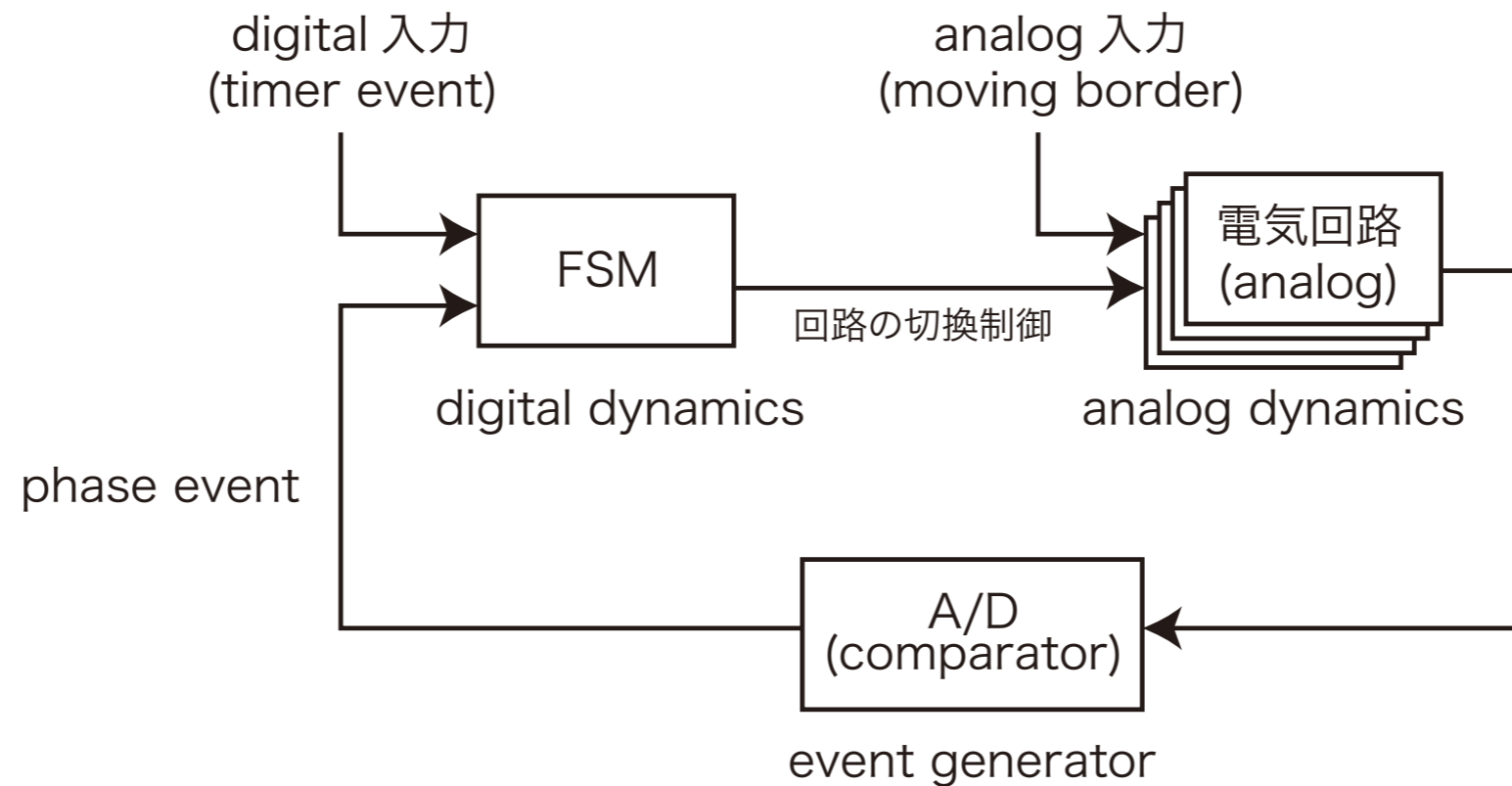


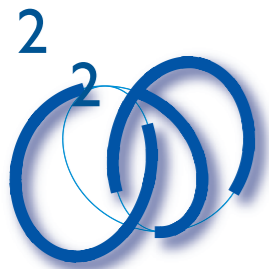


Hybrid 回路の定性論 (1)



川上 博

2014(H26).01.20



話の流れ

1. Hybrid回路の例

- ◎ スイッチ, コンパレータ, 論理素子を含むRLC回路
- ◎ これまでに研究した回路との関連性

2. Hybrid回路の数学モデル

- ◎ FSMとODE混合系の定式化法

3. Hybrid回路の解析法

- ◎ 貼合わされた(FSM)相空間の流れ(ODE)に関する幾何学

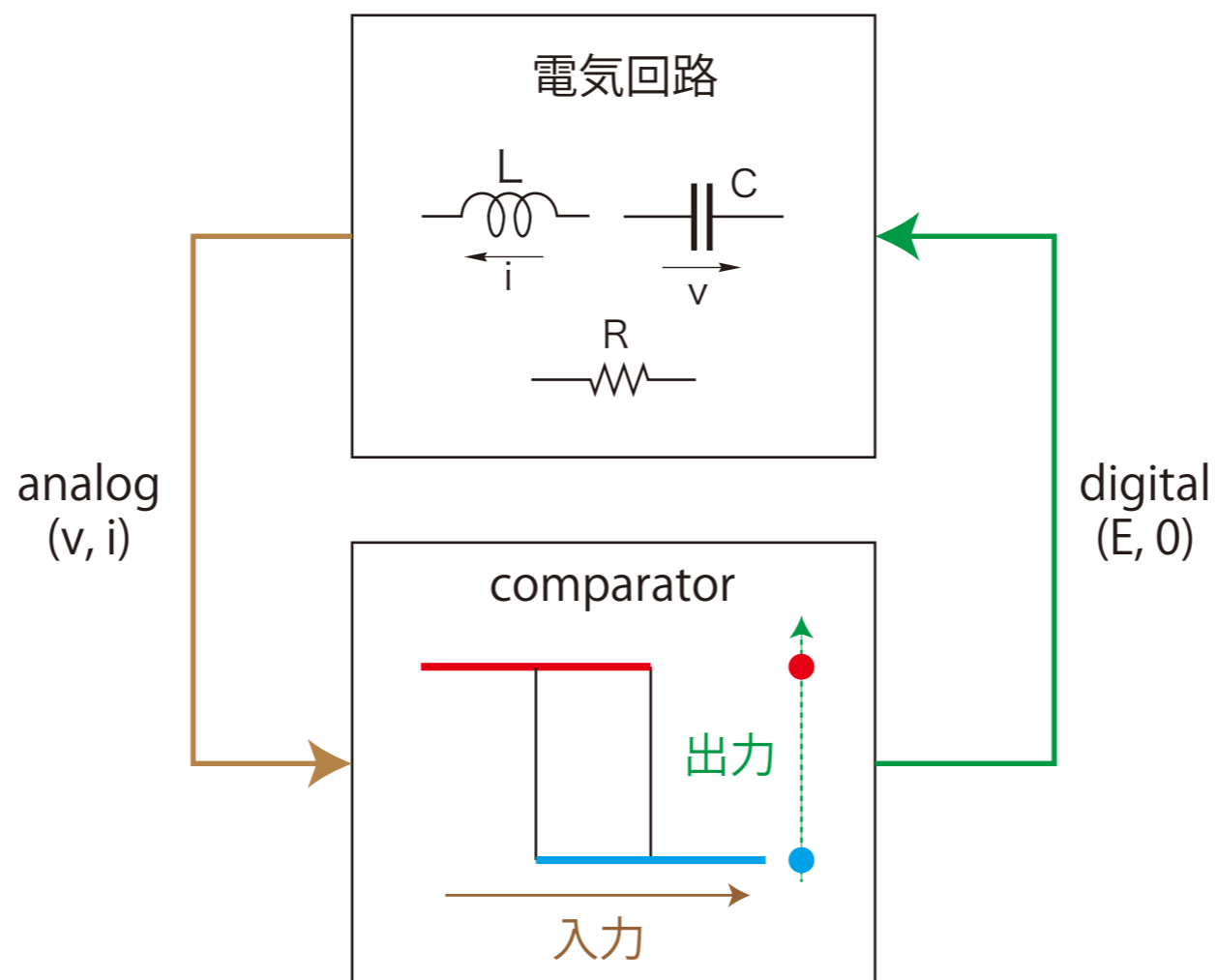
4. Hybrid回路の数値計算

- ◎ FSMと力学系を実現するdesign patternをつくる



今日の内容

1. Hybrid回路の例：Hybrid系の回路実現を意識して



HADC(1 bit hysteresis A/D converter)



ハイブリッド回路の回路方程式

2. Hybrid回路の数学モデル：ODE+FSM

		時 間	
		連続	離散
状 態	連続	微分方程式 ODE	差分方程式 Poincare map
	離散	FSM in continuous time	Finite State Machine FSM

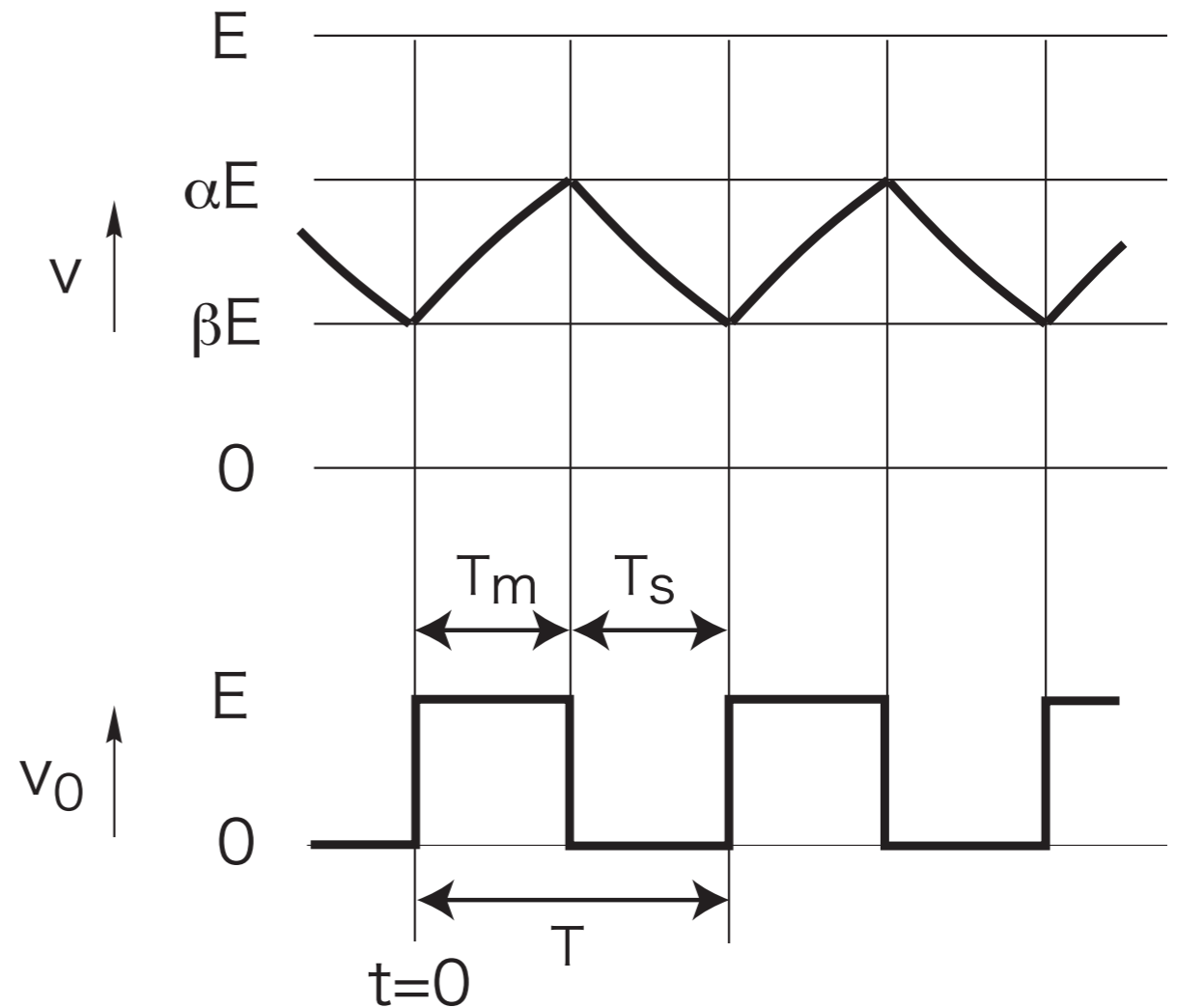
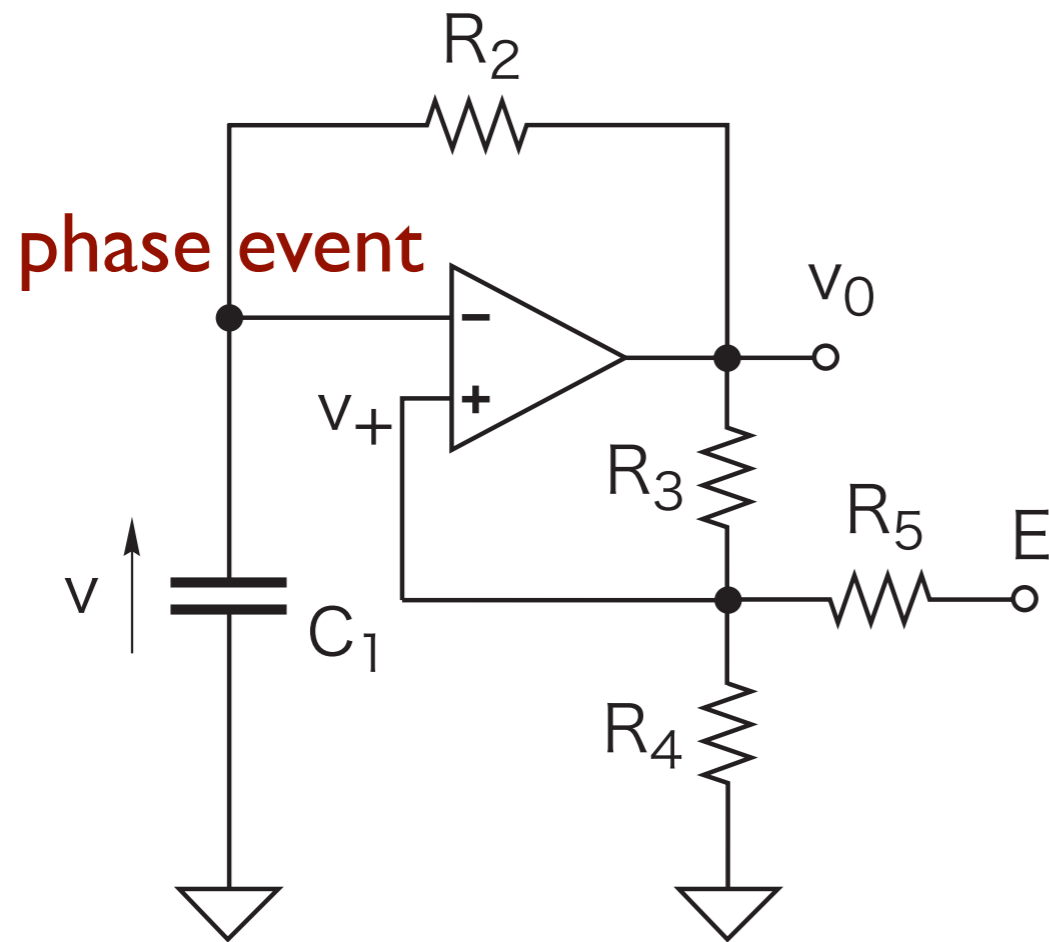
ordinary differential equations: vector field
 finite state machine(有限状態機械)



