Electric Circuits for Physicists

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電子回路論　第１回

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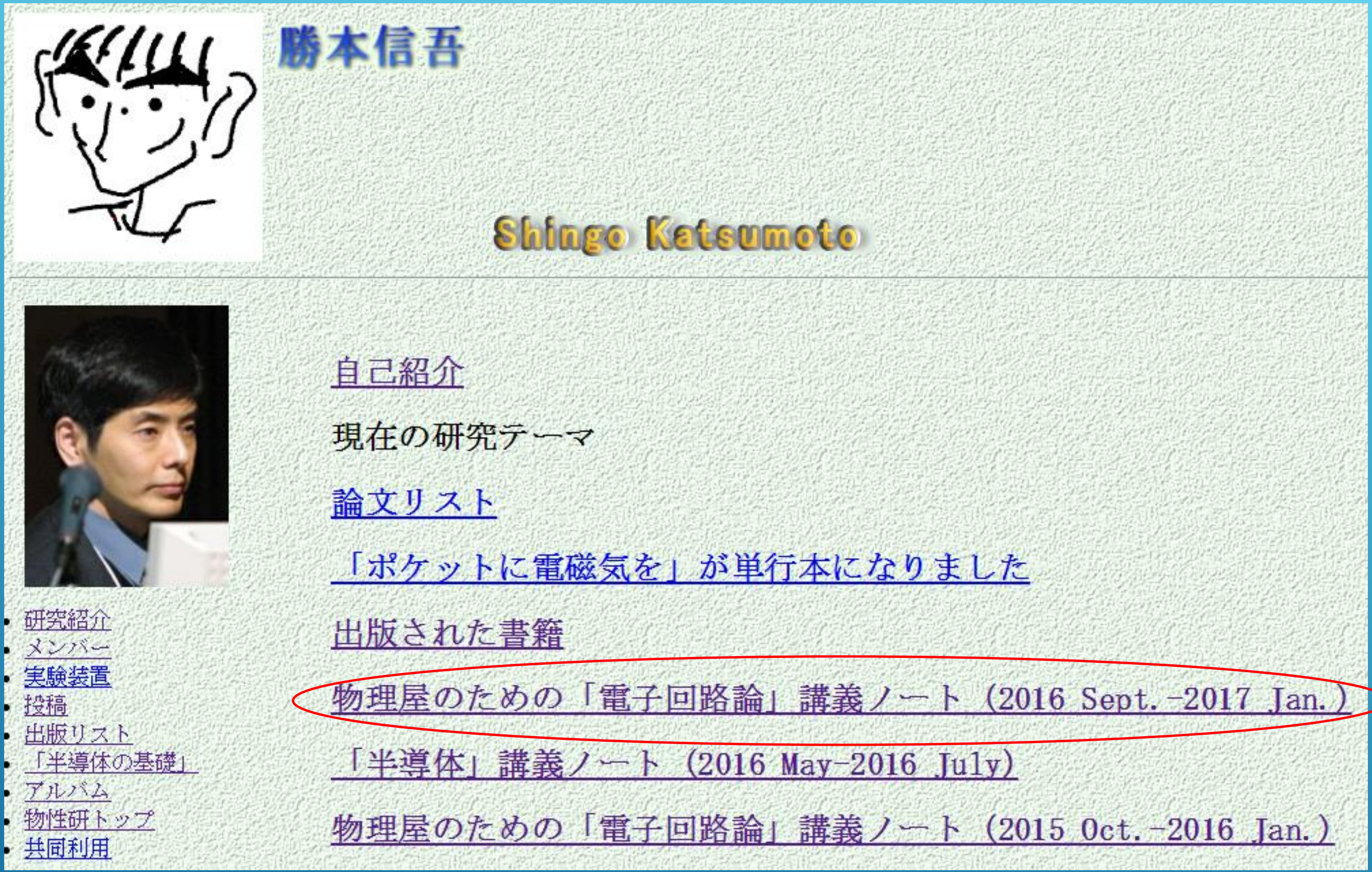
ノート・資料等の置き場



2週に１回簡単な練習問題を出題　→　2週間以内に解答を提出

TAが採点してコメントをメール送付します

試験は期末レポート．練習問題と合わせて採点します

シラバス

1. 電磁場と電子回路
   - 1.1 この講義について
   - 1.2 電子回路とは
   - 1.3 ２端子素子
   - 1.4 回路図
   - 1.5 抵抗器
   - 1.6 キャパシタ
   - 1.7 インダクタ
2. 線形回路序論
   - 2.1 線形システムと電子回路
   - 2.2 電源
   - 2.3 回路網
   - 2.4 4端子(2端子対)回路
   - 2.5 端子対回路の諸定理
   - 2.6 双対性
   - 2.7 受動素子と能動素子
3. 伝達関数と周波数応答・過渡応答
   - 3.1 受動素子2端子回路の伝達関数
   - 3.2 ２端子受動素子回路
   - 3.3 受動素子回路の過渡応答
4. 増幅回路
   - 4.1 増幅回路と系の制御
   - 4.2 OPアンプ
   - 4.3 トランジスタ
   - 4.4 電場効果トランジスタ
5. 分布定数回路
   - 5.1 伝送路
   - 5.2 伝送路の伝播現象
   - 5.3 S行列(Sパラメタ)
   - 5.4 シュレディンガー方程式とLC伝送路

シラバス２

6. 信号，雑音，波形解析
- 6.1 ゆらぎ
- 6.2 増幅器の雑音
- 6.3 変調とアナログ信号伝送
- 6.4 離散化信号

7. ディジタル信号とディジタル回路
- 7.1 ディジタル信号序論
- 7.2 論理ゲート
- 7.3 論理ゲートの実装
- 7.4 論理演算の回路化と簡単化
- 7.5 A-D/D-A コンバータ
- 7.6 ディジタルフィルター
- 7.7 ハードウェア記述言語：HDL

Syllabus

1. Electromagnetic field and electric circuits
   1.1 About this lecture
   1.2 What is electric circuit?
   1.3 Two-terminal devices
   1.4 Circuit diagrams
   1.5 Resistors
   1.6 Capacitors
   1.7 Inductors
2. Introduction to linear circuits
   2.1 Linear systems and electric circuits
   2.2 Power sources
   2.3 Networks
   2.4 4-terminal (2-terminal pair) circuits
   2.5 Theorems in terminal pair circuits
   2.6 Duality
   2.7 Passive devices, active devices

Syllabus

3. Transfer function and transient response
   3.1 Transfer function of passive two-terminal pair circuits
   3.2 Two-terminal passive circuits
   3.3 Transient response of passive circuits
4. Amplifiers
   4.1 System control and amplifiers
   4.2 Operational amplifiers
   4.3 Transistors
   4.4 Field effect transistors
5. Distributed constant circuits
   5.1 Transmission lines
   5.2 Propagation through transmission lines
   5.3 S matrix (S parameters)
   5.4 Schrodinger equation and LC transmission circuit

