MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

# Construction and measurement examples of a wireless sampling-synchronized measurement system.

**Nakajima, Yasutaka**[1]
**Kurosawa, Yu**[2]
**Yoshino, Kuniyuki**[3]
**Ueta, Toshihiro**[4]
**RION Co., Ltd.**
**3-20-41 Higashi-motomachi, Kokubunji, Tokyo, JAPAN**

**ABSTRACT**

**We have developed a portable wireless sampling-synchronized measurement system that can provides accuracy to within one micro-second. Our systems use radio waves from wireless LAN access points to synchronize all analog to digital converters of different amplifier units making it possible to measure transfer functions at different points. This is especially useful in environments such as buildings and automobiles where measurements from both sides of glass walls or windows are required allowing measurements of transfer function and propagation of sound and vibration to be measured accurately. Until recently, wireless synchronized sampling was not possible due to the availability of only IEEE 1588 or wired sampling-synchronized systems. Having only start trigger functionality is insufficient when continuous synchronized sampling is required. Considering crystal oscillator units which generate clock for analog to digital converters operate independently from each other, the crystal oscillator units have to be synchronized continuously and repeatedly throughout the entire measurement time. During evaluation of the system performance, we kept the input cable lengths the same for the test signal of each unit as radio waves used for synchronization and electric current used for test signal travel 300 meters per micro-second. We introduce the system and provide some measurement examples.**

**Keywords:** Synchronized sampling, Wireless, Data recorder, Transfer function.
**I-INCE Classification of Subject Number:** 11.02

---

[1] yasutaka@ rion.co.jp
[2] y-kurosawa@ rion.co.jp
[3] k-yoshino@ rion.co.jp
[4] tueta@ rion.co.jp

## 1. INTRODUCTION

In order to reduce sound and vibration emitting from machines and to take proper countermeasures, we measure transfer functions or frequency response functions in various situations such as sound or vibration insulation, modal analysis. However, it is difficult to lay down cables if there is no path between two target objects when barriers such as walls or glasses exist between them. As such, wireless synchronized sampling is required and useful in these situations. Until recently, wireless synchronized sampling was not possible due to the availability of only IEEE 1588 or wired sampling-synchronized systems. Amagai devised a wireless synchronized method using common wireless LAN radio wave, which means we do not require any special radio wave and need not be concerned with the Wireless Radio Act.[1,2]

Generally, analog to digital converters of two different measuring instruments which are located at different points such as data recorders or FFT analysers work independently. Even if the precise point of start time is the same, their independent clocks tick differently after the start. Thus, data or their sampling data is not synchronized and cannot be used to calculate frequency response functions.

We have developed a wireless synchronized sampling system based on Amagai's method. The purpose of the proposed system is to conduct wireless measurement of synchronized sampling at different points that provides accuracy to within one micro-second, which is equivalent to 3.6 degrees of phase difference at 10 kHz and 7.2 degrees at 20 kHz between channels. The system uses usual Wireless LAN or IEEE802.11b/g access points and all units which receive the wireless signal from the access point are synchronized. This is especially useful in an environment such as a building, bridge, or vehicle where measurements from both sides of glass walls are required allowing measurements of transfer function and propagation of sound and vibration to be measured most accurately. The system also can be synchronized with Global Positioning System (GPS) units or wired LAN cables. Synchronized sampling over a longer distance, at different places, or between barriers are now possible.