1. Hybrid回路の例



Hybrid 力学系の例：RC方形波発振器

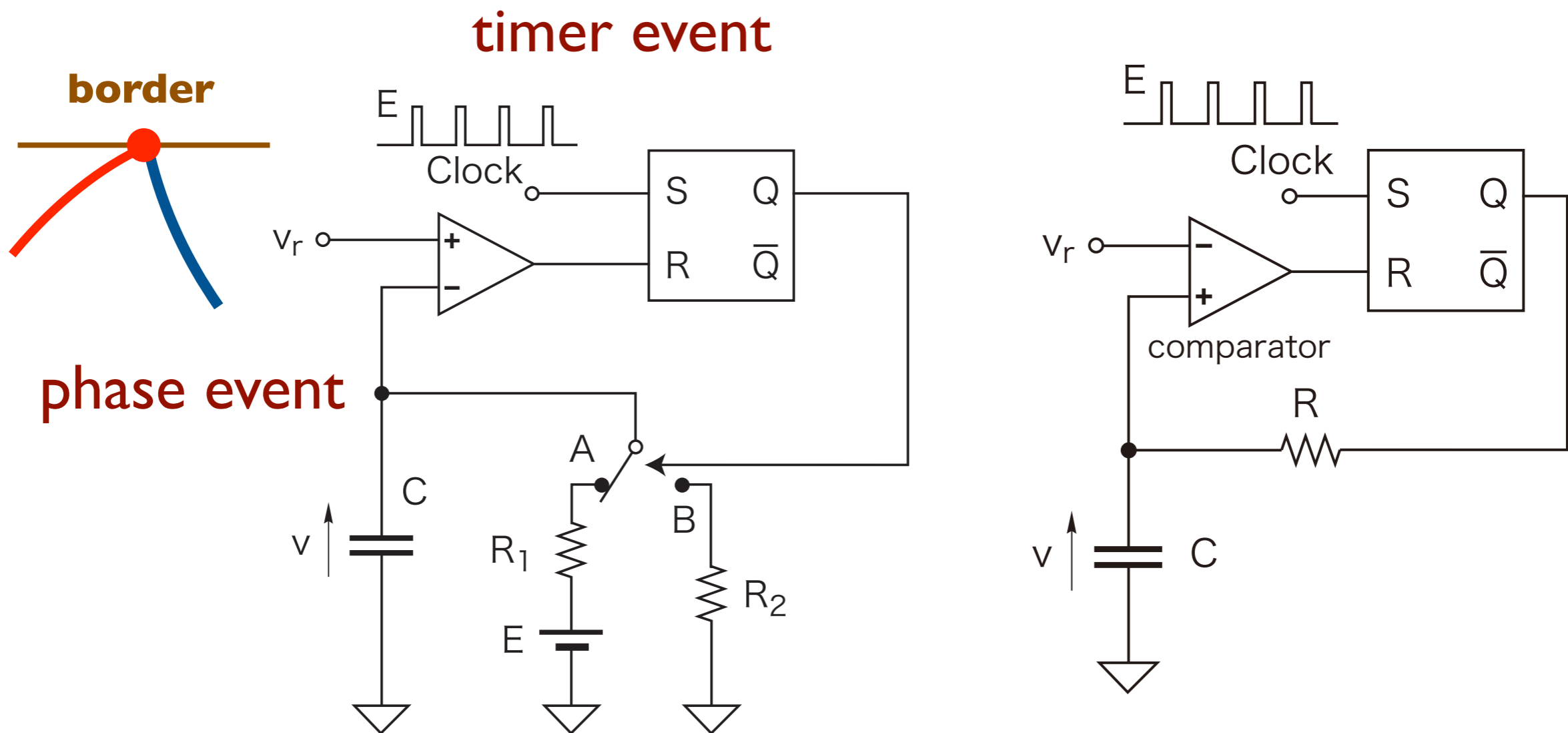


$$R_2 C_1 \frac{dv}{dt} + v = E$$

$$R_2 C_1 \frac{dv}{dt} + v = 0$$

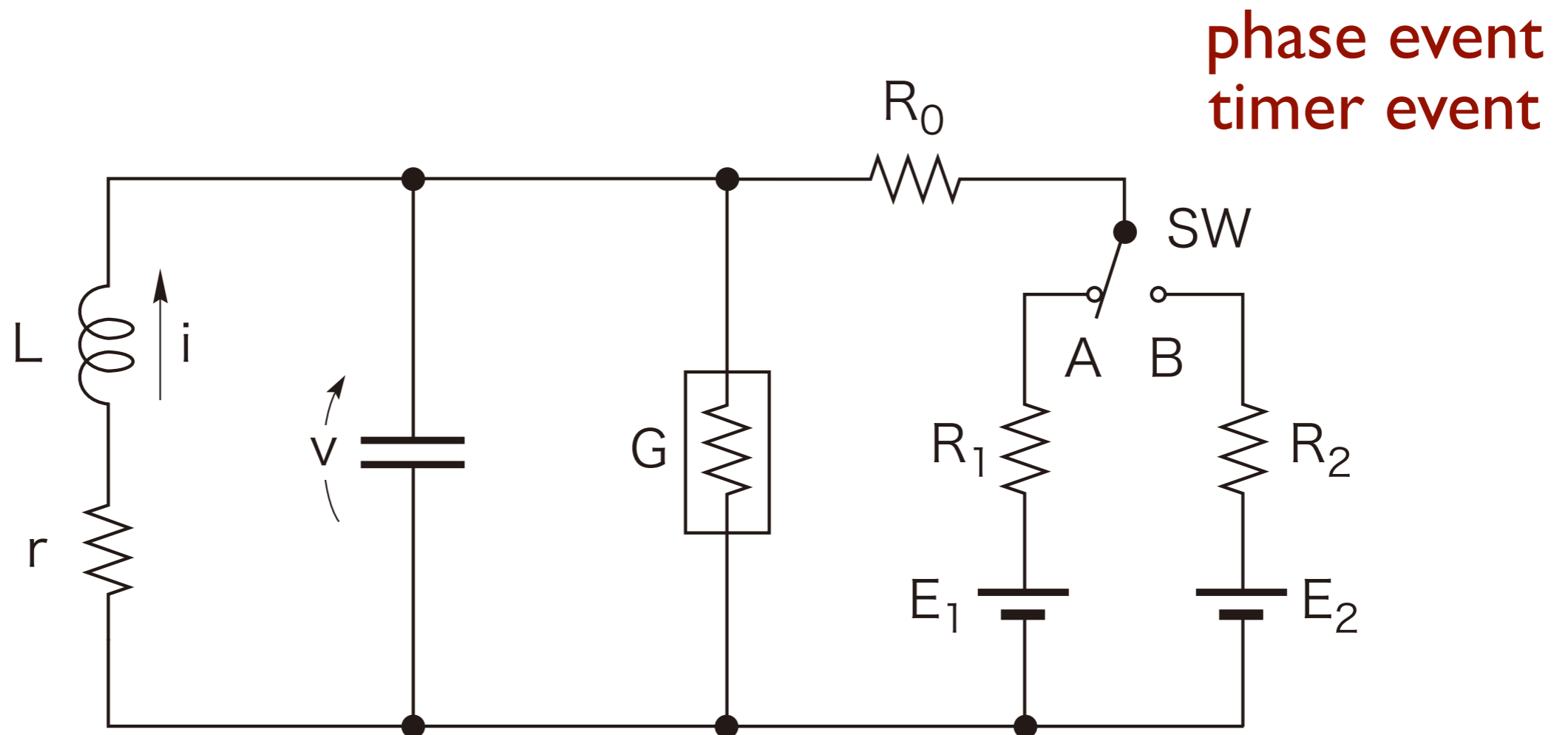


Kousaka's BC Circuit

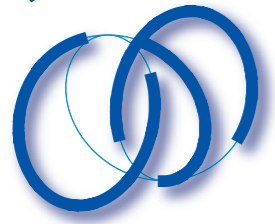




Alpazur Oscillator

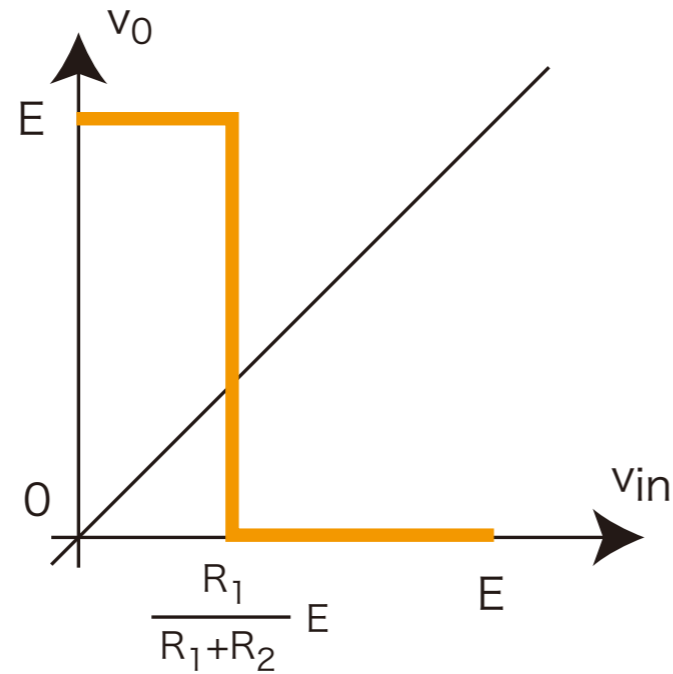
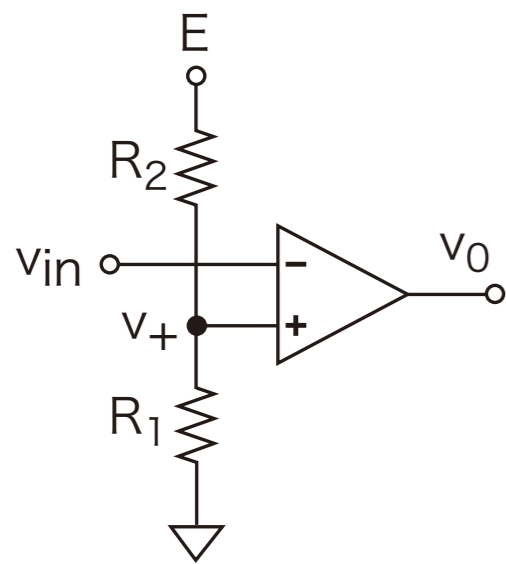


swの動作が一意的に定まる回路：swをTrで実現とか



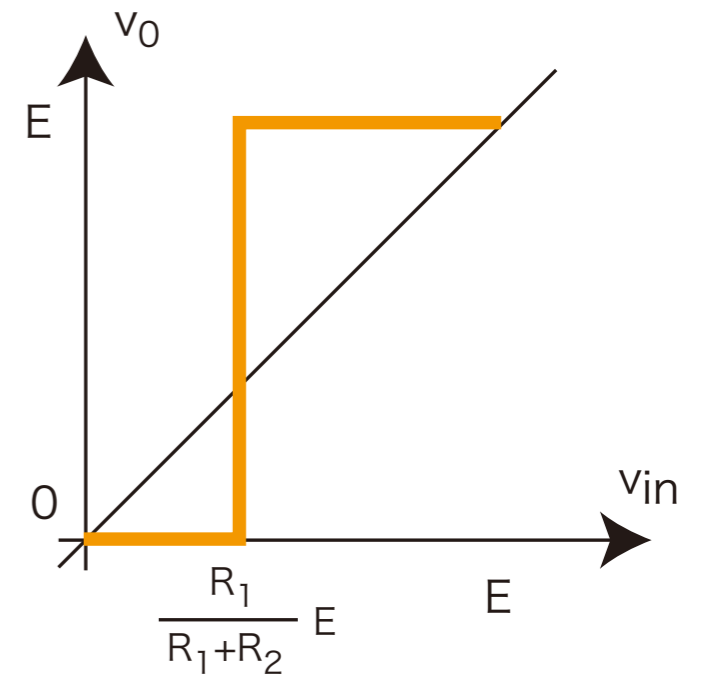
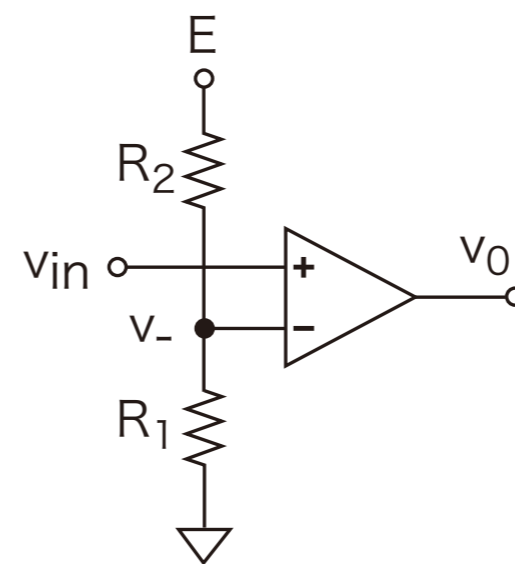
Comparator

入力 : analog 出力 : digital



(a)

v_+ を固定

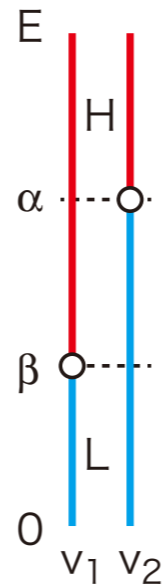
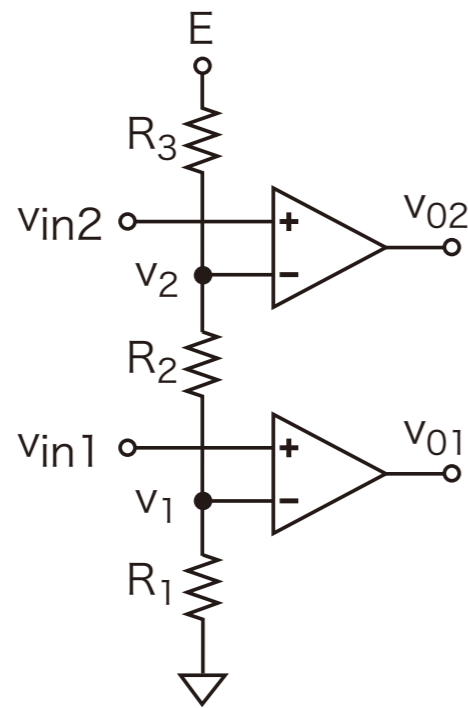


(b)

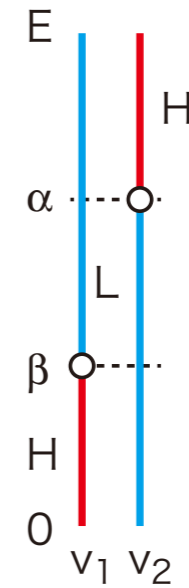
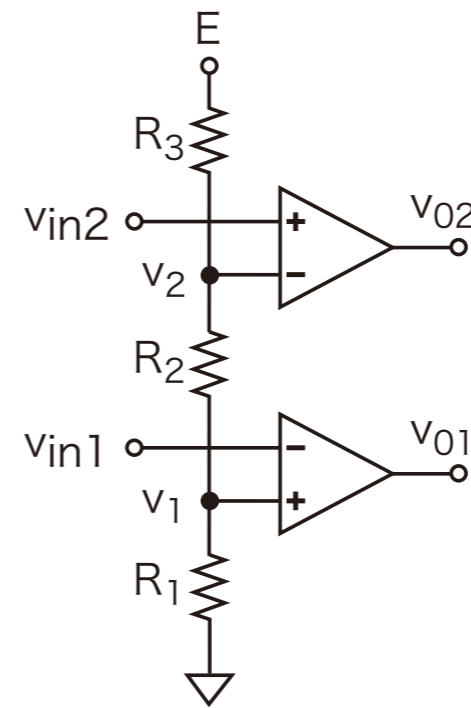
v_- を固定



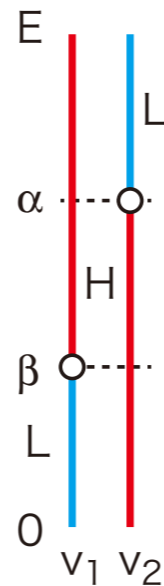
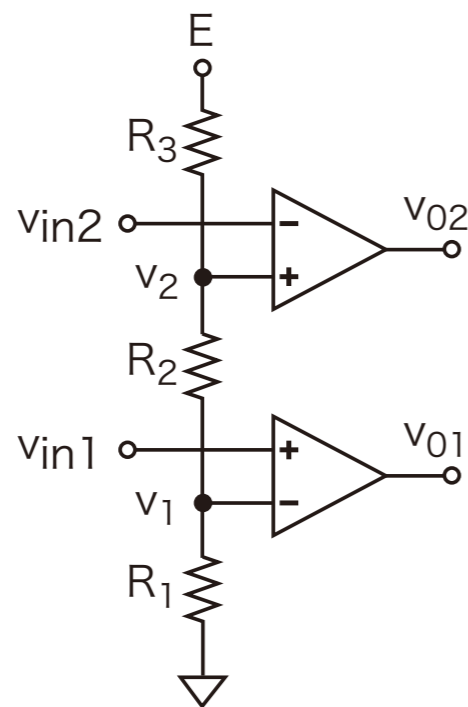
2 Comparators



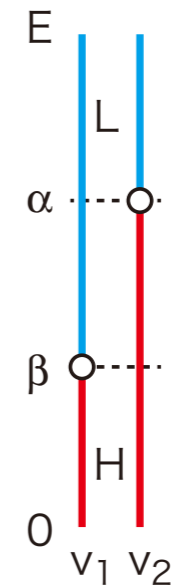
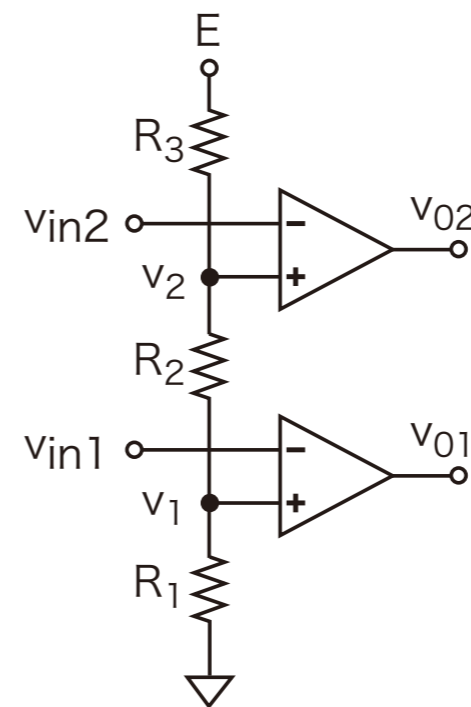
(a)



(b)



(c)

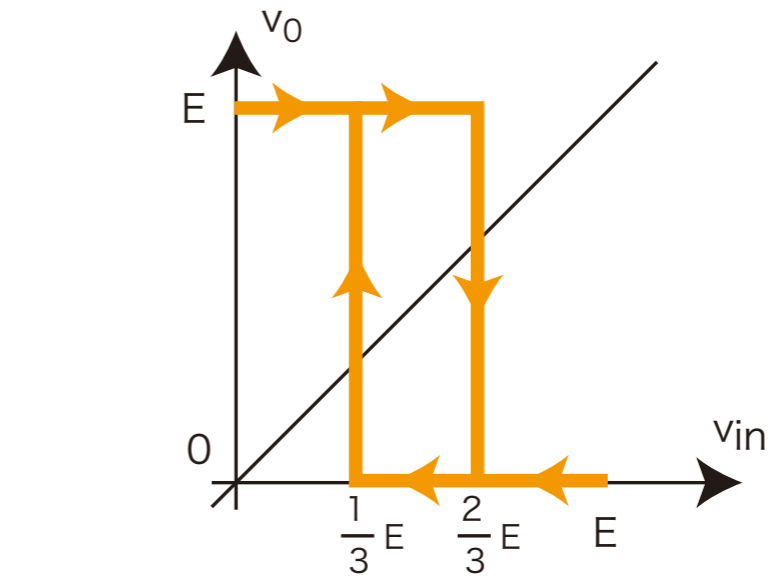
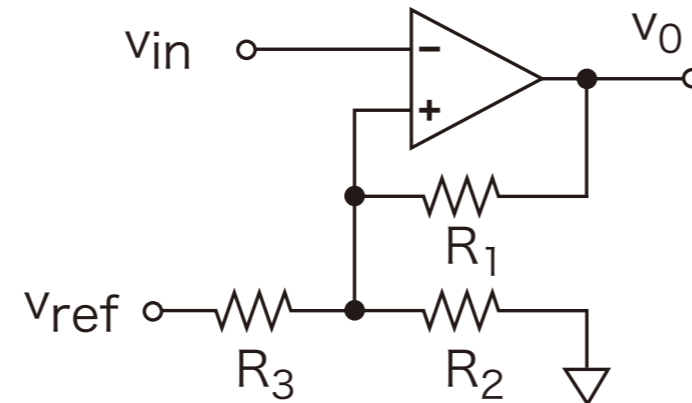


(d)



