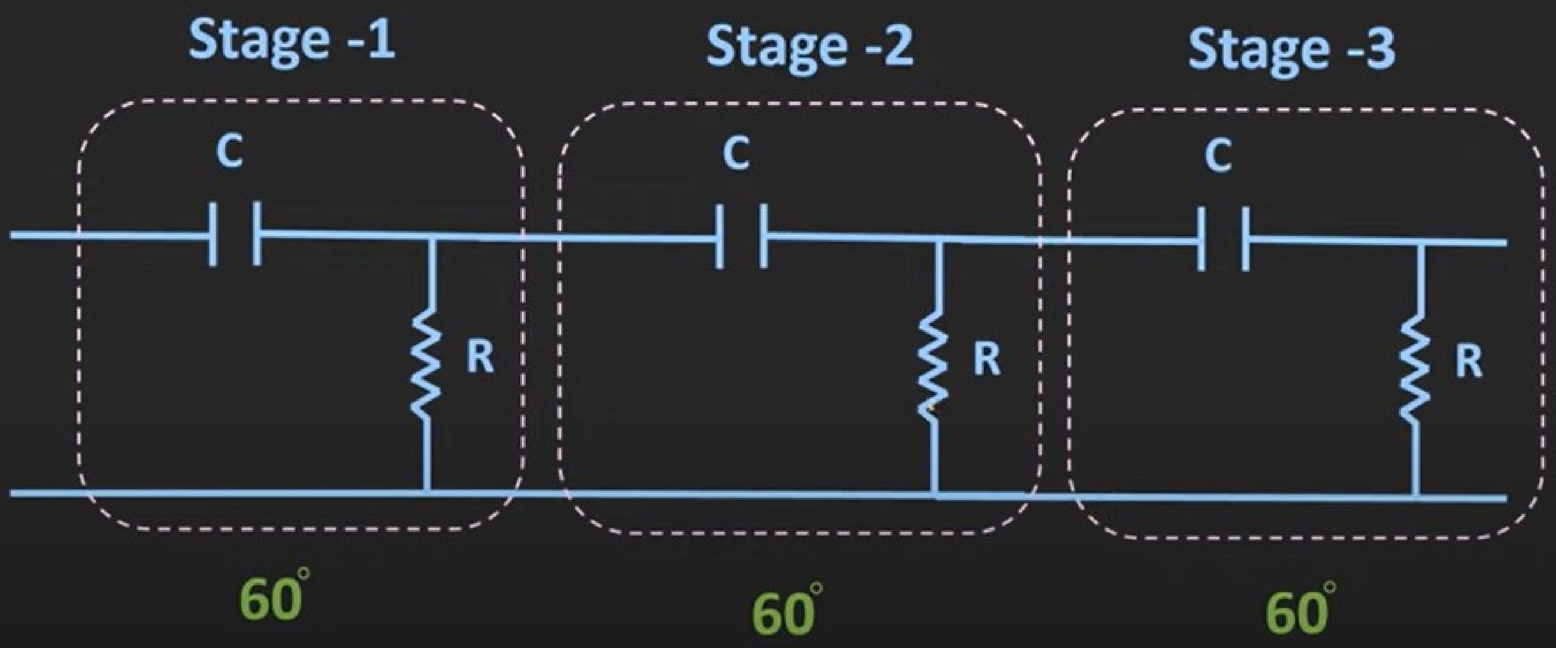
- RC ckt is used in the f/b path.
- Generates stable sine wave.
- Usually used in the low freq generations. Typically in the AF range.
- The op amp is used in inverting mode and hence provides 180^0 phase shift.
- The additional 180^0 phase shift is provided by RC n/w.

