EIE2102 Cluesheet

L1

history

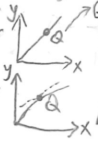
1904 Flemming: diode vacuum tube
1925 Lilienfeld = field-effect device
1947 3 people at Bell Lab = BJT
1958 IC 1961 commercial digital IC
1968 Op-amp ($\mu A709$) → Fairchild Semi.
1970 IBM = 1-transistor dy. memory cell
1971 Intel: 4004 microprocessor
1984 Mb memory
2009 Kao: Charge-Coupled Device (CCD) in optical communication

Foreign Spectrum of signals (characterize periodic signals)
Representing a $v_s(t)$ or $i_s(t)$ as $\sum A\sin(\omega t+\phi)$

sq. wave $V(t)=\frac{4V}{\pi}(\sin\omega_0 t+\frac{1}{3}\sin 3\omega_0 t+\dots)$

L2

Signal Processing ! Problem: some signals too small for reliable processing ⇒ Signal Amp ; ! Problem = non-linear = $V_o(t)=A_1V_i(t)+A_2V_i^2(t)$, lead to unwanted distortion 失真



Signal Amp
- linear: → Quiescent Point = no AC signal; $A=\frac{y}{x}$ (large or small are ok)
- non-~: $A=\left.\frac{dy}{dx}\right|_{Q\text{-point}}$ (only small)

- Voltage gain $A_V=\frac{V_o}{V_i}$ in dB $=20\log_{10}\left|\frac{V_o}{V_i}\right|$
- Current gain $A_i=\frac{i_o}{i_i}$ $=20\log_{10}\left|\frac{i_o}{i_i}\right|$
- Power gain $A_P=\frac{V_o i_o}{V_i i_i}=A_VA_i$ $=10\log_{10}|A_P|$

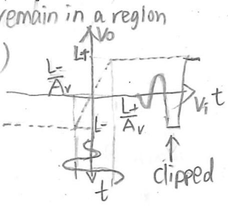
Energy: $P_{dc}+P_I=P_L+P_{dis}$
- $P_{dc}=V_{CC}I_{CC}+V_{EE}I_{EE}$: DC deliver energy for amplification
- P_I: from signal
- P_L: to load
- P_{dis}: consumed by amplifier

$\eta=\frac{P_L}{P_{dc}}$

Amplifier saturation

Output voltage should remain in a region (eg. powered by DC supply)

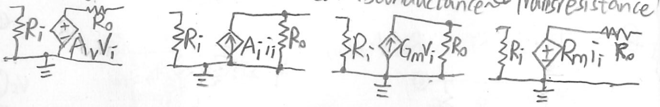
⇒ $\frac{L-}{A_V}\le V_I\le\frac{L+}{A_V}$



Amplifier Symbol convention
- I_C: DC component
- i_c: AC component
- i_C: total instan. value
- I_c: peak amplitude/phasor

Amp type

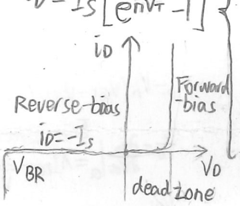
① Voltage ~ ② Current ③ Transconductance ④ Transresistance



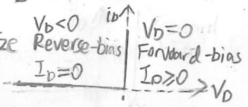
L3 Diode

P N: anode → V, cathode ← X; $+V_D-$, → i_D

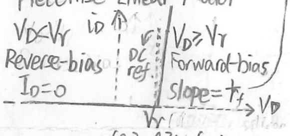
$i_D=I_S\left[e^{\frac{V_D}{nV_T}}-1\right]$
- $V_T=\frac{kT}{q}$ (Thermal voltage); k = Boltzman const, q = charge; $V_T(300K)=0.026V$
- n (Ideality factor, $1\le n\le 2$)
- I_S (Sat. Current) silicon: $10^{-15}\sim10^{-13}A$ (Rev. I_{Drift})