## 2. CONVENTIONAL FRONT-END UNITS

Each analog to digital converter of different front-end units are driven by a respective crystal oscillator and the crystal oscillator ticks differently as shown in Figure 1. For example, a typical or relatively good precision for crystal oscillators is about 4 ppm, or $4x10^{-6}$. The time difference between two different units after 3 minutes can be about 648 degree or almost a couple periods at 10 kHz if the start point is simultaneous. The more time that laps from start point, the larger the phase difference becomes. Figure 2 shows the signal wave measured or digitally sampled by each analog to digital converter of the two different units near the start time. The sampling start of each analog to digital converter are precisely synchronized within a few degrees of phase difference. Input signal frequency is 1 kHz and the signal appear synchronized as shown in Figure 2. On the other hand, Figure 3 shows the signal wave of the two different units after three minutes. The x axis denotes time and y axis denotes voltage. The red line on the left and dot in the upper graph marks peak position of the wave measured by unit A. The red line on the right and dot in the lower graph marks peak position of the wave measured by unit B. The phase difference of signals is about $270 \pm 180n$ degrees. $n$ denotes an integer. We can only determine that there is 270 degrees of phase difference because the input signal is sin wave in this case. The two units are apparently not synchronized and the phase difference between them is too large for calculation between channels, namely, for calculation of frequency response functions. Thus, the precise synchronized sampling only at start is insufficient for two or multiple analog to digital converters of the units. The analog to digital converters must be synchronized continuously throughout the measurements.

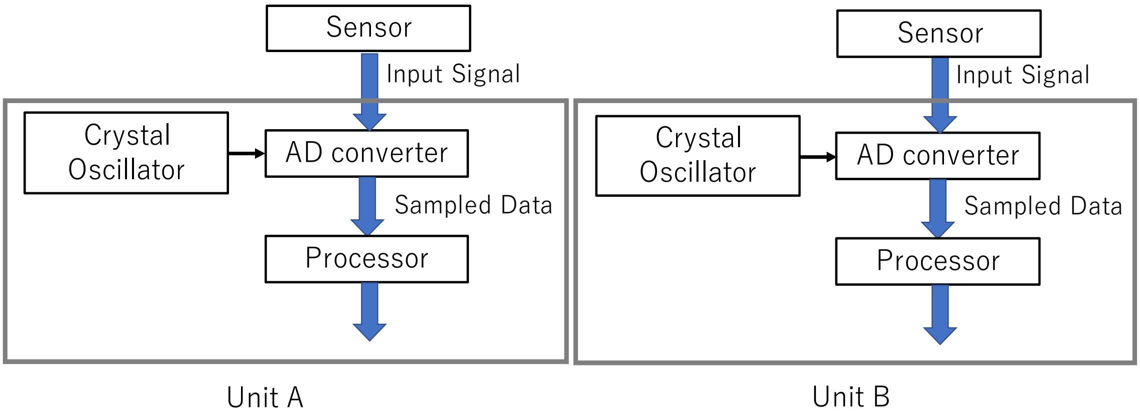


Figure 1. Block diagram of conventional measuring front-end units including analog to digital converters. Each independent crystal oscillator unit drives an analog to digital converter independently.

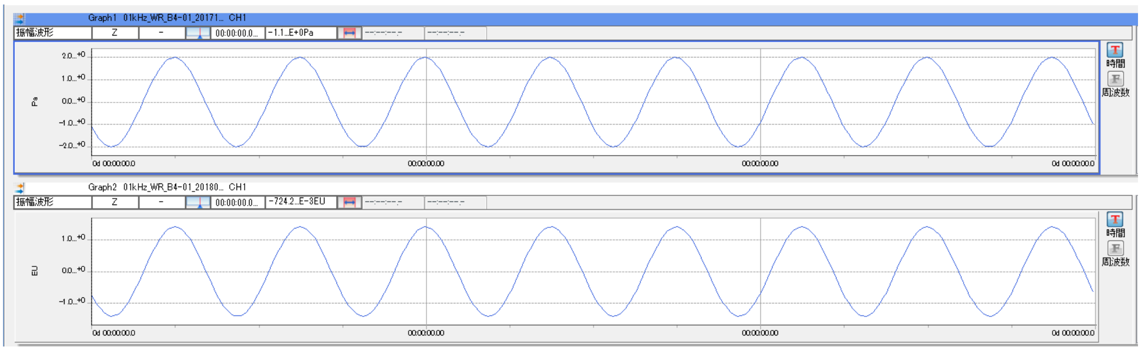

Figure 2. An example of a signal near the start time in the case of unsynchronized sampling. (Upper: unit A. Lower: unit B)

