In an antenna for a UHF RFID reader of wireless sensor networks (WSN), receiver sensitivity in sensing multitags from remote distances is an important performance index. This study designed a dual structured Z-slot antenna with optimized receiver sensitivity to enhance the sensitivity to a circularly polarized antenna with an isotropic pattern for a UHF RFID. Through analysis of performance in the designed antenna, the following was verified: return loss ($S_{11}$) was about $-62.21$ dB at 925.25 MHz, antenna gain was 7.36 dBi, and $\Delta P_r$, isotropic gain deviation, was 1.3 dB. Impedance matching was about 50.069 $\Omega$ at 925.25 MHz and VSWR was from 1.001 to 1.028. Through this research it was discovered that this can be applied to the design of all RFID readers of WSN. Based on the above results, it is suggested that a circularly polarized Z-slot antenna which can enhance receiver sensitivity over a wide range can be widely applied to UHF RFID readers of WSN.
for a directional pattern antenna, gain is high but recognition ranges of tags are low [11]. For an isotropic pattern, antenna gain is low but the recognition range of tags is wide, so studies to enhance receiver sensitivity with an isotropic antenna over a wide range have been carried out [12–15].

This study designed an isotropic antenna with high receiver sensitivity and an isotropic pattern for UHF RFID. To design and manufacture circularly polarized isotropic antennas, the signals of readers were divided into two signals of the same magnitude and an incidence difference of 90°. Electricity was supplied to a strip line with a length of λ/2. The radiation board was connected to the feeding point of the strip line to enhance receiver sensitivity and the Z-slot was designed in a section of the radiation board to enhance receiver sensitivity so that passive tags could be recognized over a wide range.

This study is composed of the following: Section 1 describes the design of circularly polarized antennas with an isotropic pattern for UHF RFID readers of WSN, Section 2 describes the design, manufacture, and simulation of the antennas for readers, Section 3 measures the parameters of the antennas manufactured and their performance, and Section 4 concludes the antennas designed.

2. Design and Simulation of an Antenna for Readers

We have designed and manufactured a circularly polarized antenna and Z-slot antenna with an isotropic pattern.

The processes are as follows.

2.1. Design and Manufacture of the Proposed Antenna. The block diagram of circularly polarized antennas for UHF RFID readers of WSN with an isotropic pattern is presented in Figure 1. For compatibility with different RFID readers, a microstrip line was designed as shown in Figure 2. The inductance value \( L_1 \) was adapted and impedance matching was 50 Ω.

![Diagram](image)

**Figure 1:** Composition of antennas for the UHF RFID reader of WSN designed.

As seen in Figure 2, a hybrid coupler with insertion loss of 0.16 dB and a status difference of 90° was used to give a status difference of 90° from the original signal. To divide signals into two right-angled linear signals with the same amplitude, two strip lines with a length of λ/2 were designed. We called the shape the dual structured antenna. The circularly polarized antenna designed was characterized by left-turn circular polarization (LHCP). For the PCB, a 1 mm thick FR4 epoxy substrate with a relative permittivity of 4.8 was used. To receive the minute power reflected from tags, two strip line feeding points with a length of λ/2 and a Z-slot radiation plate with cross section of 13.4 cm × 13.4 cm were used for a double antenna.

To achieve an isotropic pattern, the diagonal length of the radiation plate was λ/4 (80 mm), and length of each line (d) was 30 mm and the slot home span (t) was 6 mm as seen in Figure 3.

2.2. Simulated Results for Radiation Pattern Characteristics. We used the ADS (advanced design system) 2004A of Agilent company for simulating the manufactured antenna. The simulation direction of the designed circular polarization antenna is as shown in Figure 4. The simulation result presented that it had high power density at 0° to 360° direction to \( x \), \( y \), and \( z \)-axis (isotropic pattern) as shown in Figure 5.

3. Parameter Measurement of the Designed Antenna and Performance Analysis

We measure and analyze the performance of the designed antenna as shown in the following.

3.1. Measurement of Return Loss \( (S_{11}) \). If there are unmatched impedance points in the transmission system, power reflection occurs there and part of the input power is reflected. Here, the ratio of the input power to reflected power is the return loss.

Measurement results for the return loss \( (S_{11}) \) of the designed UHF RFID reader of WSN are presented in Figure 6 and as shown in Table 1, the return loss decreased at 925.25 MHz to −62.21 dB. The wideband of the return loss of −10 dB was between 720.25 MHz and 1.12 GHz and the wideband of the axis rate of 3 dB was within 1.2 dB.

