Noise-induced synchronization of Pierce oscillators

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Abstract—Noise-induced synchronization is a phenomenon that autonomous oscillators are synchronized by common external noise. In this study, we paid attention to crystal oscillators which are utilized in a variety of electrical circuits. When the independently oscillating crystals in each circuits are synchronized, it is conceivable that simultaneous information processing become possible. Furthermore, utilization of noise, which is originally undesirable, is useful from the perspective of engineering. To observe the synchronization, we designed the circuit which consists of two pierce circuits with a branching path for the common gaussian noise source. Finally, we show that the gaussian noise has possibility to efficiently synchronize two oscillators without mutual interactions.

1. introduction

Noise-induced synchronization is a phenomenon that unidirectional interaction through commonly injected gaussian noise synchronize uncoupled oscillators. This phenomenon has been proven that common white noise synchronize uncoupled limit-cycle oscillators[1]. The theory of noise-induced synchronization has been extended to others noise [2, 3, 4, 5].

Moreover, the noise-induced synchronization are also observed in biological systems [6, 7, 8]. This result suggest that biological system process information utilizing the synchronization in their neural systems.

Recently, the application of noise-induced synchronization are investigated. Natural environmental noise are utilized to synchronize oscillators in the distributed sensors which consists network [9, 10]. Numerical simulation indicate noise can synchronize spin torque oscillators array for improving output power[11].

In this study, we employ the approach of noise-induced synchronization to crystal oscillator[12]. The crystal oscillator is utilized as a device of a piezoelectric resonator that determines the natural frequency. Because they oscillate precisely and stably, they has been widely used to provide clock signals to a variety of digital circuits(CPUs, sensors, and so on).

Under these conditions, synchronized information processing under multiple clocks should be of important technology in a future. For instance, it is getting difficult to integrate all the circuit elements into a single chip, because of the difficulties of microfabrication of transistors in nanoscale. Diving the functional circuits into multiple chips is

Table 1: Circuit parameters of two Pierce circuits and unidirectional paths.

Circuit components of Pierce oscillators	
$XTAL_1$ and $XTAL_2$	3.58 MHz
INV_1, INV_2, INV_3 and INV_4	74HCU04AP
R_1 and R_3	1 MΩ
C_2, C_3, C_5 and C_6	22 pF
Unidirectional branches for external inputs	
D_1 and D_2	Diode
R_2 and R_4	10 kΩ
C_1 and C_4	20 pF

one of the plans to solve the abovementioned problems, thereby synchronized clocks of the divided chips are required.

2. The circuit implementation of crystal oscillators

To observe noise-induced synchronization [1, 3] on crystal oscillators, we implemented two pierce oscillators with unidirectional signal paths that gaussian noise passes in a discrete circuit as shown in Fig.1.

Each pierce oscillators are consisted of a crystal oscillator, an inverter, a resistor and two capacitors. Natural frequencies of the crystals are around 3.579 [MHz] ($XTAL_1$ and $XTAL_2$). Inverters 74HCU04AP (INV_1, INV_2, INV_3 and INV_4) amplify oscillations from the crystals and generate output signals ($output_1$ and $output_2$). Capacitors (C_2, C_3, C_5 and C_6), which are 22 [pF], adjust oscillation frequencies on each crystals. Feedback resistors (R_1 and R_3) are 1[MΩ].

A branching paths are composed of two registers, capacitors and diodes. Schottkey diodes (D_1 and D_2) rectify the input and isolate these circuits from each other. Coupling capacitors (C_1 and C_4) are 22 [pF] and transfer the alternating input signal. R_2 and R_4, which are 10 [kΩ], discharge the voltages of these coupling capacitors.

Parameters of electric components are summarized in table 1.

