The Circularly Polarized Corner-Truncated Rectangular Patch Antenna with Double Slits for UHF RFID System

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***Abstract*—This paper presents a circularly polarised rectangular patch antenna for ultra-high-frequency (UHF) radio frequency identification (RFID) applications using for Thailand standard. The antenna consists of a corner-truncated patch with double slits and a ground plane. The rectangular patch is fed by a single probe. The circular polarisation can be achieved by using three techniques such as adding double slits, using square shape and using a slanted cutting corner. The antenna has a compact size and appropriate for RFID system of Thailand standard. The measurement results show that |S_{11}| (dB) is less than -10 dB. The antenna gain is 8.83 dBic with the unidirectional radiation pattern. The 3-dB axial ratio beamwidth is 65º over the frequency band of 914.4 - 929.9 MHz covering the UHF RFID applications for Thailand standard.**

***Index Terms*—Circular Polarised Patch Antenna; Truncated Corners Antenna; Slit Antenna; UHF RFID System.**

I. Introduction

Radio-frequency identification (RFID) was born since World War II [1]. The RFID has been developed and used to solve the problems of barcode systems. The advantage of RFID is that the data can read\write with high accuracy without touching the label and resistant to dampness and damage of texture [2].

RFID systems are the communication of an RFID tag and an RFID reader using the electromagnetic wave. The RFID tag looks like a tag or label, that consist of a small integrated circuit (IC) chip and an antenna. The RFID reader includes a control unit and a reader antenna. The function of the reader is to connect data to write or read data into the RFID tag by radio frequency [3].

The radio frequencies spectrum of RFID systems is operated in industrial-scientific-medical (ISM) band having four frequency bands namely; low frequency (LF) < 150 kHz, high frequency (HF) of 13.56/27.125 MHz, ultra-high frequency (UHF) of 433/868/915 MHz and a microwave frequency of 2.45/5.8 GHz [4]. For Thailand standard, the allocated frequency of the UHF RFID system is from 920 to 925 MHz [5].

The communication of UHF RFID system is related with the far-field communication. Normally, the polarisation of a commercial RFID tag antenna is a linear polarisation (LP) while the RFID reader antenna has the both of linear and circular polarisation (CP). The RFID reader which has LP antenna can properly access data of LP tag antenna when the reader and tag antenna have the same polarisation. Whereas, the CP RFID reader can access the data of a tag antenna although the tag is located in vertical or horizontal direction. Nevertheless, the farthest reading-range is declined when compared to the use of the reader and the tag having the same polarisation of [1]. The CP antenna for UHF RFID reader is one of the choices to resolve a problem when a direction of a tag antenna cannot be controlled due to changing of environmental conditions such as a baggage tag for a conveyor line in the airport [6], [7].

The rest of the article is organised as follows; Section II described the geometry of the proposed antenna. The comparison of |S_{11}| (dB), AR (dB), radiation pattern and gain from the simulation results and actual measurements are discussed in Section III. Section IV demonstrates the results of the parametric study. The conclusions are provided in Section V.

II. Antenna Configuration

CP antenna is obtained from two configurations of a linear electric field having the same amplitude but different phases with 90º [8]. In general, the feeding structures of the CP antenna can be classified into a single, and a hybrid feeds. Although a disadvantage of the single-fed single patch is a narrow impedance bandwidth and AR of 1-2%, it is enough to use for the frequency band of UHF RFID Thailand standard. Therefore, the single-fed single patch is used as the main structure in the design. CP of the proposed antenna is improved by three techniques, e.g., a square and a slant truncated corner, and a slit [8], [9].

Figure 1 shows the configurations of the proposed antenna. The antenna consists two primary layers of PCB including a suspended radiating patch and a ground plane fabricated by a 0.8-mm-thick FR-4 (ε_r = 4.4) with a loss tangent of 0.245 having the single-sided copper with the thickness of 0.05 mm. The antenna is a single-fed antenna, and it is fed by subminiature version A (SMA) connector. The single probe is defined to standard wire gauge (SWG) No. 19 with the diameter of 1.016 mm. The height between the highest edge of the radiator patch and the lowest edge of the ground plane (h) is 10 mm for easy to fabricate.

