UHF RFID Reader Antenna with High Gain

I.Ismail, S.M.Norzeli

Abstract— **An E-shaped microstrip single layer patch antenna with high gain is designed and analyzed for RFID (Radio Frequency Identification) reader applications. It has one port excited with microstrip line feed mechanism. To obtain an optimum peak gain, the effects of adding parasitic elements and slots are respectively investigated. The physical parameters of the novel structure as well as its partial ground plane are analyzed and optimized using commercial computer simulation technology (CST) simulation packages. Return loss (S_{11}), voltage standing wave ratio (VSWR), directivity and gain are carried out. The results show that the proposed antenna has good impedance and radiation characteristics over the required bandwidth, 860-960 MHz (UHF RFID band). The return loss of the optimized E-shaped microstrip patch antenna is below 10dB over the UHF frequency band. The proposed antenna is very promising for various modern communication applications.**

Index Terms*— *E-shaped, microstrip patch antenna, computer simulation technology (CST), return loss (S_{11}), voltage standing wave ratio (VSWR).

I. Introduction

RADIO frequency identification (RFID) is a technology that provides wireless identification and tracking capability and is more robust than a bar code. Now RFID system in the ultra high-frequency (UHF) bands (860-960 MHz) finds many applications in various areas such as electronic toll collection, asset identification in retail item management, access control, animal tracking, and vehicle security [1-5]. This is because the UHF band can provide high data transfer rate and broad readable range.

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I.Ismail Ismarani Ismail is a Senior lecturer at the Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM).
S.M.Norzeli is a PhD student at Faculty of Electrical Engineering, Universiti Teknologi Mara. (email:syamimi.uitm@gmail.com)

RFID system generally consists of a reader, a tag and a data processing system. In RFID system, the role of antennas (for reader and tag) is very important. The antenna allows the chip to transmit the information that is used for identification. Commonly, the UHF tag antennas are linearly polarized. Therefore, reader antenna should have circular polarization (CP) characteristic since the tag antenna can be arbitrary positioned on the target. The size reduction and gain enhancement of UHF RFID reader antenna have been the key issues in the system developer [6, 7].

A reader (now more typically referred to as an RFID interrogator) is basically a radio frequency (RF) transmitter and receiver, controlled by a microprocessor or digital signal processor. An RFID reader emits electromagnetic signals where an RFID tag draws power from it. This power is then used to energize the microchip's circuits. The chip then modulates the waves and sends back this modulated wave to the reader. This process is called backscattering where the reader sees the tag. The reader antenna must have high gain and directivity. Every additional 3 dB of reader antenna gain increase the tag range approximately by 40% [2, 8].

In telecommunications, microstrip patch antenna is widely used because of their several advantages such as light weight, low volume, low fabrication cost and capability of dual or triple frequencies operations. However microstrip antenna suffers from numbers of disadvantages. Narrow bandwidth is a serious limitation of these microstrip patch antenna [9].

In this paper, an E-shaped microstrip patch antenna with high gain for RFID reader and wireless communications is designed to resonate on the Ultra High Frequency (UHF) RFID bands of 860MHz-960Mhz. The effects of adding parasitic elements and slots are respectively investigated. The theoretical simulations are performed using CST software.

II. ANTENNA DESIGN CONFIGURATION

When two parallel slots are incorporated into the rectangular microstrip patch antenna, it becomes an E-shaped microstrip patch antenna. The E-shaped microstrip patch antenna is simpler in construction. In this design, the center frequency of antenna is chosen as fo = 915MHz. The front view of the design is shown in Fig.1 and the side view of the design is shown in Fig.2.

