Directive Antenna Design at 2.4 GHz on Foot Surface for Wanderer Location Identification

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***Abstract*—A directional patch array antenna was designed for wanderer location identification. The antenna was used for foot-mounted BLE beacons at 2.4 GHz band. Its directional performance was evaluated by simulation and it was found that the antenna can sweep diagonally upward from 7° to 35°.**

***Keywords*—Location identification, patch array antenna, antenna directivity, BLE beacon.**

I. Introduction

The incidence of dementia among people over the age of 65 is increasing as the number of elderly people increases. Symptoms of dementia are disability, disorientation, and the most serious one is wandering behavior. As a solution to identify the wanderer location, global positioning system (GPS) terminals are typically used. However, They require charging every few days. In contrast, Bluetooth low energy (BLE) beacons can operate on button batteries for over a year. A monitoring system using BLE beacons at 2.4 GHz band has been proposed in [1]. The monitoring system provides an elderly person with a BLE beacon for early detection of wandering elderly. The signal from the BLE module is received by a base station installed in a building or a power pole, or by a smart phone owned by a person who happens to pass by. Then the position of the elderly person can be detected from the received signal and accumulated in a server, because the position of the base station is known in advance and the position of the person holding the smart phone is known from the smart phone signal. This enables early detection during loitering.

In this study, the BLE beacon is assumed to be mounted on foot or shoes. This is to prevent forgetting to carry the beacons. Another reason is based on the consideration of energy harvesting from piezoelectric elements mounted on the shoe sole. The antenna needs to radiate signals diagonally upward instead of forward, because the base station or the smart phone has a height from the ground. Its beam width needs to be narrowed to enable more accurate position estimation. Its main beam direction needs to be swept to expand the beacon's detection range. Therefore, a transmitting antenna for the BLE beacon mounted on the foot is designed to have high directivity by forming an array. The antenna performances are evaluated by computer simulation.

II. Foot Mounted Antenna Design

The antenna for BLE beacon is assumed on the foot of the wandering person. Fig. 1(a) shows a simplified foot and leg model. The relative permittivity ε_r and conductivity σ are set to 36.33 and 1.23 S/m respectively which indicate 2/3-muscle. The antenna has a planar patch structure for easy mounting on the foot as shown in Fig. 1(b). Fig. 2 shows the schematic diagram and structure of the designed phase-controlled patch array antenna. Since the antenna is mounted on the foot, it is easily affected by the human body. The patch antenna structure with a ground plane can prevent impedance mismatch due to the foot. The antenna is built on a 1.6 mm thick FR4 board. The antenna elements are arrayed to improve directivity and control the main beam direction. The combined directivity $E(\theta)$ is approximately expressed as

$$E(\theta) = G(\theta) \sum_{n=0}^{N-1} a_n e^{j\phi_n} e^{jk_0 nd \sin\theta} \quad (1)$$

where $G(\theta)$ is the directivity of a single antenna, a_n is excitation amplitude, ϕ_n is excitation phase, N is the number of elements, d is the spacing between two adjacent elements, and k_0 is the wave number in free space.

For feeding power to each antenna element, the feeding line is bent in a meandering shape as a delay line as shown in Fig. 2(b), and the line is switched by a switch to control the phase to each element. When the delay length is Δl, the phase difference $\Delta\phi$ is

$$\Delta\phi = 2\pi \frac{\Delta l}{\lambda_g} \quad (2)$$

where λ_g is the wavelength when the signal propagates along the micro strip lines. To direct the main beam in the desired direction, the excitation phase ϕ_n to each antenna element should be adjusted. The delay length Δl of the feed line is Δl_1 = 3 mm and Δl_2 = 6 mm. The excitation phase is adjusted by controlling two switches S_1 and S_2 to produce required delay lengths in the power supply circuit of the array. Four types of excitation phases can be adjusted by combining ON and OFF of the two switches. Table I shows the excitation phase ϕ_n to each antenna element and the state of the switch in each structure for different feeding line lengths. Impedance matching is performed by loading a $\lambda/4$

TABLE I
EXCITATION PHASE AND STATE OF THE SWITCHES IN EACH ROUTE

Route	Elem. 1	Elem. 2	Elem. 3	Elem. 4	SW1	SW2
1	0°	0°	0°	0°	OFF	OFF
2	0°	31°	62°	93°	ON	OFF
3	0°	62°	123°	185°	OFF	ON
4	0°	93°	185°	278°	ON	ON

TABLE II
SUMMARY OF THE ARRAY ANTENNA PERFORMANCES

Route	Return loss [dB]	Gain [dBi]	Beam width	Main direction
1	−41.56	4.84	41.55°	6.98°
2	−20.00	5.81	43.44°	20.53°
3	−25.67	4.96	43.54°	30.00°
4	−24.56	3.18	29.75°	35.05°

transformer on the branches. The schematic diagram of the power supply circuit and the patch array antenna structure shown in Fig. 2 (b) is for Route 2.

