2015.12.3

Electric Circuit for Physicists
電子回路論 第8回

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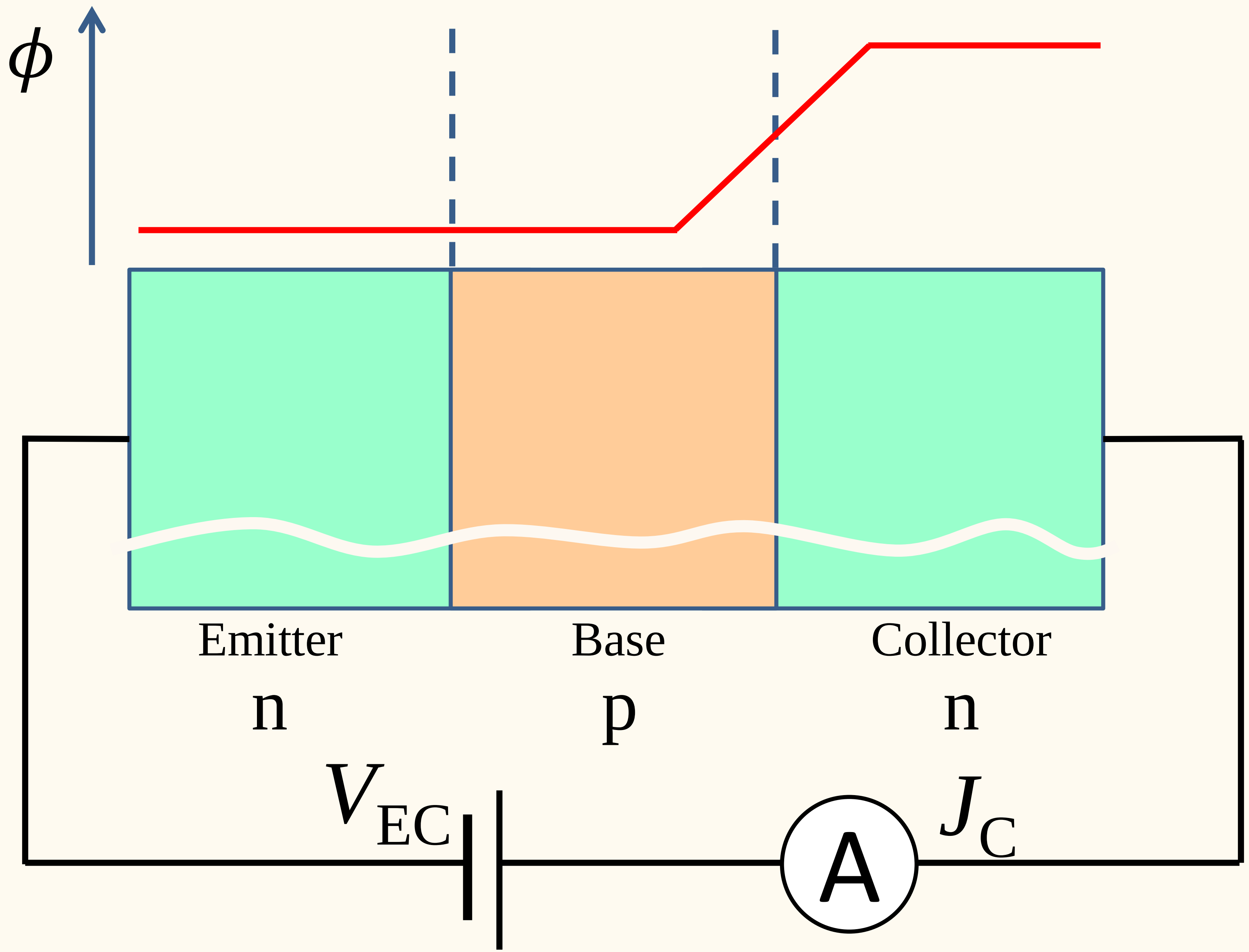
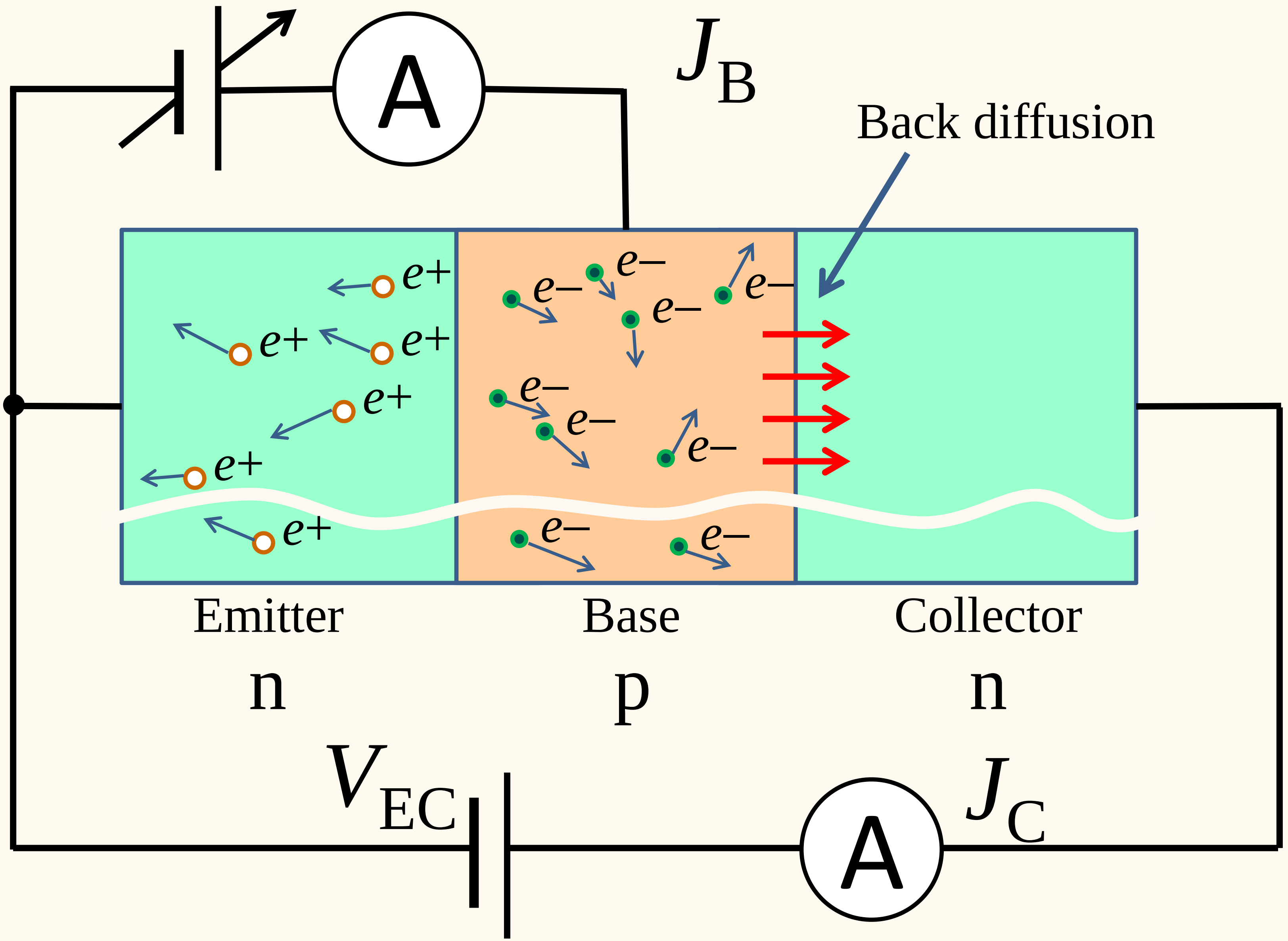
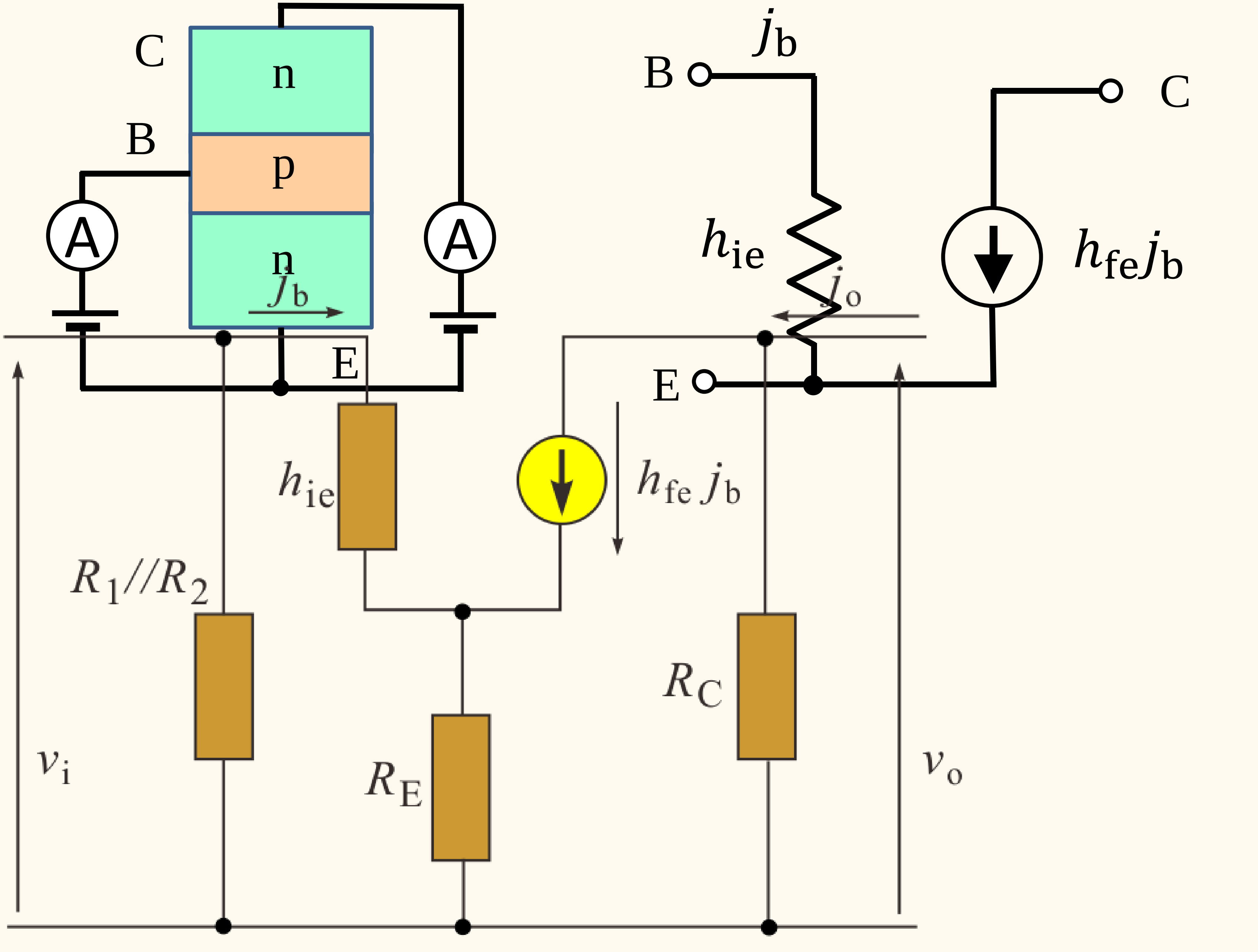
Review: How a bipolar transistor amplifies?