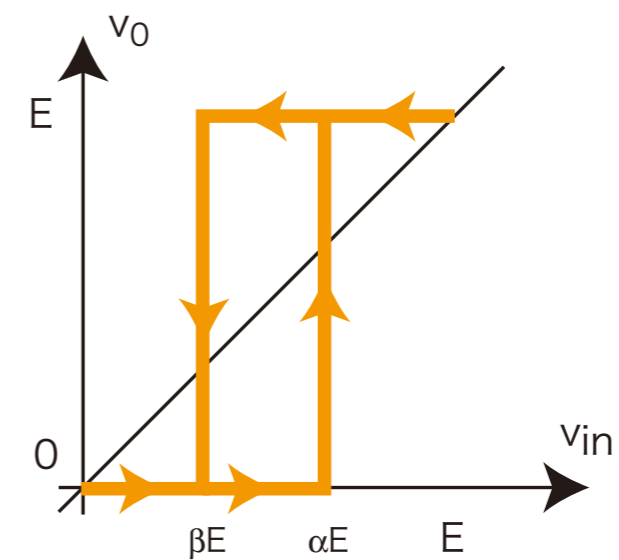
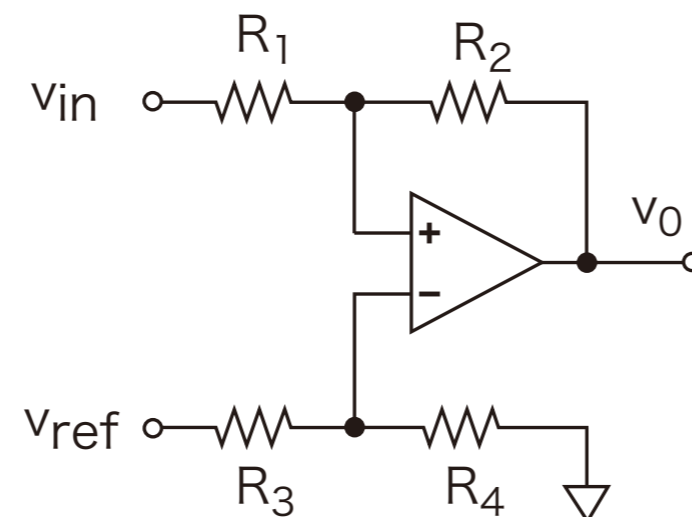
Comparator with Hysteresis

Z type



(a)

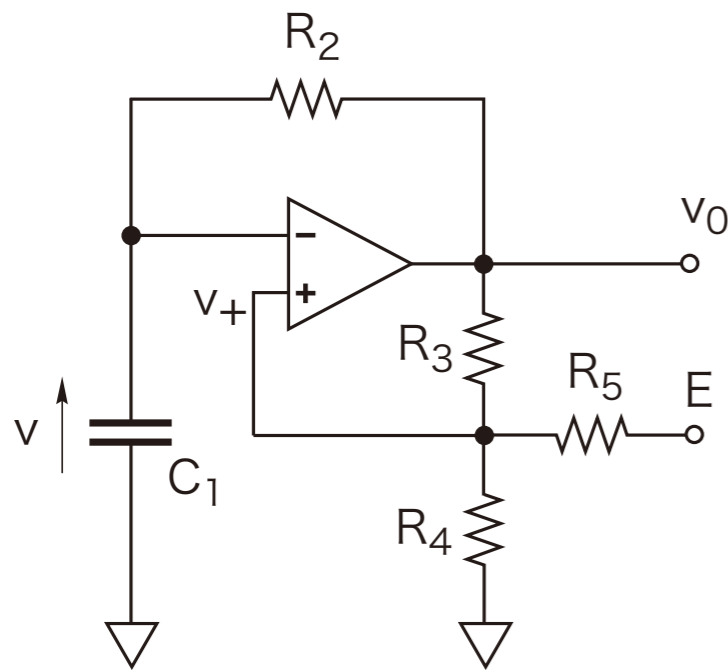
S type



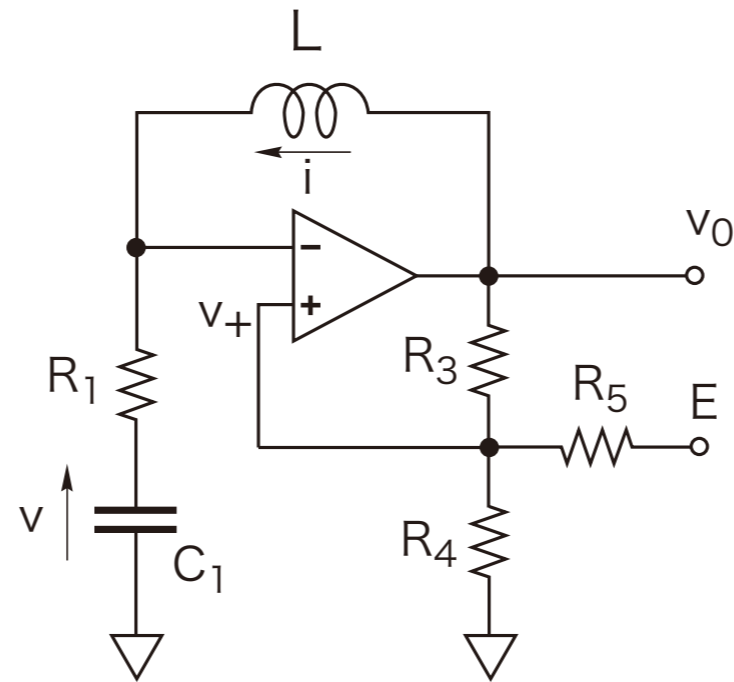
(b)



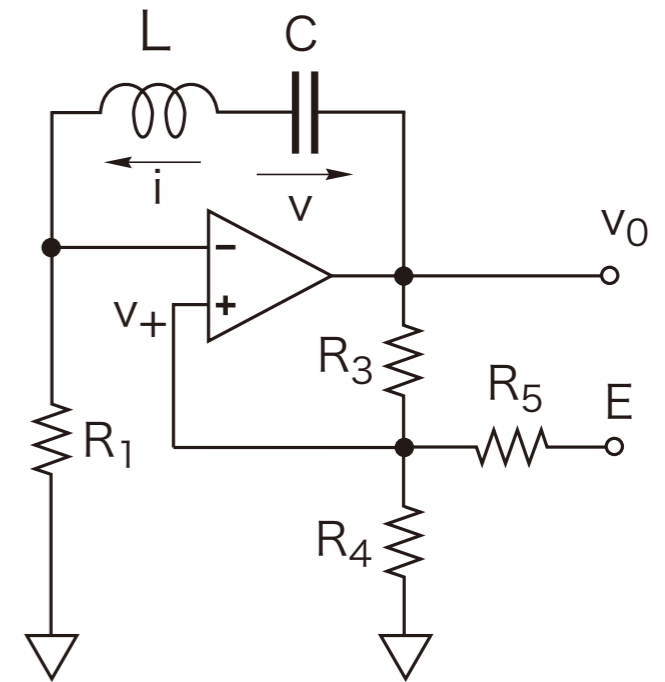
Hybrid circuits



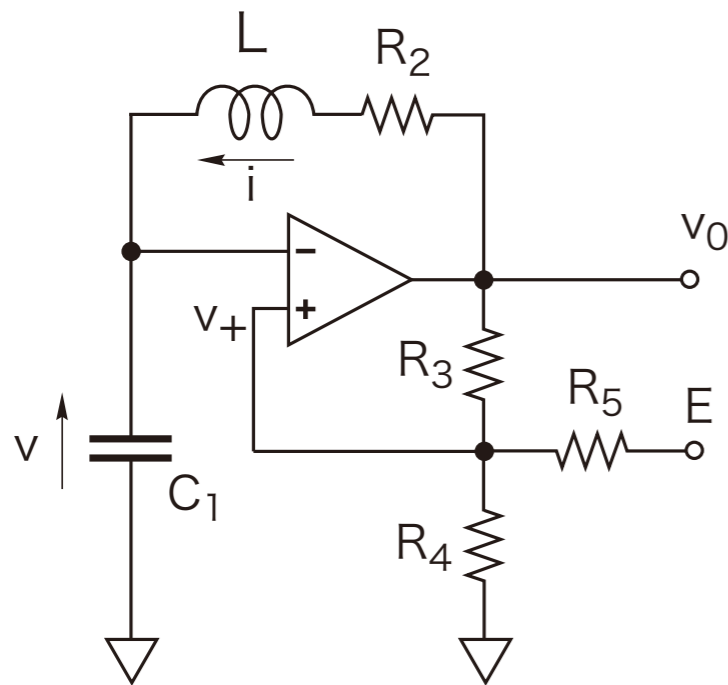
(a)



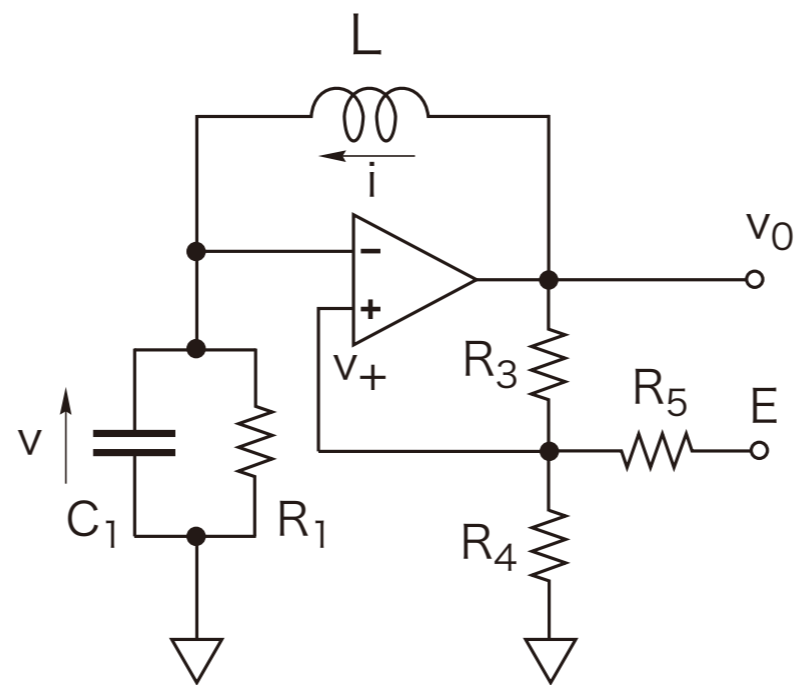
(b)



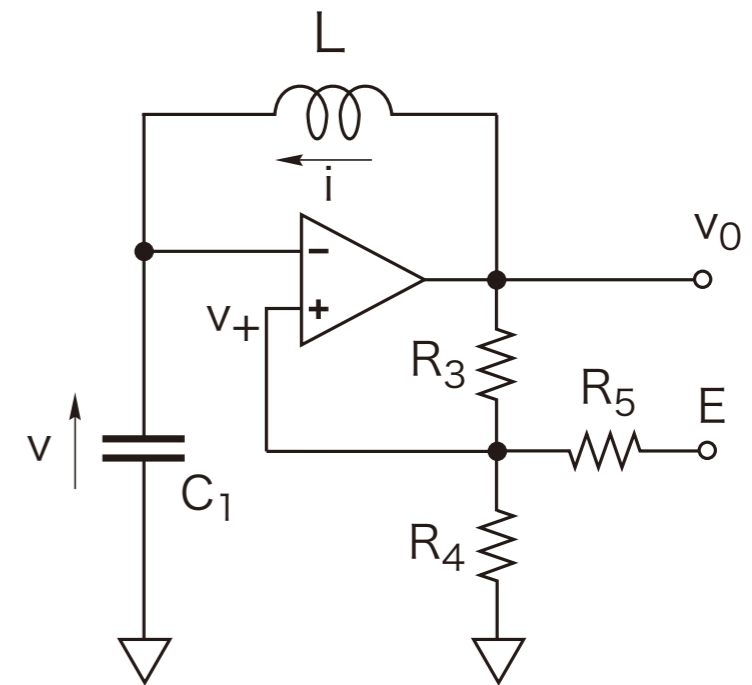
(c)



(d)



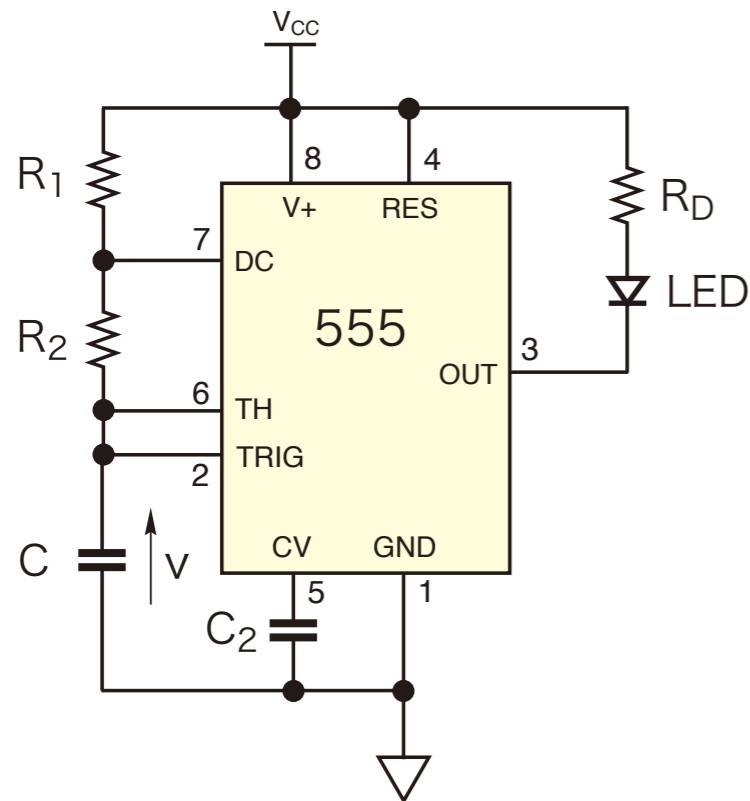
(e)



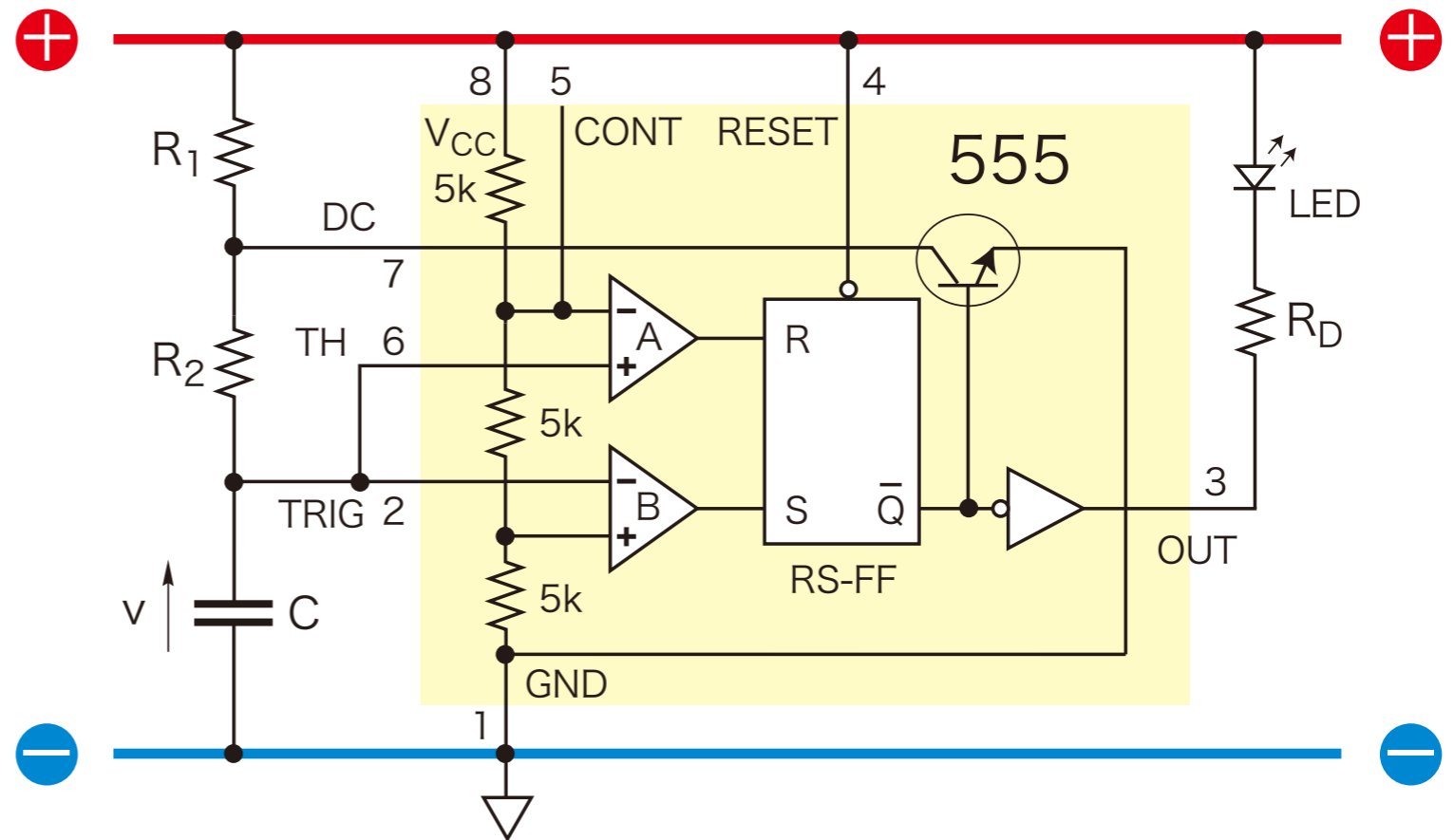
(f)