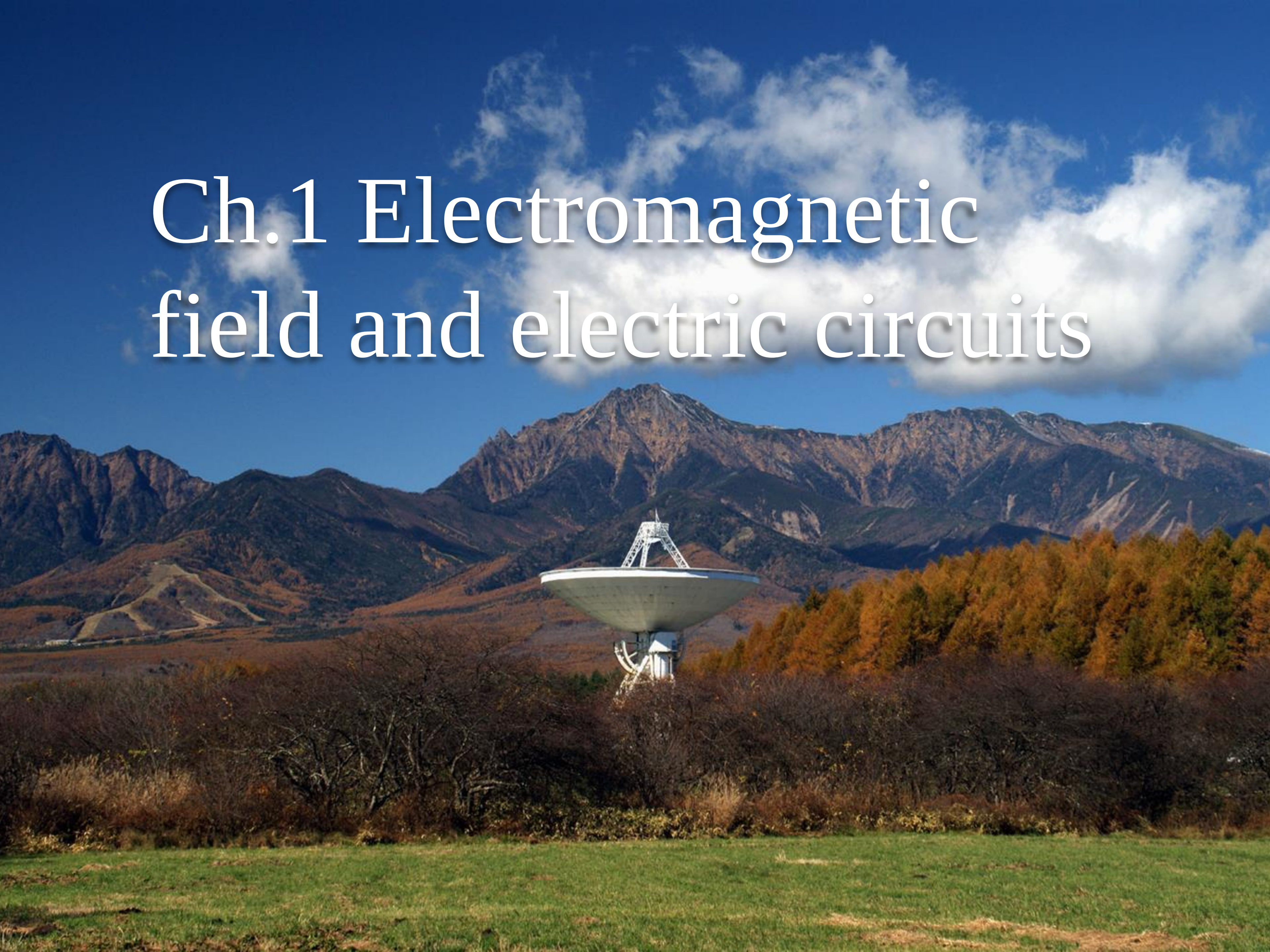
Syllabus

6. Signal, noise, waveform analysis
   6.1 Fluctuation
   6.2 Noise from amplifiers
   6.3 Modulation and analog signal transfer
   6.4 Discrete signal
7. Digital signal and digital circuits
   7.1 Introduction to digital signal
   7.2 Logic gates
   7.3 Logic circuits implementation
   7.4 Circuit implementation and simplification of logic operation
   7.5 AD/DA converters
   7.6 Digital filters
   7.7 Language to describe hardware: HDL

Outline Today

1. Electromagnetic field and electric circuits
   1.1 About this lecture
   1.2 What is electric circuit?
   1.3 Circuit diagrams
   1.4Two-terminal devices
   1.5 Resistors
   1.6 Capacitors
   1.7 Inductors
2. Introduction to linear circuits
   2.1 Linear systems and electric circuits

Ch.1 Electromagnetic field and electric circuits



For what this lecture is?

Experimentalists:

Knowledges on electric circuit are indispensable.

Purposes:

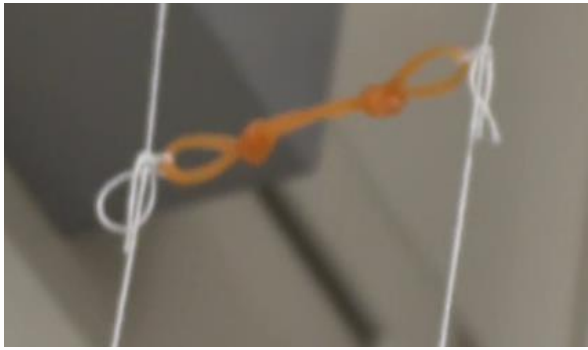
Understand how circuits work.

Design circuits along research plans

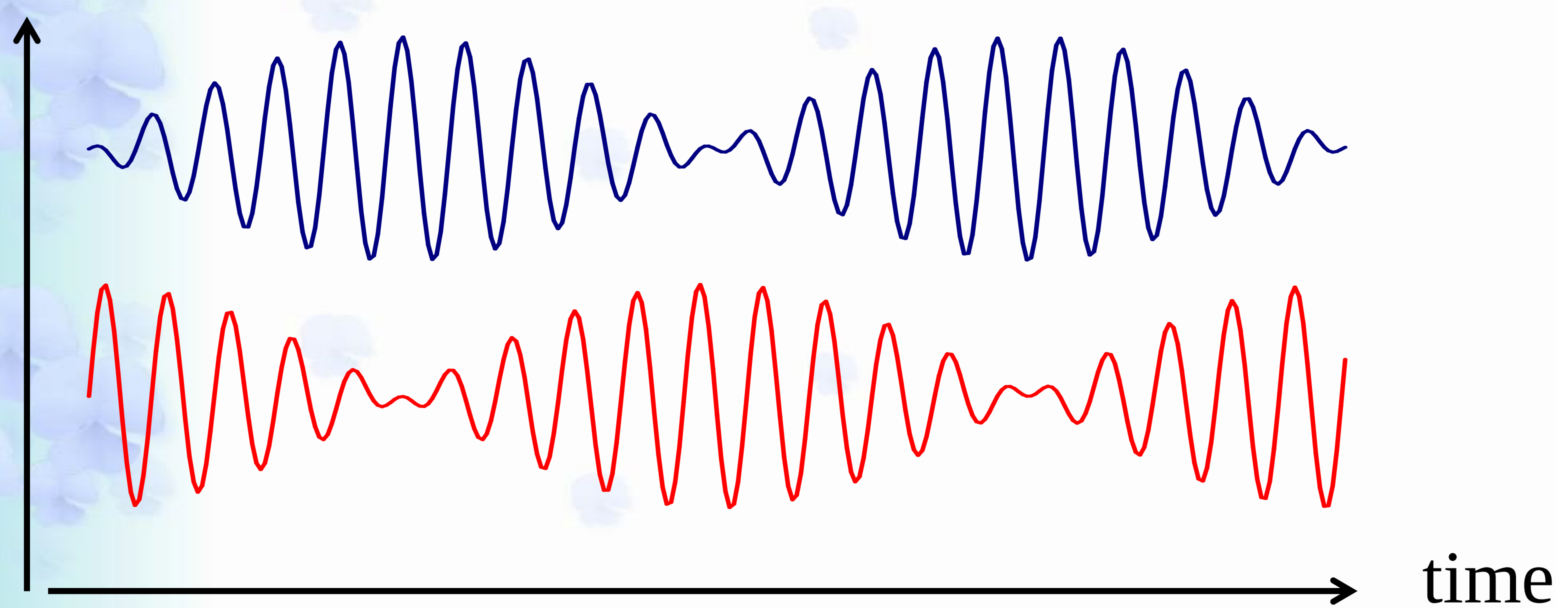
General physicists:

Meta physics

Coupled pendulum and neutrino oscillation



Pendulum oscillation



Electric Circuit: A treasure house of concept and language

Electric Circuit

Electromagnetic Field
- Lumped constant Circuit
- Distributed constant Circuit

Signal
- Noise
- Modulation
- Discrete signal

Material Science
- Metal
- Semi-conductor
- Ferromagnet

Linear response
- Transfer function
- Resonance
- Transient response

System stability
- Amplifier
- Feedback
- Nyquist diagam

Analog and digital
- Fourier tr.- z-tr.
- Analog filter - Digital filter

1.2 What is electric circuits?: Thunderbolt struck a plane!

Your answer?

1.

Fell down and crashed

2.

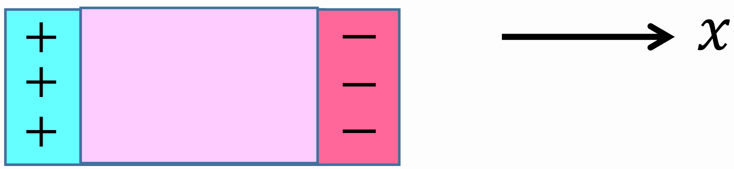
Damaged

3.

Nothing happened

Plasma frequency

$$m\frac{d^2x}{dt^2} = -eE$$



$$E = E_0 e^{-i\omega t}, \quad x = x_0 e^{-i\omega t} \rightarrow m\omega^2 x_0 = eE_0$$

Electric polarization: $P = -nex_0 = -\frac{ne^2E_0}{m\omega^2}$

$$\epsilon(\omega) = \frac{D(\epsilon)}{\epsilon_0 E(\omega)} = 1 + \frac{P(\omega)}{\epsilon_0 E(\omega)} = 1 - \frac{ne^2}{\epsilon_0 m\omega^2} = 1 - \frac{\omega_{\mathrm{p}}^2}{\omega^2}$$

$$\omega_{\mathrm{p}}^2 \equiv \frac{ne^2}{\epsilon_0 m}$$: Plasma frequency

Cu: $n = 8.5 \times 10^{22}$ /cc $\quad m^* = 1.3m_0$

$f_{\mathrm{p}} = \omega_{\mathrm{p}}/(2\pi) = 2.3 \times 10^{15}$ Hz $\quad$ λ = 130nm Near ultra-violet

Metals are super-screening materials!

