Analog & Digital Electronics

Course No: PH-218

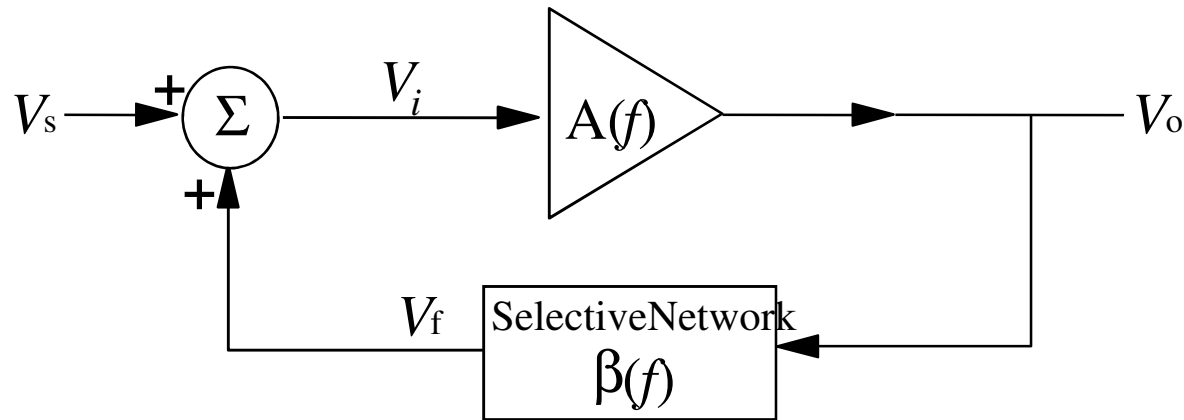## Lec-16: Oscillator

Course Instructors:

❖ **Dr. A. P. VAJPEYI**

Department of Physics,
Indian Institute of Technology Guwahati, India

Positive Feedback

➢ **When input and feedback signal both are in same phase, It is called a positive feedback.**

➢ **Positive feedback is used in analog and digital systems.**

➢ **A primary use of +ve feedback is in the production of oscillators.**

$V_o = AV_i = A(V_s + V_f)$ and $V_f = \beta V_o$

$$\frac{V_o}{V_s} = \frac{A}{1 - A\beta}$$

Barkhausen Criterion: for oscillator βA=1 and +ve feedback

Oscillator Circuit

➤ **Oscillator is an electronic circuit which converts dc signal into ac signal.**

➤ **Oscillator is basically a positive feedback amplifier with unity loop gain.**

➤ **For an inverting amplifier- feedback network provides a phase shift of 180° while for non-inverting amplifier- feedback network provides a phase shift of 0° to get positive feedback .**

$$\frac{V_o}{V_s} = \frac{A}{1 - A\beta}$$ **If βA=1 then V$_o$ = ∞ ; Very high output with zero input.**
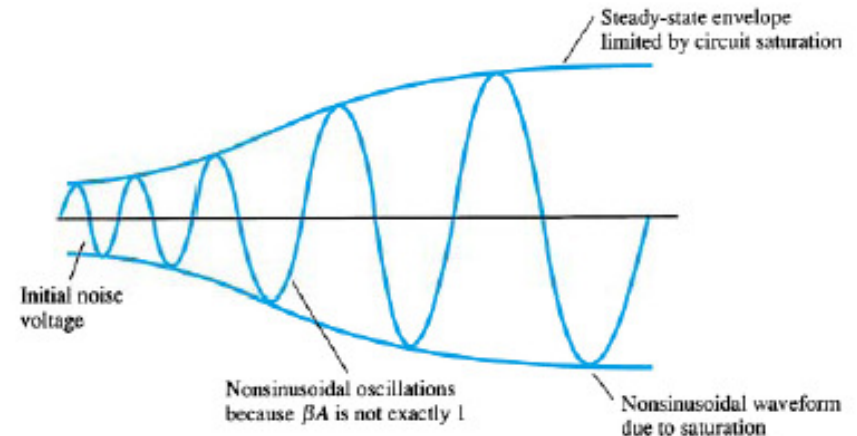
Use positive feedback through frequency-selective feedback network to ensure sustained oscillation at ω_0

Use of Oscillator Circuits

❖ Clock input for CPU, DSP chips …
❖ Local oscillator for radio receivers, mobile receivers, etc
❖ As a signal generators in the lab
❖ Clock input for analog-digital and digital-analog converters