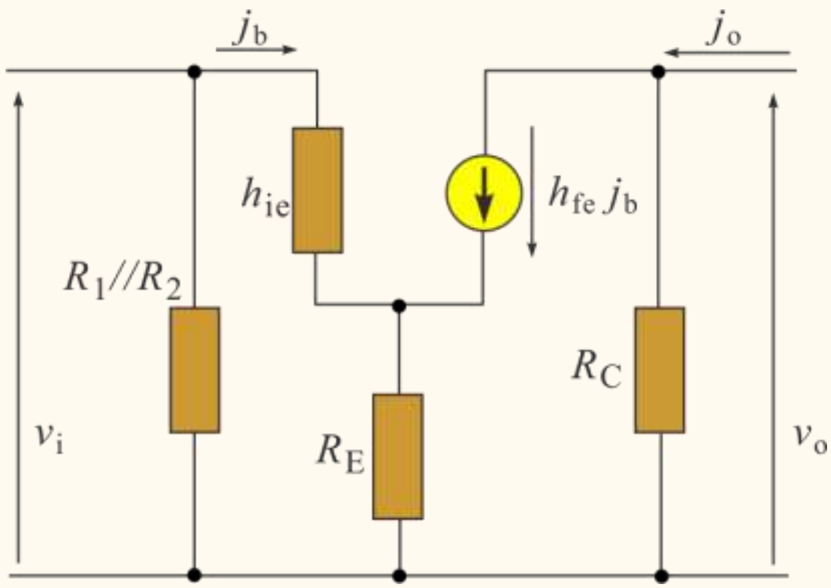
Review: How a bipolar transistor amplifies?

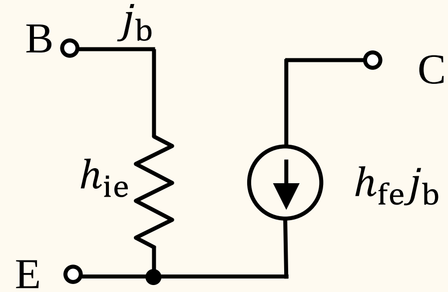


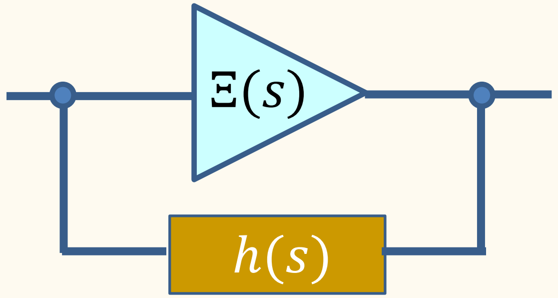
Concept of equivalent circuit

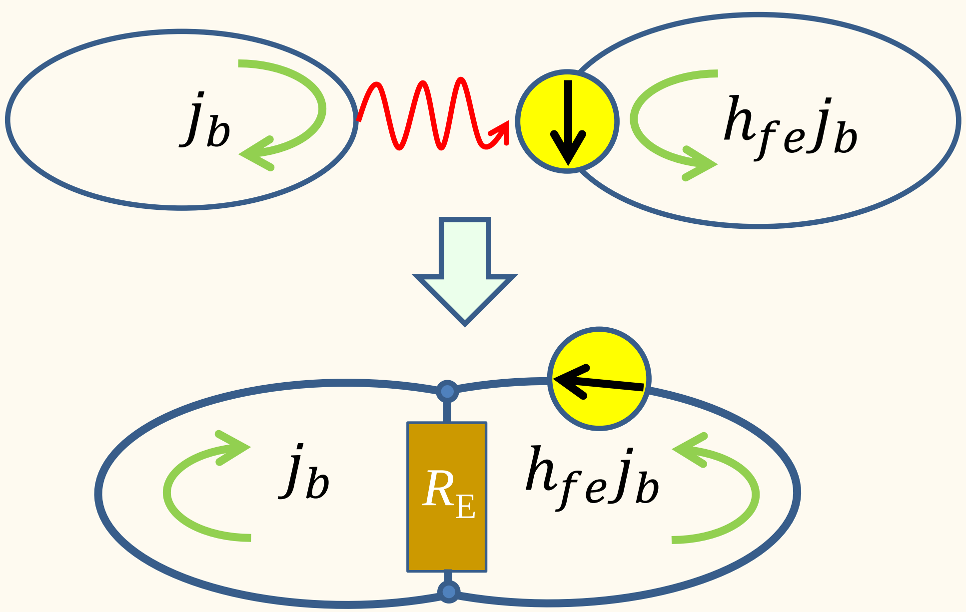


Concept of equivalent circuit: Where is feedback?