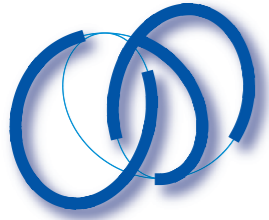
Astable multivibrator



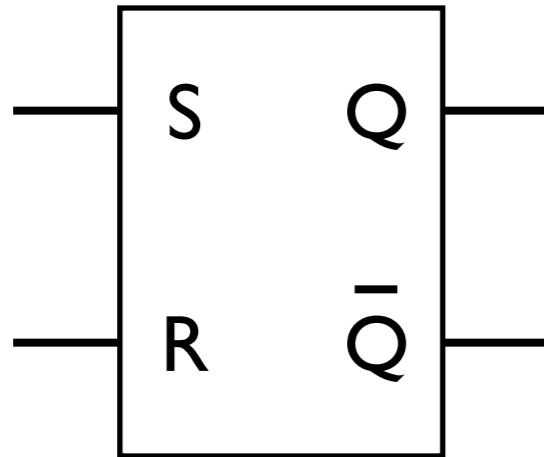
(a) 無安定発振回路



(b) (a) の回路の説明図

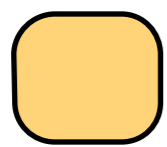


Finite State Machine



SR Flip-Flop

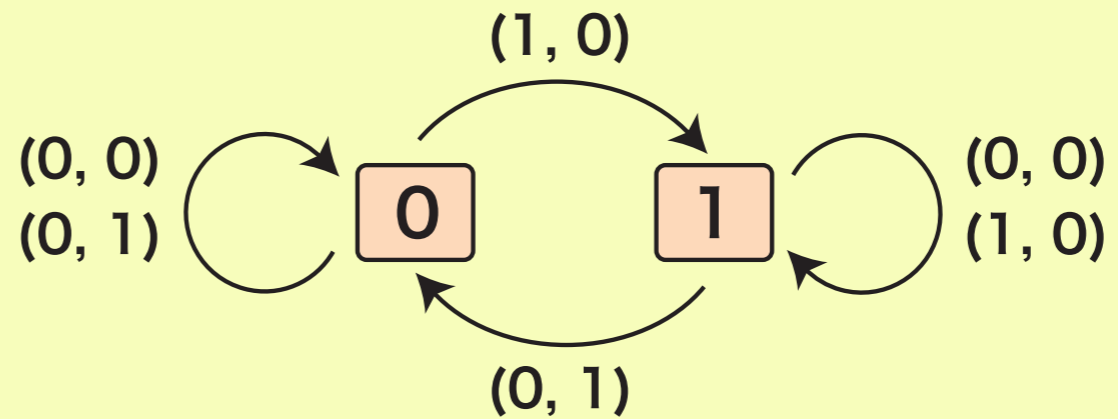
S	R	Q_{t+1}	動作
0	0	Q_t	保持
1	0	1	set
0	1	0	reset
1	1	x	禁止



state

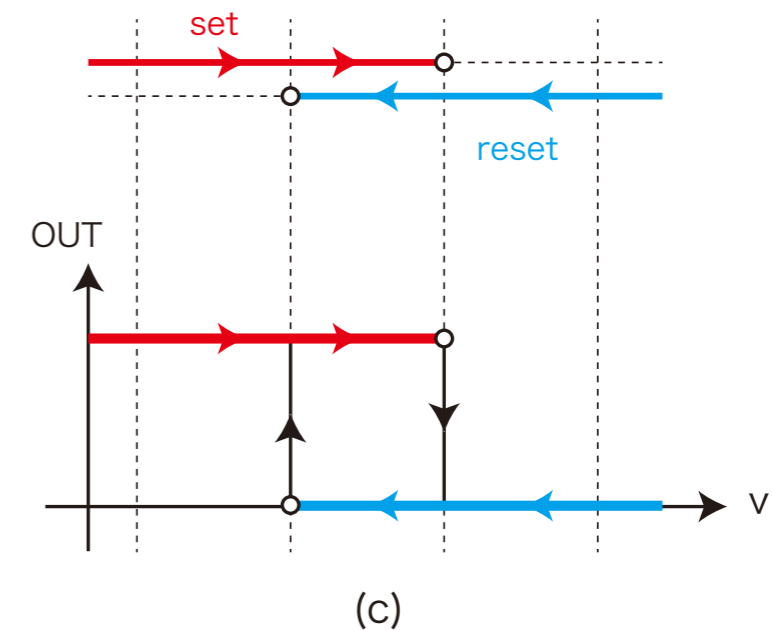
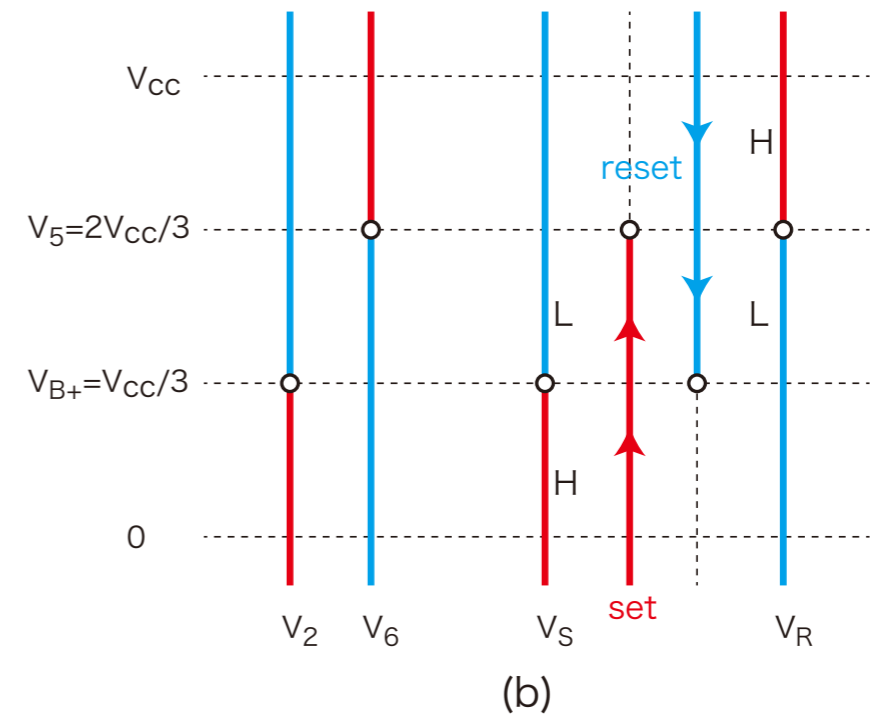
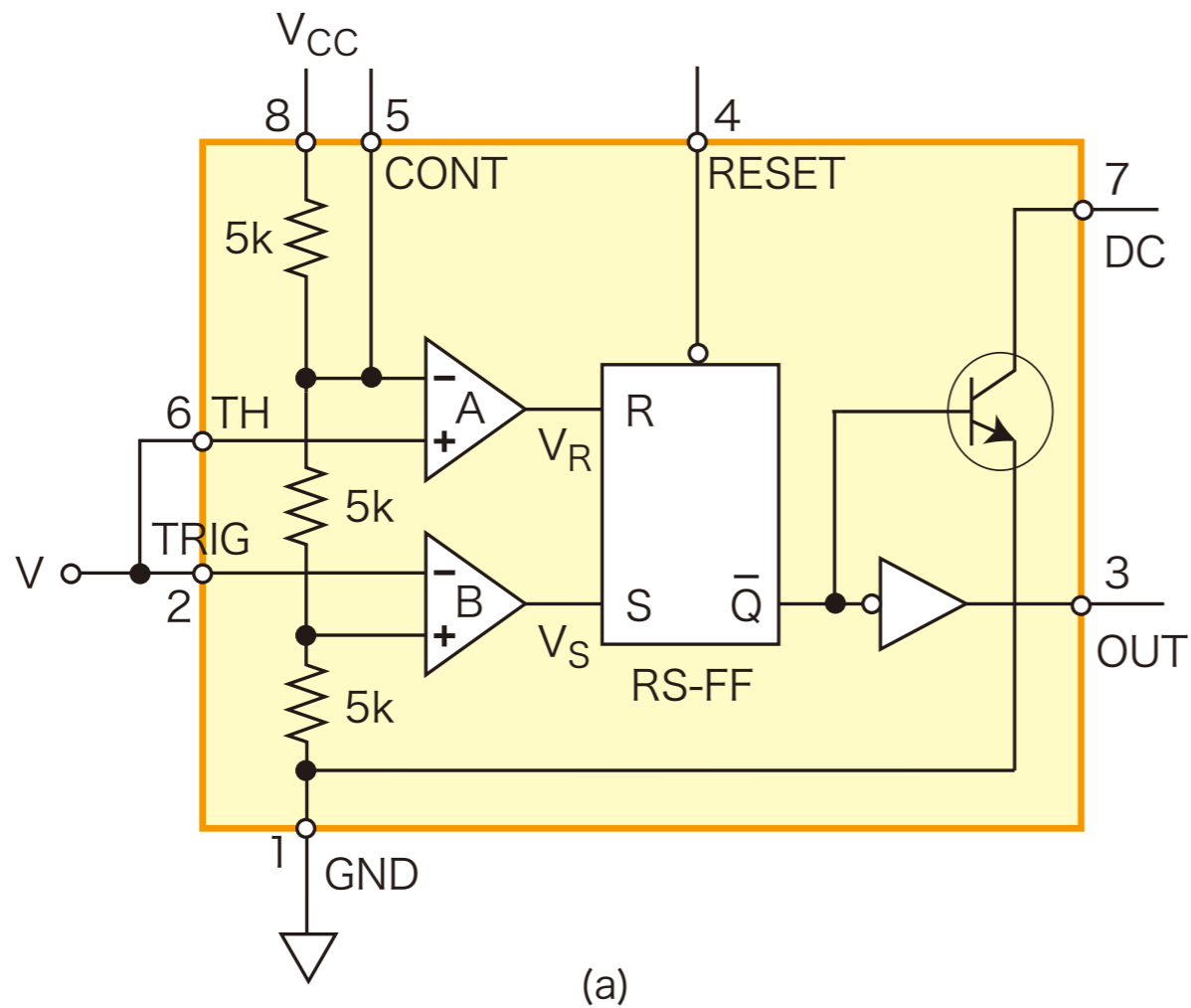


