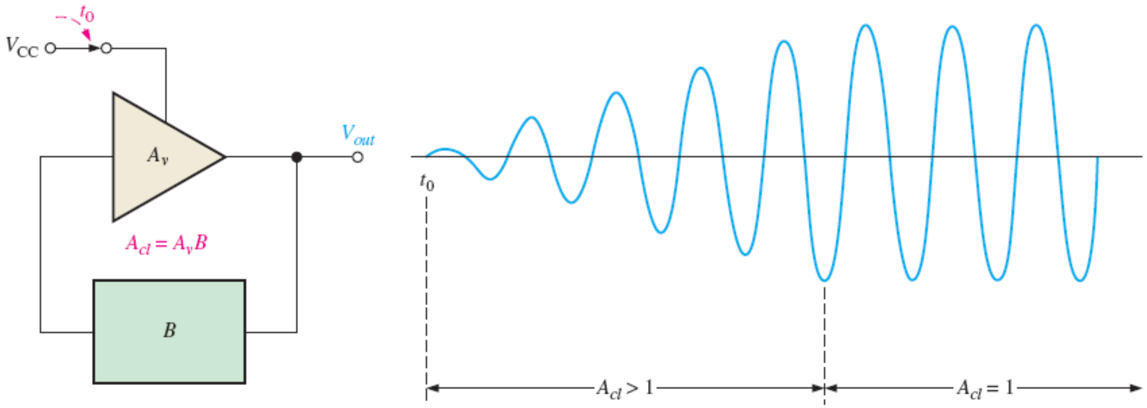
Electrical, Electronic and control Engineering
Engineering

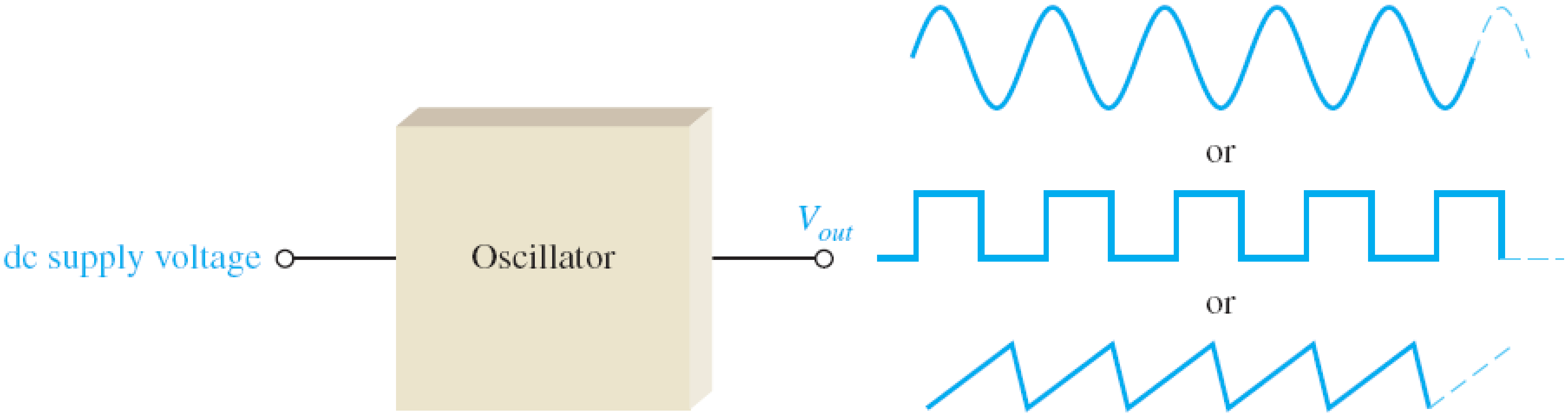
국립한경대학교
HANKYONG NATIONAL UNIV.

Ch. 16
Oscillators



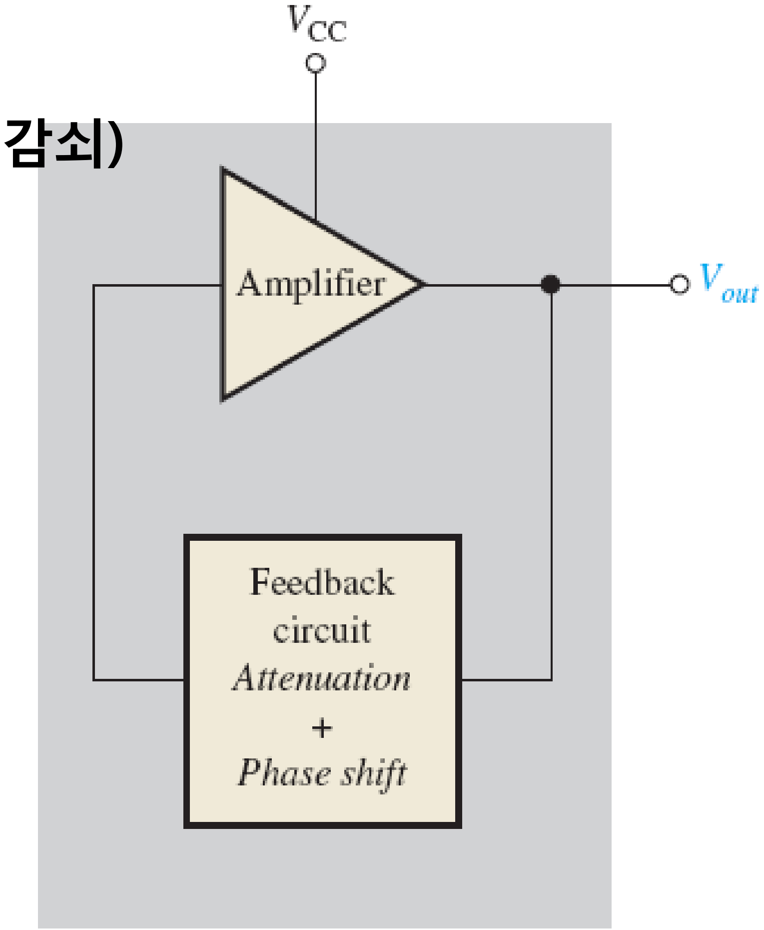
발진기(Oscillator)

- 발진기: 전원이 인가된 상태에서 외부의 입력신호 없이 회로 자체의 동작에 의해 특정 주파수의 신호(정현파, 구형파, 삼각파, 톱니파)를 생성하는 회로
- 종류: 귀환 발진기(Feedback oscillator), 이완 발진기(Relaxation oscillator)



귀환 발진기

- 귀환 발진기: 출력신호의 일부분이 위상변이 없이 입력으로 인가되어 출력을 강화
  - 정귀환 이용
  - 구성: 증폭기, 정귀환회로 (위상변이와 감쇠)



Oscillator

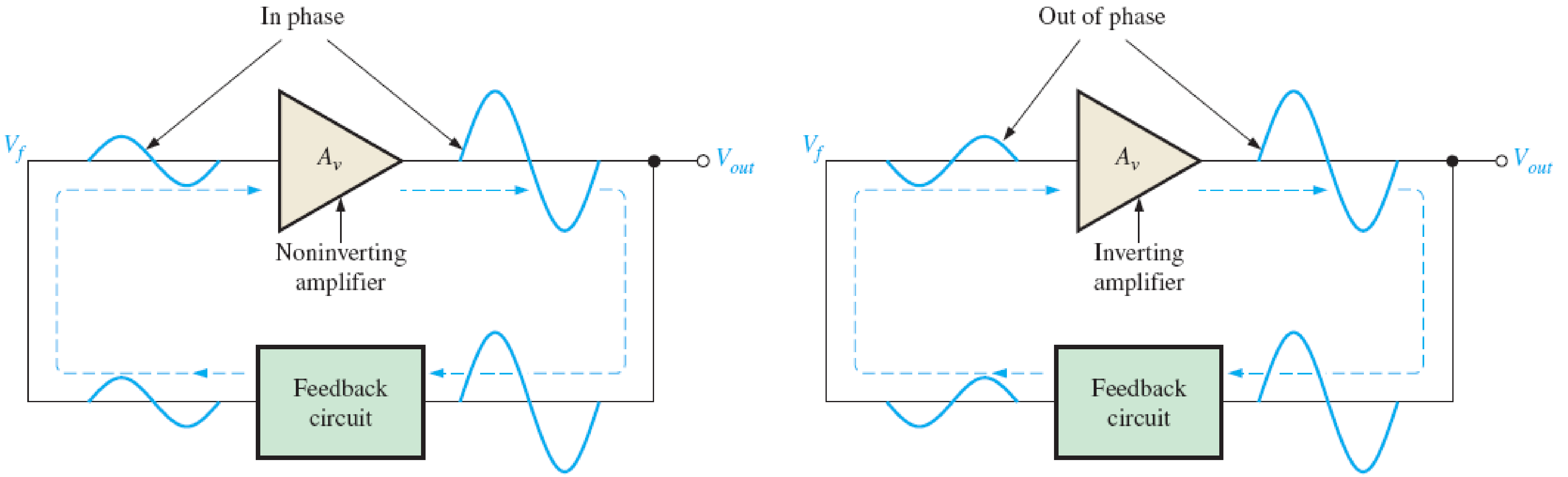
이완발진기

- 이완발진기: RC 회로를 사용하여 구형파 등과 같은 정현파 이외의 파형 발생
  - 귀환 이용 안 함
  - 구성: 슈미트트리거 회로나 저항을 통한 캐패시터의 충전과 방전을 위한 소자

귀환발진기

정귀환 이용

- 정귀환 : 증폭기 출력 일부가 위상변위 없이 입력에 되돌려져서 출력을 보강



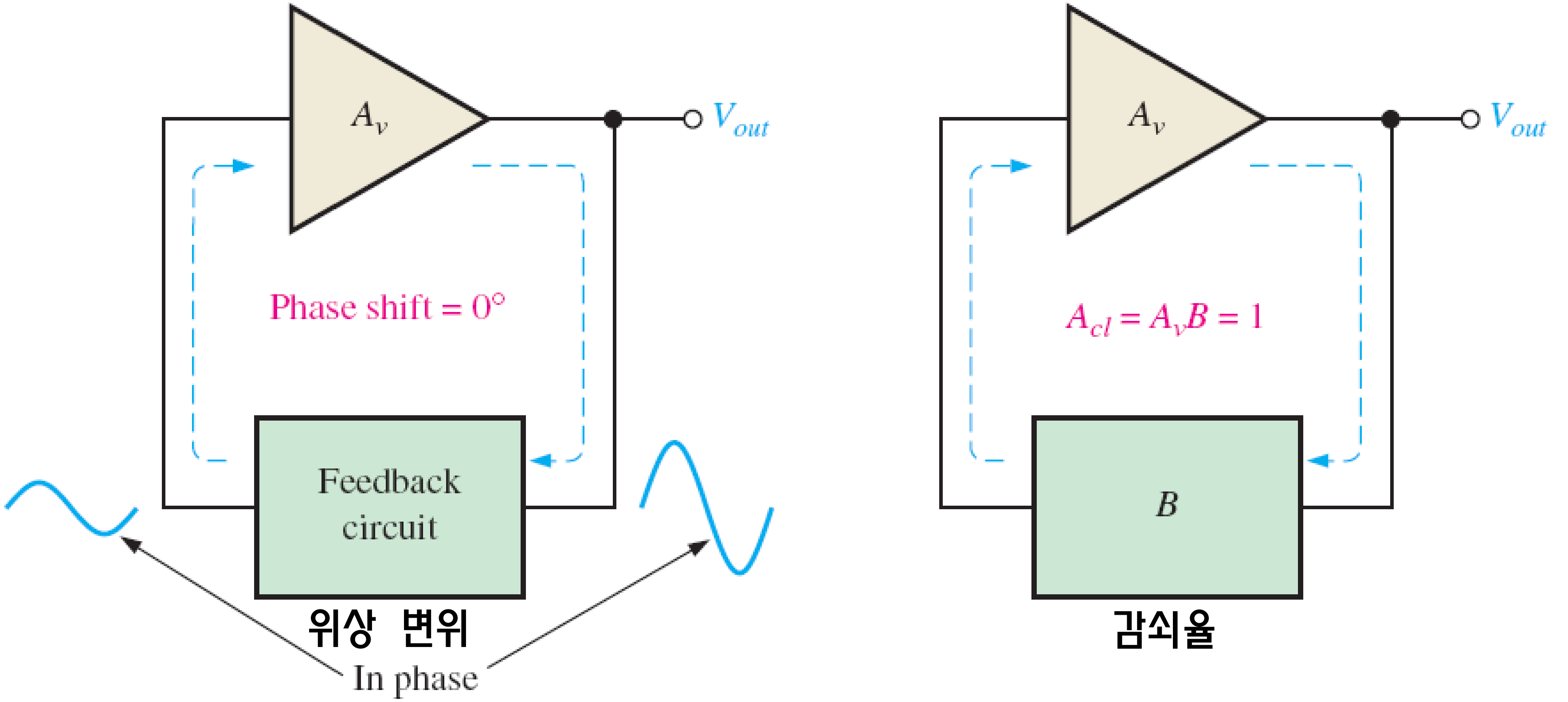
180° 위상 변위

귀환발진기

발진 조건

$$\boxed{A_vB = 1 \angle 0^\circ}$$

- 위상변위 : 0°
- 폐루프 이득 $A_{cl} = 1 \ (= A_vB \ )$



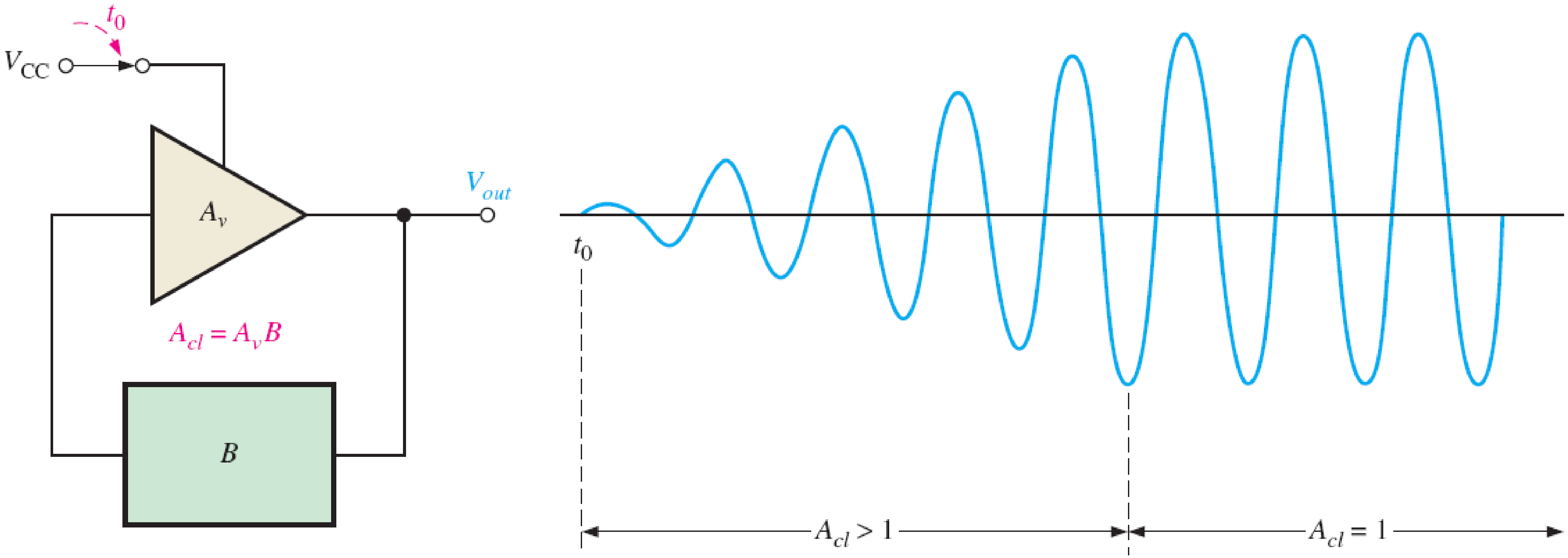
(a) The phase shift around the loop is 0°.

(b) The closed loop gain is 1.

