情報ネットワーク科学研究会

非線形振動子の同期とその実験について

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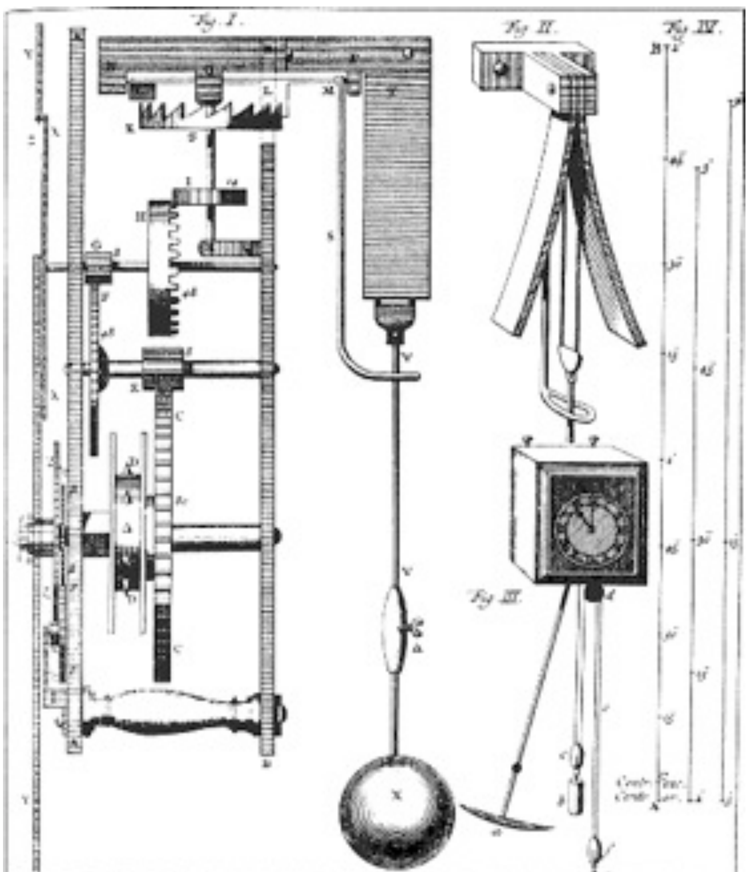
振り子時計

クリスチャン ホイヘンス
(1629-1695)