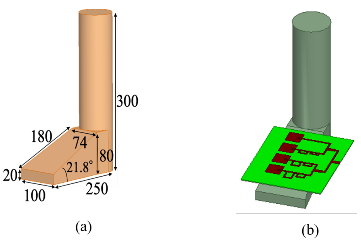

Fig. 1. (a) Simplified foot and leg model. (b) Antenna mounted on the foot.

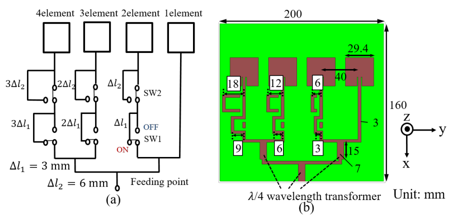

Fig. 2. (a) Schematic diagram of power supply circuit. (b) Patch antennas array structure.

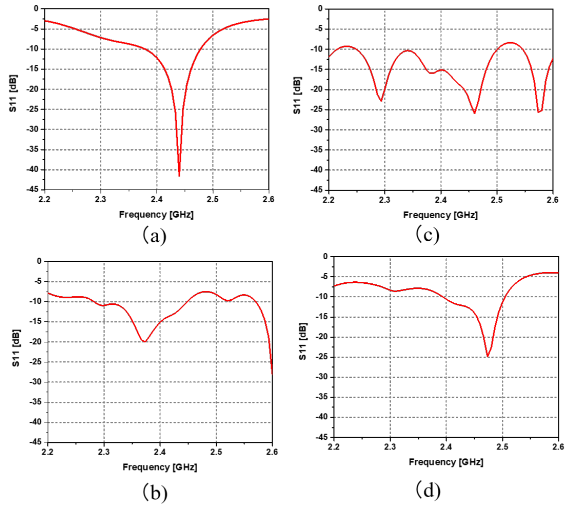

Fig. 3. Reflection coefficient performances of the patch array antenna with foot. (a) Route 1, (b) Route 2, (c) Route 3, (d) Route 4.

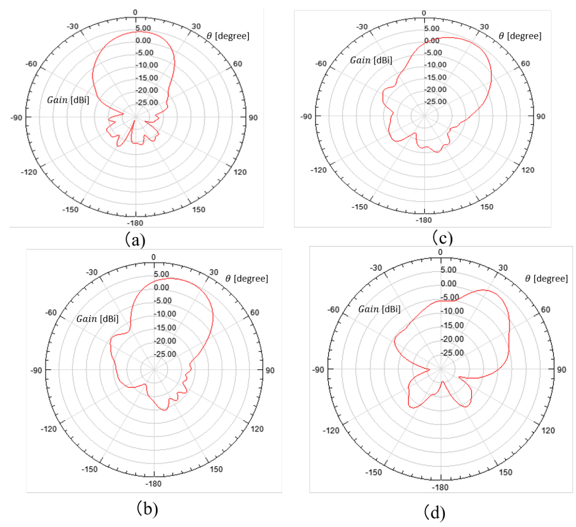

Fig. 4. Radiation patterns of the patch array antenna on the foot. (a) Route 1, (b) Route 2, (c) Route 3, (d) Route 4.

III. SIMULATED RESULTS

Fig. 3 shows the simulation results of S_{11} for the four different feeding routes. It can be seen that the S_{11} performances are basically less than -10 dB at 2.4 GHz, which suggests that they can be used for BLE beacons. Fig. 4 shows the radiation patterns of the patch array antennas. The main beam direction is changed by combining ON and OFF of the two switches in each route to adjust the excitation phases. This allows to sweep the main beam direction of the antenna and expand the beacon detection range and position estimation accuracy. Table II summarizes the simulation results of the array antenna performances. The maximum beam direction has been found to be 35.05° with a half-power beam width of 29.75° when using Route 4. It has a strong diagonal directivity towards the front of the toes, and is suitable for long distance transmission.

IV. CONCLUSION

A patch array antenna has been designed for BLE beacons mounted on the foot for wanderer location identification. The performances have been evaluated by simulation, and the main beam direction has been found to sweep from 7° to 35° by combining ON and OFF of two switches in the feeding routes to adjust the excitation phases. This property can expand the beacon detection range and position estimation accuracy.

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REFERENCES

[1] A. Iwata, J. Wang, S. Shiramatsu, M. Suto, G. Mauricio, N. Magatsuma, "Monitoring plus-watching system using improved BLE beacon and LPWA communication," (In Japanese), Measurement and Control, vol. 58, no. 2, pp. 109–114, Feb. 2019.