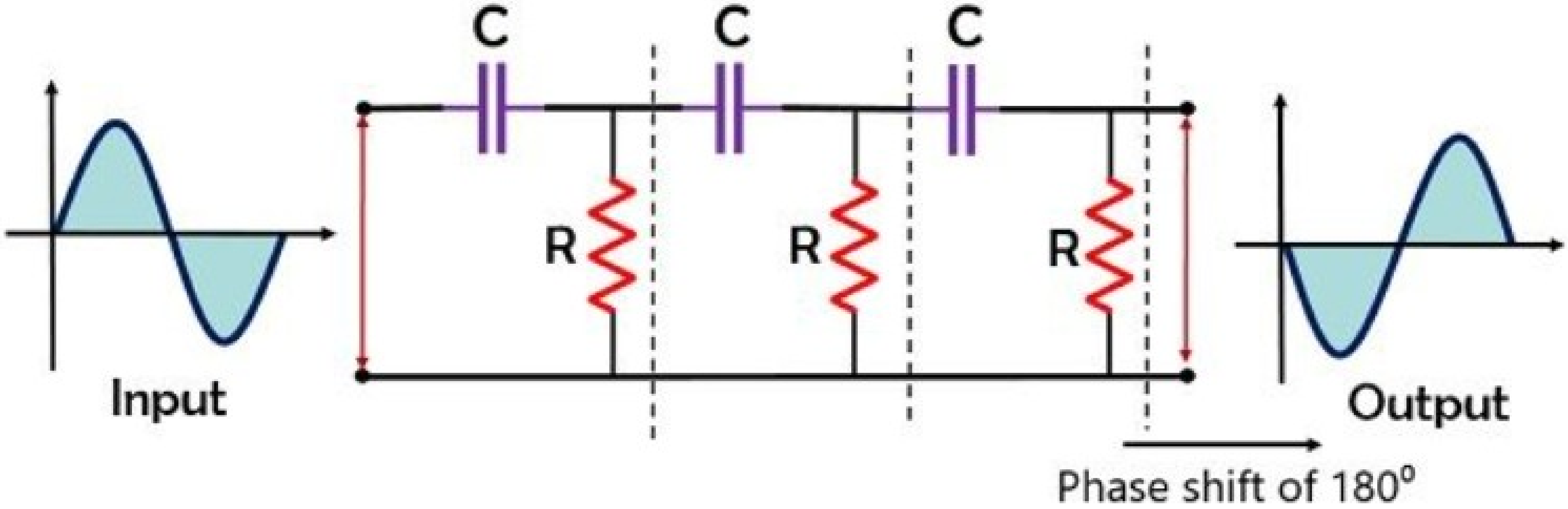
$$|A\beta| = 1$$

$$\angle A\beta = 0$$

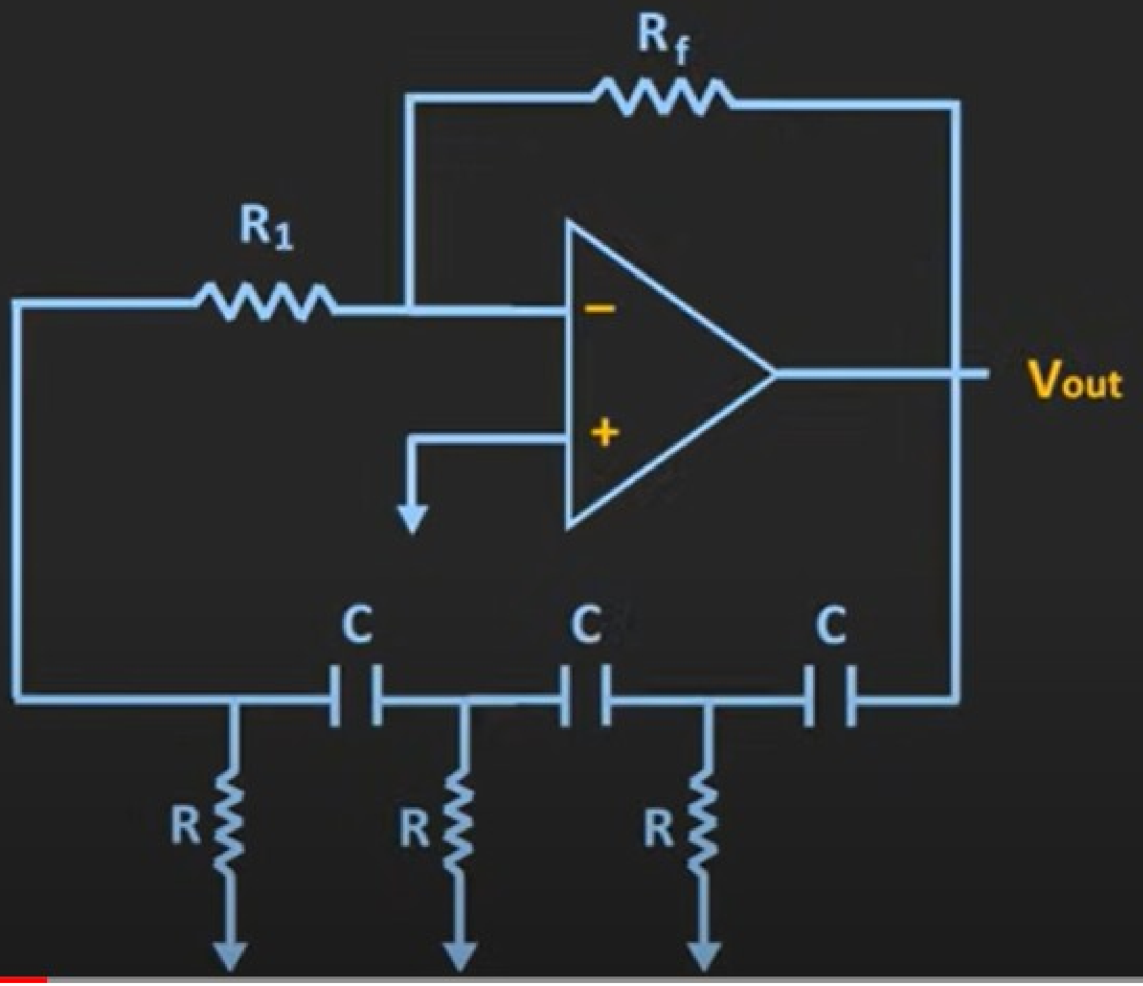
- To satisfy Barkhausen criterion, phase shift introduced by ampr & f/b ckt should be 0 or multiples of 2π .
- So to get sustained oscn, f/b ckt shud also provide 180^0 phase shift.
- So overall phase shift = 360^0
- By tuning the gain of ampr and f/b ckt, we can achieve loop gain $|A\beta|$=1.

