電子回路論第3回
Electric Circuits for Physicists

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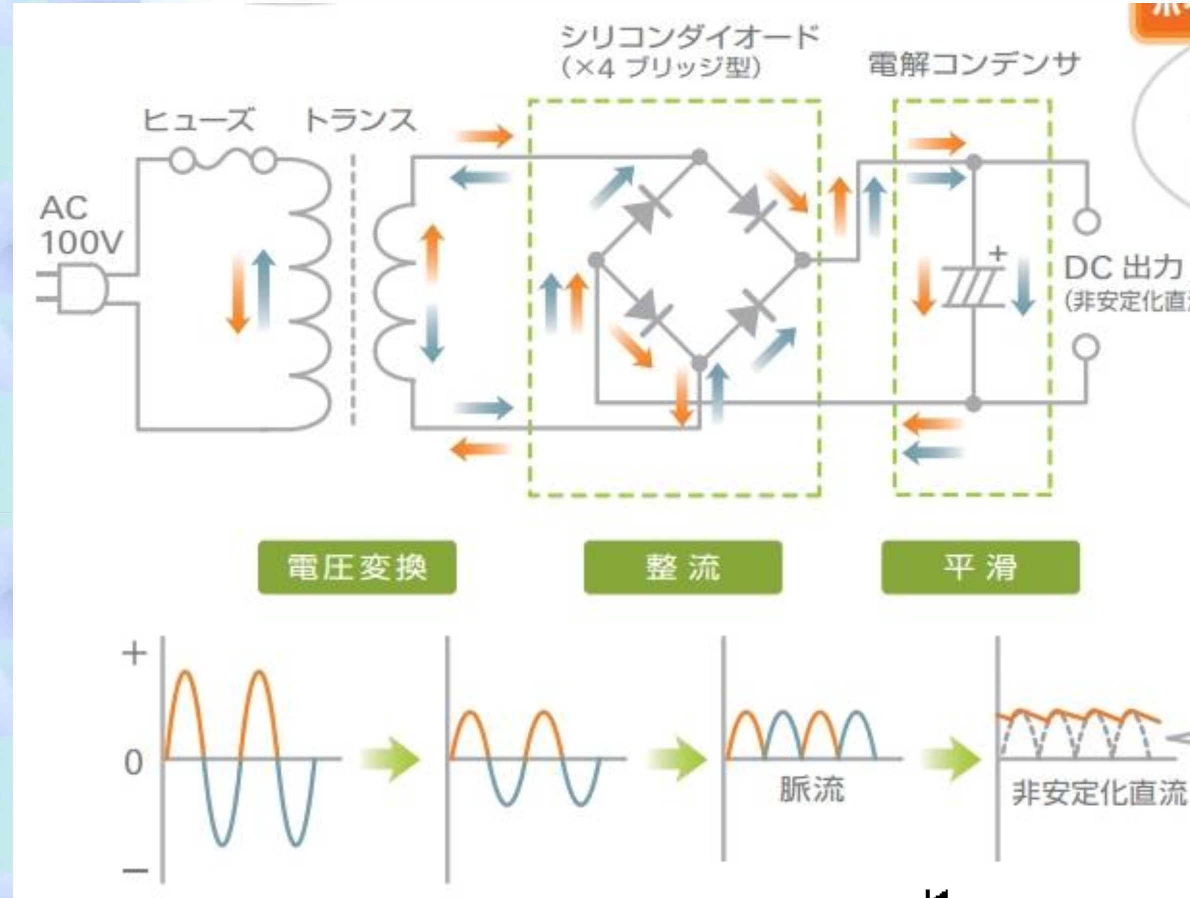
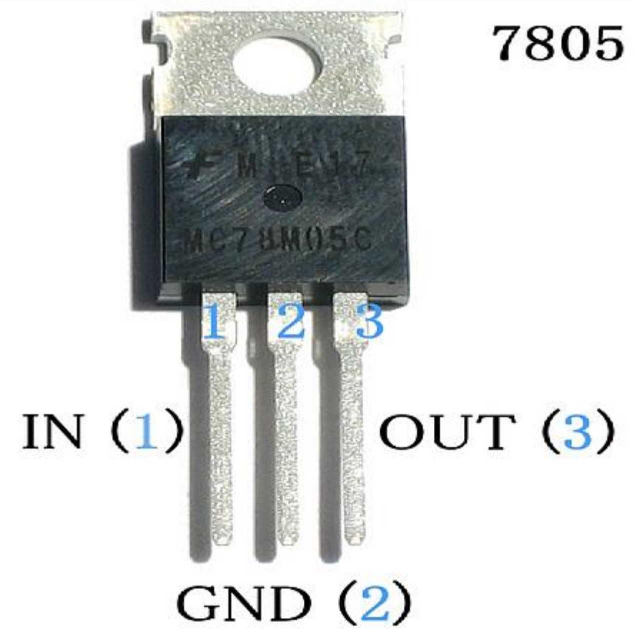
電源の雑知識 (続き）

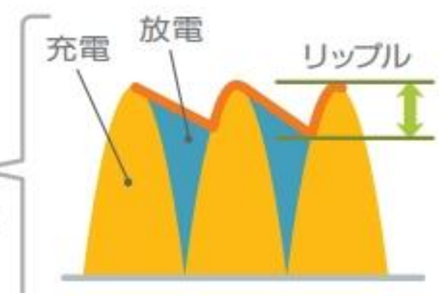
Miscellaneous knowledge on power supplies (continued)