귀환발진기

시동(Start-up) 조건

- 직류전압이 처음 인가되었을 때 발진이 일어나기 위한 조건
- 직류전원인가시에 $A_{cl} > 1$일 때 출력이 원하는 레벨까지 증가하면 출력을 일정하게 유지하도록 $A_{cl} = 1$로 감소하여 유지

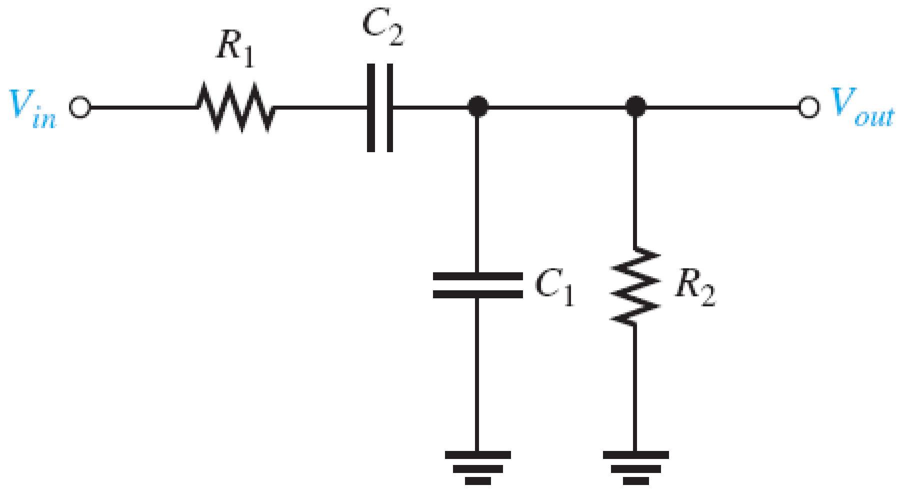


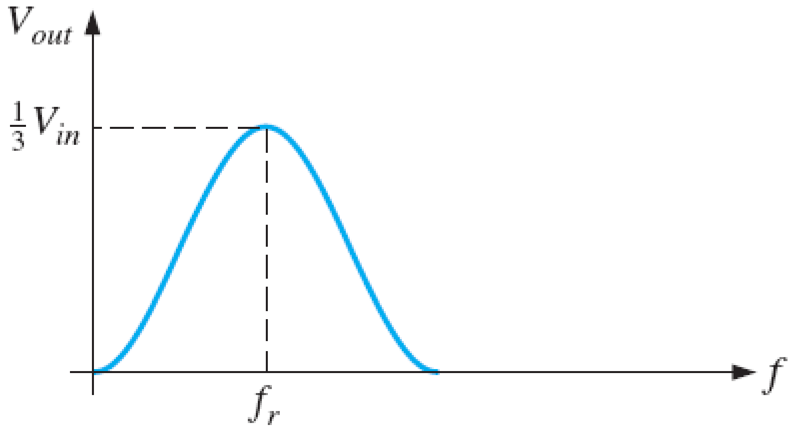
Oscillators with RC feedback circuits

- 정현파 발진
- 종류: Wien-bridge oscillator, phase-shift oscillator, twin-T oscillator
- Wien-bridge oscillator가 가장 널리 사용
- 주파수 범위: 대개 1MHz 까지

Wien-bridge oscillator

- 윈브리지 발진기(Wien-bridge oscillator)
  - 정현파 발진기
  - 진상-지상(lead-lag) 회로로 구성:
    - 지상회로: R_1, C_1 - 고주파에서 roll-off (low-pass filter)
    - 진상회로: R_2, C_2 - 저주파에서 roll-off (high-pass filter)



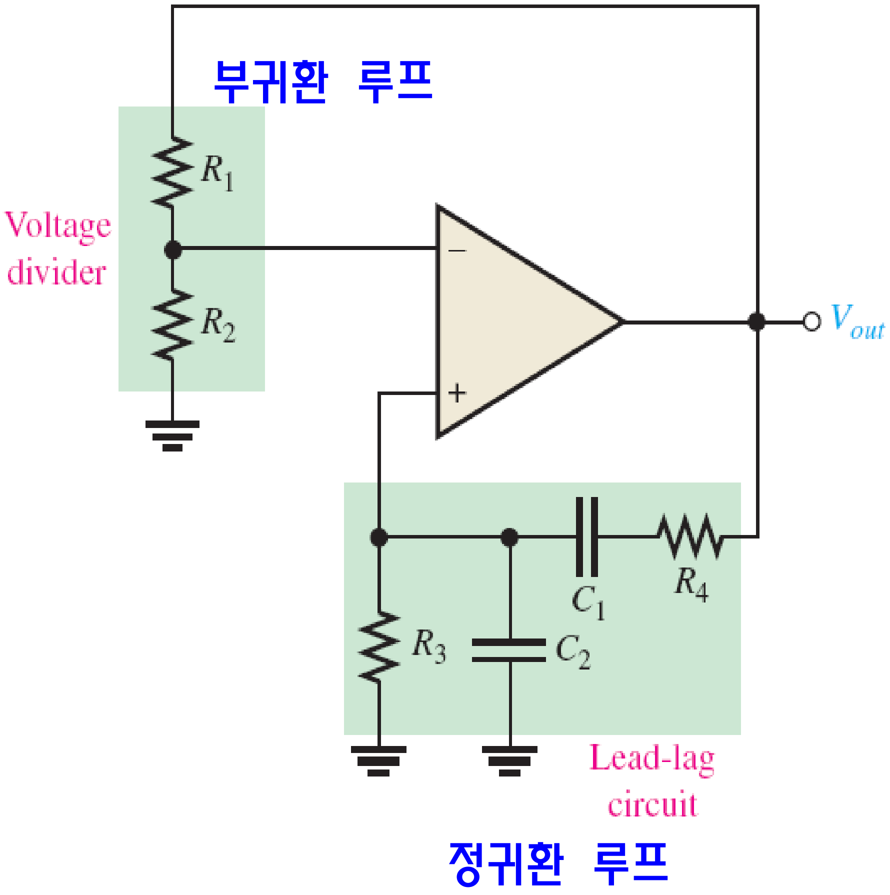


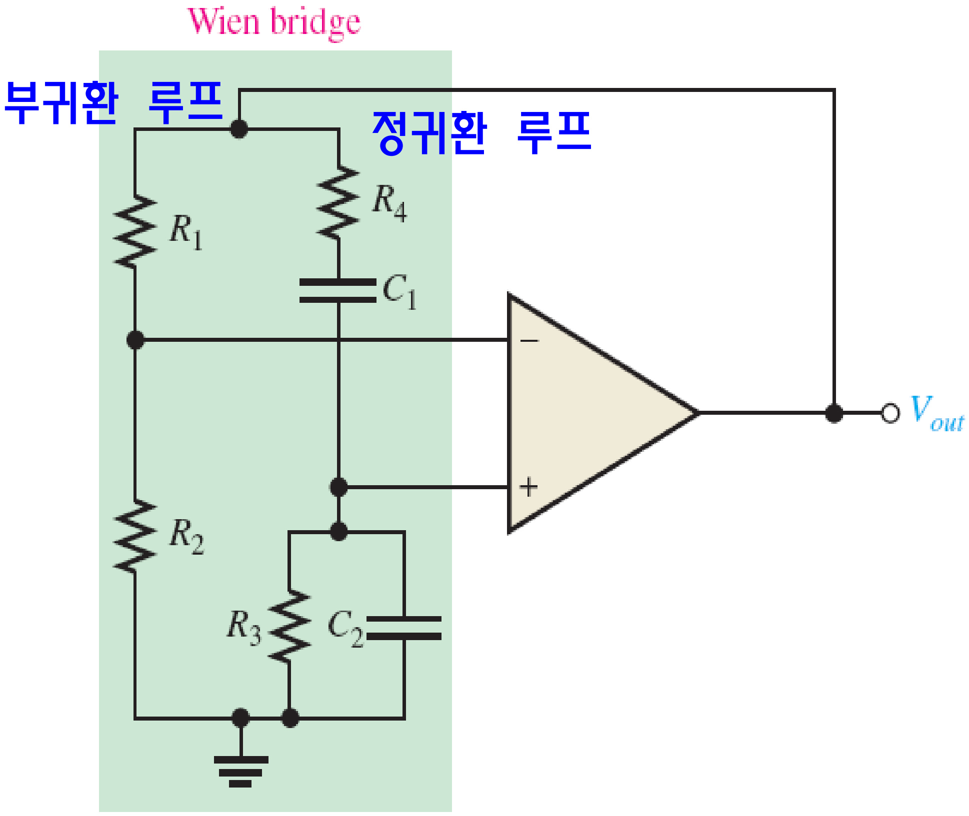
$R_1 = R_2$ and $X_{C1} = X_{C2}$ $\longrightarrow$ 공진주파수(resonance freq.)

$$\frac{V_{out}}{V_{in}} = \frac{1}{3} \qquad f_r = \frac{1}{2\pi RC}$$

Wien-bridge oscillator

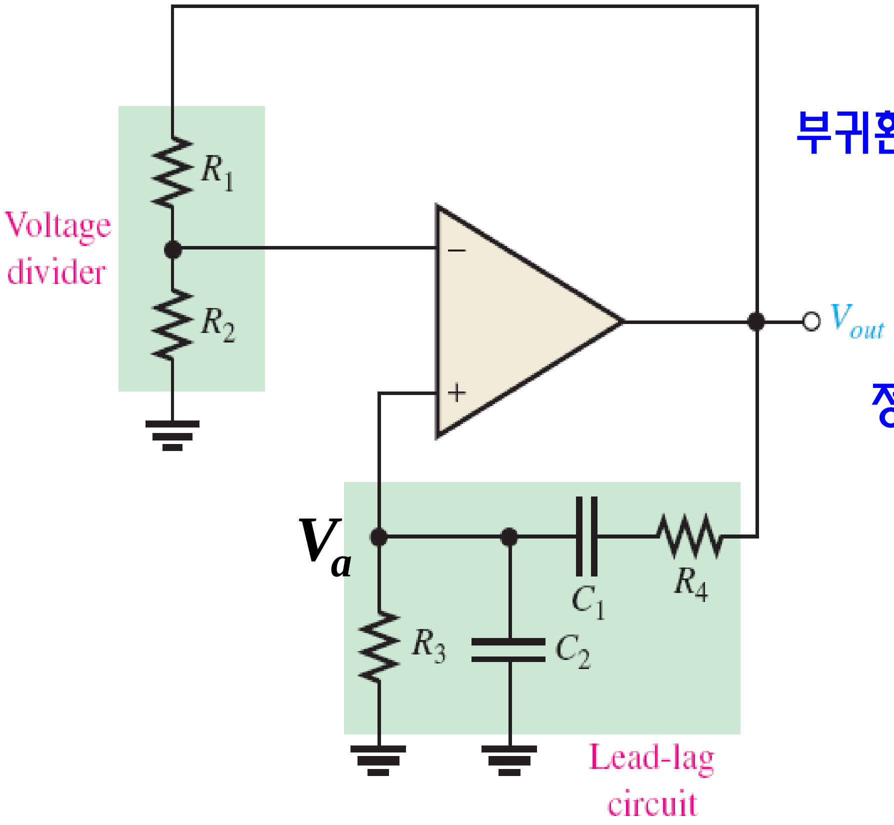
기본 회로





$$A_{cl} = \frac{1}{B} = \frac{1}{R_2/(R_1 + R_2)} = \frac{R_1 + R_2}{R_2}$$

Wien-bridge oscillator



부귀환 루프

$$A_{cl}(s) = \frac{V_{out}(s)}{V_a(s)} = 1 + \frac{R_1}{R_2}$$

정귀환 루프

$R_3 = R_4 = R$
$C_1 = C_2 = C$

$$B(s) = \frac{V_a(s)}{V_{out}(s)} = \frac{Z_C // R}{(Z_C + R) + Z_C // R}$$

$$L(s) = A_{cl}(s)B(s) = (1 + \frac{R_1}{R_2})\frac{Z_C // R}{(Z_C + R) + Z_C // R}$$

$Z_C = 1/sC$ **이므로,**

$$L(s) = (1 + \frac{R_1}{R_2})\frac{sCR}{1 + 3sCR + s^2C^2R^2}$$

Wien-bridge oscillator

- 발진 조건 : $L = A_{cl}B = 1\angle 0°$

$s = jw$를 대입하면,

$$L(jw) = (1+\frac{R_1}{R_2})(\frac{jwCR}{1-w^2C^2R^2+3jwCR})$$

$$L(jw_0) = (1+\frac{R_2}{R_1})(\frac{jw_0CR}{1-w_0{}^2C^2R^2+3jw_0CR}) = 1\angle 0°$$

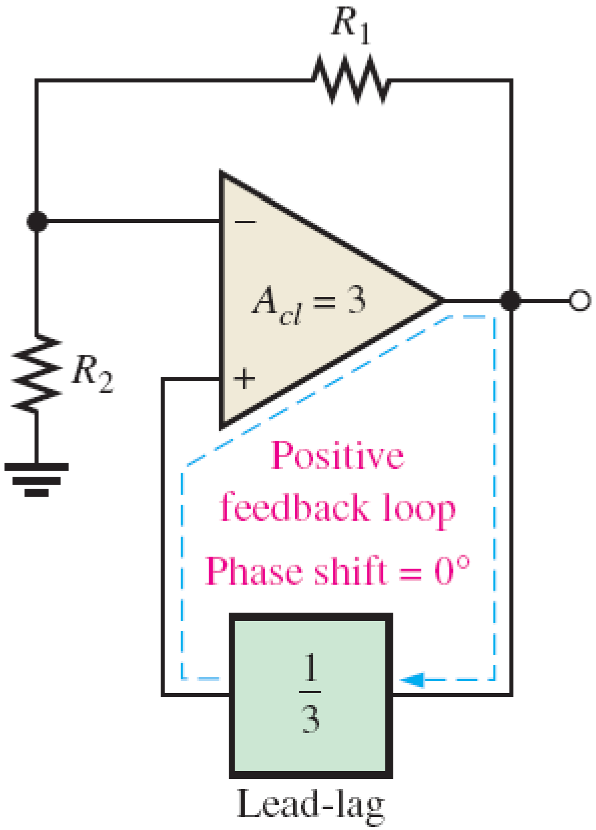
위상 조건 : $1-w_0{}^2C^2R^2 = 0 \longrightarrow w_0 = 1/CR$

진폭 조건 : $(1+\frac{R_2}{R_1})(\frac{1}{3}) = 1 \longrightarrow R_2/R_1 = 2$

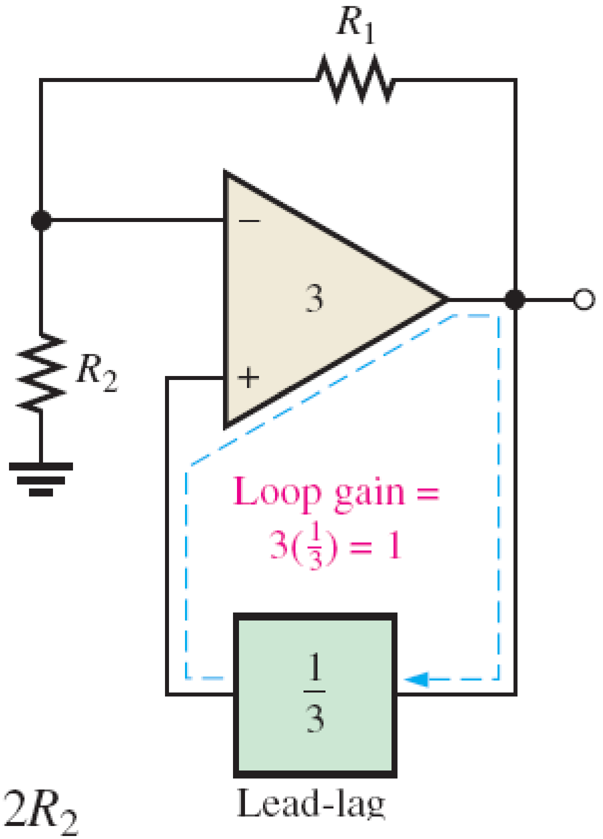
Wien-bridge oscillator

발진을 위한 정귀환 조건

위상변위 : 0°
← 공진주파수 f_r에서



폐루프 이득 : $A_vB = 3\times(1/3) = 1$

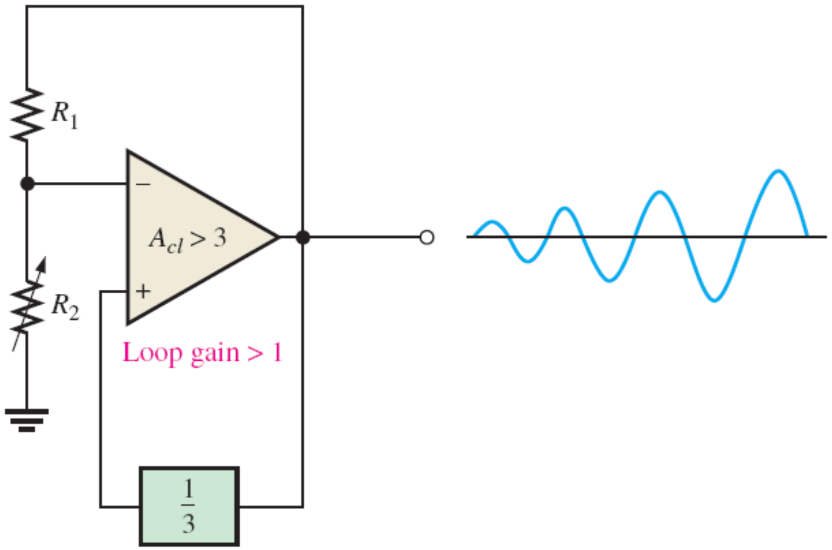


$$R_1 = 2R_2$$

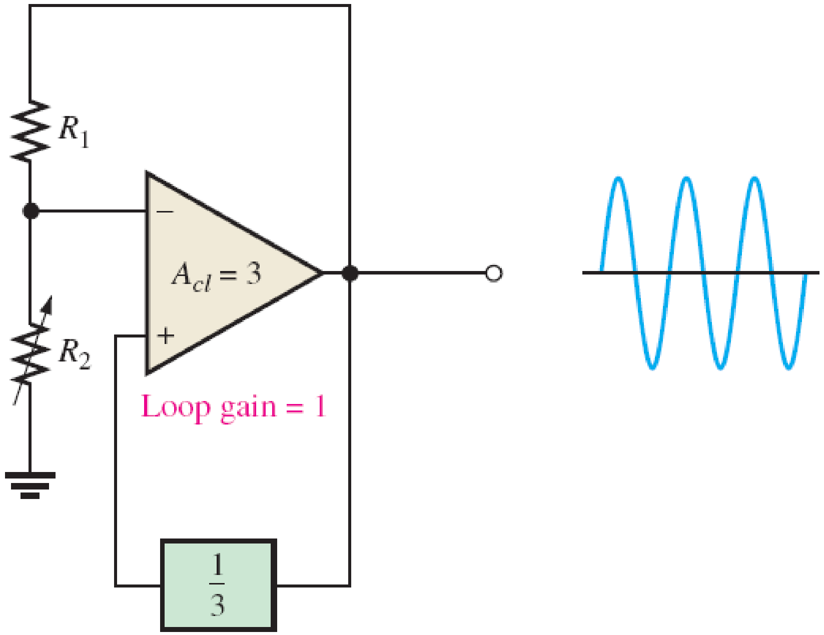
$$A_{cl} = \frac{R_1 + R_2}{R_2} = \frac{2R_2 + R_2}{R_2} = \frac{3R_2}{R_2} = 3$$

