Parametric Study of Modified U-shaped Split Ring Resonator Structure Dimension at Ultra-Wide-band Monopole Antenna

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***Abstract*—This paper discusses the parametric study work U-shaped split ring resonator (SRR) structure effect on the ultra-wide-band (UWB) monopole. Five different stages are done, consisted from Design *A* to Design *E*, with three stages are considered with parametric study – Design *B*, Design *C*, and Design *D*. Firstly, Design *A* represent the basic UWB monopole antenna without SRR structure while the last design, Design *E* shows the proposed UWB monopole antenna with modified SRR structure. The Design *E* successfully resonate at first resonant frequency of 6.272 GHz with return loss performance of – 25.91 dB while resonate at second resonant frequency at 7.82 GHz with a return loss of – 26.165 dB. This antenna operates at UWB range frequency from 2.572 GHz to 10.746 GHz of with bandwidth performance of 8.174 GHz. It shows that a 0.972 GHz range of band-notch frequency bandwidth, starting with 5.028 GHz to 6.0 GHz.**

***Index Terms*—Parametric Study; Band-Notch; Split Ring Resonator; Return Loss; UWB Antenna.**

I. INTRODUCTION

The rapid growth of wireless communication desires the need of dual-band, tri-band or multiband antenna. Many techniques are done previously to cater this needed. Besides that, the ultra-wide-band (UWB) band covers the frequency between 3.1 GHz and 10.6 GHz. Several researchers apply the antenna design with UWB technique to create an ultra-wide-band effect such as in [1-4]. Azizi designed a staircase patch antenna technique for UWB frequency range that functions for human arm model [5] while in his other works it applies complimentary patch technique to create the UWB on the nerve fibre action potential of the human body [6].

Another work on UWB antenna is by Elobaid [7] that design for future wireless networks on flexible polymer-fabric tissue in frequency band range between 2.2 GHz and 25 GHz. On the other hand, Lu [8] proposed the CPW-fed UWB antenna that has band notches function at 5.1-5.9 GHz for WLAN rejection. The microstrip patch antenna technology is the basic type in fabricating the antenna because of many advantages such as the lightweight, and easy to construct. This microstrip patch using FR-4 also suitable for UWB technique without using a high-cost substrate such as Roger Duroid substrate.

In this work, several parametric studies of a different dimension of the split ring resonator at UWB monopole antenna had been done. The parameters such as return loss, resonant frequency and antenna gain are considered to observed the best performance of antenna design.

II. SPLIT RING RESONATOR DESIGN

The split ring resonator structure was firstly presented in 1999 by Pendry [9] and 2000 by Smith [10] to create a material with negative permeability. This structure sometimes called left-handed material (LHM) structure or metamaterial. This SRR structure potentially to reduce the size and function to create tri-band antenna effect [11]. In his paper, the researcher design tri-band fractal SRR structure at WLAN 2.4 GHz, WiMAX 3.5 GHz and WLAN 5.2 GHz antenna. In other paper of Rajasekhar [12], he proposed a triple-band monopole SRR antenna for WiMAX, WLAN and RFID applications. Yang [13] introduced the CPW-fed slot antenna with SRR structure that covers WLAN and WiMAX application with a bandwidth between 1.96 GHz and 4.33 GHz while at another part between 5.05 GHz and 7.23 GHz. Other works on SRR antenna is stated in [14-17]. There is also the combination technique of UWB antenna with embedded of SRR structure to affect the wider bandwidth and miniaturise the size of the antenna [18-22].

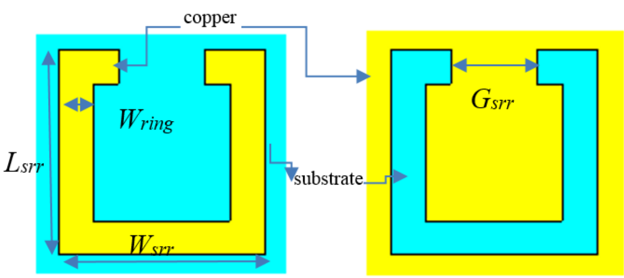

Figure 1: The design of the SRR, (a) basic SRR, (b) complimentary SRR

The SRR consist of several types such as the basic SRR or sometimes called the edge couple SRR, the broadside couple SRR, spiral type of SRR and other types called open shaped SRR structure. Beside apply in the antenna, this structure is found in several applications such as microwave absorber, RF filter, oscillator and sometimes used as the structure in the frequency selective surface. Figure 1 shows the basic SRR and complimentary SRR (C-SRR). A basic SRR consist of a copper ring (represent the inductor) that have a gap between ring (represent the capacitor effect). A complimentary SRR is the mirror situation of the basic SRR that contain an FR-4 substrate base ring while the outer part is copper based with a thickness of 0.035 mm. Table 1 shows the dimension of the SRR.