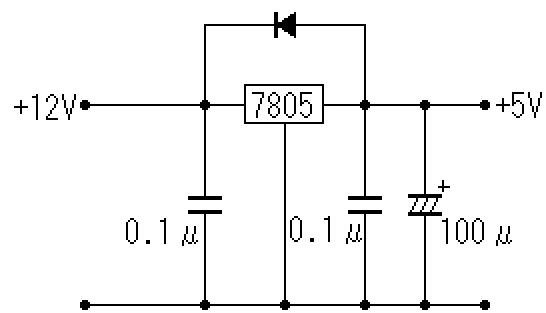
DC Stabilized Power Supply 直流安定化電源

Series (Dropper) regulation









From TDK web page

Series regulator power supply

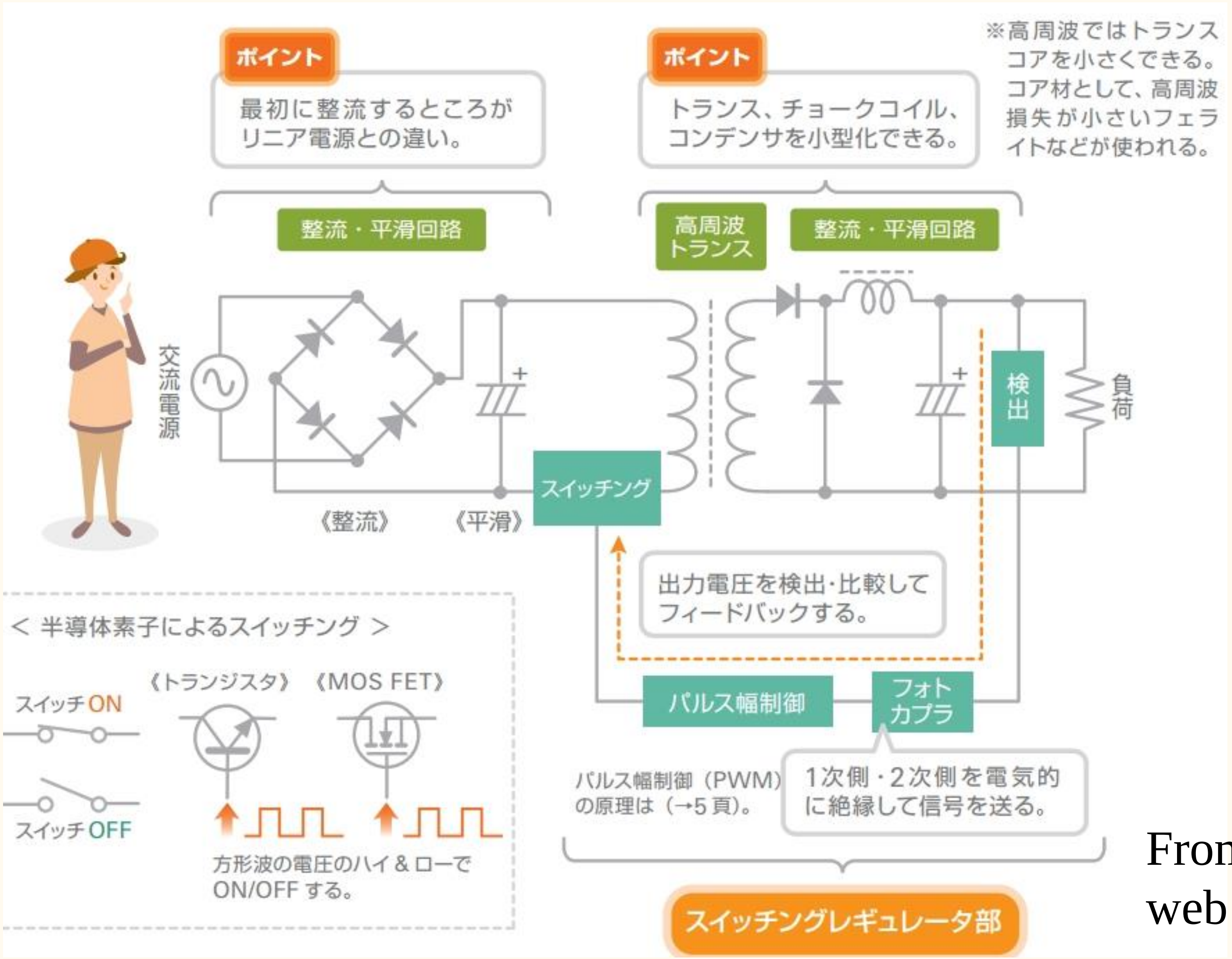
Uni-polar

Dual tracking

High precision

Bi-polar current source

Switching regulation

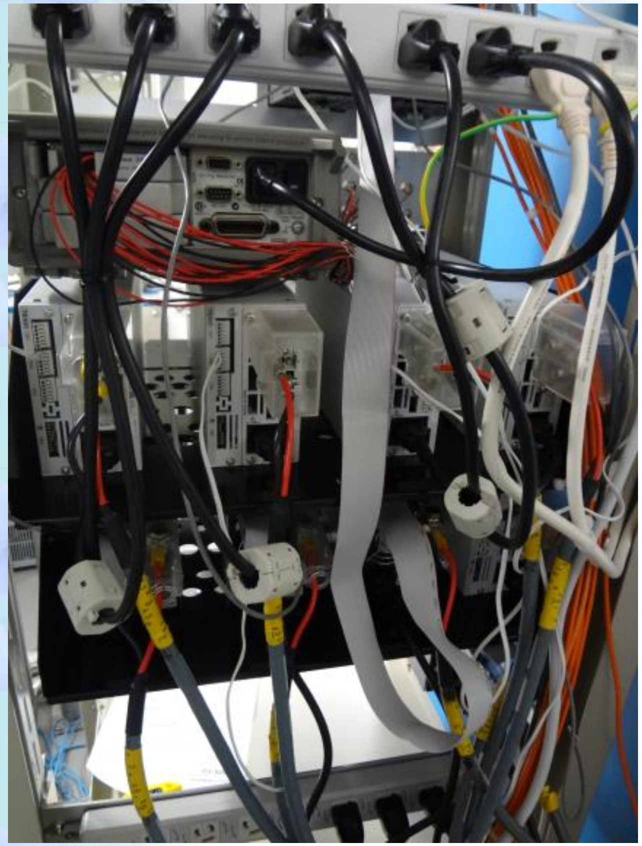


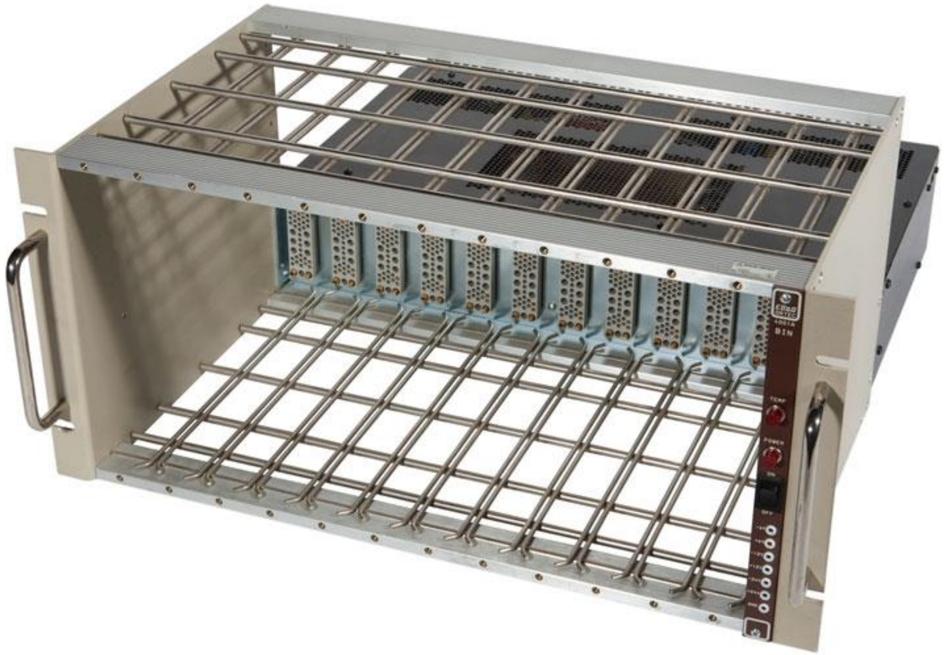
From TDK web page

Switching regulator power supply

Molecular beam epitaxy
Control panel

Bin 電源ビン





Complicated power lines ⟶ Bin

Outline Today

2.5 Theorems for paired terminal circuits

Superposition, Ho-Tevenin, Reciprocity

2.6 Duality

2.7 Passive devices (elements) and active devices

Ch.3 Transfer function and transient response

3.1 Transfer function of single-pair terminal circuits

Resonance circuit

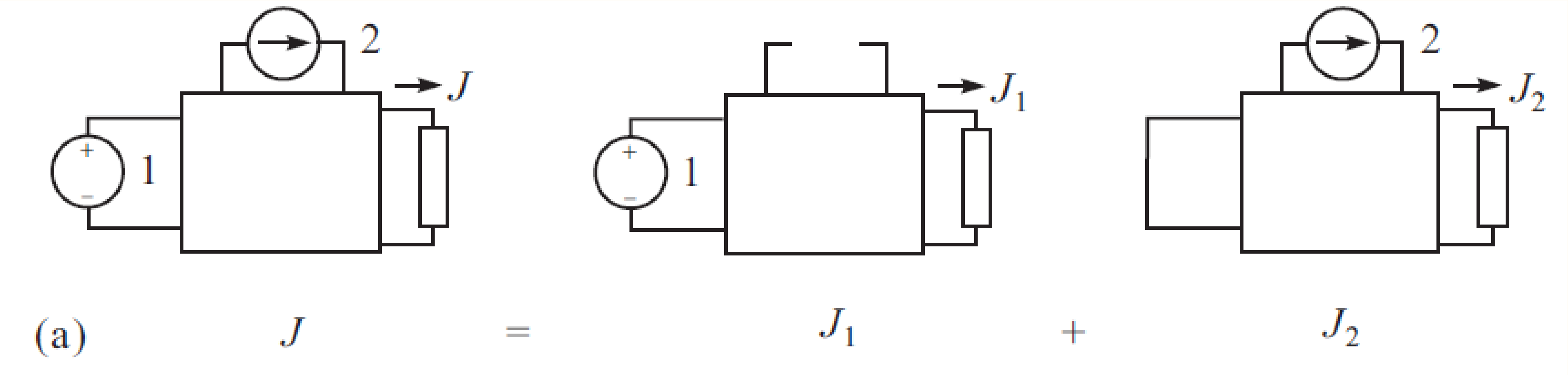
Bode plot

General properties