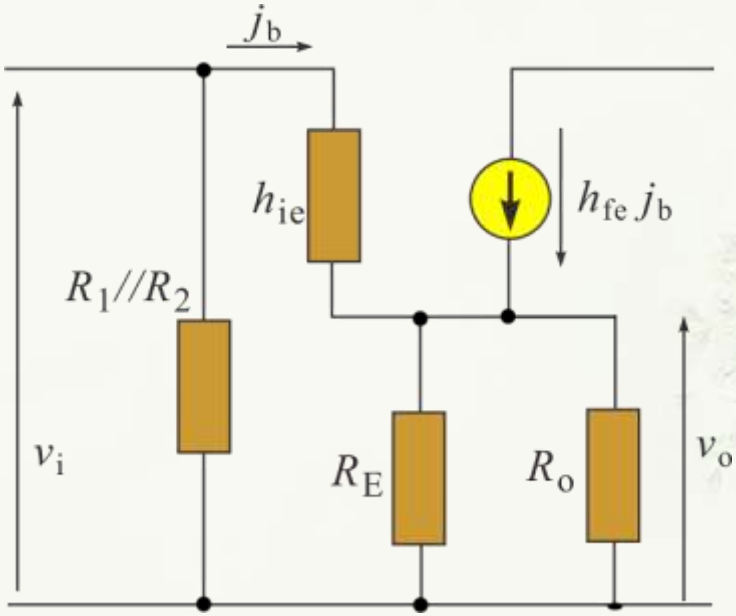


$$A = \frac{v_o}{v_i}$$

$$= \frac{h_{fe}R_C}{h_{ie} + R_E(1 + h_{fe})}$$

$$\approx \frac{R_C}{R_E} \quad h_{fe} \gg 1$$

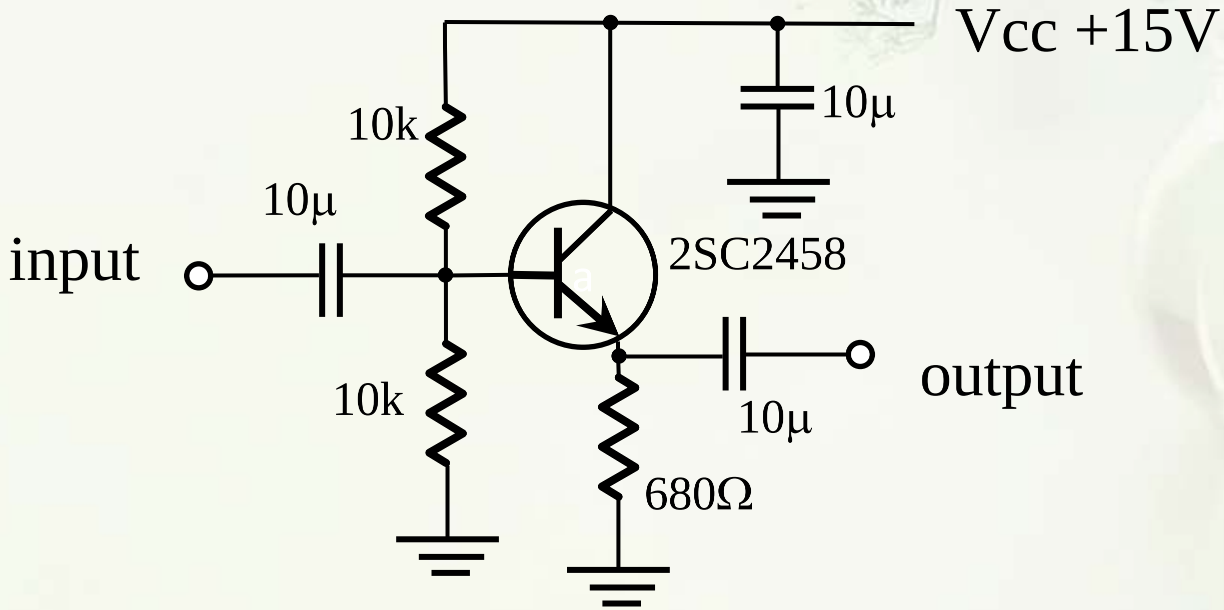
Current amplification: Emitter follower



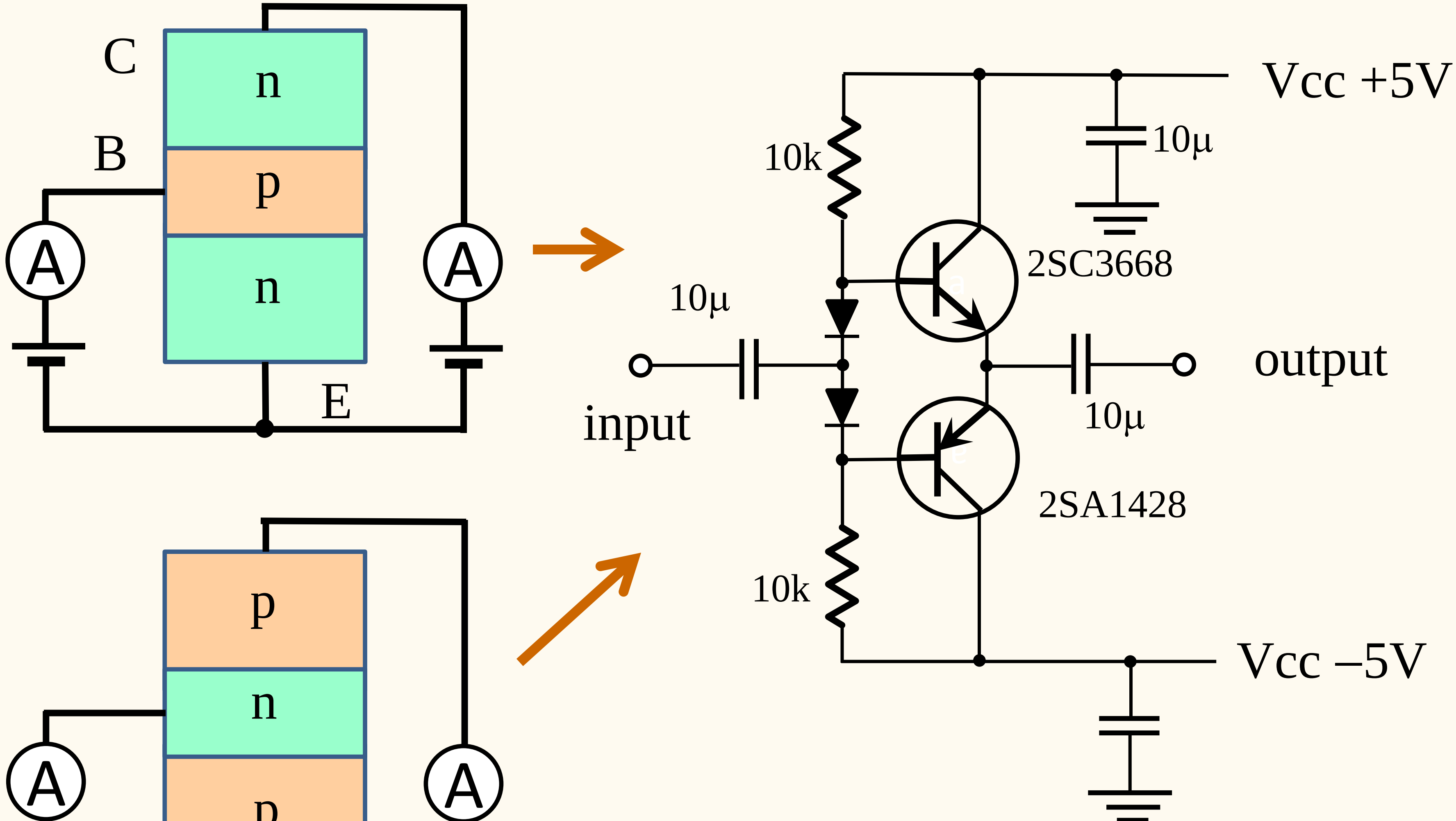
$$\frac{v_o}{v_i} = \frac{j_b(1+h_{fe})(R_E \parallel R_o)}{j_b[h_{ie} + (1+h_{fe})(R_E \parallel R_o)]}$$
$$\approx 1 \qquad (h_{fe} \gg 1)$$

v_o does not depend on load resistance

⇒ Very low output resistance



Complementary transistors



Symmetric characteristics: Complementary

Symmetric: Small collector current
(idling current) for zero input.

Example of transistor datasheet

TOSHIBA Transistor Silicon NPN Epitaxial Type (PCT process)

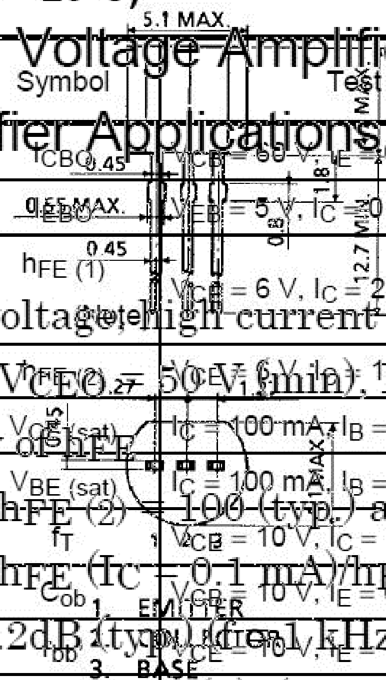
2SC1815(L)

Audio Frequency Voltage Amplifier Applications

Low Noise Amplifier Applications

- High breakdown voltage, high current capability
  : V_{CEO} = 50 V (min), I_C = 150 mA (max)
- Excellent linearity of h_{FE}
  : h_{FE} (2) = 100 (typ.) at V_{CE} = 6 V, I_C = 150 mA
  : h_{FE} (I_C = 0.1 mA)/h_{FE} (I_C = 2 mA) = 0.95 (typ.)
- Low noise: NF = 0.2dB (typ.) (f = 1 kHz)
- Complementary to 2SA1015 (L) (O, Y, GR class).

Unit: mm



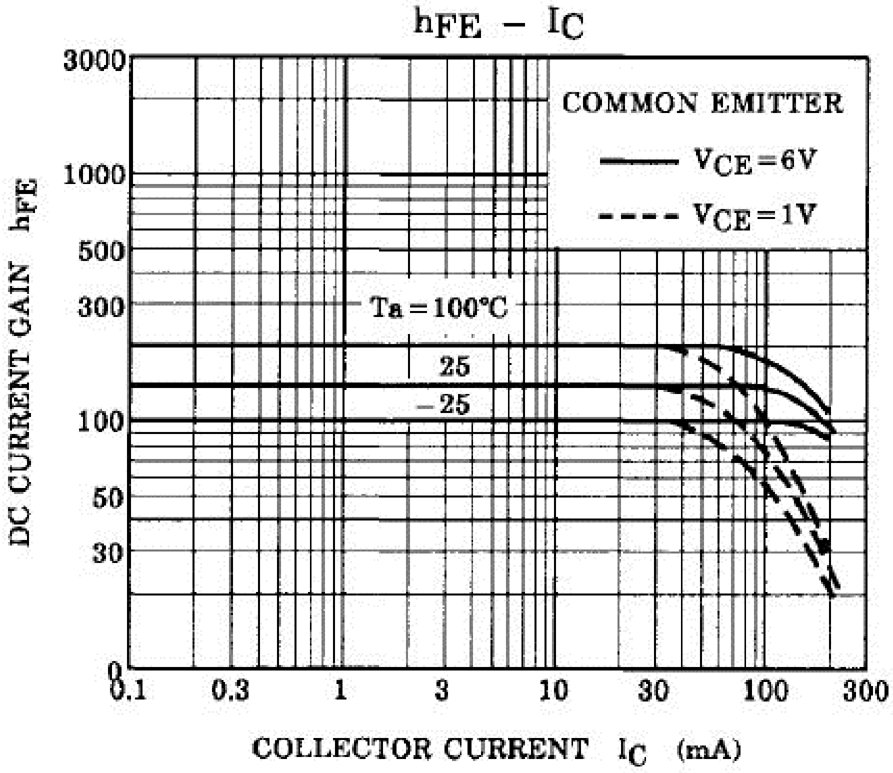
JEDEC	TO-92
JEITA	SC-43
TOSHIBA	2-5F1B

Electrical Characteristics (Ta = 25°C)

Characteristics		Symbol	Test Condition	Min	Typ.	Max	Unit
Collector cut-off current		I_{CBO}	V_{CB} = 60 V, I_E = 0	—	—	0.1	μA
Emitter cut-off current		I_{EBO}	V_{EB} = 5 V, I_C = 0	—	—	0.1	μA
DC current gain		h_{FE} (1) (Note)	V_{CE} = 6 V, I_C = 2 mA	70	—	700	
		h_{FE} (2)	V_{CE} = 6 V, I_C = 150 mA	25	100	—	
Saturation voltage	Collector-emitter	V_{CE} (sat)	I_C = 100 mA, I_B = 10 mA	—	0.1	0.25	V
	Base-emitter	V_{BE} (sat)	I_C = 100 mA, I_B = 10 mA	—	—	1.0	
Transition frequency		f_T	V_{CE} = 10 V, I_C = 1 mA	80	—	—	MHz
Collector output capacitance		C_{ob}	V_{CB} = 10 V, I_E = 0, f = 1 MHz	—	2.0	3.5	pF
Base intrinsic resistance		$r_{bb'}$	V_{CE} = 10 V, I_E = −1 mA, f = 30 MHz	—	50	—	Ω
Noise figure		NF (1)	V_{CE} = 6 V, I_C = 0.1 mA, R_G = 10 kΩ, f = 100 Hz	—	0.5	6	dB
		NF (2)	V_{CE} = 6 V, I_C = 0.1 mA, R_G = 10 kΩ, f = 1 kHz	—	0.2	3	

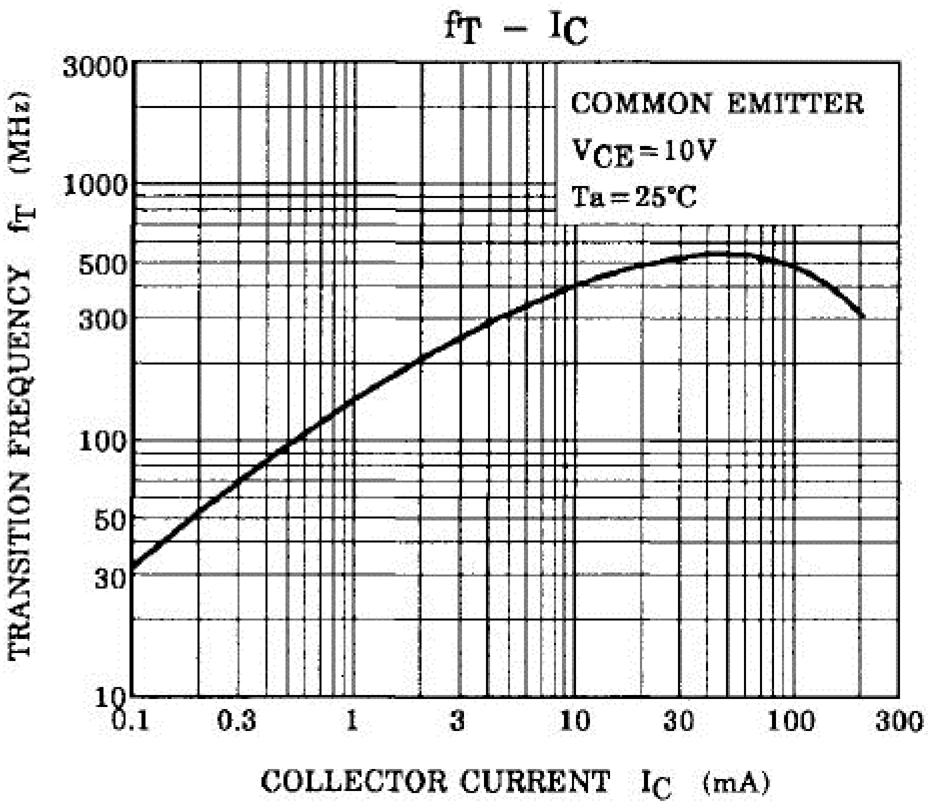
Note: $h_{FE\ (1)}$ classification O: 70~140, Y: 120~240, GR: 200~400, BL: 350~700

