Week 14: Positive Feedback and Oscillator

Topics to cover …

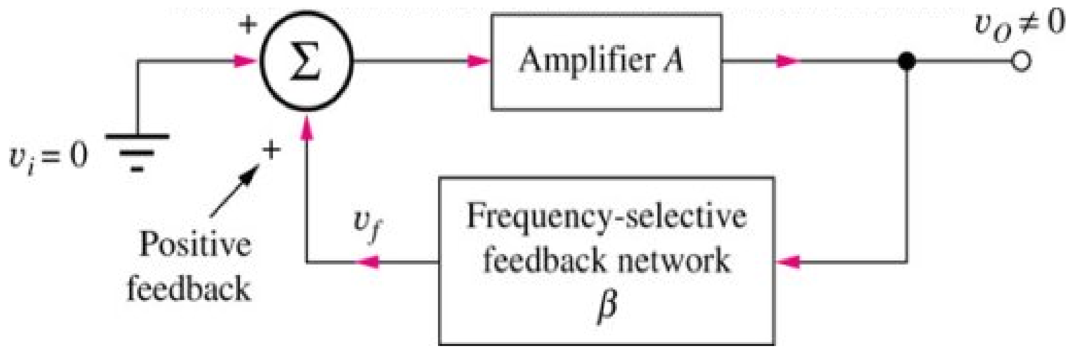
- Positive feedback
- Wien-Bridge Oscillator
- Phase Shift Oscillator

Reading assignment:
Chap 17.13 of Jeager and Blalock

Applications of Oscillators

- Clock input for CPU, DSP chips …
- Local oscillator for radio receivers, mobile receivers, etc
- Signal generation for signal generators in your lab
- Clock input for analog-digital and digital-analog converters
- …

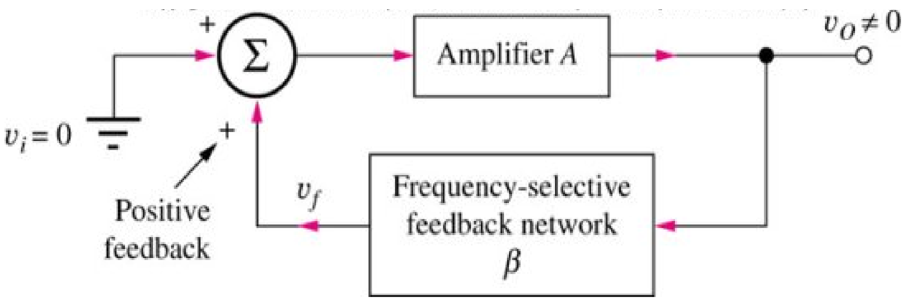
Positive Feedback



$$A_f(s) = \frac{A(s)}{1 - A(s)\beta(s)} = \frac{A(s)}{1 - T(s)}$$

- Designed to produce an output even thought the input is zero
- Use positive feedback through frequency-selective feedback network to ensure sustained oscillation at ω_0

Barkhausen's Criteria for Oscillation



$$A_f(s) = \frac{A(s)}{1 - A(s)\beta(s)} = \frac{A(s)}{1 - T(s)}$$

- For sinusoidal oscillations,

  $$1 - T(j\omega_o) = 0 \Rightarrow T(j\omega_o) = +1$$

- Barkhausen's criteria:

  $\angle T(j\omega_o) = 0^\circ$ or multiples of 360^0

  $|T(j\omega_o)| = 1$

- An impulse input starts the oscillation
  - Circuit noises, e.g., resistor thermal noise, serve this purpose

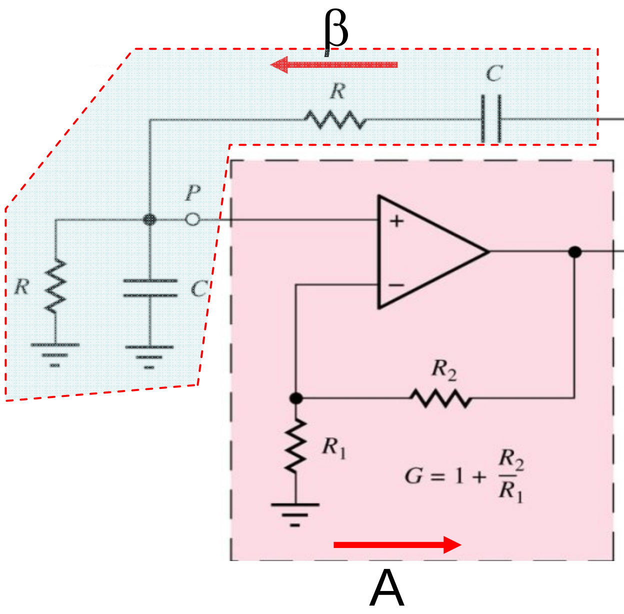
- Loop gain greater than unity causes a distorted oscillation to occur

