Analog Electronic Circuits

Short notes for B.Tech ECE · EEE · GATE EC

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1. Diode Circuits

- Diode models: **ideal** (short when ON), **constant drop** (0.7 V for Si, 0.3 V for Ge), **piecewise linear** (0.7 V + rf).
- Thermal voltage VT = kT/q ≈ 26 mV at 300 K.

➤ Rectifiers

Parameter	Half-wave	Full-wave (centre tap)	Bridge
Diodes	1	2	4
Vdc (average)	Vm / π	2Vm / π	2Vm / π
Irms	Im / 2	Im / sqrt(2)	Im / sqrt(2)
Ripple factor	1.21	0.482	0.482
Max efficiency	40.6%	81.2%	81.2%
PIV per diode	Vm	2Vm	Vm
Ripple frequency	f	2f	2f

FORMULA Ripple factor γ = sqrt((Irms / Idc)^2 − 1). With a capacitor filter (full-wave): γ = 1 / (4 sqrt(3) f R C).

➤ Clippers and clampers

- **Clipper**: cuts off part of the waveform above or below a level (series or shunt diode + battery).
- **Clamper**: shifts the whole waveform up or down by a DC level, shape unchanged (diode + capacitor). Needs RC >> T.
- **Voltage multiplier**: doubler gives 2Vm (uses two diodes and two capacitors).
- **Zener regulator**: Zener in reverse bias holds Vout = VZ as long as IZ stays between IZmin and IZmax.

2. BJT Biasing

- Aim: fix a stable **Q-point** (ICQ, VCEQ) in the active region, away from cut-off and saturation.
- $I_C = \beta I_B$, $I_E = I_B + I_C = (\beta + 1) I_B$, $\alpha = \beta / (\beta + 1)$.

➤ Biasing methods

Method	Stability	Note
Fixed bias	Poor, $S = \beta + 1$	Q-point depends strongly on β
Collector-to-base bias	Better	Negative feedback through RB
Voltage divider (self) bias	Best, S close to 1	Most used; RE gives feedback

FORMULA Stability factor $S = \partial I_C / \partial I_{CO}$. For voltage divider bias: $S = (1 + \beta) / (1 + \beta R_E / (R_E + R_{Th}))$.

➤ Solved example (voltage divider bias)

- $V_{CC} = 12$ V, $R_1 = 40$ kΩ, $R_2 = 10$ kΩ, $R_C = 2$ kΩ, $R_E = 1$ kΩ, $\beta = 100$, $V_{BE} = 0.7$ V.
  - $V_{Th} = 12 \times 10 / 50 = 2.4$ V, $R_{Th} = 40 \parallel 10 = 8$ kΩ
  - $I_B = (V_{Th} - V_{BE}) / (R_{Th} + (\beta + 1) R_E) = 1.7 / (8k + 101k) =$ 15.6 µA
  - $I_C = \beta I_B = 1.56$ mA, $I_E = 101 \times 15.6$ µA $= 1.575$ mA
  - $V_{CE} = 12 - (1.56\text{ m} \times 2k) - (1.575\text{ m} \times 1k) = 12 - 3.12 - 1.575 =$ 7.3 V
  - $V_{CE} > 0.2$ V, so the BJT is in the active region.

TIP Thermal runaway: IC rises → heat rises → ICO rises → IC rises again. RE and heat sinks prevent it.

3. Small-Signal Models and BJT Amplifiers

- **re model**: $r_e = V_T / I_E = 26$ mV $/ I_E$. Input resistance of CE ≈ $\beta r_e = r_\pi$.
- **Hybrid-π model**: $g_m = I_C / V_T$, $r_\pi = \beta / g_m$, $r_o = V_A / I_C$ (V_A = Early voltage).

Comparison of BJT configurations

Parameter	CE	CB	CC (emitter follower)
Voltage gain	High (−gm RC)	High (non-inverting)	≈ 1
Current gain	High (β)	≈ 1 (α)	High (β + 1)
Input resistance	Medium	Low	High
Output resistance	Medium–high	High	Low
Phase shift	180°	0°	0°
Use	Voltage amplifier	High-frequency, current buffer	Buffer, impedance matching

FORMULA CE voltage gain (no RE) Av = −gm (RC || RL) = −(β RC) / rπ. With unbypassed RE: Av ≈ −RC / (re + RE).

FET amplifiers

- gm = 2 IDSS / |VP| x (1 − VGS / VP) for JFET. For MOSFET in saturation: gm = 2 ID / (VGS − VT).
- CS amplifier: Av = −gm (RD || ro). CD (source follower): Av ≈ gm RS / (1 + gm RS) < 1.

4. Frequency Response and Multistage Amplifiers

- Low-frequency cutoff fL: set by coupling and bypass capacitors. High-frequency cutoff fH: set by transistor internal and stray capacitances.
- Bandwidth = fH − fL. **Gain–bandwidth product** is roughly constant.
- **Miller effect**: a capacitor C between input and output of an inverting amplifier (gain −A) looks like Cin = C (1 + A) at the input.

FORMULA For n identical stages, fH(n) = fH x sqrt(2^(1/n) − 1), fL(n) = fL / sqrt(2^(1/n) − 1).

- **Cascode** (CE + CB): high bandwidth because the Miller effect is reduced. **Darlington**: β total ≈ β1 β2, very high input resistance.

- **Differential amplifier**: amplifies V1 − V2. CMRR = Ad / Ac (ideally infinite).

5. Feedback Amplifiers

- Negative feedback: Af = A / (1 + Aβ). Loop gain = Aβ. Desensitivity factor D = 1 + Aβ.

