

2.45-GHz Wireless Power Transmitter with Dual-Polarization-Switching Cantenna for LED Accessories

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Abstract—We have developed a wireless power transfer scheme with a dual-polarization-switching cantenna that varies the supply power of two adjacent LED accessories with ultra-small rectennas and changes the light intensity of the LEDs. Such operation is enabled through the use of a dual-polarization-switching cantenna composed of two antennas embedded in the can so that radiated waves are orthogonally polarized. Each antenna enables high-power emission compared with a dipole antenna, and the difference between the gains of the antennas becomes small. In this way, switching between the antennas makes it possible to vary the supply power to the LED accessories. We fabricated a 2.45-GHz cantenna composed of two monopole antennas 8.5 cm in length and a can with a diameter of 12 cm and height of 20.5 cm. The antenna gains of the horizontal and vertical antennas were 12.2 dBi and 0.4 dBi, respectively. The difference of the two gains was suppressed within 12 dB. We also fabricated a wireless power transfer system that consists of a transmitter and LED false nails with an ultra-small rectenna. Experimental results show that our system can vary the luminous intensity of the LEDs in false nails in time to the music of a CD.

Keywords—Cantenna, Polarization, Polarization switching, Intermittent power transmission, Batteryless wearable devices.

I. INTRODUCTION

The advantage of batteryless wearable devices without primary and secondary batteries is that they are small and light, and that there is no need for battery replacement. Wireless power transmission by radio waves is suitable for such devices.

We previously developed a power-controlled 2.45-GHz wireless power transmitter with a distance sensor [1] that measures the distance from the transmitter to the human body. The transmitter emits controlled electromagnetic waves with an electric field strength below that of the national guidelines [2] while maintaining a constant power supply to the target device even if the distance between the human body and the transmitter changes. We also developed an intermittent power transfer system [3] that increases the distance from the transmitter to the wearable devices while maintaining an average transmitted power of the transmitter. Intermittent operation with a peak power that increases in proportion to the reciprocal of the duty cycle provides an increase of the distance. We embedded an LED in a false eyelash and verified that our intermittent wireless power transfer system with a duty cycle of

10% and an average transmission power of 1 W makes the LED flash at a distance of 1.3 m.

In the present study, our objective is to resolve the issue that LED accessories powered by wireless transmission always turn of when the polarization between the transmitting and receiving antenna is shifted. This paper describes a wide-angle coverage wireless power transfer scheme. A dual-polarization-switching cantenna enables such operation. The structure of the cantenna and the switching method of two antennas are explained in detail. We also describe how the cantenna makes the supply power to fabricated LED false nails vary and changes the luminous intensity of the LED.

II. WIRELESS POWER TRANSFER SCHEME FOR PLURAL LED ACCESSORIES

Figure 1 shows a photograph of our wireless power transmission system composed of a 2.45-GHz intermittent wireless power transmitter with a dual-polarization-switching cantenna and two types of LED false nails with an ultra-small rectenna. The transmitter radiates power intermittently according to the rhythm of a song played on a CD. It also changes the magnitude of the transmission power and alternately switches between the cantenna's horizontally polarized antenna and vertically polarized antenna according to the loudness of the music. This system makes it possible to light two types of LED false nails with different brightness according to the rhythm and the loudness of the music.

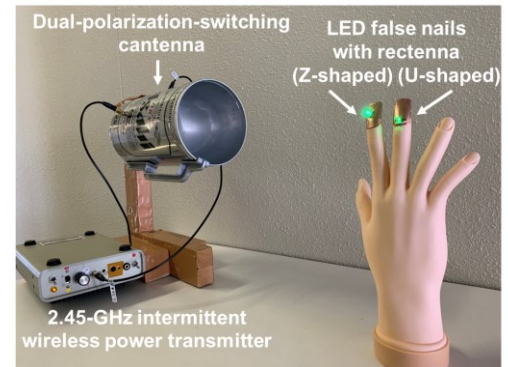


Fig. 1. Photograph of wireless power transmission system featuring transmitter with dual-polarization-switching cantenna.