Types of Oscillators

- Oscillators can be categorized as follows according to the types of feedback network used:
  - RC oscillator
  - LC oscillator
  - Crystal oscillator

- We will discuss the first type only

Wien-Bridge Oscillator



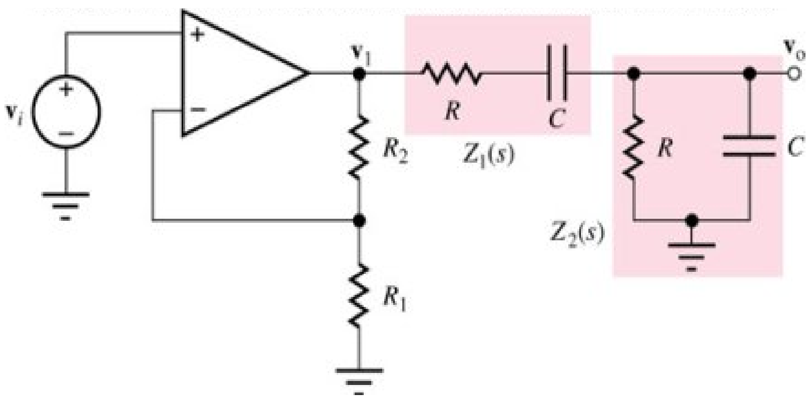
$$V_1(s) = (1 + \frac{R_2}{R_1})V_I(s) = GV_I(s), \qquad G = 1 + \frac{R_2}{R_1}$$

$$V_o(s) = V_1(s)\frac{Z_2(s)}{Z_1(s) + Z_2(s)}, \quad s = j\omega$$

Loop gain:

$$T(s) = \frac{V_o}{V_I} = \frac{j\omega RCG}{(1 - \omega^2 R^2 C^2) + 3j\omega RC}$$

Break the loop at P to find loop gain:



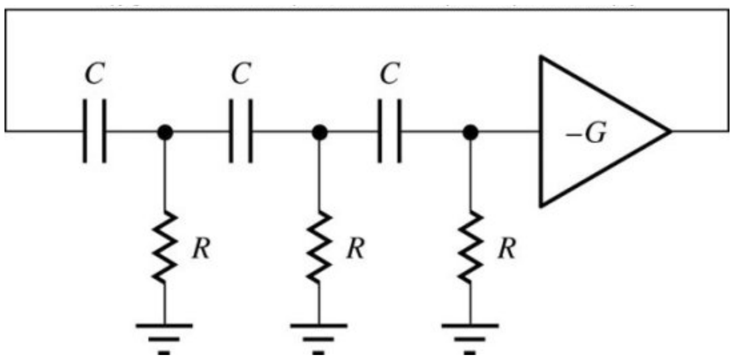
Phase shift will be zero if $(1 - \omega^2 R^2 C^2) = 0$,

At $\omega_0 = 1/RC$, $\quad T(j\omega_o) = +\frac{G}{3}$

If G=3, sinusoidal oscillation is achieved.

This oscillator is used for frequencies up to few MHz, limited primarily by characteristics of amplifier.

Phase-Shift Oscillator



- The RC network is to provide 180º phase shift at the desired oscillation frequency
- At least three RC section is required:
  - One RC section can provide 90º phase shift at most:

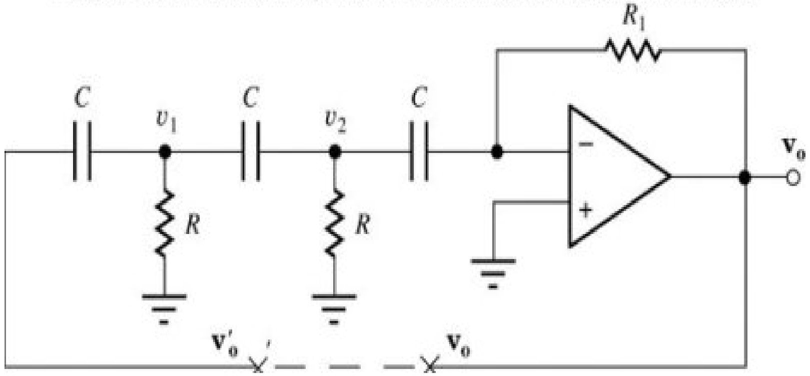
$$H_{RC}(s) = \frac{R}{R + 1/j\omega C} = \frac{j\omega CR}{1 + j\omega CR}$$

$$\angle H_{RC}(s) = 90^\circ - \tan^{-1}(\omega RC) \le 90^\circ$$

  - Two RC sections provide 180º phase shift only at $\omega \to \infty$.