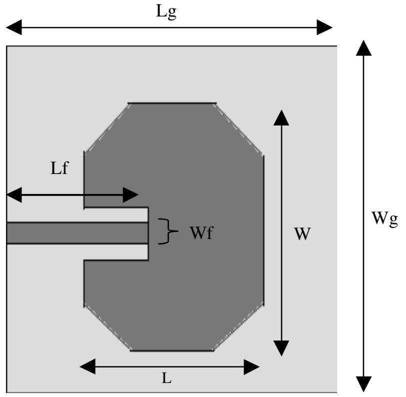


Fig.1: Front view of the E-shaped microstrip patch antenna

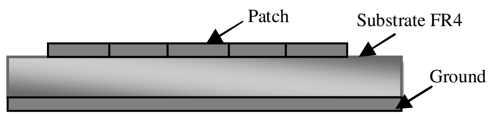


Fig.2: Side view of the E-shaped microstrip patch antenna

The design of E-shaped microstrip patch antenna consist of substrate width (Wg), substrate length (Lg), antenna width (W), antenna length (L) and a feed line which have impedance of 50 ohm where its feed width (Wf) and feed length (Lf) are introduced symmetrically with respect to the probe position. Dielectric substrate materials are used for design E-shaped microstrip patch antenna. A FR4 (loss-free) substrate was used while designing the antenna. The substrate used has thickness (h) of 1.6 mm, dielectric constant (ε_r) of 4.7 and loss tangent of 0.019. PEC material was used for patch and ground of the antenna with the thickness of 0.035mm.

There were equations used to calculate Lg, Wg, L, W, Wf and Lf. The calculations used are given by equations (1)-(7) [10]:-

Patch width,

$$W = \frac{c}{2fo}\sqrt{\frac{\varepsilon r + 1}{2}} \tag{1}$$

where;
f_o=operating frequency
ε_r=dielectric constant
c=speed of light ($3\text{x}10^8$)m/s

Effective dielectric constant,

$$\varepsilon\text{reff} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\sqrt{1 + 12\frac{h}{W}} \tag{2}$$

Effective length,

$$Leff = \frac{c}{2\,fo\,\sqrt{\varepsilon reff}} \tag{3}$$

Length extension,

$$\Delta L = 0.412h\,\frac{(\varepsilon reff + 0.3)(W/h + 0.264)}{(\varepsilon reff + 0.258)(W/h + 0.8)} \tag{4}$$

where;
h=substrate thickness

Actual patch length,

$$L = \text{Leff} - 2\Delta L \tag{5}$$

Ground plane extension Lg≠Wg,

$$Lg = 6h + L \tag{6}$$

$$Wg = 6h + W \tag{7}$$

where;
h=substrate thickness

Microstrip feed line use for patch antenna determine to be fed for 50 ohm for line impedance (Zo). Length and width for microstrip feed line calculated using Equations [10] (8) and (9):-

Feed length,

$$Lf = \frac{L}{2\sqrt{\varepsilon reff}} \quad (8)$$

Feed width,

$$Zo = \frac{60}{\sqrt{\varepsilon reff}} \ln \left[\frac{8h}{Wf} + \frac{Wf}{4h}\right] \quad (9)$$

where;
h=substrate thickness
Zo=line impedance

Table I shows the calculation result of E-shaped microstrip patch antenna operating at center frequency 915 MHz.

TABLE I
Calculation for design of E-shaped microstrip patch antenna

Parameter	Value (mm)
Wg	108.3
Lg	86.3
W	98.7
L	76.7
Wf	1.45
Lf	28.9

The substrate used for E-shaped microstrip patch antenna is FR4 (loss free). FR4 was chosen because it is cheap, greater design flexibility, ease of fabrication and reduce in weight [11]. A FR4 substrate was selected to obtain a compact radiation structure.

The Front-to-Back Ratio is a parameter used in describing the directional radiation patterns for antenna. If an antenna has a unique maximum direction, the front-to-back ratio is the ratio of the gain in the maximum direction to that in the opposite direction (180 degrees from the specified maximum direction). This parameter is usually given in dB [10]. Having a high front to back ratio also may help with forward gain (gain in the direction that the front of the antenna points to) because some of the signal that may otherwise escape out the back of the antenna and be wasted is now reflected and captured by the driven element(s).

Return loss (S_{11}) also described as power relations and involves the reflected power. The return loss which can be recorded with a network analyzer provides immediate access to the reflection coefficient magnitude and thus the degree of impedance mismatch between the transmission line and generator.

Voltage Standing Wave Ratio (VSWR) was measured to indicate the degree of mismatch between a transmission line and its load, or evaluate the effectiveness of impedance matching efforts. The ideal value of VSWR is 1, but typically the value ranges from 1.5 to 2.5.

III. RESULTS AND DISCUSSIONS

From the original design of E-shaped microstrip patch antenna, it has been altered to obtain the required specification at center frequency (915MHz). The parameters that have been optimized were patch width, substrate length and width. Table II below shows the result simulation obtained from E-shaped microstrip patch antenna before being optimized.

TABLE II
Parameter values from design of E-shaped microstrip patch antenna

Parameter	Value
Zo	50.269 Ω
Gain	3.324 dB
S_{11}	6.721 dB
VSWR	2.263

A final result of E-shaped microstrip patch antenna has been optimized for S_{11}, VSWR, gain, front-to-back ratio, beamwidth and bandwidth. Fig.3 showed an optimized E-shaped microstrip patch antenna.