Figure 2 shows a photograph of the fabricated LED false nails with an ultra-small rectenna. Each nail is composed of a dipole antenna that is used for receiving the 2.45-GHz power along with an ultra-small rectifier and an LED. We propose two types of dipole antenna for this system: a U-shaped one that acts as a horizontally polarized antenna (Fig. 2(a)) and a Z-shaped one that acts as a vertically polarized antenna (Fig. 2(b)).

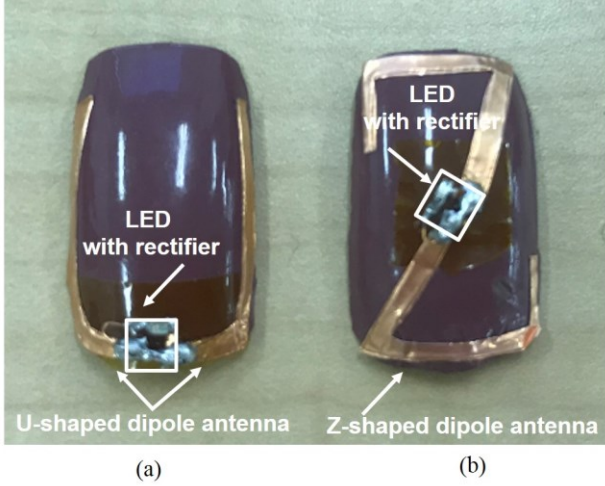


Fig. 2. Photograph of fabricated false nails with rectennas and LEDs: (a) with U-shaped dipole antenna, (b) with Z-shaped dipole antenna.

Figure 3 shows the antenna patterns of the receiving antennas embedded in the false nails. We found that the U-shaped antenna has a higher gain for horizontal polarization and the Z-shaped one has a higher gain for vertical polarization. This result demonstrates that when these two types of LED false nail adjacent to each other receive the wireless power at the same time, the LEDs shine a different luminous intensity in accordance with the polarization.

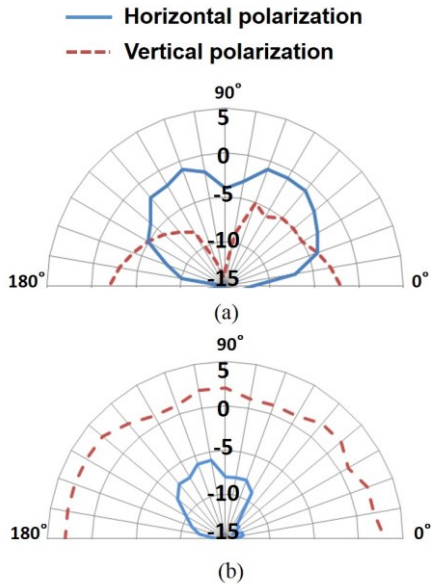


Fig. 3. Antenna pattern of receiving antenna: (a) U-shaped dipole antenna, (b) Z-shaped dipole antenna.

III. DUAL-POLARIZATION-SWITCHING CANTENNA STRUCTURE

Figure 4 shows a photograph of the 2.45-GHz dual-polarization-switching cantenna we fabricated. It is composed of two monopole antennas 8.5 cm in length embedded in a can with a diameter of 12 cm and a height of 20.5 cm. A vertically polarized antenna is placed at a quarter-wave from the bottom of the can. A horizontally polarized antenna is placed 5 mm away and rotated 90° from the vertically polarized antenna.



Fig. 4. Photograph of dual-polarization-switching cantenna: (a) side view, (b) top view.

The radiation pattern of the dual-polarization-switching cantenna was measured and compared with that of a typical dipole antenna (Fig. 5). For this measurement, the antennas were oriented horizontally. We found that the gain of the cantenna is higher than that of the dipole antenna. This is because the antennas have directivity due to the monopole antennas being placed near the bottom of the can. The horizontal and vertical polarization of the antenna gains of the cantenna are 12.2 dBi and 0.4 dBi, respectively. The vertical polarization characteristic of the cantenna includes not only vertical polarization but also other polarization due to the curved face of the wall of the can.