Wien-bridge oscillator

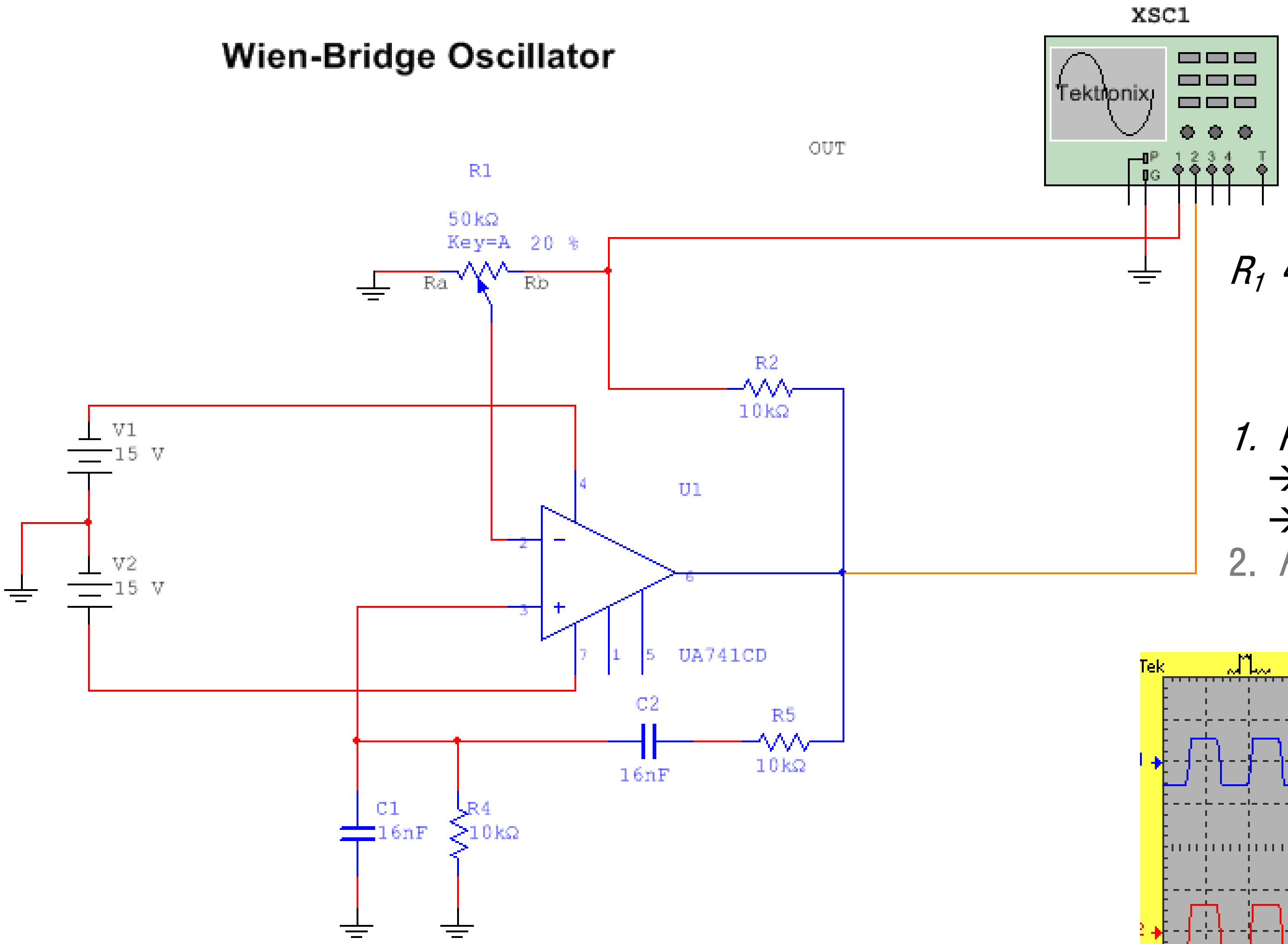
- 시동을 위한 조건
  - 발진이 일어날 때까지 폐루프 이득 3보다 커야 함 (A_{cl} > 3)



  - 발진 일어난 이후: A_{cl} = 3 유지

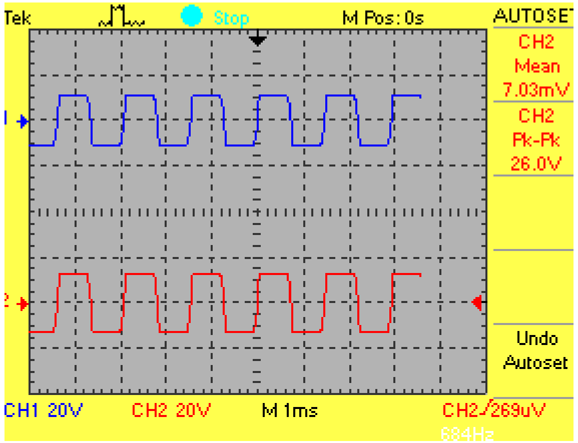


Wien-bridge oscillator - 시뮬레이션

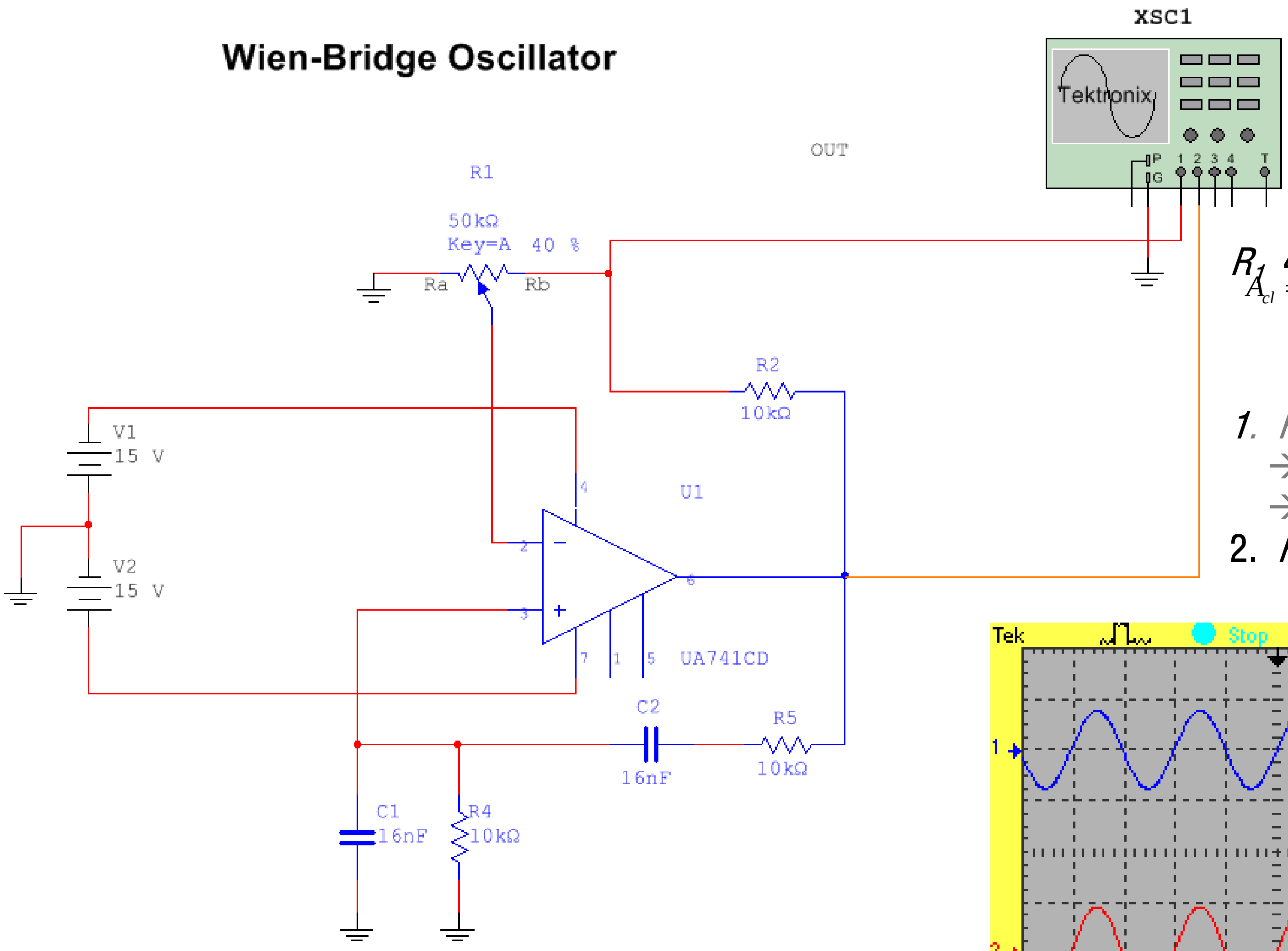


R_1 40% → R_a=20kΩ, R_b=30kΩ

1. R_1 40% 이하에서 동작 후에
   → R_a ≤ 20kΩ, R_b ≥ 30kΩ
   → A_{cl} > 3 (시동조건)
2. R_1 = 40% 고정 → A_{cl} = 3



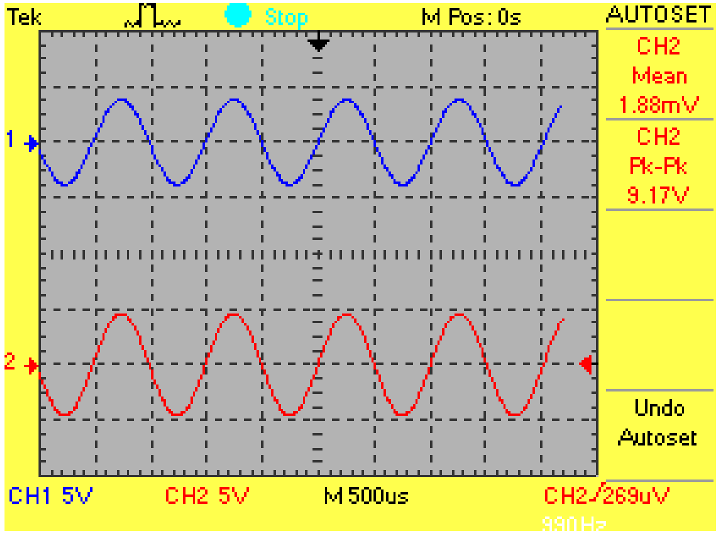
Wien-bridge oscillator - 시뮬레이션



R₁ 40% → Rₐ=20kΩ, R_b=30kΩ

$$A_{cl} = \frac{R_a + R_b + R_2}{R_a} = \frac{20k + 30k + 10k}{20k} = 3$$

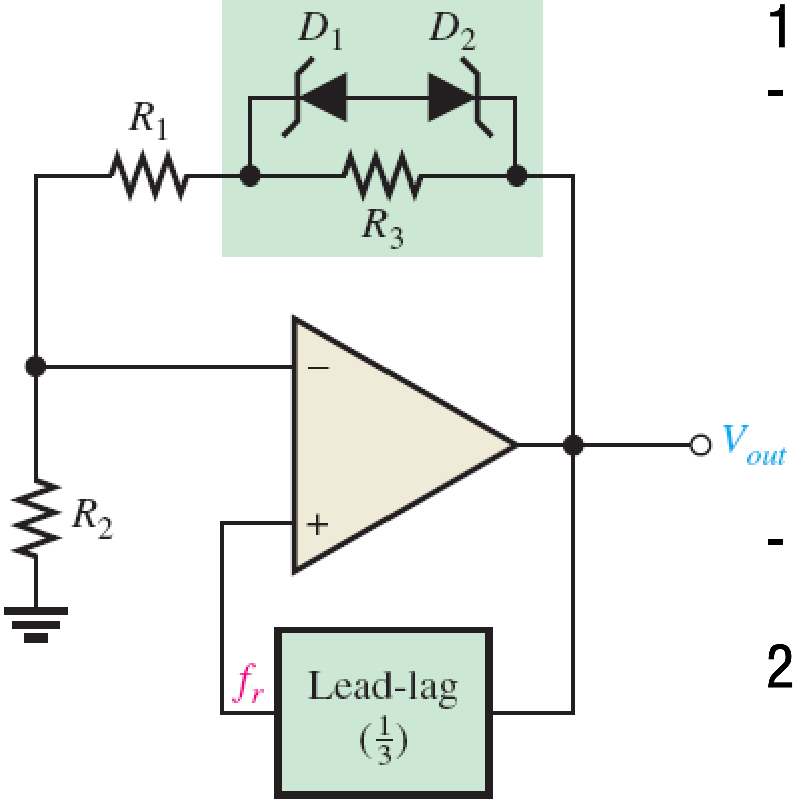
1. *R₁* 40% 이하에서 동작 후에
   → $R_a \le 20k\Omega$, $R_b \ge 30k\Omega$
   → $A_{cl} > 3$ (시동조건)
2. *R₁* = 40% 고정 → $A_{cl} = 3$



Wien-bridge oscillator

- 시동을 위한 조건
  - 발진을 유지하는 방법(예)

$$R_1 = 2R_2$$



1. 직류전압이 처음 인가되었을 때

- 부귀환 회로: Zener Diode들 개방(open)

$$A_{cl} = \frac{R_1 + R_2 + R_3}{R_2}$$

$$= \frac{3R_2 + R_3}{R_2} = 3 + \frac{R_3}{R_2} > 3$$

- 정귀환 회로: 공진주파수 f_r에서 위상변위 0°

2. $V_{out} > V_z$: Zener Diode들 단락(short)