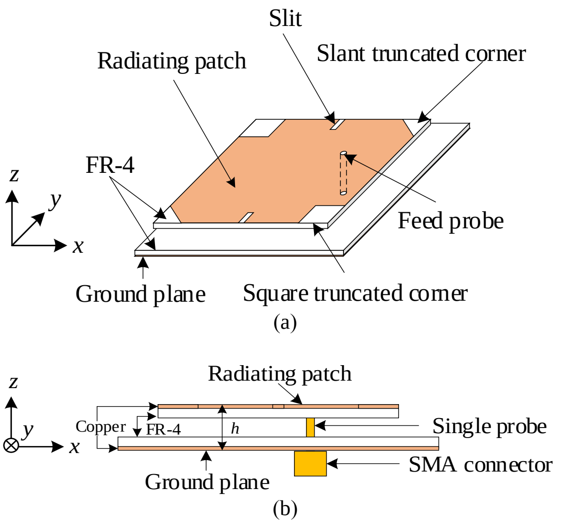


Figure 1: Configuration of the proposed antenna: (a) exploded view, and (b) side view.

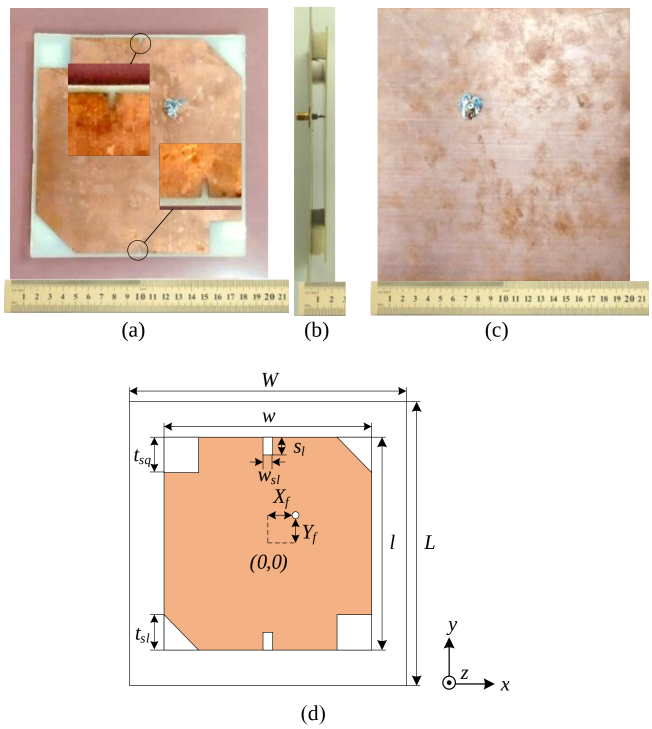


Figure 2: Geometry and photograph of the proposed CP antenna: (a) top, (b) side and (c) rear view photograph of the antenna prototype, and the detailed of antenna parameter: (d) from top view.

The prototype and detailed dimensions of the proposed antenna is illustrated in Figure 2. In Figure 2 (a), (b) and (c), the radiating patch and the ground plane was fixed by using foam to be a platform. One SWR 19 is used as the probe to connect the radiating patch. An SMA is connected between a single probe and a ground plane by soldering. Figure 2 (d) shows the magnified geometry of the radiating patch part. The feeding point X_f and Y_f are significantly related to the operating frequency and an axial ratio [10], [11]. Therefore, the feeding point X_f and Y_f are selected to appropriate position with 23 mm and 25 mm, respectively, representing the feed point position consider from the origin point (*0,0*). The width (w) and length (l) of the radiating patch are 142×152 mm^2, and the width (W) and length (L) of ground plane are 200×200 mm^2. The truncated square shape (t_{sq}) is 22.5 mm, and the truncated slant (t_{sl}) is 19 mm. The width and the length of the slit are respectively w_{sl} = 4 mm and s_l = 7 mm.