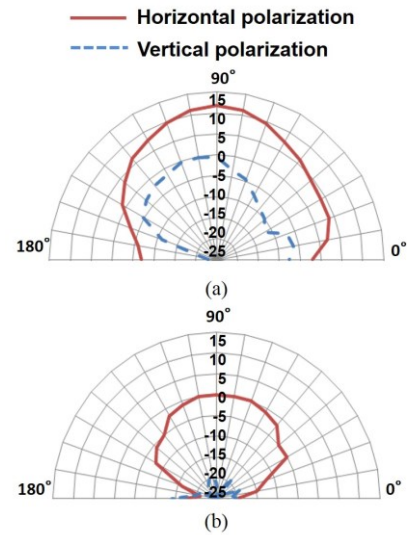


Fig. 5. Radiation pattern of dual-polarization-switching cantenna: (a) cantenna, (b) dipole antenna.

IV. POLARIZATION SWITCHING SCHEME FOR ANTENNA

Figure 6 shows a block diagram of the polarization switching of the dual-polarization-switching antenna using a rhythm signal extracted from the musical signals of a CD. A rhythm detection circuit provides a high/low signal (V_{RHYTHM}) to the gate of a power-switch transistor to control the RF amplifier. Furthermore, V_{RHYTHM} is used to control the RF-switch for switching between two antennas according to the rhythm of the music. The measured waveforms of the antenna switching signal using the extracted rhythm signal are shown in Fig. 7.

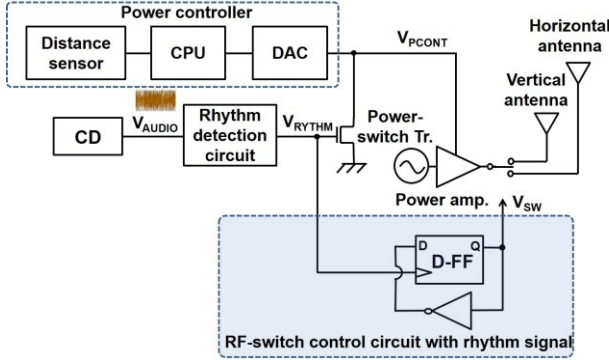


Fig. 6. Block diagram of beam switching of dual-polarization-switching antenna using rhythm signal extracted from musical signals of a CD.

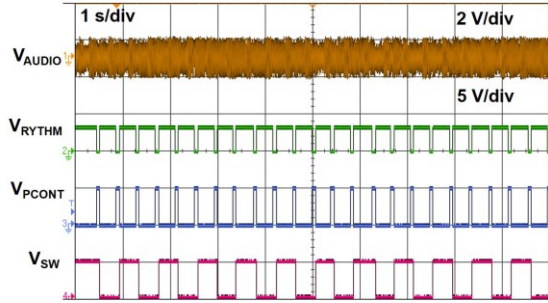


Fig. 7. Measured waveforms of antenna switching signal using extracted rhythm signals.

Figure 8 shows a block diagram of the polarization switching dual-polarization-switching antenna using loudness signals extracted from the musical signals of the CD. The loudness extraction circuit provides an analog signal ($V_{LOUDNESS}$) to the gate of a power-switch transistor (power switch Tr.2) so the transistor acts as a variable resistance. The two power-switch transistors are connected in parallel, so they generate a pulse signal with an analog signal superimposed thereon (V_{PCONT}). This signal makes it possible to radiate power intermittently according to the rhythm of the music and to control the magnitude of the transmission power according to the loudness of the music. Furthermore, $V_{LOUDNESS}$ controls the RF-switch for switching between two antennas according to the loudness of the music. An RF-switch control circuit switches the antennas while the power amplifier stops the radiation of power. The measured waveforms of the antenna switching signal when the extracted loudness signal is an ideal sine wave are shown in Fig. 9.