同期の発見

1665年2月

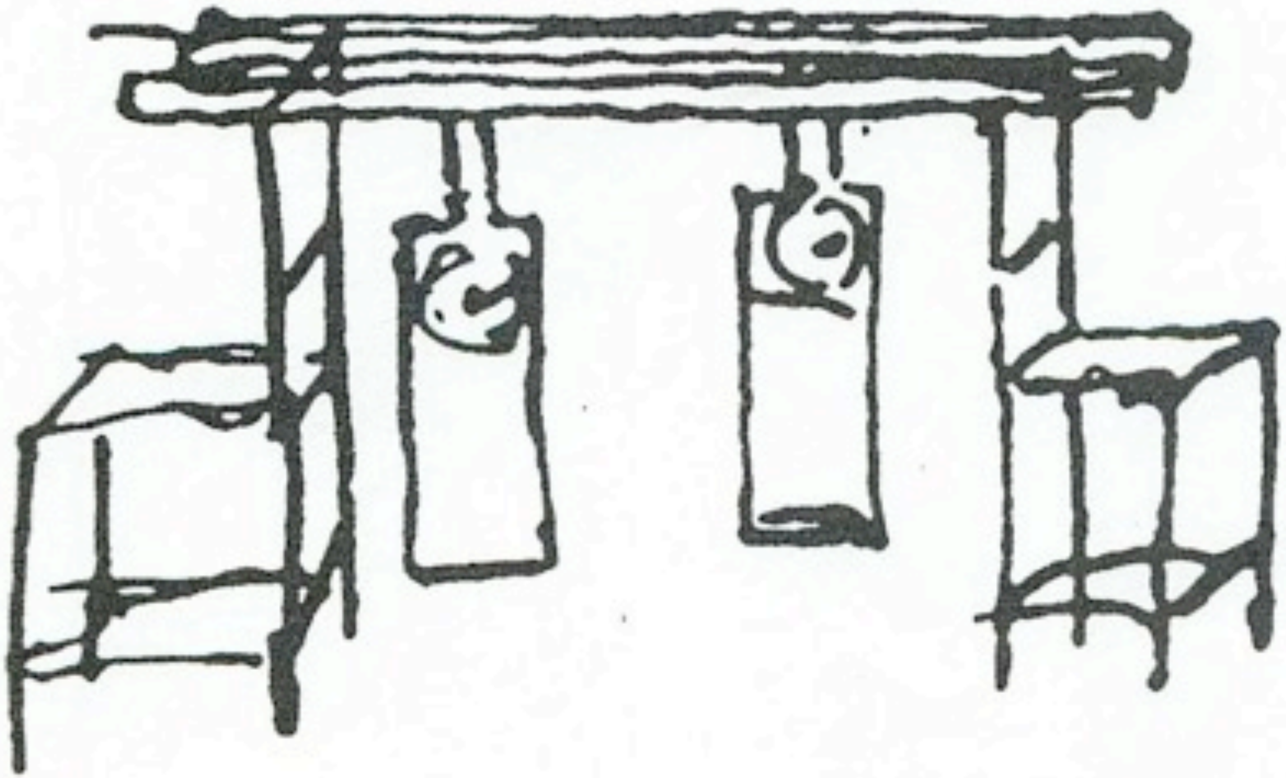
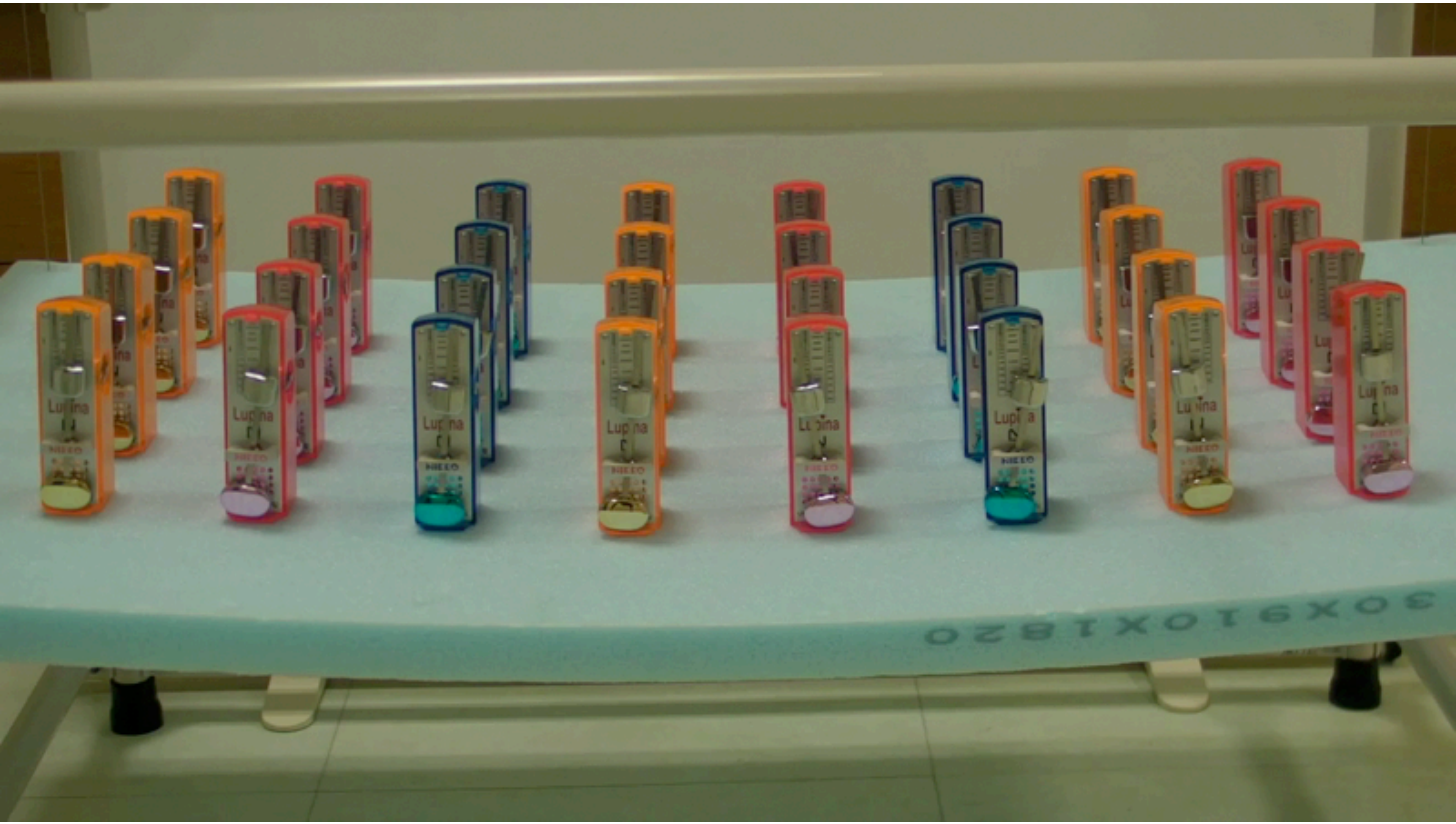
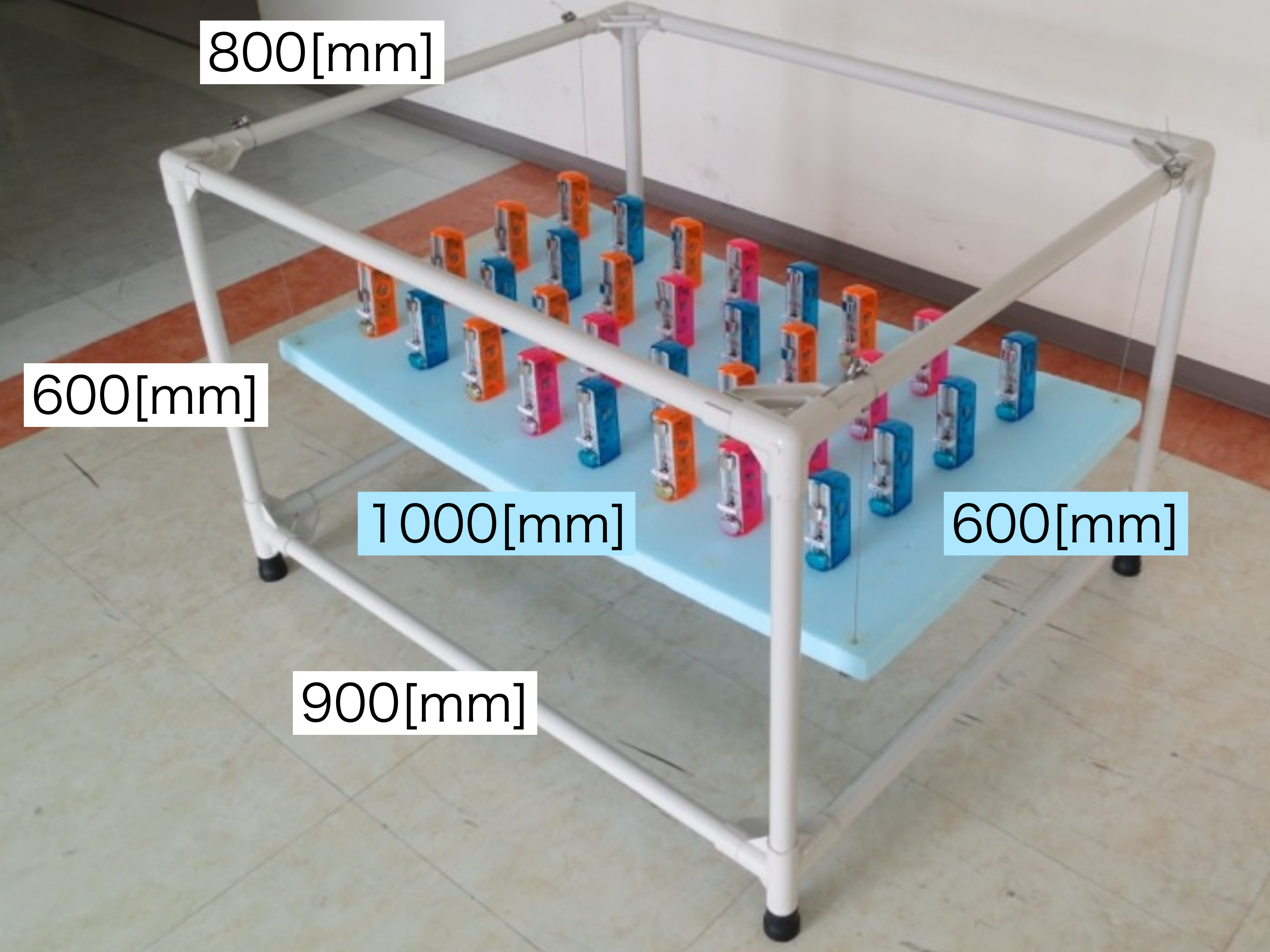


Figure 1.2. Original drawing of Christiaan Huygens illustrating his experiments with two pendulum clocks placed on a common support.

