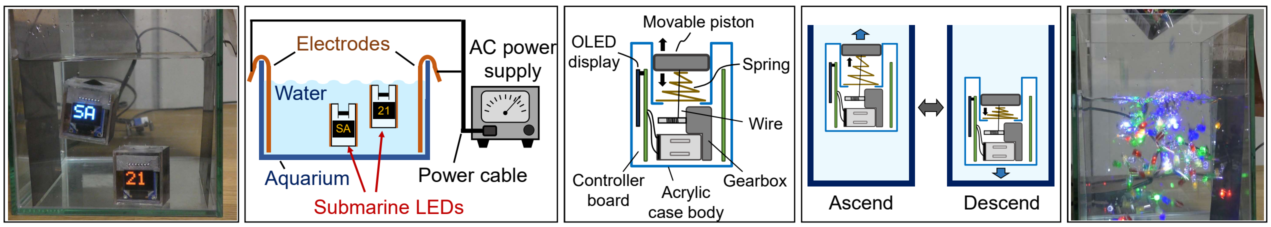
Submarine LED: Wirelessly powered underwater display controlling its buoyancy

Ryo Shirai
Kyoto University
Kyoto, Japan
shirai@i.kyoto-u.ac.jp

Masanori Hashimoto
Kyoto University
Kyoto, Japan
hashimoto@i.kyoto-u.ac.jp



(a) (b) (c) (d) (e)

Figure 1: Proposed underwater display and wireless power transfer (WPT) method. (a) Prototyped underwater display controlling own buoyancy. (b) Overview of the entire system including the proposed WPT method. (c) Structure of each Submarine LED equipped with a movable piston allowing the display to control its own buoyancy. (d) Submarine LED can change the position by controlling its buoyancy. (e) Proposed WPT method can deliver mW-class power even to the mm^3-scale LEDs.

ABSTRACT

This work proposes the wirelessly powered underwater display that can control its position by changing its own buoyancy. The proposed display is equipped with a motor-based actuator to control its effective volume for buoyancy control. The newly proposed underwater AC wireless power transfer (WPT) function drives the power-consuming OLED display and actuation motor. This work confirmed that the proposed WPT function could deliver mW-class power even to hundreds of mm^3-class volume LEDs.

CCS CONCEPTS

• **Hardware** → **Displays and imagers**; **Sensors and actuators**; *Power networks.*

KEYWORDS

underwater display, wireless power transfer, actuator

ACM Reference Format:

Ryo Shirai and Masanori Hashimoto. 2021. Submarine LED: Wirelessly powered underwater display controlling its buoyancy. In *SIGGRAPH Asia 2021 Posters (SA '21), December 14–17, 2021, Tokyo, Japan.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3476124.3488655

1 INTRODUCTION

Thanks to the improvement of the device implementation technology, novel types of displays are emerging. These newly developed displays can present various information (e.g., force, temperature) in addition to image information and sometimes alter the way information is presented to us. A self-moving display is one of the displays that create a new Human-Computer-Interaction (HCI) by changing the information presentation method. [Uno et al. 2018] proposed "Luciola", which is the wirelessly powered light-emitting particle moving in mid-air. Luciola can change the position and direction in which information is presented by taking advantage of its ability to move. On the other hand, a large external ultrasonic irradiation device is required to levitate only one Luciola. This is because the buoyancy acting on the object in the air is too small. [Koike et al. 2017] propose a method of controlling the position of display objects in the water, where the buoyancy is more significant. However, the system proposed by [Koike et al. 2017] also requires an external device to float the object. The buoyancy control mechanism consumes a lot of power and cannot be embedded into a small underwater display, in which the available energy is highly limited. Wireless power transfer (WPT) is one of the solutions to increase the energy available to the underwater display. However, WPT methods that can supply sufficient power to many small underwater devices from outside the aquarium have not been developed [Zhang et al. 2018].

2 OUR APPROACH

Fig. 1(b) shows the overview of the entire proposed system. Two electrodes connected to the external AC power supply (200V, 60Hz) deliver the energy to each "submarine LED," where the water is used as a conducting medium. Each submarine LED is implemented in the volume of 40mm × 40mm × 45mm. As shown in Fig. 1(c), each submarine LED is equipped with a motor to control the piston responsible for determining the volume, and the resultant buoyancy acting on the submarine LED. As depicted in Fig. 1(d), when the

SA '21, December 14–17, 2021, Tokyo, Japan

ACM ISBN 978-1-4503-8687-6/21/12.
https://doi.org/10.1145/3476124.3488655

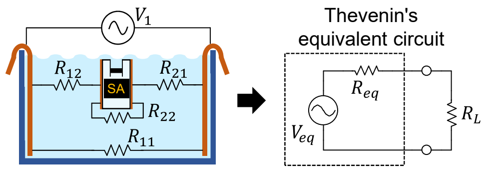


Figure 2: Circuit model of the proposed underwater WPT.