Example of transistor datasheet

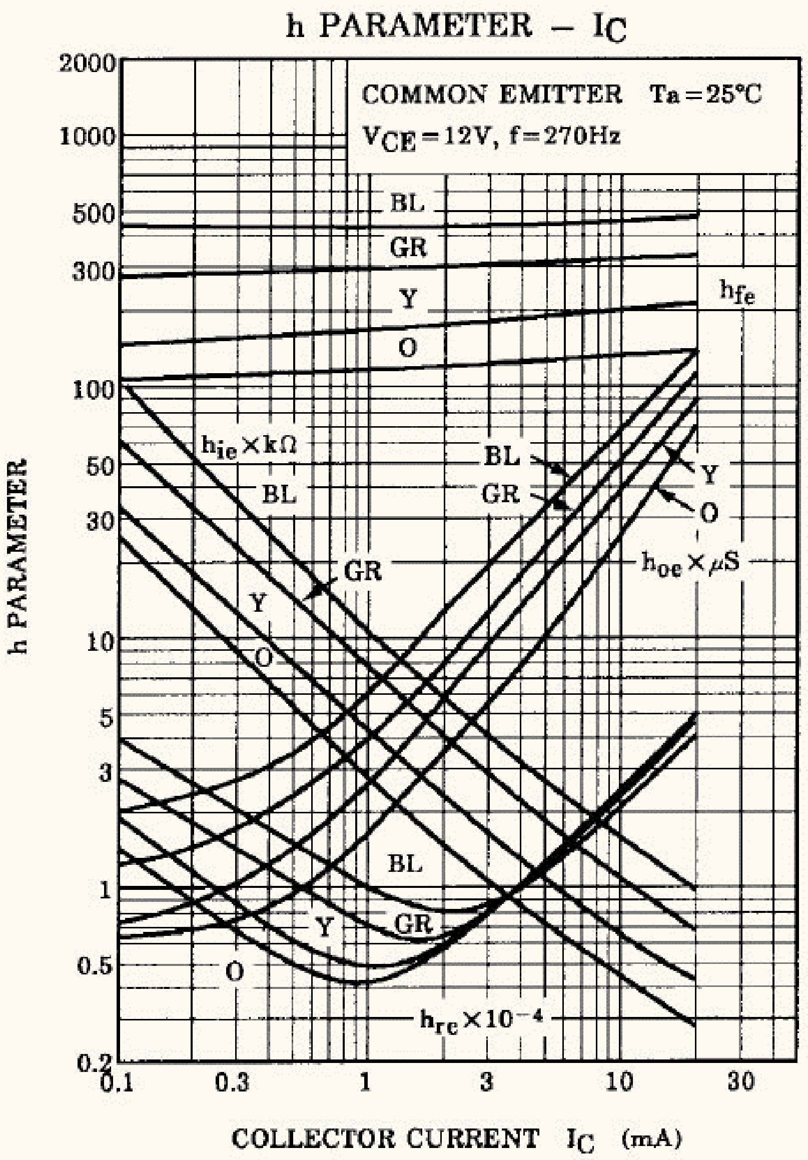


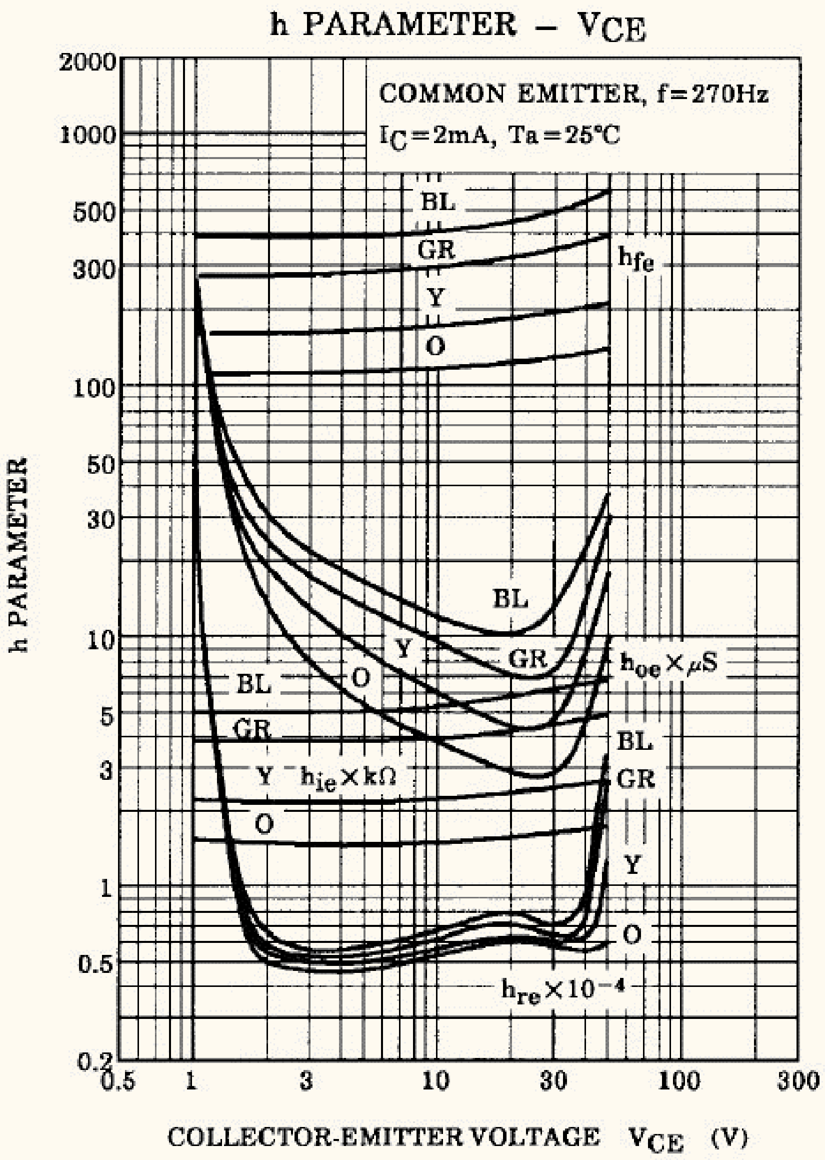
h_{fe} linear model availability in the range of J_C.

Cut-off frequency as a function of J_C



Example of transistor datasheet

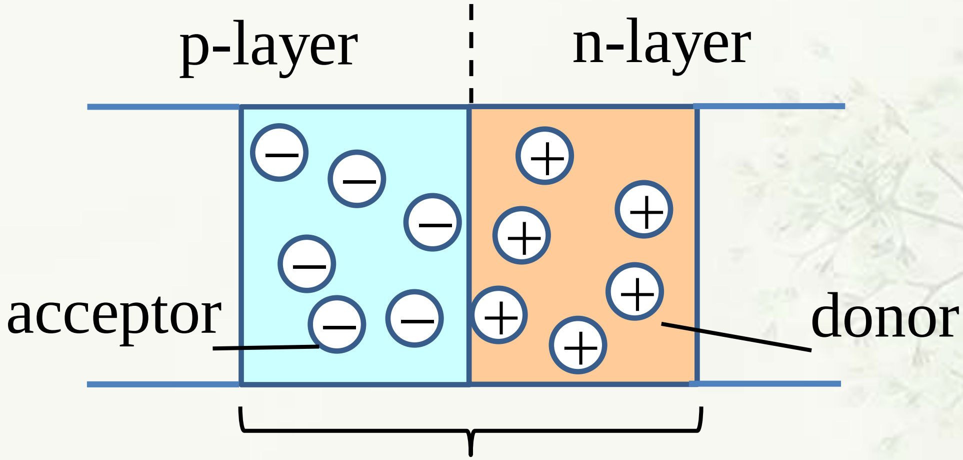




4.4 Field effect transistor (FET)

$$C = \frac{\varepsilon\varepsilon_0 S}{d} \equiv \frac{\varepsilon_s}{d} S$$

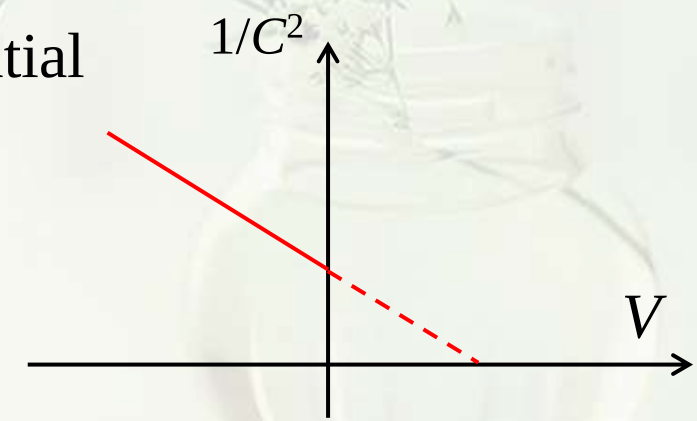
pn junction in reverse bias condition



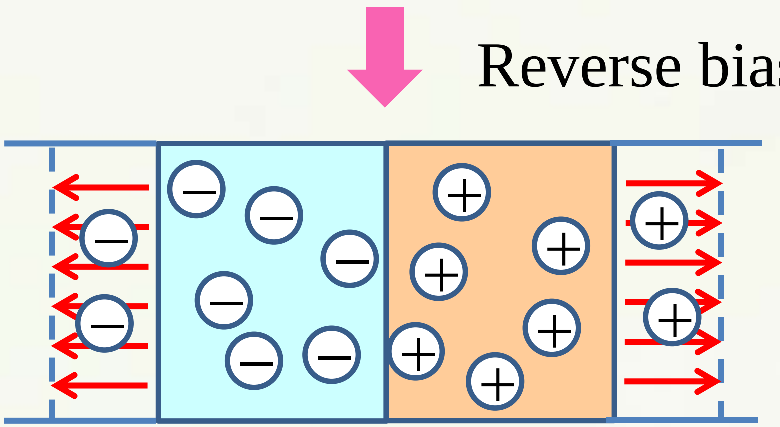
depletion layer (空乏層) forms built-in potential

$$W_D = \sqrt{\frac{2\varepsilon_s}{eN}\left(V_{bi} - V - \frac{2k_B T}{e}\right)}$$

