Review Question

1. *Draw the subtractor using op-amp and derive the expression for its output voltage.*
APJAKTU : 2006-07, 2007-08, 2009-10, Marks 5

9.19 Integrator

APJAKTU : 2006-07, 2007-08, 2012-13, 2014-15, 2015-16

- In an integrator circuit, the output voltage is the integration of the input voltage.
- The integrator circuit can be obtained without using active devices like op-amp, transistors etc. In such a case an integrator is called **passive integrator.**
- While an integrator using an active devices like op-amp is called **active integrator.**

9.19.1 Ideal Active Op-amp Integrator

- Consider the op-amp integrator circuit as shown in the Fig. 9.19.1.
- The node B is grounded. The node A is also at the ground potential from the concept of virtual ground.

$\therefore \quad V_A = 0 = V_B$

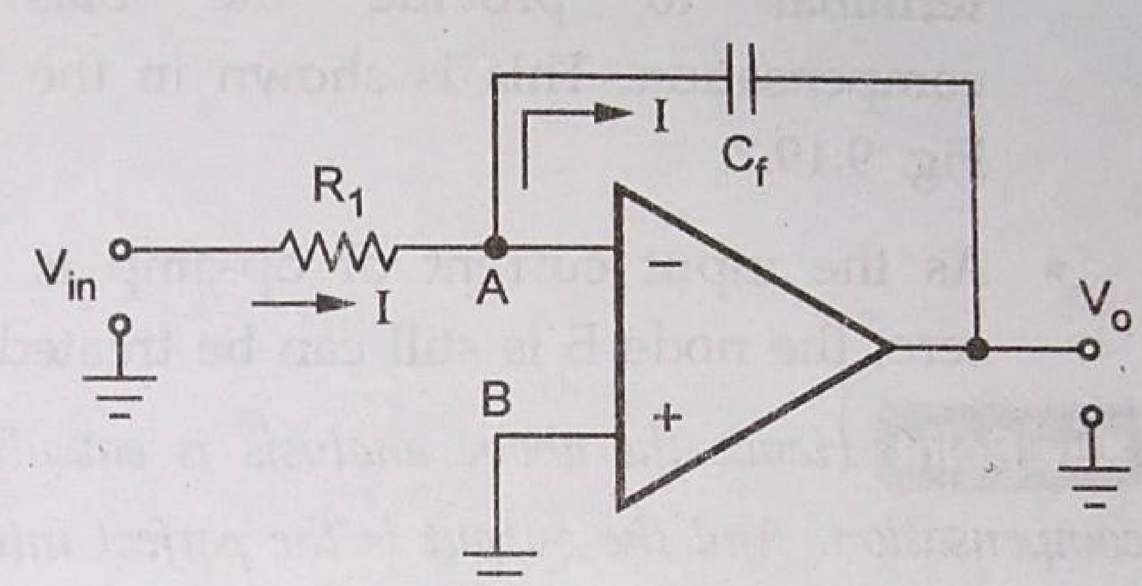

Fig. 9.19.1 Op-amp integrator

- As input current of op-amp is zero, the entire current I flowing through R_1, also flows through C_f, as shown in the Fig. 9.19.1.
- From input side we can write, $I = \frac{V_{in} - V_A}{R_1} = \frac{V_{in}}{R_1}$ ... (9.19.1)
- From output side we can write,

$$I = C_f \frac{d(V_A - V_o)}{dt} \quad \text{i.e.} \quad I = -C_f \frac{dV_o}{dt} \qquad \text{... (9.19.2)}$$

- Equating the two equations (9.19.1) and (9.19.2),

$$\frac{V_{in}}{R_1} = -C_f \frac{dV_o}{dt} \qquad \text{... (9.19.3)}$$

- Integrating both sides,

$$\int_0^t \frac{V_{in}}{R_1} dt = -C_f \int \frac{dV_o}{dt} dt \quad \text{i.e.} \quad \int_0^t \frac{V_{in}}{R_1} dt = -C_f V_o \qquad \text{... (9.19.4)}$$

$$\therefore \quad \boxed{V_o = -\frac{1}{R_1 C_f} \int_0^t V_{in}\, dt + V_o(0)} \quad \ldots (9.19.5)$$

where $V_o(0)$ is the constant of integration, indicating the initial output voltage.