III. Results and Discussion

A. |S_{11}| (dB)

The measurement was performed in the anechoic chamber using an Agilent E5071C vector network analyser (VNA). Figure 3 shows the |S_{11}| (dB) from the simulation and measurement of the proposed antenna covering the frequency band of 892-950 MHz. The impedance bandwidth of the proposed antenna considering at 58 MHz and 66.8 MHz are respectively from 899.9 to 966.7 MHz and from 899.9 to 966.7 MHz.

The |S_{11}| (dB) of the proposed antenna from the simulation at lower-limit, middle and upper limit frequency of Thailand UHF RFID standard are respectively -12.69 dB, -12.23 dB and -11.88 dB and from the measurement of -12.38 dB, -12.14 dB and -11.79 dB, respectively.

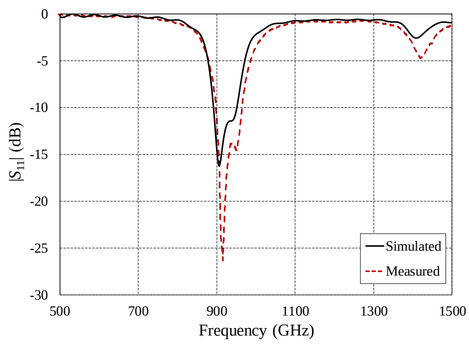
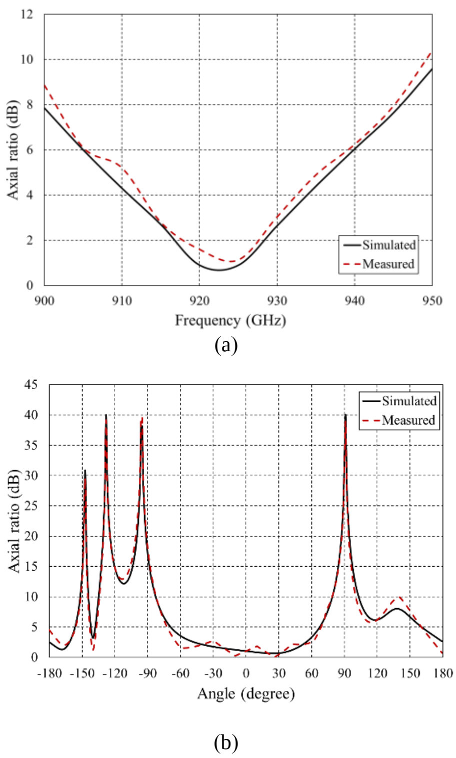
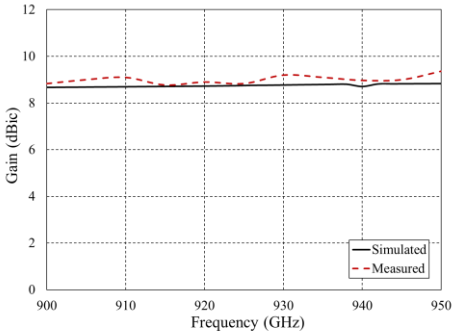


Figure 3: Simulated and measured |S_{11}| (dB) of the proposed antenna.

B. Axial Ratio (dB) and Gain





(c)

Figure 4: Simulated and measured results of the proposed antenna: (a) AR (dB) at boresight, (b) AR at the frequency band of 922.5 MHz and (c) Gain.

Figure 4 (a) shows the simulated and measured 3-dB AR at boresight are respectively 914.1-930.9 MHz and 914.4-929.9 MHz. The 3-dB AR angle at the frequency band of 922.5 MHz (the centre frequency band of Thailand UHF RFID) from simulation and measurement are 113º and 128º, respectively as shown in Figure 4 (b). The simulated gain of the proposed antenna is higher than 8.71 dBic, and measurement gain is more than 8.83 dBic as shown in Figure 4 (c). The gain in the frequency domain can be calculated via the antenna transfer function as given by [12].

$$G(f,\theta,\psi)=\frac{4\pi f^2}{c_0^2}\left|H(f,\theta,\psi)\right|^2 \tag{1}$$

It is essential that the transfer function is multiplied by f^2.