A. Pikovsky, M. Rosenblum, J. Kurths, Synchronization: A Universtal Concept in Nonlinear Science, Cambridge University Press, 2001

メトロノーム

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日工精機株式会社製　ルピーナ

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▶ メトロノーム同期 (32個) – YouTube
www.youtube.com/watch?v=JWToUATLGzs
リーダー
アップル
Researches
Google
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ニュース
お役立ち
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メトロノーム同期 (32個)
IkeguchiLab · 42 本の動画
チャンネル登録
916
3,704,291
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グッド！
概要
共有
追加
相原みぃ、AKB48のコ
でAK47を撃つ
作成者: ハイパー道楽
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Perpetual motion mac
(hypothetical)
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再生回数 5,881,310 回
5:56
魔裟斗のローキックを
渡辺一久
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地球～宇宙の果てまで
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Pendulum Waves
作成者: Harvard Natural Sc
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Tomatoes - Superfoo
Episode 4
TOMATOES
作成者: watchsuperfoods
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Synchronization of metronomes

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(Received 1 April 2002; accepted 24 June 2002)

Synchronization is a common phenomenon in physical and biological systems. We examine the synchronization of two (and more) metronomes placed on a freely moving base. The small motion of the base couples the pendulums causing synchronization. The synchronization is generally in-phase, with antiphase synchronization occurring only under special conditions. The metronome system provides a mechanical realization of the popular Kuramoto model for synchronization of biological oscillators, and is excellent for classroom demonstrations and an undergraduate physics lab.
[DOI: 10.1119/1.1501118]

I. INTRODUCTION AND SUMMARY

Synchronization is the process where two or more systems interact with each other and come to move together. It is commonly observed to occur between oscillators. Synchronization differs from the well-known phenomena of resonance, where an oscillator responds to an external periodic signal. Collections of oscillators are observed to synchronize in a diverse variety of systems, despite the inevitable differences between the oscillators. Synchronization is a fundamental theme in nonlinear phenomena and is currently a popular topic of research.[1]

Biology abounds with examples of synchronization.[2,3] Populations of certain cicada species emerge simultaneously with periods of 13 or 17 years.[4] Huge swarms of fireflies in South-East Asia gather in the same tree to flash in synchrony (see, for example, Ref. 5). Networks of pacemaker cells in the heart beat together.[6] An example from psychology is the synchronization of clapping in audiences.[7] There are many physical examples also. The voltage oscillations of superconducting Josephson junctions are observed to synchronize.[8,9] Neutrino oscillations in the early universe may also exhibit

Here we examine a variant of Huygens' original system, two pendulum metronomes on a light, easily movable platform. For small intrinsic frequency differences, the oscillators generally synchronize with a small phase difference, that is, in-phase. This system makes an excellent classroom demonstration: it can be assembled quickly, synchronization occurs in a few tens of seconds, the mechanical motion is visually appealing, and the metronomes' ticks provide an added indication of the pendulum bob's motion. The system is also useful for an experimental study of synchronization. The audible ticks (and/or the base motion) provide an easy way to quantify the relative motion of the pendulum bobs. The ticks can be recorded and used to study the approach to synchronization and the small phase difference between the synchronized metronomes.

The results are well described by a simple model. The metronomes are described as van der Pol oscillators[17] and the coupling between the metronomes comes from the undamped motion of the base. Using this model, the absence of the antiphase synchronization that Huygens and others observed is readily explained. The large oscillation amplitudes (45 degrees) of the pendulum bobs' motion destabilize the

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振動系の同期現象*
(2 台のメトロノームを対象とした実験と解析)

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長嶺 拓夫*2, 布施 誠*3

Synchronized Phenomena of Oscillators
(Experimental and Analytical Investigation for Two Metronomes)

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This paper describes experimental and analytical investigation on synchronized phenomena conducted with two metronomes on a base plate suspended by four wires. Two modes of synchronized phenomena, i. e., in-phase synchronization and out-of-phase synchronization, are experimentally observed. The synchronization mode and frequency in synchronization is strongly influenced by the natural frequency of the base plate. Calculated results based on a physical model of the experimental apparatus show good agreement with the experimental ones, not only qualitatively but also quantitatively.

Key Words : Synchronization, Entrainment, Phase-Locking, Frequency-Locking,Nonlinear Vibration, Self-Excited Vibration, Pendulum

1. 緒　　言

る同期現象について検討した．共通の構造系に設置された複数の不平衡ロータについては，発生する同期現

ロンドン ミレニアム橋

http://www.youtube.com/watch?v=eAXVa__XWZ8

BRIEF COMMUNICATIONS

Crowd synchrony on the Millennium Bridge

Footbridges start to sway when packed with pedestrians falling into step with their vibrations.

Soon after the crowd streamed on to London's Millennium Bridge on the day it opened, the bridge started to sway from side to side: many pedestrians fell spontaneously into step with the bridge's vibrations, inadvertently amplifying them. Here we model this unexpected and now notorious phenomenon — which was not due to the bridge's innovative design as was first thought — by adapting ideas originally developed to describe the collective synchronization of biological oscillators such as neurons and fireflies. Our approach should help engineers to estimate the damping needed to stabilize other exceptionally crowded footbridges against synchronous lateral excitation by pedestrians.