- The equation (9.19.5) shows that the output is $-1/R_1 C_f$ times the integral of input and $R_1 C_f$ is called **time constant** of the integrator.
- The negative sign indicates that there is a phase shift of 180° between input and output.
- Sometimes a resistance $R_{comp} = R_1$ is connected to the non-inverting terminal to provide the bias compensation. This is shown in the Fig. 9.19.2.

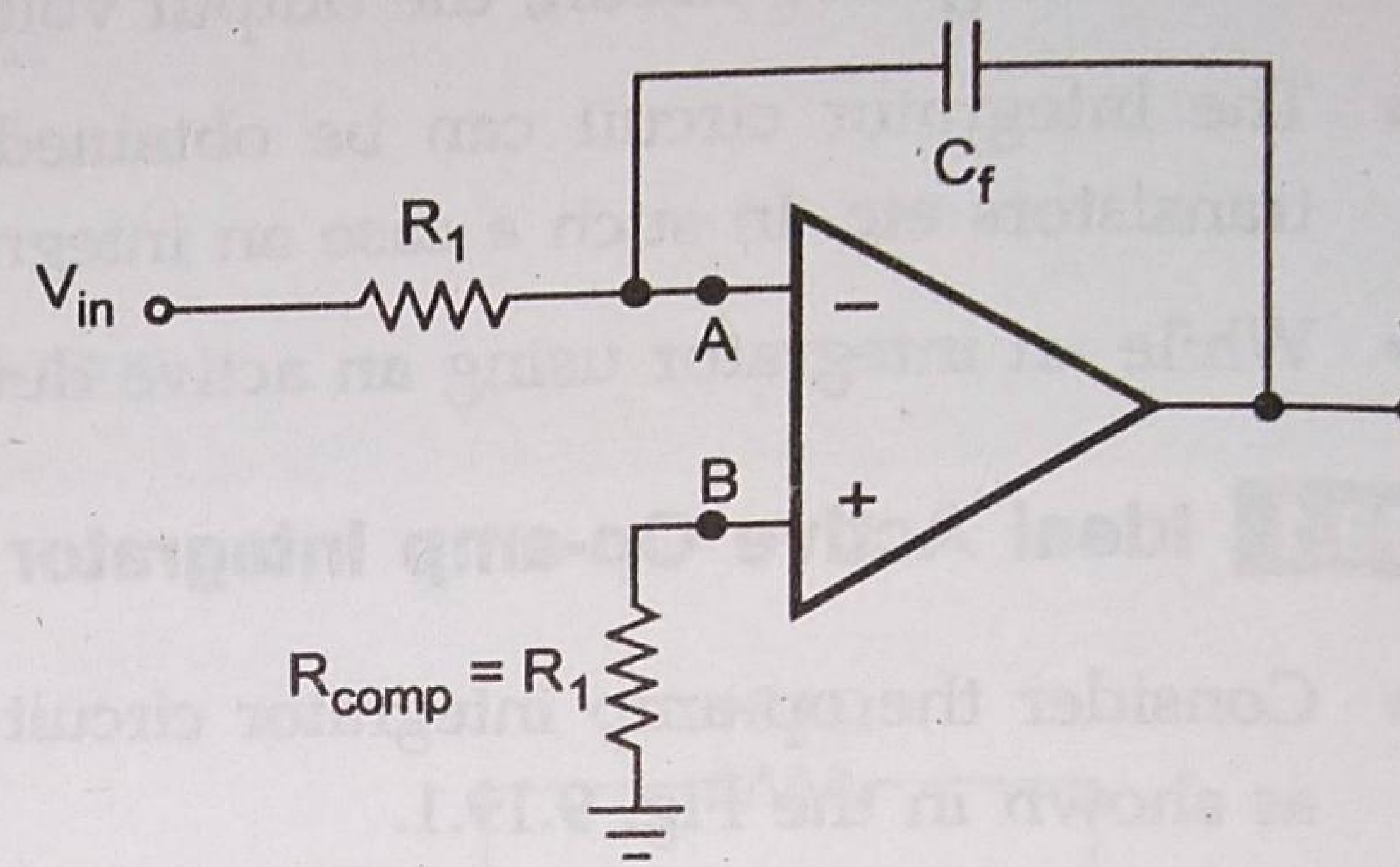

Fig. 9.19.2 Integrator with bias compensation

- As the input current of op-amp is zero, the node B is still can be treated at ground potential in this circuit.