⇒ Idealize: Ideal Diode Model



Piecewise-Linear Model



V_γ: (0.2~0.3V Ge, 0.6~0.7V Si)

$\frac{1}{r_f}=\left.\frac{\partial\left(I_S(e^{\frac{V_D}{nV_T}}-1)\right)}{\partial V_D}\right|_Q=\frac{I_Se^{\frac{V_D}{nV_T}}}{nV_T}\overset{n=1}{\approx}\frac{I_{DQ}}{V_T}$

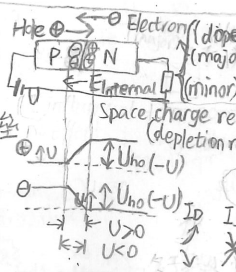
Analysis:
① DC: $V_D=V_\gamma$ ON or $0\le V_D<V_\gamma$ OFF (Assumption, trial-and-error)
② AC: diode → open (OFF) or r_f (ON)

L4 Semiconductors

Semiconductors: Single-element, Compound ⇐ P-N Junction

T=300K thermal generation → covalent bond broke → free electrons & holes → til $V_{generation}=V_{recombine}$ → p(n) → const (p may ≠ n, however too small for intrinsic)

Sol: Dope impure atoms (B for N-type, P for P-type, small amount) (more hole) (more electron)

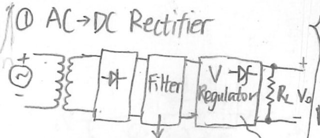


- (doped diffusion, I_D) (major) 多子扩散
- (minor) thermal: drift (I_S) 少子漂移
- Space charge region (depletion region)
- susceptible to T
- $\sigma_{drift}=q(p\mu_p+n\mu_n)$; q: charge, p(n): density, μ: mobility

V_{BR} (Reverse bias)
① Avalanche Breakdown 雪崩击穿 T↑ V_{BR}↑ $E_K=q\frac{U}{d}$
Low doping density, enough $-U$ and PNJ length → ≈ Tevatron → high speed e. easier to activate valence e. & C. Bond → original e. & activated e. H. pair → activate more e. H. pair
② Zenor Breakdown 齐纳击穿 T↑ V_{BR}↓
High doping density → same U_{int}, lower L_{PNJ}, higher E_{int} → valence e. activated (no need too high $-U_{ext}$)
①② may → ③ Thermal Breakdown (irreversible, 热击穿, 二次击穿)

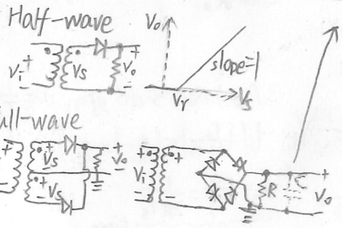
L5 Diode Application

① AC→DC Rectifier

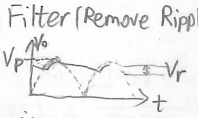


Lowpass, reduce ripple; Keep V_{out} for different R_L

Half-wave / Full-wave



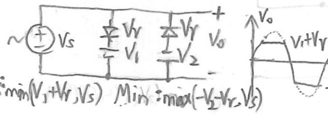
Filter (Remove Ripple)



$V_r\lessapprox V_P-V_Pe^{-\frac{t}{\tau}}$
$\approx V_P(1-(1-\frac{t}{\tau}e^0+o(t)))$
$\approx V_P\frac{t}{\tau}=\frac{V_Pt}{RC}=\begin{cases}\frac{V_P}{2fRC} & \text{(Full-w)}\\ \frac{V_P}{fRC} & \text{(H.w.)}\end{cases}$

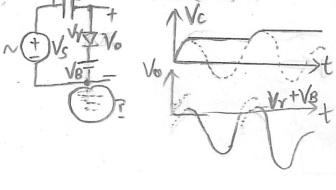
② Zener Diode Circuit

③ Clipper circuit

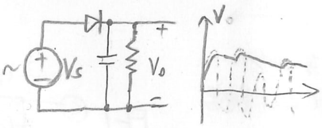


Max = min(V_1+V_γ, V_s) Min = max($-V_2-V_\gamma$, V_s)