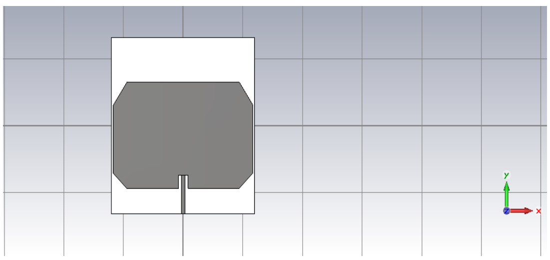


Fig.3: Optimized E-shaped microstrip patch antenna

From Fig.4 and Fig.5, it can be observed that S_{11} value has met the desired value (<10dB) which is 11.116 dB. As well for the VSWR value of 1.77which is approaching to 1.

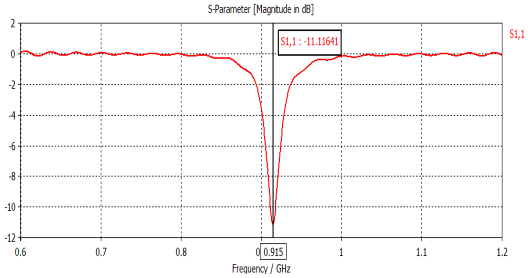


Fig.4: S_{11} (dB)

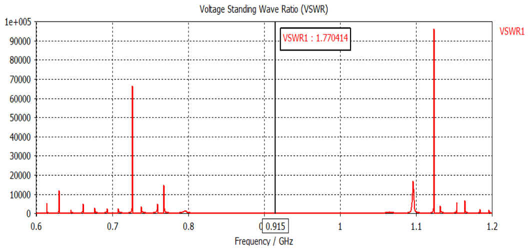


Fig.5: VSWR

Fig.6 and Fig.7 gives the view of gain in far-field and polar plot. It is observed from far-field view the value of gain is 5.799dB and approaching to 6dB. Beamwidth is the angle between the two points (on the same plane) at which the radiation falls to "half power" or 3dB below the point of maximum radiation [10]. From Fig.7, the beamwidth was carried out and the value was 89.4 degree when the main direction was at 0 degree. Front-to-Back ratio of the antenna can be obtained from gain polar plot view in Fig.7. It was observed that the F/B ratio of the antenna is 5.8 dB.

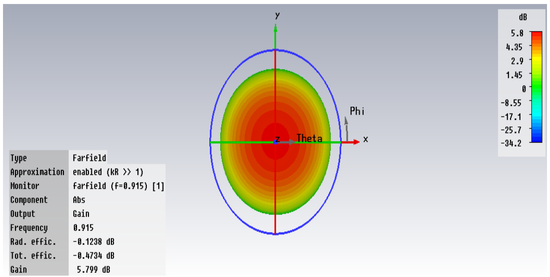


Fig.6: Far-field view for Gain

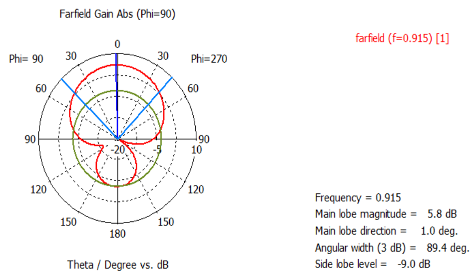


Fig.7: Polar Plot for Gain

A. *PARAMETRIC STUDIES OF EFFECT ON GAIN*

In this section, the proposed antenna is redesigned to investigate the effect on gain. Parametric studies of the proposed antenna are presented to provide more detailed information about the antenna design and optimization. The parameters under study include adding parasitic elements and slot. To better understand the influence of the parameters on the performance of the antenna, only one parameter at a time will be varied, while others are kept unchanged unless especially indicated.

1) *Adding Parasitic Elements*

Fig. 8 below shows the proposed antenna adding with parasitic elements. Two rectangular are placed at the left and right of the patch. The rectangular have a minor truncated at the top and PEC material was used with the thickness of 0.035mm.