Equipotential lines

1.3 Various circuit diagrams

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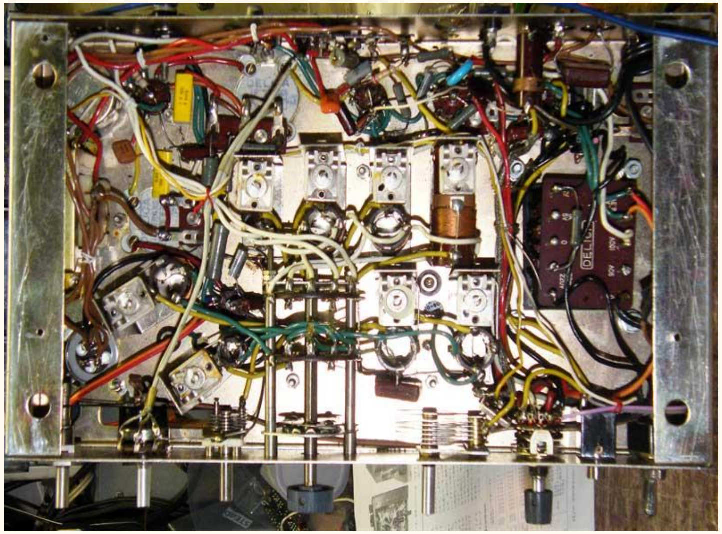
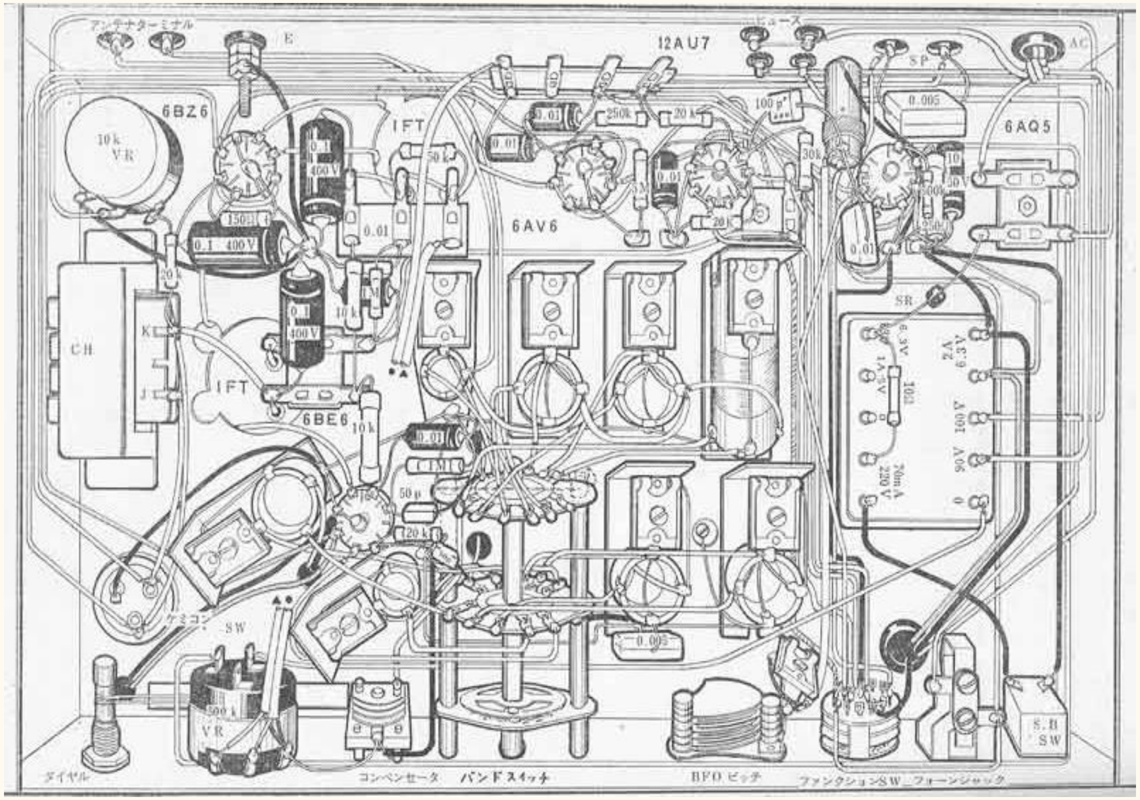
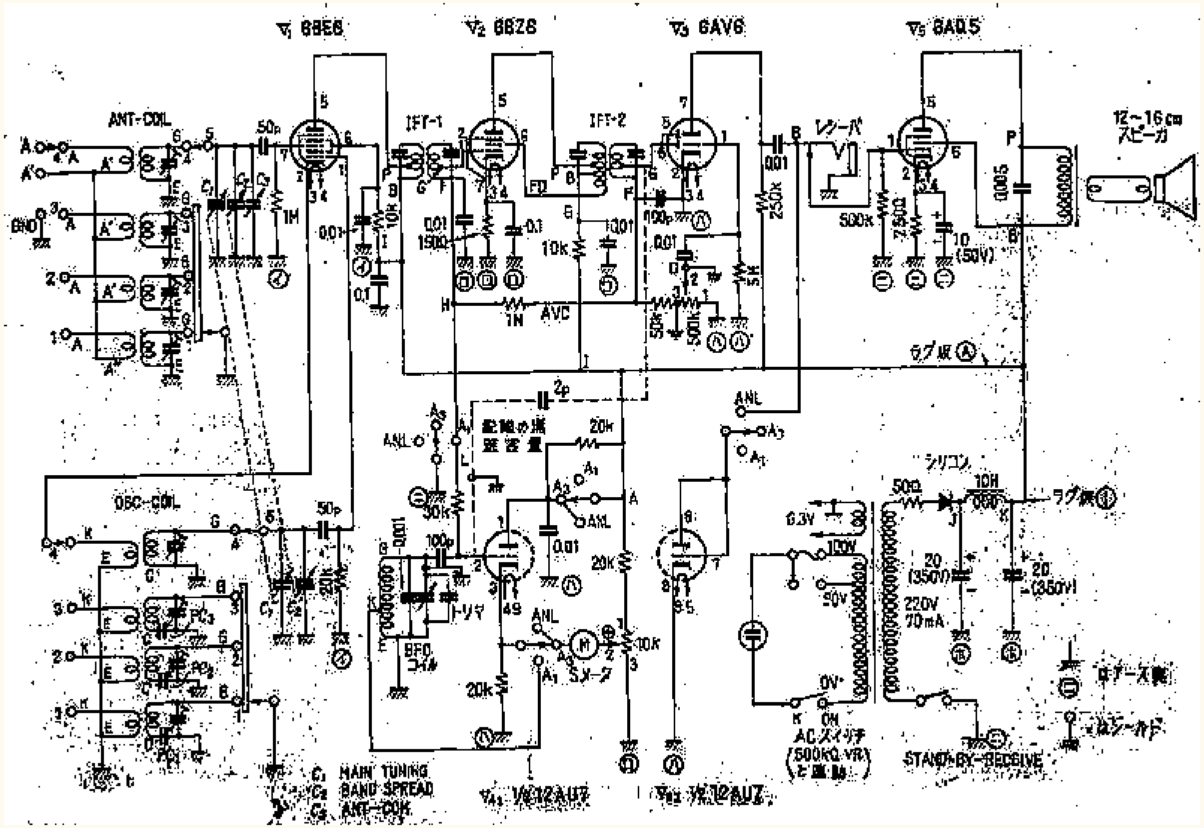