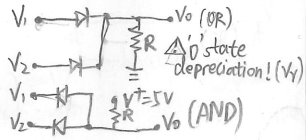
④ Clamber Circuit (shift)



⑤ Detector Circuit



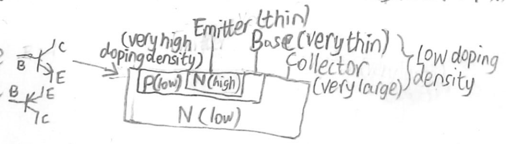
⑥ Logic Gate



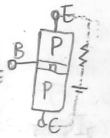
'0' state depreciation! (V_γ)

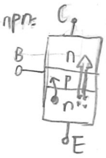
L6 Transistors (3-terminal)
- Bipolar Junction T~ 双极结晶体管
- Metal Oxide Semiconductor Field Effect T~ 金属氧化物半导体场效应晶体管 (MOS管)
  - Insulated Gate MOSFET 绝缘栅型~
    - n-Channel (Enhancement Mode) ~ n沟道(增强型)~
    - P-Channel (~) ~ P沟道 (~)~
  - Junction MOSFET 结型~

BJT { npn type, pnp type }



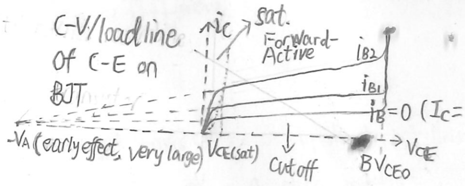
Mode of Operation: BE, BC; npn status; pnp status
- Cutoff: ✗ ✗ $V_B - V_{BE(on)} < V_E$; $V_B + V_{BE(on)} > V_E$
- Active: → ✗ $V_C > V_B - V_{BE(on)} > V_E$; $V_C < V_B + V_{BE(on)} < V_E$
- Sat.: → → $V_B - V_{BE(on)} > V_E$; $V_B + V_{BE(on)} < V_E$





When active: ⓔ in E diffuse to C (high n → low n).
→ til recombine of ⓗⓔ in P form barrier
→ for each ⓔ pick up by base → barrier temp. fail
→ E ⓔ → C diffuse temp. cont. → β ⓔs can diffuse to C

C-V/load line of C-E on BJT

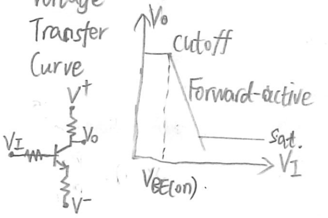


$i_C = I_S e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CE}}{V_A}\right)$ Early effect → r_o

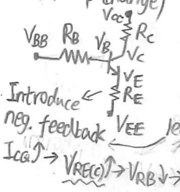
$\frac{1}{r_o} = \frac{\partial i_C}{\partial V_{CE}}\Big|_Q = \frac{I_S e^{\frac{V_{BEQ}}{V_T}}}{V_A} = \frac{I_{CQ}}{V_A}$

in AC: r_o

Voltage Transfer Curve



Bias stability (V_{CEQ}) (upon β change)

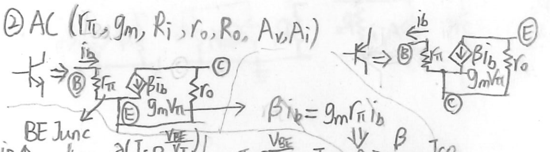


For fixed $V_{CC}, V_{EE}, V_{BB}, R_B, R_C, R_E$, variable β. If $I_{CQ} \approx I_{EQ}$ → stable:
→ V_{CEQ} → stable