Appendix B Bridges and balance circuits

Appendix C General properties of resonance circuits

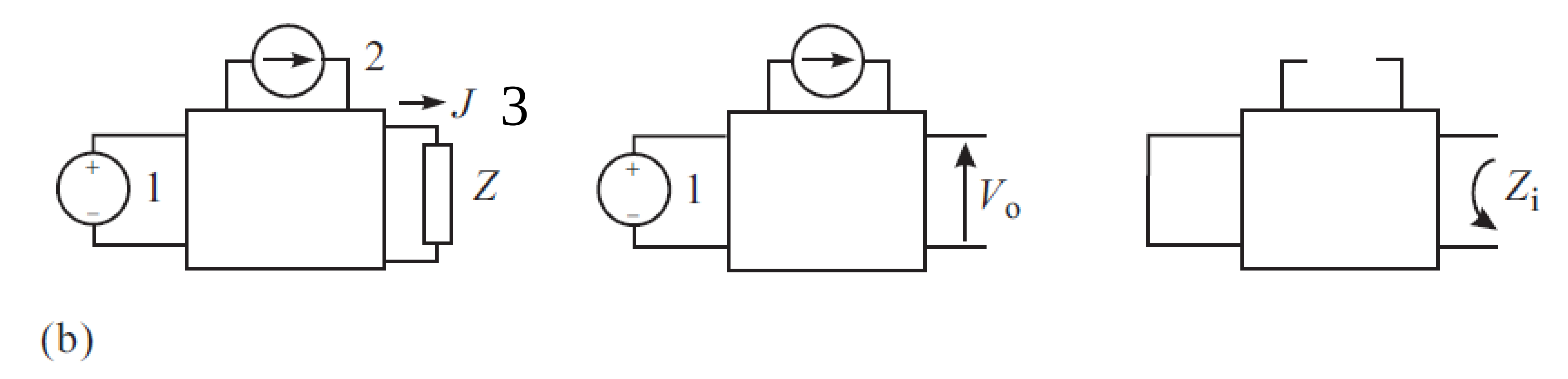
Superposition theorem



$$J = \sum_{i} J_i$$

J_i: The current caused by i-th power source.

Ho-Thevenin's theorem



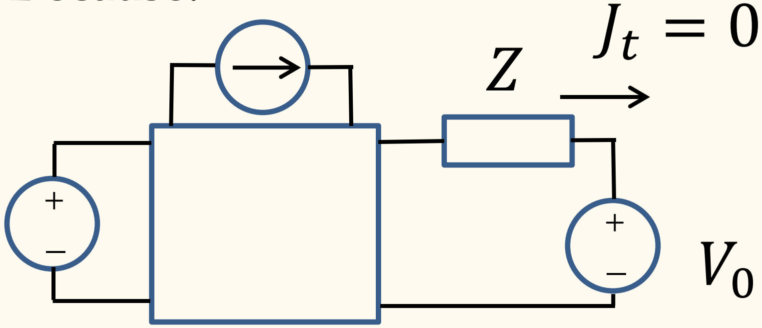
Consider a circuit with an open terminal pair (No.3). Obtain current J when the open pair is connected with impedance Z.

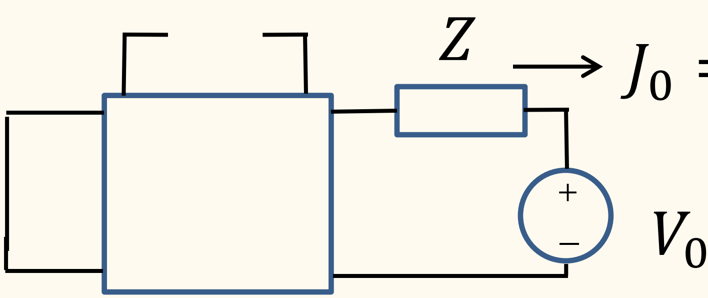
1. Measure the open terminal voltage V_0.
2. Turn off all the power sources (voltage sources: short, current sources: open). Measure the open circuit impedance Z_i.

Then

$$J = \frac{V_0}{Z + Z_i}$$

Because:

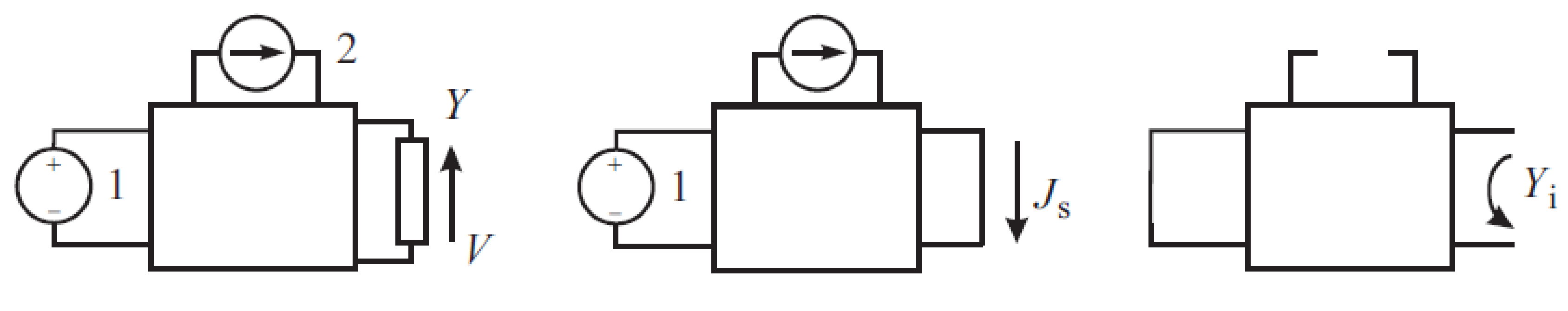




$$J_0 = -\frac{V_0}{Z + Z_i}$$

$$J = J_t - J_0 = \frac{V_0}{Z + Z_i}$$

Norton’s theorem



$$V = \frac{J_s}{Y + Y_i}$$

Dual theorem for Ho-Tevenin.