Picture diagram

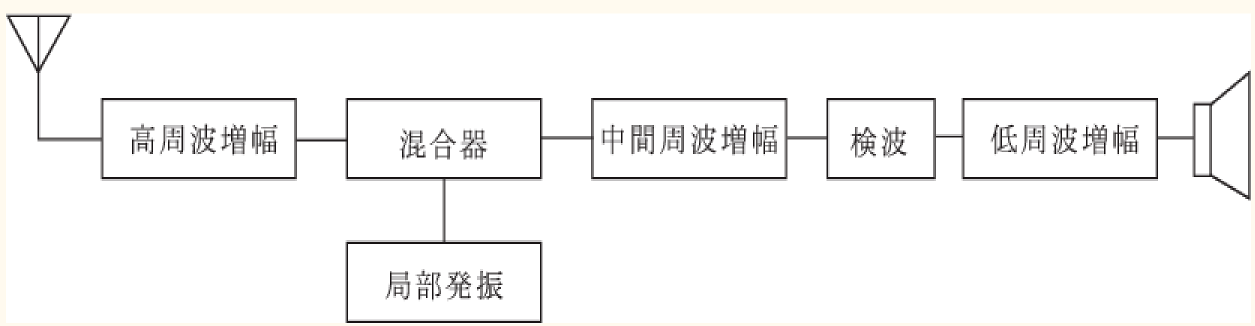


Various circuit diagrams

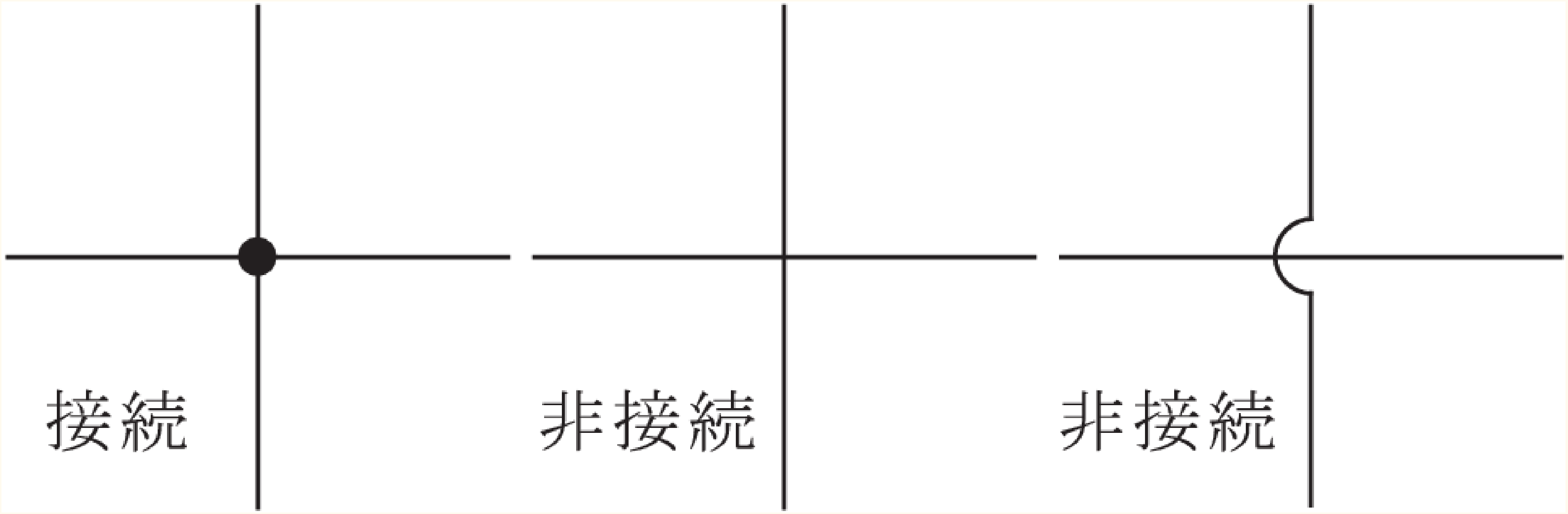


Parts + Wiring
= Wiring (Circuit) diagram

Block diagram



Wirings in electric circuits

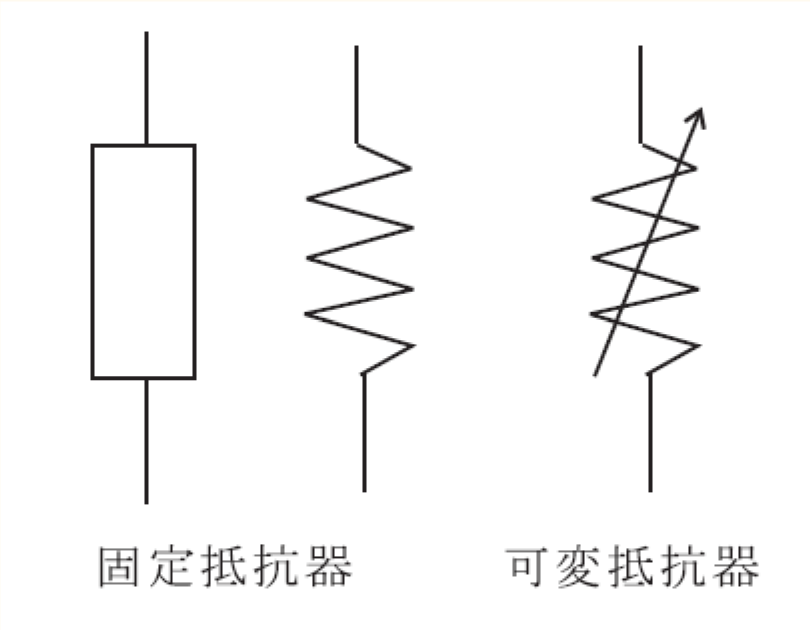


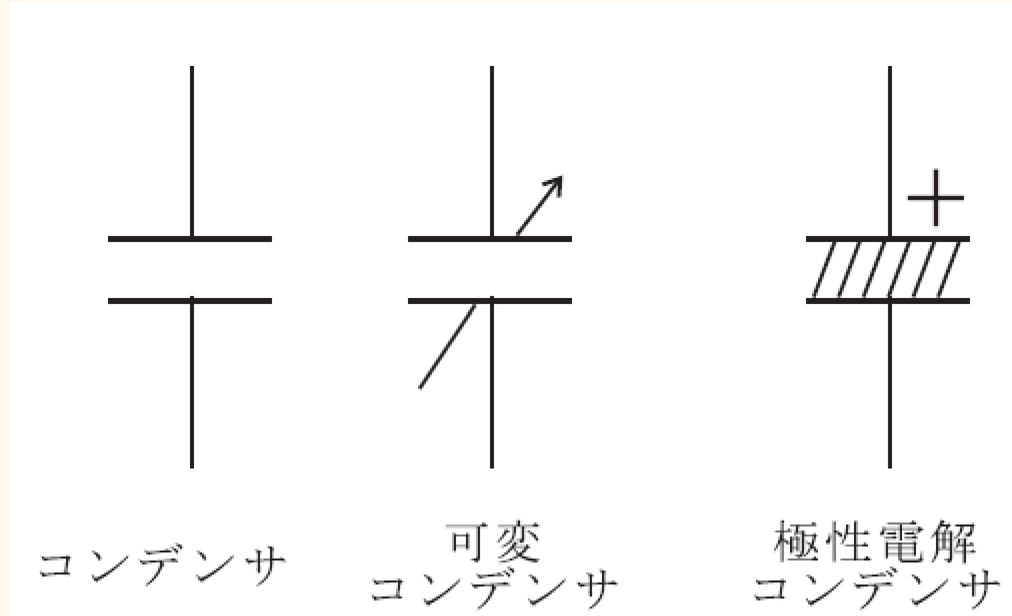
Connected   Not connected   Not connected

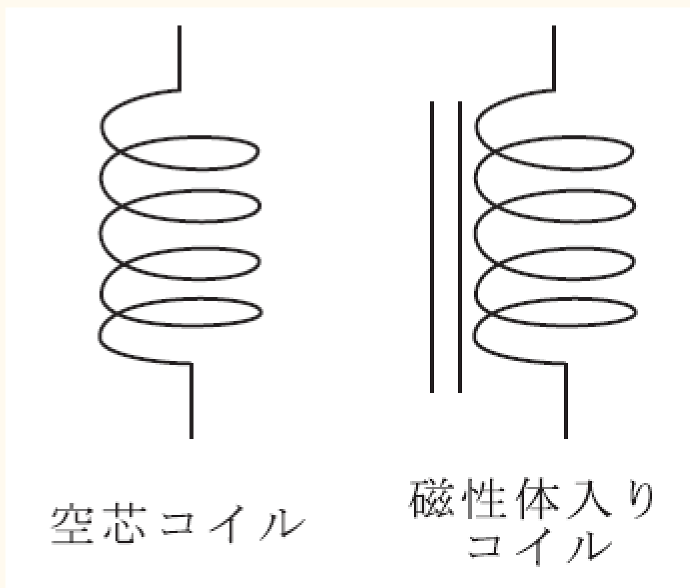
Violate electromagnetism theory

Concept of local electromagnetic field
= Lumped constant circuits (集中定数回路)

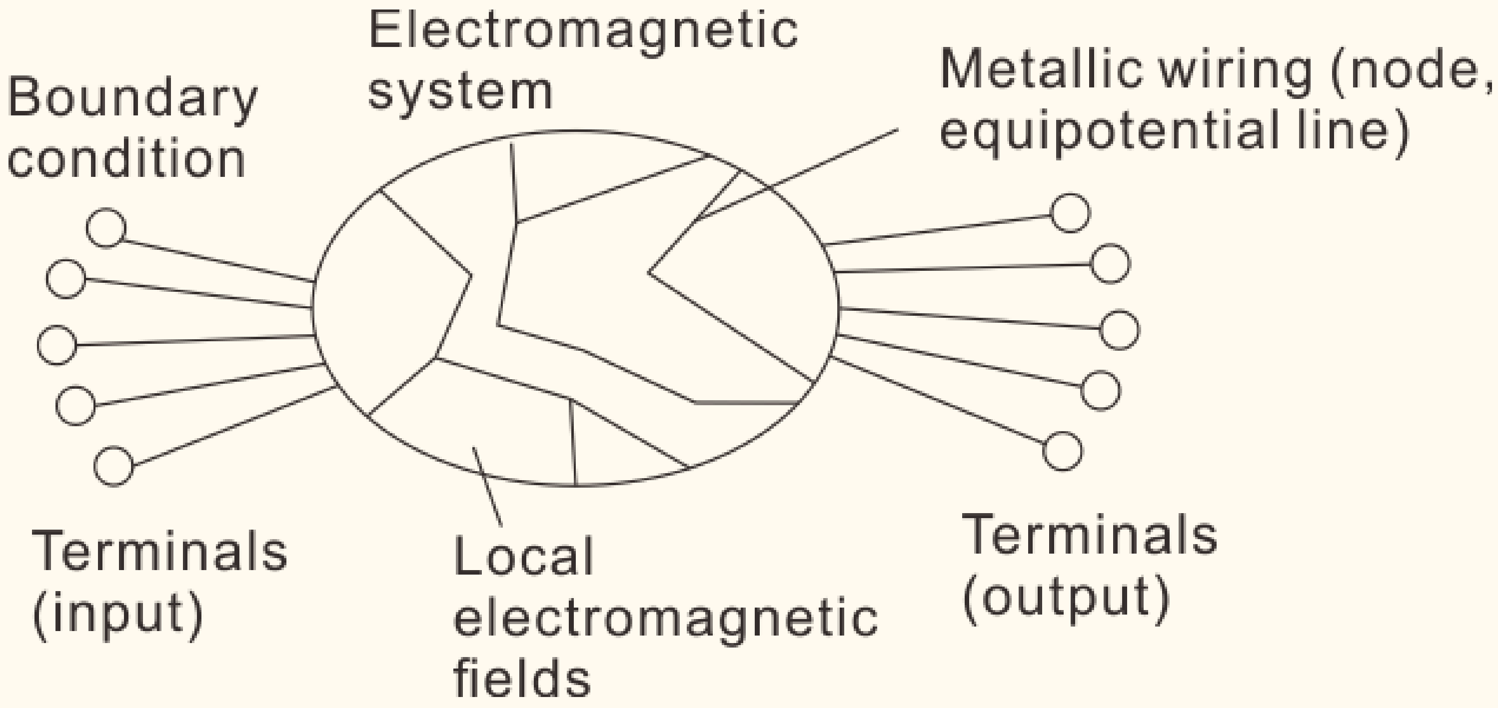
Circuit symbols for two-terminal devices