Cascade Connection of RC Stages

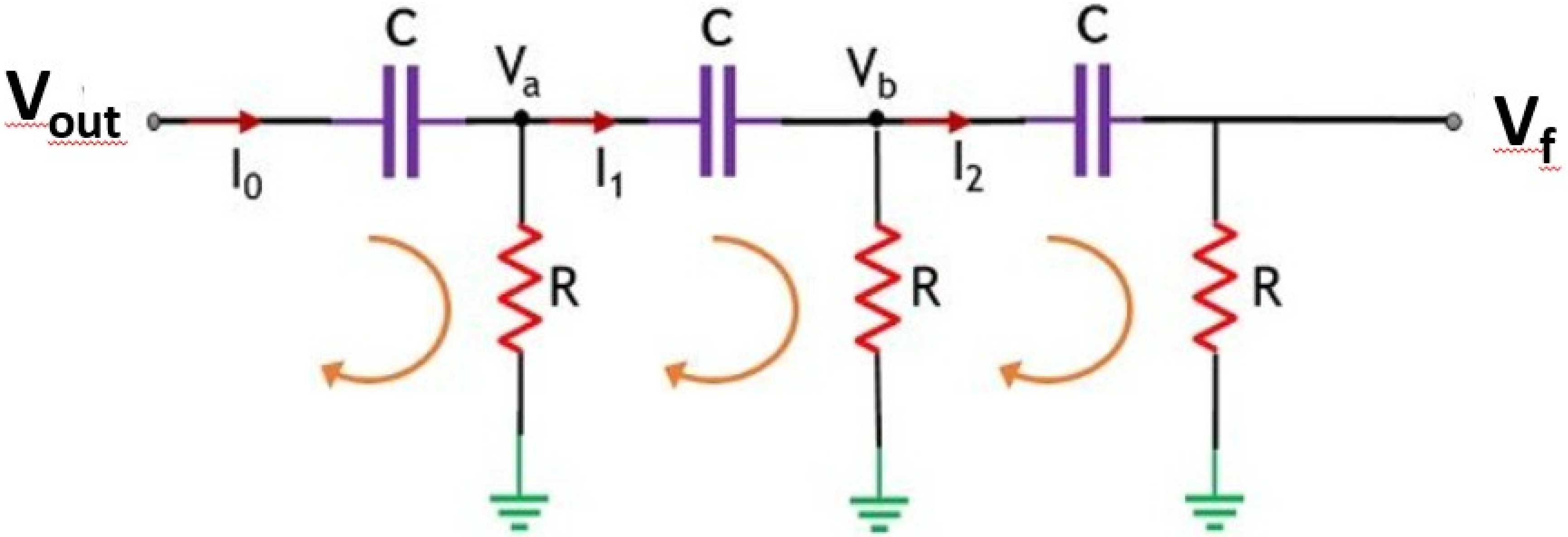



C
C
C
R
R
R
Input
Output
Phase shift of 180°

RC Phase Shift Oscillator using op-amp



Feedback network



- At node V_b,the overall voltage will be equal to the sum of output voltage V_{out} and drop across the capacitor.

