UNIT VI · LESSON 02

Amplifiers, Feedback & Oscillators

multistage & frequency response · differential amplifier · feedback topologies · oscillators · power amplifiers · tuned amplifiers

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questions in Unit VI
Devices · Amplifiers · Op-amps · Logic

GAINS AMPLIFIER BASICS

- $A_v = V_o/V_i$, A_i, $A_p = A_vA_i$; in dB: **20 log A_v**, 10 log A_p
- **Cascade**: $A = A_1 \times A_2 \times \ldots$ (dB add)
- Bandwidth = $f_H - f_L$ (−3 dB points, half-power)
- **Gain–bandwidth product** constant for a given device
- n identical stages: $\mathbf{f_H^* = f_H\sqrt{(2^{1/n} - 1)}}$, $f_L^* = f_L/\sqrt{(2^{1/n} - 1)}$ → bandwidth **shrinks**
- 2 stages: factor 0.643; 3 stages: 0.51
- Coupling: **RC** (audio, cheap; blocks dc), **transformer** (impedance matching, bulky), **direct** (dc amplifiers, drift)
- **Darlington pair**: $\beta \approx \beta_1\beta_2$, very high input impedance, $V_{BE} \approx 1.4$ V
- **Cascode** (CE + CB): high bandwidth (reduces Miller effect)

NEGATIVE FEEDBACK FEEDBACK

- $\mathbf{A_f = A/(1 + A\beta)}$; loop gain Aβ; **desensitivity** $D = 1 + A\beta$
- If $A\beta \gg 1 \rightarrow A_f \approx 1/\beta$ (set by passive components)
- Effects of negative feedback: gain ↓ (by D), **bandwidth** ↑ ($f_H' = f_H \cdot D$), distortion ↓, noise ↓, gain stability ↑
- $dA_f/A_f = (1/D)(dA/A)$

CAPACITORS FREQUENCY RESPONSE

- Low-frequency cut-off due to **coupling & bypass** capacitors ($f_L = 1/2\pi RC$)
- High-frequency cut-off due to **junction / stray** capacitances
- **Miller effect**: $C_{in} = C_f(1 - A_v) \rightarrow$ large input capacitance in inverting high-gain stages
- Rise time $\mathbf{t_r = 0.35/f_H}$; tilt (sag) in square-wave response due to f_L
- Bode plot: −20 dB/decade per pole, +20 dB/decade per zero

DIFF-AMP DIFFERENTIAL AMPLIFIER

- Output $V_o = A_dV_d + A_cV_c$; $V_d = V_1 - V_2$, $V_c = (V_1 + V_2)/2$
- **CMRR = $|A_d/A_c|$**, in dB 20 log CMRR (ideal ∞)
- Improve CMRR with a large R_E or **constant current source** (current mirror)
- Dual-input balanced output $A_d = g_mR_C$ ($= \beta R_C/r_\pi$)
- Input stage of every op-amp

NEGATIVE FEEDBACK FEEDBACK (CONTD.)

- Example: A = 1000, β = 0.01 → A_f = 1000/11 = **90.9**; 10 % change in A → 0.91 % in A_f

4 TYPES FEEDBACK TOPOLOGIES

Topology (sampling–mixing)	Amplifier type	R_{in}	R_{out}
Voltage-series (series–shunt)	voltage amplifier	× D (↑)	÷ D (↓)
Voltage-shunt (shunt–shunt)	transresistance	÷ D (↓)	÷ D (↓)
Current-series (series–series)	transconductance	× D (↑)	× D (↑)
Current-shunt (shunt–series)	current amplifier	÷ D (↓)	× D (↑)

- Series mixing ↑ input resistance; shunt mixing ↓ it
- Voltage sampling ↓ output resistance; current sampling ↑ it
- Emitter follower = voltage-series feedback (β = 1)

BARKHAUSEN OSCILLATORS

- Positive feedback with **Aβ = 1**: |Aβ| = 1 and total phase shift **0° or 360°**
- In practice |Aβ| slightly > 1 to start; amplitude limited by non-linearity