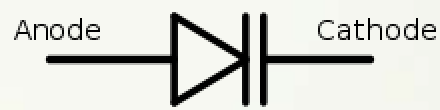
$$C_D = \frac{\varepsilon_s}{W_D} S$$



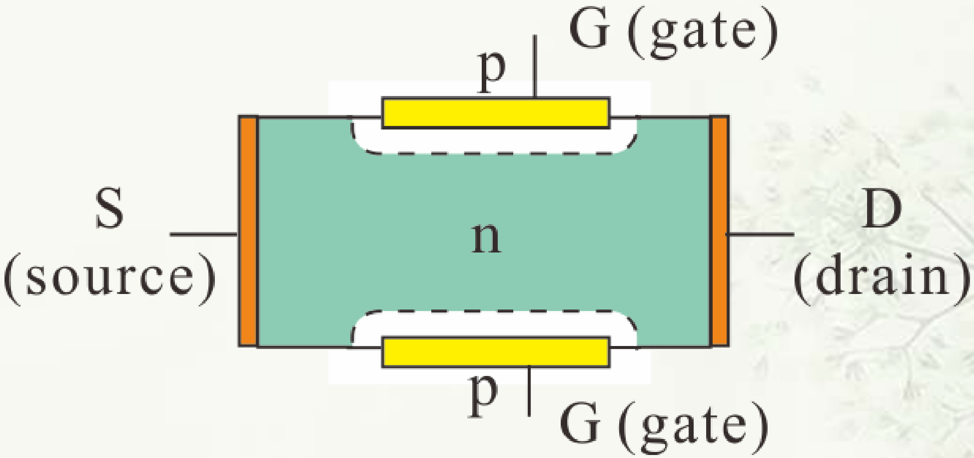
Reverse bias voltage

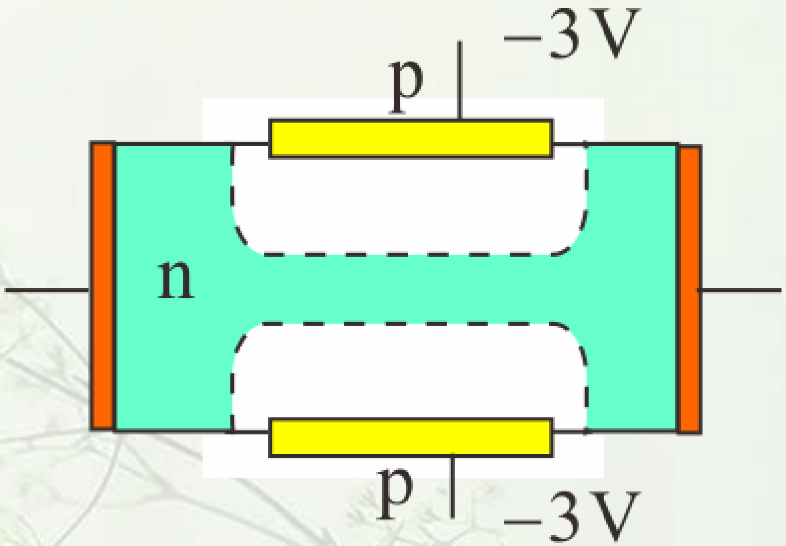


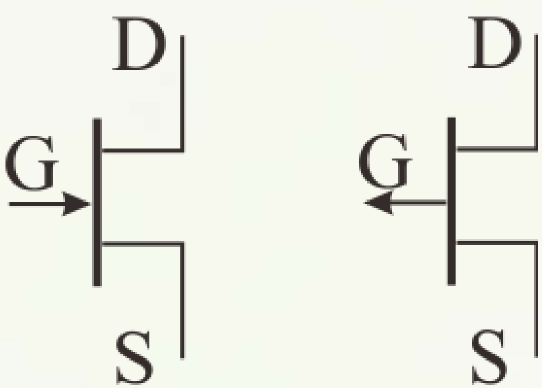
Varicap diode

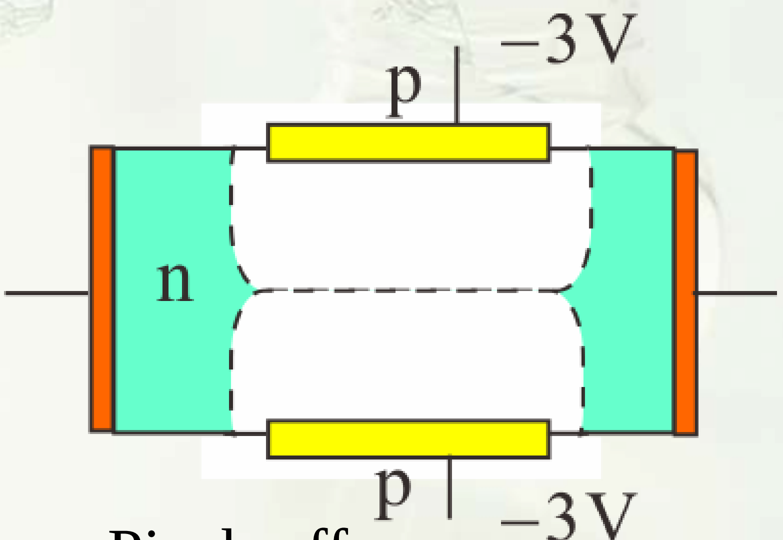


Junction FET (JFET)