9.20 Differentiator

APJAKTU : 2006-07, 2007-08, 2011-12, 2013-14, 2014-15

- The circuit which produces the differentiation of the input voltage at its output is called **differentiator.**
- The differentiator circuit which does not use any active device is called **passive differentiator.**
- While the differentiator using an active device like op-amp is called an **active differentiator.**

9.20.1 Ideal Active Op-amp Differentiator

- The op-amp differentiator circuit is shown in the Fig. 9.20.1.
- The node B is grounded. The node A is also at the ground potential hence $V_A = 0$.

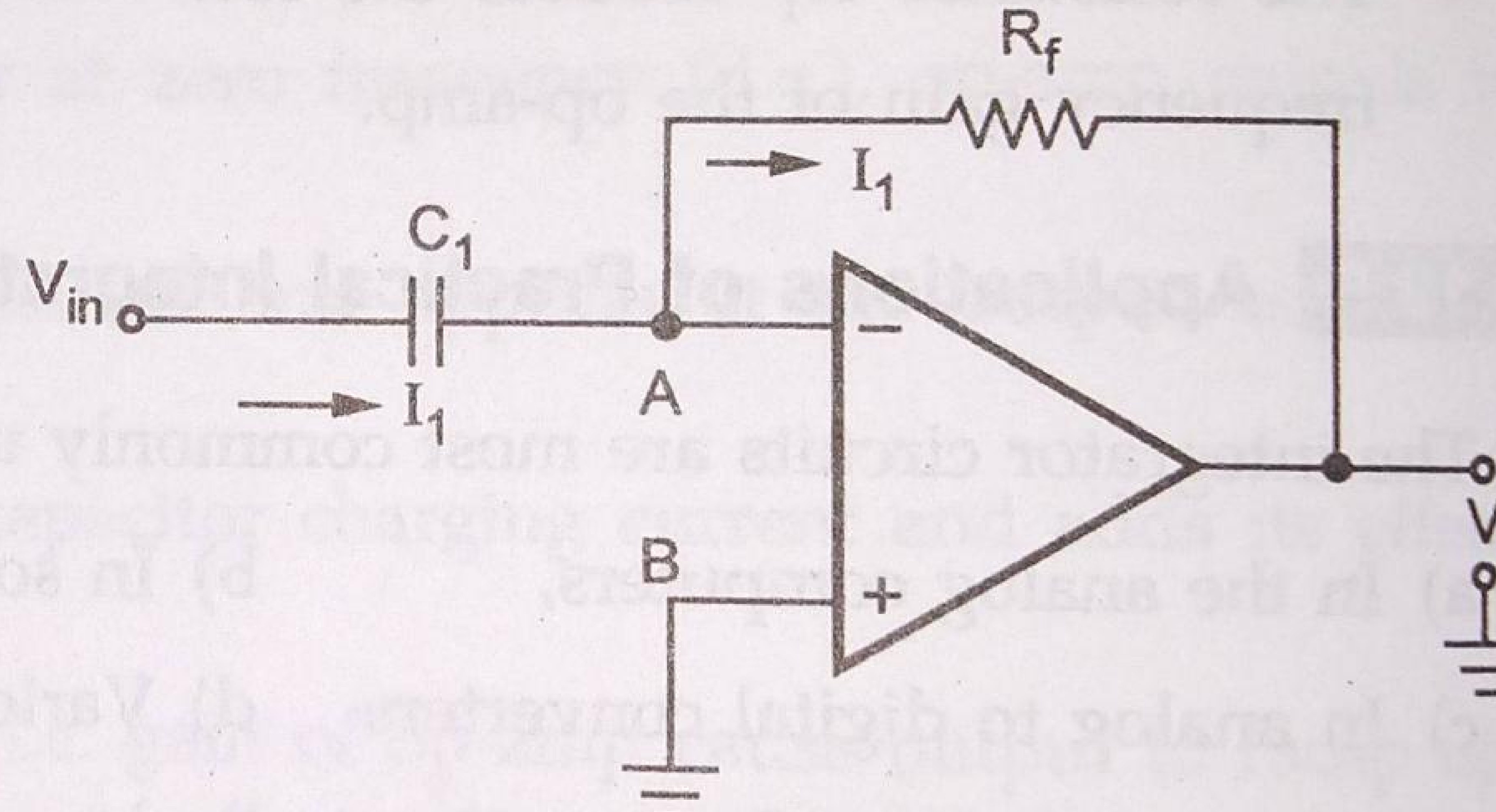

Fig. 9.20.1 Op-amp differentiator

- As input current of op-amp is zero, entire current I_1 flows through the resistance R_f.
- From the input side we can write,

$$I_1 = C_1 \frac{d(V_{in} - V_A)}{dt} = C_1 \frac{dV_{in}}{dt} \quad \dots (9.20.1)$$