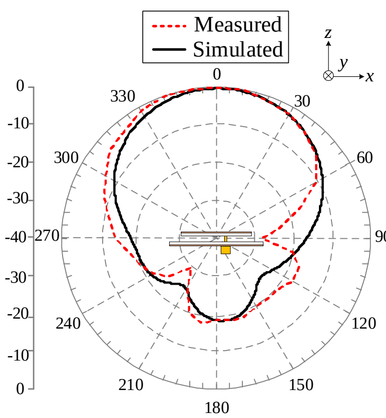
C. Radiation Pattern

Figure 5 shows the radiation pattern on of the proposed antenna at the frequency band of 922.5 MHz. The antenna radiates unidirectional radiation along the Thailand UHF RFID frequency. The simulated and measured results of the half power beamwidth (HPBW) in the *x-z* plane are 68º and 70º, respectively. The measured HPBW results are more than that of the simulation results of 2º. The HPBW from simulation and measurement in the *y-z* plane are 68º and 65º, respectively. It is found that the measured HPBW is less than that of the simulation results of 3º.

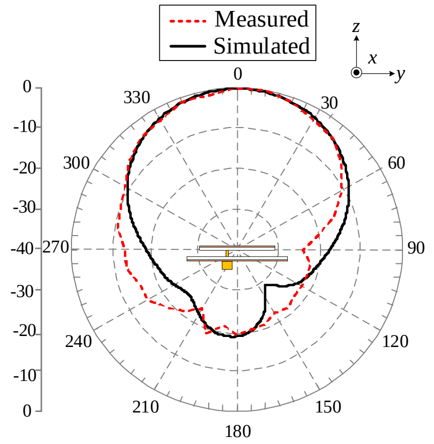
IV. Parametric Studies

A. The Initial antenna

The radio frequency band of UHF RFID Thailand Standard is 920-925 MHz [5]. Then, the initial resonant frequency (f_r) is defined as the frequency of 925 MHz.



(a)



(b)

Figure 5: Radiation pattern of the proposed antenna from simulation and measurement: (a) *x-z* plane and (b) *y-z* plane at 922.5 MHz.

Typically, the length (l) of a rectangular patch microstrip antenna is followed to the theory. It is approximately a half wavelength of the operating frequency in a fundamental mode. However, for a microstrip patch antennas, $h << l$ and $h << w$. If $l > w > h$, the mode with the lowest frequency or dominant mode is the TM_{010}^{x}. The resonant frequency is according to the theory of cavity model, and its cut off frequency is according to the waveguide model having the same equation [8] as given by:

$$(f_r)_{010}=\frac{1}{2l\sqrt{\mu\varepsilon}}=\frac{c}{2l\sqrt{\varepsilon_r}} \tag{2}$$

Then, the parameter l, w and h are defining as $l > w > h$ because it causes a dominant mode with [8]. The resonant frequency can be calculated via equation 2 when l and w are the length and width of the rectangular radiator patch, respectively. Parameter "l" can be calculated by:

$$l=\frac{c}{2f_r\sqrt{\varepsilon_r}}=\frac{3\times10^8}{2\left(925\times10^5\right)\sqrt{1}}=162.2\text{ mm}, \tag{3}$$

The initial design of w is defined to be 160 mm, that is slightly smaller than l in order to achieve the dominant mode according to equation 3. The ratio of l/w as shown by:

$$\frac{l}{w}=\frac{162.2}{160.0}=1.013 \tag{4}$$

The length and width of the ground plane are defined by L and W. To be a compact size antenna for fabricating easily, the decimal number of the size is rounded off. The length and width of the ground plane are set to be 200 mm. The initial parameters of the antenna are shown in Figure 6 tabulated in Table 1.