Phase-Shift Oscillator

One implementation:



KCL at v_1 and v_2:

$$\begin{bmatrix} sCV_o'(s) \\ 0 \end{bmatrix} = \begin{bmatrix} (2sC+G) & -sC \\ -sC & (2sC+G) \end{bmatrix} \begin{bmatrix} V_1(s) \\ V_2(s) \end{bmatrix}$$

From v_2 to v_o:

$$\frac{V_o(s)}{V_2(s)} = -sCR_1$$

We have:

$$\therefore T(s) = \frac{V_o(s)}{V_o'(s)} = \frac{s^3C^3R^2R_1}{3s^2R^2C^2 + 4sRC + 1}$$

Phase shift will be zero if $(1-3\omega_o{}^2R^2C^2) = 0$,

$$\therefore \omega_o = \frac{1}{\sqrt{3}RC}$$

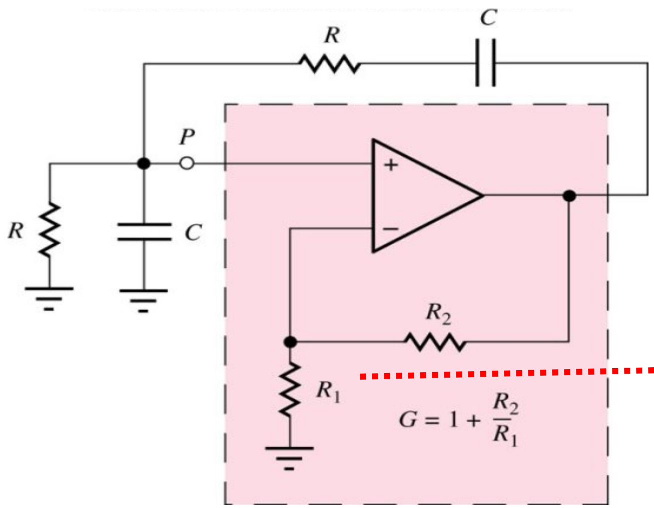
At ω_0

$$T(j\,\omega_o) = \frac{\omega_o{}^2C^2RR_1}{4} = \frac{1}{12}\frac{R_1}{R}$$

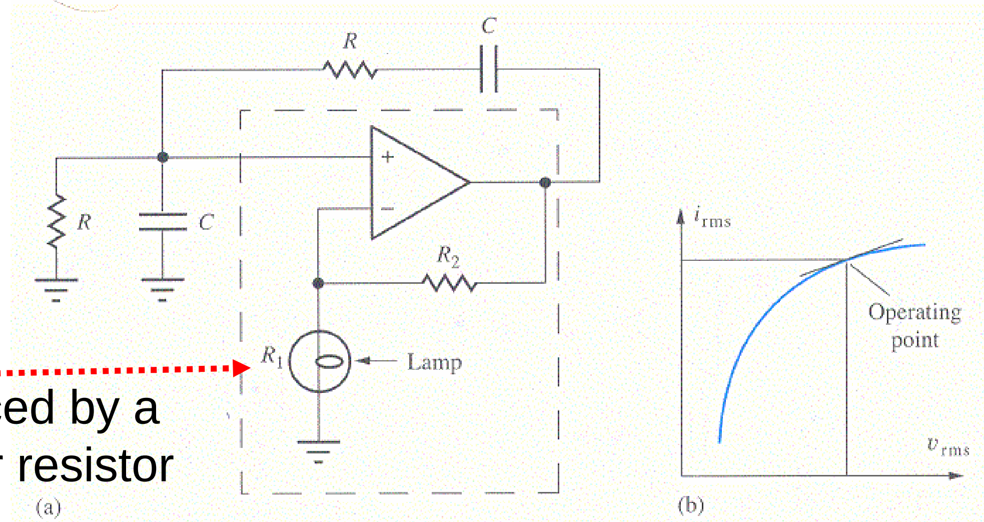
For R_1=12R, the Barkhausen's criterion is met.