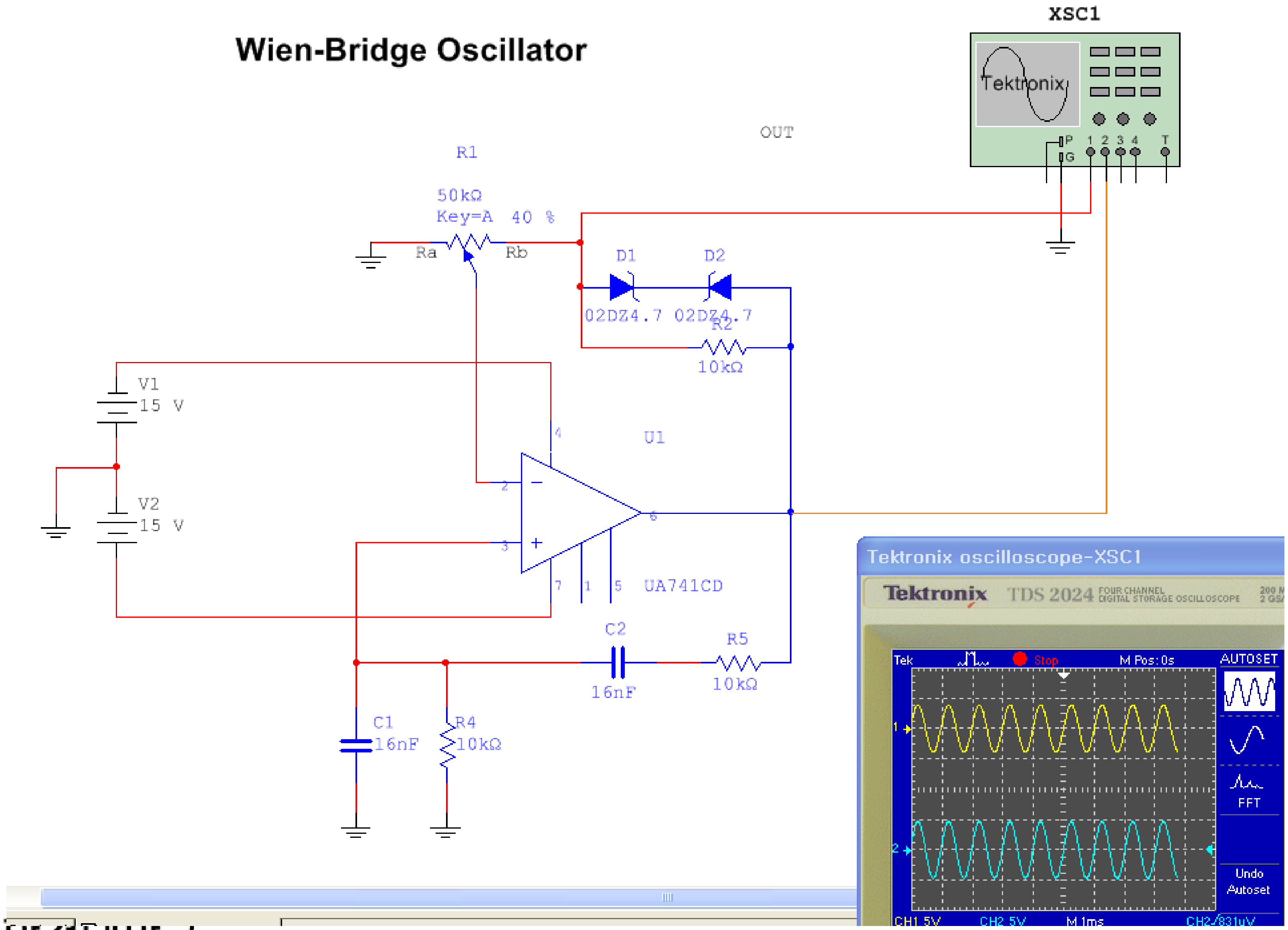
$$A_{cl} = \frac{R_1 + R_2}{R_2} = \frac{2R_2 + R_2}{R_2} = \frac{3R_2}{R_2} = 3$$

3. V_{out} 발진 유지

문제점: Non-linerity (Zener diode)

Wien-bridge oscillator

Yun SeopYu

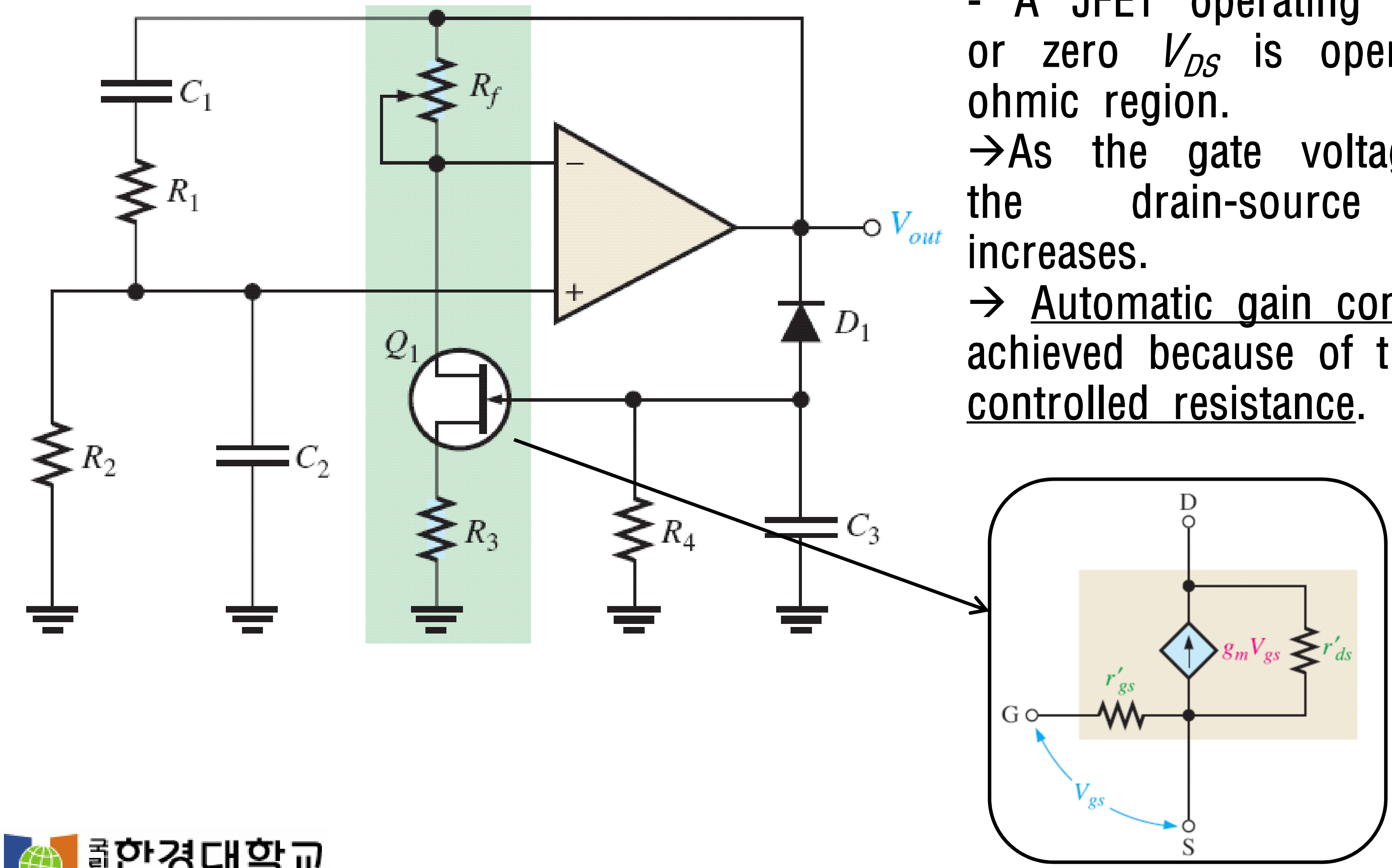


M Pos: 0s

CH1 5V CH2 5V M 1ms CH2 ╱831uV

Wien-bridge oscillator

- A better method to control the gain uses a JFET as a voltage-controlled resistor in a negative feedback path



- A JFET operating with a small or zero V_{DS} is operating in the ohmic region.

→As the gate voltage increases, the drain-source resistance increases.

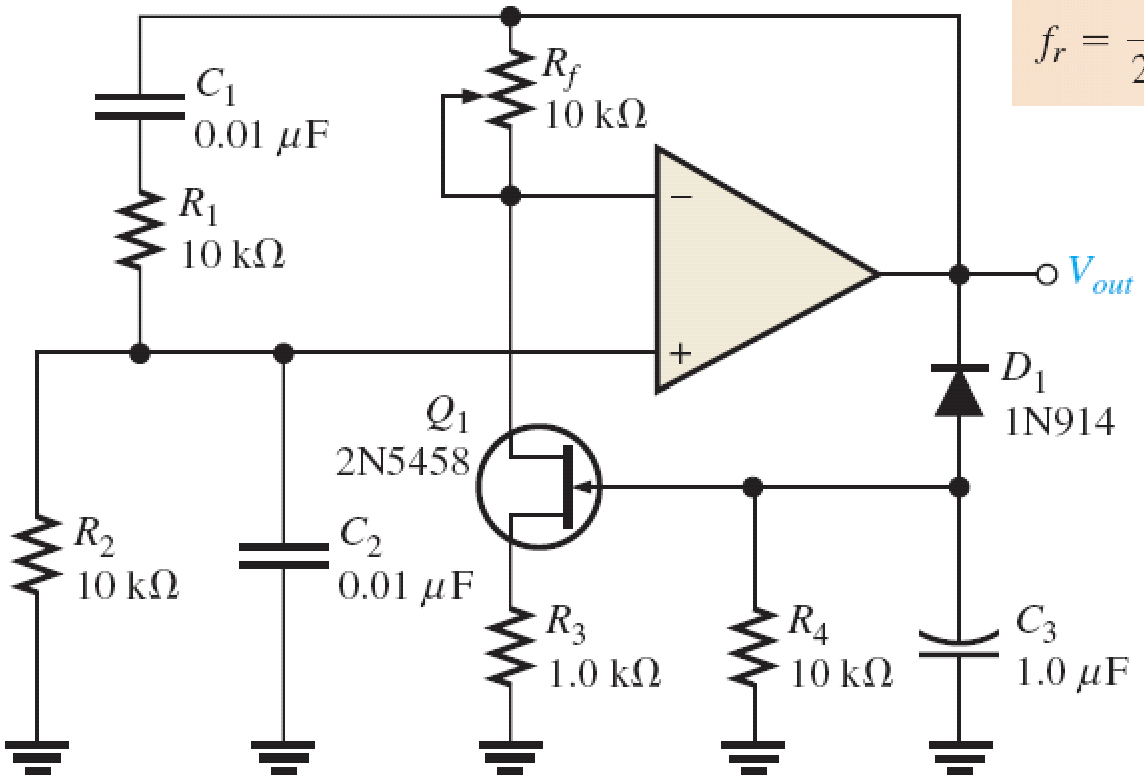
→ <u>Automatic gain control</u> can be achieved because of this <u>voltage-controlled resistance</u>.

Wien-bridge oscillator

- EXAMPLE 16–1
  - f_r, R_f ?

Internal drain-source resistance, of the JFET is 500 Ω when oscillations are stable

$$R_1 = R_2 = R = 10\,\text{k}\Omega \text{ and } C_1 = C_2 = C = 0.01\,\mu\text{F}$$



$$f_r = \frac{1}{2\pi RC} = \frac{1}{2\pi(10\,\text{k}\Omega)(0.01\,\mu\text{F})} = \mathbf{1.59\,kHz}$$

$$A_v = \frac{R_f}{R_3 + r'_{ds}} + 1$$ =3

$$R_f = (A_v - 1)(R_3 + r'_{ds})$$

$$= (3 - 1)(1.0\,\text{k}\Omega + 500\,\Omega)$$

$$= \mathbf{3.0\,k\Omega}$$

Phase-Shift Oscillator

- 위상변이 발진기(Phase-Shift Oscillator): 정현파 귀환 발진기 (sinusoidal feedback oscillator)

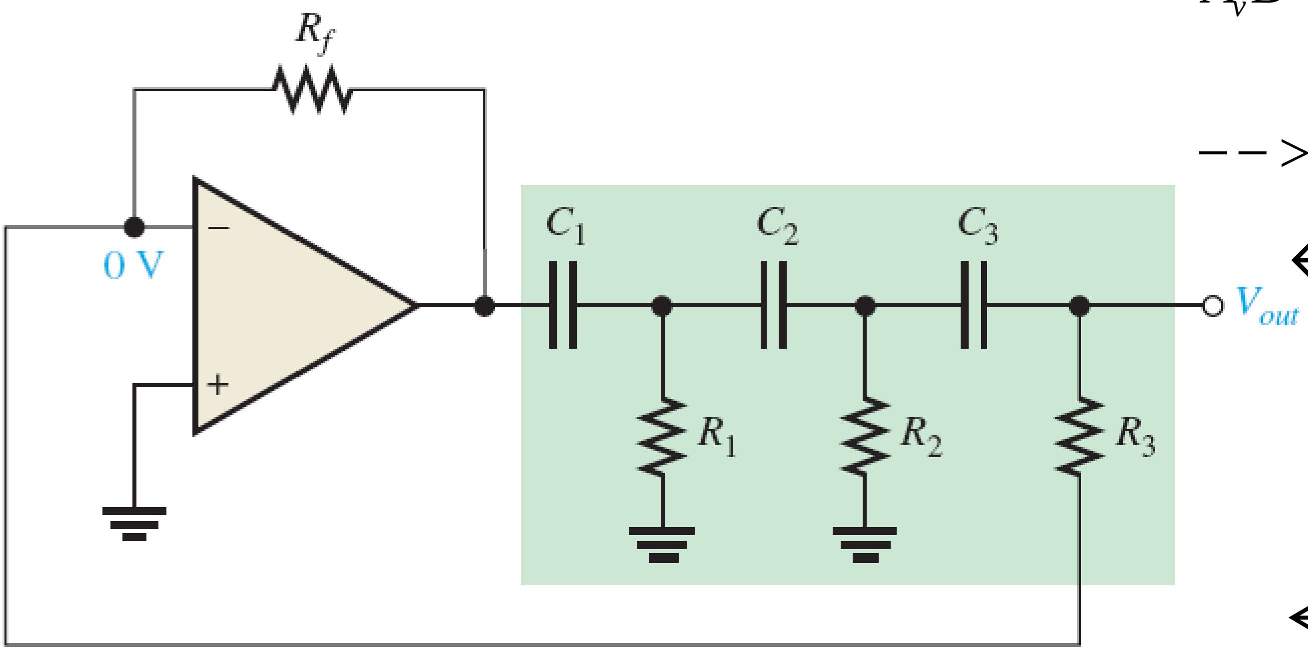
-위상변위 : 0° ← 공진주파수 f_r에서
-$A_v B$ = 1

- 1개 RC 최대 위상 지연 = 90°
- 3개 RC 위상 지연 ➔ 180° 로 하면
- 연산증폭기 위상 지연 180° + 3개 RC 위상 지연 180° = 360° ➔ 발진

$$A_v B = \left| -\frac{R_f}{R_i} \right| \cdot B = \left(\frac{R_f}{R_3} \right) \cdot B = 1$$

$$--> B = \frac{R_3}{R_f} = \frac{1}{29}$$

← 세개 RC 귀환회로 감쇠율

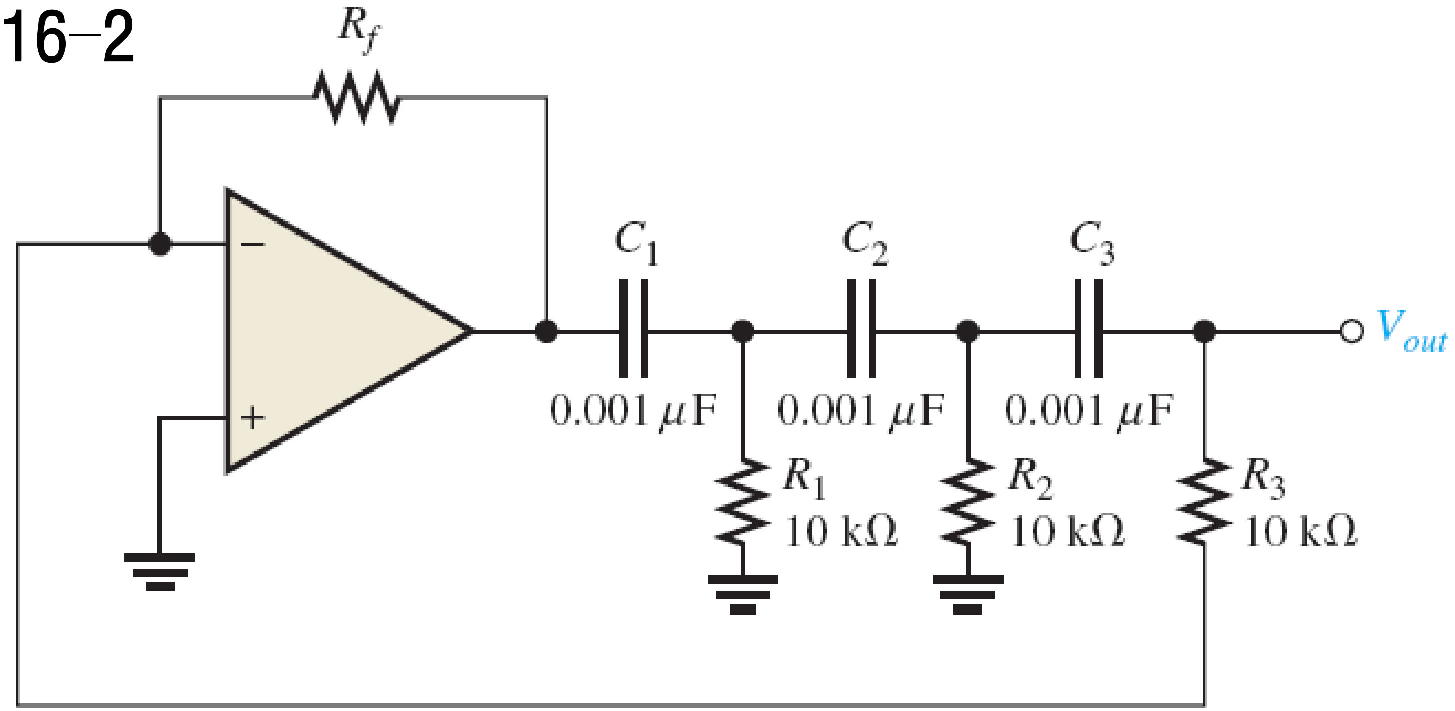


$$f_r = \frac{1}{2\pi\sqrt{6RC}}$$

← $R_1 = R_2 = R_3 = R$ and $C_1 = C_2 = C_3 = C.$

Phase-Shift Oscillator

- EXAMPLE 16–2
  - f_r, R_f ?