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Oscillators

> **If the feedback signal is not positive and gain is less than unity, oscillations dampen out.**

> **If the gain is higher than unity then oscillation saturates.**

Steady-state envelope
limited by circuit saturation

Initial noise
voltage

Nonsinusoidal oscillations
because βA is not exactly 1

Nonsinusoidal waveform
due to saturation

Type of Oscillators

Oscillators can be categorized according to the types of feedback network used:

> **RC Oscillators: Phase shift and Wien Bridge Oscillators**

> **LC Oscillators: Colpitt and Hartley Oscillators**

> **Crystal Oscillators**

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RC Oscillators

$$V_o = (\frac{R}{R - jX_c})V_{in} \text{ and } \phi = \tan^{-1}(\frac{X_C}{R})$$
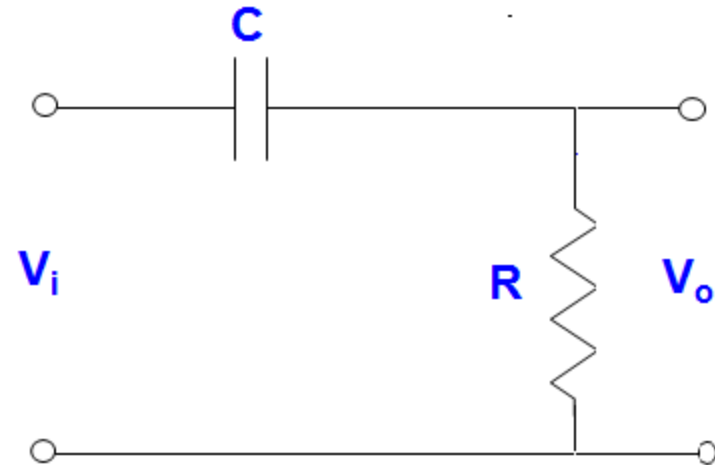
➢ Φ =0° if X_c=0 and Φ =90° if R=0

➢ However adjusting R to zero is impractical because it would lead to no voltage across R, thus in a RC circuit, phase shift is always ≤ 90° and it is a function of frequency.

➢ Hence to get 180° phase shift from the feedback network, we need 3 RC circuits.

➢ RC oscillators build by using inverting amplifier and 3 RC circuits is known as phase shift oscillator.

RC Oscillators: Phase shift Oscillator

- **Use of an inverting amplifier.**

- **The additional 180° phase shift is provided by an RC ladder network.**

- **It can be used for very low frequencies and provides good frequency stability.**
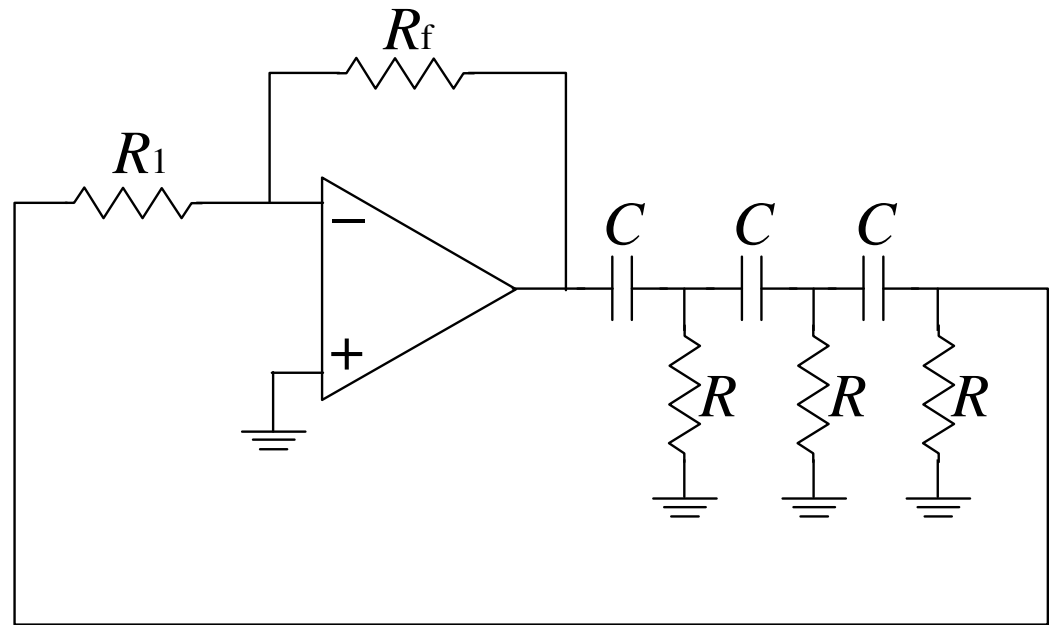
A phase shift of 180° is obtained at a frequency f, given by