Table 1
The Dimension of the SRR Structure

Parameter of the antenna	Symbol	Dimension (mm)
SRR width	W_{srr}	6.0
SRR length	L_{srr}	6.0
SRR gap	G_{srr}	2.5
SRR ring width	W_{ring}	1.0

III. ANTENNA DESIGN

This section describes the parametric study of different stages of UWB monopole antenna design, starting with the basic antenna of Design *A* to last antenna design in Design E. The parameters that are considered in this section are the return loss with resonant frequency, the band-notch frequencies, gain and bandwidth of the antenna.

A. Design A – Basic UWB Monopole Antenna

This Design *A* is the starting basic design that consists a staircase patch antenna at the front side on 32.0 mm substrate width, W_s and 32.0 mm substrate length L_s while a 32.0 mm W_g x 16.0 mm L_g partial ground at the ground plane. The feedline dimension is 3.6 mm W_f x 17.0 mm L_f. Figure 2 shows the Design of basic UWB monopole antenna.

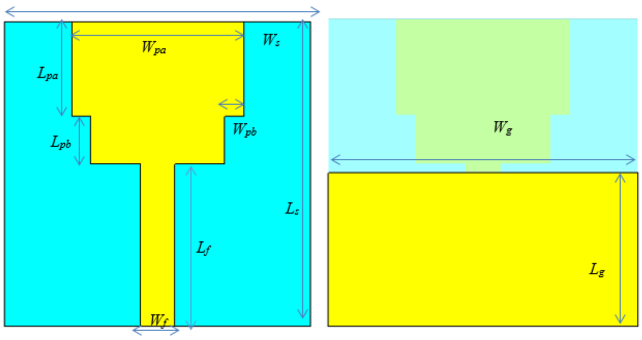

Figure 2: Design of basic UWB monopole antenna

Figure 3 shows the return loss of basic UWB monopole antenna. From the graph, it shows that this antenna covers operate frequency starting from 2.777 GHz to 10.847 GHz of frequency and covers in 8.07 GHz of bandwidth performance. At 4.916 GHz of resonant frequency had been achieved with – 29.992 dB of return loss while at 8 GHz and 9.124 dB, it shows the performance of – 25.401 dB and – 27.754 dB, respectively. The gain performance for all resonant frequency is 1.522 dB, 3.316 dB and 3.905 dB, respectively.

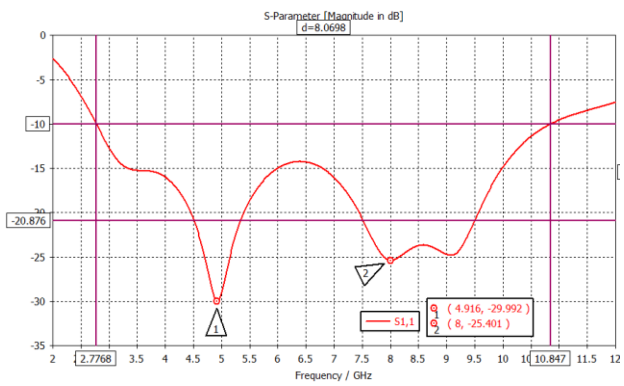

Figure 3: Return loss of basic UWB monopole antenna

B. Design B – UWB Monopole Antenna with Modified SRR Ring Gap

The second stage (Design *B*) of the design consist an addition of the basic SRR structure on the patch part UWB monopole antenna. The dimension of this UWB antenna stage is similar to the Design *A* except for the SRR part. The dimension of the SRR is 6.0 mm W_{srr} x 6.0 mm L_{srr} of a split ring resonator with SRR gap, G_{srr} of 2.5 mm. For the first parametric study is on the different dimension of the SRR gap, G_{srr} starting from 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm and 2.5 mm, with an increment of 0.5 mm. Figure 4 represents the Design of UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR ring top width, G_{srr}).