Existing theories[1–6] of what happened on the bridge's opening day focus on the wobbling of the bridge but have not addressed the crowd-synchronization dynamics. In our

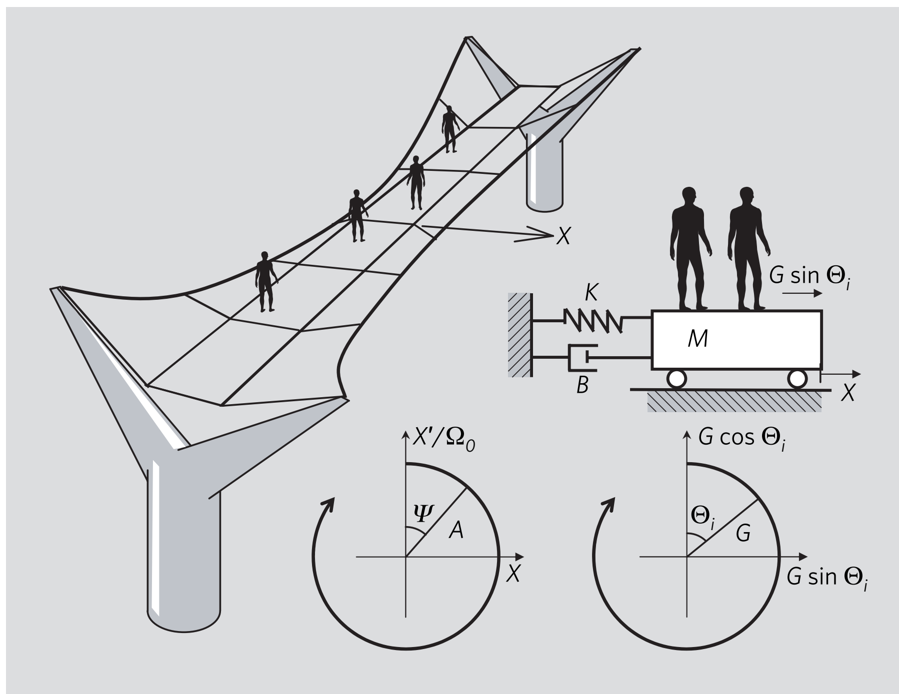

Figure 1 | Effect of pedestrian crowding on London's Millennium Bridge. The resonant lateral mode of vibration of the bridge (left) can be represented by a mass-spring-damper system (top, right). The angular phases (bottom) for the bridge displacement X (left) and the individual pedestrian forces, $G\sin\Theta_i$ (right), are indicated (see text for definitions of variables).

bridge's resonant frequency); and α is a phase

instability until the crowd reaches a critical size, N_c, after which wobbling and synchrony erupt simultaneously (Fig. 2b, c).

We can calculate N_c analytically, using methods[8–10] created to study large systems of biological oscillators (see supplementary information). To take the simplest case, suppose $\alpha = \pi/2$ and $P(\Omega)$ is symmetrical about Ω_0 (also a 'worst case' for the bridge, in the sense that pedestrians then drive it most efficiently). We find

$$N_c = \frac{4\varsigma}{\pi}\left(\frac{K}{GC\,P(\Omega_0)}\right) \qquad (3)$$

where $\varsigma = B/\sqrt{4MK}$ is the damping ratio. All the parameters have known values, except for C. Comparing our simulations with data obtained from crowd tests on the Millennium Bridge[2], we estimate $C \approx 16\ \mathrm{m}^{-1}\,\mathrm{s}^{-1}$. Then, with no further adjustable parameters, the model predicts

戸田公園大橋 (埼玉県戸田市)

EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS, VOL. 22, 741–758 (1993)

SYNCHRONIZATION OF HUMAN WALKING OBSERVED DURING LATERAL VIBRATION OF A CONGESTED PEDESTRIAN BRIDGE

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AND

PENNUNG WARNITCHAI[§‖]

Division of Structural Engineering and Construction, Asian Institute of Technology, Bangkok, Thailand

SUMMARY

Observation of human-induced large-amplitude lateral vibration of an actual pedestrian bridge in an extremely congested condition is reported. Walking motions of pedestrians recorded by a video camera are analysed. It is found that walking among 20 per cent or more of the pedestrians on the bridge was synchronized to the girder lateral vibration. With this synchronization, the total lateral force from the pedestrians to the girder is evidently increased and it acts as a resonant force on the girder lateral vibration.