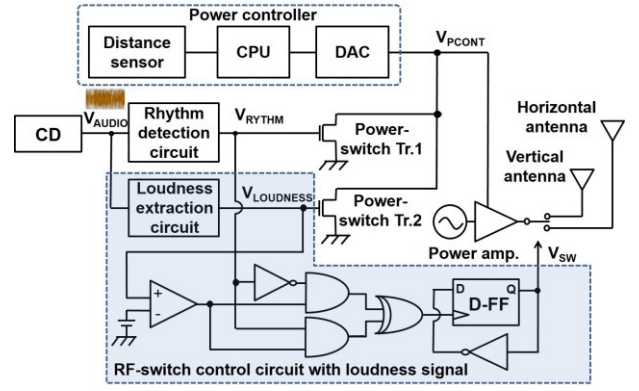


Fig. 8. Block diagram of beam switching of dual-polarization-switching antenna using loudness signals extracted from musical signals of a CD.

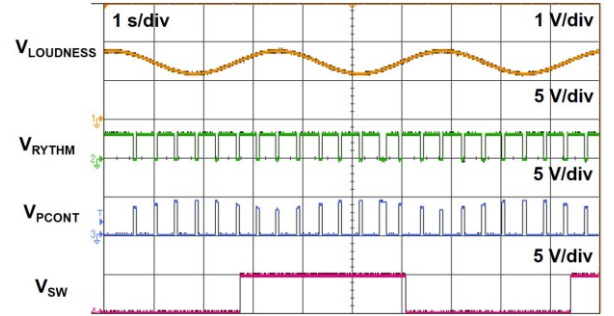


Fig. 9. Waveforms of antenna switching signal when extracted loudness signal is ideal sine wave.

V. EXPERIMENTS

Figure 10 shows a photograph of the fabricated wireless power transmitter with the antenna switching circuit. It consists of an oscillator with phase-lock loop (PLL), a power amplifier, a rhythm detection circuit, an RF-switch control circuit with a loudness extraction circuit, and an RF-switch. The maximum output power of the transmitter is 15 W at 2.45 GHz.

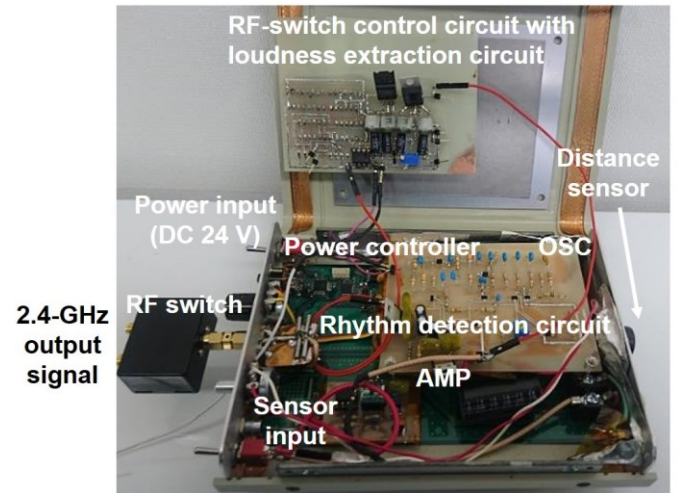


Fig. 10. Photograph of fabricated wireless power transmitter with antenna switching circuit.

Figure 11 shows a circuit diagram of the loudness extraction circuit. The circuit is composed of a filter circuit, an AM detection circuit, and an amplification circuit. The measured waveforms of the loudness extraction circuit are shown in Fig. 12.

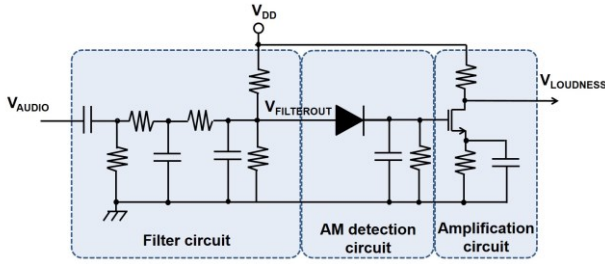


Fig. 11. Circuit diagram of loudness extraction circuit.