3. Experimental setup

First, these pierce oscillators independently oscillate without synchronization. Then, we swept standard devia-
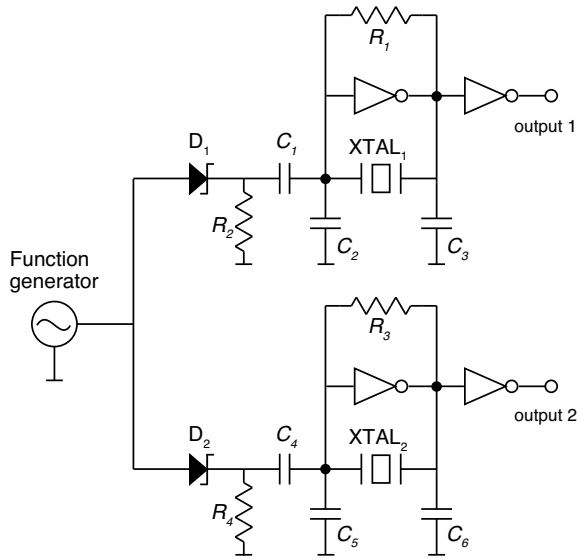
Figure 1: Pierce oscillators which have branching unidirectional paths for gaussian noise input.
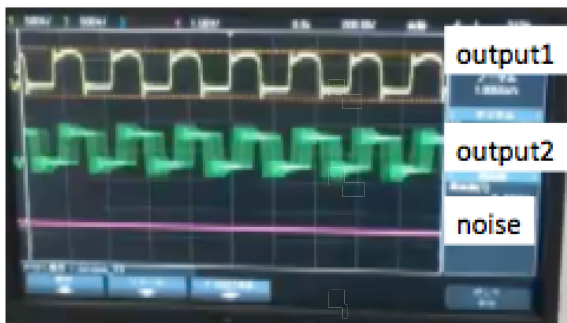

Figure 2: Time series: Without the gaussian noise input. (The top line is $output_1$, the middle line $output_2$, and the bottom line the gaussian noise input.)
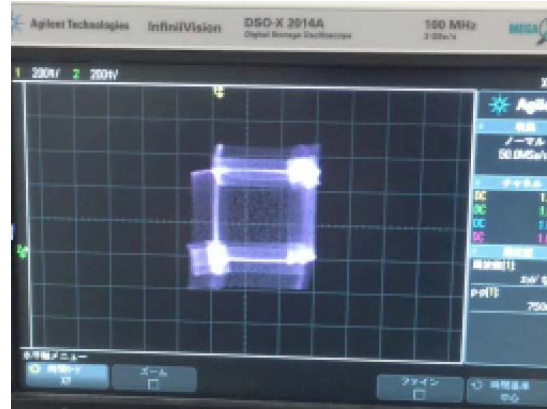

Figure 3: Phase planes between the output1 and output2 without the gaussian noise input. The Lissajous curve are not closed.
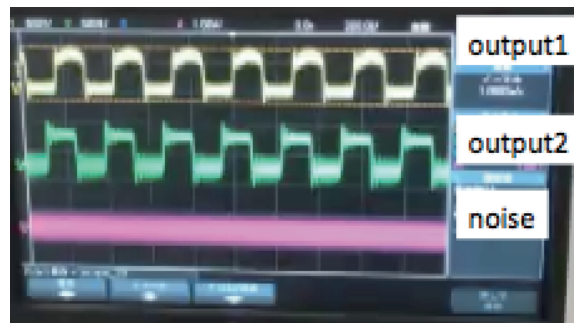

Figure 4: Time series: With the gaussian noise($5[V_{pp}]$) input. (The top line is $output_1$, the middle line $output_2$, and the bottom line the gaussian noise input.)

tion of the gaussian noise from a function generator, which passes the unidirectional paths, to observe operating characteristics of the proposed circuit. Thus, we analyzed relations between the input and the outputs from the pierce circuits.

Further, we changed waveform of the input signal(gaussian noise, square and sinusoidal waveform) to observe variations of characteristics on the circuits. We set frequencies of these periodic signals 3.58 MHz which is the same values of the natural frequencies of crystals.

In this study, we sampled waveform snapshots from the outputs of these oscillators by an oscilloscope.

4. results

Figure 4 shows time series of the outputs from each pierce oscillators without the gaussian noise. The top line is $output_1$, the middle line $output_2$ and the bottom line gaussian noise which has not been inputed. Because we set trigger to $output_1$ on the oscilloscope, waveform of the output2 move under desynchronization between them. Figure 3 shows phase plane between outputs. This unclosed curve indicate desynchronization between these outputs.

When standard deviation of the gaussian noise is sufficient($5[V_{pp}]$), these waveforms are fixed on the oscilloscope as shown in Fig. 4. Figure 5 shows phase plane between outputs. This closed curve indicate noise-induced synchronization between these outputs.

Furthermore, we input periodic signals(sinusoidal and square wave), which has same natural frequencies as the crystal oscillators, to the proposed circuit instead of the gaussian noise. Figure 6 shows synchronization with the common sinusoidal input which is drawn in the bottom line. Then, Fig. 7 shows synchronization with the common square input which is drawn in the bottom line.