INTRODUCTION

戸田公園大橋 昔と今

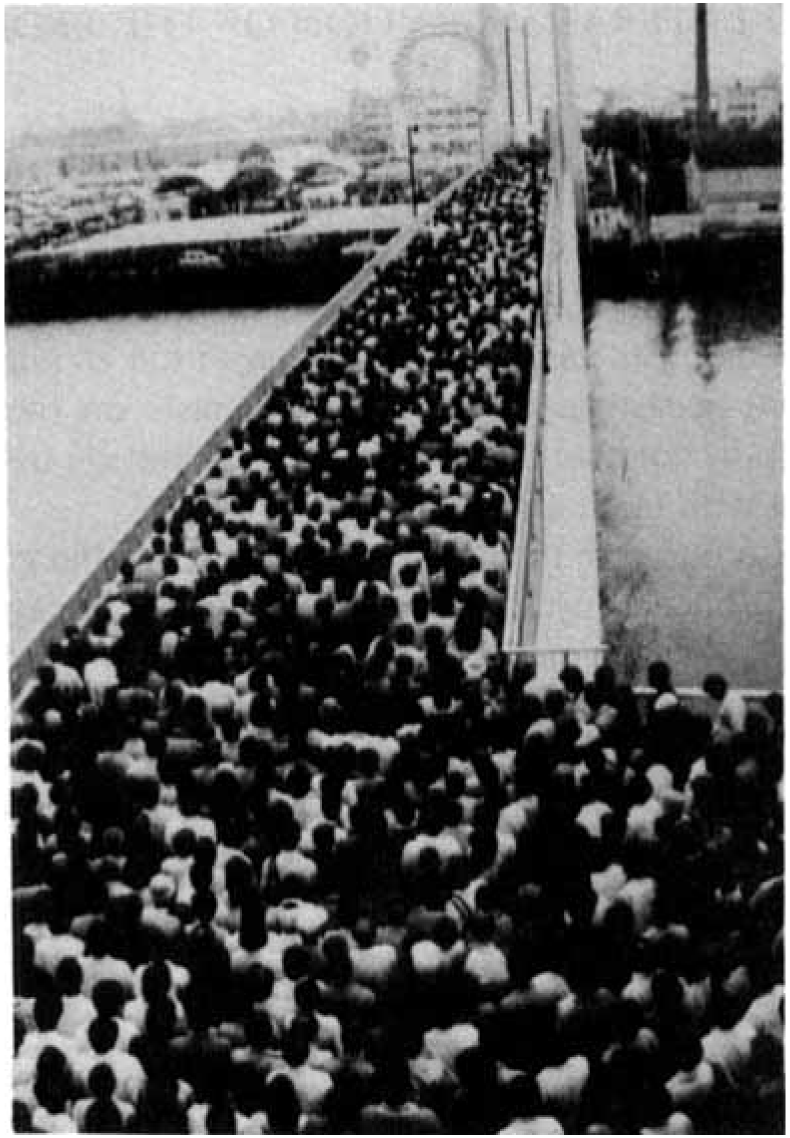


Figure 3. Congested condition

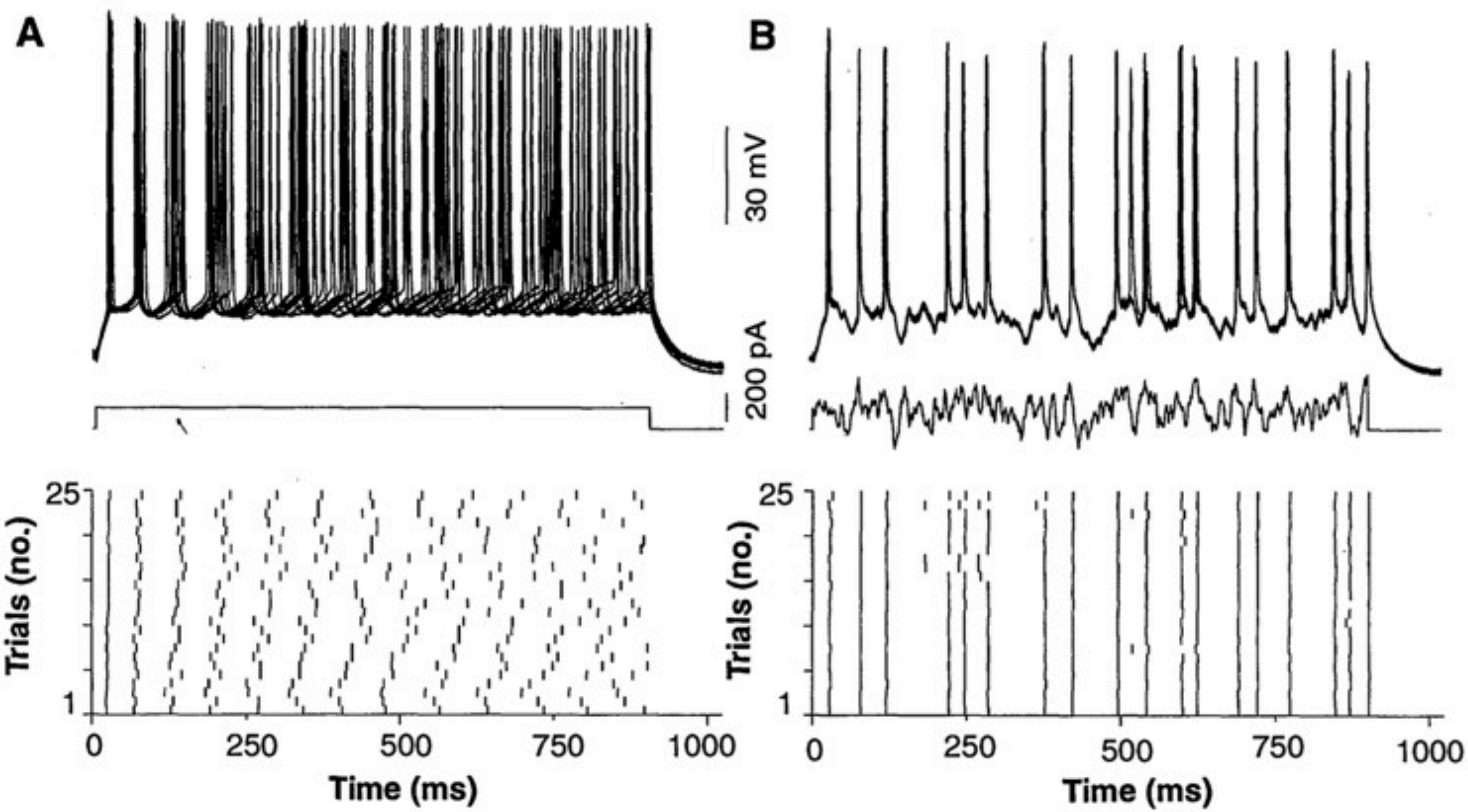
Y. Fujino et al, Earthquake Engineering and Structural Dynamics, 2, 741-758, 1993

周期振動子の共通ノイズ同期

ノイズ	理論	実験
白色	Teramae & Tanaka, 2004	Yoshida et al., 2006 Arai & Nakao, 2008
有色	Teramae & Tanaka, 2006 Kurebayashi, Fujiwara & Ikeguchi, 2012	Nagai & Nakao, 2009 Kawai, Fujiwara, Jinno, Horio & Ikeguchi, 2012, 2013

