# Batteryless Speed and Timestamp Recorder with Multi-channel FM Radio Featuring Bicycle Frame Antenna

Shogo Umemoto, Norifumi Kashiyama, Hisashi Nishikawa, Ami Tanaka, and Takakuni Douseki
Ritsumeikan University
Kusatsu, Japan
ri0057he@ed.ritsumei.ac.jp

***Abstract—*** A batteryless bicycle speed recorder has been developed that has a robust timestamp function using a multi-channel FM broadcast receiver. A robust media search technique that searches audio data stored in the recorder corresponding with a time tagged database of a broadcaster guarantees the precise time. For robust time identification, a gamma-matched bicycle frame antenna is proposed that improves the signal-to-noise and distortion ratio (SINAD) of the received audio signal and detects FM broadcast signals at multiple channels. We fabricated a batteryless speed recorder with a two-channel FM receiver and verified its effectiveness in bicycle road tests.

***Keywords— Batteryless speed recorder; Timestamp; Gamma-match; Bicycle frame antenna; Multi-channel FM receiver; Robust media search***

## I. Introduction

Pedestrian-bicycle accidents can result in the payment of large sums of money as damages. For example, one settlement required the court-ordered payment of as much as 95 million yen (approximately $850,000US) to an elderly victim [1]. Japanese local governments have started to enforce a law that obligates cyclists to take out bicycle liability insurance [2]. Thus, non-life insurance companies need to obtain a record of the bicycle's speed and acceleration per driving time leading up to an accident.

We previously developed a batteryless speed recorder with a hub dynamo that functions as both a power source and a speed sensor [3]. We also developed a batteryless speed recorder with a timestamp function that utilizes a single-channel FM broadcast receiver [4]. A robust media search (RMS) technique [5] that searches audio data stored in the recorder corresponding with a time tagged database of a radio broadcaster guarantees the precise time. However, a receiver with a built-in shortened monopole antenna cannot detect FM radio signals at places where the signal intensity of the FM radio wave is faint. A nearly 2-m-long external dipole antenna improves antenna sensitivity and detects weak radio waves for typical FM-radio frequencies. However, a long external antenna obstructs the rider. In addition, even if the receiver detects FM radio signals, the RMS method cannot guarantee the precise time when the broadcast data is repeated, such as commercials.

In the present study, our objective is to fabricate a speed recorder with a robust timestamp function so that the recorder can guarantee the precise time for repeated audio data on weak radio waves without a long external dipole antenna. This paper describes an antenna structure that utilizes the bicycle frame by using a gamma-match technique and improves antenna sensitivity. This paper also describes a RMS method that identifies the duplicate audio data by using multi-channel FM signals.

## II. Batteryless Speed and Timestamp Recorder with Hub-dynamo and FM Radio

Figure 1 shows a photograph of our batteryless speed and timestamp recorder consisting of a hub dynamo, a speed recorder module, and a gamma-matched bicycle frame antenna. The hub dynamo provides power to drive the recorder module and signals to calculate the bicycle speed. The bicycle frame antenna receives multi-channel FM radio signals for the timestamp function.

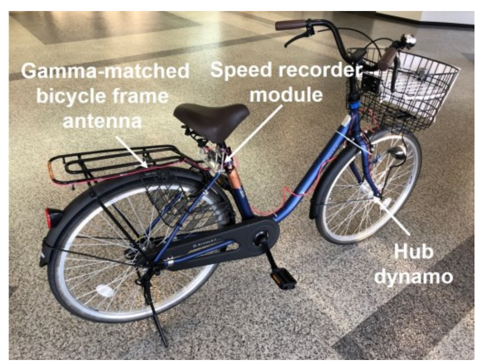



Fig. 1. Photograph of batteryless speed recorder with multi-channel FM broadcast receivers for timestamp function.

Figure 2 shows a block diagram of the speed recorder composed of a hub dynamo, an AC-DC converter, a pulse converter, a multi-channel FM broadcast receiver, a micro-processing unit (MPU), and a non-volatile memory. The hub dynamo supplies power to all components through the AC-DC converter and generates AC signals corresponding to the bicycle speed. The pulse converter converts the AC into pulses to calculate speed data. The multi-channel FM broadcast receiver consisting of an antenna and two receivers detects FM broadcast signals at two channels and outputs the mixed audio data. The speed data and the audio data are associated with each other and are stored to the non-volatile memory by the MPU. A robust media search technique searches the audio data stored in the memory corresponding to a time tagged database of the broadcaster.

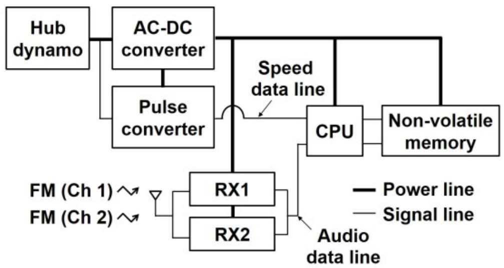



Fig. 2. Block diagram of batteryless speed recorder.