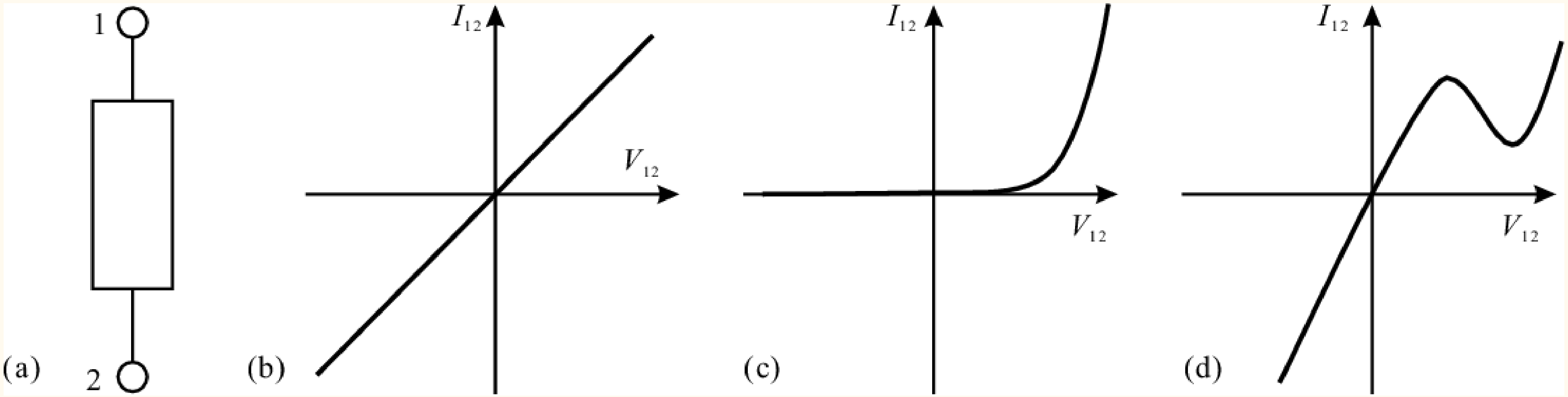




Basic concepts in electric circuits



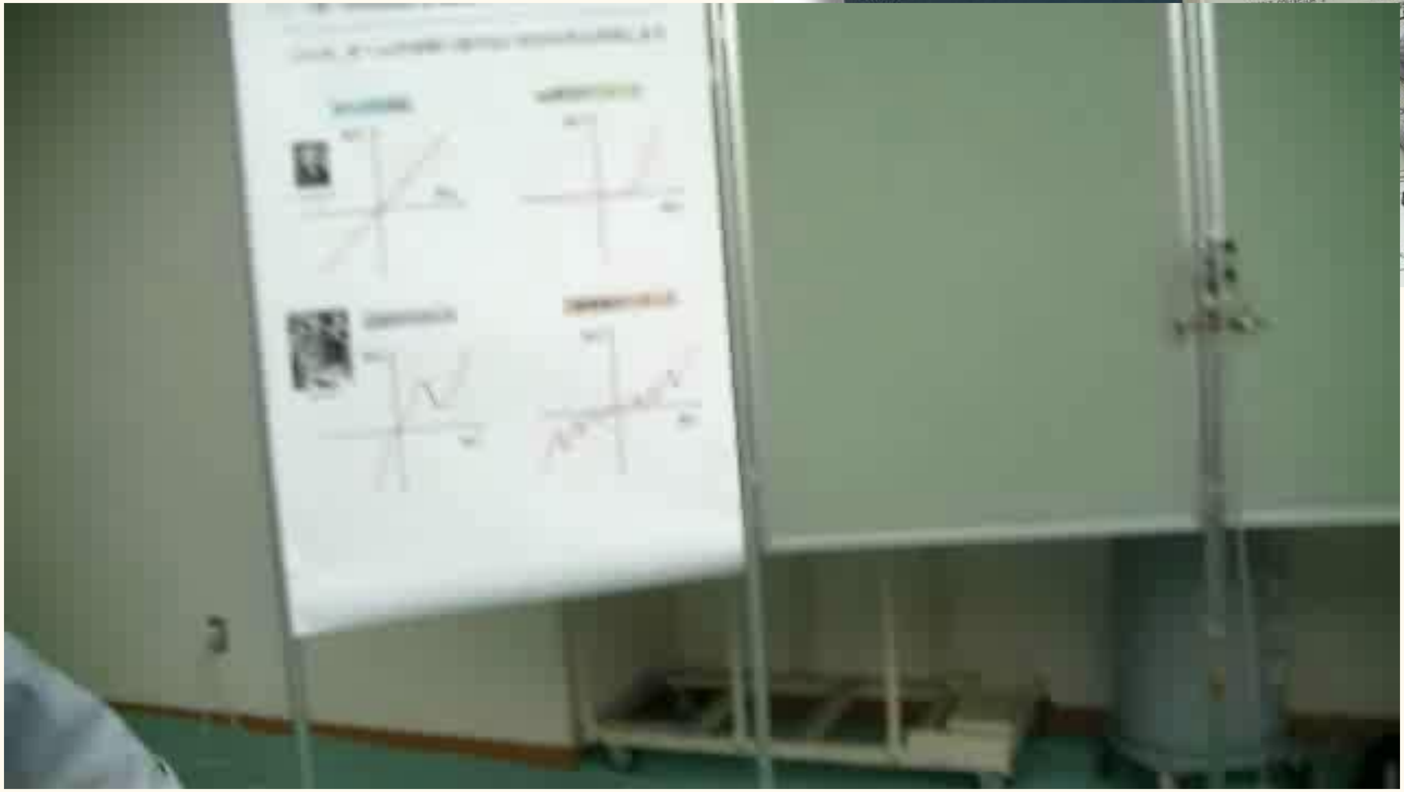
What is current-voltage characteristics?



Resistor

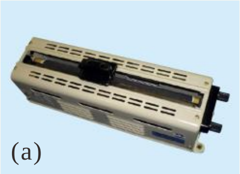
What is current-voltage characteristics?

Curve tracer



Variable resistors

Slide


(a)

(b)

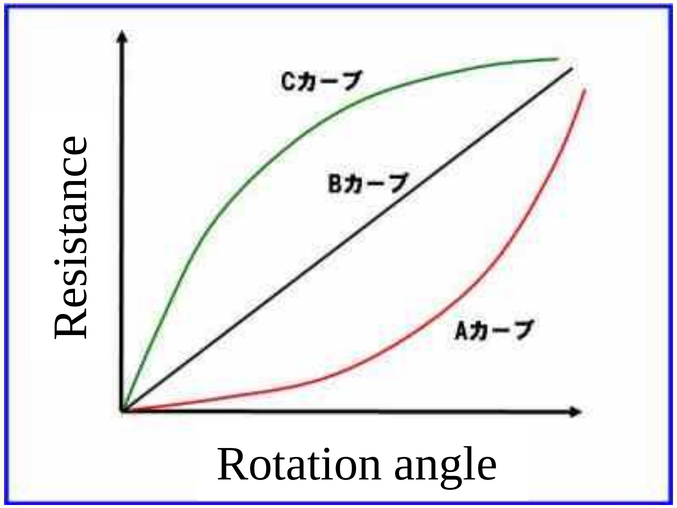

(c)


(d)