Comments on Tellegen's theorem

$i = 1, \cdots, n$: index of nodes, $j = 1, \cdots, m$: index of branches

$$a_{ij} = \begin{cases} 1 : & i \text{ is the start of } j, \\ -1 : & i \text{ is the end of } j, \\ 0 : & \text{others} \end{cases}$$ incidence matrix

redundancy $\rightarrow (n-1) \times m$ matrix D : irreducible incidence matrix

J_j, V_j : current and voltage along branch j, W_i : potential of node i.

Kirchhoff's first law: $D\boldsymbol{J} = 0$ Second law: $\boldsymbol{V} = {}^t\mathcal{D}\boldsymbol{W}$

$$\sum_{i=1}^{m} V_i J_i = ({}^t\mathcal{D}\boldsymbol{W}) \cdot \boldsymbol{J} = {}^t\boldsymbol{W}\mathcal{D}\boldsymbol{J} = 0 \qquad \boldsymbol{V} \perp \boldsymbol{J}$$

($V_i J_i$:) Power of i-th branch

Comments

1. Power conservation law
2. Holds for any kind of circuit (irrespective of linear, or non-linear)
3. Holds for two independent circuit conditions (as long as D is the same)

Reciprocity theorem

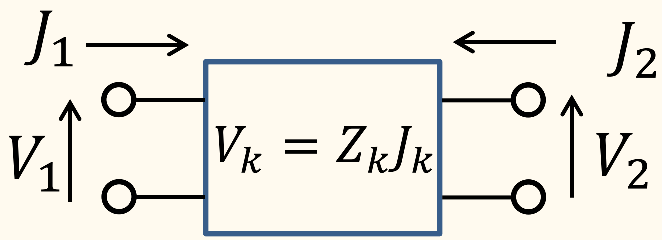
An n-terminal pair linear circuit

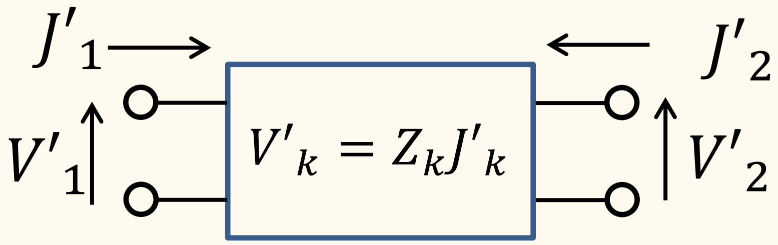
At one state $(V_1, J_1), (V_2, J_2), \cdots, (V_n, J_n)$,

at another state $(V'_1, J'_1), (V'_2, J'_2), \cdots, (V'_n, J'_n)$

$$\sum_{i=1}^{n} V_i J'_i = \sum_{i=1}^{n} V'_i J_i$$

Proof: Consider a two terminal-pair circuit with m branches.





Tellegen's theorem
(and comment no.3)

$$-V_1 J'_1 - V_2 J'_2 + \sum_k V_k J'_k = 0$$

$$-V'_1 J_1 - V'_2 J_2 + \sum_k V'_k J_k = 0$$

$$V_k J'_k = V'_k J_k = Z_k J_k J'_k$$

$$\therefore V_1 J'_1 + V_2 J'_2 = V'_1 J_1 + V'_2 J_2 \quad //$$

(This also holds for circuits with mutual inductances.)

2.6 Duality 双対性

直列接続	並列接続
開放	短絡
電場	磁場
キルヒホッフの第 2 法則	キルヒホッフの第 1 法則
電圧	電流
インピーダンス	アドミッタンス
抵抗	コンダクタンス
静電容量	インダクタンス
鳳-テブナンの定理	ノートンの定理

2.6 Duality

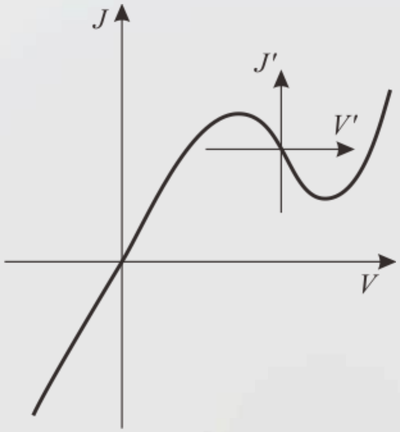
Series	Parallel
Open	Short
Voltage	Current
Impedance	Admittance
Capacitance	Inductance
Electric field	Magnetic field
Resistance	Conductance
Ho-Thevenin	Norton
Kirchhoff's 2^{nd} law	Kirchhoff's 1^{st} law

2.7 Definition: Passive elements and active elements

Two terminal: current J, voltage V

$JV \geq 0$: passive element

$JV < 0$: active element



Locally active two-terminal element

More than three-terminal: treat as a terminal pair circuit

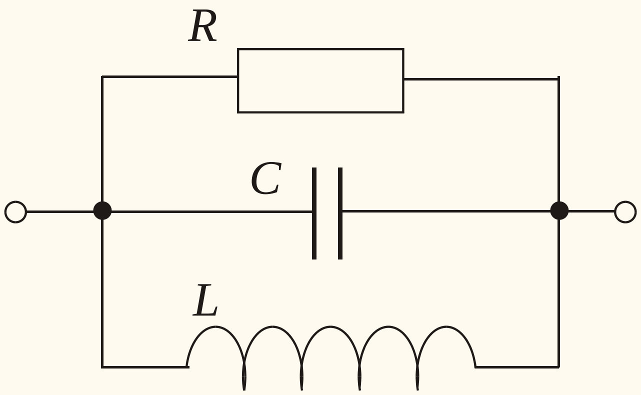
$$P = J_{\mathrm{in}} V_{\mathrm{in}} + J_{\mathrm{out}} V_{\mathrm{out}}$$

$P \geq 0$: passive element

$P < 0$: active element

Ch.3 Transfer function and transient response

3.1.1 Resonance Phenomena



Harmonic oscillator: $\dfrac{d^2q}{dt^2} = -\omega_0^2 q$

Kirchhoff's law

$$L\frac{dJ_{\rm L}}{dt} = -L\frac{d^2q_{\rm L}}{dt^2} = \frac{q}{C} = RJ_{\rm R} = R\frac{dq_{\rm R}}{dt}$$

$$dq_{\rm L} + dq_{\rm R} + dq = 0$$

$$\frac{d^2q}{dt^2} + \frac{1}{CR}\frac{dq}{dt} + \frac{1}{LC}q = \frac{d^2q}{dt^2} + \frac{1}{\tau}\frac{dq}{dt} + \omega_0^2 q = 0$$

$$q = \exp(\lambda t) \qquad \lambda = \frac{1}{2\tau}\left[-1 \pm \sqrt{1-4(\omega_0\tau)^2}\right] \approx -\frac{1}{2\tau} \pm i\omega_0 \quad (\omega_0\tau \gg 1)$$