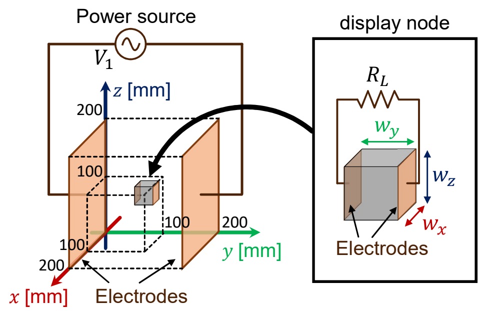


Figure 3: Simulation environment.

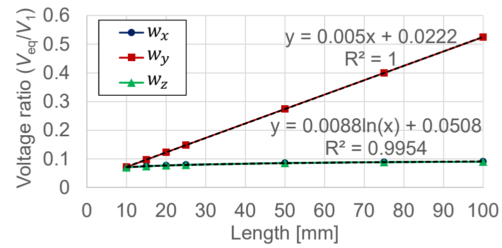


Figure 4: Simulated voltage ratio (V_{eq}/V_1).

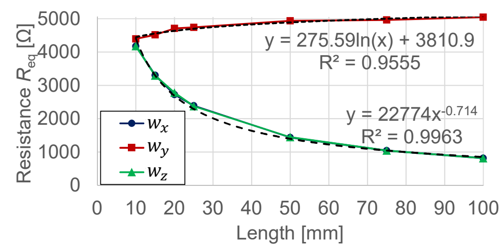


Figure 5: Simulated equivalent output resistance.

motor pulls the piston, the display volume decreases, and hence the display descends to the bottom, and vice versa. Although the motor is a power-consuming device (>200mW), the proposed WPT method can deliver sufficient power to each submarine LED, which will be explained in the next section.

3 UNDERWATER WPT

This section proposes the underwater WPT method that enables us to deliver more than 800 mW power to each submarine LED.

3.1 Deliverable Power Analysis

Fig. 2 shows the circuit model of the proposed WPT method and its equivalent circuit. V_{eq} and R_{eq} are the equivalent voltage source and output resistance in the Thevenin's equivalent circuit, respectively, and satisfy the following relationships:

$$V_{eq} = \frac{R_{22}V_1}{R_{12} + R_{21} + R_{22}}, \quad R_{eq} = \frac{(R_{12} + R_{21})\,R_{22}}{R_{12} + R_{21} + R_{22}}. \tag{1}$$

The deliverable power P_{max} is expressed by $P_{max} = V_{eq}^2/R_{eq}$ and values of V_{eq} and R_{eq} vary according to the display size. The following section evaluates the relationship between these values and the display volume.

3.2 Evaluation

This section investigates the effect of display size on V_{eq} and R_{eq} with ANSYS Electronics 2021 R1 HFSS electromagnetic simulator. Fig. 3 shows the simulation setup. The aquarium size is 200 mm × 200 mm × 200 mm, and the display size is determined by w_x, w_y and w_z. The center of the display is fixed to the position of (100 mm, 100 mm, 100 mm). In the simulation, one out of w_x, w_y and w_z is swept from 10 mm to 100 mm and others are fixed to 10 mm.

Figs. 4 and 5 show the simulation results. In both Figs. 4 and 5, the curves of w_x and w_z are overlapped each other. Fig. 4 suggests that the voltage received at the display node is proportional to w_y while the others do not impact significantly. On the other hand, Fig. 5 indicates that the equivalent resistance is reduced significantly according to w_x and w_z. The size of the prototyped submarine LED is (w_x, w_y, w_z) =(40, 40, 45) [mm] and $V_1 = 200$[V], and hence the receivable power can be 820.1 mW when the impedance is correctly matched. Moreover, even when the node size is reduced to 10 mm × 10 mm × 10 mm, the receivable power remains 11.9 mW, still sufficient for running a small actuator device.

4 CONCLUSION AND FUTURE WORK

This paper presented the wirelessly powered underwater display that can control its position by changing its own buoyancy. To enable the display to run the power-consuming motor, this work proposed an underwater WPT method that can deliver several hundreds of mW to the cm^3-class display.

Our ultimate goal is to scale down the display to mm^3 scale. We already confirmed that our WPT method could deliver sufficient power for mm^3-volume LEDs as shown in Fig. 1(e). Our next step is to actualize tiny mechanism to control the buoyancy.

ACKNOWLEDGMENTS

This research has been executed in response to support of KIOXIA Corporation.

REFERENCES

Amy Koike, Satoshi Hashizume, Kazuki Takazawa, Mose Sakashita, Daitetsu Sato, Keisuke Kawahara, and Yoichi Ochiai. 2017. Digital fabrication and manipulation method for underwater display and entertainment. In *ACM SIGGRAPH 2017 Posters*. 1–2.

Yuki Uno, Hao Qiu, Toru Sai, Shunta Iguchi, Yota Mizutani, Takayuki Hoshi, Yoshihiro Kawahara, Yasuaki Kakehi, and Makoto Takamiya. 2018. Luciola: a millimeter-scale light-emitting particle moving in mid-air based on acoustic levitation and wireless powering. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 4 (2018), 1–17.

Zhen Zhang, Hongliang Pang, Apostolos Georgiadis, and Carlo Cecati. 2018. Wireless power transfer?An overview. *IEEE Transactions on Industrial Electronics* 66, 2 (2018), 1044–1058.