Table 1
The Parameters of an Initial Antenna

Parameters	h	l	w	W	L	X_f	Y_f
Size (mm)	10.0	162.2	160.0	200.0	200.0	23.0	25.0

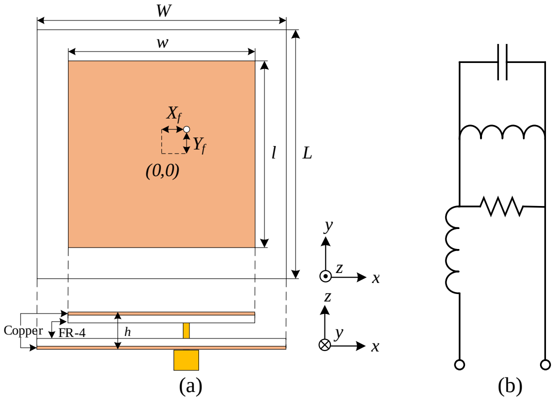


Figure 6: The initial parameters: (a) antenna structure and (b) equivalent circuit of coaxial feed/probe feed path antenna.

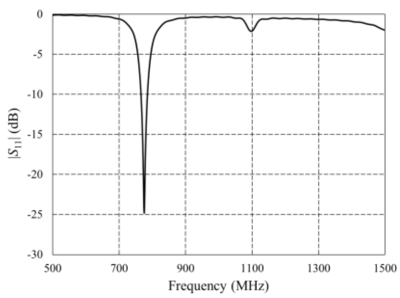


Figure 7: $|S_{11}|$ (dB) of the initial antenna.

Figure 7 shows the simulated result of the initial antenna. It is found that $|S_{11}|$ (dB) is ≤−10 dB, covering the frequency of 770-790 MHz which is lower than that of the required frequency of 925 MHz around 135 MHz. Moreover, it can produce the other resonance frequency at 1.1 GHz because, the feeding point of the antenna that does not feed at the centre point of TM_{010}^{x} mode. Then, the antenna might have more than one mode to resonant (second order). Although the antenna is fed at the centre point, the others mode is still occurred such as the higher mode.

It is necessary to improve the antenna parameters to achieve $|S_{11}|$ (dB) which covers the desired frequency band. Hence, in the next step parameter w and l are studied.

B. Parametric Studies of w and l

In section A, it can be seen that the frequency response of the initial antenna is lower than of the desired frequency due to the extremely width and height of *w* and *l*. In this section, *w* and *l* are varied by decreasing of *w* and *l* in order to adjust the $|S_{11}|$ (dB) moving to a higher frequency. *w* and *l* are varied from 152 mm to 132 mm and 162 mm to 142 mm, respectively.

Figure 8, it is found that when *w* =152 mm and *l* =162 mm $|S_{11}|$ (dB) is ≤ -10 dB moving to the frequency band of 770-820 MHz. However, it still lowers the expected frequency band. Then, *w* =142 mm and *l* = 152 mm are varied to search for the appropriated $|S_{11}|$ (dB) which covers the frequency band of UHF RFID of Thailand. In this step, the frequency band can be obtained from 911 to 942 MHz and cover. However, when *w* of 132 mm and *l* of 142 mm, impedance bandwidth covers the frequency band of 1000-1047 MHz, which is higher than that of the desired frequency band approximately 54 MHz. Hence, the *w* and *l* with 142 mm and 152 mm are selected. The axial ratio (dB) is illustrated in Figure 9.

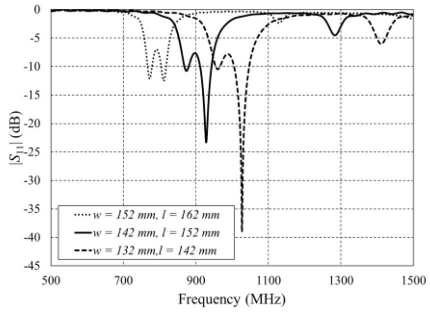


Figure 8: $|S_{11}|$ (dB) of the antenna for various of *w* and *l*.

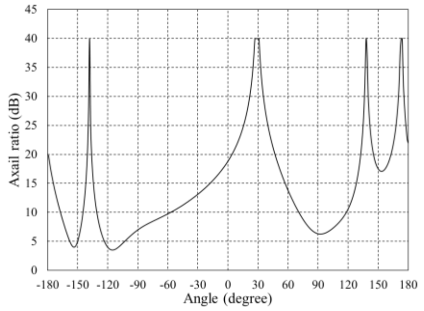


Figure 9: Axial ratio (dB) of the antenna when *w* = 142 mm and *l* = 152 mm.