$$f = \frac{1}{2\pi CR\sqrt{6}}$$

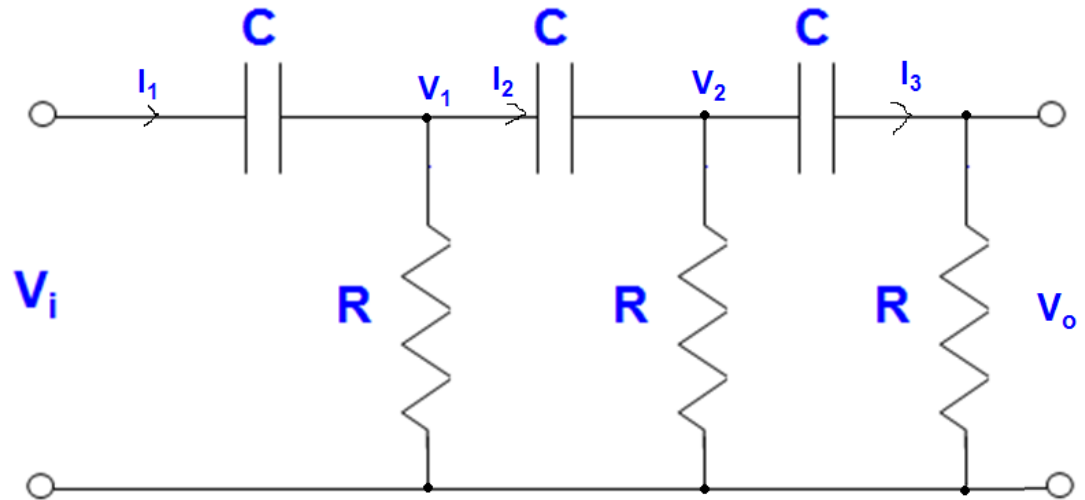**At this frequency the gain of the network is** $\dfrac{v_o}{v_i} = -\dfrac{1}{29}$

RC Oscillators: Phase shift Oscillator

At node V_2

$$V_2 = V_o + I_3 X_c = V_o + \frac{I_3}{jwC}$$

But $I_3 = \dfrac{V_o}{R}$

$$\boxed{V_2 = V_o \left(1 + \frac{1}{j\omega CR}\right)}$$

$$I_2 = I_3 + \frac{V_2}{R} = \frac{V_o}{R} + \frac{V_o}{R}\left(1 + \frac{1}{j\omega CR}\right) \qquad \boxed{I_2 = \frac{V_o}{R}\left(2 + \frac{1}{j\omega CR}\right)}$$

At node V_1
$$\boxed{V_1 = V_2 + \frac{I_2}{j\omega C} = V_o\left(1 + \frac{3}{j\omega cR} - \frac{1}{\omega^2 C^2 R^2}\right)}$$

RC Oscillators: Phase shift Oscillator

$$V_1 = V_2 + \frac{I_2}{j\omega C} = V_o(1 + \frac{3}{j\omega cR} - \frac{1}{\omega^2 C^2 R^2})$$

$$I_1 = I_2 + \frac{V_1}{R} = \frac{V_0}{R}(3 + \frac{4}{j\omega cR} - \frac{1}{\omega^2 C^2 R^2})$$

$$V_i = V_1 + \frac{I_1}{j\omega C} = V_o(1 + \frac{6}{j\omega cR} - \frac{5}{\omega^2 C^2 R^2} - \frac{1}{j\omega^3 C^3 R^3})$$