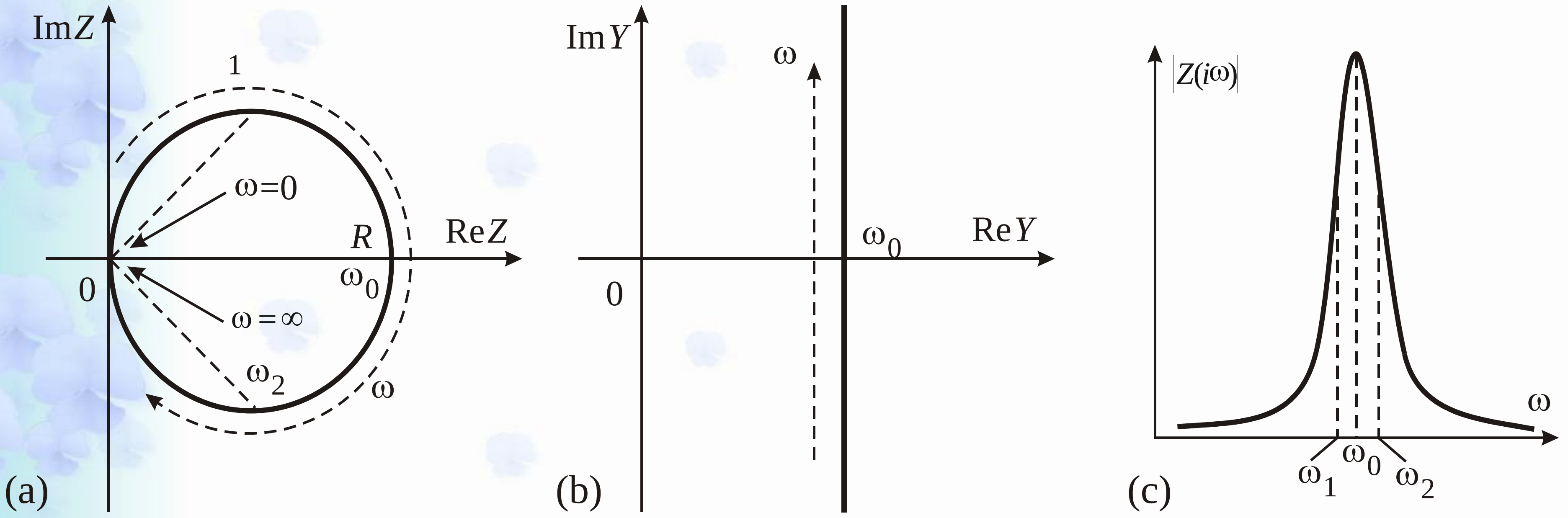
Resonant (angular) frequency $\omega_0 \equiv \dfrac{1}{\sqrt{LC}}$

Transfer function, resonance and phase shift

$$Z_{\text{tot}}(i\omega) = \left[\frac{1}{R} + i\left(\omega C - \frac{1}{\omega L}\right)\right]^{-1} \qquad \omega_0 \equiv \frac{1}{\sqrt{LC}}$$

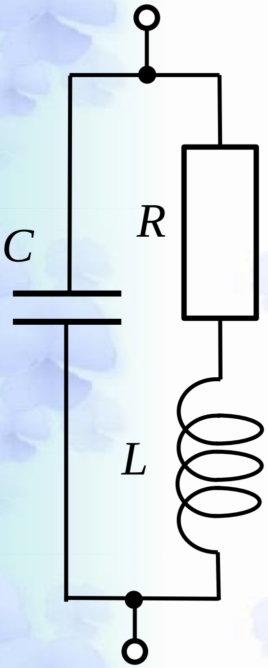
Resonance: Reactance =0

Total Phase Shift Change: π

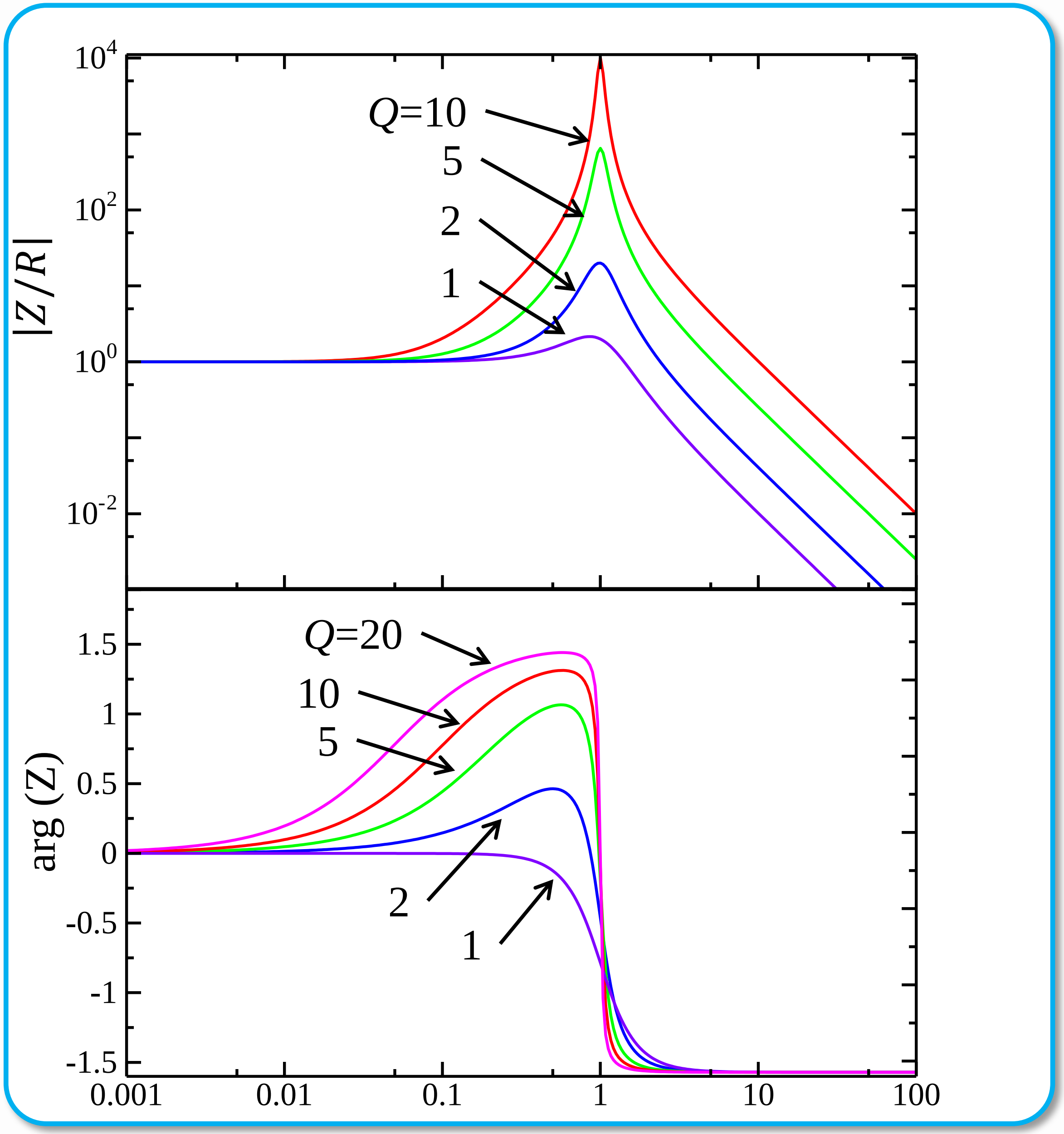


Bode diagram

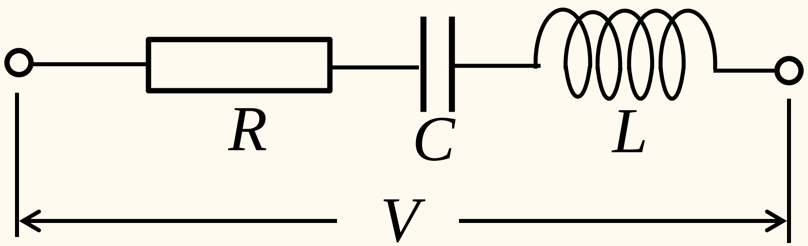
$$Z(i\omega) = \frac{R + i\omega L}{1 - \omega^2 LC + i\omega CR} = \frac{R + i\omega L}{1 - \frac{\omega^2}{\omega_0^2} + i\omega CR}$$