3.2. Measurement of the Impedance Matching Parameter. As a result of measuring the matching parameters of the designed antenna, matching was carried out with 50.069 Ω at 925.25 MHz as shown in Figure 7 and VSWR was from 1.001 to 1.028. It was discovered that this is compatible with different RFID readers of WSN. The impedance of the designed antenna is presented in Table 2.
Reflection plate feed point (13.4 cm²)

Ground

Hybrid coupler

Microstrip line
$L = 4$ cm
$W = 2$ mm

Strip line ($\lambda/2$)
$L = 18$ cm
$W = 2$ mm

Figure 2: Design and manufacture of the PCB.

Figure 3: Design and manufacture of a Z-slot reflection plate.

Figure 4: Simulation of the direction of the designed antenna.
3.3. Test Environment and Radiation Pattern Measurements

3.3.1. Test Environment for Antenna Radiation Pattern. The designed antenna radiation pattern was measured by an absorber system. To measure performance, the circularly polarized Z-slot antenna was placed as a target, as seen in Figure 8, and a horn antenna was used as a standard for comparison. The two antennas had a separation distance of 2.36 m. For the standard, a BBHA-9120-D made by SCHWARZBECK was used and the parameters are as presented in Table 3.

| Frequency | Return loss ($S_{11}$) |
|-----------|------------------------|
| 917.25 MHz | -35.595 dB             |
| 925.25 MHz | -62.213 dB             |
| 929.25 MHz | -43.300 dB             |

| Frequency | Impedance |
|-----------|-----------|
| 917.25 MHz | 51.415 Ω  |
| 925.25 MHz | 50.069 Ω  |
| 929.25 MHz | 49.486 Ω  |
The equation defined by H. T. Friis which describes this wave behavior in "free space," called the Friis Transmission Equation, is [16–18] as follows:

\[ P_r = \left( \frac{\lambda}{4\pi d} \right)^2 G_t G_r P_t, \]  

(1)

where \( P_r \) represents received power level, \( P_t \) represents transmit power level, \( \lambda \) represents transmit wave length, \( G_t \) represents gain of the transmit antenna, \( G_r \) represents gain of the receive antenna, and \( d \) represents separation distance between antennas.

It is convenient to express Friis formula in terms of \( S_{21}^2 \) and dB:

\[ S_{21}^{dB} = P_{L}^{dB} + G_t^{dB} + G_r^{dB}, \]  

(2)

where the path loss is defined as

\[ P_L^{dB} = 20 \log \left( \frac{\lambda}{4\pi d} \right). \]  

(3)
3.3.2. Measurements of Antenna Radiation Pattern and the Gain Parameter. To measure the radiation pattern and antenna gain according to the directions of the designed antenna, the standard antenna and the designed antenna were rotated horizontally and vertically and the pattern and gain were measured in the four different aspects.

Figure 9 presents the results of the test where the standard antenna was set horizontally and the designed antenna was set in front. The antenna gain was 5.28 dBi and $\Delta P_r$, a deviation of isotropic gain, was 3.2 dB.

Figure 10 presents the results of the test where the standard antenna was set vertically and the designed antenna was set in front. The antenna gain was 5.83 dBi and $\Delta P_r$, the deviation in isotropic gain, was 7.2 dB.

Figure 11 presents the results of the test where the standard antenna was set horizontally and the designed antenna was turned at 90°. The antenna gain was 7.36 dBi and $\Delta P_r$, a deviation of isotropic gain, was 1.3 dB.

Figure 12 presents the results of the test where the standard antenna was set vertically and the designed antenna was turned to 90°. The antenna gain was 7.42 dBi and $\Delta P_r$, a deviation of isotropic gain, was 16.4 dB.

Table 4 presents the results of comparing the antenna gains measured and the deviations of the isotropic gains under the four different test environments. The gain of the antenna manufactured through a Z-slot formed on the radiation plate was about 7.36 dBi. The largest gain is a little low, but the deviation in isotropic gain was 1.3 dB, which indicates that the radiation pattern is superior.

3.3.3. Radiation Pattern Comparison according to the Z-Slot Plate Parameters. The design parameters of the Z-slot formed on the antenna radiation plate, that is, the diagonal length ($L$),
Figure 11: Radiation pattern for the antenna gain 3 (the standard antenna: horizontal and the designed antenna: turned 90°).

Figure 12: Radiation pattern for the antenna gain 4 (the standard antenna: vertical and the designed antenna: turned 90°).

3.3.3. Analysis of the Radiation Pattern according to the Radiation Plate. To analyze radiation patterns according to the presence of the Z-slot on the radiation plate, the radiation pattern was measured with the standard antenna set vertically and the designed antenna turned 90°.