## III. Gamma-matched Bicycle-frame Antenna

An embedded shortened monopole had been used for the receiving antenna of the previous module [4] (Fig. 3). However, detection of radio waves was unstable in a week signal environment such as basin or mountain area.

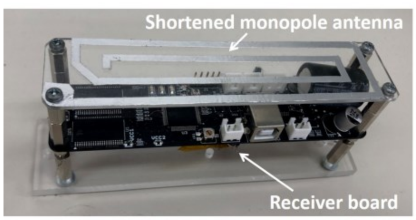



Fig. 3. Shortened monopole antenna attached to FM receiver.

Therefore, a more efficient antenna was required to improve the sensitivity of the receiver to support a wide service area. An external antenna, such as λ/4 whip antenna or λ/2 dipole antenna, effectively maximizes the receiving sensitivity. However, a dedicated antenna is not practical to place on the bicycle because it can hinder and obstruct the rider. Thus, a hidden antenna embedded in the bicycle frame is required.

A bicycle body is around 180 cm long, which is close to the λ/2 of typical FM-radio frequency, and the body is electrically isolated from the ground via rubber tires. Therefore, it should work as a λ/2 dipole antenna if a proper feeding method can be implemented. A dipole antenna is generally formed by two separated wires placed into a linear shape, and a feed line is connected to the two wires at the center. The bicycle frame is a monolithic construction and electrical separation at the center is not possible, thus the traditional feeding method cannot be used. A gamma-match technique, in which the element at the feed point does not need to be separated, is used for the feeding method. One end of the feed line is connected to the frame directly, and the other end is connected to a different point of the frame via a matching rod. As a result, the whole bicycle becomes a λ/2 dipole antenna (Fig. 4).

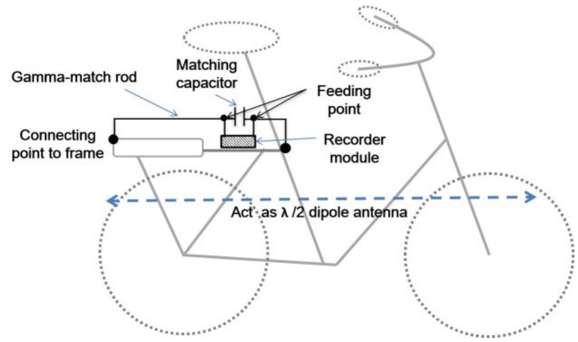



Fig. 4. Antenna embedded in bicycle frame with gamma-match scheme.

The input impedance of the receiver used in the system is 4 kΩ, whereas the feed impedance of a typical λ/2 dipole antenna is 73 Ω. The kΩ range needs impedance to be adjusted to connect to the receiver. The impedance of a dipole antenna becomes higher when the feed point is shifted toward the end of the element (Fig. 5). This characteristic was utilized to obtain a high impedance antenna for the receiver.

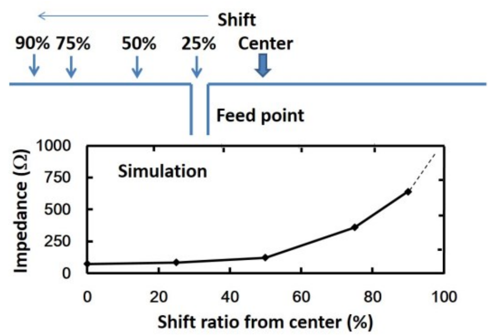



Fig. 5. Impedance vs. feed point of off-center-dipole antenna.

The feed point to the bicycle frame was intentionally shifted from the center to the rear, a gamma rod was connected at the edge of a luggage carrier, and then the measured feed impedance became 2.7 kΩ (Fig. 6). The voltage standing wave radio (VSWR) was less than 2.0 to 4 kΩ, which enabled sufficient connection between the antenna and the receiver (Fig. 7).

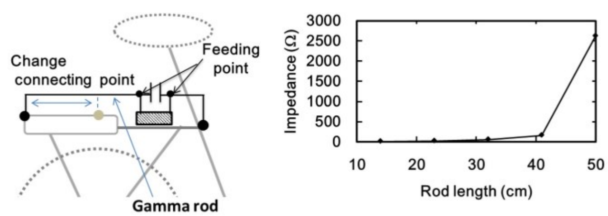



Fig. 6. Impedance change by changing connecting point to frame.

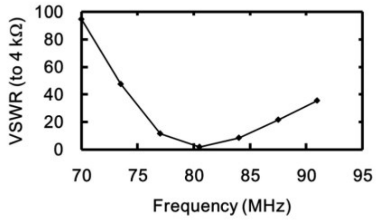
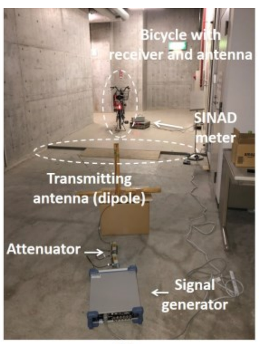



Fig. 7. VSWR of bicycle-frame antenna (to 4 kΩ).