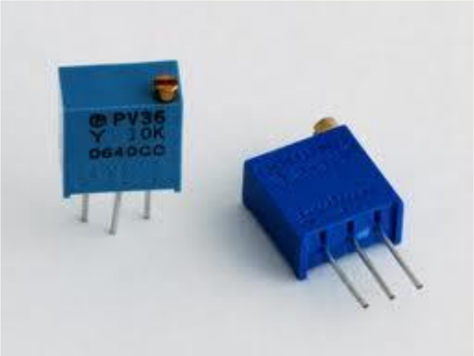

Carbon helical

Helical potentiometer

Rotary switch potentiometer

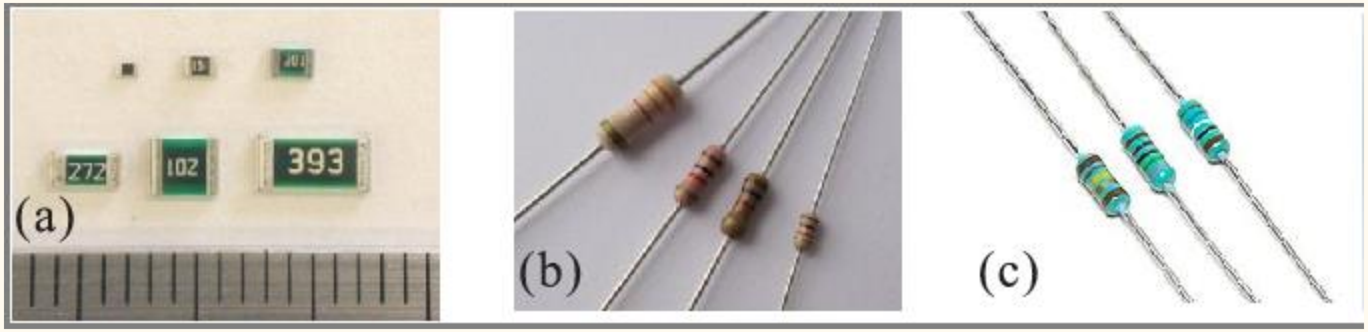


trimmer



Cermet trimmer

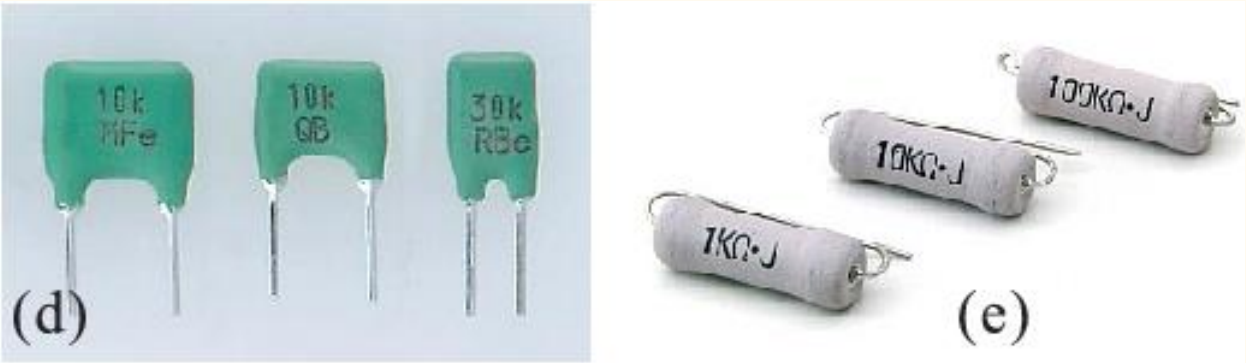
Fixed resistors



Chip resistors

Carbon film resistors

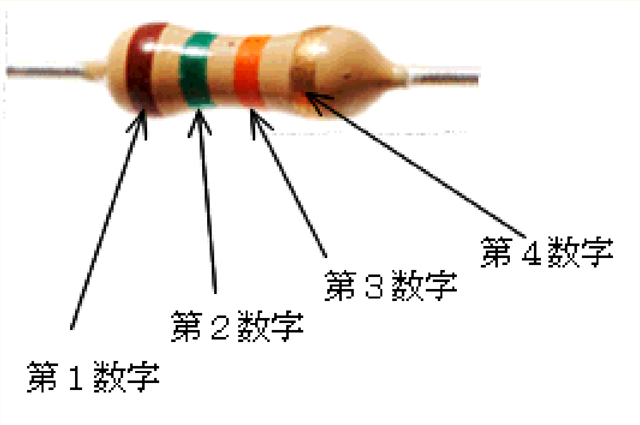
Metallic film resistors (spiral)

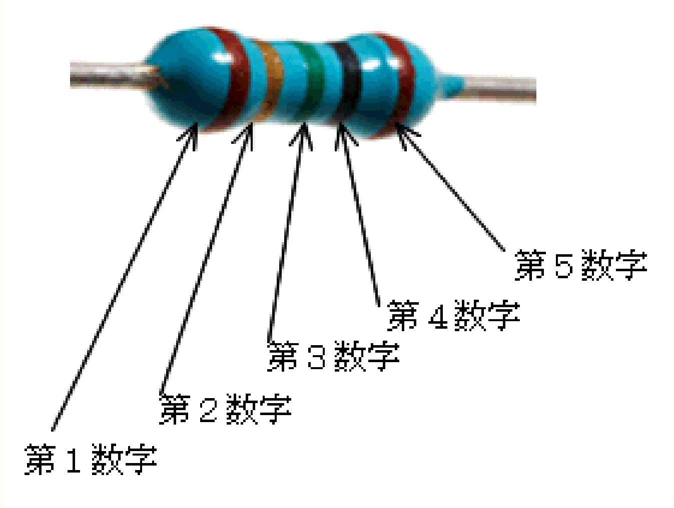


Metallic film resistors (meander)

High power type

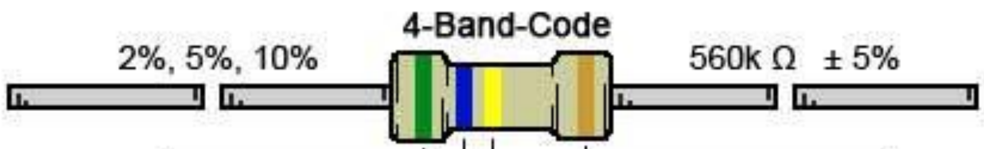
抵抗器のカラーコード



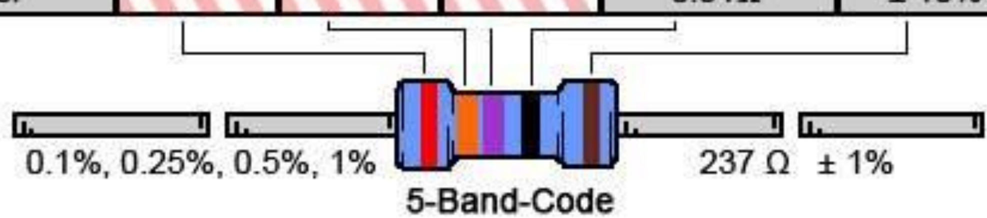


色	第1数字	第2数字	第3数字	第4数字	第5数字
黒	0	0	0	10^{0}	X
茶	1	1	1	10^{1}	±1%
赤	2	2	2	10^{2}	±2%
橙	3	3	3	10^{3}	X
黄	4	4	4	10^{4}	X
緑	5	5	5	10^{5}	X
青	6	6	6	10^{6}	X
紫	7	7	7	10^{7}	X
灰	8	8	8	10^{8}	X
白	9	9	9	10^{9}	X
金	X	X	X	10^{-1}	±5%
銀	X	X	X	10^{-2}	±10%
無色	X	X	X	X	±20%

Color code for resistors



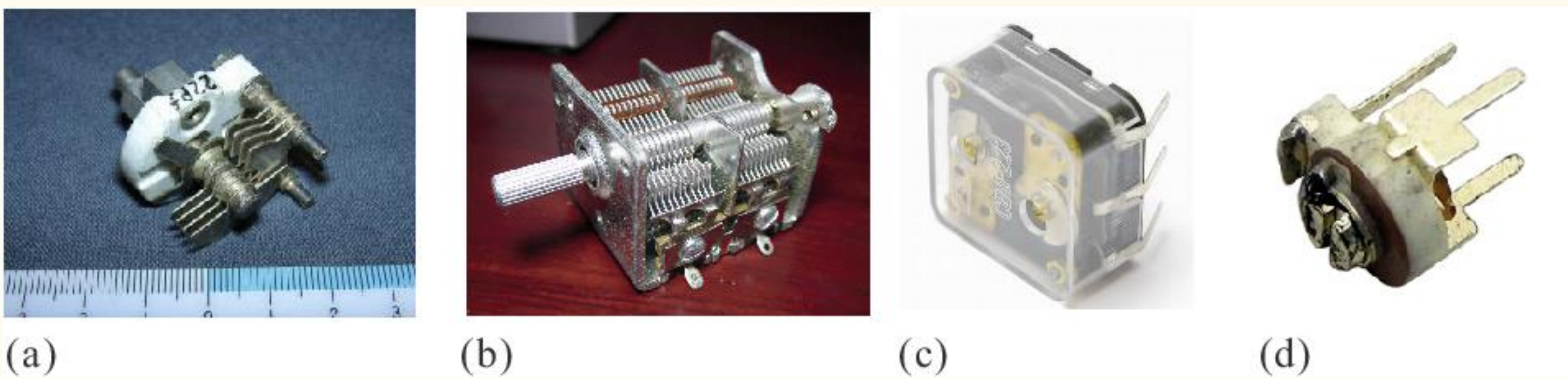
COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)



Big
boys
race
our
young
girls
but
Violet
generally
wins.