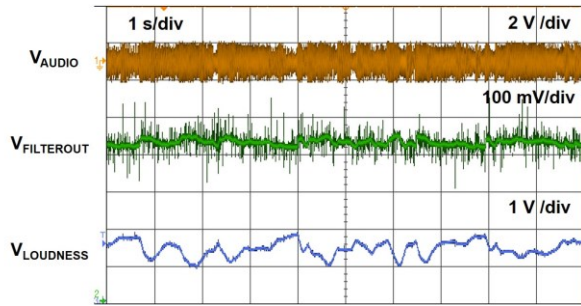


Fig. 12. Measured input and output waveforms of loudness extraction circuit.

Figure 13 shows the measured waveforms of antenna switching signals using the loudness signal extracted from the musical signals of a CD. We obtained a pulse signal with an analog signal superimposed thereon (V_{PCONT}) and a pulse signal (V_{SW}) for switching the RF-switch.

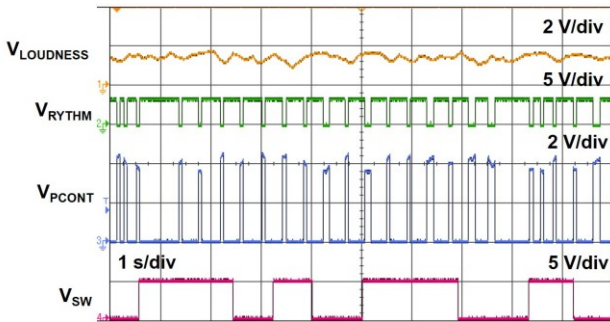


Fig. 13. Measured waveforms of antenna switching signals using loudness extraction circuit.

Figure 14 shows the relationship between the receiving power of the dipole antenna and the distance from the antenna.

Figure 15 shows a photograph of the experimental setup of the wireless power transfer scheme with the dual-polarization-switching antenna and LED false nails. It was confirmed that the LED false nails shone intermittently in accordance with the rhythm of the music at the distance of 0.7 m from the antenna. The supply power of the LED false nails was 8.13 mW.

Furthermore, the LEDs of the false nail with the U-shaped dipole antenna and the one with the Z-shaped dipole antenna shone at different luminous intensities at the same time. We also found that the luminous intensity of the same false nail was changed in accordance with switching between the two antennas.

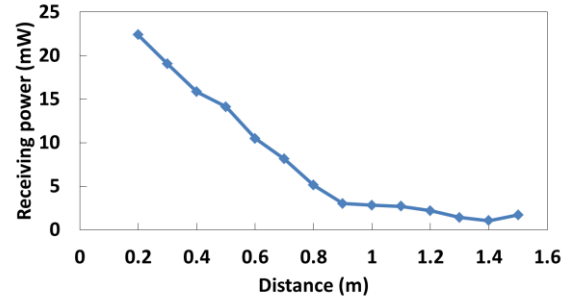


Fig. 14. Receiving power of dipole antenna vs. distance from antenna.



Fig. 15. Photograph of experimental setup of wireless power transfer scheme with dual-polarization-switching antenna and LED false nails.

VI. CONCLUSION

In this paper, we proposed a wireless power transfer scheme with a dual-polarization-switching antenna that enables the light intensity of two adjacent LED accessories to be adjusted. The dual-polarization-switching antenna, which consists of two antennas with vertical and horizontal polarizations embedded in the can, makes it possible to reduce the gain difference between the two antennas. Polarization switching enabled such operation. We fabricated a wireless power transmitter with a antenna and two LED accessories featuring a rectifier and an LED embedded in a false nail. Experimental results showed that the wireless power transmission system makes the light intensity of the LED in the false nail change in time to the music of a CD.

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