transition



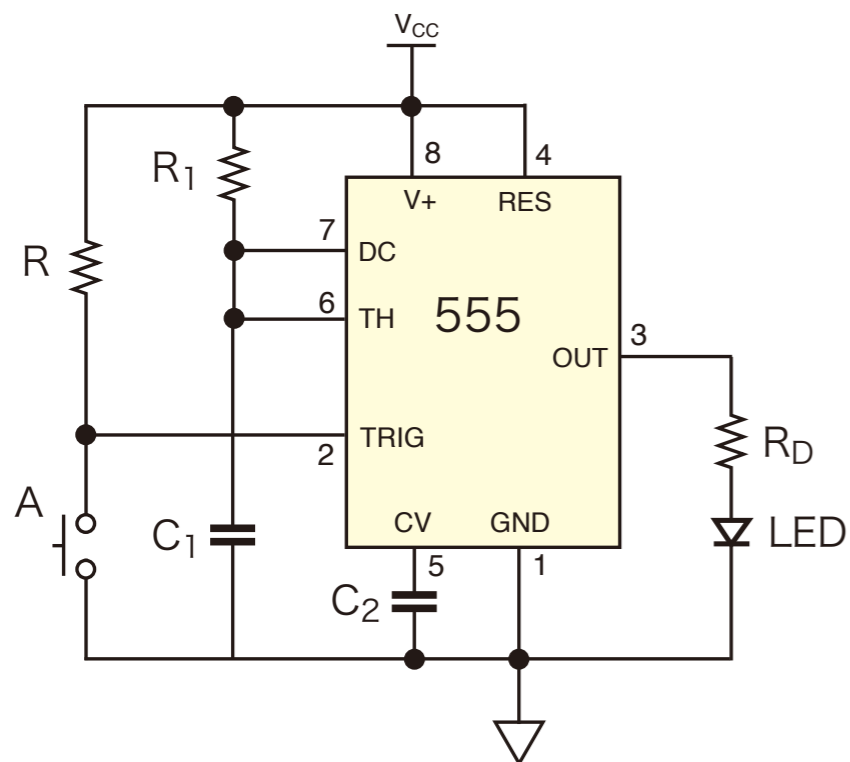


555を使った Z type comparator

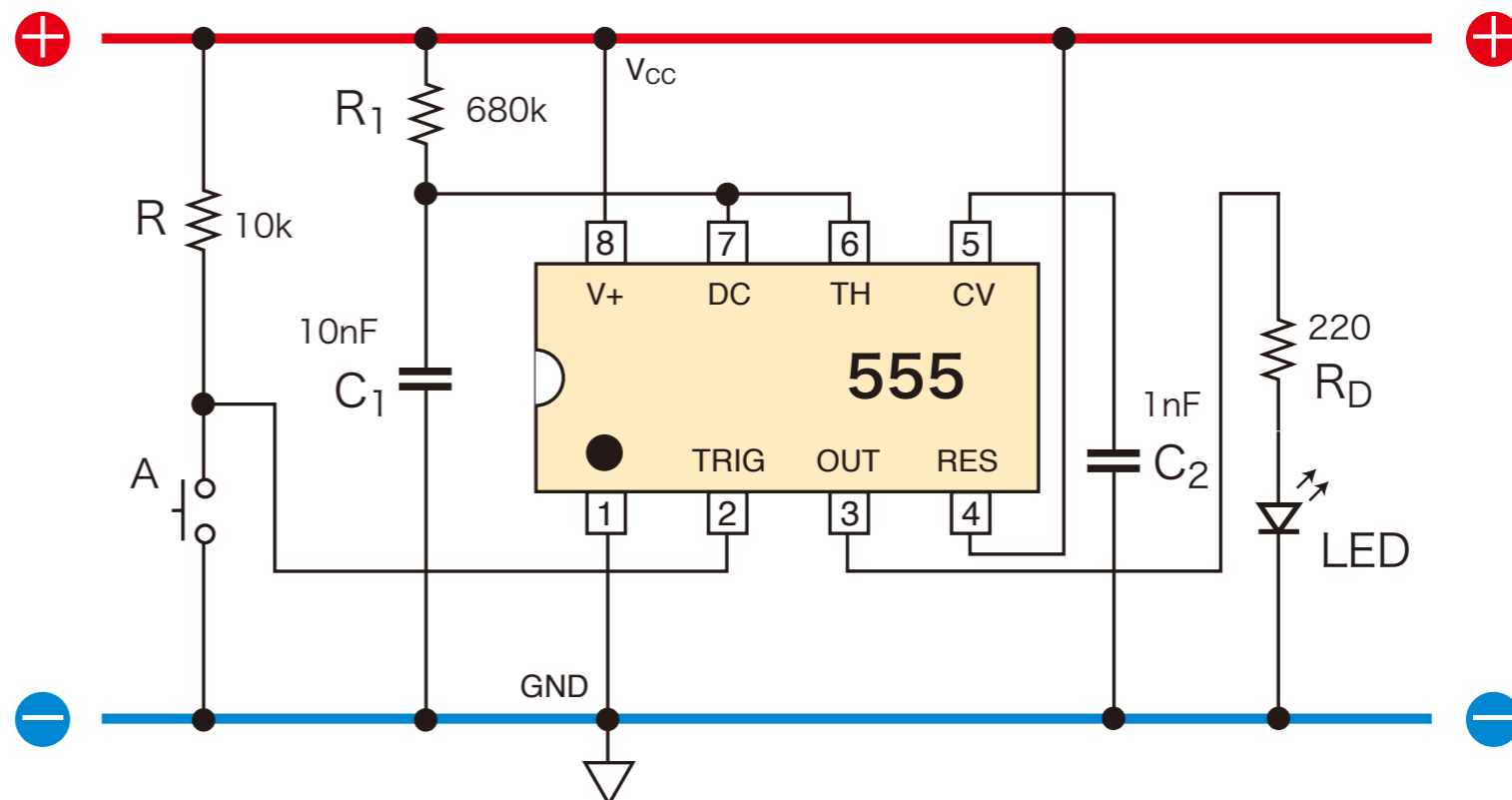




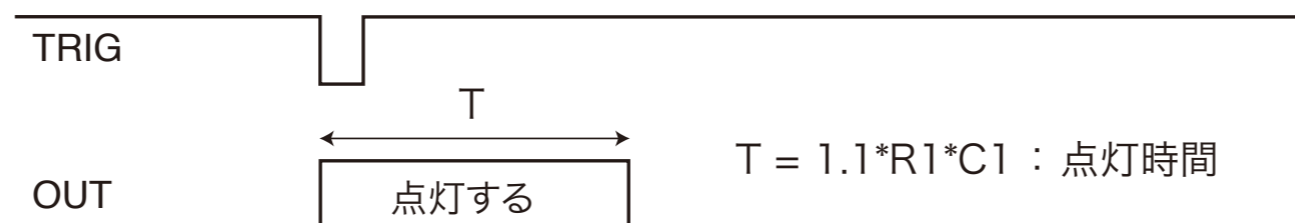
555を使った単安定発振回路



(a) 単安定発振回路

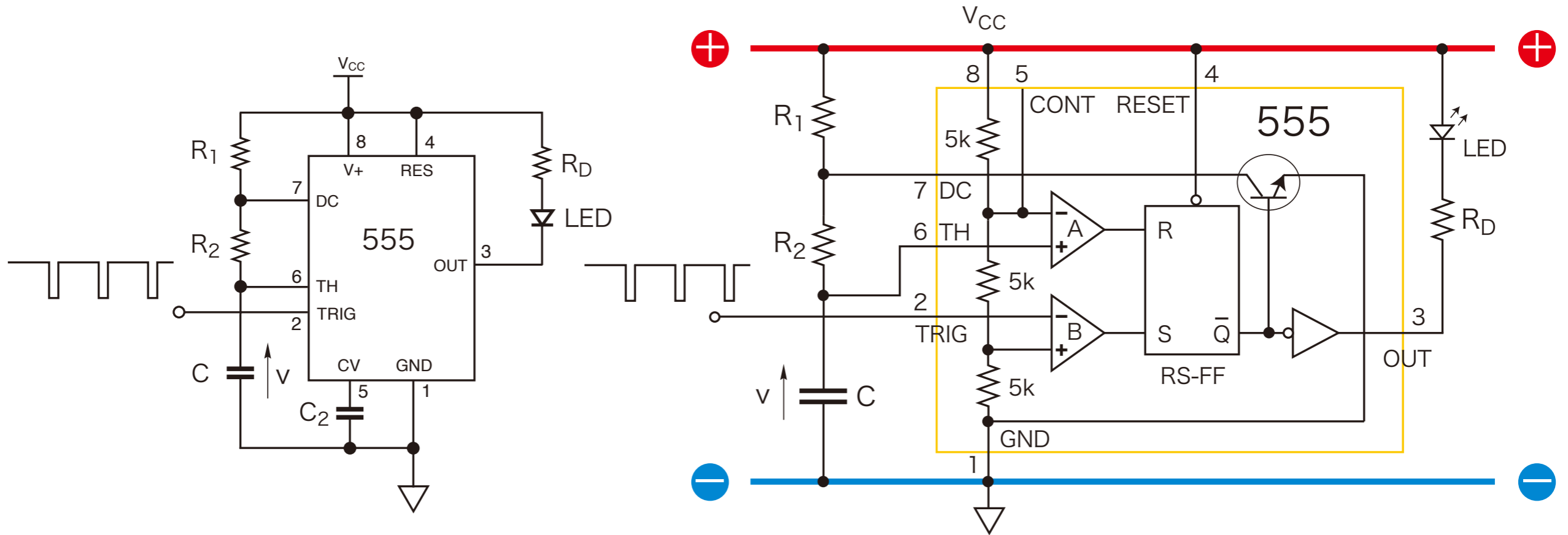


(b) (a) の配線図

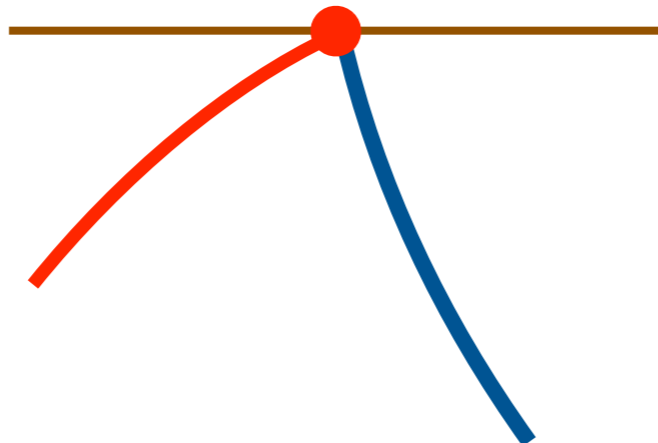




Kousata's BC circuit

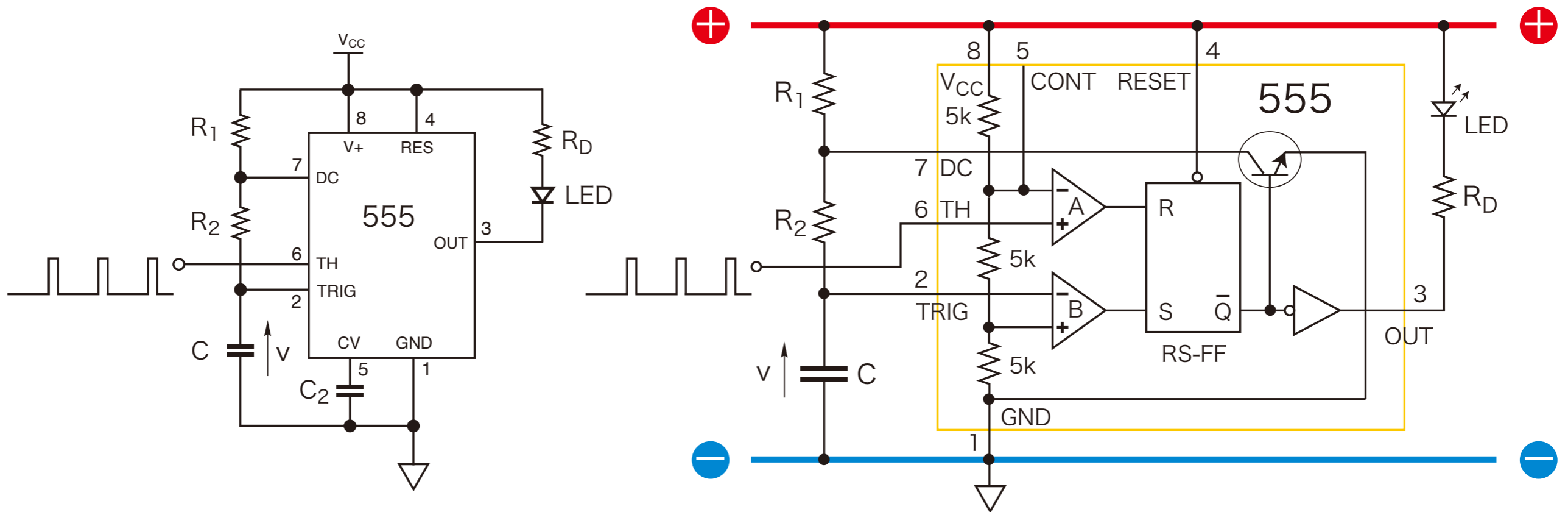


border

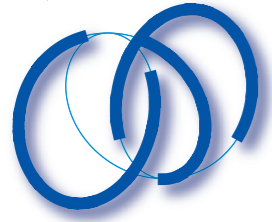




Complementary Kousata's BC circuit



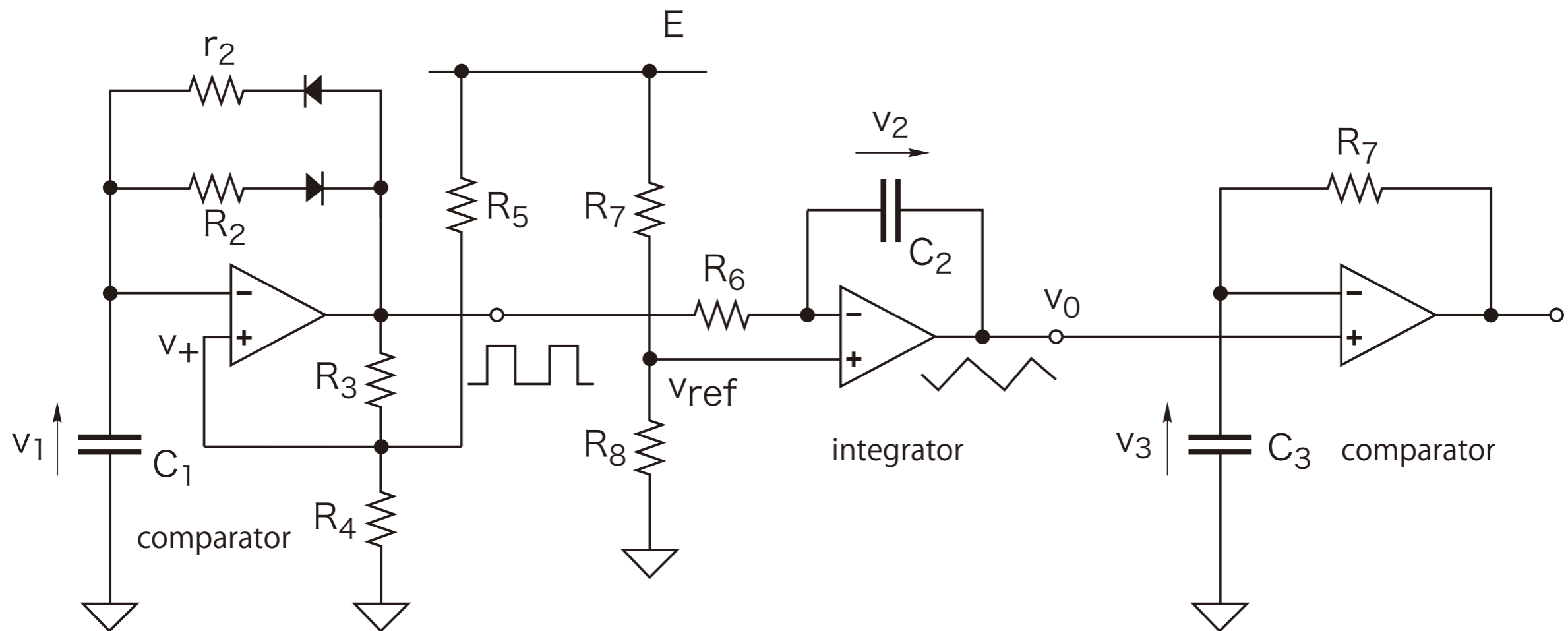
border



Hybrid circuits

triangular-wave generator

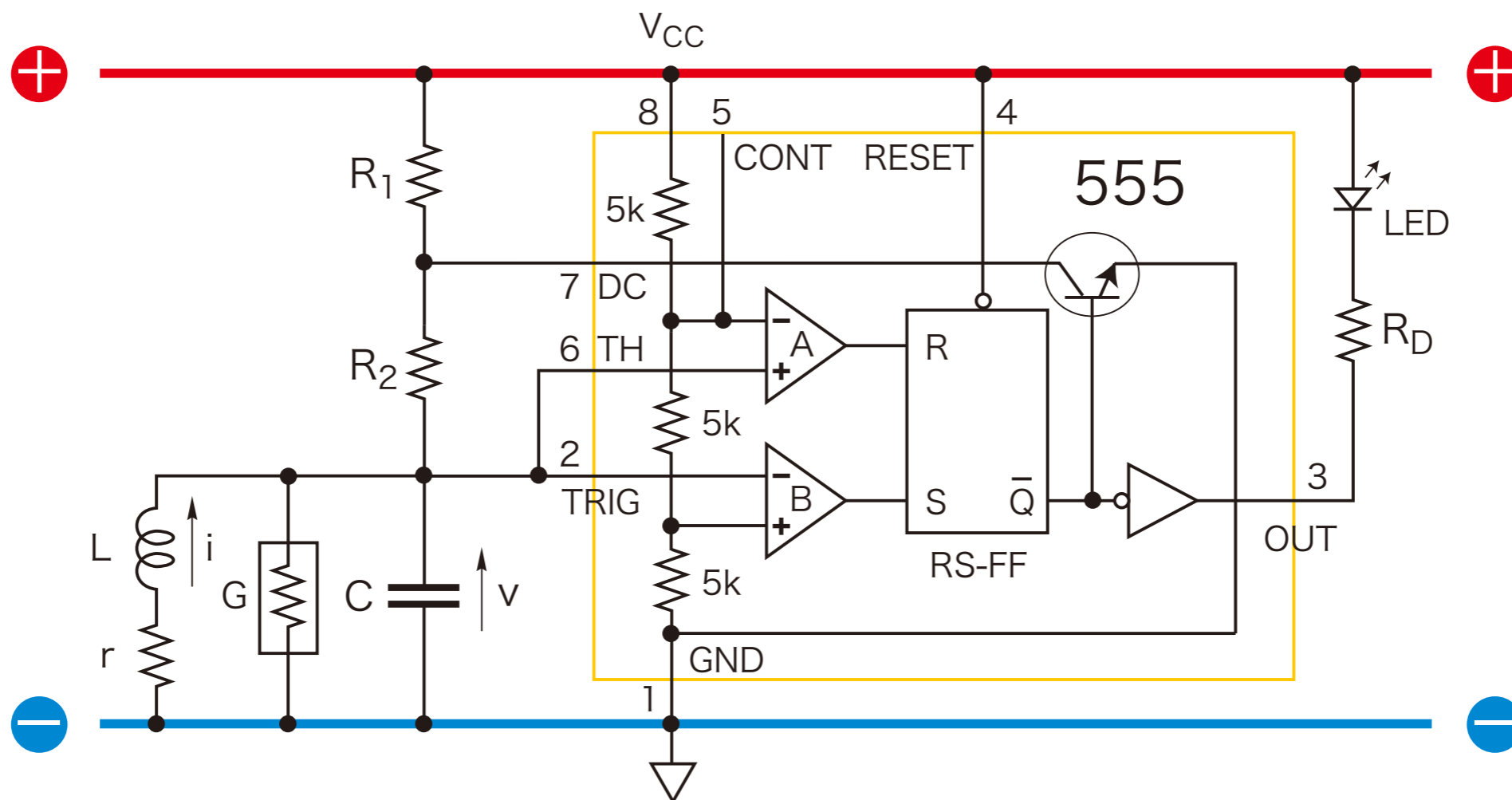
square-wave generator
with moving border



mixed event(moving border)



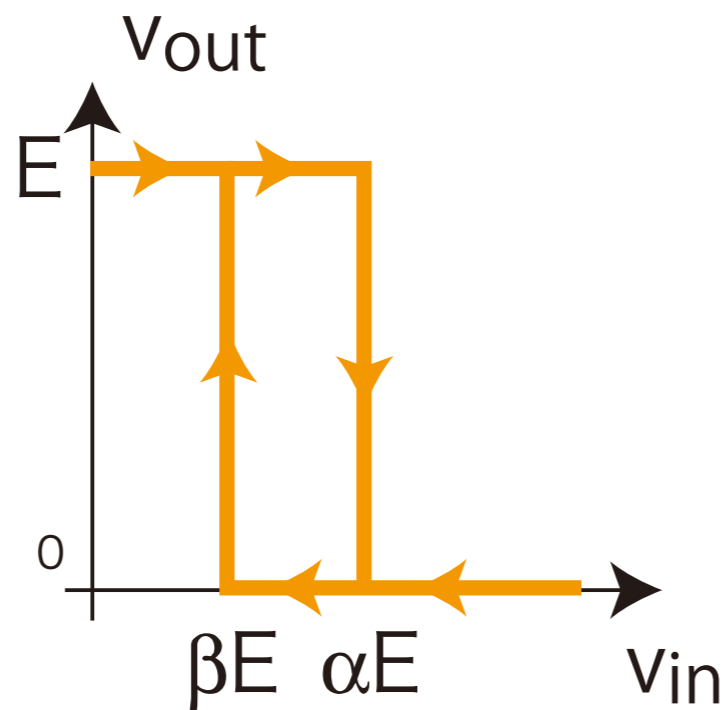
555 Alpacur oscillator ?



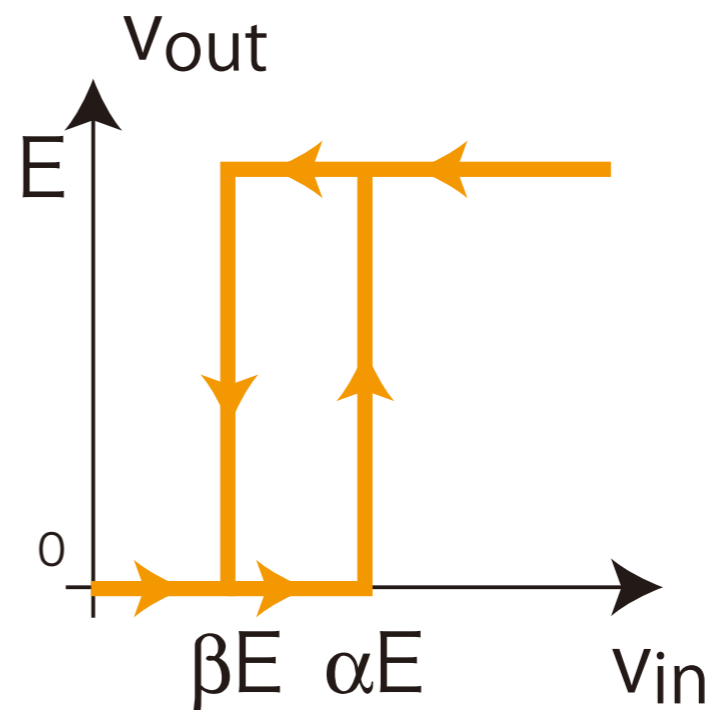
S type comparatorにする必要あり



1 bit hysteresis A/D converter : HADC



Z type

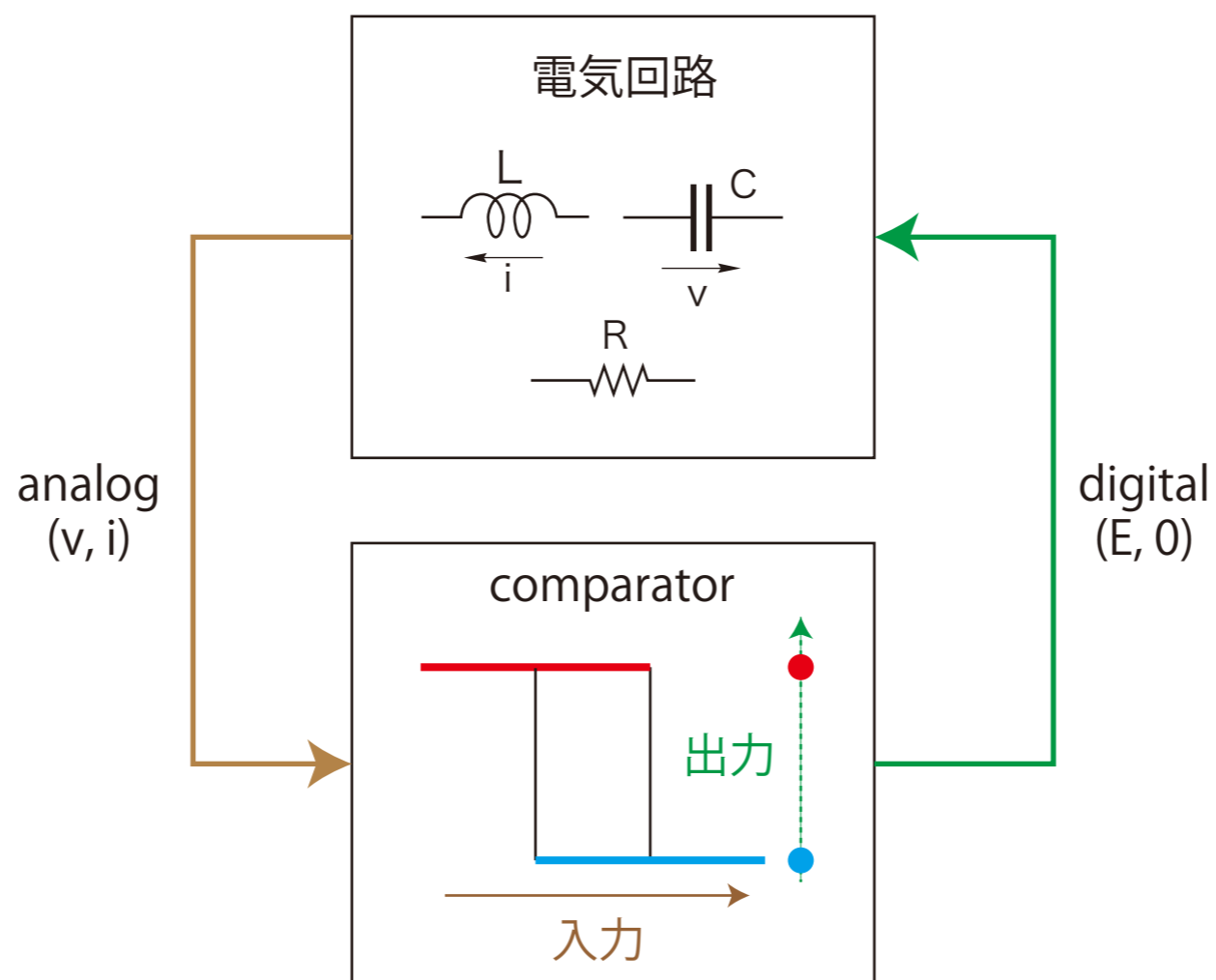


S type



Hybrid 回路のシンセシス

- ◎ スイッチ, コンパレータ, 論理素子を含むRLC回路
- ◎ 発展させた回路設計がしたい





Hybrid 回路のシンセシス

- ◎ FSMのmodes → comparatorやflip-flopの出力
- ◎ borderの条件 : センサー入力 $g(x)=0$
→ Op ampを含むアナログ回路
- ◎ RLC + comparator + IC logic elements
- ◎ RLC + comparator + MC(micro controller)
- ◎ RLC + PSoC(programmable system on chip)