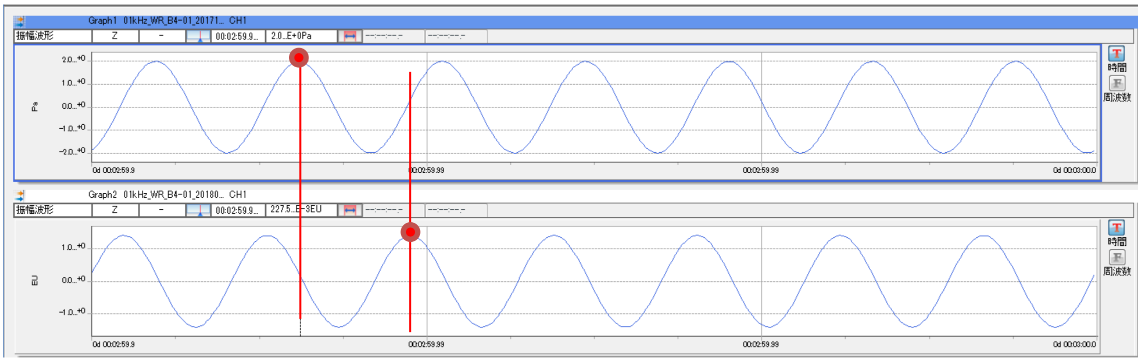

Figure 3. An example of a signal after 3 minutes in the case of unsynchronized sampling. (Upper: unit A. Lower: unit B)

## 3. PROPOSED SYSTEM

### 3.1 Configuration of the proposed measurement system

Our proposed measuring system uses standard Wireless LAN or IEEE 802.11b/g to synchronize all the units. An access point (AP) sends beacon signals at every 100 milli-seconds. One of the units is a master that sends and receives packets wirelessly with other units to control them as shown in Figure 4. As a result, all the units are precisely synchronized while also allowing start and stop measurement commands and data to be transferred via wireless LAN.

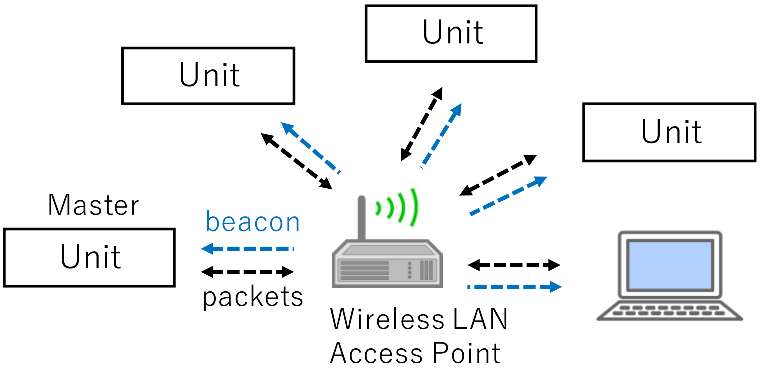


Figure 4. Configuration of the proposed wireless synchronized system.

**3.2 How it works inside**

Figure 5 shows a block diagram of inside the unit. Received beacon signal are processed in a field-programmable gate array or FPGA and a CPU sends/receives packets to/from other units to synchronize each crystal oscillator of each unit. Analog to digital converters can sample input signals simultaneously if each crystal oscillator of each unit is precisely synchronized throughout the entire measurement.