Introduce neg. feedback: $I_{CQ}\uparrow \to V_{RE(C)}\uparrow \to V_{RB}\downarrow \to I_{BQ}\downarrow \to V_{RE(C)}\downarrow$

So, from $I_{CQ} = \beta I_{BQ} = \frac{\beta(V_{BB} - V_{EE} - V_{BE(on)})}{R_B + (1+\beta)R_E}$, let $R_B \ll (1+\beta) R_E$:
$\frac{\beta(V_{BB} - V_{EE} - V_{BE(on)})}{(1+\beta)R_E} \approx \frac{V_{BB} - V_{EE} - V_{BE(on)}}{R_E}$

L7 BJT Analysis: ① DC ($I_{BQ(CQ,EQ)}$, V_{CEQ})
② AC (r_π, g_m, R_i, r_o, R_o, A_v, A_i)

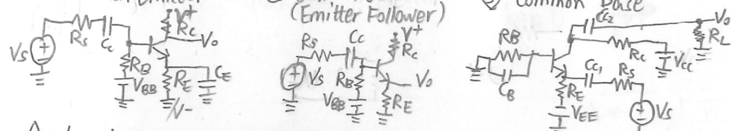


$\beta i_b = g_m r_\pi i_b$ ⇓ $g_m = \frac{\beta}{r_\pi} = \frac{I_{CQ}}{V_T}$

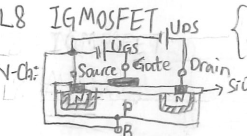
BE Junc

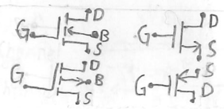
$\frac{1}{r_\pi} = \frac{\partial\left(I_S e^{\frac{V_{BE}}{V_T}}\right)}{\partial V_{BE}}\Big|_Q = \frac{I_S e^{\frac{V_{BE}}{V_T}}}{V_T} = \frac{I_{BQ}}{V_T}$

BJT Amp. Conf.
① Common Emitter — $A_v > 1$, $A_i > 1$, mod R_i, mod to high R_o
② Common Collector (Emitter Follower) — $A_v \approx 1$, $A_i > 1$, high R_i, low R_o
③ Common Base — $A_v > 1$, $A_i \approx 1$, low R_i, mod to high R_o



L8 IGMOSFET { N-Channel, P-Channel }

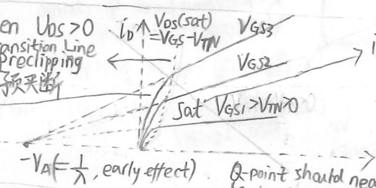




When $U < U_{GS} < U_{TN}$, ⓗ↓ ⓔ↑ in P → PNJ forms below G (in B)
When $U_{GS} > U_{TN}$, n-Channel between S, D forms below G above PNJ (in B)

$U_{GS}\uparrow$ $d_{N\text{-}ch}\uparrow$. I_D forms when $U_{DS} > 0$

non-sat.
$i_D = K_n[2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2]$
$[K_n] = A/V^2$

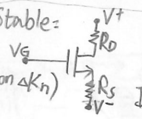


$i_D = K_n(V_{GS} - V_{TN})^2(1 + \lambda V_{DS})$

Early Effect: $\frac{1}{r_o} = \frac{\partial i_D}{\partial V_{DS}}\Big|_Q = \lambda I_{DQ} = \frac{I_{DQ}}{V_A}$

Q-point should near mid-sat. to maximize sym. Vout swing

Bias-Stable: (V_{DSQ} upon ΔK_n)



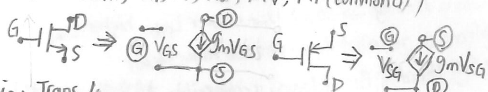
$V_D = V^+ - R_D I_{DQ}$
$V_S = R_S I_{DQ} + V^-$
$I_{DQ} = K_n(V_G - V_{TN} - V^- - R_S I_{DQ})^2$

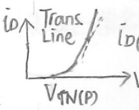
$b = 2K_n(V_G - V_{TN} - V^-)(R_S) - 1$ ⇒ let $b \propto K_n$
$a = K_n R_S^2 \propto K_n$
$c = K_n(V_G - V_{TN} - V^-)^2 \propto K_n$

So let $2K_n(V_G - V_{TN} - V^-)R_S \gg 1$ (n-ch.)
or $2K_n(V^+ - V_G - V_{TP})R_S \gg 1$ (P-ch.)