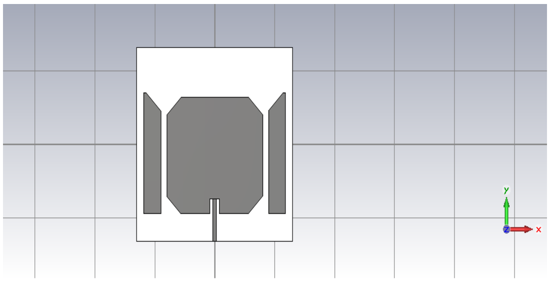


Fig.8: Adding Parasitic Elements

From the simulations result, it was observed that gain is increased to 5.966 dB. Fig.9 and Fig.10 below show the gain in far-field and polar plot. From Fig.10, the beamwidth was carried out and the value was 90.3 degree when the main lobe direction was at 0 degree.

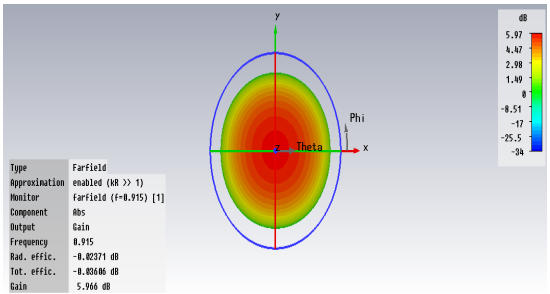


Fig.9: Far-field view for parasitic elements Gain

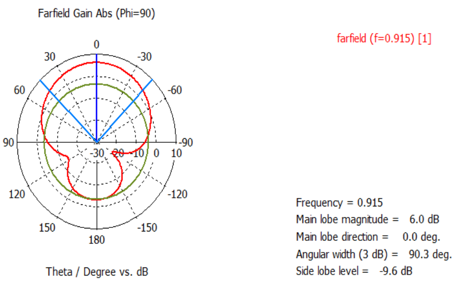


Fig.10: Polar plot for parasitic elements Gain

From Fig.11, it can be observed that S_{11} value has met the desired value (<10dB) which is 25.465 dB.

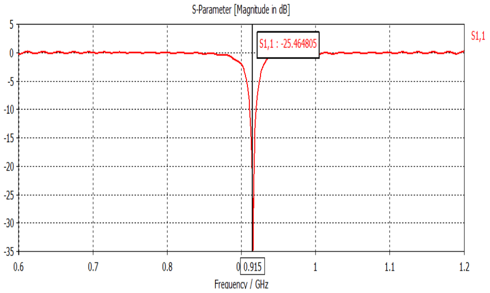
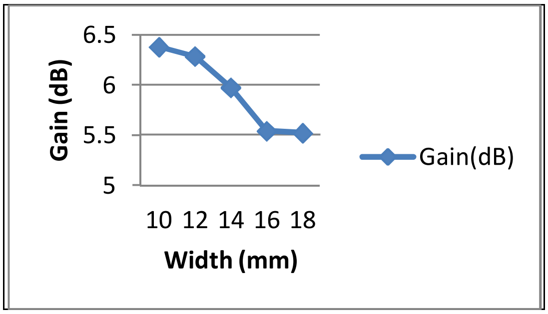


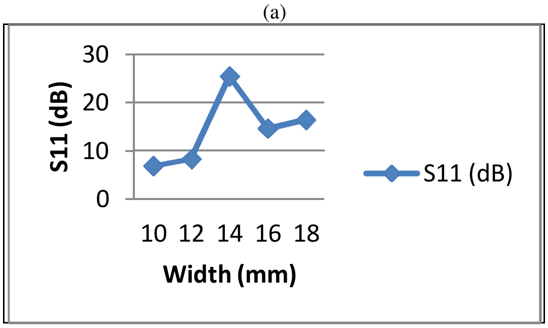
Fig.11: S_{11} (dB)

1) Width of Parasitic Elements (*w*)

Fig. 12 shows the antenna performance curve for different values of w: 10 mm, 12 mm, 14 mm, 16 mm, and 18 mm. It is clearly observed that



(a)



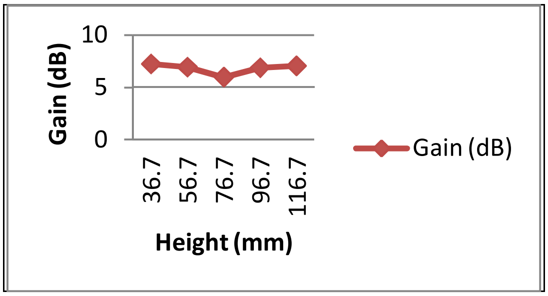
(b)