$$V_b = I_2 * \ + V_f$$

$$V_f = I_2R \text{ ----- } I_2 = V_f/R$$

- $V_b = \ \ + V_f$ ----- $V_b = V_f[1+$

Applying KCL

$I_1 = \ + I_2$ ------ $I_1 = \ [2+$

- $V_a = V_b + I_1 *$ ----- $V_a = V_f\,[\,1+\ \ -\ \ ]$

KCL at V_a

$I_0 = \ \ + I_1$ ------ $I_0 = \ [\,3+\ \ -\ \ ]$

Now $V_{out} = V_a +$

--- $V_{out} = V_f\,[\,1+\ \ -\ \ -\,]$

- Equating imaginary part, we get

$- \quad = 0$

$\omega =$ **$f =$**

Equating real part,

$V_{out} = V_f\,[\,1- \quad]$

Substitute **$\omega =$** in the above eqn, we get

$V_{out} = -29\ V_f$

- Gain of f/b n/w, $\beta = =$

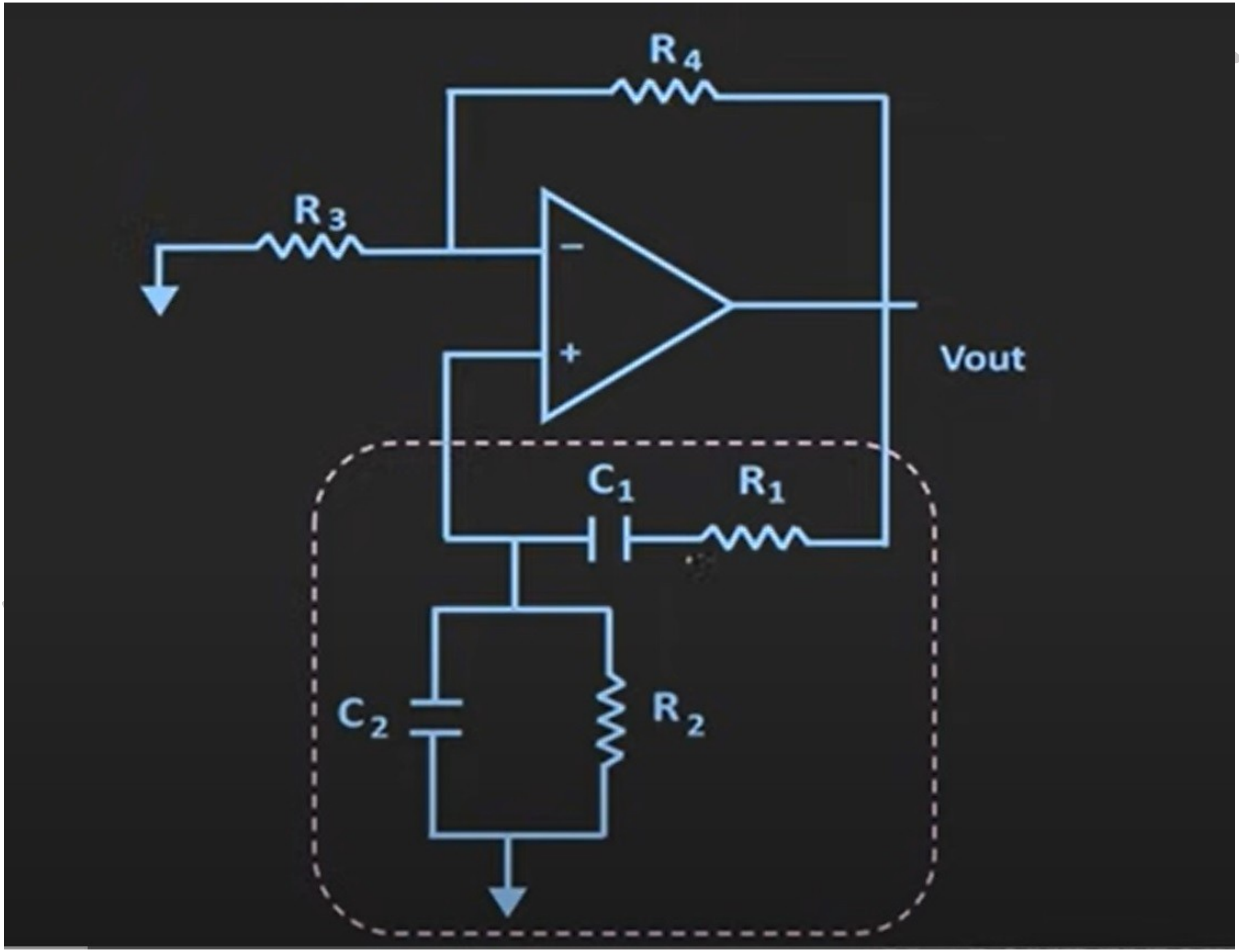
- the negative sign indicates that f/b n/w produces a phase shift of 180^{o}.
- Since $|A\beta|$ $\beta| =$
- Therefore for sustained oscn, $|A|$ 29.
- That is gain of inv op amp should be atleast 29 or $R_f=29\ R_1$.