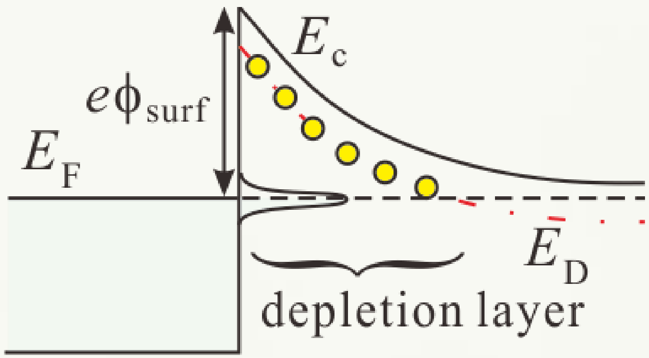


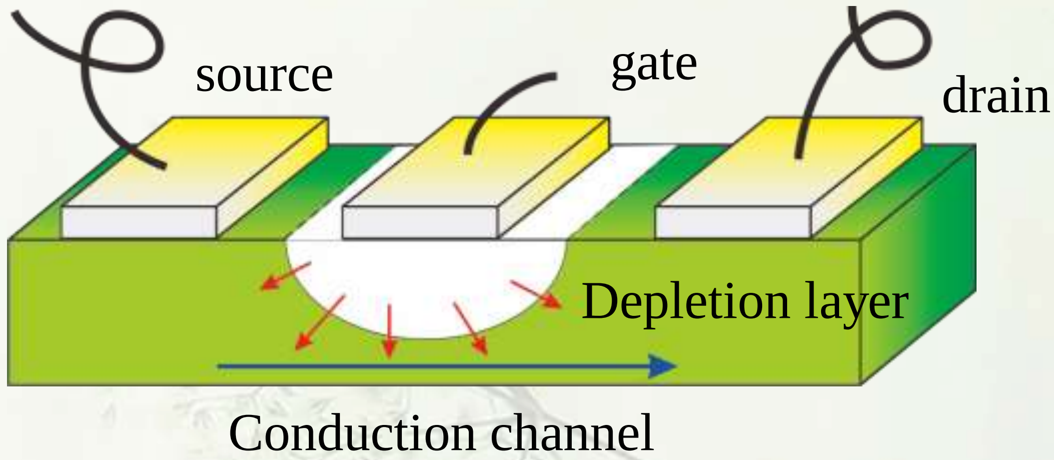


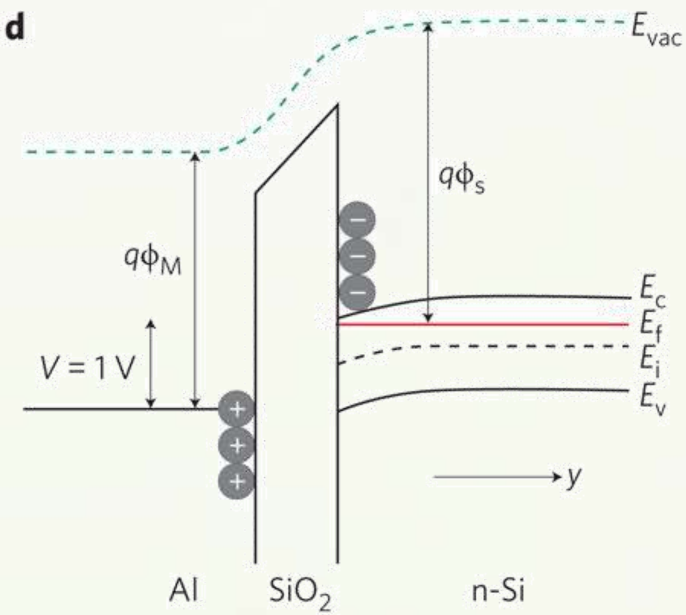


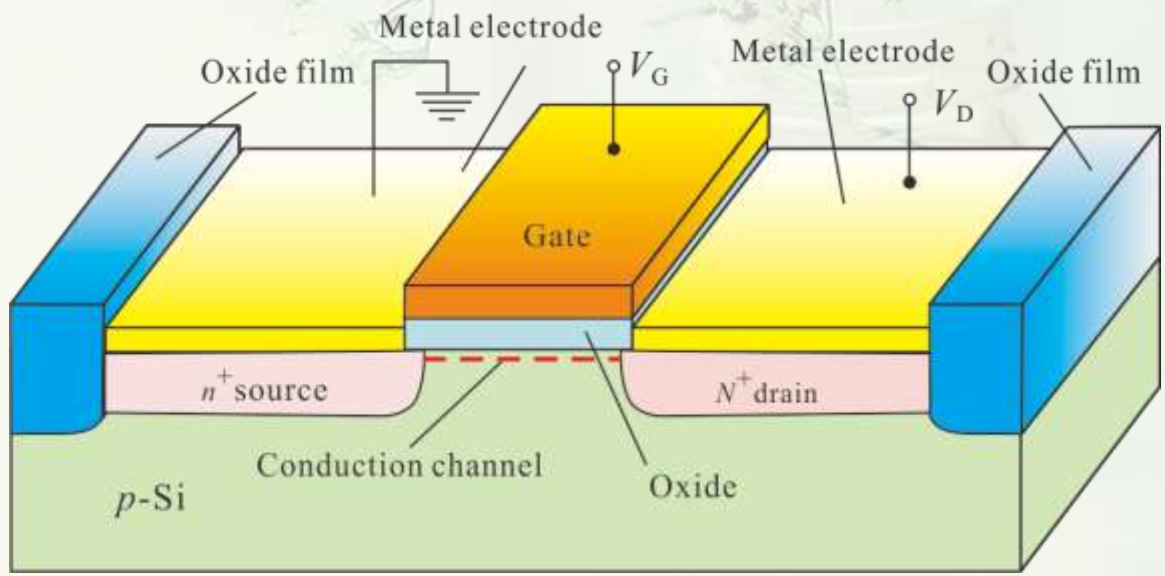
Pinch-off

MESFET, MOSFET

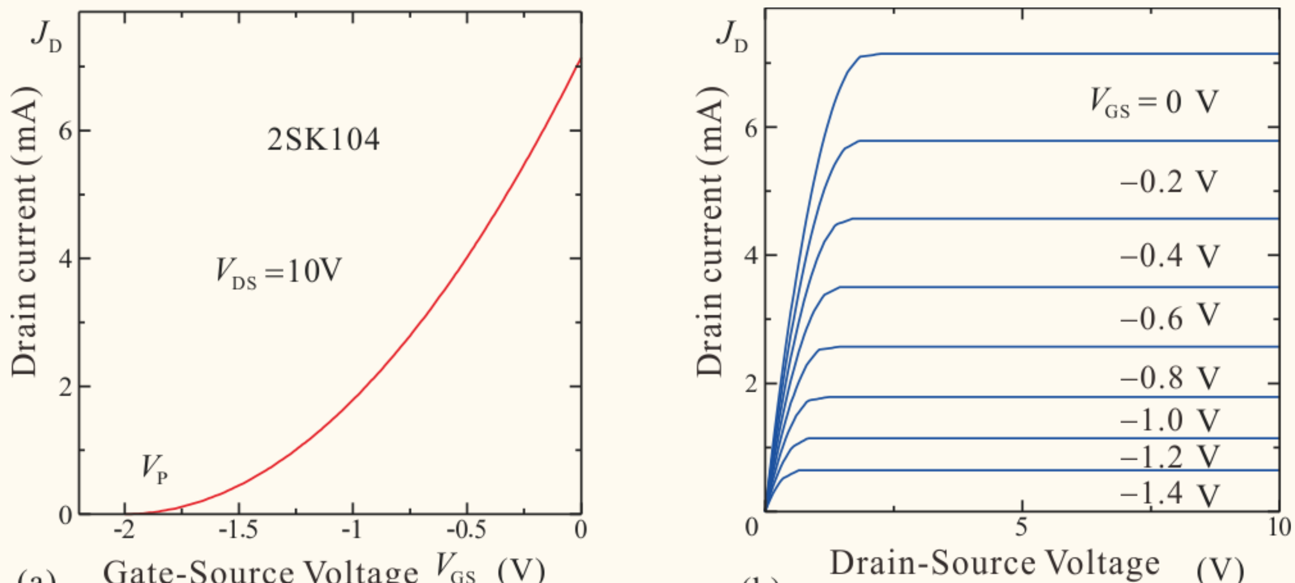








Static characteristics of FET



(a) (b)

$$J_{\mathrm{G}} \simeq 0,$$

$$J_{\mathrm{D}} = f(V_{\mathrm{G}}, V_{\mathrm{D}})$$

$$g_m \equiv \left(\frac{\partial J_D}{\partial V_{GS}}\right)_{V_D=\text{const.}},$$ transconductance

$$r_d \equiv \left(\frac{\partial V_D}{\partial J_D}\right)_{V_{GS}=\text{const.}}$$ drain resistance

Locally linear approximation

$$j_d = g_m v_{gs} + \frac{v_d}{r_d}$$

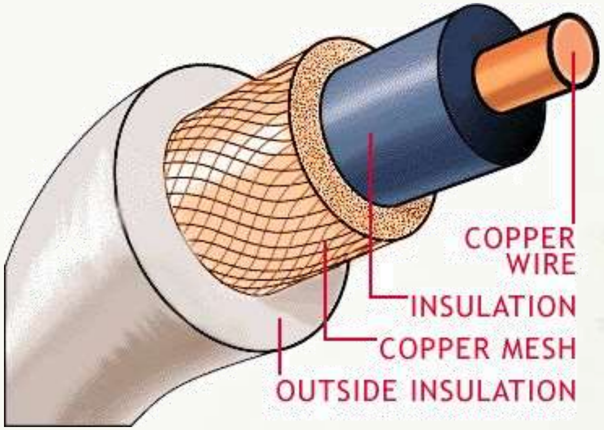
References

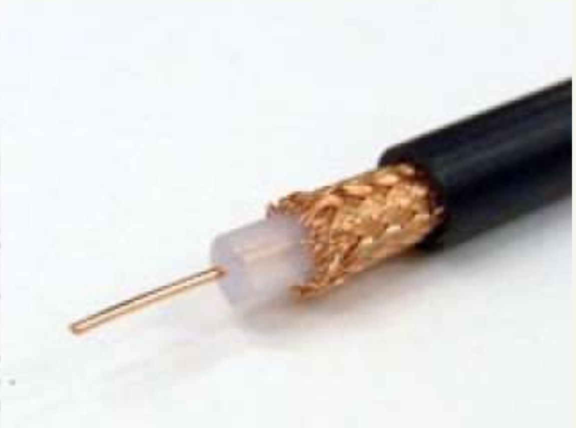
岡村迪夫 「OPアンプ回路の設計」 CQ出版社
松澤昭「基礎電子回路工学」電気学会

A. Agarwal, J. H. Lang “Foundations of Analog and Digital Electronic Circuits” (Elsevier, 2005).

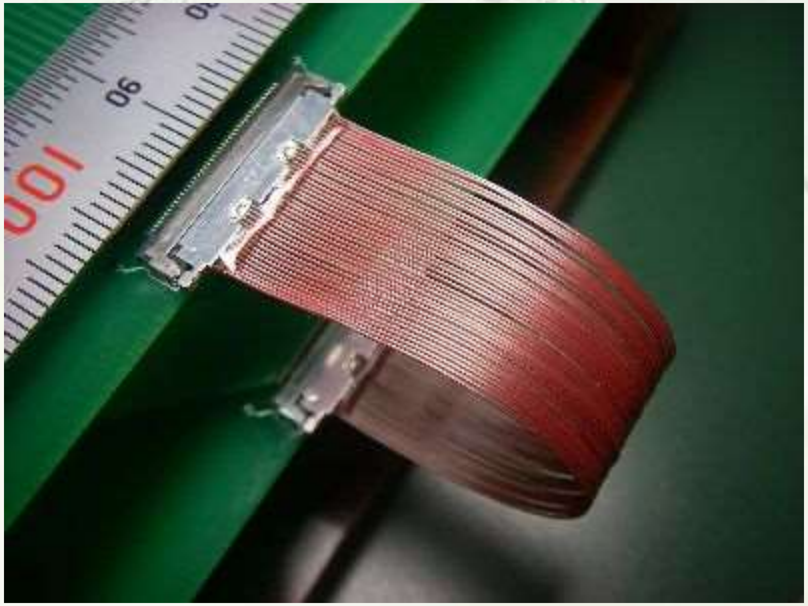
S. M. Sze, K. K. Ng, “Physics of Semiconductor Devices” (Wiley, 2007).

Coaxial cable

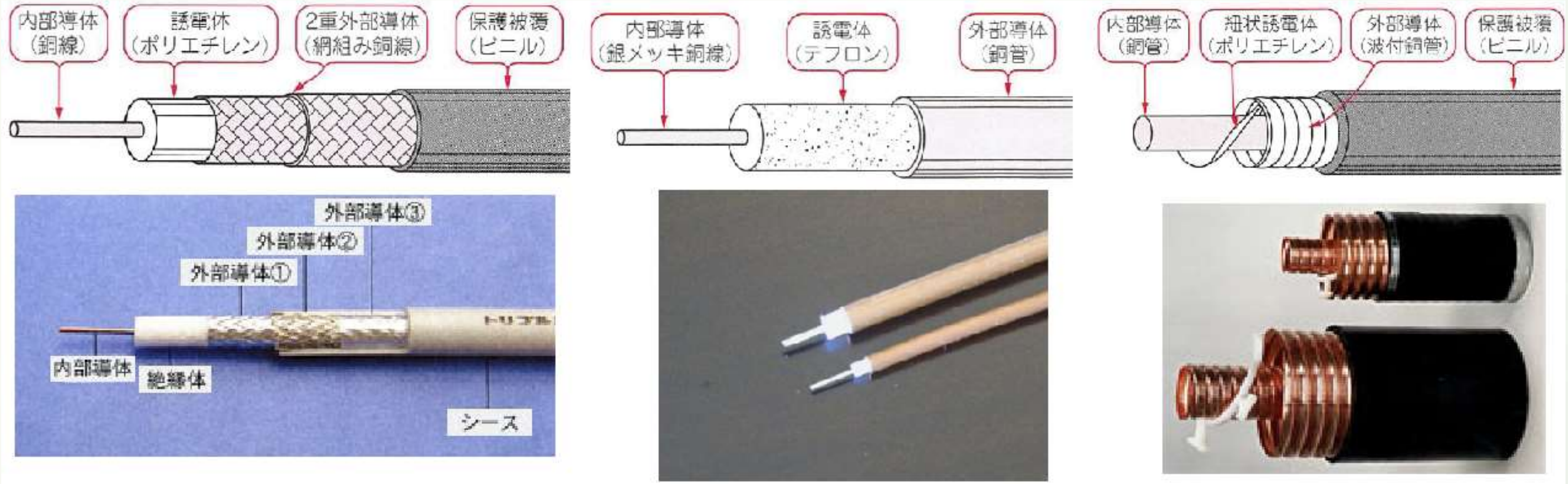




Thin coaxial cable AWG50 ($\phi 25\mu m$)