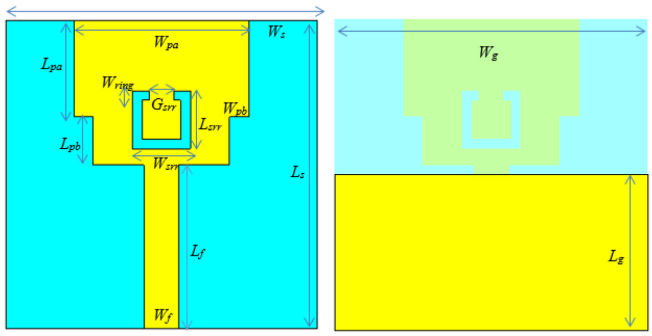

Figure 4: Design of UWB monopole antenna with modified U-shaped SRR (with parametric study of SRR ring gap, G_{srr})

Figure 5 illustrates the parametric study of return loss for UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR ring gap, G_{srr}). It shows that the increment of the SRR width will effect to shifted to higher band-notch frequency. For example, the G_{srr} = 0.5 mm have a band-notch at 4.988 GHz with - 8.222 dB of return loss, while it can be shifted to 5.732 GHz (return loss of - 6.893 dB**)** with the increment of G_{srr} to 2.5 mm. Besides that, it had been shown the increment of the ring gap effect to increase the bandwidth performance of the UWB monopole antenna. From Table 2, it shows the increment from 239.0 MHz to 370.0 MHz for the G_{srr} = 0.5 mm to G_{srr} = 2.5 mm.

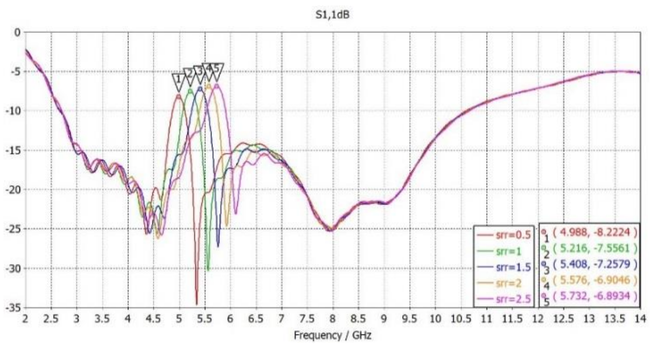

Figure 5: Parametric study of return loss for UWB monopole antenna with modified U-shaped SRR (with parametric study of SRR ring gap, G_{srr})

Table 2
UWB monopole antenna with SRR with different width of SRR ring gap, G_{srr}

Gsrr	Band-notch frequency (GHz)	Return loss (dB)	Frequency range (GHz), Bandwidth
0.5	4.988	- 8.222	4.871 - 5.110 (239 MHz)
1.0	5.216	- 7.556	5.081 - 5.362 (281 MHz)
1.5	5.408	- 7.258	5.240 - 5.558 (318 MHz)
2.0	5.576	- 6.905	5.397 - 5.741 (344 MHz)
2.5	5.732	- 6.893	5.535 - 5.905 (370 MHz)

C. Design C – UWB Monopole Antenna with Modified SRR Ring Top Width

Design *C* is consisting of the modified SRR ring top width, $W_{ringtop}$ at UWB monopole antenna. At this stage four increment in the parametric study had been work with $W_{ringtop}$ = 0.5 mm, 1.0 mm, 1.5 mm and 2.0 mm. Another dimension of the SRR structure is remaining as before. Figure 6 represents the Design of UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR ring top width, $W_{ringtop}$). Figure 7 shows the parametric study of return loss performance for UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR ring top width, $W_{ringtop}$).

Table 3 shows the UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR ring top width, $W_{ringtop}$). It shows that the increment of the $W_{ringtop}$ will effect to shifted the band-notch frequency to lower part, from 5.76 GHz to 4.738 GHz. It also shows that the bandwidth also reduces from 373 MHz to 335 MHz.