Oscillator	Frequency	Note
RC phase-shift (3 RC sections)	$f = 1/(2\pi RC\sqrt{6})$	amplifier gain ≥ **29**
Wien bridge	$f = 1/(2\pi RC)$	gain ≥ **3**, low distortion, audio
Hartley	$f = 1/(2\pi\sqrt{((L_1 + L_2 + 2M)C)})$	tapped inductor
Colpitts	$f = 1/(2\pi\sqrt{(L C_{eq})})$, $C_{eq} = C_1C_2/(C_1 + C_2)$	tapped capacitor

BARKHAUSEN OSCILLATORS (CONTD.)

Oscillator	Frequency	Note
Clapp	series C added to Colpitts	better stability
Crystal	series $f_s = 1/(2\pi\sqrt{(LC)})$, parallel $f_p > f_s$	**very stable** (Q 10^4–10^6)
Tuned collector / Armstrong	LC tank	RF

- RC oscillators: audio frequencies; LC: RF; crystal: precise frequency (clocks)
- Crystal works on the **piezoelectric effect** (quartz)
- Example Wien: R = 10 kΩ, C = 10 nF → f = **1.59 kHz**

WAVEFORMS MULTIVIBRATORS

- **Astable** (free-running, square wave): no stable state; $T = 0.69(R_1C_1 + R_2C_2)$
- **Monostable** (one-shot): one stable state; pulse width $T = 0.69RC$
- **Bistable** (flip-flop): two stable states; triggered
- **Schmitt trigger**: bistable with **hysteresis** (UTP, LTP), squares up noisy signals

RF TUNED AMPLIFIERS

- Load is a parallel **LC tank**: $f_r = 1/(2\pi\sqrt{(LC)})$; **$Q = f_r/BW$**
- Single tuned, **double tuned** (flatter response, wider BW), **stagger tuned** (cascade with offset frequencies)
- Instability from C_{bc} feedback → **neutralisation** (Hazeltine, Rice)
- Used in IF amplifiers of radio receivers

CLASSES POWER AMPLIFIERS

Class	Conduction angle	Max efficiency	Feature
A	**360°**	25 % (series-fed), **50 %** (transformer)	lowest distortion
B (push-pull)	**180°**	**78.5 %** (π/4)	crossover distortion
AB	180°–360°	50–78.5 %	removes crossover distortion
C	< 180°	**> 90 %**	tuned RF amplifiers only
D	switching (PWM)	≈ 90–98 %	audio, motor drives

- Class B max transistor dissipation = **$0.2 \times P_{o(max)}$** each (at $V_p = 2V_{CC}/\pi$)
- **Complementary-symmetry** push-pull (npn + pnp) needs no centre-tapped transformer
- Push-pull cancels **even harmonics**
- Heat sinks: $\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$; $T_J = T_A + P_D\theta_{JA}$
- Harmonic distortion $D = \sqrt{(D_2^2 + D_3^2 + \ldots)}$

Q → A RAPID RECALL

Bandwidth effect of cascading stages	decreases
Miller input capacitance	$C_f(1 - A_v)$
CMRR formula	A_d/A_c

Q → A RAPID RECALL (CONTD.)

Gain with A = 100, β = 0.1	9.09
Negative feedback effect on bandwidth	increases
Topology raising R_{in}, lowering R_{out}	voltage-series

Q → A RAPID RECALL (CONTD.)

Barkhausen phase condition	0° or 360°
Gain needed for RC phase-shift oscillator	29
Oscillator with tapped capacitor	Colpitts
Most stable oscillator	crystal
Max efficiency of class B	78.5 %
Class with crossover distortion	B
Class used for RF tuned amplifiers	C

TRAP EXAM TRAPS

- Negative feedback **reduces** gain but improves almost everything else
- Wien bridge needs gain 3, phase-shift needs 29 — do not swap
- Class A transformer-coupled max efficiency is 50 %, not 25 %
- Rise time $0.35/f_H$: bandwidth in Hz, not rad/s
- Series crystal frequency is lower than parallel (anti-resonant) frequency