2. Hybrid回路の数学モデル



Hybrid回路の数学モデル

- ◎ 1つのFSM (Finite State Machine: 有限状態機械)と
このFSMのモード数と同じ数の力学系からなる複合系

mode — FSM の状態 state — 力学系の状態

- ◎ 系の運動 — FSMのeventと力学系のflowで時間発展する

event — phase event, timer event, mixed event

mode遷移図
(graph)

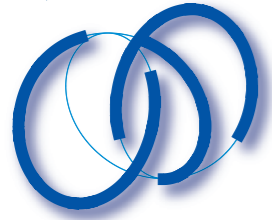
vector場
(ODE)



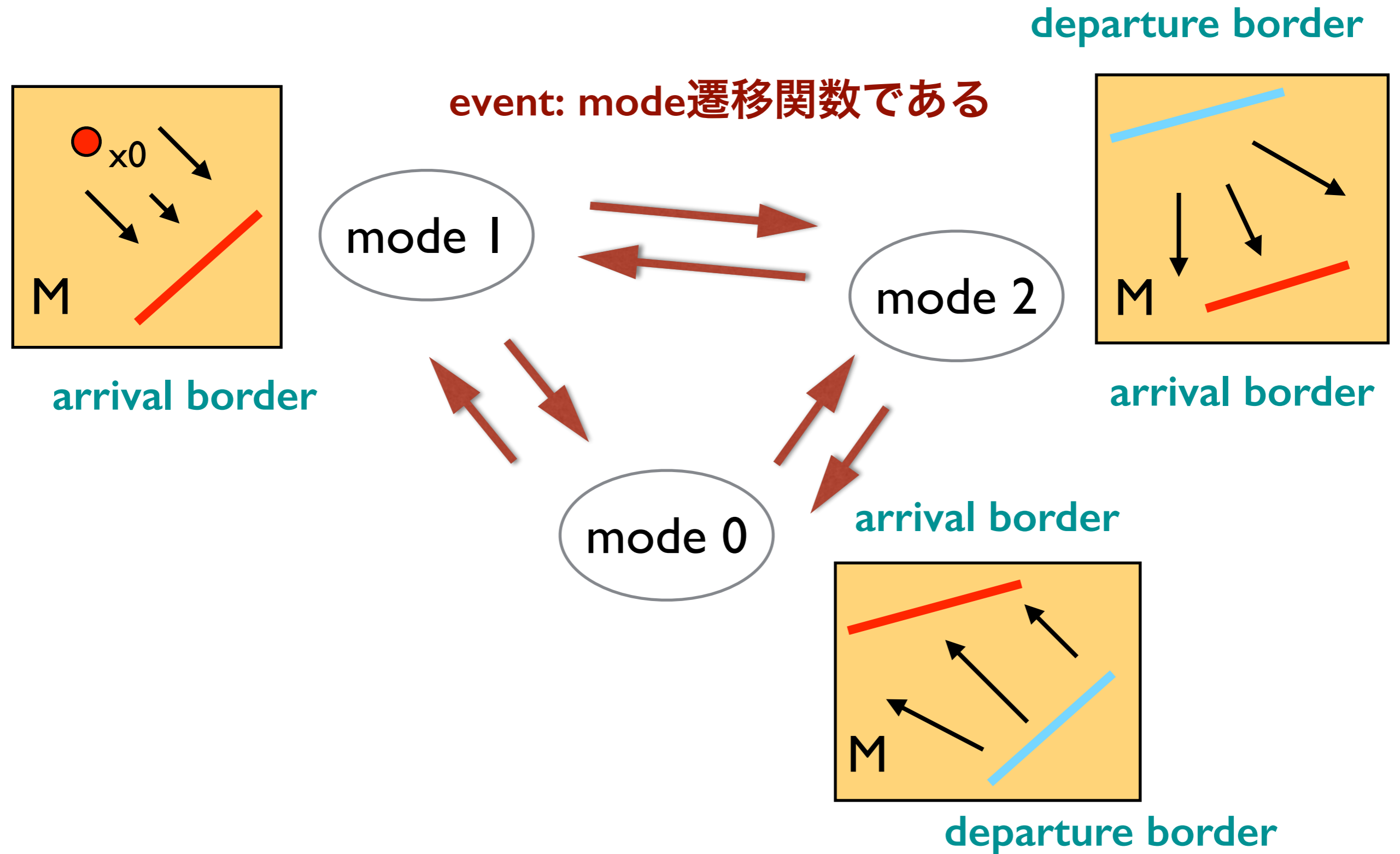
hybrid系 : states & motions

	FSM(digital)	dynamical system(analog)
state	$m = \#mode$	state $x \in M$
motion	mode transition	flow
dynamics	event	vector field

eventがflowを切換え, flowの時間発展がeventを生起する

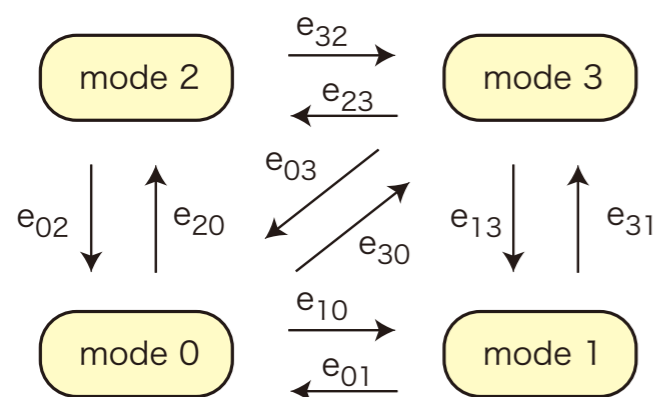


hybrid系の運動

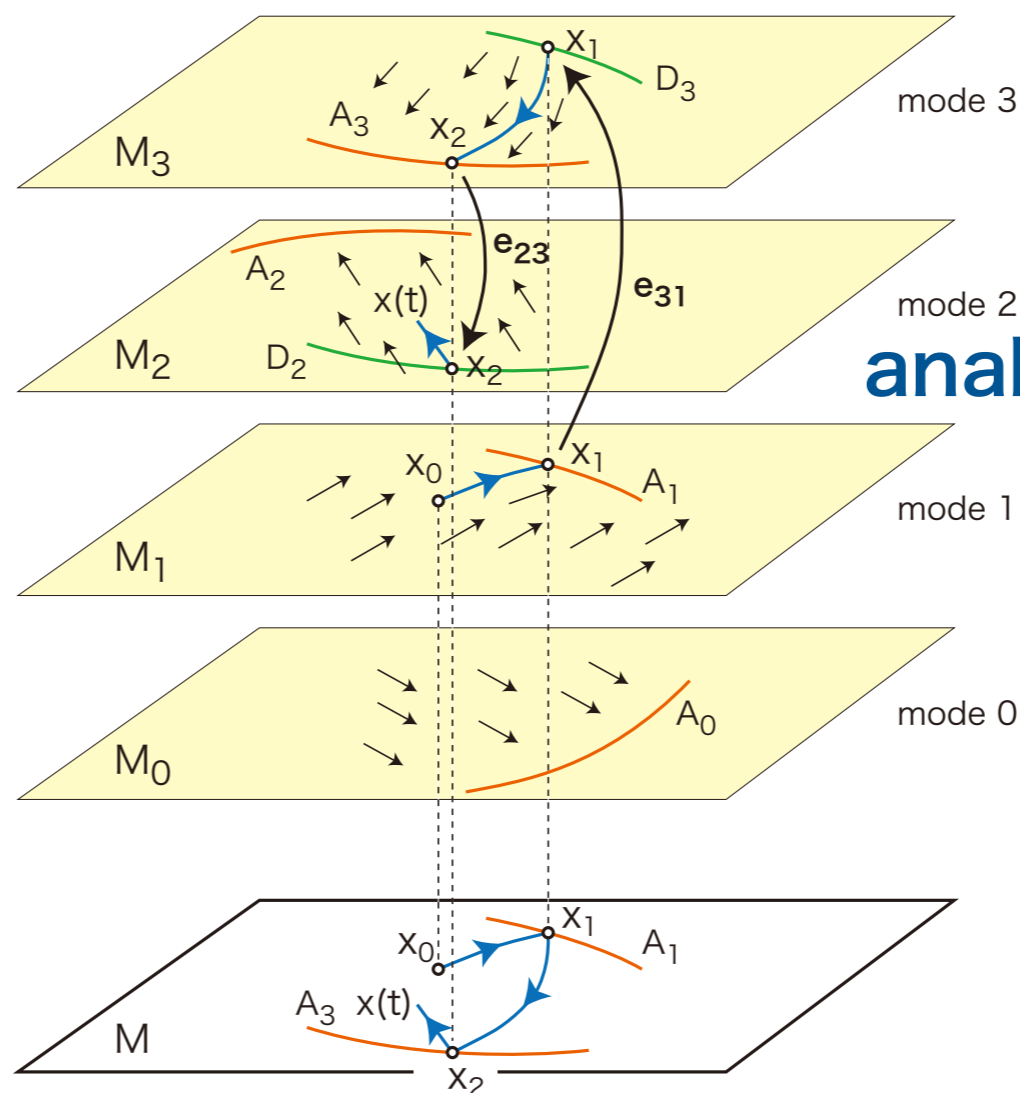




hybrid系の運動



digital dynamics

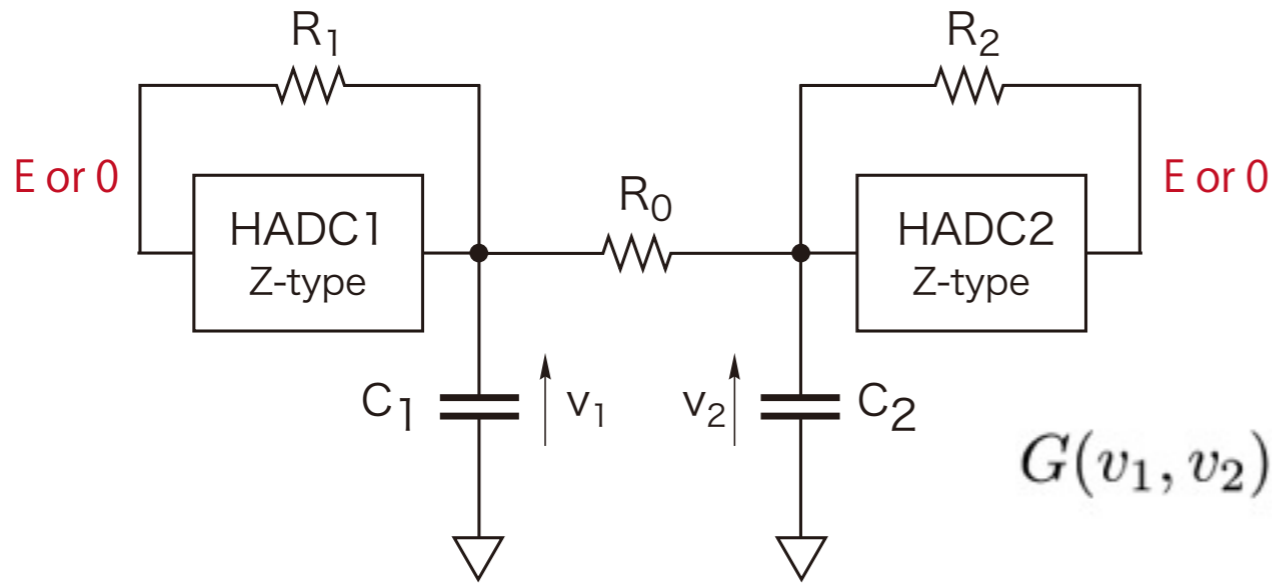


analog dynamics

hybrid dynamics



回路例 1 [4: 2]

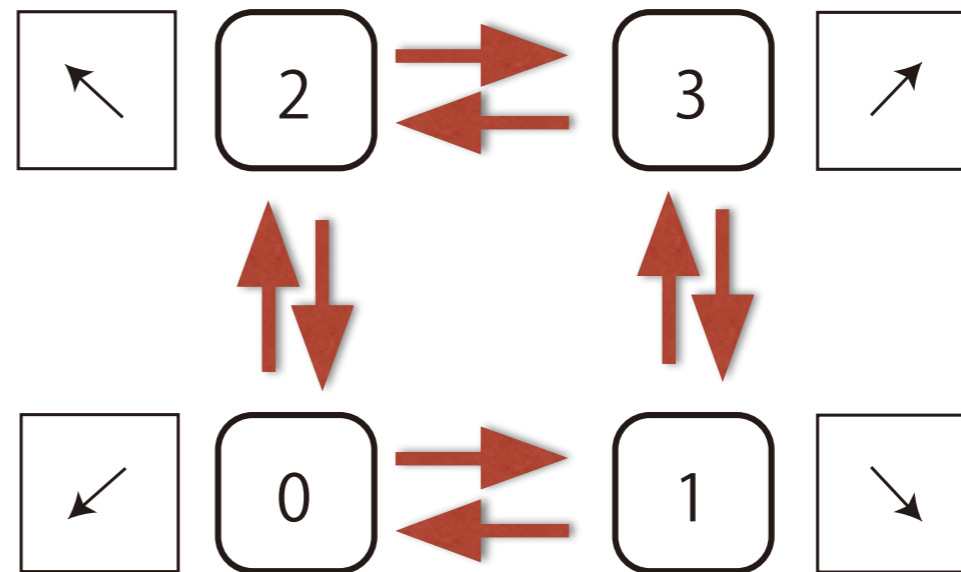


$$C_1 \frac{dv_1}{dt} = -\frac{\partial G}{\partial v_1} + v_{01}$$

$$C_2 \frac{dv_2}{dt} = -\frac{\partial G}{\partial v_2} + v_{02}$$

$$G(v_1, v_2) = \frac{1}{2} \left(\frac{1}{R_0} + \frac{1}{R_1} \right) v_1^2 + \frac{1}{2} \left(\frac{1}{R_0} + \frac{1}{R_2} \right) v_2^2 - \frac{1}{R_0} v_1 v_2$$

mode	HADC2	HADC1	vector field
0	0	0	
1	0	E	
2	E	0	
3	E	E	





Hybrid回路の回路方程式

◎ FSM の運動の記述

mode と mode間の遷移(transition)を記述する

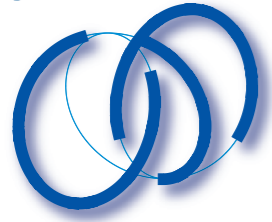
- ① mode数 = 2^n ; n = 回路に含まれる記憶素子の数
- ② mode間の遷移 : eventによる各記憶素子の出力変化
- ③ events : a) phase event, b) timer event and c) mixed event

◎ 回路方程式の記述

mode が決まれば回路も決まる : 回路方程式

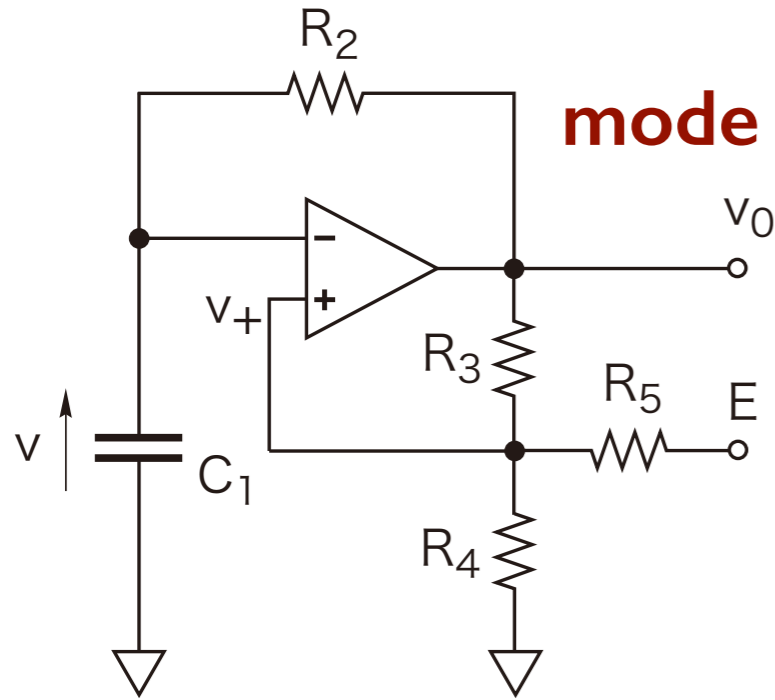
◎ 運動の次元

[modeの数 : stateの次元]

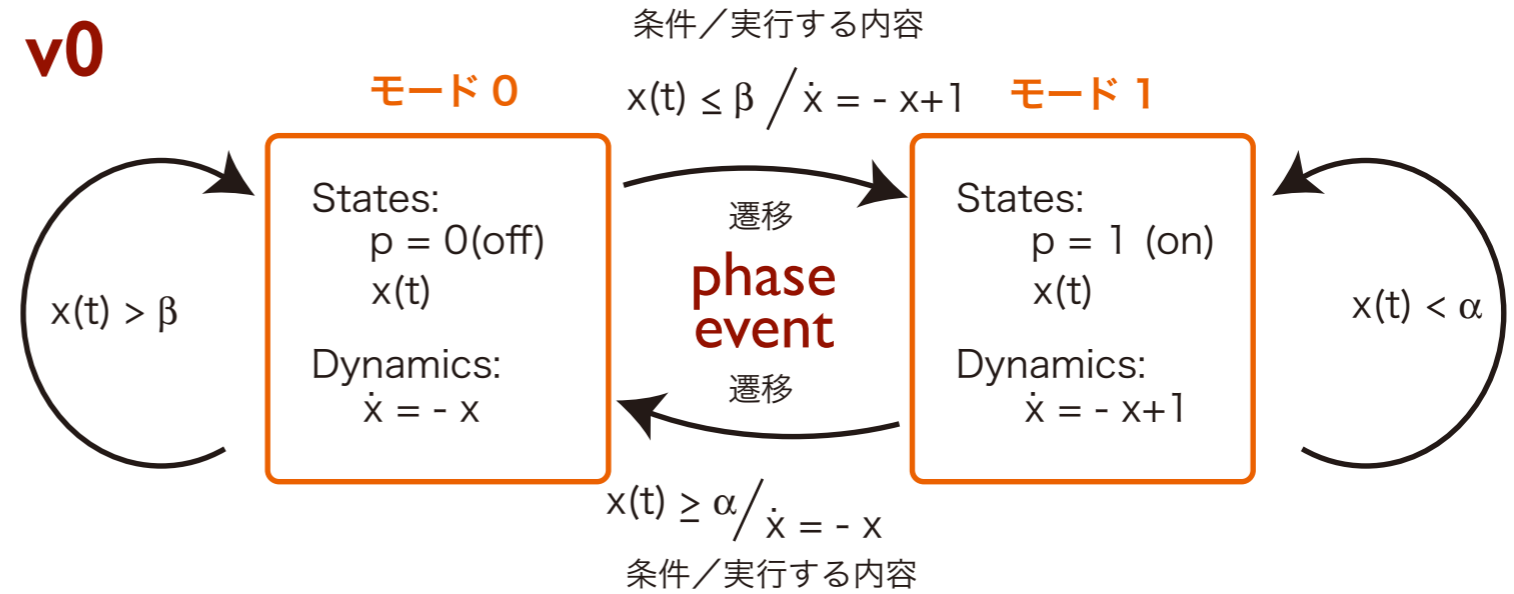


回路例 2 : SW oscillator [2:1]

