

# River Monitoring Technology using Millimeter-Wave Radar

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In recent years, the increasing frequency and severity of flooding due to the effects of climate changes have become serious social issues. Monitoring river conditions and accurately predicting disasters are essential to protecting the safety of local communities and residents.

OKI has developed the Zero-Energy IoT Series, a series of devices that enables remote infrastructure monitoring, and starting with the remote monitoring of river levels, it has been working on disaster prevention digital transformation to support disaster response operations<sup>1)</sup>.

This article introduces a technology that goes a step beyond the conventional river level monitoring, measuring water levels and current speeds across a wide area using millimeter-wave radar.



(Left) With Ultrasonic Water Level Gauge,  
(Center) With Pressure Water Level Gauge,  
(Right) With High-Sensitivity Camera

Photo 1. Zero Energy Gateways (Zero-Energy IoT Series)

## Background

Due to global climate changes, extreme weather such as torrential rains and powerful typhoons has become more frequent, causing repeated large-scale floods and inundations both in Japan and overseas. These disasters not only cause human casualties and property damages, but also disrupt social infrastructures and economic activities. Moreover, the disasters can have long-term impacts on local communities, making it urgent to strengthen countermeasures. River management, in particular, requires the establishment of advanced disaster prevention systems that accurately determine/predict fluctuations in rainfall and water levels, leading to early warnings and quick initial responses.

Against this social background, water level meters specialized for flood monitoring, developed through the Ministry of Land, Infrastructure, Transport and Tourism's Innovative River Technology Project, have become increasingly widespread. OKI's Zero-Energy IoT Series (Photo 1) and other products developed by various companies have been installed at river sites, including small and medium-sized rivers, across Japan. This has enabled more precise collection of water level data and faster provisioning of information, significantly contributing to disaster response and regional safety.

## Necessity of Current Speed Monitoring

River managers, particularly those of major rivers, have traditionally monitored not only water levels but also current speeds and volume flow rates. For example, at the confluence of a main river and a tributary, the volume flow rate of the main river increases sharply. By appropriately monitoring this fluctuation in volume flow rate, managers can accurately assess levee safety and flood risks. Furthermore, even when the water level is rising, if current speed remains slow, the risk of flooding is low. On the other hand, if the current speed remains high, the risk of overflowing river banks and flooding increases. Therefore, current speed and volume flow rate data serve as a basis for predicting dynamic changes throughout the river, and for taking appropriate flood control and emergency response measures according to the situation.

For this reason, river managers order flow monitoring services periodically or during floods, and collect current speed and volume flow rate data mainly using the float method. The float method calculates current speed by placing a float in the river and measuring the time the float takes to travel a specified distance. However, for manual monitoring such as the float method, it is becoming difficult to find monitoring companies willing to take on orders due to a shortage of personnel caused by a decrease in skilled

workers and an aging workforce, as well as the increasing danger of manual monitoring due to intensifying floods. Against this background, there are growing expectations for unmanned and labor-saving flow monitoring as part of an advanced river monitoring.

### Issues with Conventional Technology

Conventional ways to measure a river's current speed without contact include radio wave current meters using millimeter-wave radar and image-based current meters using camera images. Radio wave current meters use the Doppler method, in which radio waves emitted by a device strike and reflect off waves on the water surface. The current speed is calculated from the frequency change that occurs due to the Doppler shift. This method generally cannot separate and identify specific measurement locations. Therefore, if reflections from multiple points on the water surface are detected simultaneously, measurement errors can occur. To reduce errors, the antenna directionality is increased and measurements are only taken from a specific point on the water surface. Although, current meters using this method are useful for real-time measurements of local speed changes and anomalies on the water surface, their single-point monitoring limits the ability to accurately understand the entire flow of the river.

Particularly with large rivers, the spatial distribution of current speeds varies significantly across the cross section. While it is possible to monitor the entire river by installing current meters at multiple points along the river's cross section, such highly dense installation is, in practicality, difficult due to the cost of equipment installation, installation space, and maintenance requirements. Therefore, installation of conventional current meters that perform single-point monitoring can be much as several tens of meters apart in large rivers, making it difficult to understand the overall flow conditions, temporary changes in the flow, and the movement of the channel (the main flow section).

On the other hand, image-based current meters can simultaneously monitor a wide area of a river, but the processing time required for image analysis makes real-time measurements problematic.

### Technology Concept

To achieve the difficult goal of monitoring a wide area of a river all at once and measuring volume flow rate in real-time, OKI focused on FMCW radar technology, which is

increasingly used in the transportation field. FMCW radar emits radio waves over a wide area and analyzes the reflected signals received from multiple objects. It is able to simultaneously obtain highly accurate position and speed information for each object. This technology has primarily been used to detect, classify, and track the movements of vehicles and pedestrians. For example, installing a roadside sensor equipped with the technology at an intersection could alert entering vehicles to the presence of pedestrians in their blind spots, thereby helping to streamline traffic (Figure 1).