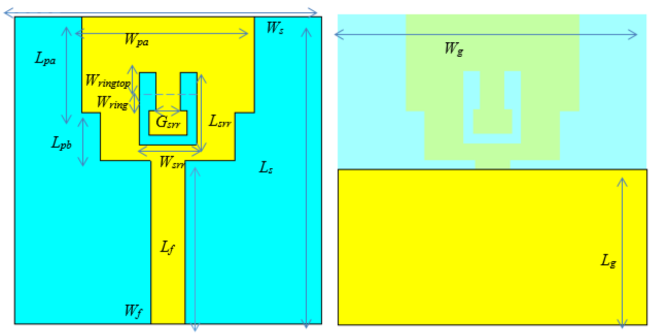

Figure 6: Design of UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR ring top width, $W_{ringtop}$)

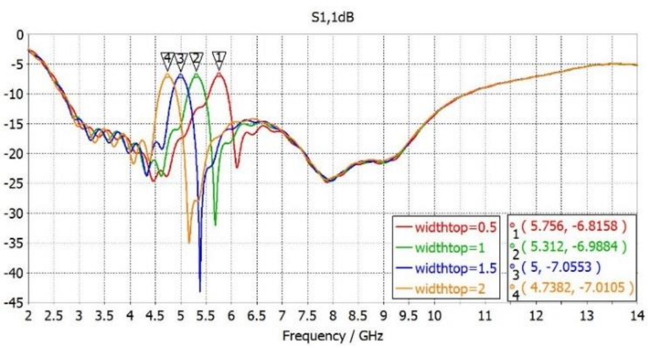

Figure 7: Parametric study of return loss for UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR ring top width, $W_{ringtop}$)

Table 3
UWB Monopole Antenna with Modified U-shaped SRR (with parametric Study of SRR Ring Top Width, $W_{ringtop}$)

$W_{ringtop}$	Band-notch frequency (GHz)	Return loss (dB)	Frequency range (GHz), Bandwidth
0.5	5.756	- 6.816	5.532 – 5.905 (373 MHz)
1.0	5.312	- 7.988	5.125 – 5.463 (338 MHz)
1.5	5.000	- 7.055	4.816 – 5.145 (329 MHz)
2.0	4.738	- 7.011	4.569 – 4.904 (335 MHz)

D. Design D – UWB Monopole Antenna with Modified Side Width

Next, the work followed by Design *D*, UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR side width, $W_{ringside}$, shown in Figure 8. In this case, four different dimensions of $W_{ringside}$ are considered, starting with 0.5 mm, 1.0 mm, 1.5 mm and 2.0 mm. Figure 9 shows the parametric study of UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR side width, $W_{ringside}$).

In Figure 9, it shows that the notch-band frequency had been reduced by increasing the $W_{ringside}$ dimension. In this case, $W_{ringside}$ = 0.5 mm shows the performance of the band-notch frequency at 5.216 GHz with a return loss of – 5.491 dB while the $W_{ringside}$ = 2.0 mm effect to shifted the band-notch frequency to 4.724 GHz with – 3.213 dB. Table 4 shows the UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR side width, $W_{ringside}$)

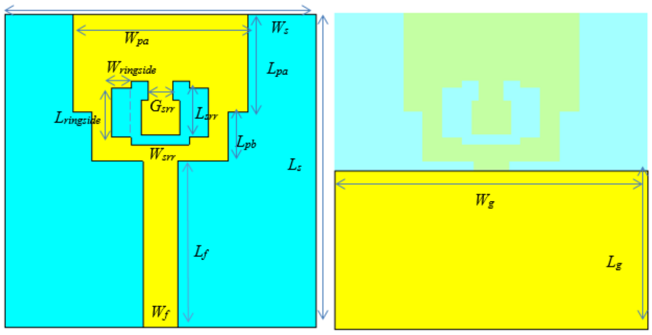

Figure 8: Parametric study of return loss for UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR side width, $W_{ringside}$)