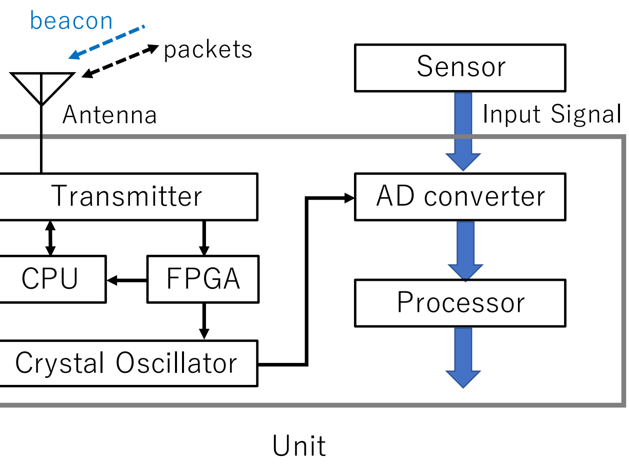


Figure 5. Block diagram of unit.

It is not synchronized sampling if each crystal oscillator of different units ticks independently. The sampling of each analog to digital converter samples analog signal to convert to digital data exactly at the same timing. Currently, a lot of sigma-delta analog to digital converters are widely used for not only audio use but also measuring instruments due to their performance. Those sigma-delta analog to digital converters requires, for example, 128 times of sampling frequency and they down-samples data into sampling frequency of output data. The timing of down-sampling also must be synchronized precisely. If clock frequency from crystal oscillators fluctuate quickly, this causes jitters and results in increased distortions. Moreover, typical sigma-delta analog to digital converters usually cannot follow quick frequency clock changes which lead to malfunctions. The frequency from oscillators must be controlled very carefully.

### 3.3 Examples of configurations

There are mainly three examples of measurement configurations. First, the units are synchronized in an area where radio wave of the access point can reach, which is the same range that normal wireless LAN access point covers. The distance is less than 100 meters without special external antennas. Of course a radio wave can reach up to some hundred meters if you use special external antennas in unobstructed conditions. Second, each unit can be connected by wired LAN cables or Ethernet cables via one LAN hub. Regarding usual IEEE1588 wired synchronized sampling, a dedicated LAN hub specially designed for IEEE1588 is required because LAN hub itself can cause errors of synchronizations. Our system requires just a commercially available LAN hub. Third, the units are synchronized with GPS units as shown in Figure 6. The units which also have GPS functionality controls other two units which are connected wirelessly like the first example. As a result, all the units at different places can be synchronized.

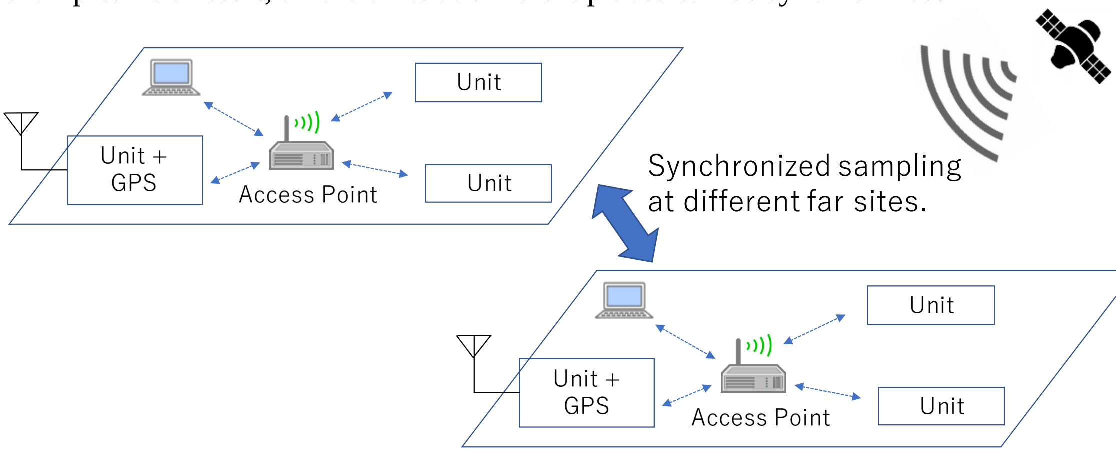


Figure 6. Synchronized sampling with GPS at different places

## 4. PHASE DIFFERENCE IN REAL SITUATIONS

We evaluated the precision of synchronized sampling in a real case. We put one of the units at the red circle in Figure 7 and we moved the other unit on the orange arrow line. The delay that radio wave or light transmits can be calculated as shown in Table 1. If we ignore the effect of reflections, the delay caused by light speed is significant and cannot be ignored.