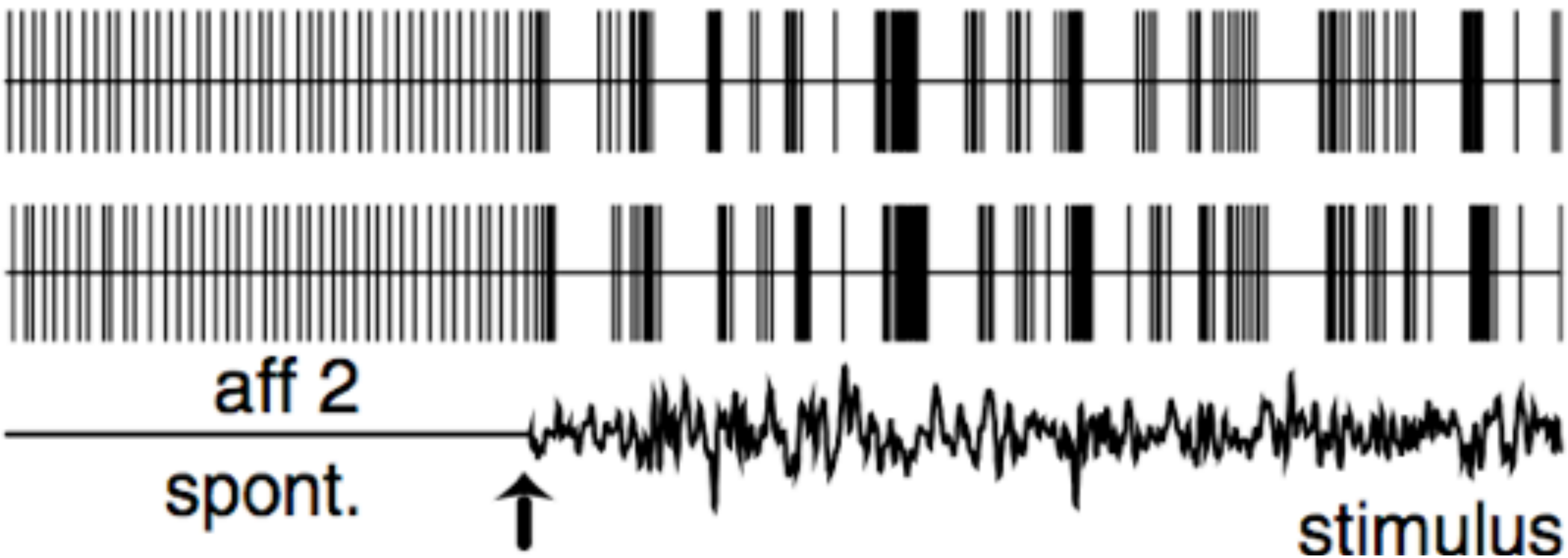
ノイズ同期

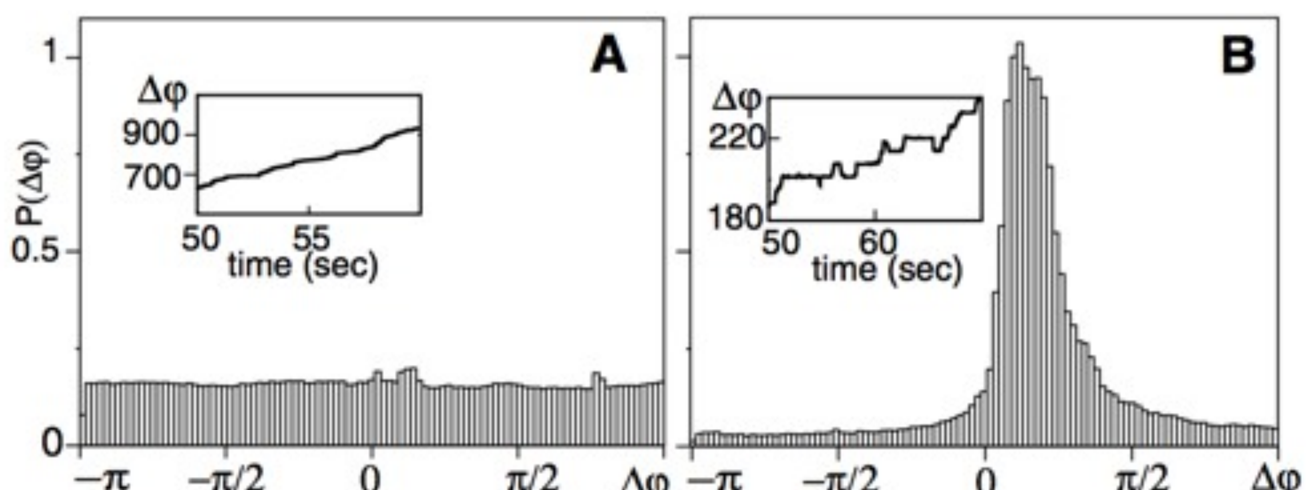
[Z. F. Mainen and T. J. Sejnowski, Science (1995)]