$A_{cl} = 29$, and $B = 1/29 = R_3/R_f$.

$$\frac{R_f}{R_3} = 29$$

$R_f = 29R_3 = 29(10\,\text{k}\Omega) = \mathbf{290\,k\Omega}$

$R_1 = R_2 = R_3 = R$ and $C_1 = C_2 = C_3 = C$.

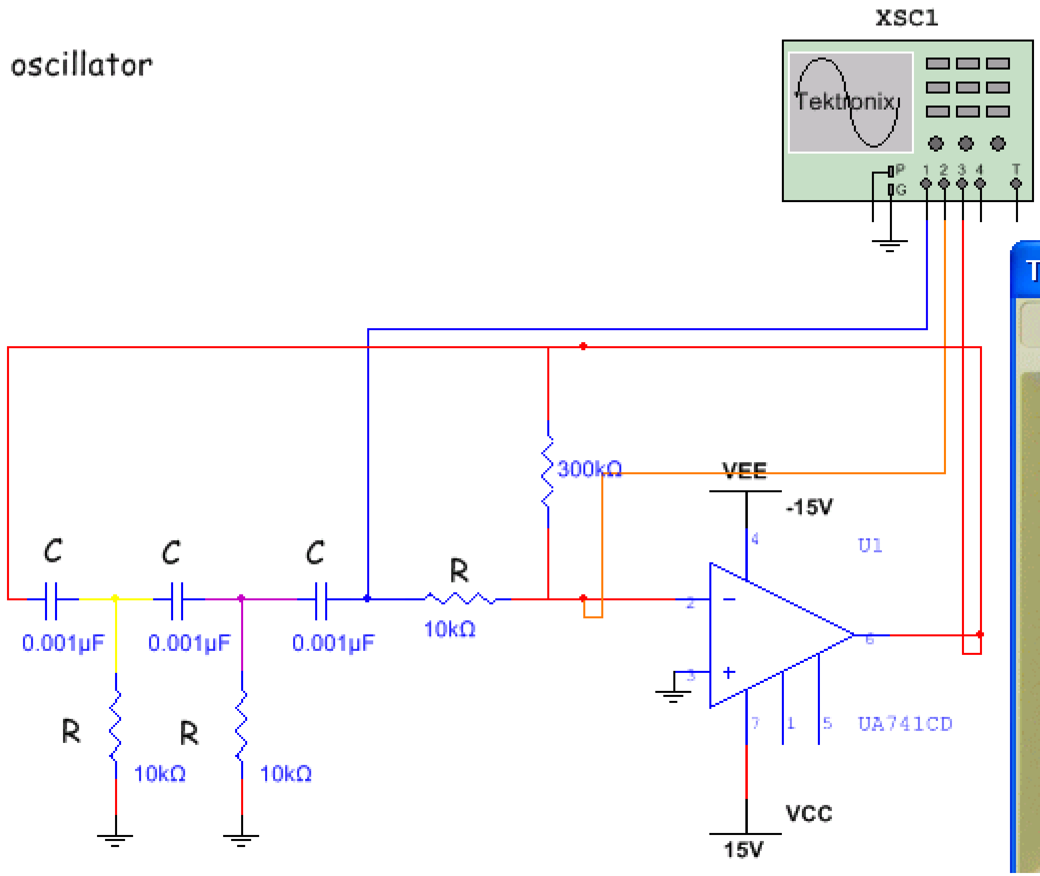
$$f_r = \frac{1}{2\pi\sqrt{6}RC}$$

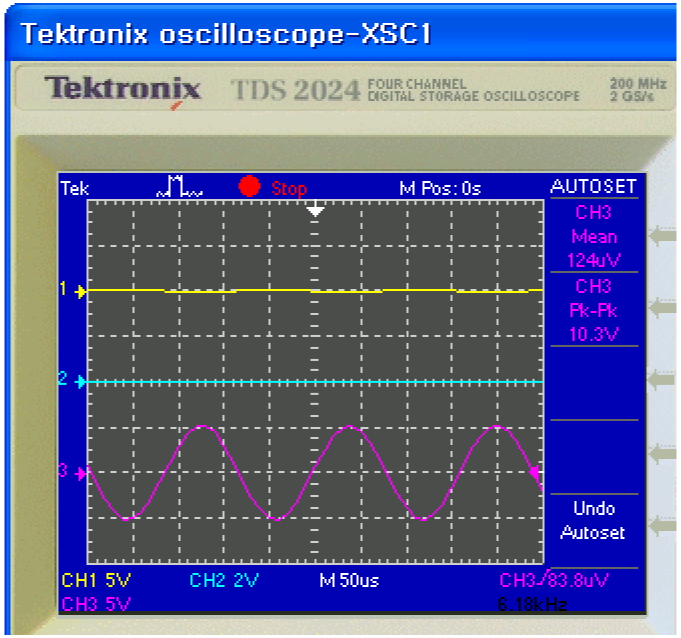
$$= \frac{1}{2\pi\sqrt{6}(10\,\text{k}\Omega)(0.001\,\mu\text{F})} \cong \mathbf{6.5\,kHz}$$

Phase-Shift Oscillator -시뮬레이션

Yun SeopYu

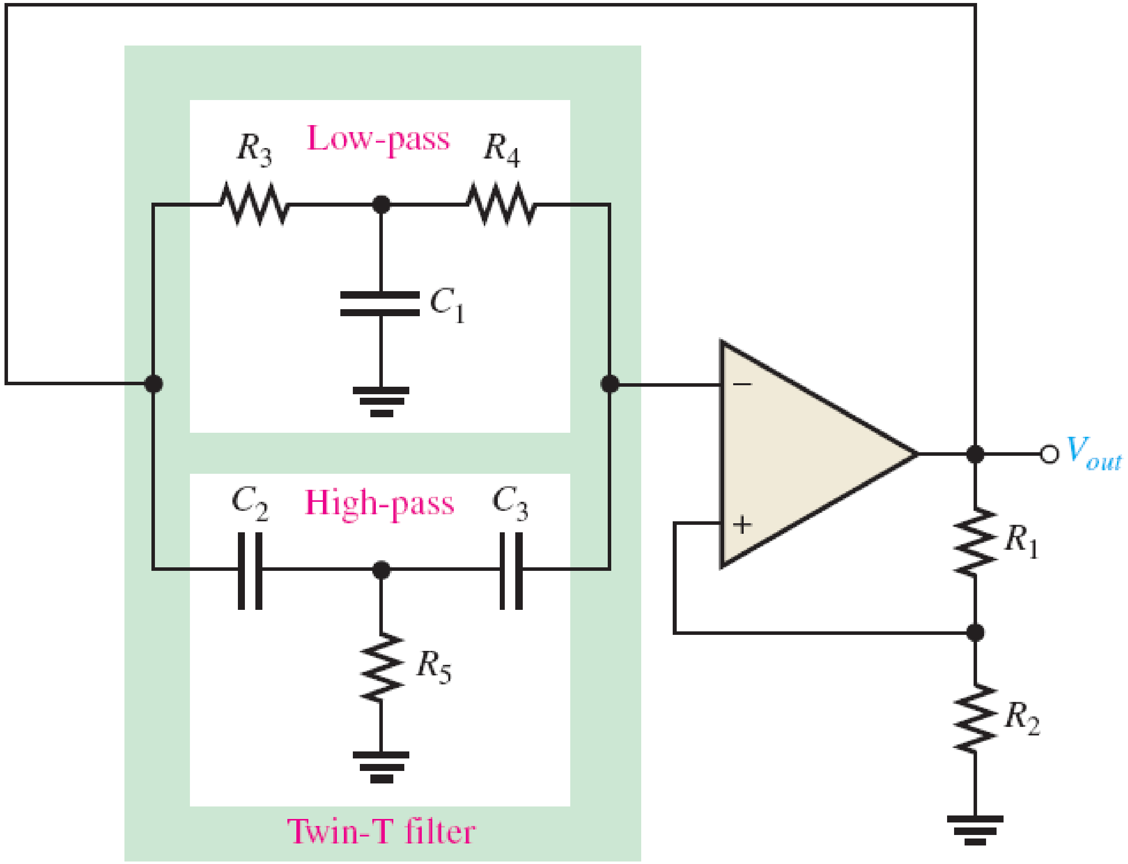
Phase shift oscillator

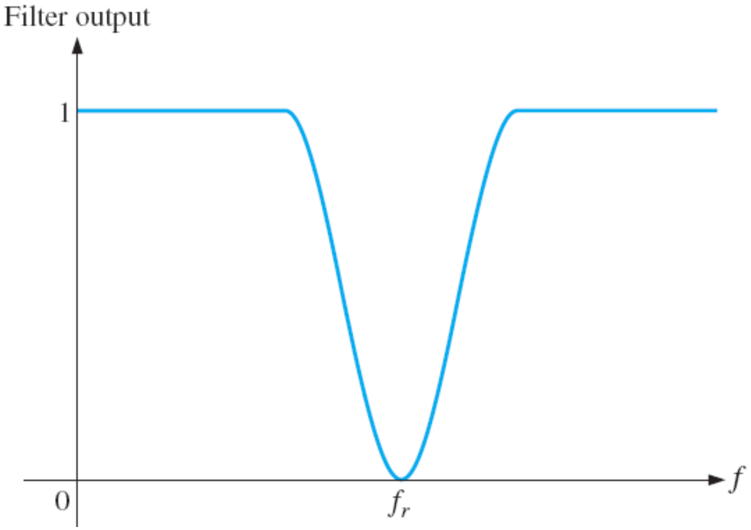




Twin-T Oscillator

- 트윈 T-형 발진기(Twin-T Oscillator): 두 개의 T형 RC 필터 채용
  - LPF + HPF : Band-Stop Filter(notch filter)
  - f_r에서 공진



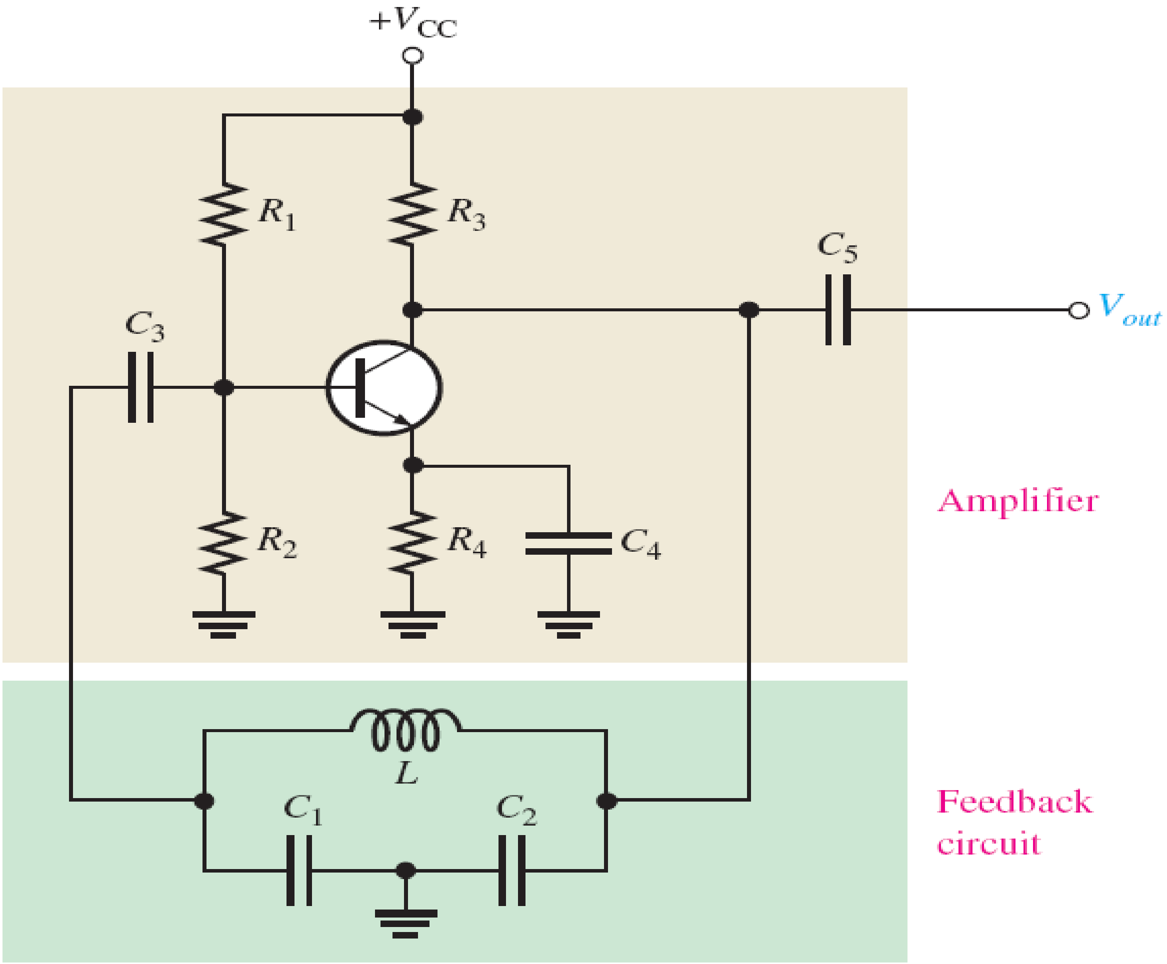


Oscillators with LC feedback circuits

- 윈브리지 발진기 : $f_r < 1$ Mhz
- LC 귀환 발진기(LC feedback oscillator): $f_r > 1$ Mhz (고주파 발진)
  - 연산증폭기 주파수 제한으로 BJT, FET을 사용되기도 함
  - 종류: 콜피츠 (Colpitts), 클랩 (Clapp), 하틀리 (Hartley), 암스트롱 (Armstrong), 수정 발진기 (crystal-controlled) oscillators

Colpitts Oscillator

- Colpitts가 발명
- LC 귀환 회로 : 위상 변이 + 공진 필터



공진주파수

$$f_r \cong \frac{1}{2\pi\sqrt{LC_T}}$$

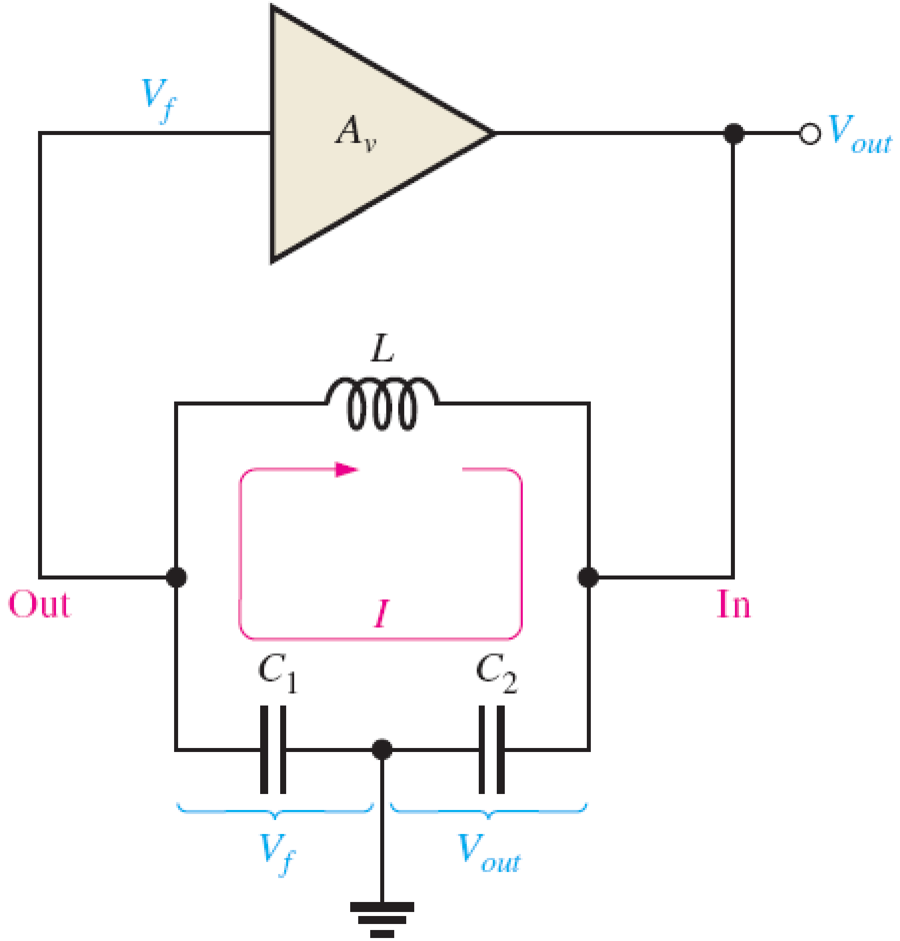
$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

← C_1과 C_2는 직렬

Colpitts Oscillator

발진과 시동조건

- LC 탱크회로 귀환 감쇄율 *B*: C_1, C_2 값에 의 결정



$$B = \frac{V_f}{V_{out}} \cong \frac{IX_{C1}}{IX_{C2}} = \frac{X_{C1}}{X_{C2}} = \frac{1/(2\pi f_r C_1)}{1/(2\pi f_r C_2)}$$

$$B = \frac{C_2}{C_1}$$

a condition for oscillation is $A_v B = 1$.