FORMULA Af = A / (1 + Aβ). Bandwidth with feedback = BW (1 + Aβ). Distortion and noise reduce by (1 + Aβ).

➤ Four topologies

Topology (sampling–mixing)	Amplifier type	Rin	Rout
Voltage–series (series–shunt)	Voltage amplifier	Increases x D	Decreases / D
Current–series (series–series)	Transconductance	Increases x D	Increases x D
Voltage–shunt (shunt–shunt)	Transresistance	Decreases / D	Decreases / D
Current–shunt (shunt–series)	Current amplifier	Decreases / D	Increases x D

REMEMBER Series mixing raises Rin, shunt mixing lowers Rin. Voltage sampling lowers Rout, current sampling raises Rout.

EXAMPLE A = 1000, β = 0.01. Aβ = 10, Af = 1000 / 11 = 90.9. If A drops 10%, Af changes only about 10% / 11 ≈ 0.9%.

6. Oscillators

- **Barkhausen criterion**: loop gain |Aβ| = 1 and total phase shift around the loop = 0° or 360°.
- In practice |Aβ| is kept a little above 1 to start oscillation.

Oscillator	Frequency	Condition
RC phase shift (3 RC sections)	f = 1 / (2π RC sqrt(6))	Amplifier gain >= 29
Wien bridge	f = 1 / (2π RC)	Gain >= 3
Hartley (LC)	f = 1 / (2π sqrt((L1 + L2 + 2M) C))	Tapped inductor
Colpitts (LC)	f = 1 / (2π sqrt(L Ceq)), Ceq = C1 C2 / (C1 + C2)	Tapped capacitor
Crystal	Series fs and parallel fp, very close	Very high Q, most stable

TIP RC oscillators suit audio frequencies. LC and crystal oscillators suit RF frequencies.

7. Power Amplifiers

Class	Conduction angle	Max efficiency	Distortion
A (resistive load)	360°	25%	Lowest
A (transformer coupled)	360°	50%	Low
B (push-pull)	180°	78.5% (π/4)	Crossover distortion
AB	180° to 360°	Between A and B	Removes crossover distortion
C	< 180°	> 78.5% (up to ~90%+)	High, used with tuned load (RF)

- In class B, maximum power dissipated per transistor = 0.2 x Pout(max) approximately (occurs at Vm = 2VCC / π).
- Push-pull cancels even harmonics.

8. Operational Amplifier

➤ Ideal op-amp

- Infinite open-loop gain, infinite Rin, zero Rout, infinite bandwidth, infinite CMRR, zero offset.

- With negative feedback: **virtual short** (V+ = V−) and no current into the inputs.

Circuit	Output
Inverting amplifier	Vo = −(Rf / R1) Vin
Non-inverting amplifier	Vo = (1 + Rf / R1) Vin
Voltage follower	Vo = Vin (gain 1)
Summing (inverting)	Vo = −Rf (V1/R1 + V2/R2 + V3/R3)
Difference amplifier (equal ratio)	Vo = (Rf / R1)(V2 − V1)
Integrator	Vo = −(1 / RC) integral of Vin dt
Differentiator	Vo = −RC dVin/dt

FORMULA Slew rate SR = max dVo/dt. For a sine output Vm sin ωt: needed SR = 2π f Vm. fmax = SR / (2π Vm).

➤ Solved example (op-amp)

- Non-inverting amplifier: Rf = 90 kΩ, R1 = 10 kΩ, Vin = 0.5 V, SR = 0.5 V/µs.
  - Gain = 1 + 90/10 = 10, Vo = 10 x 0.5 = 5 V
  - For a 10 V peak output: fmax = 0.5 x 10^6 / (2π x 10) = 7.96 kHz
  - Above this frequency the output becomes triangular (slew-rate limited).

➤ Non-ideal parameters

- **Input offset voltage**, **input bias current**, **offset current**, **CMRR**, **PSRR**, **slew rate**, **GBW** (unity-gain bandwidth).
- Closed-loop bandwidth ≈ GBW / closed-loop gain (non-inverting).

➤ Other op-amp circuits

- **Comparator**: no feedback, output saturates at +Vsat or −Vsat.
- **Schmitt trigger**: positive feedback, two thresholds (hysteresis), removes noise. For the inverting type, thresholds = ± β Vsat, where β = fraction of output fed back to V+.
- **Precision rectifier**, **log / antilog amplifier**, **instrumentation amplifier** (high CMRR, gain set by one resistor).
- Active filters: Butterworth low pass, Sallen-Key. First-order cutoff fc = 1 / (2πRC).

9. 555 Timer (basics)

- Astable: $f = 1.44 / ((R_A + 2R_B)\,C)$, duty cycle $= (R_A + R_B) / (R_A + 2R_B)$.
- Monostable: pulse width $T = 1.1\,R\,C$.

10. Most Asked Questions (practice)

1. Derive Vdc, ripple factor and efficiency of half-wave and full-wave rectifiers.
2. Find the Q-point of a voltage divider bias circuit and its stability factor.
3. Draw the small-signal model of a CE amplifier and find Av, Ri and Ro.
4. Explain the Miller effect and its effect on high-frequency response.
5. Classify the four feedback topologies and their effect on Rin and Rout.
6. Derive the frequency and gain condition of an RC phase shift oscillator.
7. Show that the maximum efficiency of a class B amplifier is 78.5%.
8. Derive the output of inverting, non-inverting, integrator and differentiator circuits.
9. Define slew rate and CMRR; solve a slew-rate numerical.
10. Explain a Schmitt trigger and find its threshold voltages.

TIP GATE EC asks BJT/MOSFET biasing, small-signal gain, op-amp circuits and oscillator conditions almost every year. Practise numericals with the virtual short idea.