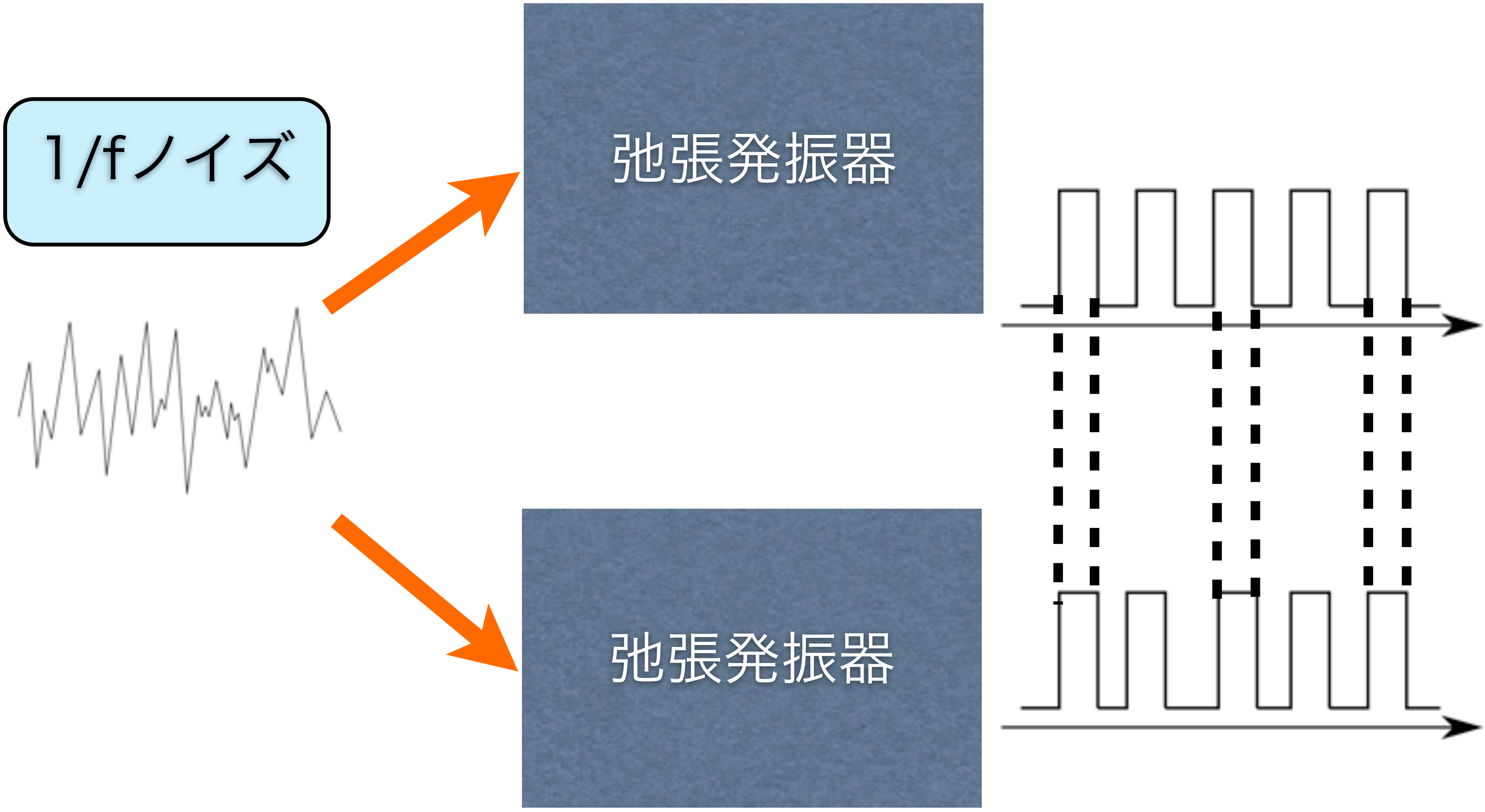
神経細胞におけるノイズ同期

[A. B. Neiman et al., Phys. Rev. Lett.(2002)]