From Figure 9, when *w* = 142 mm and *l* = 152 mm the axial ratio (dB) at 0º (main beam) is equal to 18 dB, while the standard of the axial ratio for a circular polarised antenna must be ≤ 3 dB. It is shown that the AR is considerably high. Hence, the AR should be improved.

C. Parametric Studies of Corner-Truncated Rectangular Corner

The truncated-corner is a well-known technique that can produce a circular polarisation as described in the antenna design book [8]. Therefore, it is the selected techniques to improve the circular polarisation of the proposed antenna in this paper. Corner-truncated rectangular length (t_{sq}) is a technique to improve an axial ratio. A squared shape truncated the diagonal corners of the radiating patch. The width and length of the patch were fixed. The corner-truncated patch is illustrated in Figure 10.

The simulated axial ratio (dB) for various t_{sq} is shown in Figure 11. With t_{sq} of 5 mm, the axial ratio (dB) at main beam is 16.7 dB and t_{sq} of 15 mm the axial ratio (dB) is 11.2 dB. It can be seen that when t_{sq} is increased the trend of the axial ratio is decreased.

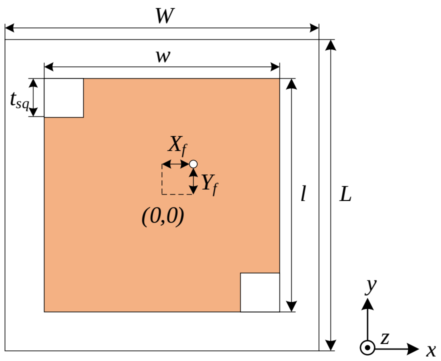


Figure 10: The antenna structure for various t_{sq} from top view.

While t_{sq} = 20 mm and 25 mm, axial ratio (dB) are 3.5 dB and 5.5 dB, respectively. It is found that the axial ratio (dB) is rebounded when t_{sq} = 25 mm. However, at t_{sq} of 20 mm, the axial ratio is the most nearly 3 dB.

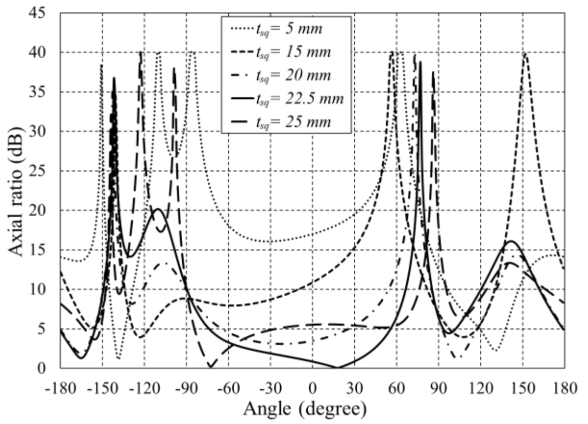


Figure 11: Axial ratio (dB) when various t_{sq}.

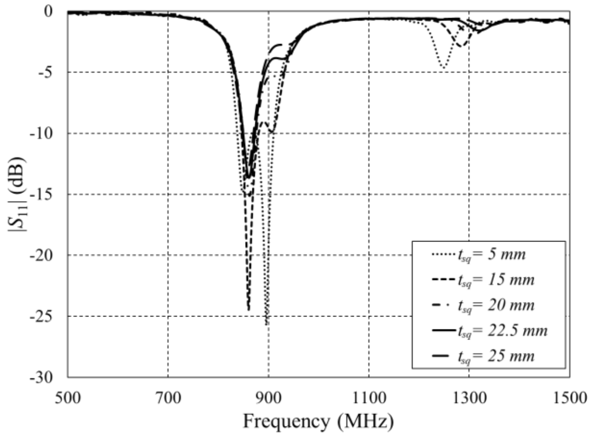


Figure 12: $|S_{11}|$ (dB) for various t_{sq}.