CMPLX: 3→A, 3→B, 3→C; $(-B-C)/2A \to B$; $\sqrt{B^2 - 4AC} \to C$; $B+C/A \to A$ | 1, 1, -6 → 2, -3, 5; 1, 2, 1 → -1, -1, 0

L9 IGMOSFET Analysis ① DC ($V_{GSQ(SGQ)}$, $V_{DSQ(SDQ)}$, I_{DQ})
② AC (g_m, R_i, r_o, R_o, A_v, A_i (Common G))

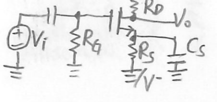


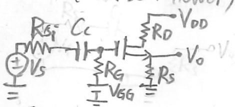


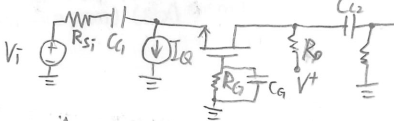
$I_{D(sat)} = K_n(V_{GS(SG)} - V_{TN(TP)})^2$

$g_m = \frac{\partial i_{D(sat)}}{\partial V_{GS}} = 2K_n(\sim) = 2\sqrt{K_n I_{DQ}}$

IGMOSFET Amp. Conf
① Common-Source — $A_v > 1$, $R_i = R_{TH}$, Mod to high R_o
② Common-Drain (Source-Follower) — $A_v \approx 1$, $R_i = R_{TH}$, Low R_o
③ Common-Gate — $A_v > 1$, $A_i \approx 1$, low R_i, mod to high R_o

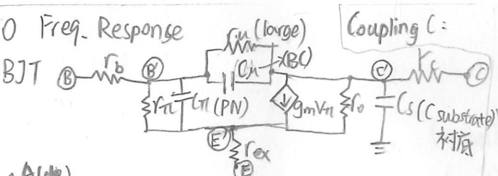


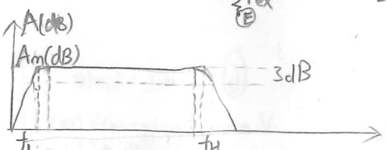




L10 Freq. Response

BJT





coupling C.
bypass C.
stray C. 杂散电容
transistor C. 晶体管电容

Coupling C:

let $s = j\omega$, $\tau_s = (R_{Si} + R_i)C_C$

$i_i = \frac{V_i}{R_{Si} + \frac{1}{sC_C} + R_i}$, $i_b = \left(\frac{R_B}{R_B + R_{ib}}\right) i_i$

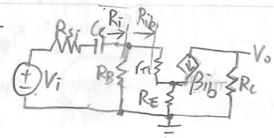
$V_o = -\beta R_C i_b = -\frac{\beta R_B R_C}{(R_B + R_{ib})} \frac{V_i}{(R_{Si} + \frac{1}{sC_C} + R_i)}$

$= \frac{-\beta R_B R_C V_i}{(R_B + R_{ib})} \frac{sC_C\tau_s}{(1 + s\tau_s)(R_{Si} + R_i)}$

A_v lowers 3-dB upon $\omega = \frac{1}{\tau_s}$

$\left(\left|\frac{s\tau_s}{1 + s\tau_s}\right| = \left|\frac{j}{1 + j}\right| = \frac{1}{\sqrt{2}}\right)$

$f_L = \frac{\omega}{2\pi} = \frac{1}{2\pi\tau_s}$ time const. method



FET