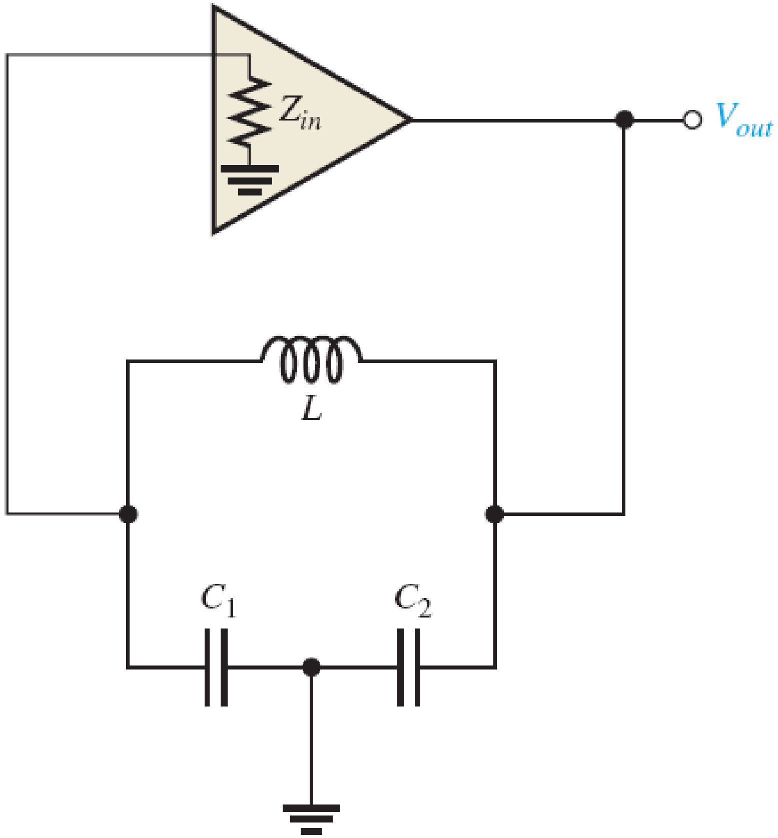
$$A_v = \frac{C_1}{C_2}$$

- 초기 시동조건: $A_v B > 1$

  → $A_v > C_1/C_2$

Colpitts Oscillator

- 귀환회로의 부하가 발진주파수에 미치는 영향
  - 증폭기의 입력임피던스 Z_{in}이 LC 탱크회로(공진 귀환 회로)의 부하로 동작 → 회로의 Q를 감소 → 발진주파수 감소 (Q값에 의존)



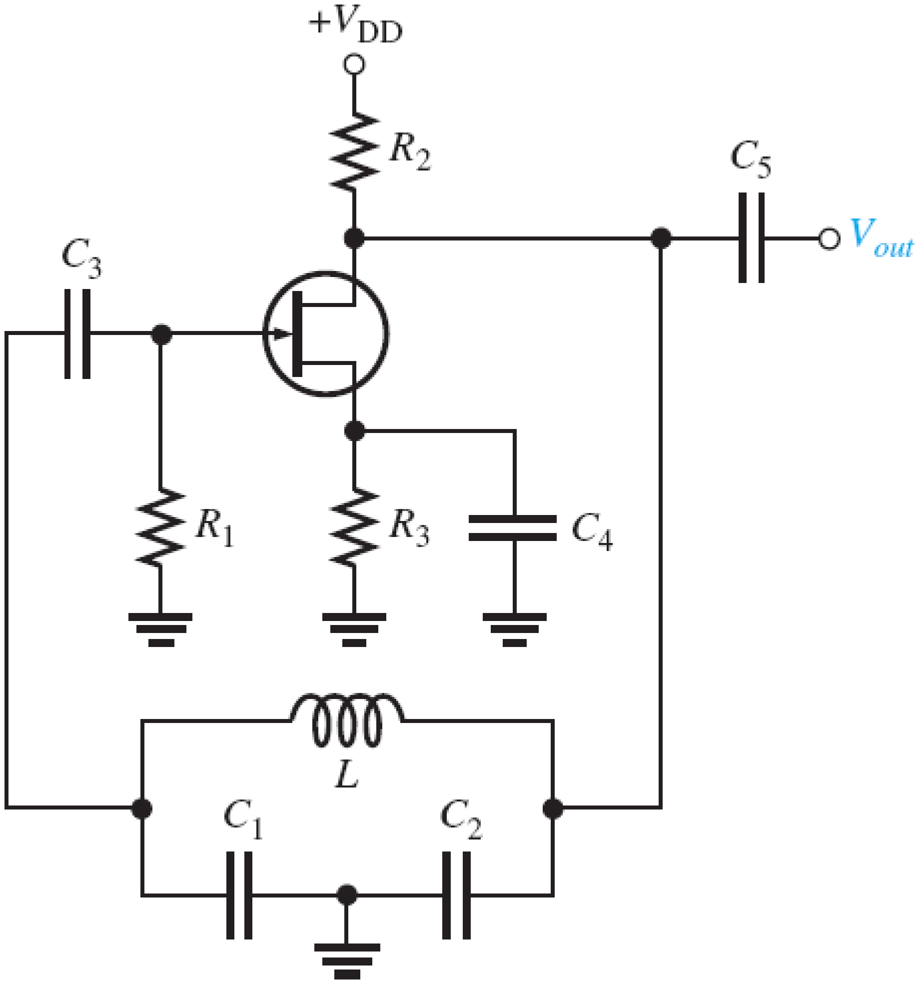
$$f_r = \frac{1}{2\pi\sqrt{LC_T}}\sqrt{\frac{Q^2}{Q^2+1}}$$

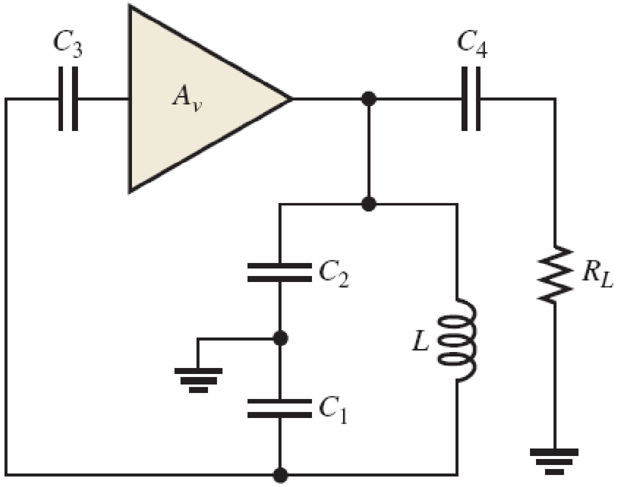
- Q > 10 : $f_r = \frac{1}{2\pi\sqrt{LC_T}}$

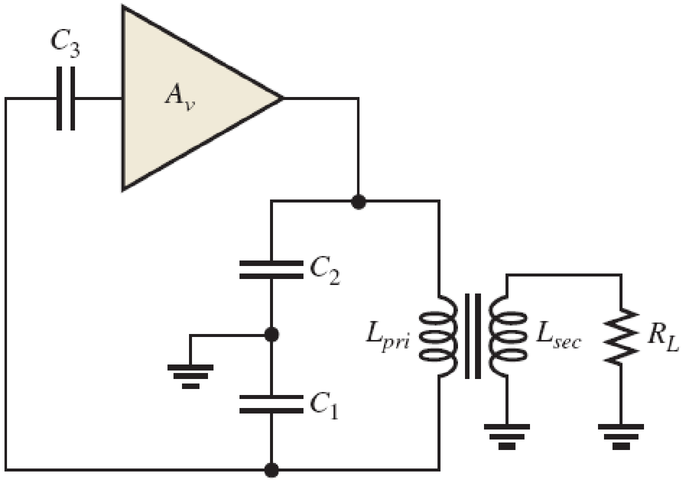
- Q < 10 : f_r 현저히 감소

Colpitts Oscillator

- FET을 이용한 콜피츠 발진기
  - FET이 입력 임피던스가 높기 때문에 임피던스 부하 효과를 최소화 가능

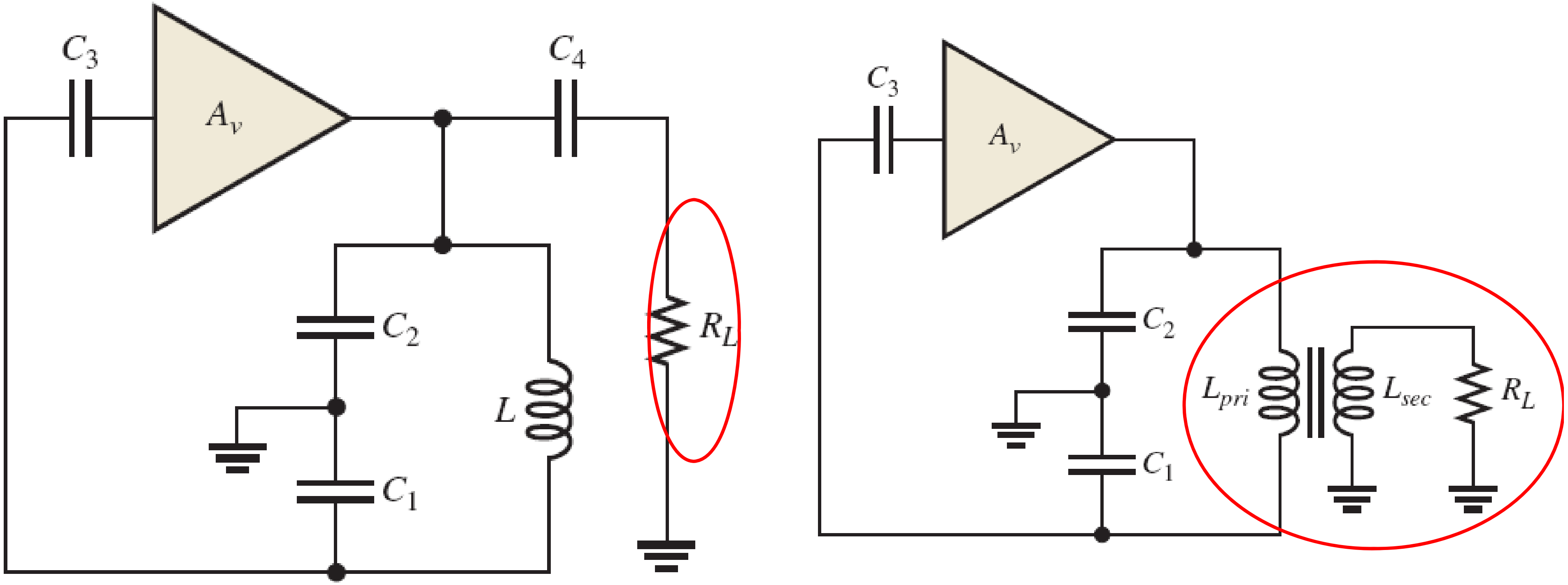






Colpitts Oscillator

- **콜피츠 발진기 외부 부하효과**
  - 외부 부하 → Q 감소 → f_r 감소 ➔ 해결방안 : 변압기 결합



Colpitts Oscillator- 예제 16-3

- 예제 16-3:
  - f_r ? (단, 귀환회로 부하효과 무시, Q >10)
  - Q = 8로 감소 → f_r ?

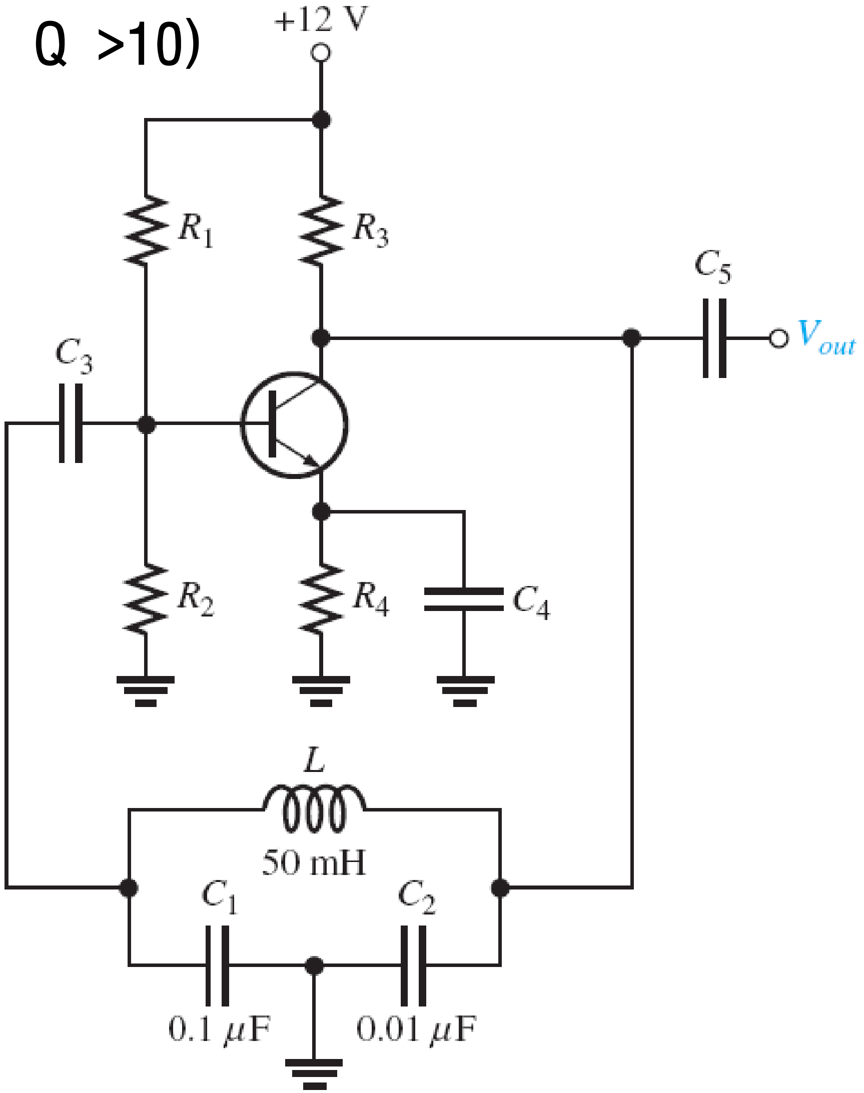
$$C_T = \frac{C_1 C_2}{C_1 + C_2} = \frac{(0.1\ \mu F)(0.01\ \mu F)}{0.11\ \mu F} = 0.0091\ \mu F$$

$$f_r \cong \frac{1}{2\pi\sqrt{LC_T}} = \frac{1}{2\pi\sqrt{(50\ mH)(0.0091\ \mu F)}}$$