- Gain A_v is kept greater than 29 to ensure that the variations in ckt parameters will not make $|A_v \beta| < 1$, otherwise oscns will die out.

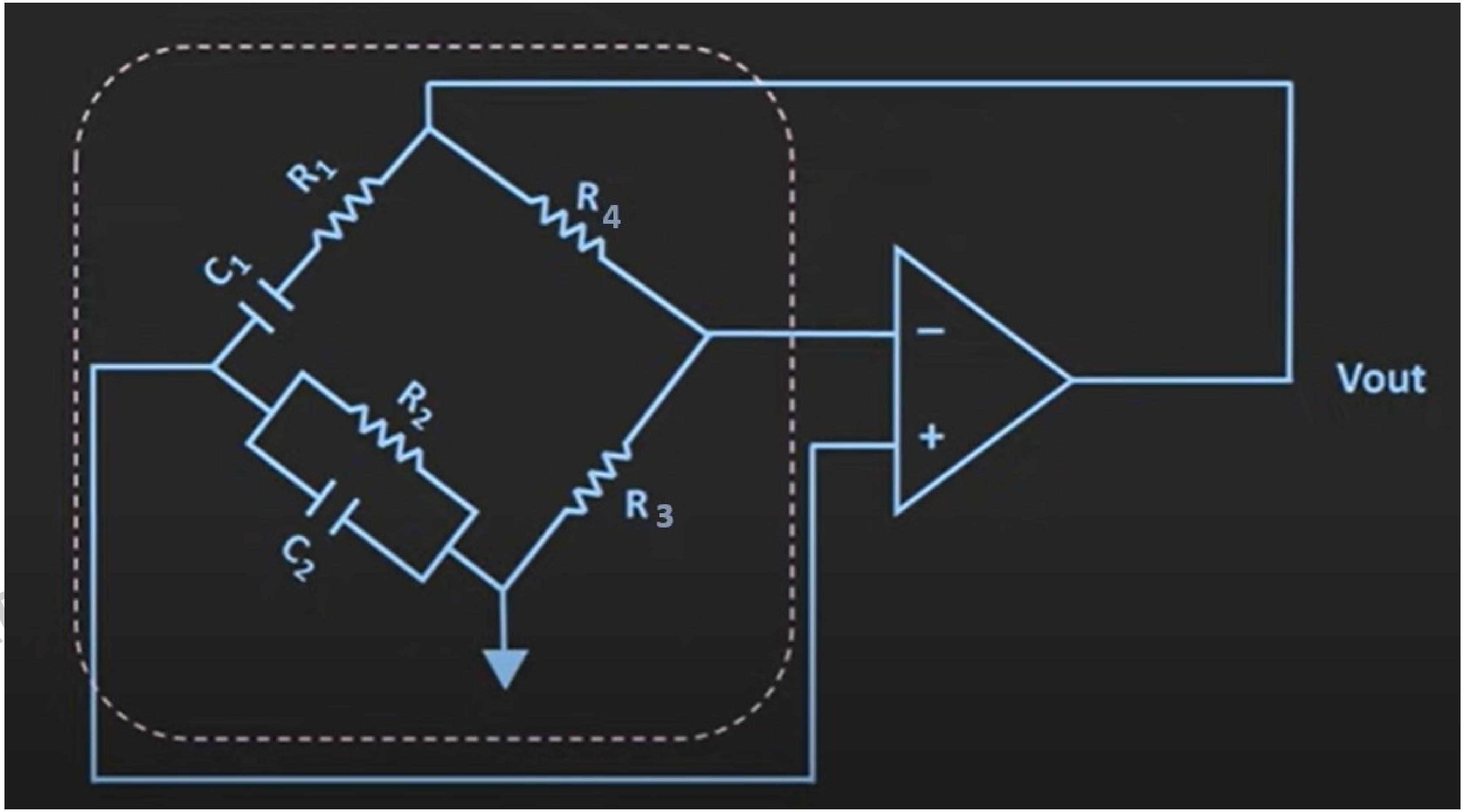
WIEN BRIDGE OSCILLATOR

- Harmonic oscr – o/p of oscr is sinusoidal s/g.
- AF oscr – generates sine wave typically in the range of AF.