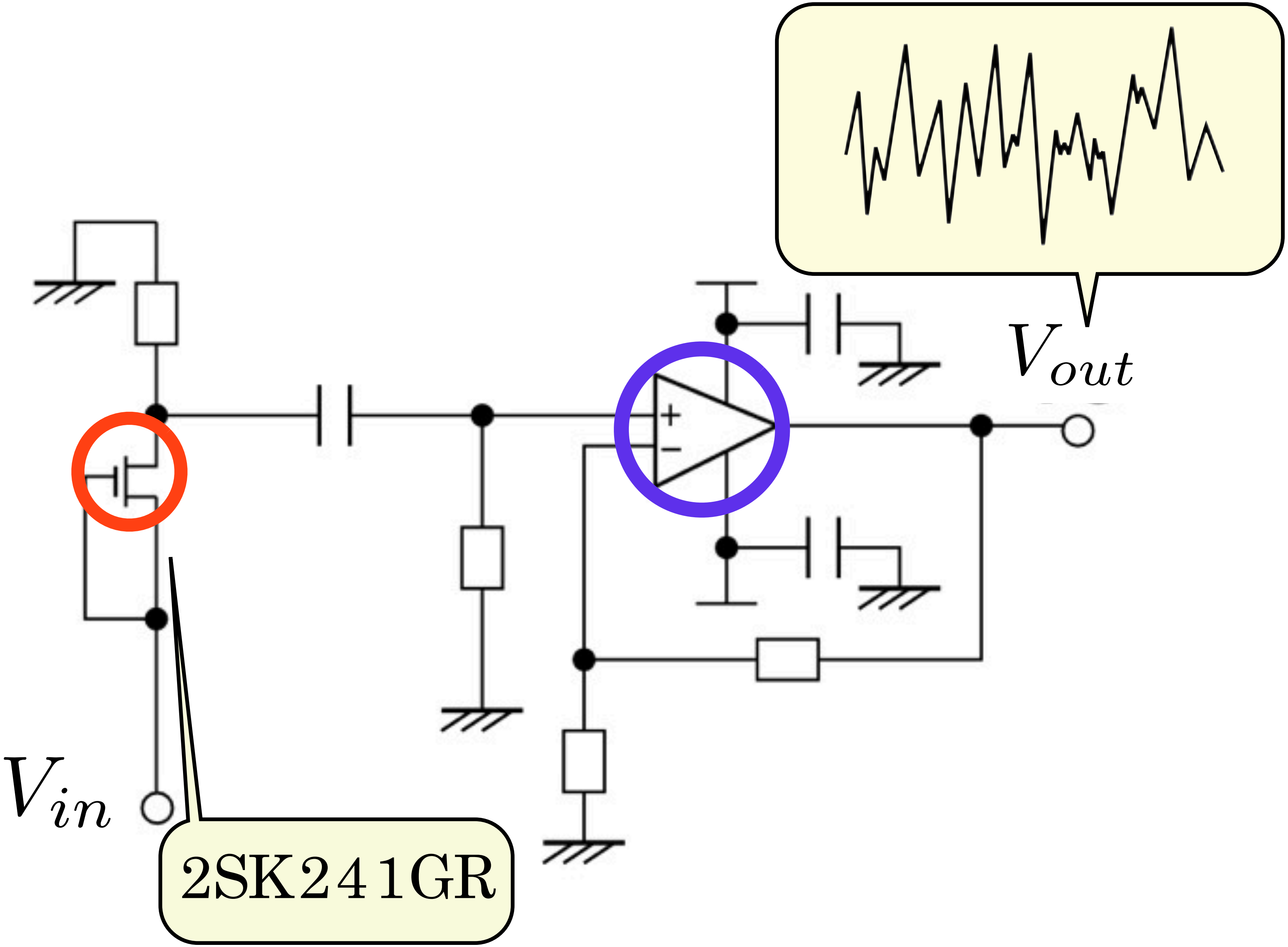




1/fノイズによる共通ノイズ同期



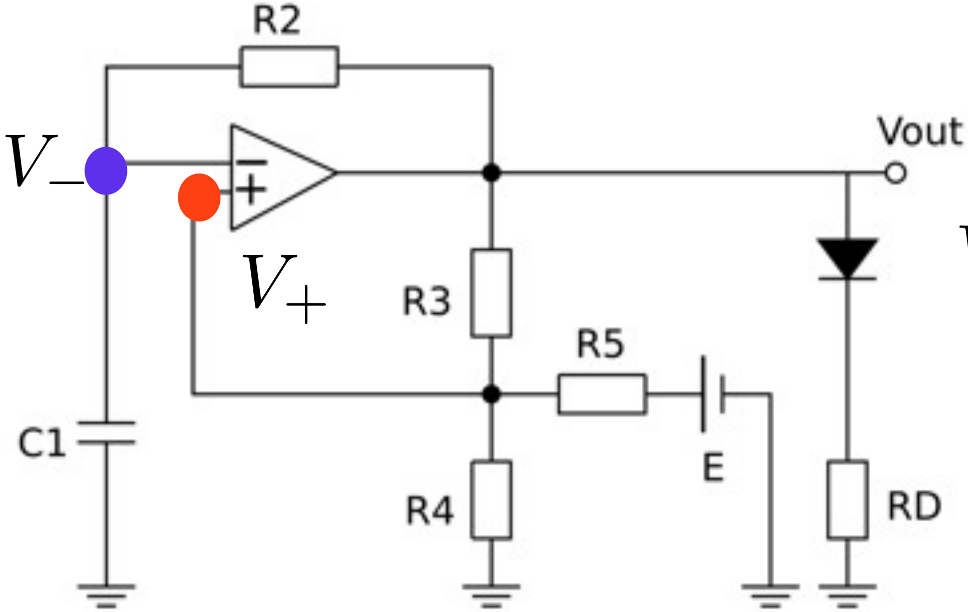
1/fノイズ発生器

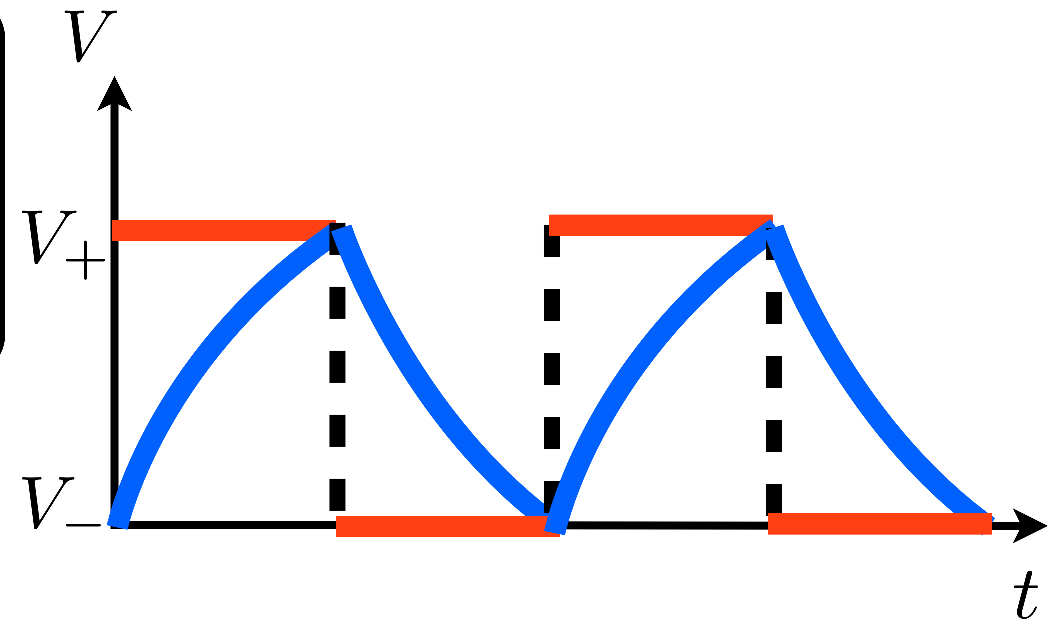


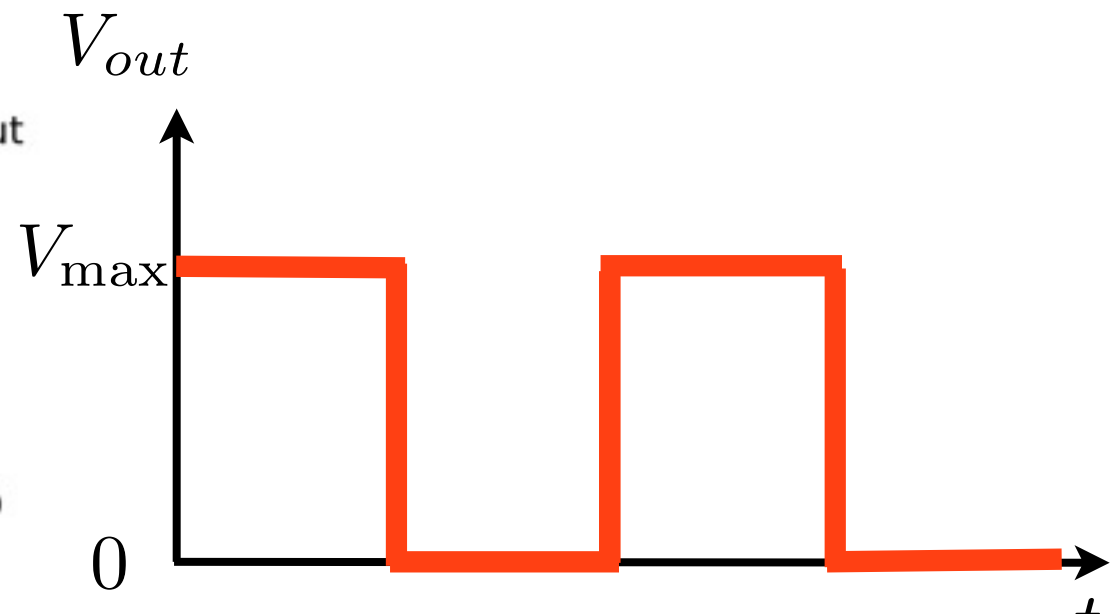
振動子 (弛張発振器)

$$V_{out} = \begin{cases} V_{\max} & (V_+ > V_-) \\ 0 & (V_+ \leq V_-) \end{cases}$$

$$\begin{cases} R_2 C_1 \frac{dV_-}{dt} = -V_- + E & (V_+ > V_-) \\ R_2 C_1 \frac{dV_-}{dt} = -V_- & (V_+ \leq V_-) \end{cases}$$







共通ノイズ同期

	周期振動子	カオス振動子
理論	Teramae & Tanaka, 2004 Teramae & Tanaka, 2006 Kurebayashi, Fujiwara & Ikeguchi, 2012	Zhou & Kurths, 2002 Wang, Lai & Zheng, 2009
実験	Arai & Nakao, 2008 Nagai & Nakao, 2009 Kawai, Fujiwara, Jinno, Horio & Ikeguchi, 2012, 2013	Uchida, McAllister & Roy, 2004 Kawai, Shimada, Fujiwara & Ikeguchi, in preparation.

非線形振動子の同期とその実験について

相互結合同期

共通ノイズ同期

メトロノーム同期の分岐