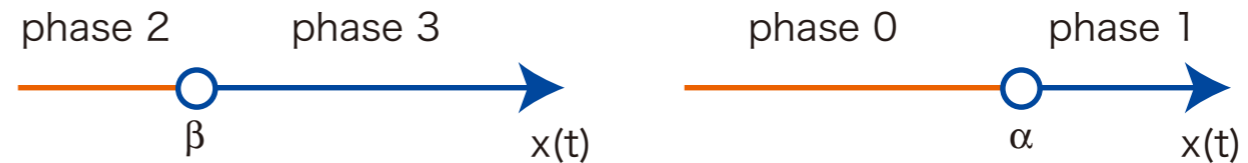
mode 遷移図



mode 変数: v_0



$$R_2 C_1 \frac{dv}{dt} + v = v_0$$

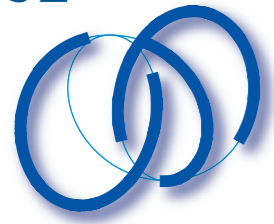


mode 1: $p=1$

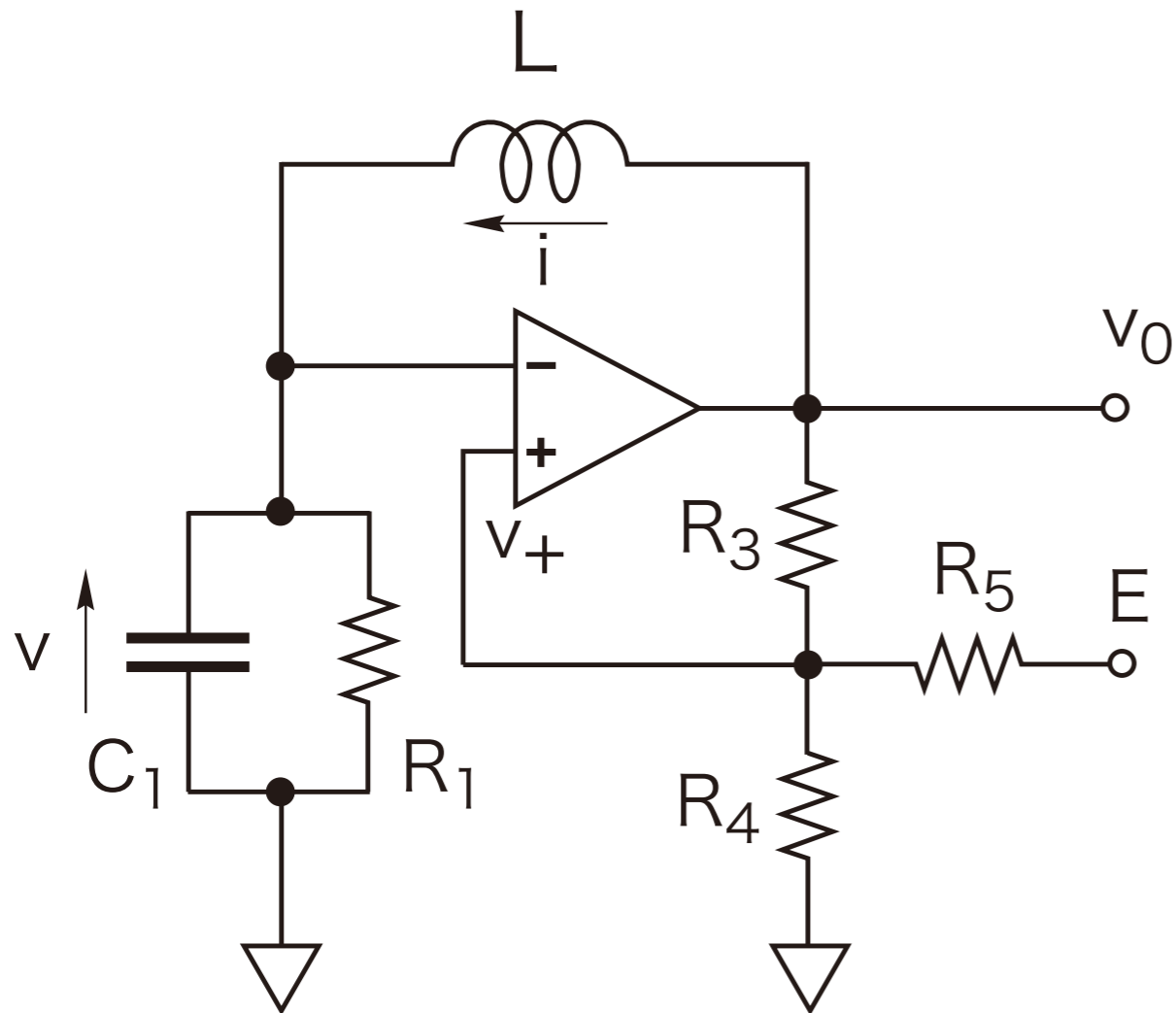
$$v_0 = E \quad v < \frac{\frac{1}{R_3} + \frac{1}{R_5}}{\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}} E$$

mode 0: $p=0$

$$v_0 = 0 \quad v > \frac{\frac{1}{R_5}}{\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}} E$$



回路例 3 : buck converter [2, 2]



(e)

$$L \frac{di}{dt} + v = v_0$$

$$C_1 \frac{dv}{dt} + \frac{v}{R_1} = i$$

$$v_0 = E \quad v < \frac{\frac{1}{R_3} + \frac{1}{R_5}}{\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}} E$$

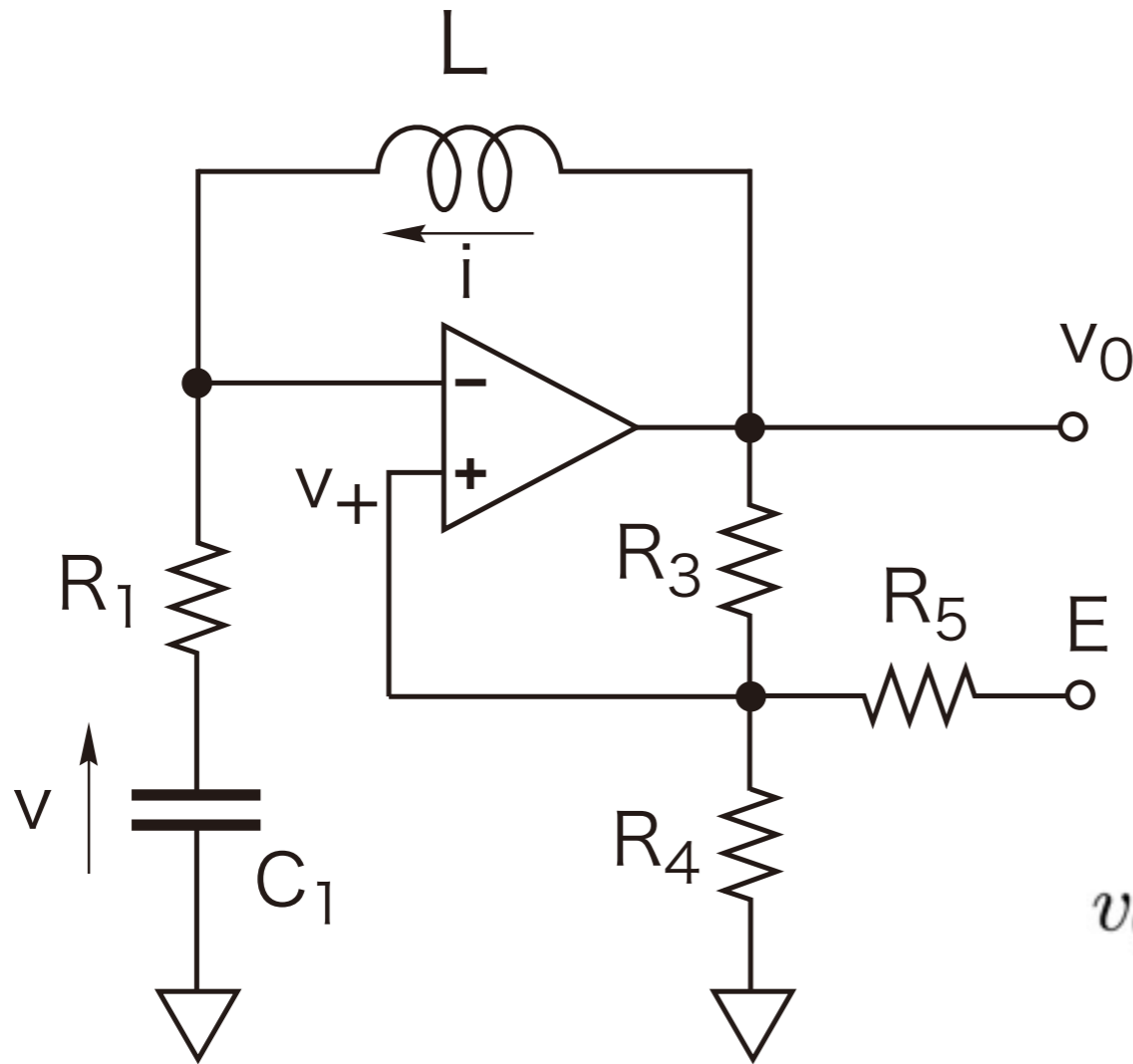
mode1: p=1

$$v_0 = 0 \quad v > \frac{\frac{1}{R_5}}{\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}} E$$

mode0: p=0



回路例 4 : linear border [2: 2]



(b)

$$L \frac{di}{dt} + R_1 i + v = v_0$$

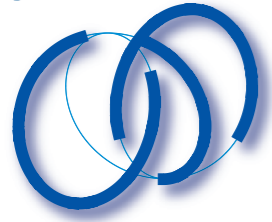
$$C_1 \frac{dv}{dt} = i$$

$$v_0 = E \quad v + Ri < \frac{\frac{1}{R_3} + \frac{1}{R_5}}{\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}} E$$

mode 1: p=1

$$v_0 = 0 \quad v + Ri > \frac{\frac{1}{R_5}}{\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}} E$$

mode 0: p=0



回路例 5 : OCO type A [4: 1]

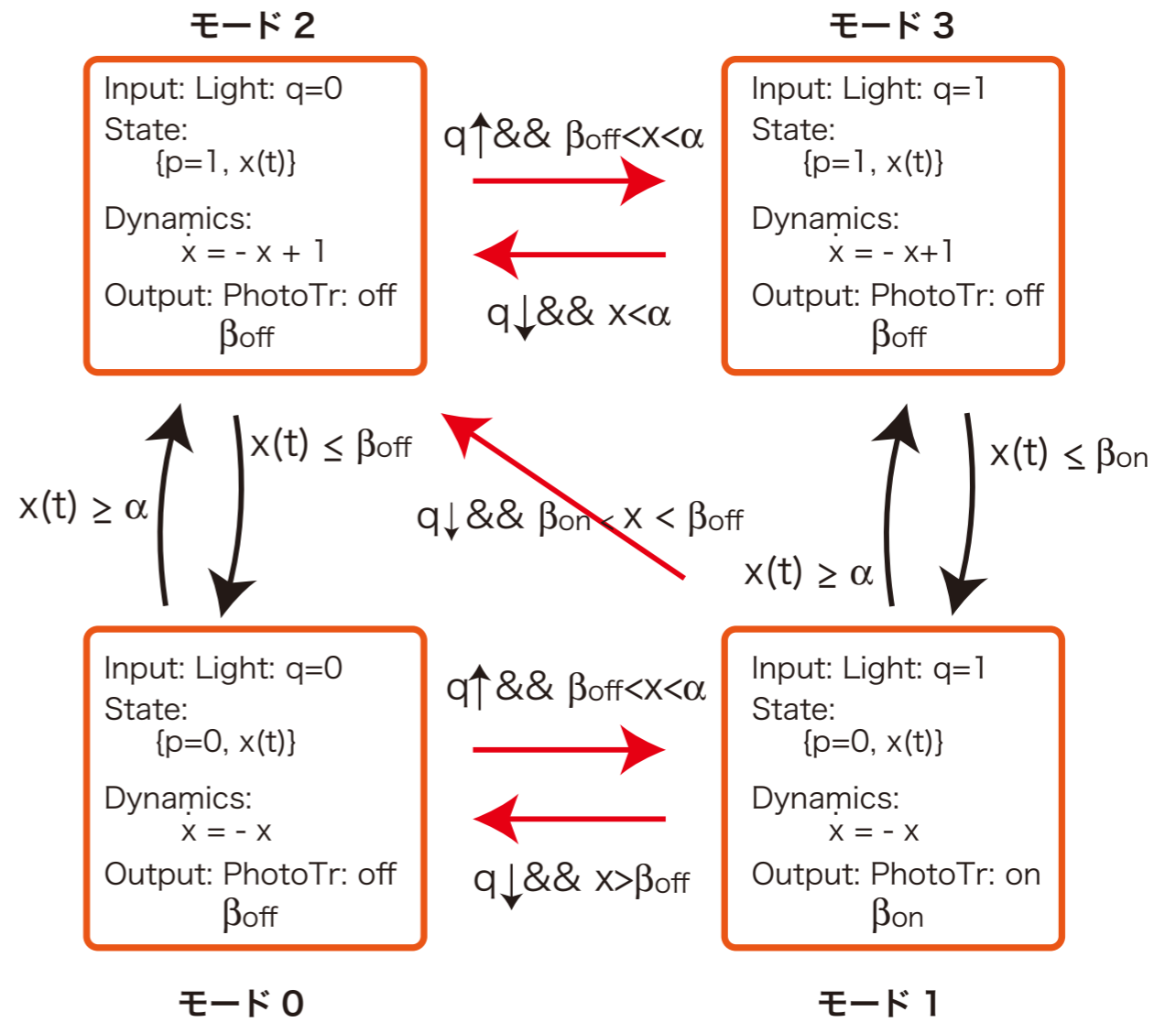
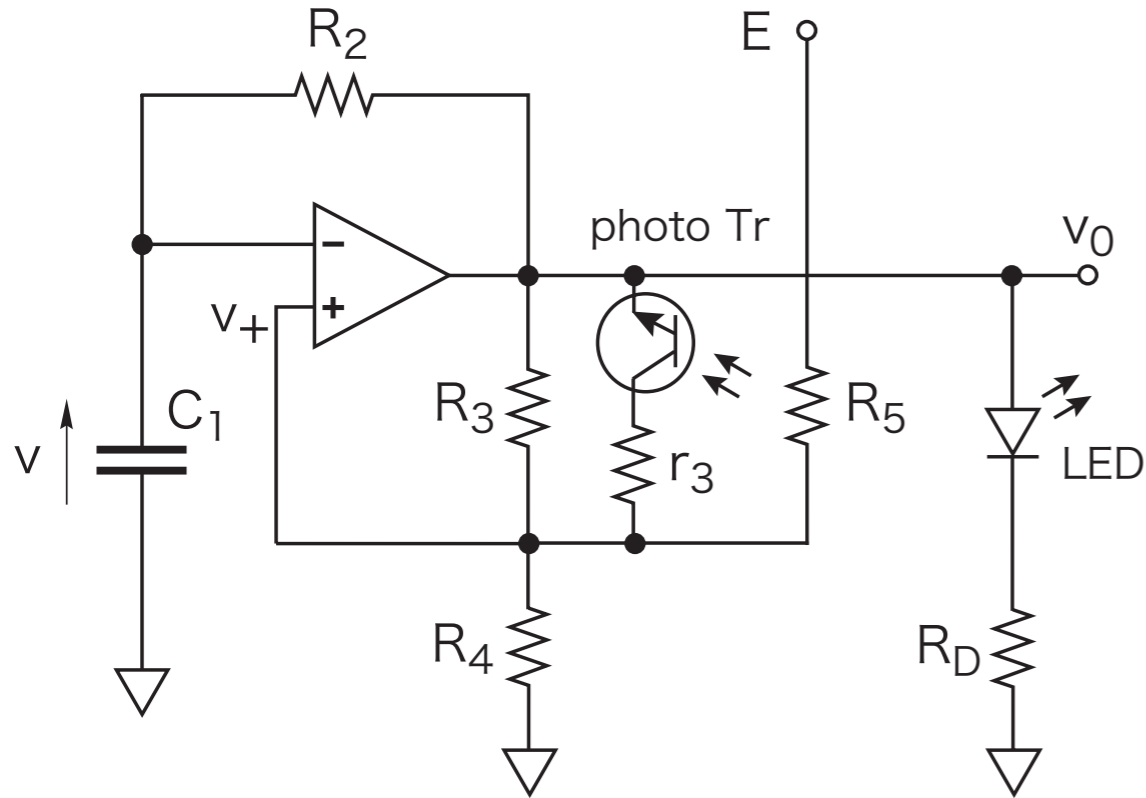
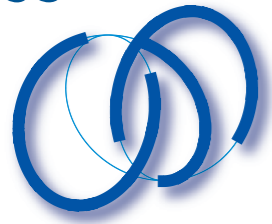
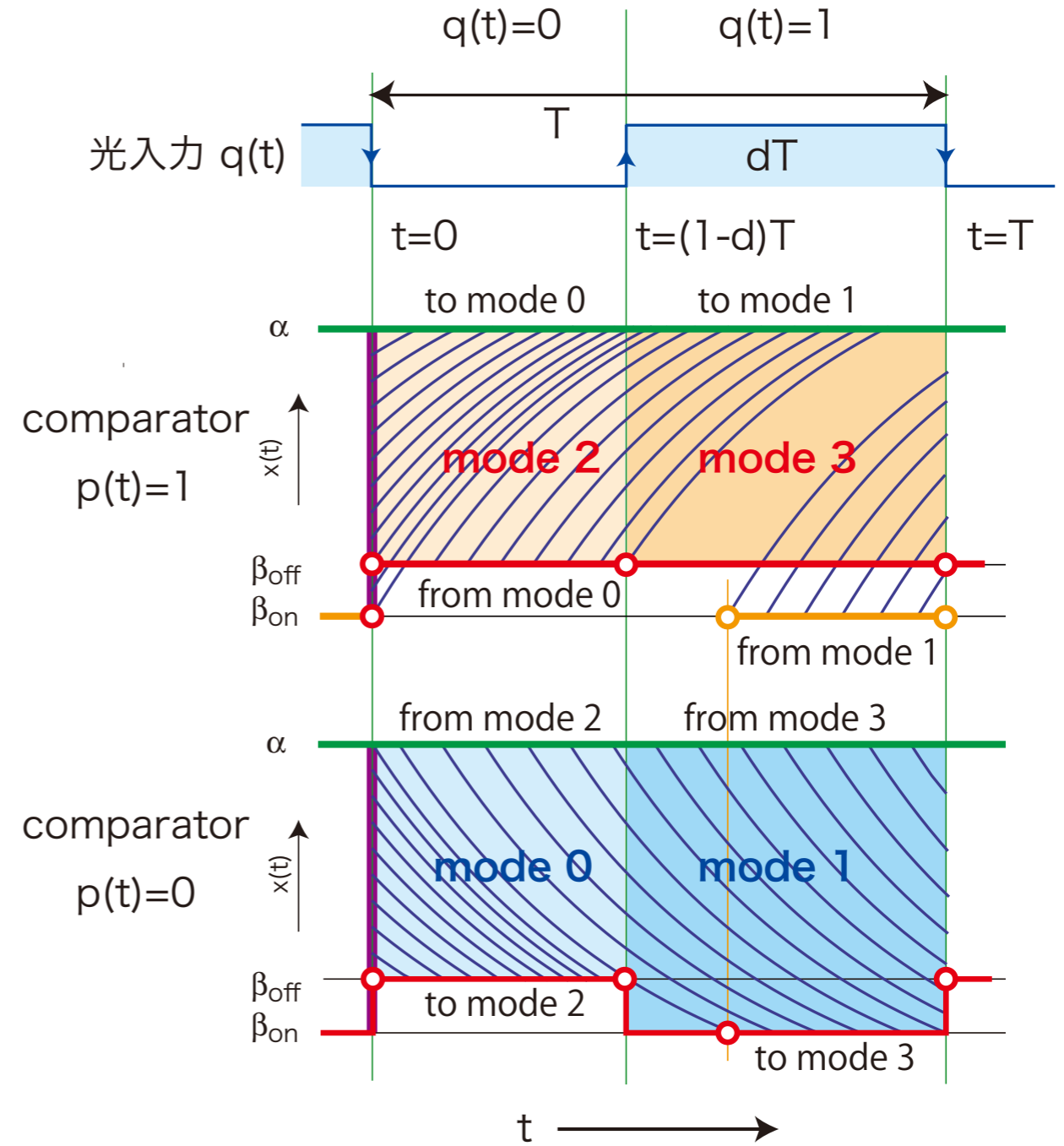
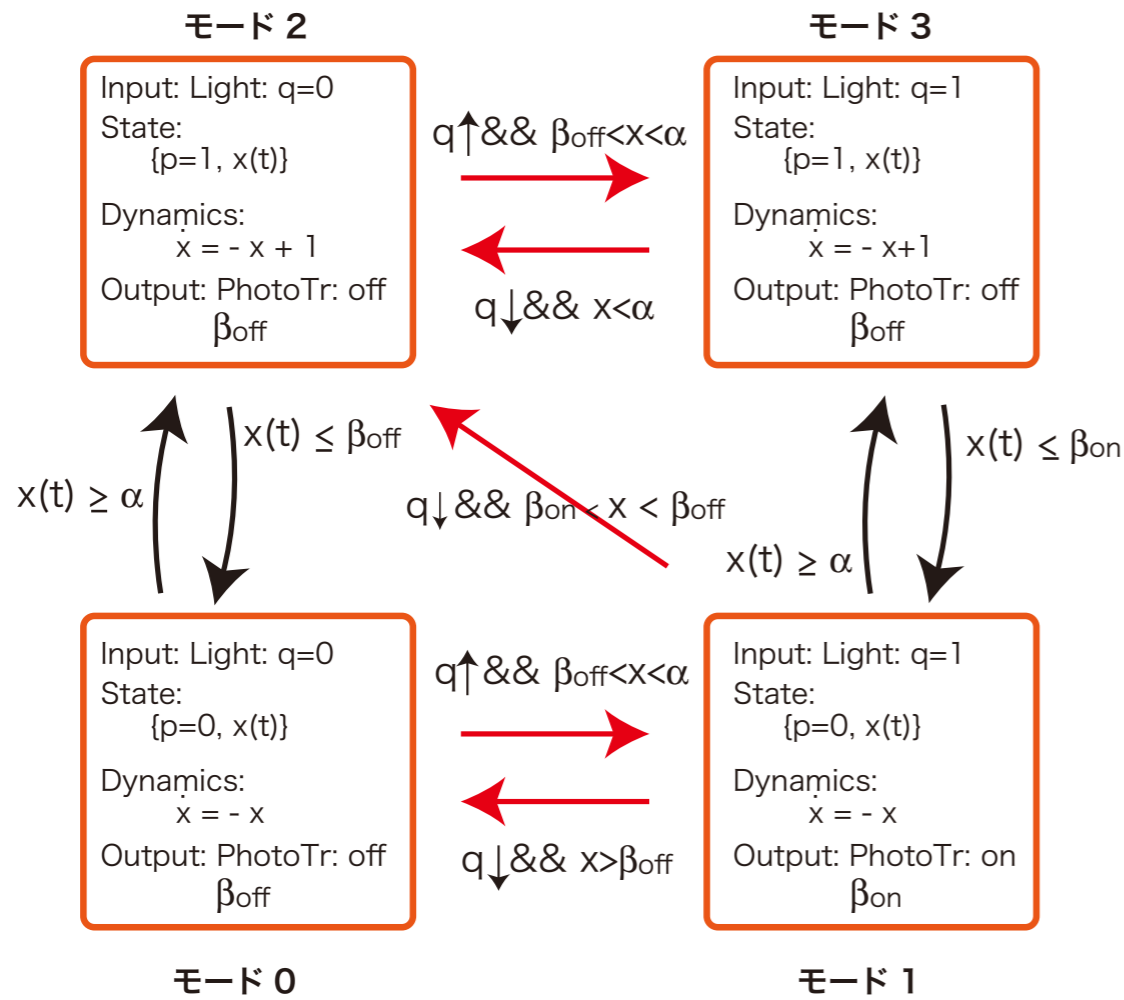