- From the output side we can write,

$$I = \frac{(V_A - V_o)}{R_f} = -\frac{V_o}{R_f} \quad \dots (9.20.2)$$

- Equating the two equations,

$$C_1 \frac{dV_{in}}{dt} = -\frac{V_o}{R_f} \quad \dots (9.20.3)$$

$$\boxed{V_o = -C_1 R_f \frac{dV_{in}}{dt}} \quad \dots (9.20.4)$$

- The equation shows that the output is C_1R_f times the differentiation of the input and product C_1R_f is called **time constant** of the differentiator.
- The negative sign indicates that there is a phase shift of 180° between input and output. The main advantage of such an active differentiator is the small time constant required for differentiation.
- In practice a resistance $R_{comp} = R_f$ is connected to the non-inverting terminal to provide the bias compensation. This is shown in the Fig. 9.20.2.

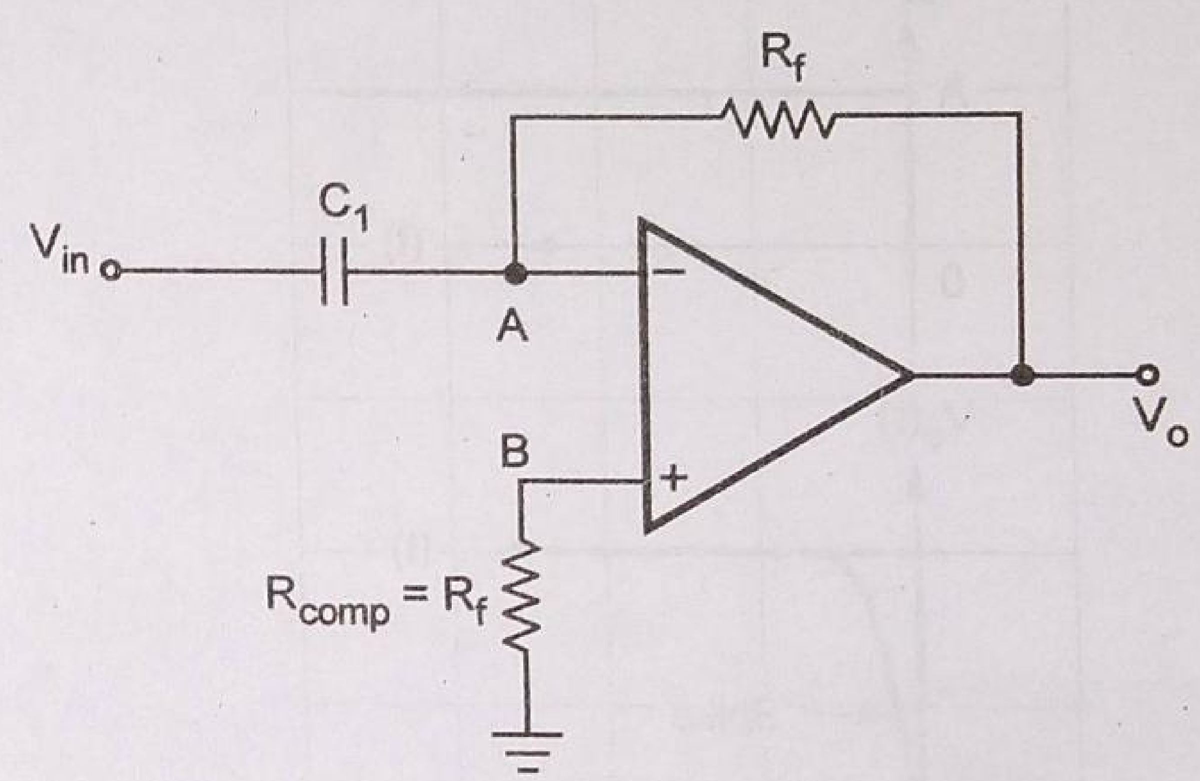

Fig. 9.20.2 Differentiator with bias compensation

- At low frequencies, capacitance acts as an open circuit gain of the circuit is very low.
- As frequency increases, the gain increases. At a frequency f_a, gain becomes 0 dB. The frequency f_a is given by,

$$\boxed{f_a = \frac{1}{2\pi R_f C_1}}$$