Coaxial cable 2



(a) (b) (c)

図12 同軸ケーブルの型名（JIS C3501）

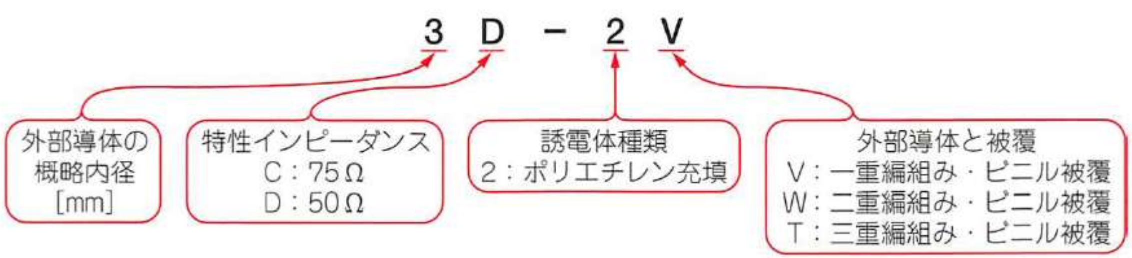
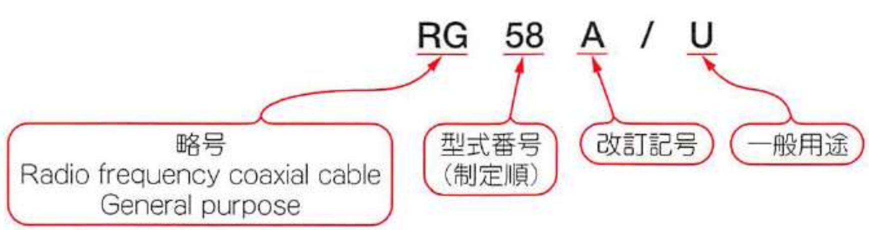
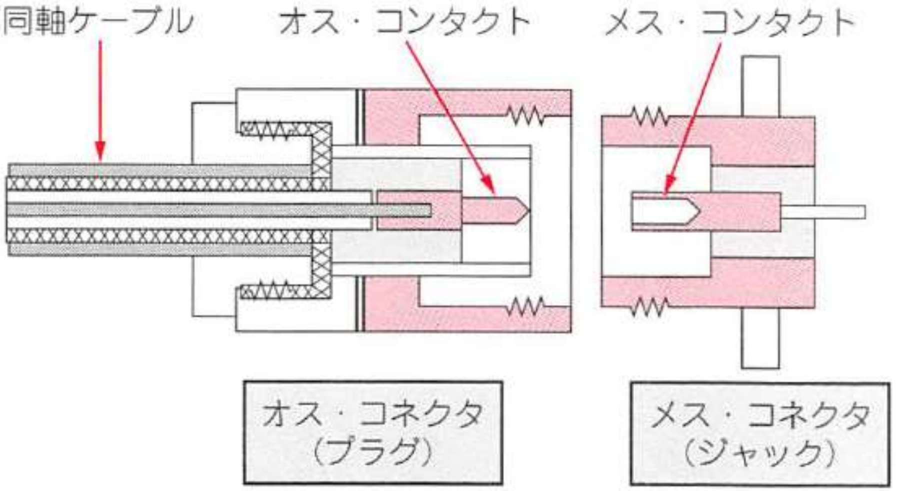


図13 MIL規格での同軸ケーブル型名の例



Coaxial connectors

図22 同軸コネクタの構造(概念図)



代表的な同軸コネクタの最高使用周波数例

形　式	外部導体内径	最高使用周波数
BNC	約 7 mm	2 ~ 4 GHz
N	約 7 mm	10 ~ 18 GHz
7 mm	7 mm	~ 18 GHz
SMA	4.15 mm	18 GHz
3.5 mm	3.5 mm	26.5 GHz
K	2.92 mm	40 GHz
2.4 mm	2.4 mm	50 GHz
V	1.85 mm	65 GHz
W	1.1 mm	110 GHz
1.0 mm	1.0 mm	110 GHz

Coaxial connectors

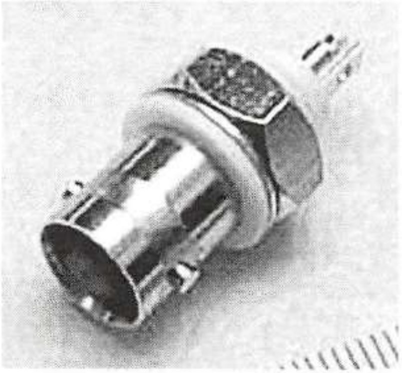
写真2 N型コネクタ

(a) フランジ付きジャック

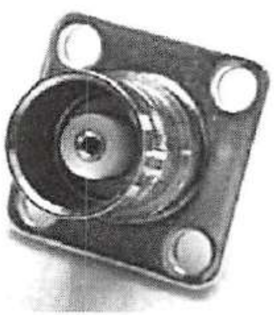
(b) プラグ

(c) プラグ[(b)を分解]

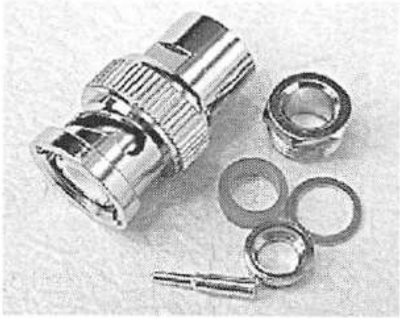
写真3 BNC型コネクタ



(a) 絶縁型ジャック
(高周波に向かない)



(b) フランジ付きジャック



(c) プラグ

Coaxial connectors 2

SMA-type

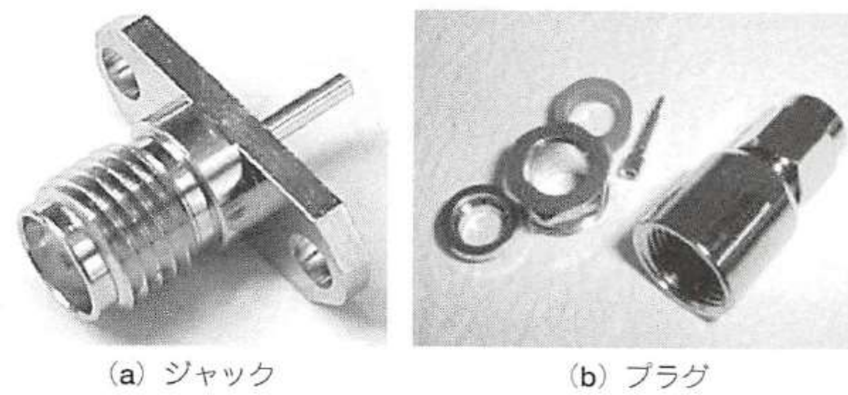


写真4 SMA型コネクタ

jack plug

K-type

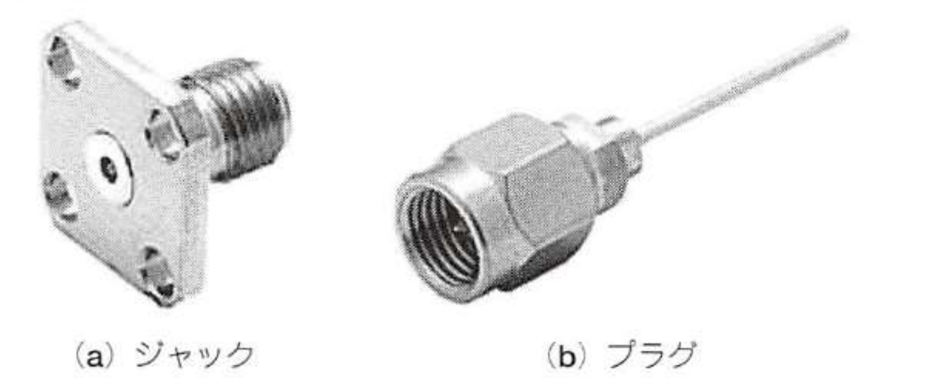


写真6 K型コネクタ

V-type

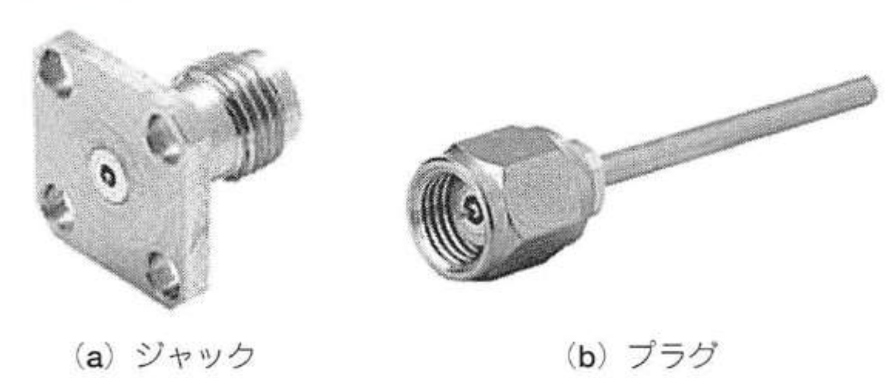


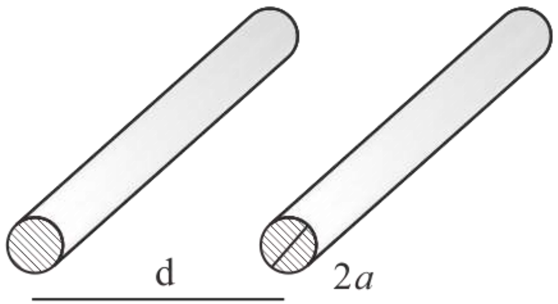
写真7 V型コネクタ

LEMO cables and connectors

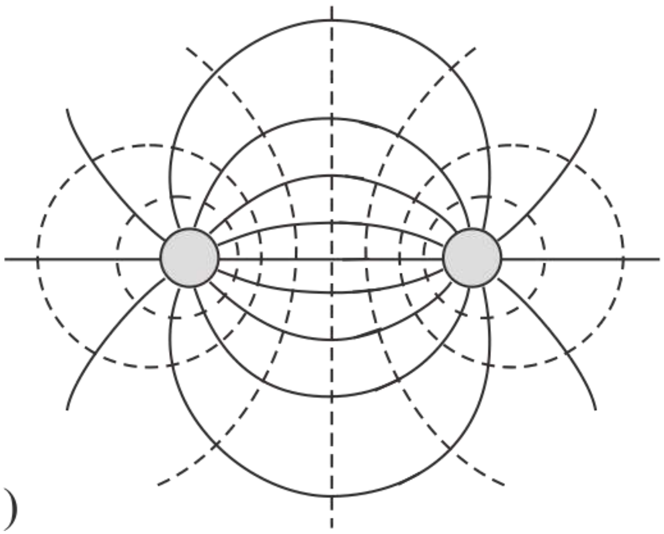
http://www.lemo.com/

High-energy physics experiment, etc.