The performance of the bicycle-frame antenna was evaluated by comparing it with a monopole antenna in terms of (a) measuring gain and (b) signal-to-noise and distortion ratio (SINAD) (Fig. 8). The measured gain of the bicycle antenna was 3~4 dB higher than that of the monopole antenna. An FM signal was transmitted from an antenna, and the SINAD value at the receiver output was monitored by switching the two antennas. The bicycle antenna showed 3~4 dB better SINAD values than the monopole antenna. The embedded antenna embedded in the bicycle frame can be said to show sufficient capability and contribute to improve the receiving sensitivity.




(a)

Antenna performance

| Antenna | Frequency (MHz) | Gain (dBi) | SINAD comparison (dB) |
|---|---|---|---|
| Shortened monopole | 77 | -7 | 6 |
| | 84 | -5 | 7 |
| Bicycle-frame antenna | 77 | -3 | 10 |
| | 84 | -2 | 10 |

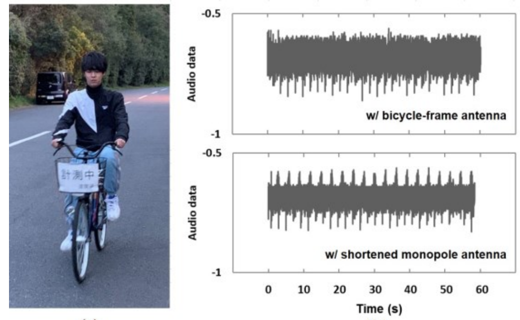
(b)

Fig. 8. Antenna performance measurement (a) Setup of SINAD comparison, and (b) Gain and SINAD data.

## IV. EXPERIMENTS

To verify the effectiveness of our batteryless speed and timestamp recorder with multi-channel FM radio featuring a bicycle-frame antenna, we recorded speed and audio data in road tests at a place where FM broadcast radio waves are weak (Fig. 9). The experimental results show that the audio data recorded by the recorder with the shortened monopole antenna did not include any broadcast contents. However, the recorder with the bicycle-frame antenna recorded audio data consisting of two broadcast contents mixed together obtained by two-channel FM radio waves.

To identify when the speed data was recorded, we used the RMS method with the recorded audio data and 6.5 hours of broadcast contents recorded by commercial radio recorders for a database. The RMS results showed that the recorded audio data matched the contents broadcasted from 4:14:35.43 pm to 4:15:30.86 pm (Fig. 10). The identified time was in good agreement with the time of the road test.




(a) (b)

Fig. 9. Road test of recorder. (a) Photograph of road test. (b) Recorded audio data.

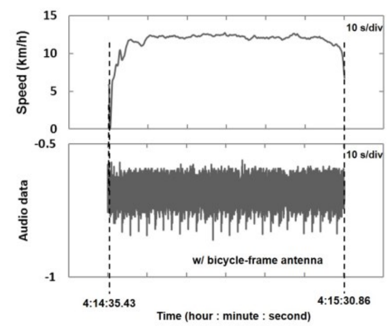



Fig. 10. Speed data and audio data obtained from road test.

## V. CONCLUSION

We proposed a batteryless speed recorder with a robust timestamp function. This function is made possible by a multi-channel FM broadcast receiver with a gamma-matched bicycle frame antenna. We fabricated a speed recorder with a two-channel FM receiver. Experimental results showed that the bicycle antenna improves the gain more than 3 dB compared with a previous built-in shortened monopole antenna. The FM receiver detected both channel FM broadcast radio waves and identified the precise times. As a result, the recorder tagged the speed data with the times.

## REFERENCES

[1] Japan Today: Japan News and Discussion [Online]. Available: http://www.japantoday.com/category/national/view/mother-ordered-to-pay-y95-mil-after-bicycle-riding-son-collides-with-elderly-woman.

[2] The Japan Times: News [Online]. Available: https://www.japantimes.co.jp/news/2019/01/11/national/japan-panel-recommend-ordinances-mandating-use-bicycle-insurance/#.XLBhAZP7Si5

[3] A. Tanaka; et al., "Batteryless Sensorless Bicycle Speed Recorder with Hub Dynamo and STT-MRAM," IEEE SENSORS 2015 Conf., pp. 1413-1416, October, 2015.

[4] A. Tanaka; et al., "Batteryless Bicycle Speed Recorder with Hub Dynama and FM/AM Radio as Time Stamp Function," IEEJ Trans. on Sensors and Micromachines, Vol. 138, No. 3, pp. 79-86, 2018.

[5] NTT Data Corporation Press Release, "New content monitoring service identifies audio and video on the Internet quickly and accurately," 2009, http://www.nttdata.co.jp/en/media/2008/120100.html.