Table 1. Delays and phase differences caused by light speed

| Distance | Delay | Phase difference caused by delys [deg] | | |
|---|---|---|---|---|
| [m] | [ns] | 1 kHz | 10 kHz | 20 kHz |
| 1 | 3.34 | 0.00 | 0.01 | 0.02 |
| 10 | 33.4 | 0.01 | 0.12 | 0.24 |
| 20 | 66.7 | 0.02 | 0.24 | 0.48 |
| 40 | 133.4 | 0.05 | 0.48 | 0.96 |
| 100 | 333.6 | 0.12 | 1.20 | 2.40 |

We kept the input cable lengths the same for the test signal of each unit as radio waves used for synchronization and electric current used for test signal travel 300 meters per micro-second. The precision of synchronized sampling is affected by transmission speed of radio wave. We can measure rough distance and make a correction. Table 2 shows the results of phase differences at 20 kHz from wirelessly remote units. All phase differences were within 1 micro-second because one micro-second corresponds to 7.2 degrees of phase difference.

Table 2. Results of phase differences at 20 kHz about wireless synchronized sampling.

| Distance [m] | Phase difference at 20 kHz [degree] |
|---|---|
| 1 | -1 to 3 |
| 20 | 2.5 to 3.5 |
| 30 | -1 to 3 |
| 40 | 0 to 3 |

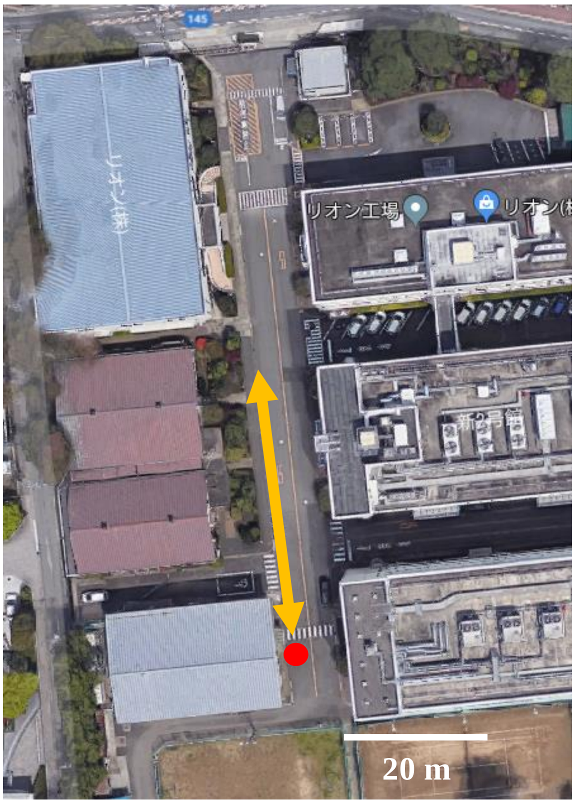


Figure 7. Aerial view of measurement location

## 5. SUMMARY

We developed a wireless measuring system for synchronized sampling that allows for both accuracy and usability in a broader range of environments. The units are controlled and send data wirelessly, but the system can also be operated wired LAN or GPS. Our evaluation showed that the precision of phase differences was less than 1 micro-second, which corresponds to less than 7.2 degrees at 20 kHz. That makes it possible to measure transfer functions between two places wirelessly. The system consists of wireless amplifier units and a laptop computer making it easily portable as they can be battery driven.

## 6. REFERENCES

1. Amagai, Akihiro, *"Sub-microsecond synchronization of data acquisition system in LAN/Wi-Fi mixed network"*, IEICE Technical Report USN2012-58. (2013).
2. Amagai, Akihiro, *"Remote I/O System and Synchronization Method in the same"*, U.S. Patent 8,369,308B2. (2010).