Thereby, noise-induced synchronization are observed on the crystals that consists of two pierce crystal oscillators with a branched unidirectional input signal path which has no mutual interactions.
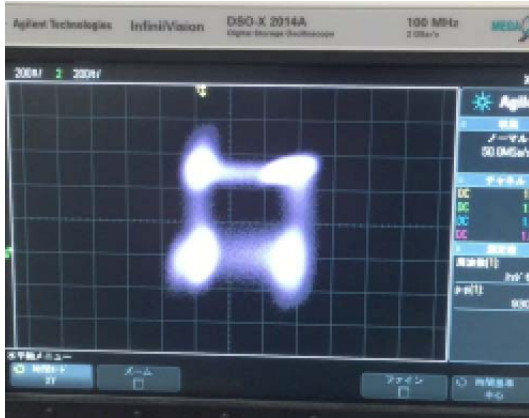
Figure 5: Phase planes between the output1 and output2 with the gaussian noise input. The Lissajous curve are closed.
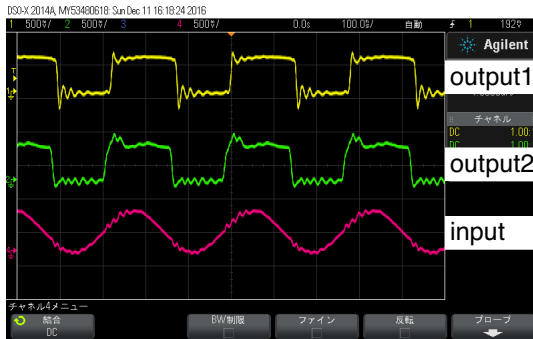

Figure 6: Time series: (a) Without the gaussian noise input. (b) With the gaussian noise input. (The top line is $output_1$, the middle line $output_2$, and the bottom line the sinusoidal input.)

5. discussion

We showed noise-induced synchronization on the proposed circuit which is composed of two pierce oscillators with a unidirectional branched path from the gaussian noise source. The synchronization is induced by gaussian noise and others periodic signals like square and sinusoidal waveforms.

However, noise generally have negative effects on electrical circuits, these results indicate the possibility that even noise can be effectively utilized. Thermal noise, electromagnetic wave, fluctuations of circuit parameters or others factors may be possible to induce noise synchronization between oscillator circuits. Thus, physically distributed sensors, processors and others electrical circuits using crystal oscillators may be able to simultaneously process information on the noise-induced synchronization.

Applications utilizing noise-induced synchronization are reported in recent years. Yasuda *et.al.* showed sensor network utilizing environmental noise[9, 10]. In electronic field, Nakada *et.al.* simulated noise-induced synchronization to overcome low output power from a spin-torque
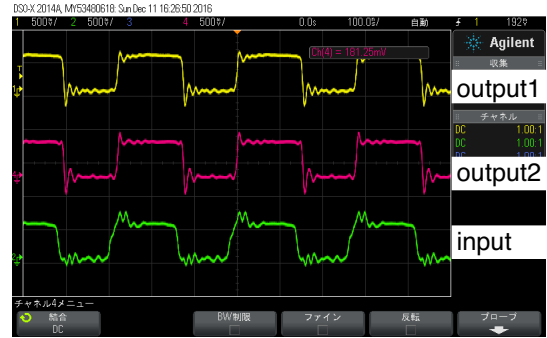

Figure 7: Time series: (a) Without the gaussian noise input. (b) With the gaussian noise input. (The top line is $output_1$, the middle line $output_2$, and the bottom line the square input.)

oscillator[11].

In our study, we took the easiest way to directly inject gaussian noise to the pierce oscillator circuits to observe noise-induced synchronization with the unidirectional paths. There are two problems for implementing applications using this synchronization method. First, how to inject noise to target devices, *e.g.*, power supply lines, receiver circuits for direct input, and so on. Then, how waveforms are optimal to induce synchronization on autonomous oscillators. Although noise randomly affects phases on each uncoupled oscillators, if common signal is added to them with optimal timing and strength, synchronization may quickly occur as compared to noise.

6. concluding remarks

In this study, we observed noise-induced synchronization on crystal oscillators without mutual interactions. We first designed two pierce crystal oscillator circuits with a branched unidirectional noise signal path. After confirming that two crystals independently oscillate, we swept an amplitude of the gaussian noise and added it to the oscillators through the path. Under sufficient standard deviation of the gaussian noise, these crystal oscillators synchronize. From these results, noise-induced synchronization on crystal oscillators may enable distributed electrical circuits using crystal oscillators to simultaneously process information.

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