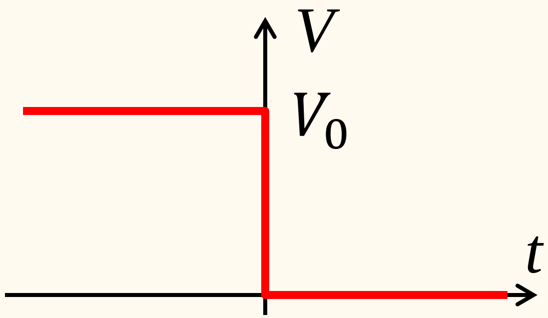


$$Q \approx \omega_0 \frac{L}{R}$$



Transient response of resonant circuit





$$L\frac{d^2q}{dt^2}+R\frac{dq}{dt}+\frac{q}{C}=0 \quad (t>0), \quad q(0)=CV_0$$

$$q(t)=CV_0e^{st} \;\rightarrow\; Ls^2+Rs+C^{-1}=0$$

$$s=\left(-\omega_0\pm\sqrt{\omega_0^2-4\alpha^2}\,\right)(\omega_0/2\alpha) \quad \alpha\equiv(CR)^{-1}$$

$$(\omega_0/2)<\alpha \;\rightarrow\; \text{imaginary part}$$

$$q(t)=CV_0\exp[(-\gamma\pm i\omega_s)t], \quad \gamma\equiv\frac{\omega_0^2}{2\alpha}, \quad \omega_s\equiv\omega_0\left(1-\frac{\omega_0^2}{4\alpha^2}\right)^{1/2}$$

Damped oscillation with time constant γ^{-1}, frequency ω_s

Transient response of resonance circuit (transfer function)

Synthesized impedance, admittance

$$Z_{\mathrm{tot}}(s) = sL + R + \frac{1}{sC}, \quad Y_{\mathrm{tot}}(s) = Z_{\mathrm{tot}}(s)^{-1}$$

Zero (pole) of $Z_{\mathrm{tot}}(s)$ ($Y_{\mathrm{tot}}(s)$) $s = (-\omega_0 \pm \sqrt{\omega_0^2 - 4\alpha^2})(\omega_0/2\alpha)$

$Z_{\mathrm{tot}}(s_0) = 0$ Time constant: $\mathrm{Re}(s_0)$ Frequency: $\mathrm{Im}(s_0)$

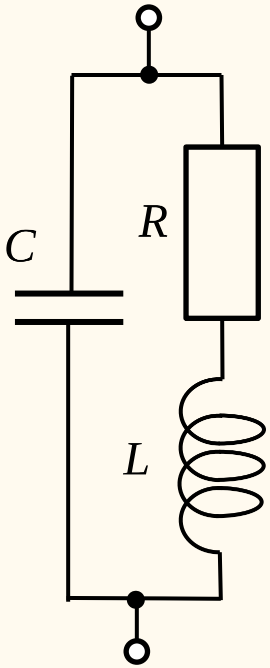
Laplace transformation of voltage: $V(s)$

$$J(t) = \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} Y(s)V(s)e^{st}ds = \sum_i R(s_i)V(s_i)e^{s_i t} \quad (c > 0)$$

Natural current

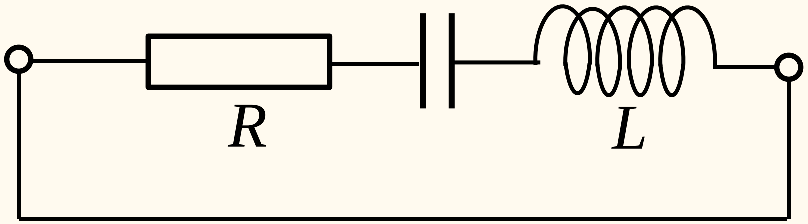
s_i: poles of $Y(s)$ $R(s_i) = Y(s)(s - s_i)|_{s=s_i}$

Driving point impedance



Open

=



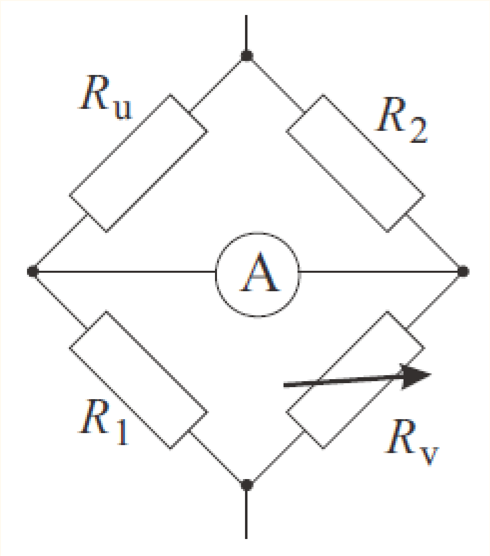
Short

$$Z_{\text{tot}}(s) = sL + R + \frac{1}{sC}$$

$$Z^{(2)}_{\text{tot}}(s) = \left(\frac{1}{R + sL} + sC\right)^{-1} = \frac{sL + R}{s^2LC + sRC + 1}$$

$$Z_{\text{tot}}(s) \text{ zero is pole for } Z^{(2)}_{\text{tot}}(s)$$

Resistance bridge 抵抗ブリッジ

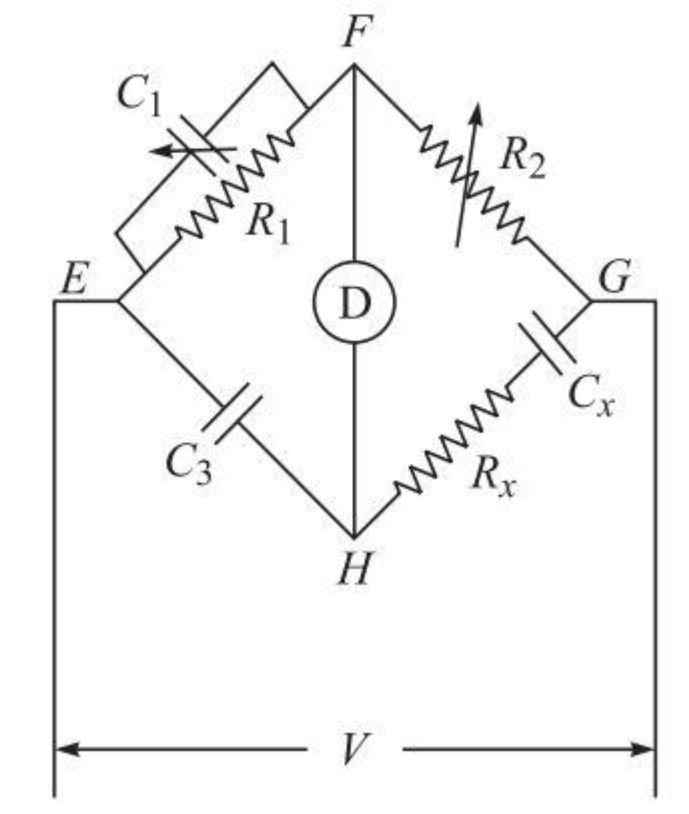


Wheatstone bridge

AVS-47 Resistance bridge

Not a “bridge” circuit!