Fig.12: Effect of width of parasitic elements (*w*) on the antenna performance. (a) Gain. (b) S_{11}

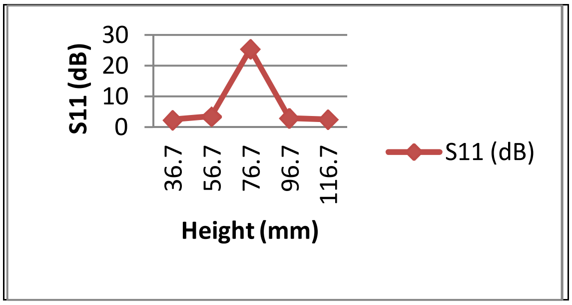
the variety of the width of both left and right rectangular parasitic elements have a significant effect on gain and $S_{11}$of the antenna. As the Fig. describes, decreasing w causes higher gain values and when *w*= 10mm and 12mm, S_{11} value doesn't meet desired value (<10dB) which was 6.92 dB and 8.35 dB. Results have revealed that the best performance is obtained when *w* = 14 mm.

2) *Height of Parasitic Elements (h)*

The effect of varying the height (*h*) of parasitic elements on gain and S_{11} of the antenna is shown in Fig.13.



(a)



(b)

Fig.13: Effect of height of parasitic elements (h) on the antenna performance. (a) Gain. (b) S_{11}

It is clearly known from the Fig.s that only h= 76.7mm has met the required specification of S_{11} (<10dB). Results have revealed that the best performance is obtained when *h* = 76.7mm.

3) *Adding Slots*

The design of adding parasitic elements were improved by slot is cut on the patch. Fig. 14 below shows the improved design. The rectangular shaped slot in the middle of the patch and slot are vacuum.

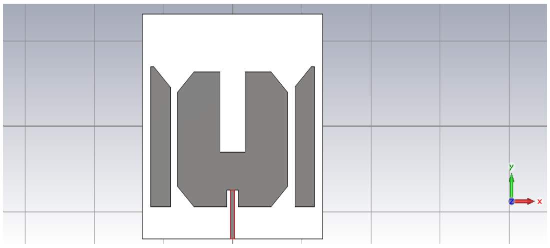


Fig.14: Improved design with slot

By improved the design by slots is cut on the patch, consequently the gain has increased to 6.145dB. Fig.15 and Fig.16 below give the view of far-field and polar plot gain. From Fig.16 the beamwidth was carried out and the value was 90.4 degree when the main lobe direction was at 0 degree.

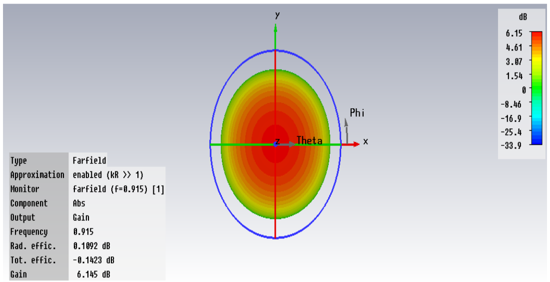


Fig.15: Far-field view for slot Gain

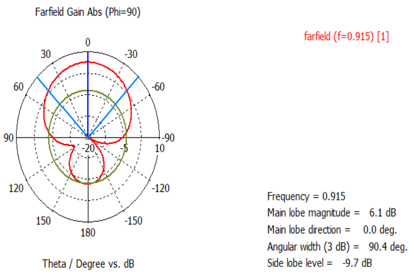


Fig.16 Polar plot for slot Gain

From Fig.17 below, it can be observed that S_{11} value has met the desired value (<10dB) which was 12.63 dB.

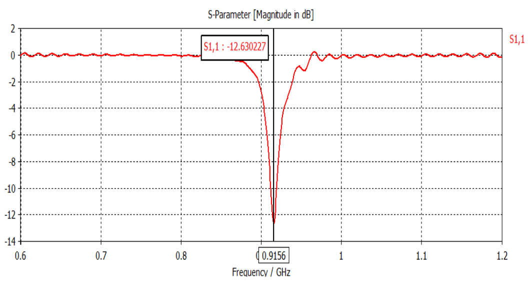
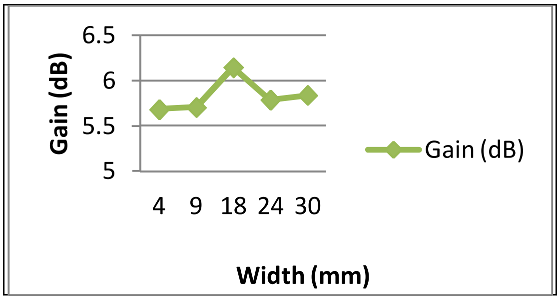