Lecher line



(a)

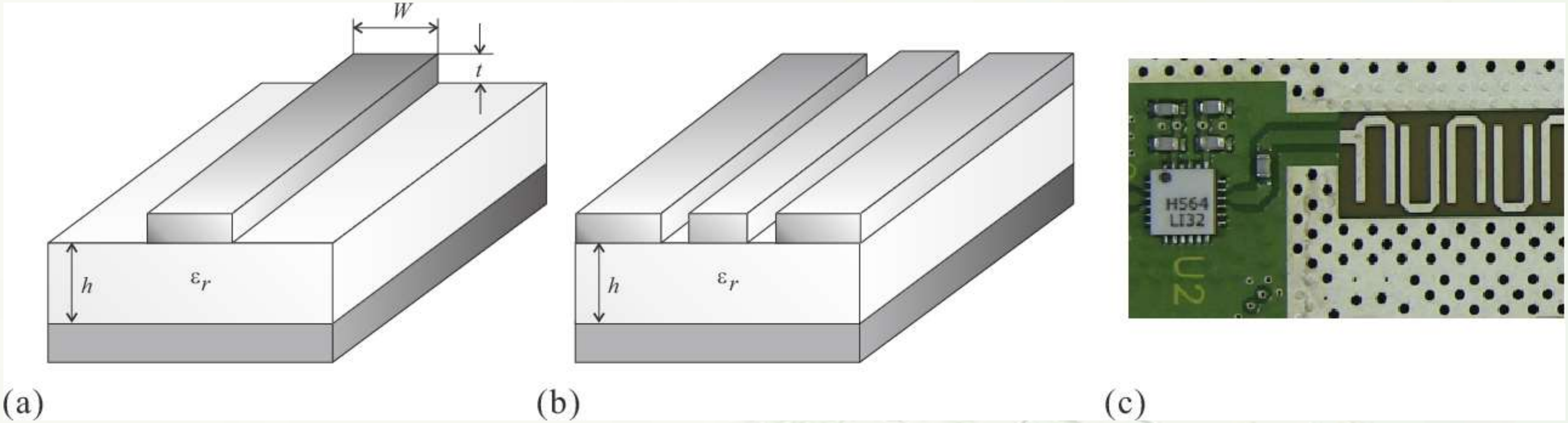


(b)

(c)

$$\phi_1 = -\phi_2 = \frac{J\sqrt{\mu}}{2\pi}\log\frac{d}{a} \qquad Z_0 = \sqrt{\frac{\mu}{\epsilon}}\frac{1}{\pi}\log\frac{d}{a}$$

Micro strip line



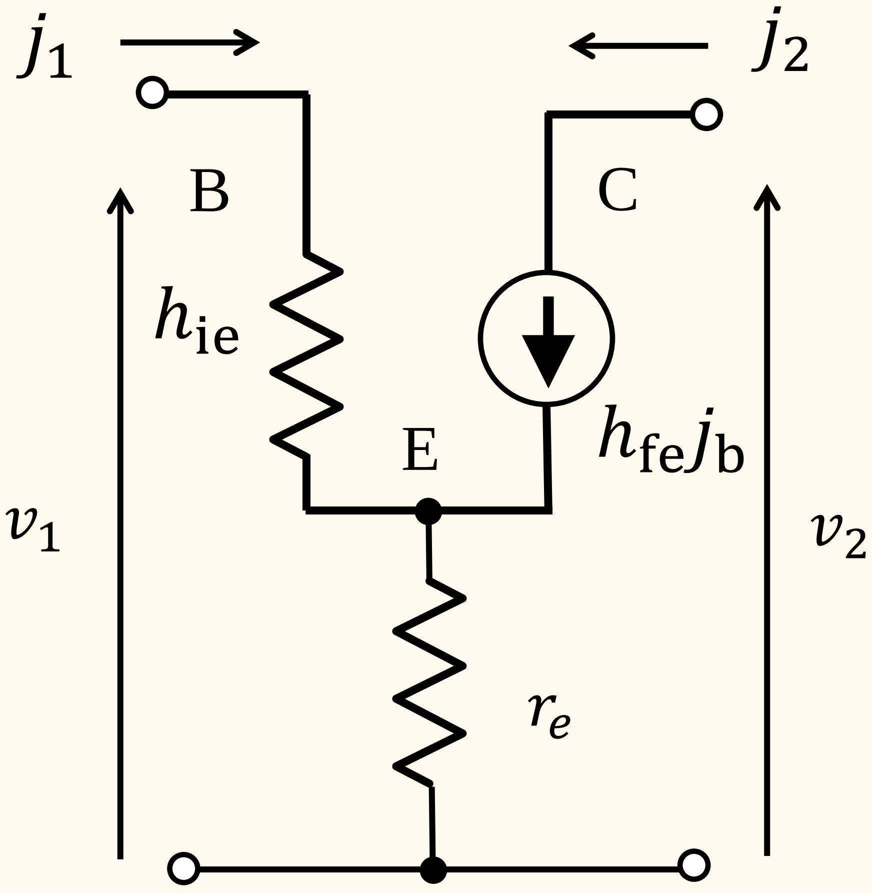
幅の広い (W/h>3.3)ストリップ

$$Z(W,h,\epsilon_r) = \frac{Z_{F0}}{2\sqrt{\epsilon_r}}\left\{\frac{W}{2h} + \frac{1}{\pi}\log 4 + \frac{\epsilon_r+1}{2\pi\epsilon_r}\log\left[\frac{\pi e}{2}\left(\frac{W}{2h}+0.94\right)\right]\frac{\epsilon_r-1}{2\pi\epsilon_r^2}\log\frac{e\pi^2}{16}\right\}^{-1}$$

幅の狭い (W/h<3.3)ストリップ

$$Z(W,h,\epsilon_r) = \frac{Z_{F0}}{\pi\sqrt{2(\epsilon_r+1)}}\left\{\log\left[\frac{4h}{W}+\sqrt{\left(\frac{4h}{W}\right)^2+2}\right] - \frac{1}{2}\frac{\epsilon_r-1}{\epsilon_r+1}\left(\log\frac{\pi}{2}+\frac{1}{\epsilon_r}\log\frac{4}{\pi}\right)\right\}$$

Exercise 4-1

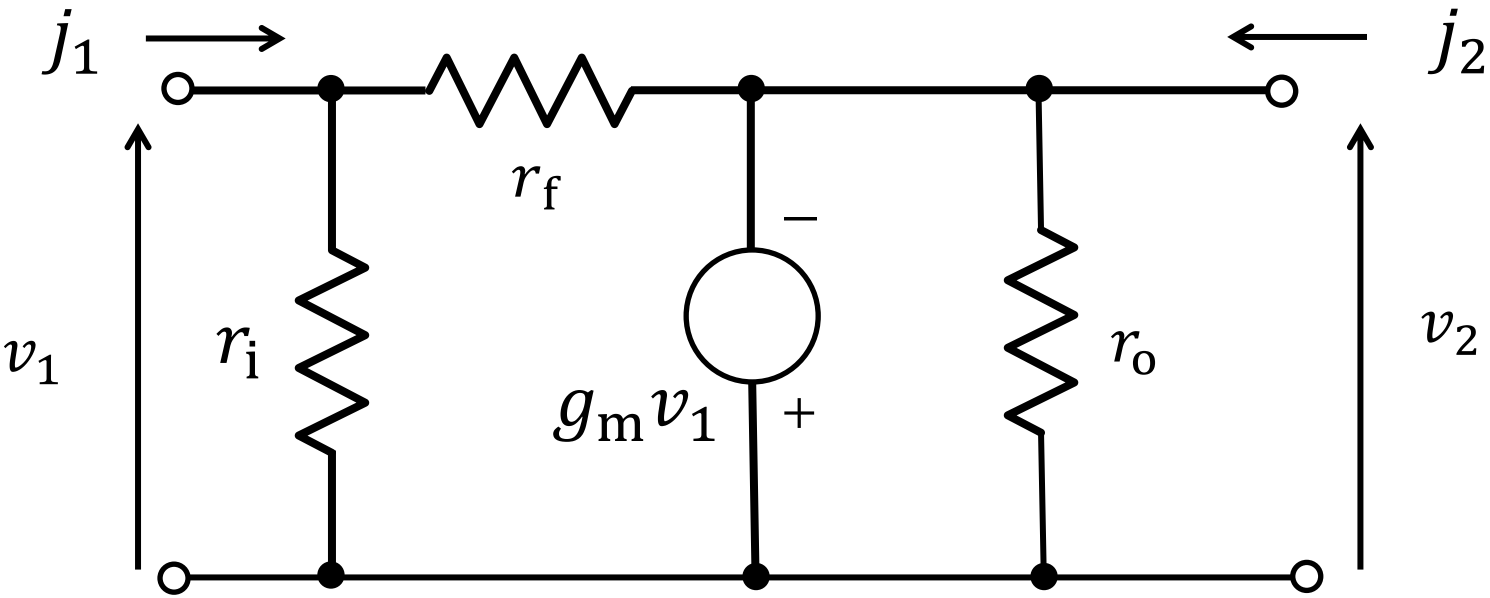


Let us view a bipolar transistor plus an emitter resistance as a four terminal circuit as shown in the left figure.
Obtain the Y (admittance) matrix defined below for this circuit.

Calculate each element in the Y matrix for
r_e =25Ω, h_{ie} =500 Ω, h_{fe}= 200

$$\begin{pmatrix} j_1 \\ j_2 \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix}$$

Exercise 4-2



Obtain the Y matrix for the above equivalent circuit (π-shape circuit).

Exercise 4-3

l =1km の伝送線路がある．終端側を短絡したところ，電源側から測定したインピダンスは0.6i Ωであった．一方，終端側を開放して電源側からアドミタンスを測定すると$4\text{x}10^{-6}i$ Sであった．

この伝送線路の特性インピダンスを求めよ．

Consider a transmission line with the length l = 1km. First we short-circuited the end and measured the impedance from the signal source and obtained 0.6i Ω. Next we opened the end and measured the admittance from the signal source and obtained $4\text{x}10^{-6}i$ S.

What is the characteristic impedance of the transmission line?