Schering Bridge



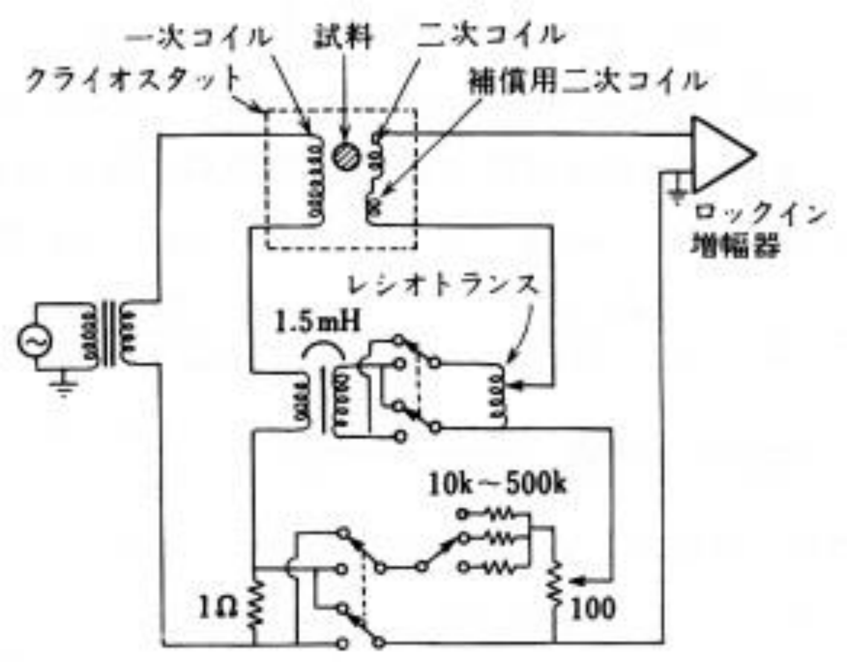
$$Z_1 Z_x = Z_2 Z_3, \quad Z_x = Z_2 Z_3 Y_1$$

$$Z_x = R_x + \frac{1}{i\omega C_x}, \quad Z_2 = R_2, \quad Z_3 = \frac{1}{i\omega C_3}, \quad Y_1 = \frac{1}{R_1} + i\omega C_1$$

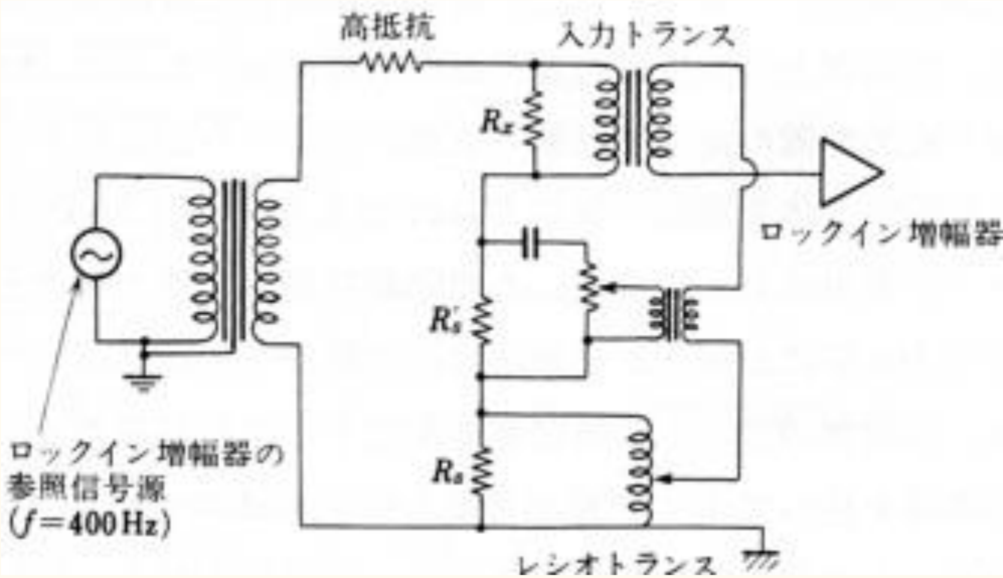
$$R_x + \frac{1}{i\omega C_x} = R_2 \frac{1}{i\omega C_3}\left(\frac{1}{R_1} + i\omega C_1\right)$$

$$R_x = \frac{R_2 C_1}{C_3}, \quad C_x = \frac{R_1}{R_2} C_3$$

Magnetic moment measurement



Resistance measurement



Capacitance bridge キャパシタンスブリッジ

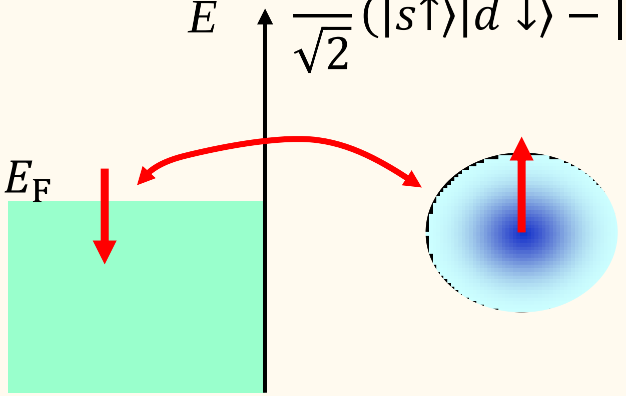
General Radio
3-terminal
Capacitance bridge

Agilent E4981A

Kondo Resonance and Phase shift

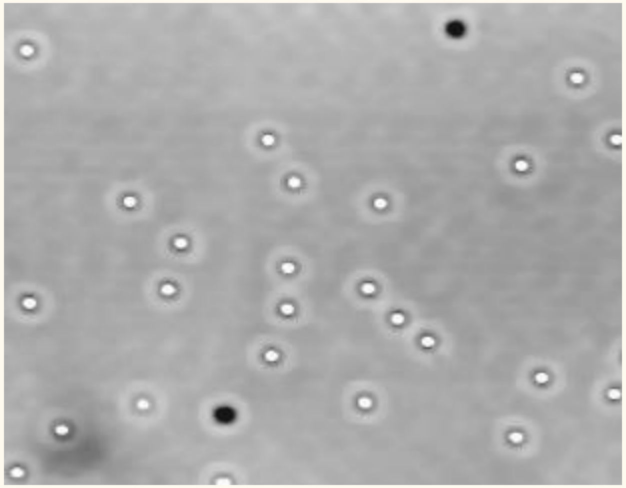
Jun Kondo

$$E \quad \frac{1}{\sqrt{2}}\left(|s\uparrow\rangle|d\downarrow\rangle - |s\downarrow\rangle|d\uparrow\rangle\right)$$

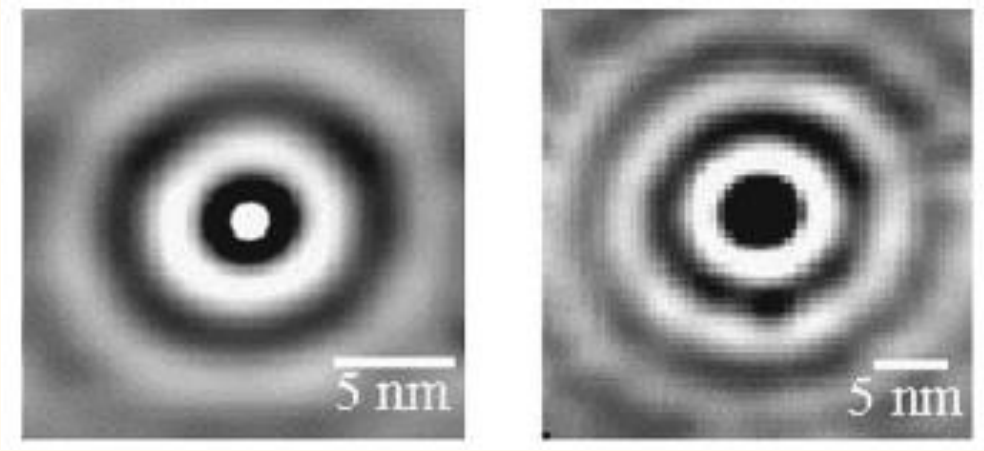


Many body resonance.
But still has the phase shift of π/2 !