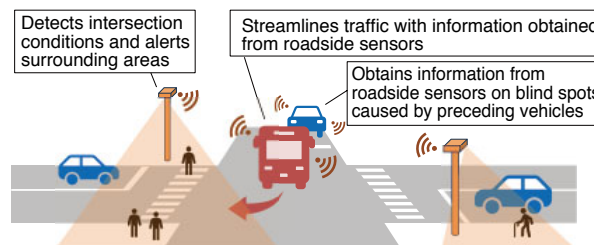


Figure 1. FMCW Radar Use in Transportation Field

To utilize this technology for river monitoring, radio waves are emitted toward a wide area of a river, and in place of vehicles and pedestrians, the position and speed of waves on the water surface are detected (Figure 2).

The position information of the detected ripples is used to estimate the water level, and the speed information is used to estimate the current speed. Furthermore, through the optimization of the signal processing and hardware configuration, such as the antenna, the method can detect target position and speed with high spatial resolution. This is expected to enable the monitoring of river flow conditions as a detailed distribution.

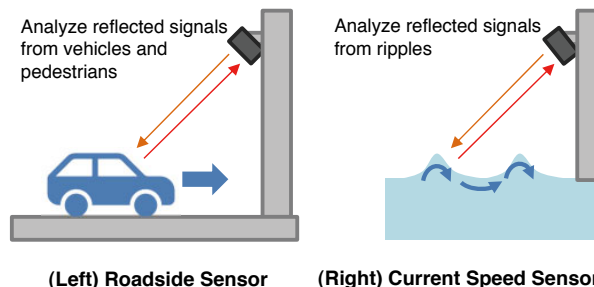
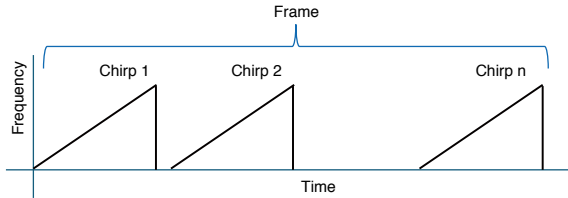


Figure 2. Technology Concept

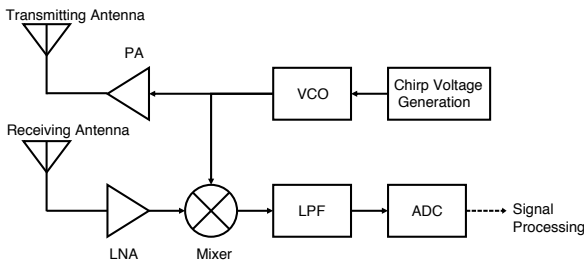
## Technology Principle

FMCW radar is a sensing technology that uses frequency-modulated continuous waves. The transmitted signal, called a “chirp,” has a characteristic in which the frequency increases linearly with time (**Figure 3**).



**Figure 3. Chirp Signals and Frame Structure**

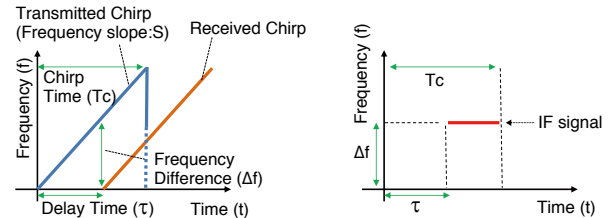
The basic configuration of an FMCW radar includes a voltage-controlled oscillator (VCO), transmitting antenna, receiving antenna, power amplifier (PA), low-noise amplifier (LNA), mixer, low-pass filter (LPA), analog-to-digital converter (ADC), and digital signal processing unit (**Figure 4**).



**Figure 4. Basic Configuration of FMCW Radar**

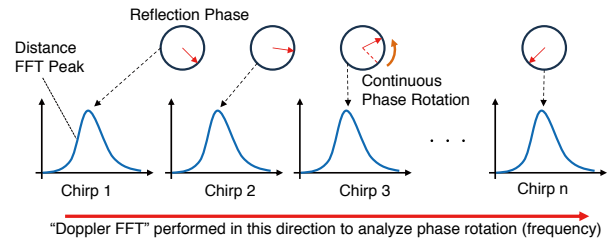
By appropriately controlling the input voltage to the VCO, a chirp waveform is generated and emitted as radio waves from the transmitting antenna. The emitted radio waves reach and reflect from targets (such as waves on the water surface), and the reflected signals are captured by the receiving antenna. Since the reception of the reflected signals requires a round-trip propagation time  $t_0$  from the targets, the frequency of the transmitted signals continue to change during this duration. Therefore, a frequency difference proportional to the distance occurs between the reflected and transmitted signals. The transmitted and received signals are combined in the mixer to obtain signals with the sum and difference frequency components of the two frequencies. The difference frequency component is extracted using an LPF to obtain an intermediate frequency (IF) signal (**Figure 5**). The frequency of this IF signal is proportional to the distance to the target, and by using techniques such as fast Fourier transform (FFT), the

distance to the target can be accurately calculated. This is called distance FFT. For example, if multiple targets are located at different distances, frequency components caused by reflection from each target appear, and through the analysis of each peak, multiple targets can be simultaneously identified.