Variable capacitors

$$C = \epsilon\epsilon_0 \frac{S}{d}$$



Steatite

Tandem

Poly-Ethylene

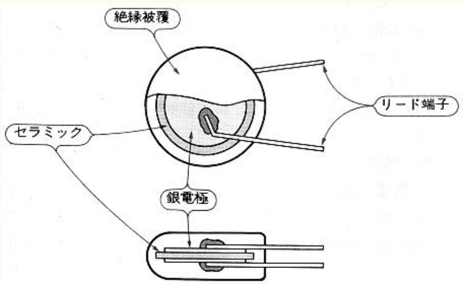
Ceramic

Air capacitor

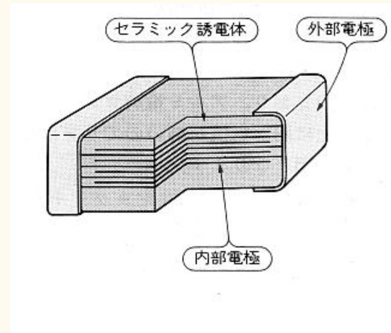
Fixed capacitors

Ceramic capacitors

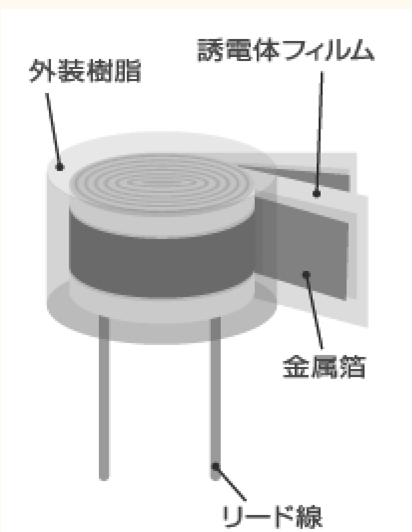
Single disk pair type



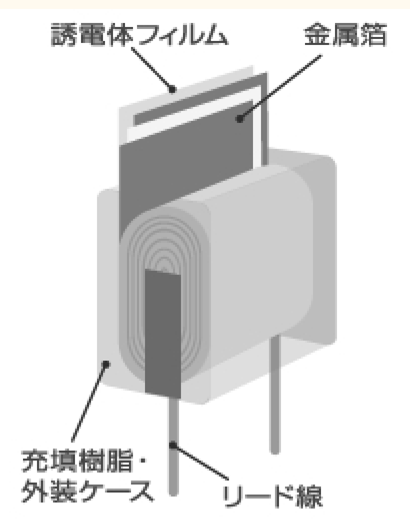
Stacked type



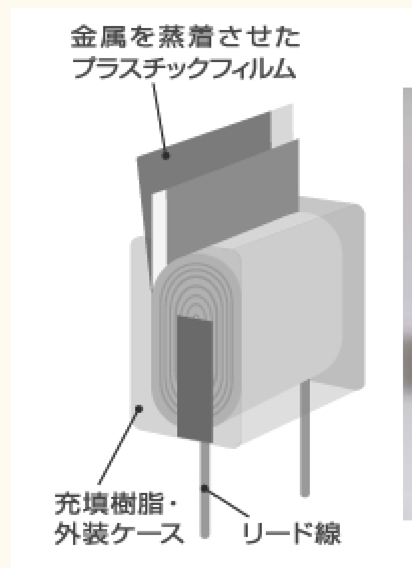
Film capacitors



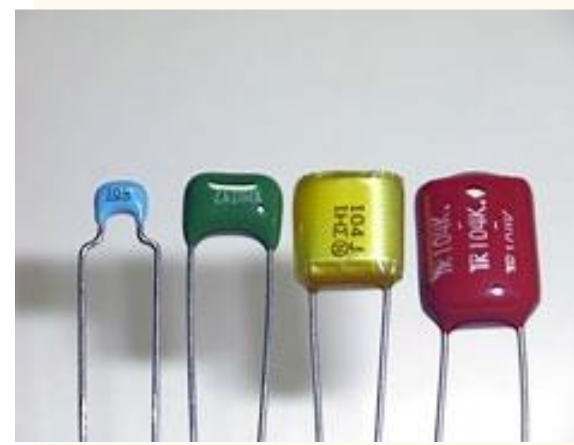
誘導



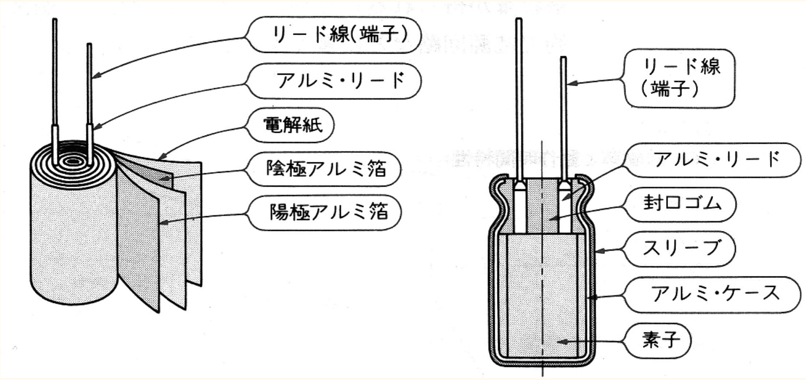
無誘導

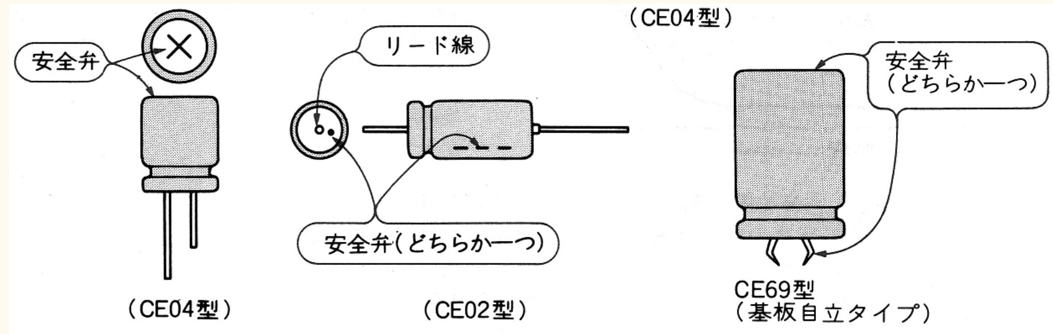


蒸着無誘導

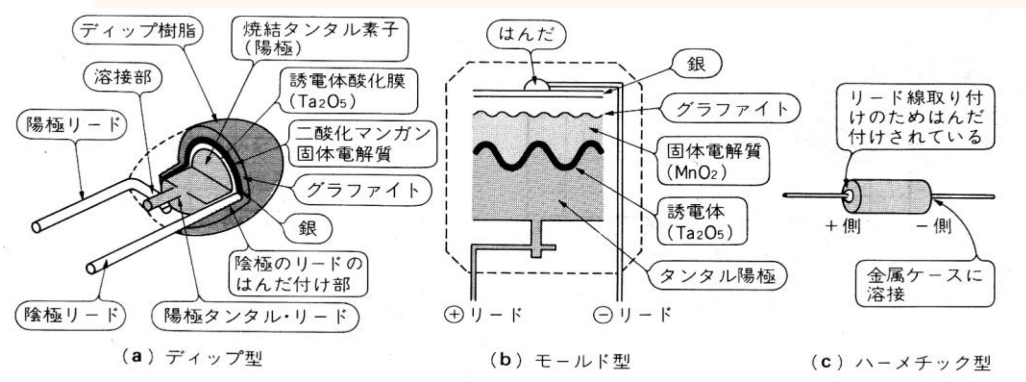


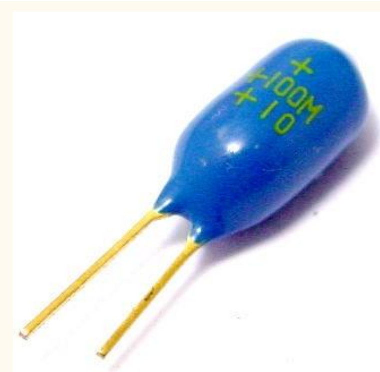
Chemical capacitors



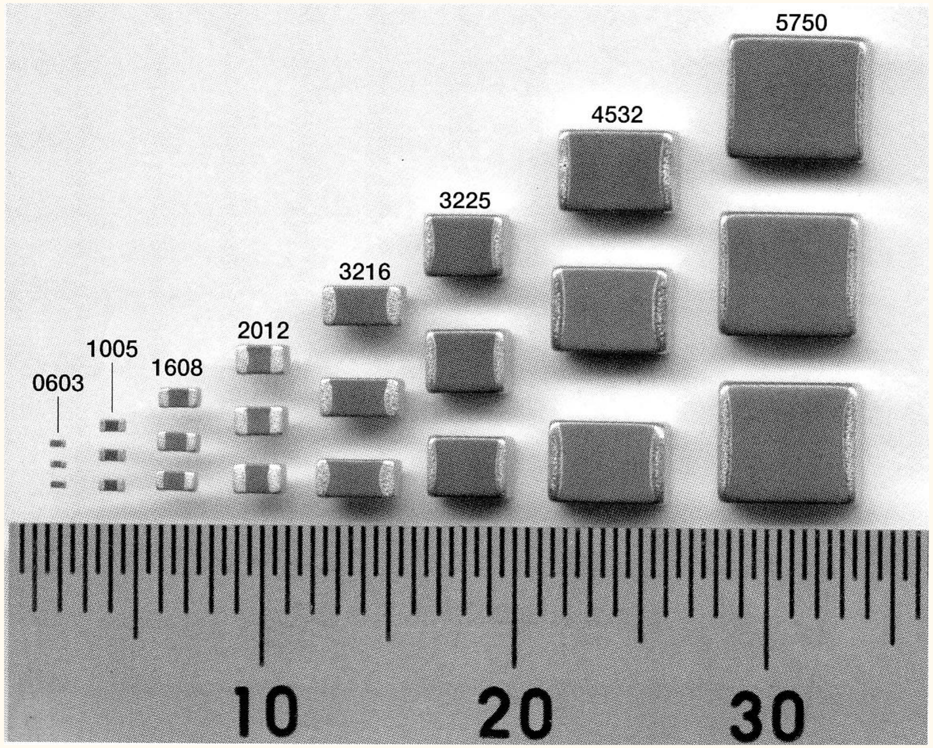


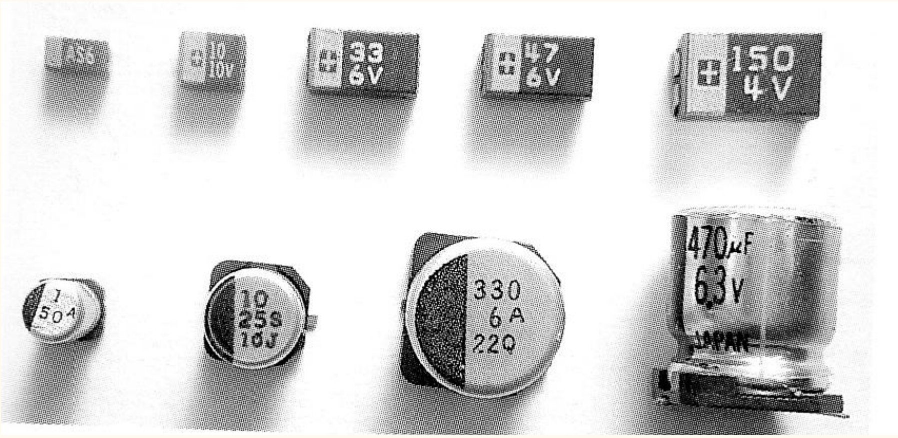
タンタル電解





Surface mount chip capacitors



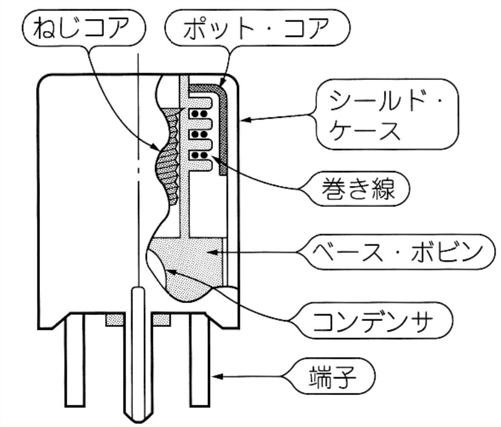


Variable inductors

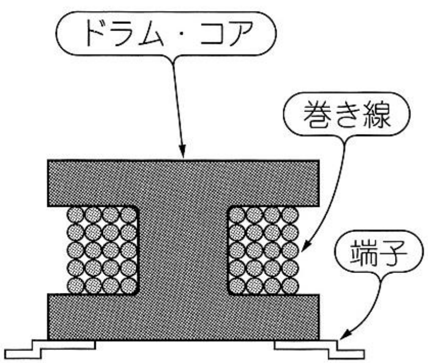
$$L = K \times \mu \frac{N^2}{l} S = K \times \mu n N S$$

$$K(\text{Nagaoka coef.}) = \frac{4}{3\pi\sqrt{1-k^2}} \left[\frac{1-k^2}{k^2} K(k) - \frac{1-2k^2}{k^2} E(k) - k \right]$$