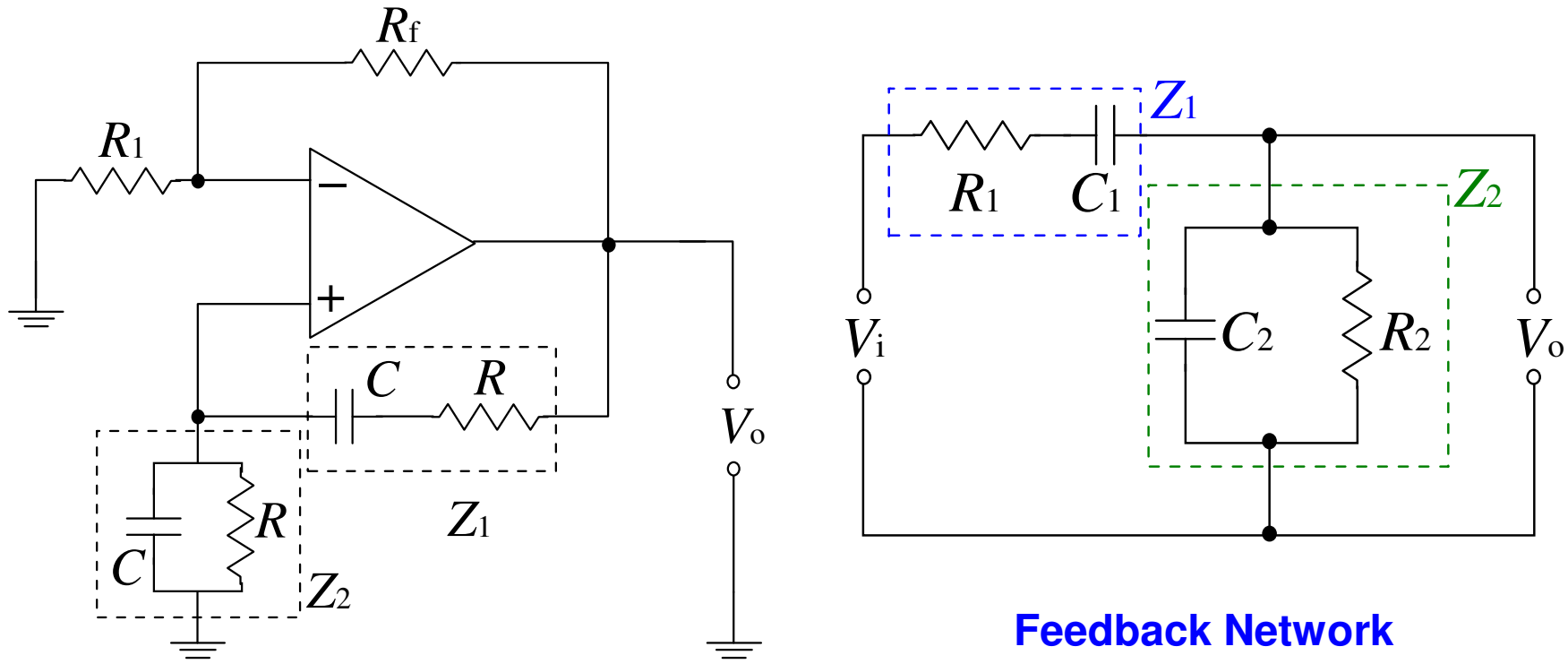**Output voltage should be real hence imaginary part equal to zero.**

$$\frac{6}{j\omega cR} - \frac{1}{j\omega^3 C^3 R^3} = 0 \qquad \boxed{6\omega^2 C^2 R^2 = 1} \qquad \boxed{\omega = \frac{1}{RC\sqrt{6}}}$$

At this frequency: $V_i = -29\ V_o$ therefore, $A_v = -29$

RC Oscillators: Wien Bridge Oscillator
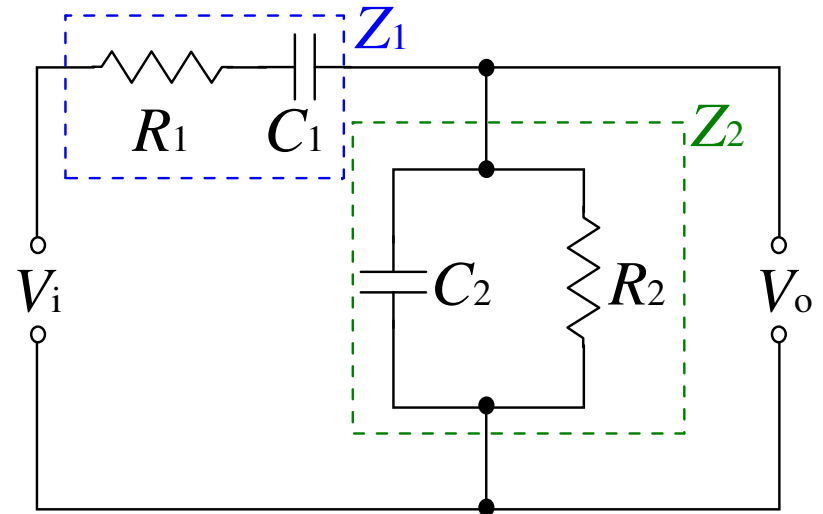

Feedback Network

➢ **Feedback network is a lead-lag circuit where R_1, C_1 form the lag portion and R_2, C_2 form the lead portion. Thus feedback network provides 0° phase shift.**