$$= \mathbf{7.46\ kHz}$$

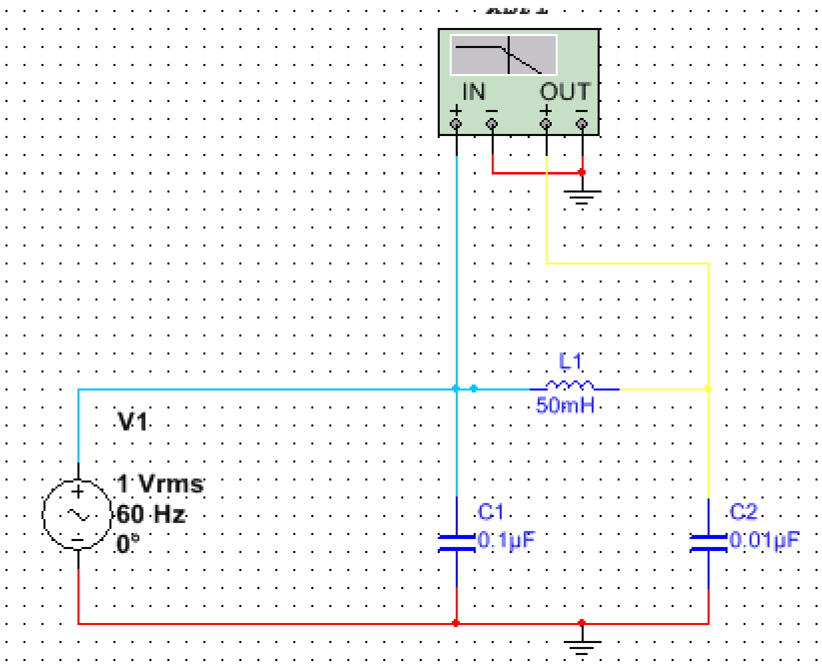
$$f_r = \frac{1}{2\pi\sqrt{LC_T}}\sqrt{\frac{Q^2}{Q^2+1}} = (7.46\ kHz)(0.9923)$$

$$= \mathbf{7.40\ kHz}$$

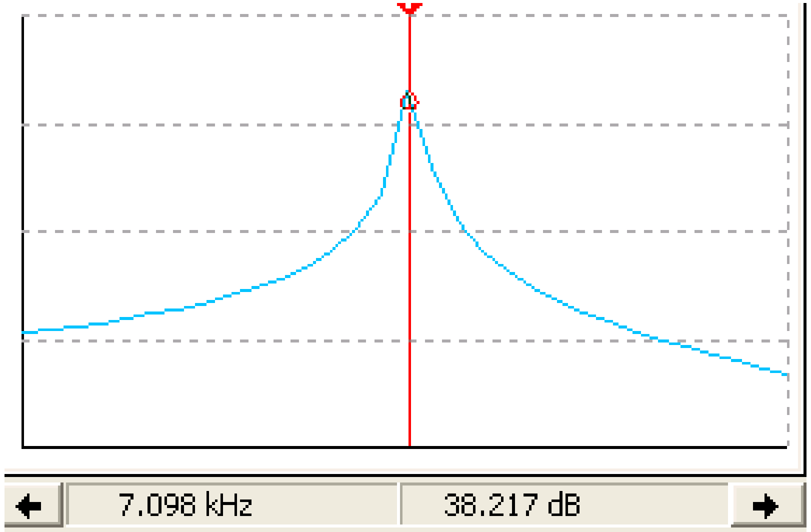


Colpitts Oscillator – 공진 필터

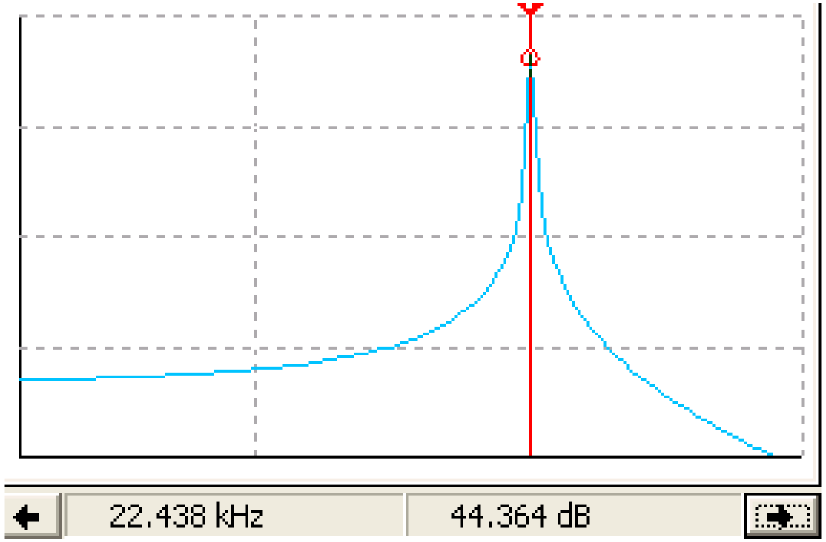
Yun SeopYu



L_1 = 50 mH → f_r = 7.1kHz

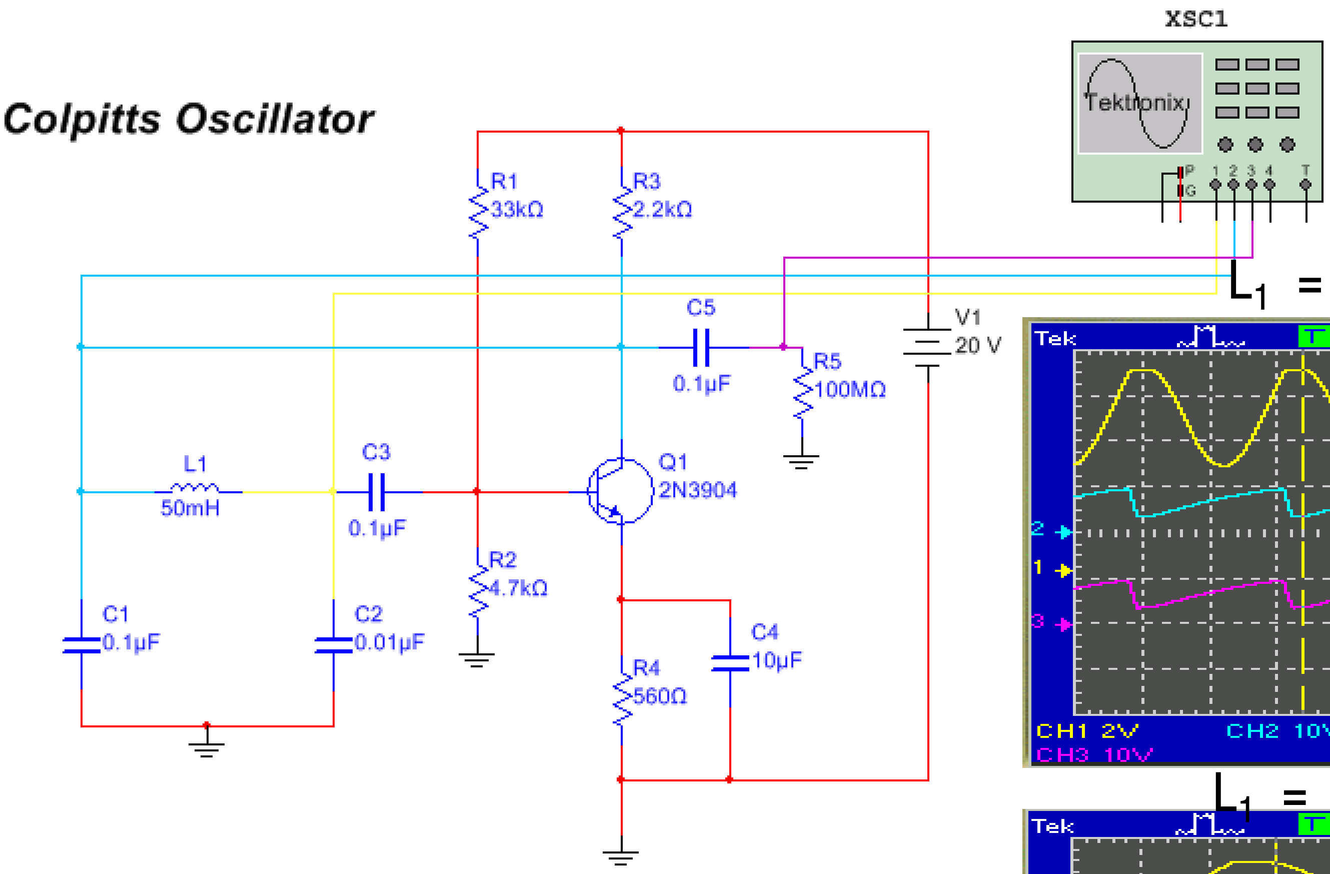


L_2 = 5 mH → f_r = 22.4kHz

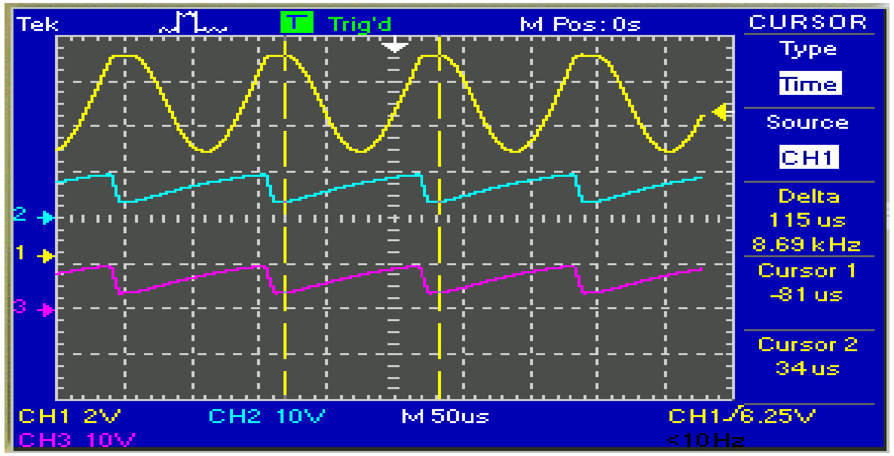


Colpitts Oscillator- 예제 16-3

Yun SeopYu



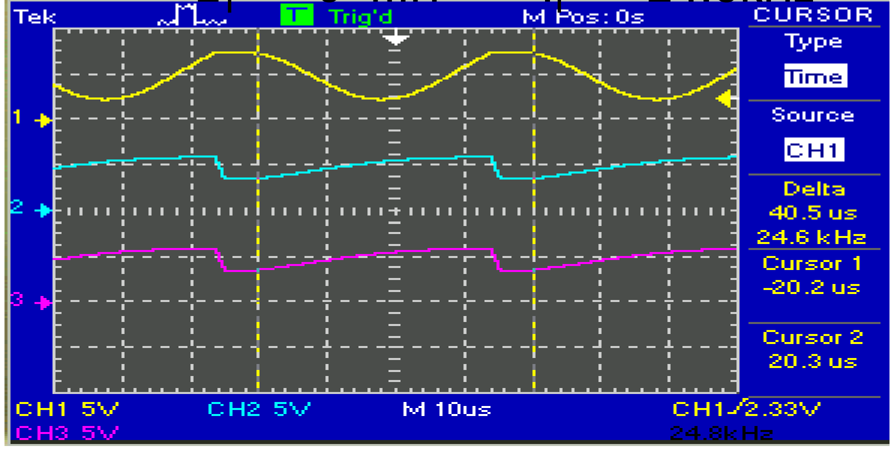
L_1 = 50 mH → f_r = 8.69kHz



CURSOR
Type
Time
Source
CH1
Delta
115 us
8.69 kHz
Cursor 1
-81 us
Cursor 2
34 us

CH1 2V CH2 10V M 50us CH1 ╱ 6.25V
CH3 10V <10Hz

L_1 = 5 mH → f_r = 24.8kHz

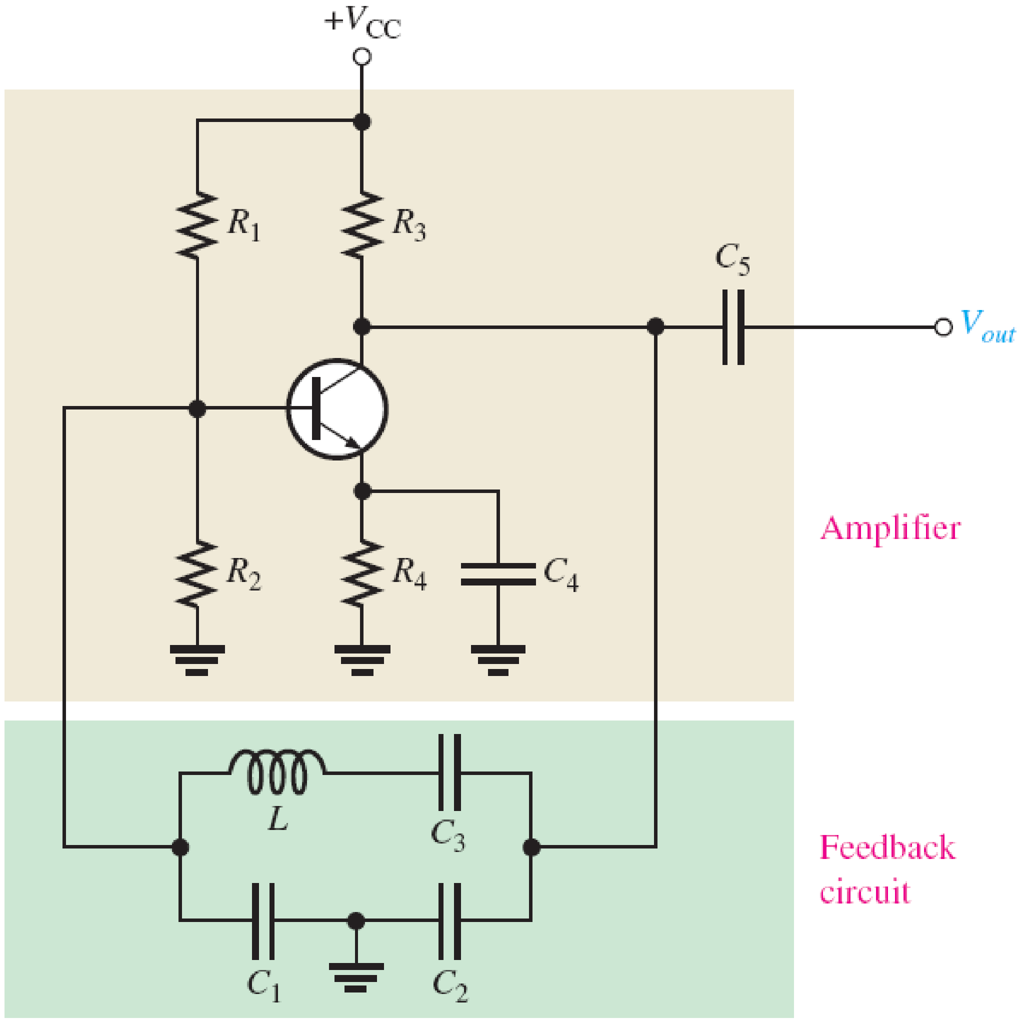


CURSOR
Type
Time
Source
CH1
Delta
40.5 us
24.6 kHz
Cursor 1
-20.2 us
Cursor 2
20.3 us