Amplitude Stabilization

- As power supply voltage, component values and/or temperature change, the loop gain $|A\beta|$ deviates from 1 → oscillation decays ($|A\beta| < 1$) or grows ($|A\beta| < 1$)
- Amplitude stabilization circuit → automatically control the loop gain such that $A\beta=1$
- Example in Wien-bridge oscillator:



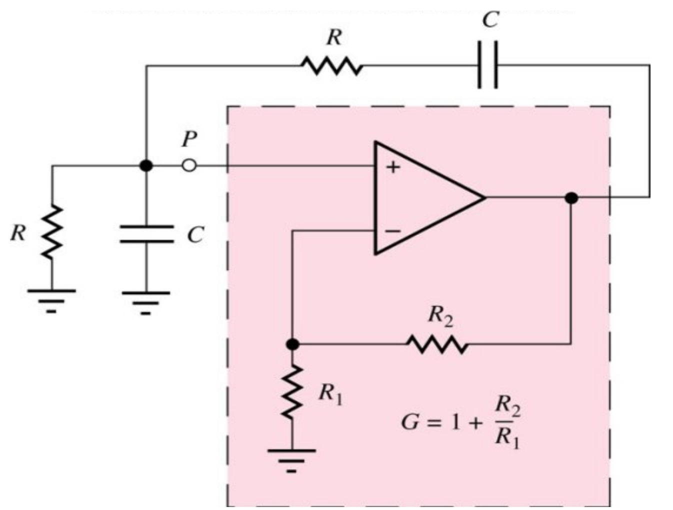
R_1 replaced by a nonlinear resistor



G must = 3
at oscillating freq.

When output amplitude increases
→ R_1 increases due to heat
→ G decreases → amplitude decreases

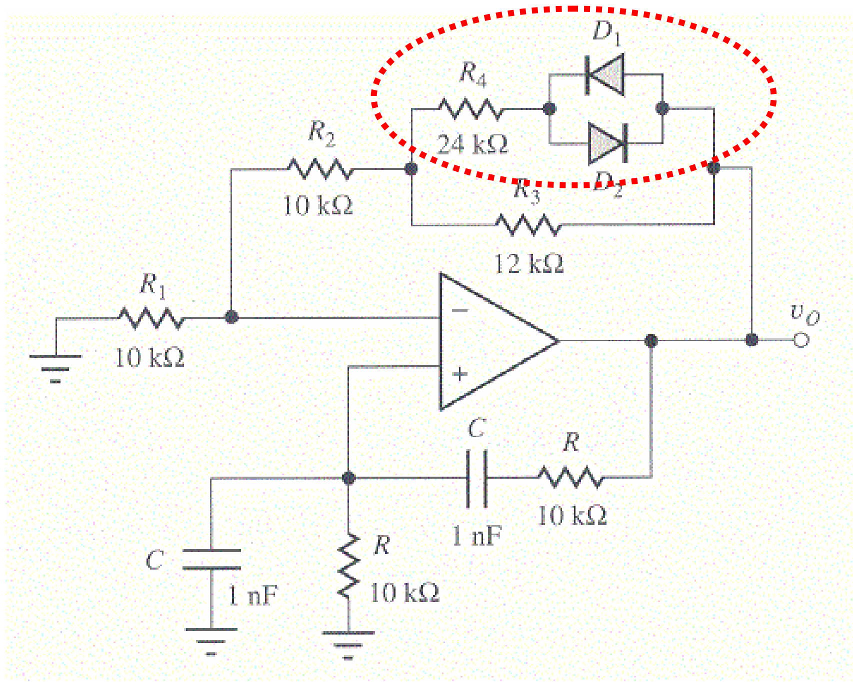
Amplitude Stabilization Circuit Example



G = 3

or

Resistance control



- R_4 and diodes D_1 and D_2 form a nonlinear resistor, whose value depends on output amplitude

Feedback Summary

- Feedback combines the advantages of passive circuits and active circuits
- Properties of negative feedback
  - Desensitize the gain
  - Extend the bandwidth
  - Reduce distortion
- Feedback circuits can be classified into four topologies
  - Series-series, series-shunt, shunt-series, shunt-shunt
- Stability is a special issue in feedback circuits. Stability can be determined by
  - Nyquist plot
  - Root locus diagram
  - Phase and gain margin in Bode plots
- Oscillators employ positive feedback circuits