photo Tr		comparator : p	
		on:1	off:0
光入力 : q	on:1	off:0	on:1
	off:0	off:0	off:0



回路例 5 : OCO type A

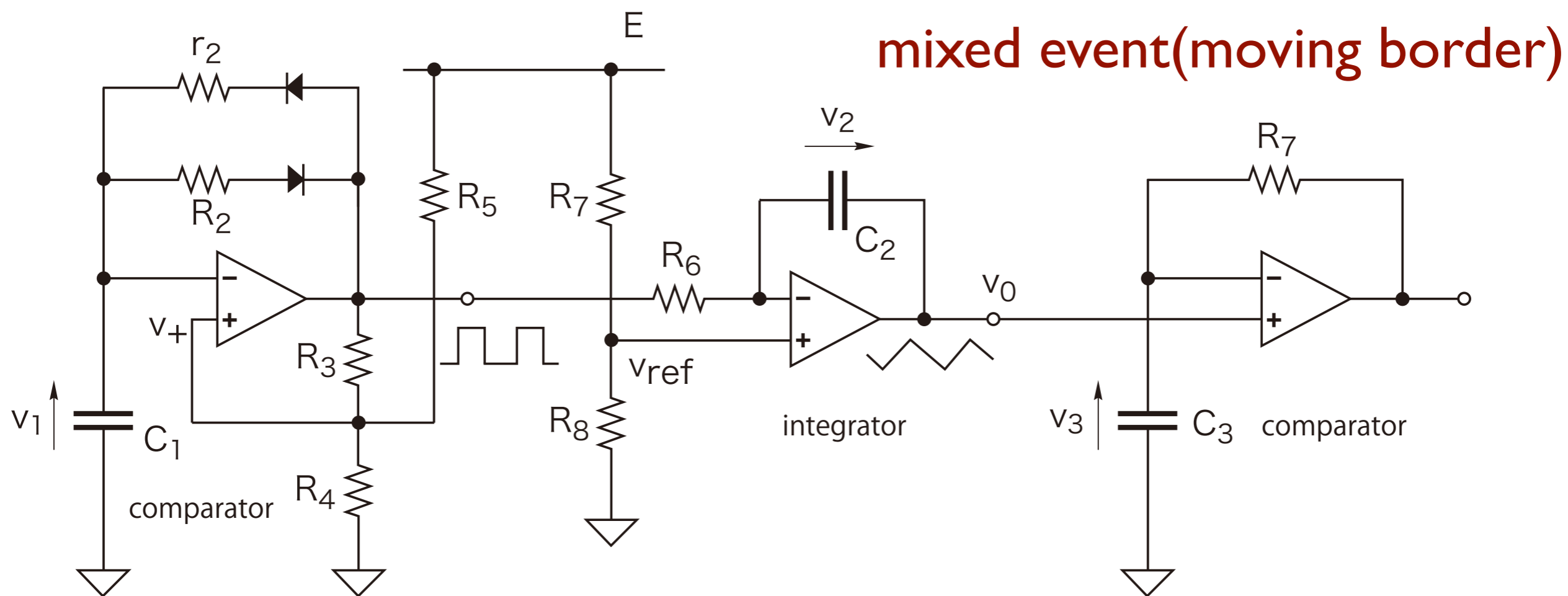




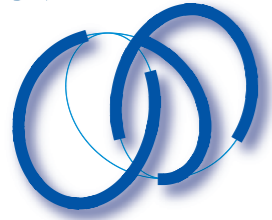
Moving Border circuits [$\infty:1$]

triangular-wave generator

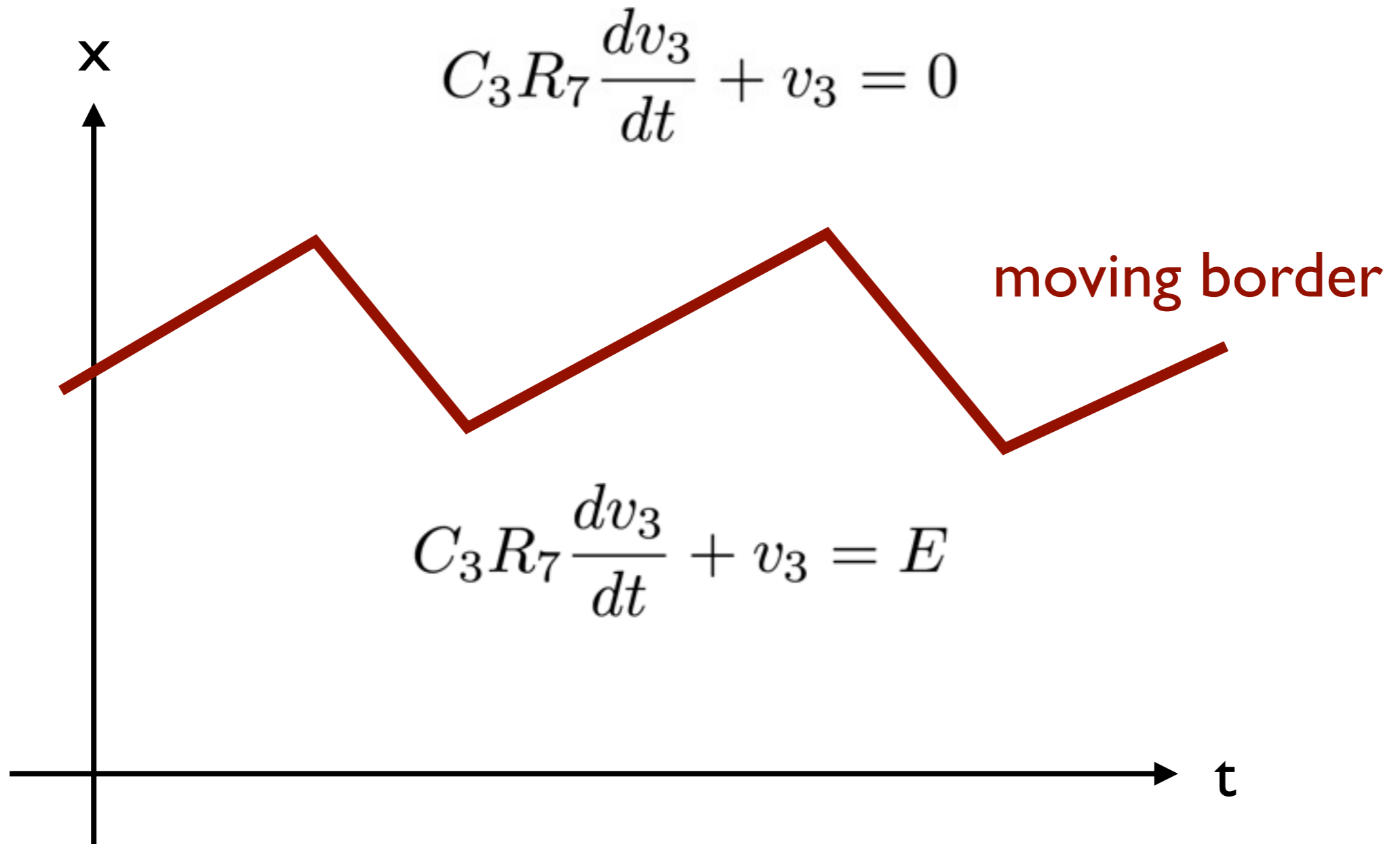
square-wave generator
with moving border



時間軸に関して運動が連続となる系



Moving border circuits





ハイブリッド回路の回路方程式

		時 間	
		連続	離散
状 態	連続	微分方程式 ODE	差分方程式 Poincare map
	離散	FSM in continuous time	Finite State Machine FSM



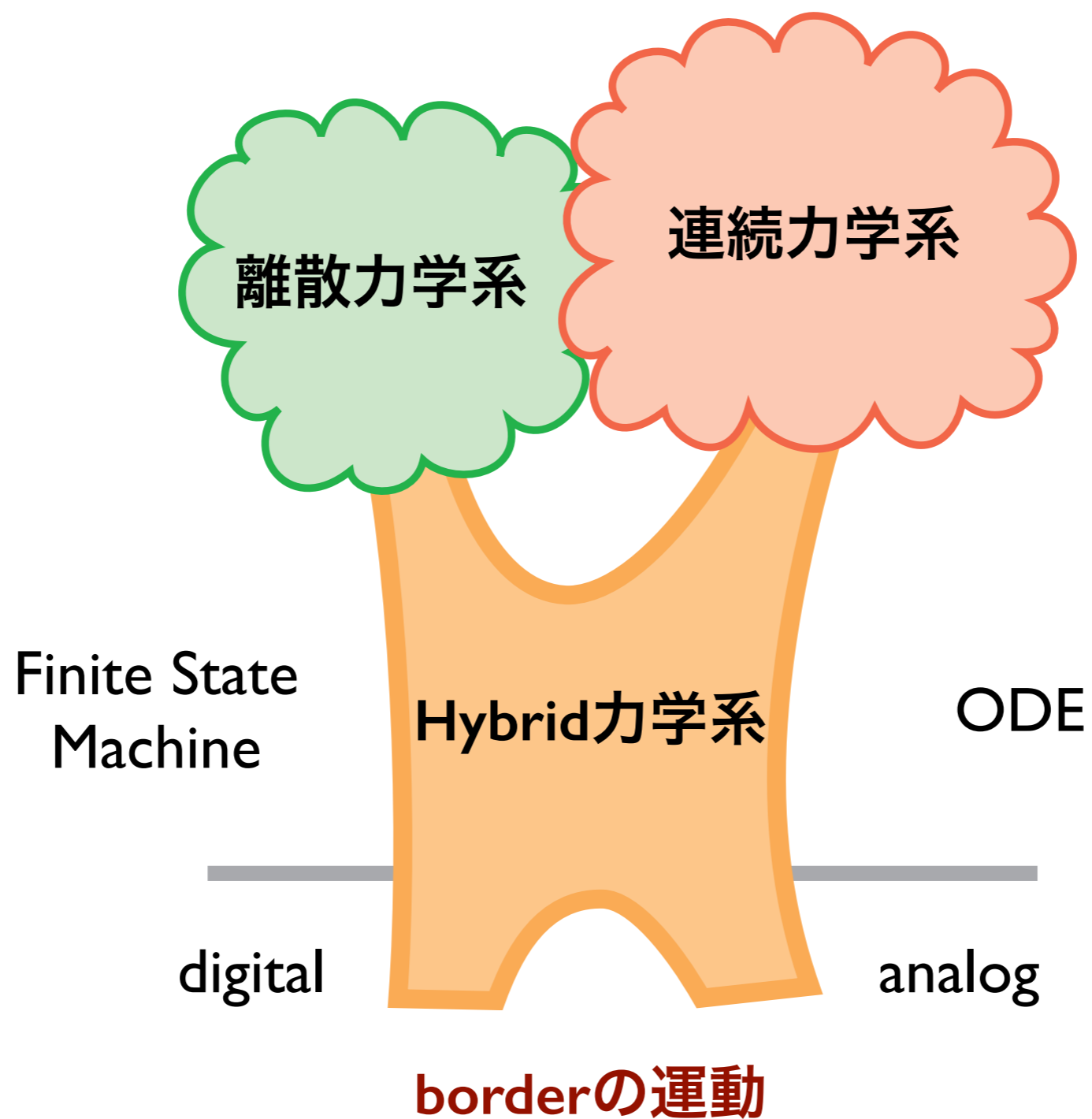
border 時変



border 時不変



Hybrid 力学系





References

- [1] Edward A. Lee and Sanjit A. Seshia, [Introduction to Embedded Systems, A Cyber-Physical Systems Approach](#), ISBN 978-0-557-70857-4, 2011
<http://LeeSeshia.org>
<http://ptolemy.eecs.berkeley.edu/ptolemyII/index.htm>

- [2] 高坂、上田、田原、川上、安部：Border-Collision分岐を呈する簡素な回路の実現と解析、電気学会論文誌 C, 平成14年11月号、pp.1908-1916.

- [3] T. Kousaka, T. Ueta and H. Kawakami, Bifurcation of Swotched Nonlinear Dynamical Systems, IEEE Trans. on Circuit and Systems II, Vol. 46, No. 7, July 1999, pp. 878-885.

- [4] 高坂拓司：断続動作特性を有する非線形力学系の分岐解析