CH1 5V CH2 5V M 10us CH1 ╱ 2.33V
CH3 5V 24.8kHz

Clapp Oscillator

- 클랩 발진기(Clapp Oscillator): 콜핀츠 발진기의 변형



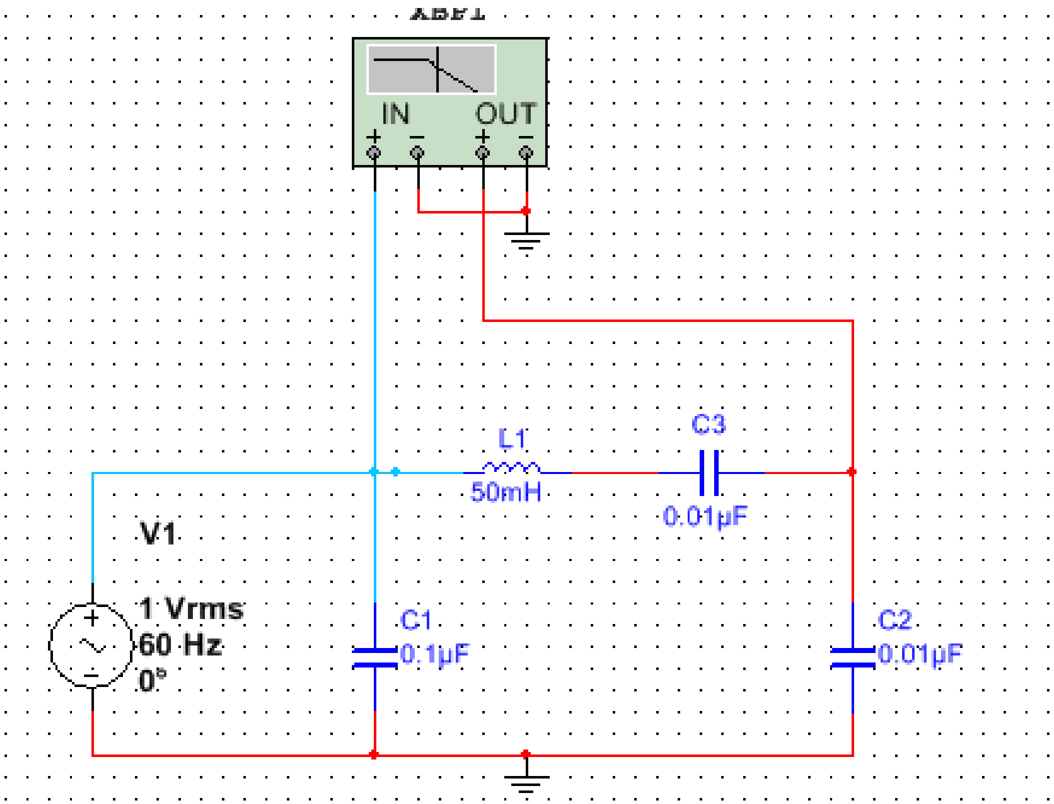
$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

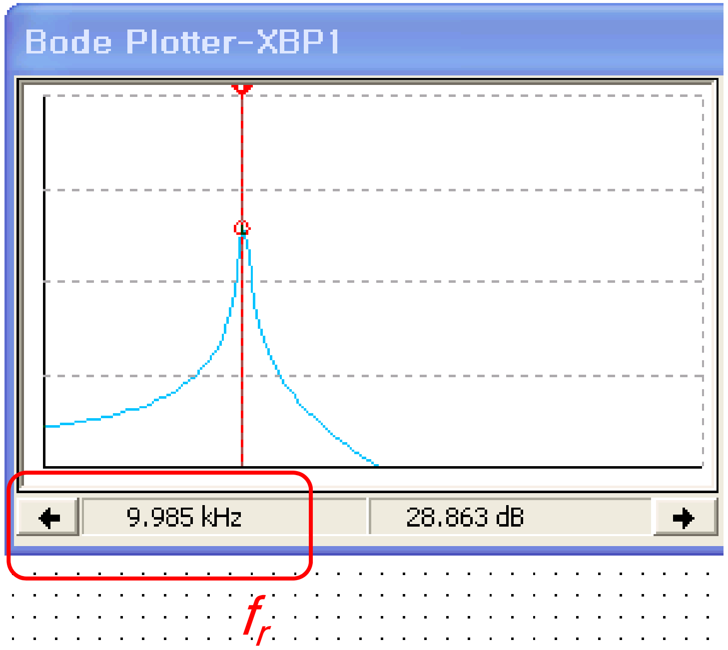
← C_1, C_2, C_3는 직렬

- C_1과 C_2는 접지와 연결
- C_1 은 BJT C_{be} 와 병렬
- C_2 는 BJT C_{ce} 와 병렬
- C_1 과 C_2 는 BJT와 기생 캐패시터 영향 받음
- C_3은 영향없어서 C_3로 정확하고 안정된 발진 주파수 발생

국립 한경대학교 HANKYONG NATIONAL UNIV.

Clapp Oscillator – 공진 필터



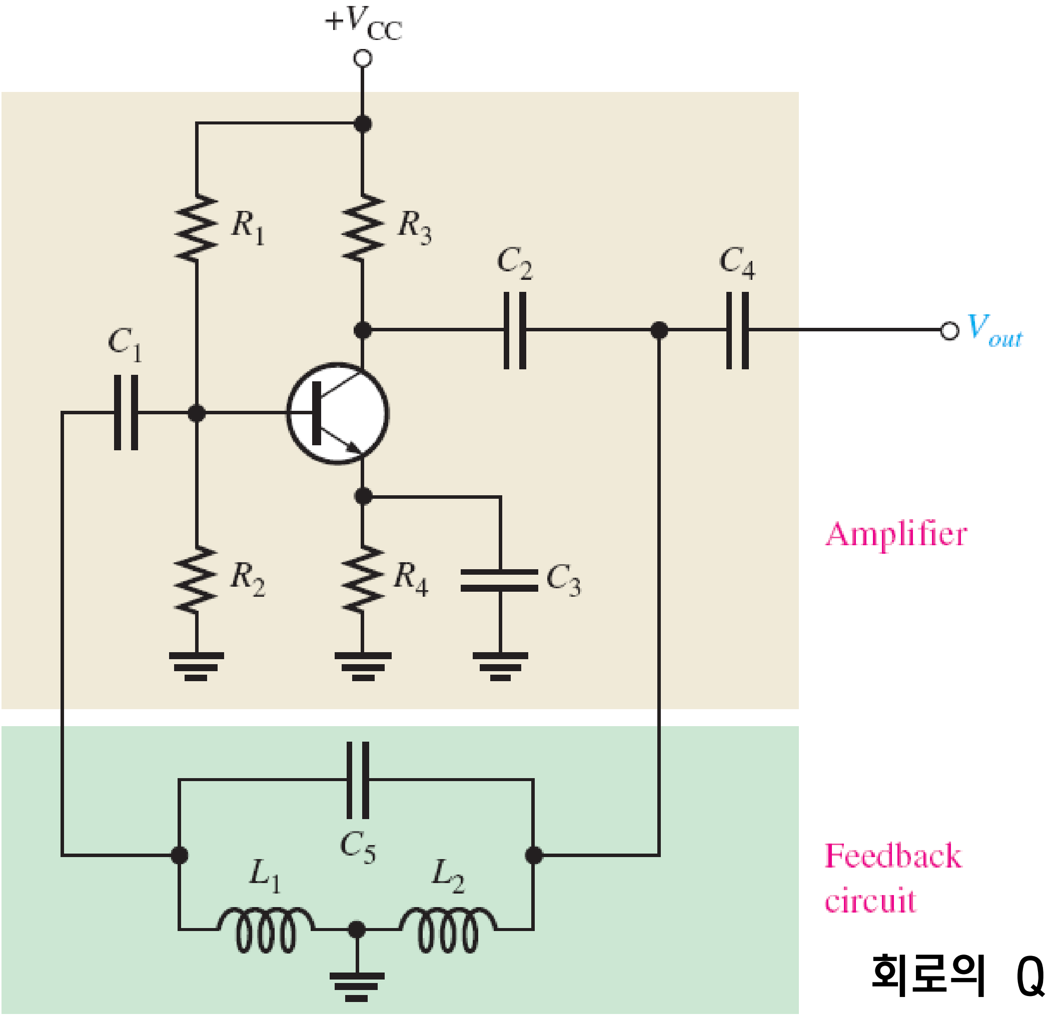


$$C_T = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}} = \frac{1}{\frac{1}{0.1u}+\frac{1}{0.01u}+\frac{1}{0.01u}} = 0.0048u\text{F}$$

$$f_r = \frac{1}{2\pi\sqrt{LC_T}} = \frac{1}{2\pi\sqrt{(50m)(0.0048u)}} = 10.3k\text{Hz}$$

Hartley Oscillator

하트리 발진기(Hartley Oscillator)



$$f_r \cong \frac{1}{2\pi\sqrt{L_T C}}$$

$$L_T = L_1 + L_2.$$

$$B \cong \frac{L_1}{L_2}$$

a condition for oscillation is $A_v B = 1$.

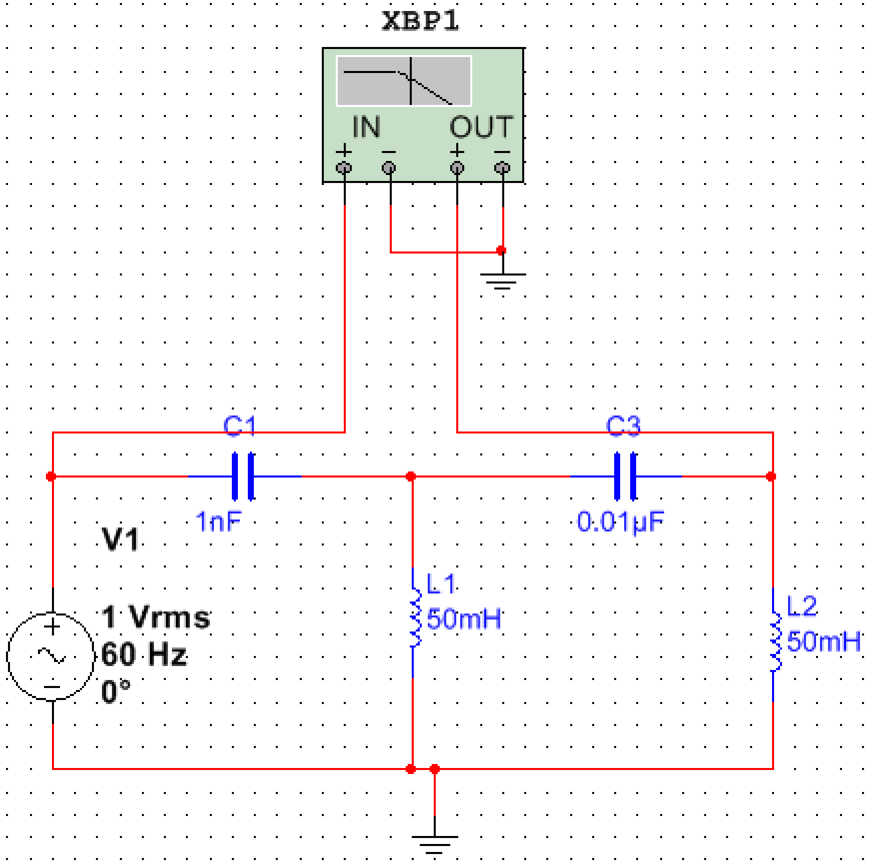
$$A_v \cong \frac{L_2}{L_1}$$

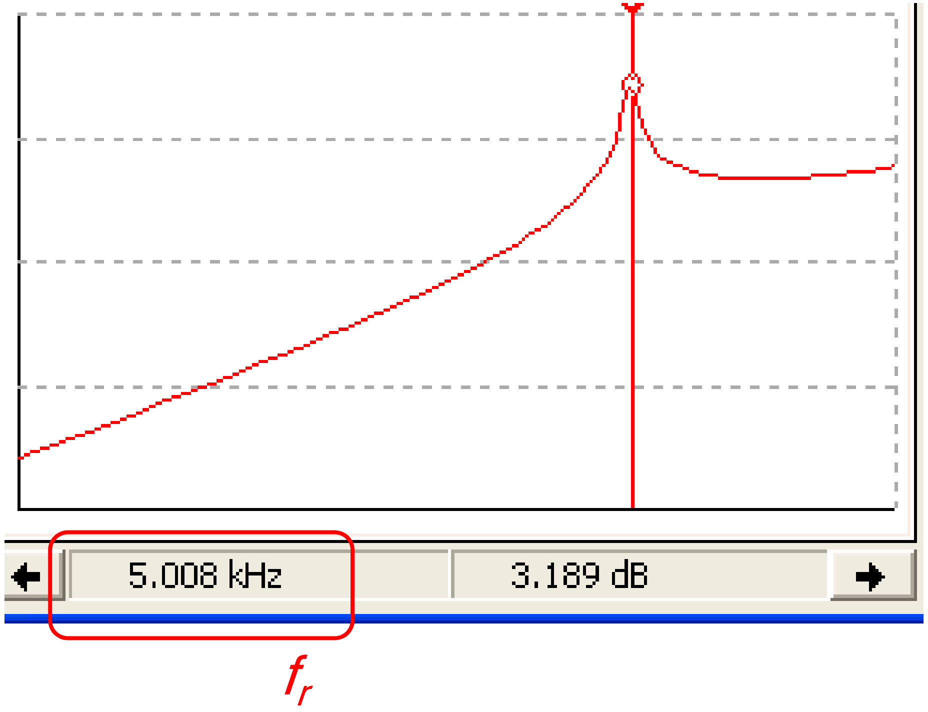
- 초기 시동조건: $A_v B > 1$

→ $A_v > L_2/L_1$

회로의 Q를 감소 → 발진주파수 감소 (Q값에 의존)

Hartley Oscillator– 공진 필터



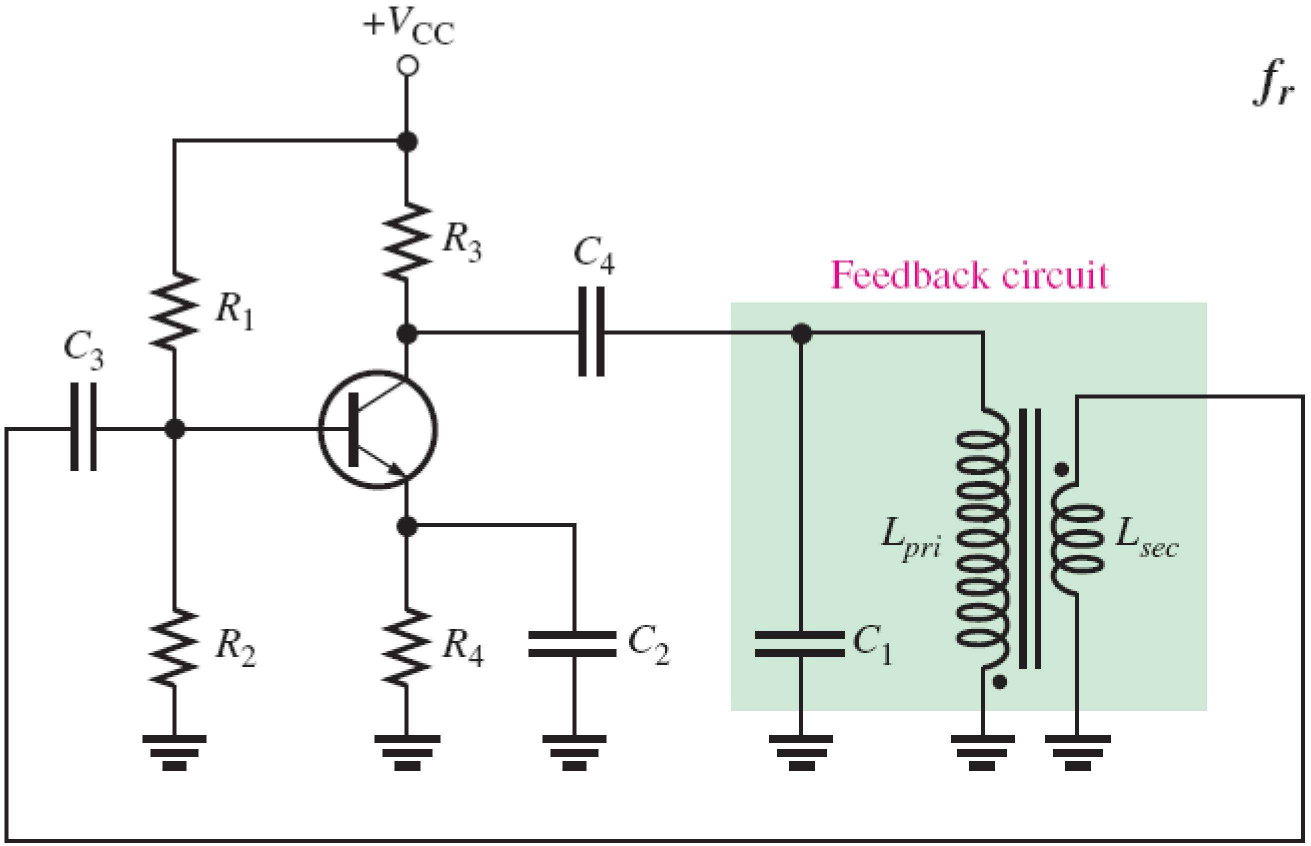


$$L_T = L_1 + L_2 = 50m + 50m = 100m\text{H}$$

$$f_r = \frac{1}{2\pi\sqrt{L_T C}} = \frac{1}{2\pi\sqrt{(100m)(0.01u)}} = 5k\text{Hz}$$

Armstrong Oscillator

- 암스트롱 발진기(Armstrong Oscillator): 귀환회로에 변압기 결합



$$f_r = \frac{1}{2\pi\sqrt{L_{pri}C_1}}$$

2차 코일: 재생 코일(tickler coil)