RC Oscillators: Wien Bridge Oscillator

Let $X_{C1} = \dfrac{1}{\omega C_1}$ $X_{C2} = \dfrac{1}{\omega C_2}$ and

$$Z_1 = R_1 - jX_{C1}$$

$$Z_2 = \left[\frac{1}{R_2} + \frac{1}{-jX_{C2}}\right]^{-1} = \frac{-jR_2 X_{C2}}{R_2 - jX_{C2}}$$

Therefore, the feedback factor,

$$\beta = \frac{V_o}{V_i} = \frac{Z_2}{Z_1 + Z_2} = \frac{(-jR_2 X_{C2}/R_2 - jX_{C2})}{(R_1 - jX_{C1}) + (-jR_2 X_{C2}/R_2 - jX_{C2})}$$

$$\beta = \frac{-jR_2 X_{C2}}{(R_1 - jX_{C1})(R_2 - jX_{C2}) - jR_2 X_{C2}}$$

$$\beta = \frac{R_2 X_{C2}}{R_1 X_{C2} + R_2 X_{C1} + R_2 X_{C2} + j(R_1 R_2 - X_{C1} X_{C2})}$$

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RC Oscillators: Wien Bridge Oscillator

For **Barkhausen Criterion**, imaginary part = 0, $\quad R_1 R_2 - X_{C1} X_{C2} = 0$

$$R_1 R_2 = \frac{1}{\omega C_1} \frac{1}{\omega C_2} \qquad \boxed{\omega = 1 / \sqrt{R_1 R_2 C_1 C_2}}$$
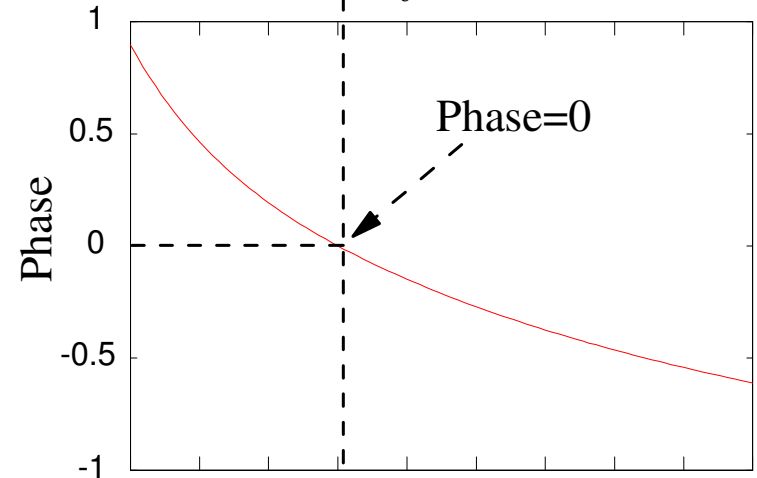
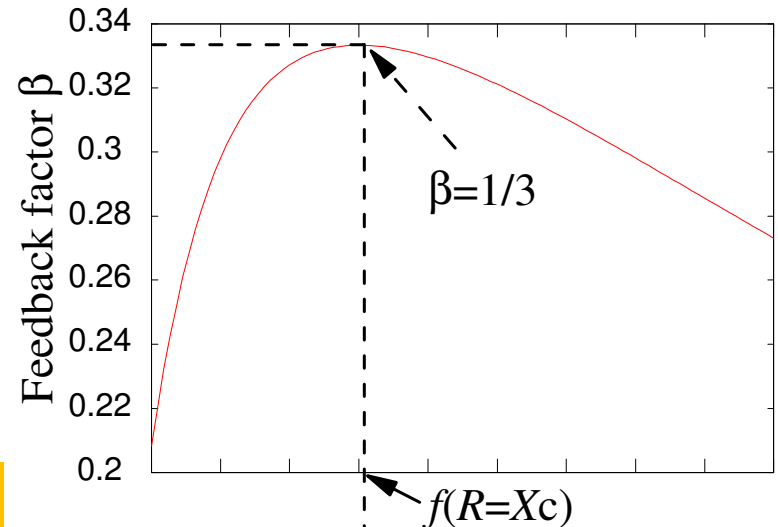Supposing, $R_1 = R_2 = R$ and $X_{C1} = X_{C2} = X_C$,