Co atoms on Ag (111) surface



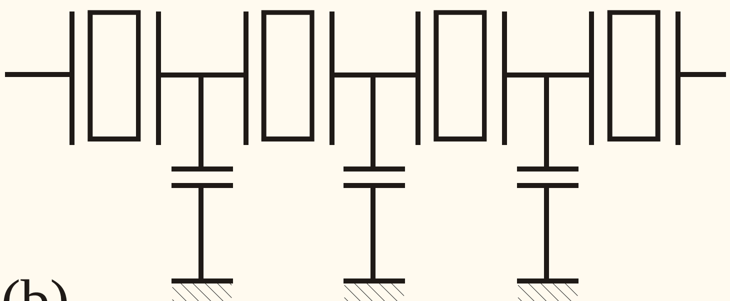
Co (magnetic) Defect (non-magnetic)



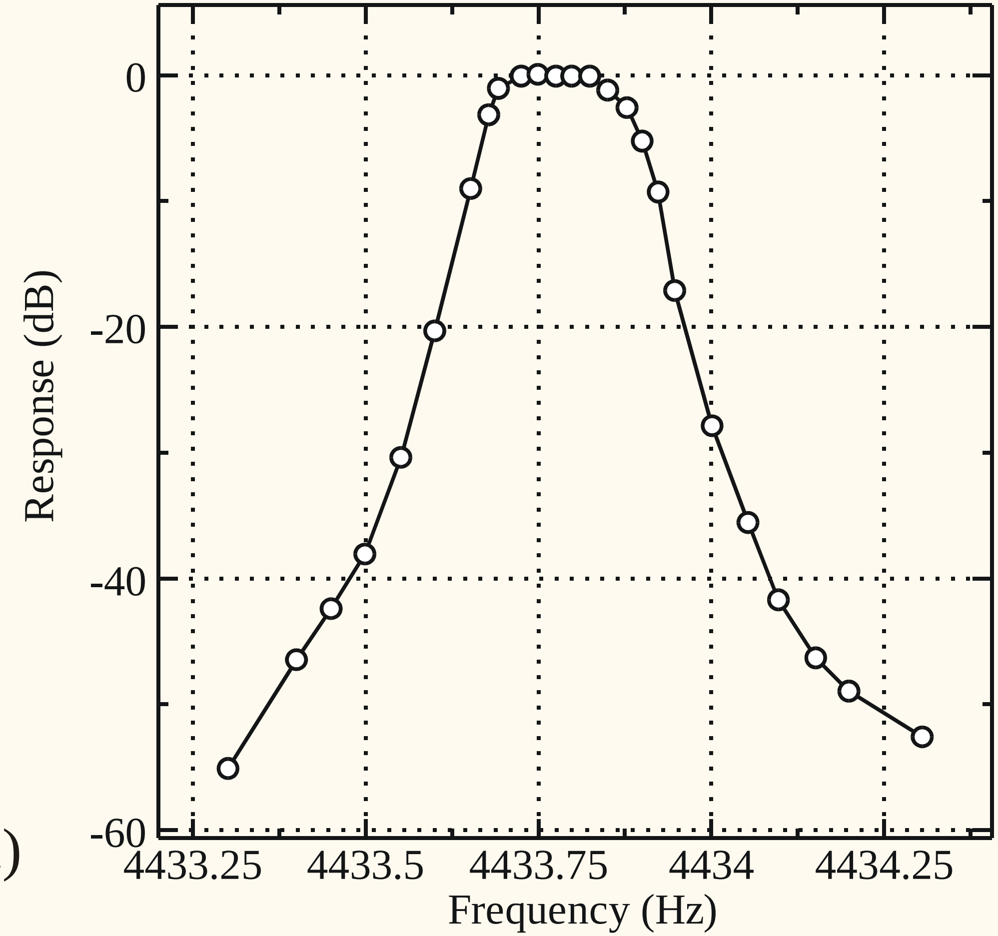
Schneider et al., Phys. Rev. B65, 121406 (2002).

Quartz crystal filter

(a)



(b)



(c)

Circuit Simulator

Download LTSpice from the web site of Linear Technology

What is Spice?

SPICE: Simulation Program with Integrated Circuit Emphasis

A language which describes electronic circuits (corresponding to circuit diagrams).

ex) a CR circuit and a dc power source

```
* 0---R1---1---C1---2---V1---0
R1 0 1 10
C1 1 2 20
V1 2 0 5
.END
```

Graphical user interface: Circuit diagram

Linear Technology web site

Operation example

TECHNOLOGY

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Design Simulation and Device Models

リニアテクノロジーは高性能なスイッチング･レギュレータやアンプ、データ･コンバータ、フィルターなどを使用した回路を、初めての設計者でも短時間に容易に評価できるよう
ムデザイン･シミュレーション･ツールを提供しています。

- LTspice IV
- LTpowerCAD
- LTpowerPlay
- Amplifier Simulation & Design
- Filter Simulation & Design
- Timing Simulation & Design
- Data Converter Evaluation Software
- Dust Networks Starter Kits

LTSPICE IV

LTspice IV

LTspice IVは高性能なSpice IIIシミュレータと回路図入力、波形ビューワに改善を加え、スイッチング･レギュレータのシミュレーションを容易にするためのモデルを搭載しています。Spiceの改善により、スイッチング･レギュレータのシミュレーションは、通常のSpiceシミュレータ使用時に比べて著しく高速化され、ほとんどのスイッチング･レギュレータにおいて波形表示をほんの数分で行なうことができます。Spiceとリニアテクノロジーのスイッチング･レギュレータの80%に対応するMacro Model、200を超えるオペアンプ用モデルならびに抵抗、トランジスタ、MOSFETモデルをここからダウンロードできます。

- **LTspice IV（Windows用）をダウンロード（2014年5月5日更新）**
- **･LTspice IV（Mac OS X 10.7+用）をダウンロード**
- 関連情報 & ショートカット
- Mac OS X用ショートカット
- スタート･ガイド
- ユーザ･ガイド（ヘルプ･ファイル参照）
- トランスの使用
- デモ回路集
- セミナーの開催予定を見る

LTspiceのツイッターをフォロー

LTspiceに関するビデオを見る

MYLINEAR ログイン

LTPOWERCAD

Summary

Theorems for paired terminal circuits

Superposition, Ho-Tevenin, Reciprocity

Duality

Passive devices (elements) and active devices

Transfer function and transient response

Transfer function of single-pair terminal circuits

Resonance circuit

Bode plot

General properties