As a result, it was discovered that the maximum antenna gain without a Z-slot was about 9.09 dBi and Δ𝑃ᵣ was about 24 dB. In the case when there is a Z-slot on the plate, the maximum antenna gain was about 7.36 dBi and Δ𝑃ᵣ was about 1.3 dB. Therefore, the maximum antenna gain was about 1.73 dBi and Δ𝑃ᵣ, a deviation of isotropic gain, was about 22 dB. Therefore, it was discovered that the isotropic pattern was superior when the Z-slot was designed on the radiation plate and the receiver sensitivity of passive tags in the wide range of the antenna for the RFID reader of WSN was superior (Figure 16).

3.3.5. Performance Comparison. Table 6 shows the electric characteristics of the designed antenna with the RFID antenna. The known antenna was more than 21 cm² in size while the designed antenna is only about 13.4 cm². However, the antenna gain was the same as that of the known antenna, 5.28 ~ 7.36 dBi, although its size is smaller. The VSWR of the designed antenna was 1.028, higher than that of the known antenna. The tag recognition distance of the known antenna was about 3 m in a narrow range while that of the designed antenna was about 3 m in a wider range.

4. Conclusion

This study designed a dual structured and circularly polarized Z-slot antenna for UHF RFID readers of WSN with an isotropic pattern.

To recognize many tags at a remote distance at the same time without errors, the designed antenna had an insertion loss of 0.16 dB and used a hybrid coupler with a status difference of 90° so there was a status difference of 90° from the original signal. Also, to separate signals into two right-angled linear signals of the same amplitude, there were two strip lines with a length of λ/2. The designed dual antenna had a left-turn circularly polarized pattern and to receive

| Antenna samples | Diagonal length (L) [mm] | Line length (d) [mm] | Slot span (t) [mm] |
|-----------------|--------------------------|----------------------|-------------------|
| 1               | λ/4 (80)                 | 3λ/32 (30)           | 2                 |
| 2               | λ/4 (80)                 | 3λ/32 (30)           | 4                 |
| 3               | λ/4 (80)                 | 3λ/32 (30)           | 6                 |
| 4               | λ/4 (80)                 | λ/8 (40)             | 2                 |
| 5               | λ/4 (80)                 | λ/8 (40)             | 4                 |
| 6               | λ/4 (80)                 | λ/8 (40)             | 6                 |
Figure 13: Antenna radiation plates according to the $Z$-slot parameters.

Figure 14: Radiation pattern data according to $Z$-slot parameters 1 (standard antenna: vertical and the designed antenna: frontal).

Table 6: Performance comparison of the known and the proposed antenna.

| Manufacturing company | S Co. | S Co. | S Co. | P Co. | I Co. | I Co. | Manufactured antenna direction (Z-slot) |
|-----------------------|-------|-------|-------|-------|-------|-------|-----------------------------------------|
| Antenna size          | 71.7 $\times$ 31.7 cm$^2$ | 22.4 $\times$ 20.6 cm$^2$ | 28.19 $\times$ 28.19 cm$^2$ | 24.5 $\times$ 24.5 cm$^2$ | 25.9 $\times$ 25.9 cm$^2$ | 21.8 $\times$ 19.8 cm$^2$ | 13.4 $\times$ 13.4 cm$^2$ |
| Gain (dBi)            | 6.75  | 5.25  | 6     | 6.5 $\pm$ 0.5 | 7     | 6     | 5.28~7.36 |
| VSWR                  | 1.25  | —     | 1.22  | 1.3   | 1.5   | 1.5   | 1.001~1.028 |
| Tag recognition distance | Narrow zone about 3 m | Narrow zone about 3 m | Narrow zone about 3 m | Narrow zone 3 m diffusion | Narrow zone 3 m diffusion | Wide zone about 3 m |
the minute amount of power returned from the tags, it was
designed to have strip line feeding points of length of $\lambda/2$
and a Z-slot radiation plate with a cross section of 13.4 cm $\times$
13.4 cm. As a result of the test of the designed antenna,
the return loss was about $-62.213$ dB at 925.5 MHz and the
antenna gain was 7.36 dBi. Impedance matching was 50.069 $\Omega$
at 925.25 MHz and the VSWR was from 1.001 to 1.028, which
indicates that it can be used for different RFID readers of
WSN.

The designed antenna was half the size of the known antenna, but it had an isotropic radiation pattern as good as and with the same electrical characteristics as the known one and recognized passive tags over a wide range. Such a dual structured and circularly polarized Z-slot antenna with an isotropic pattern can contribute to enhanced receiver sensitivity through maximizing antenna efficiency and to the development of antennas for UHF RFID readers of WSN with respect to compatibility with other systems.
Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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