$$\beta = \frac{R X_C}{3 R X_C + j(R^2 - X_C^2)}$$

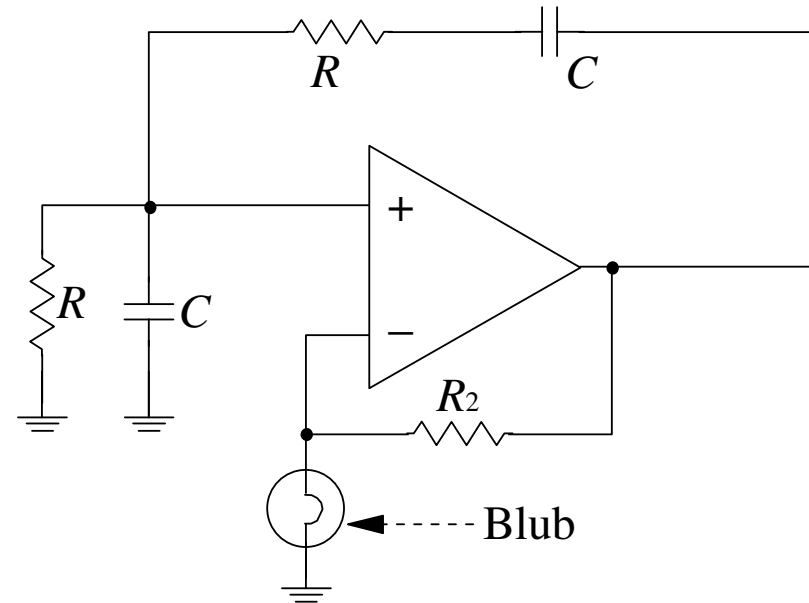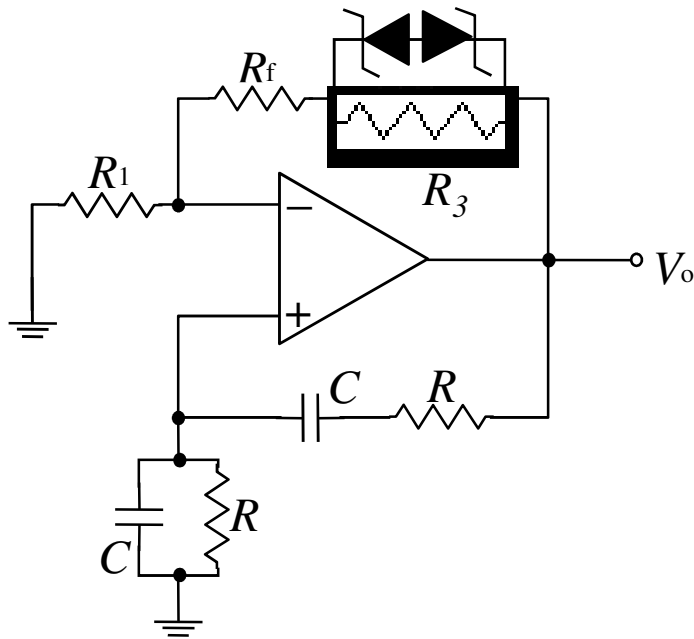**At this frequency: β = 1 / 3 and phase shift = 0°**

Due to **Barkhausen Criterion**, gain $A_v \beta = 1$

Where A_v : Gain of the amplifier

$$A_v \beta = 1 \Rightarrow A_v = 3 = 1 + \frac{R_f}{R_1} \qquad \boxed{\frac{R_f}{R_1} = 2}$$

β=1/3

$f(R=X_C)$

Phase=0

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Stabilization method for Wien Bridge Oscillator

When dc power is first applied, both zener diode is off.

$$A_v = 1 + \frac{R_f + R_3}{R_1} = 3 + \frac{R_3}{R_1} \quad \text{Because} \quad \frac{R_f}{R_1} = 2$$

Initially, a small +ve feedback signal develops from noise or turn-on transients. This feedback signal is amplified and continually reinforced , resulting in a buildup of the output voltage. When the output voltage reaches the zener breakdown voltage , zener diode conducts and effective short out R3 and thus lowers the close loop voltage gain to 3.