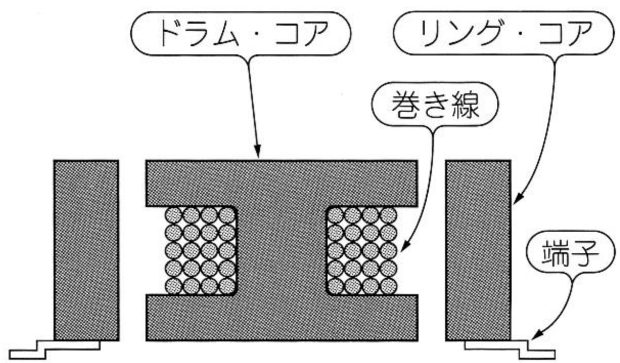
$$\frac{L}{2a} = \frac{\sqrt{1-k^2}}{k}$$



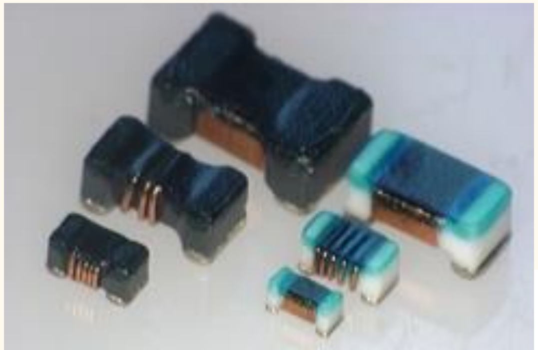
Fixed inductors

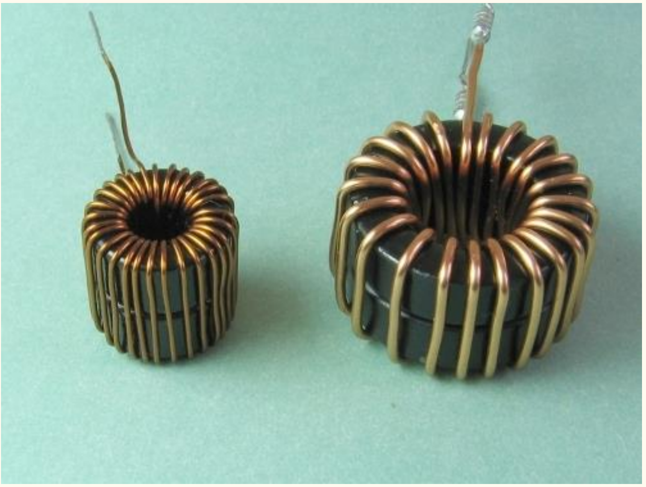


Open flux path



Closed flux path





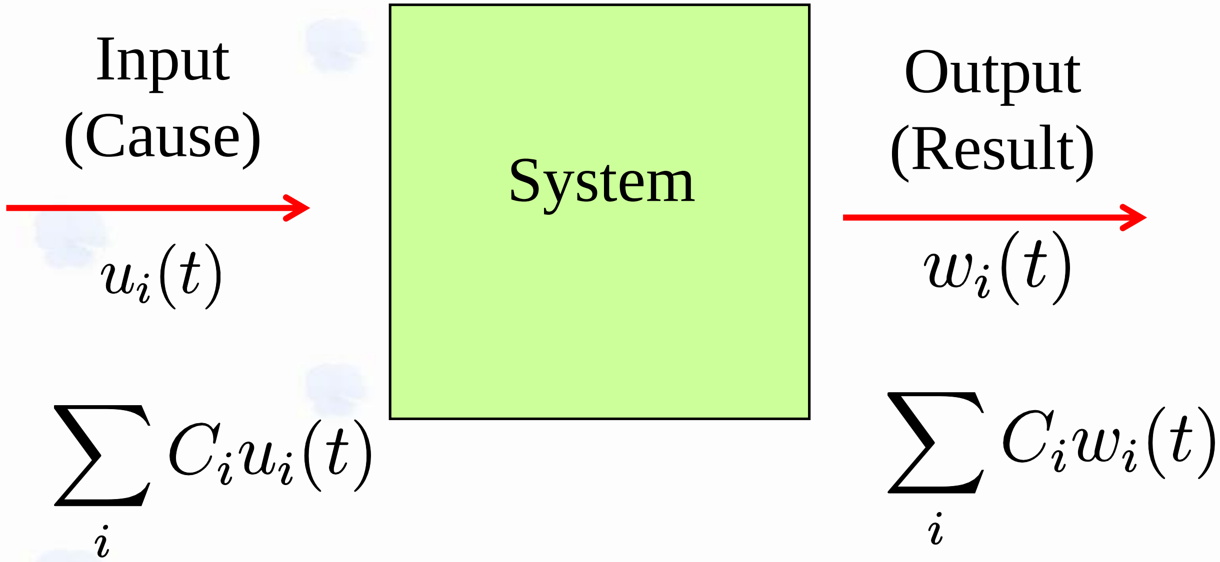
Toroidal coil

Chip inductor

Ch.2 Introduction to linear circuits

2.1.1 What is linear system?

$$f(C_1x_1 + C_2x_2) = C_1f(x_1) + C_2f(x_2)$$



Linear system: definition

$$w(t) = \mathscr{R}\{u(t)\}$$: Response

Requirements

Invariance: $\forall t_1 \quad w(t-t_1) = \mathscr{R}\{u(t-t_1)\}$

Causality: $u(t) = 0 \ (t < t_1) \ \rightarrow \ w(t) = 0 \ (t < t_1)$

Principle of superposition:

$$\forall C_1, C_2 \in C, \quad \mathscr{R}\{C_1 u_1(t) + C_2 u_2(t)\} = C_1 w_1(t) + C_2 w_2(t)$$

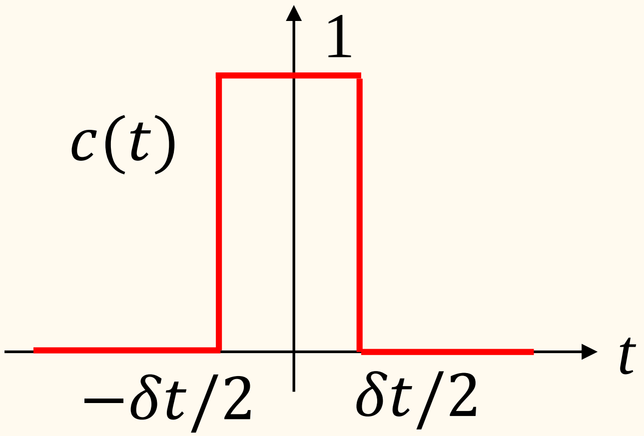
$$\mathscr{R}\left\{\sum_i C_i u_i(t)\right\} = \sum_i C_i w_i(t)$$

$$\mathscr{R}\left\{\int_{-\infty}^{\infty} c(q) u(q,t) dq\right\} = \int_{-\infty}^{\infty} c(q) \mathscr{R}\{u(q,t)\} dq$$

Transfer function

Variable q → time t

$$c(t) = \begin{cases} 1 & |t| \le \delta t/2, \\ 0 & \text{others} \end{cases}$$



$$u(t) = \sum_i u(t_i)c(t - t_i) \quad \rightarrow \quad u(t) = \int_{-\infty}^{\infty} dt' u(t')c'(t - t')$$

$$c'(t - t') = \delta(t - t')$$

$$w(t) = \mathscr{R}\{u(t)\} = \mathscr{R}\left\{\int_{-\infty}^{\infty} u(t')\delta(t - t')dt'\right\}$$

$$= \int_{-\infty}^{\infty} u(t')\mathscr{R}\{\delta(t - t')\}dt' = \int_{-\infty}^{\infty} u(t')\xi(t, t')dt'$$

Transfer function (Impulse response)

$$\xi(t,t') \equiv \mathscr{R}\{\delta(t-t')\}$$: Impulse response, weight function

$$\text{Invariance} \rightarrow \xi(t,t_1) = \xi(t-t_1)$$

$$w(t) = \int_{-\infty}^{\infty} u(t')\xi(t-t')dt' = \int_{-\infty}^{\infty} u(t-t')\xi(t')dt'$$

Convolution

Fourier transform:

$$X(\omega) = \int_{-\infty}^{\infty} x(t)e^{-i\omega t}dt, \quad x(t) = \int_{-\infty}^{\infty} X(\omega)e^{i\omega t}\frac{d\omega}{2\pi}$$

$$W(\omega) = U(\omega)\underline{\Xi(\omega)}$$

Transfer function

Summary

1. Electromagnetic field and electric circuits
   Metals: super screening material
   Circuit diagrams
   Local electromagnetic field
2. Introduction to linear circuits
   Transfer function