Then, t_{sq} is finely adjusted to improve the axial ratio (dB) by using the centre of the values between 20 mm and 25 mm which is 22.5 mm. When t_{sq} = 22.5 mm, the desired axial ratio (dB) with 0.87 dB is obtained as shown in Figure 11. The simulated $|S_{11}|$ (dB) for various t_{sq} is presented in Figure 12. It can be seen that the trends of $|S_{11}|$ (dB) is moved to a lower frequency and it is less than the frequency band of Thailand UHF RFID. Therefore, the operating frequency must be improved in the next step.

D. Parametric Studies of a Slant Truncated Corner

This section is to study a parametric of t_{sl} or a width of an oblique cutting corner as shown in Figure 13. t_{sl} is investigated by varying the space (equilateral triangle space) from 11 mm to 27 mm. It can be seen that, when the corners were cut by an oblique angle, $|S_{11}|$ (dB) is changed. When t_{sl} is equal to 11 mm, 15 mm, 19 mm, 23 mm and 27 mm, the $|S_{11}|$ (dB) which is less than -10 dB are covered the frequency band of 865-893 MHz, 879-914 MHz, 891-961 MHz, 944-986 MHz and 960-999 MHz, respectively. It is found that when t_{sl} is increased, the trend of the $|S_{11}|$ (dB) is move to the higher frequency. However, at t_{sl} of 19 mm, the operating frequency of UHF RFID for Thailand standard is obtained as shown in Figure 14

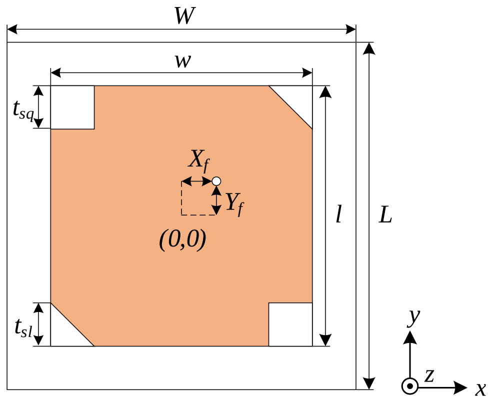


Figure 13: The antenna structure for various t_{sl} from top view.

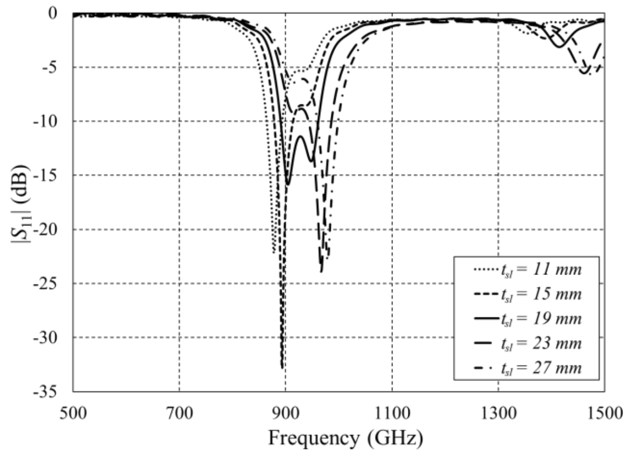


Figure 14: $|S_{11}|$ (dB) for various t_{sl}.

Meanwhile, the AR (dB) at boresight of each varied t_{sl} causes the AR (dB) which are less than 3 dB. When t_{sl} equals 11 mm, 15 mm, 19 mm, 23 mm and 27 mm, the AR (dB) are respectively 1.13 dB, 1.08 dB, 1.05 dB, 1.38 dB and 1.84 dB. It is found that t_{sl} = 19 mm is the proper parameters as shown in Figure 15.

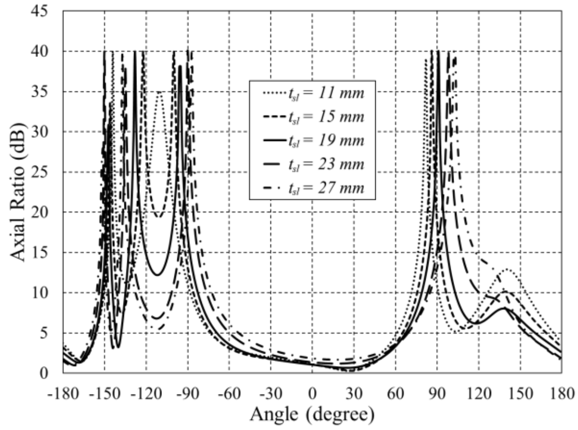


Figure 15: Axial ratio (dB) for various t_{sl}.