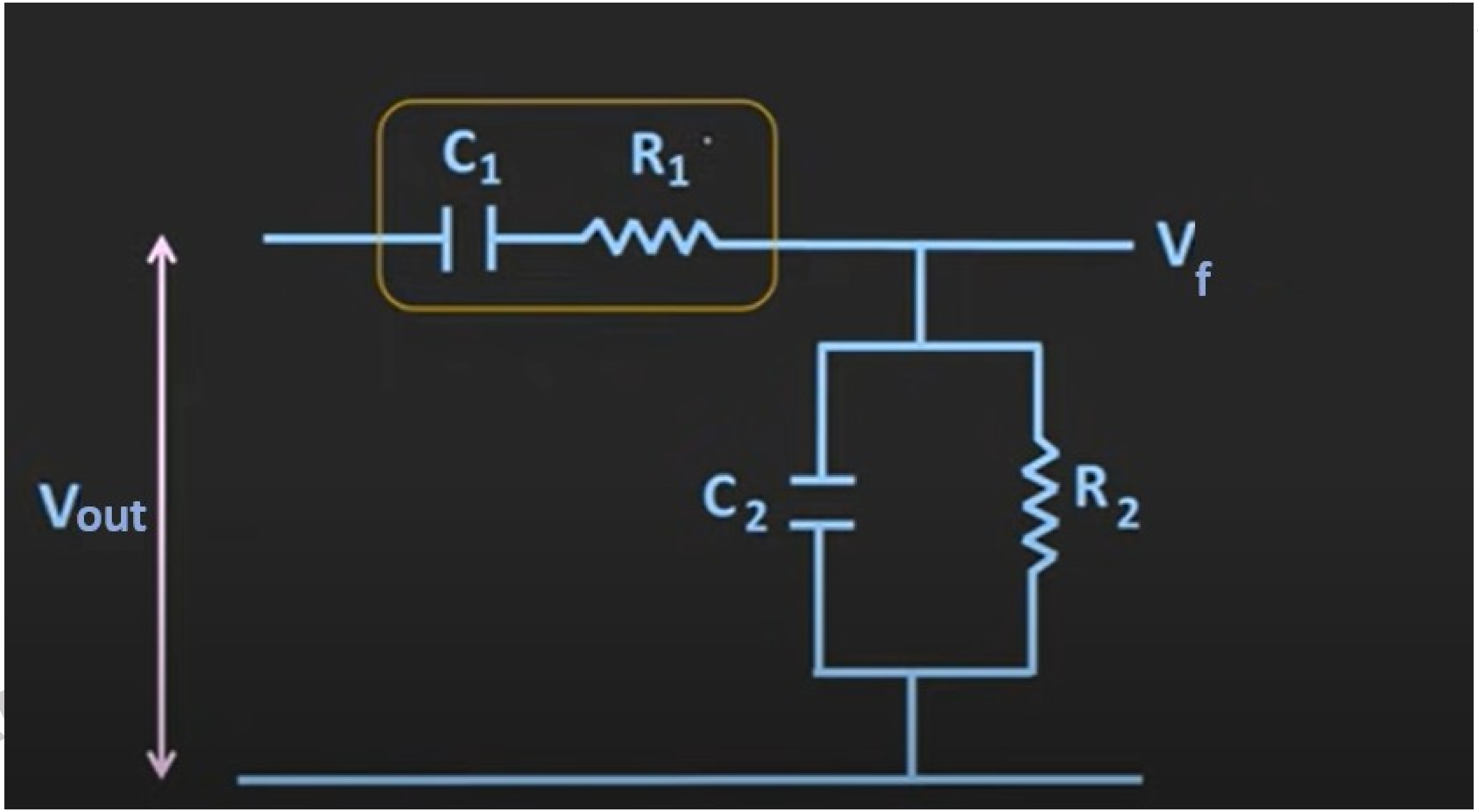
WIEN BRIDGE OSCILLATOR



Wien Bridge Oscillator Showing The Bridge Network



- Feedback RC n/w is connected to non inv terminal . So op amp – non inv ampr.
- Therefore f/b n/w need not provide any phase shift.
- Ckt can be viewed as a Wien bridge with a series RC n/w in one arm and a parallel RC n/w in the adjoining arm.
- Condition of zero phase shift around the ckt is achieved by balancing the bridge.



C1
R1
Vf
Vout
C2
R2

Series RC n/w acts like HPF .

- At low freq, $1/jX_c$ is high. So capr C1 acts like OC. So it doesnot pass low freq s/gs.
- At high freq, impedance provided by capacitor is low. So easily allows HF.