**Figure 5. IF Signal Generation**

The target’s speed measurement is achieved by analyzing data in frames consisting of multiple chirps transmitted continuously at equal intervals. The reflected signals from a moving target have slightly different phases for each chirp. By arranging these in a time series and performing a second dimension FFT (Doppler FFT), the phase change that occurs according to the target’s moving speed appears as a frequency component (Doppler frequency) (**Figure 6**). The faster the moving speed, the greater the phase change between chirps, which it is extracted as a high Doppler frequency component. Even if multiple targets exist equidistant away, as long as the speeds differ, this processing makes it possible to separate and identify the targets individually.



**Figure 6. Phase Analysis using Doppler FFT**

In addition, phased array antenna technology is used to obtain angle information. By arranging multiple receiving antennas in a one-dimensional line or a two-dimensional plane, the antenna group can obtain phase differences corresponding to the target’s direction. After performing the FFT processing described previously at each receiving antenna, a third dimension FFT (angular FFT) is performed along the array of receiving antennas, and peaks appear for each target direction, allowing the angle to be estimated. The angular resolution will become

higher as more antennas are used. Furthermore, by using MIMO technology, the antenna array size can be virtually increased with combinations of transmitting and receiving antennas, enabling more accurate angle detection.

These signal processing allows FMCW radar to obtain the range, speed, and angle of each target simultaneously and with high resolution, and from the range and angle, the target's spatial coordinates can be determined in a polar coordinate system (Figure 7).

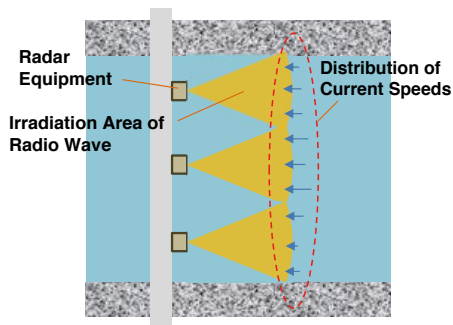


Figure 7. Monitoring using FMCW Radar

When this technique is applied to the surface of a river, it is possible to map the individual positions and speeds of numerous waves and currents on the water surface in detail. Furthermore, by combining this with the radar installation height and riverbed topography data, it will be possible to estimate water levels, analyze current speed distribution, and calculate volume flow rate.

### Benefits of Implementation

The implementation of radar technology that enables area-wide monitoring, such as FMCW, is expected to bring about major changes in river monitoring. The conventional Doppler radio current meter is only capable of measuring current speed and water level of a single point whereas the radar technology can perform a comprehensive measurement over a wider area and with high resolution, thus provides thorough understanding of the flow conditions throughout the entire river. This enables real-time, detailed tracking of complex flow changes, such as shifts in the position of the channel or sudden changes in current speed distribution due to rainfall/flooding, that were difficult to detect with conventional technology.

Furthermore, data from area-wide, multi-point monitoring is expected to contribute to more accurate predictions for river management and disaster prevention. Understanding the current speed distribution over a wide area in a time-series manner allows precise early detection

of rising water levels and flood risks, and helps optimize the design/operation of levees and revetments.

Another major advantage is the high environmental tolerance of millimeter-wave radar. Compared to the imaging method, measurements can be taken reliably even during poor visibility such as at night or in dense fog. Radar can also withstand heavy rain and other bad weather conditions if appropriate measures are taken to remove clutter.

These advantages enable stable and continuous river monitoring regardless of the season or weather, and radar technology is expected to play an important role in advancing river management and reducing disaster risks.

### Conclusion and Future Outlook

As an advanced disaster prevention digital transformation using OKI's Zero-Energy IoT Series, a new approach to monitoring a river's water level and current speed distribution based on FMCW radar technology was introduced. Compared to the point-based measurements of the conventional method, the radar technology allows a high-resolution understanding of river flow conditions over a wide area in real-time. The technology has shown significant potential in contributing to the early detection of flood risks and volume flow rate fluctuations, and the establishment of advanced flood control and disaster prevention systems. Furthermore, its contactless, unmanned operation is expected to ensure worker safety and address social issues such as the shortage and aging of skilled workers.

OKI is developing technologies and products that combine sensing and information to quickly adopt this radar technology for practical use, and thereby contribute to the realization of infrastructures for "Delivering OK! to your life." ◆◆

### References

- 1) Hiroshi Hashizume: Zero-Energy IoT Series -Realize Remote Monitoring of Infrastructure and Disaster Site with Easy Installation-, OKI Technical Review, Issue 242, Vol. 90, No.2, February 2024

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# TIPS

## 【Glossary】

**FMCW: Frequency Modulated Continuous Wave**

A technology that uses a chirp signal whose frequency changes over time. It can simultaneously measure the distance and speed of a target using a simple circuit configuration. It is increasingly being used in transportation applications such as autonomous driving.

**MIMO: Multi Input Multi Output**

A technology that uses multiple antennas for transmission and reception. In the communication field, it is used to improve communication speed and capacity, but in the radar field, appropriately configuring the antenna arrangement enables the creation of virtual antennas to artificially increase the number of antennas.