E. Optimization of a Silt

Finally, the slit technique is used to optimise the proposed antenna characteristics by using parameter variations of the length of the slit (s_l). The slit is added at the centre of the opposite edges of the radiating patches as shown in Figure 16. When the width of the slit (w_{sl}) is defined to 4 mm, and the length of the slit (s_l) is optimised.

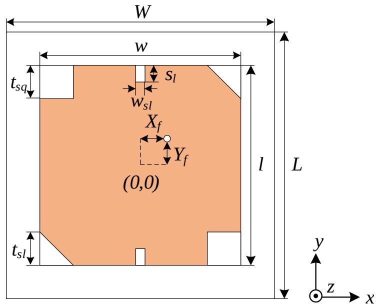


Figure 16: The antenna structure when various s_l from top view.

Figure 17 is shown the $|S_{11}|$ (dB) when the s_l is varied. It can be seen that s_l has a few effects to $|S_{11}|$ (dB). When the length of slits is equal to 1 mm, 7 mm and 13 mm, the $|S_{11}|$ (dB) are cover the frequency band of 892-951 MHz, 892-950 MHz and 894-938 MHz, respectively. All variation of parameter s_l is cover the frequency band of Thailand UHF RFID. The largest bandwidth can be achieved when s_l = 1 mm. On the other hand, s_l of 7 mm can obtain the bandwidth which is less than that of s_l of 1 mm only 1 MHz.

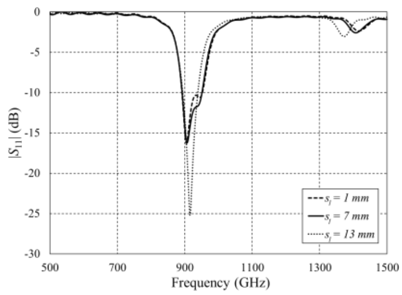


Figure 17: $|S_{11}|$ (dB) when various s_l.

The AR (dB) for various is showed in Figure 18. s_l of 13 mm provides the AR (dB) at boresight with 5.61 dB. It is found that the AR (dB) which is less than 3 dB cannot be achieved when s_l =13. While, s_l are 1 mm and 7 mm produce the desired AR (dB) at boresight with the AR of 1.10 dB and 0.81 dB, respectively. While s_l = 7 mm can provide the best of AR (dB), covering the frequency band of UHF RFID in Thailand standard.

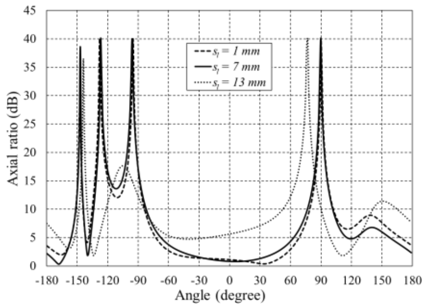


Figure 18: Axial ratio (dB) when various s_l.

V. CONCLUSIONS

In this paper, a circularly polarised rectangular patch antenna using the square shape, and slant truncated corner and slit techniques has been presented for Thailand UHF RFID applications. By using a single feeding structure, the optimised antenna achieved the desired performances over the UHF band of 914.4 -929.9 MHz with the impedance bandwidth of 15.5 MHz or 1.68%. The gain is of higher than 8.83 dBic, AR of less than 3 dB, and $|S_{11}|$ (dB) of less than -10 dB. The proposed antenna has the unidirectional pattern covering the operating frequency range of Thailand UHF RFID with the 3-dB AR beamwidth of larger than 65º.

Therefore, the antenna characteristics are appropriated for Thailand UHF RFID applications. Furthermore, the reading-range measurement has validated that the proposed antenna can be incorporated into RFID reader in the frequency band of Thailand to achieve the desired reading ranges. The proposed antenna is easy to fabricate and low cost.

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