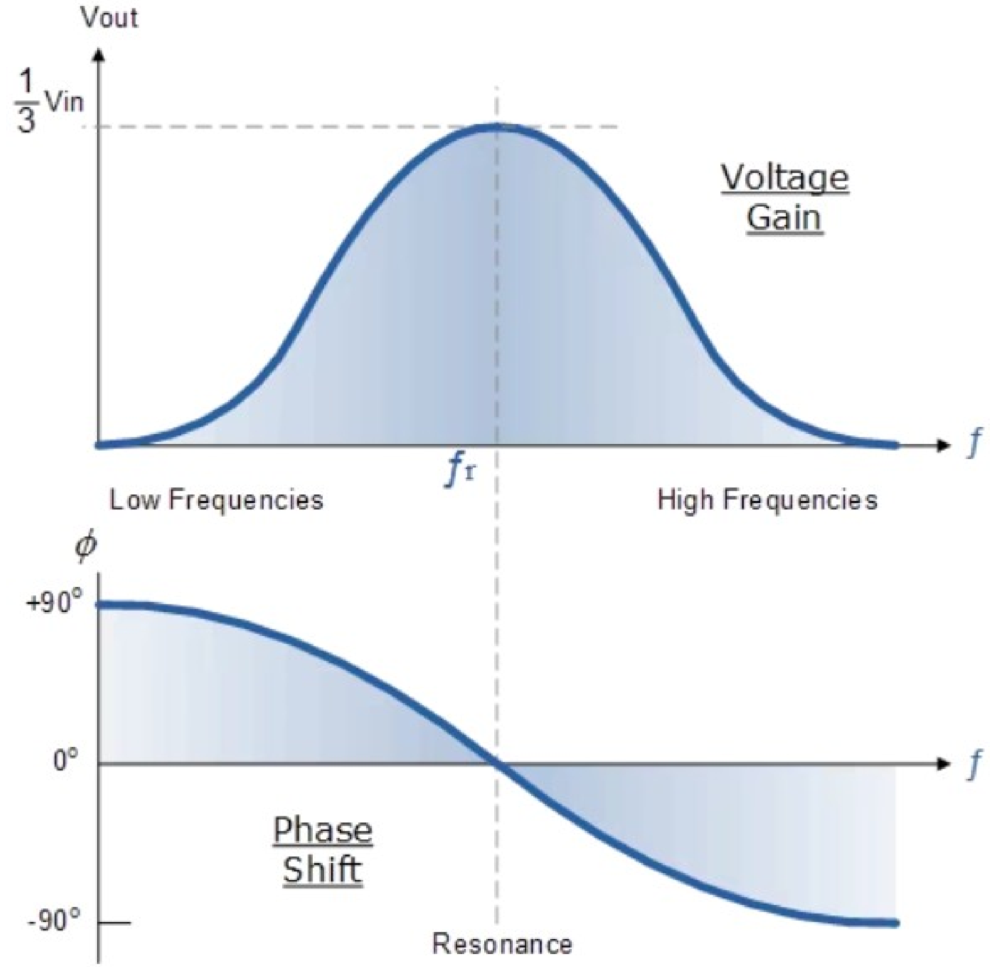
Parallel RC n/w acts like LPF

- At low freq, $1/jX_c$ is high. So capr C2 acts like OC. So o/p is taken across R2.
- At high freq, impedance provided by capacitor is very low. So o/p gets short ckted to grnd terminal.

- So this RC n/w doesnot allow low as well as high freqs.
- So there must be a frequency point between these two extremes of C1 being open-circuited and C2 being short-circuited where the output voltage, V_{OUT} reaches its maximum value.
- The frequency value of the input waveform at which this happens is called the oscillator's Resonant Frequency (fr).

- At this resonant frequency, the phase difference between the input and output equals 0 deg.
- The magnitude of the output voltage of f/b n/w is therefore at its max and is equal to one third (1/3) of the input voltage as shown.
- $\beta = 1/3$