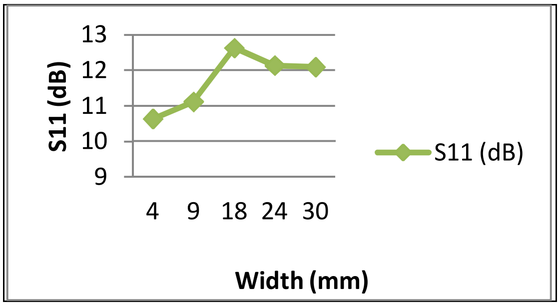
Fig.17: S_{11} (dB)

4) *Width of Rectangular Slit (w_1)*

In this part of parametric study, we change *w*1 to show effects of variation in gain on the antenna performance. Fig. 18 exhibits the simulation results for various values when other parameters are kept unchanged.



(a)



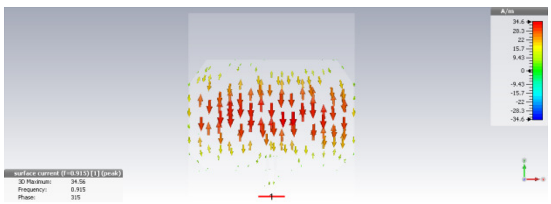
(b)

Fig.18: Effect of width of slot (*w1*) on the antenna performance. (a) Gain. (b) S_{11}

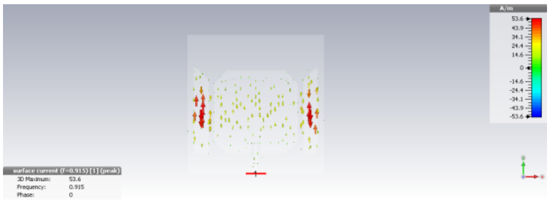
It is found that the effect of *w*1 on antenna performance is, decreasing *w*1 causes lower gain values and mounted shaped of S_{11}. It can be observed that the best S_{11} value is 12.63. Results have revealed that the best performance is obtained when *w* = 18mm.

B. *SURFACE CURRENT DISTRIBUTION*

The surface current distribution on the radiating element is shown in Fig. 19 for a frequency 915MHz. The Fig. clearly shows the current of three different antennas. The red arrows show the strongest current distributed in patch of antenna.



(a)



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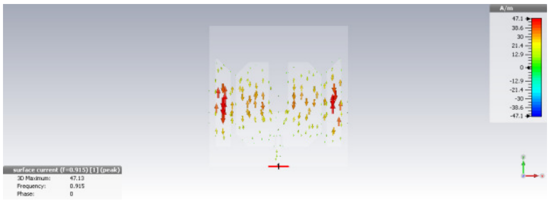

(c)

Fig.19: Surface Current Distribution on the antenna performance. (a) Without change (b) Adding Parasitic Element (c) Improved by Slot

IV. CONCLUSION

Microstrip antenna has become a rapidly growing area of research. Their potential applications are limitless, because of their light weight, compact size and ease of manufacturing. In this paper, a circularly polarized (CP) E-shaped microstrip single layer patch antenna with high gain been designed and adding parasitic elements and slot are investigated for UHF RFID reader. The return loss was below 10dB for 915 MHz. By adding slot, the value of gain becomes higher which was 6.681dB. The antenna is thin and compact with the use of low dielectric constant substrate material. These features are very useful for worldwide portability of wireless communication equipment.

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Ismarani Ismail is a Senior lecturer at the Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM). She holds an Electronics Manufacturing Engineering from University of Salford, United Kingdom and Bachelor of Engineering degrees in Electrical and Electronics Engineering from John Moores University, Liverpool, UK. Her main research interest is in Radio Frequency Identification system, electronics product development, system development and electronic and electrical manufacturing processes. She has published in a number of national and international journals. In addition to teaching, she supervises and advises Masters and Doctoral students.

Syamimi .Mohd Norzeli obtained her degree of B.Eng. (Hons) Electrical Engineering from Universiti Teknologi Mara (UiTM) Shah Alam. Currently she is pursuing her PhD in the area of RFiD Technology. Her PhD work is focusing in developing UHF RFiD reader antenna.