Oscillator o/p gain and phase shift

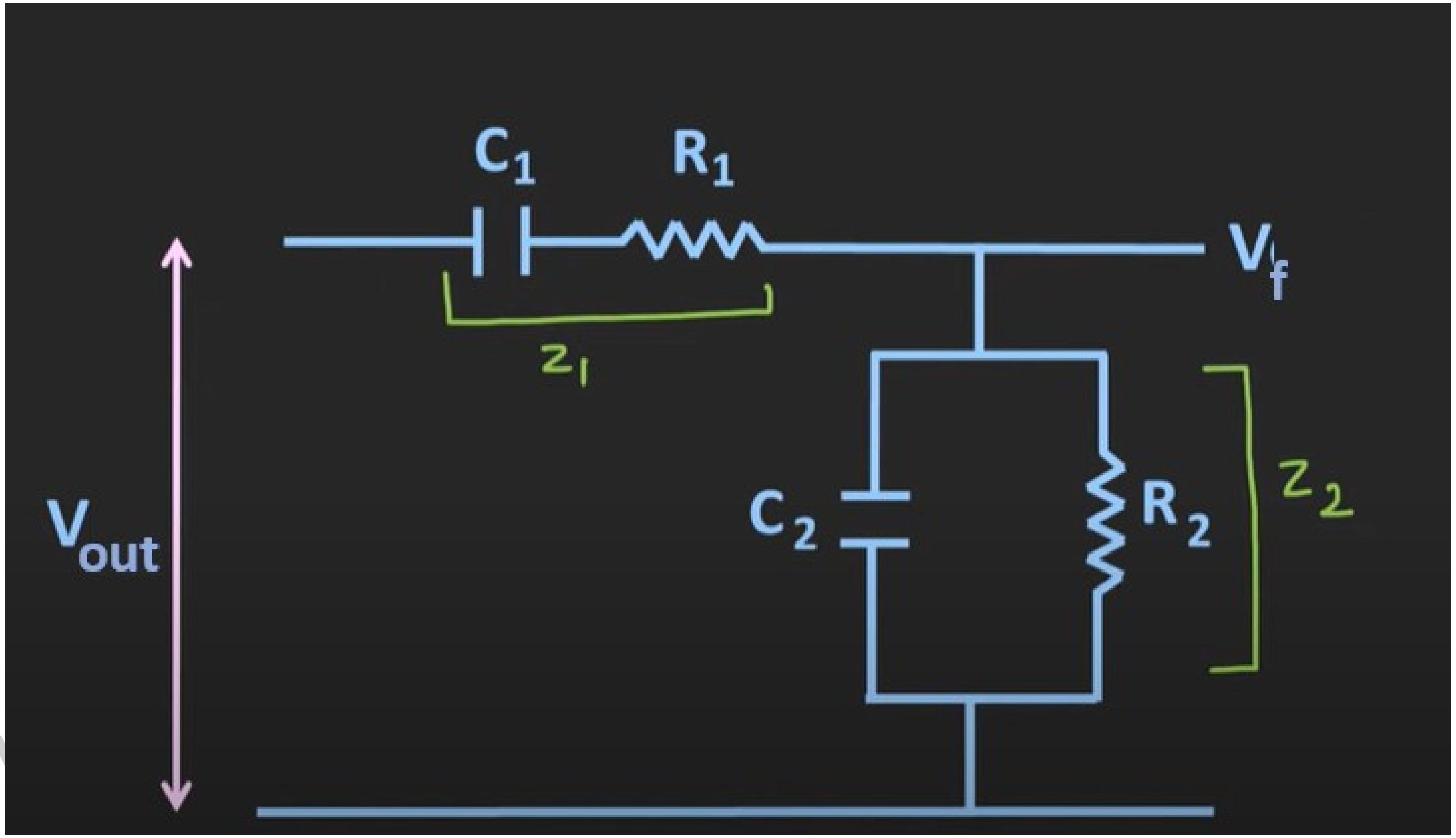


- =

- $Z_1 = R_1 + (1/j\omega C_1)$

- $Z_2 = R_2 \,||\, (1/j\omega C_2)$

  =



Substituting ,

=β =

- At resonant freq, phase shift offered by f/b n/w =0.
- = 0 (so that jω term cancel out)
- = 1

ω =

- **At resonance**, the phase angle and mag condition for oscillation is satisfied.
- This condition occurs only when **bridge is balanced.**
- The freq of oscn $\mathbf{f_o}$ = resonant freq $\mathbf{f_r}$ of balanced Wien Bridge

$$f_0 = f_r =$$

$$f_0 = f_r =$$

$$\beta = 1/3$$

A=3 (to satisfy Barkhausen criterion)

At resonance, $\beta = 1/3$

$=\beta =$

- $A\beta = 1$
- A= = + 1 = 3
- Here op amp is configured in non inverting configuration, so gain
- $A = 1 + R_4 / R_3 = 3$ **$R_4 = 2R_3$**

- 1+ = + 1
- If R1=R2 and C1=C2 , then = 2 ------- **$R_4 = 2R_3$**

Q: Design a Wien bridge oscr of freq of 10KHz.

C = 0.01μF R=1.59K   R3=10K   R4=20K