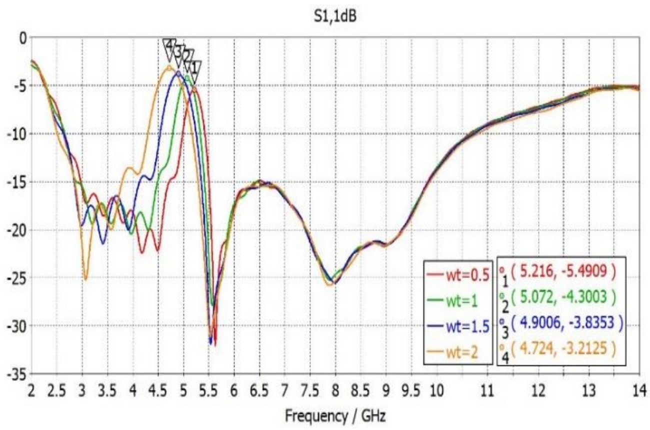

Figure 9: Parametric study of UWB monopole antenna with modified U-shaped SRR (with the parametric study of SRR side width, $W_{ringside}$)

Table 4
UWB Monopole Antenna with Modified U-shaped SRR (with Parametric Study of SRR Side Width, $W_{ringside}$)

$W_{ringside}$	Band-notch frequency (GHz)	Return loss (dB)	Frequency range (GHz), Bandwidth
0.5	5.216	- 5.491	4.986-5.422 (436 MHz)
1.0	5.072	- 4.300	4.794-5.335 (541 MHz)
1.5	4.901	- 3.835	4.543-5.250 (707 MHz)
2.0	4.724	- 3.213	4.311-5.164 (853 MHz)

E. Design E – UWB Monopole Antenna with Modified U-Shaped SRR

This is the last part of the UWB monopole antenna design with the 1.75 mm width x 2.0 mm length cut-off rectangular effect at the above part of the SRR. Figure 11 shows the Design of UWB monopole antenna with modified U-shaped SRR while Figure 11 shows the return loss of UWB monopole antenna with modified U-shaped SRR.

From the graph of Figure 11, it displays the proposed antenna is covers at the UWB range frequency. It had been radiated from 2.572 GHz to 10.746 GHz with 8.174 GHz of bandwidth. It also had been creating a band-notch frequency range between 5.028 GHz and 6.0 GHz with 0.972 GHz of bandwidth. A band-notch frequency peak is shown at 5.624 GHz with a return loss of – 3.639 dB. Besides that, this antenna has a two-different resonant frequency at 6.272 GHz 7.82 GHz with a return loss of – 25.91 dB and – 26.165 dB, respectively.

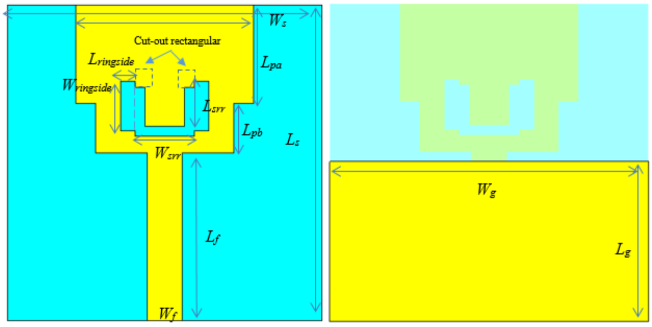

Figure 10: Design of UWB monopole antenna with modified U-shaped SRR

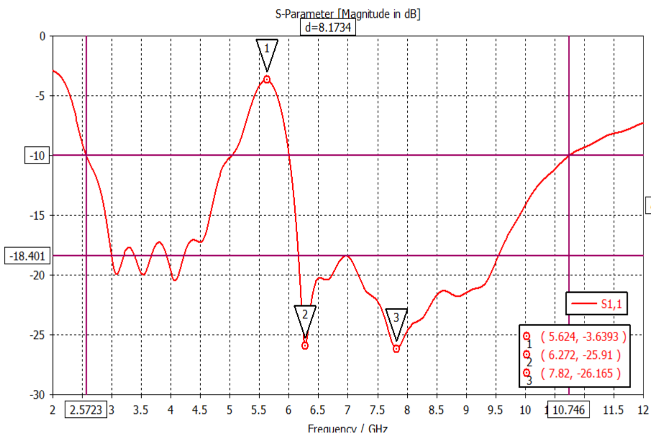

Figure 11: Return loss of UWB monopole antenna with modified U-shaped SRR

Table 5 represents the performance of the UWB monopole antenna with modified U-shaped SRR performance (Design *E*) while Figure 12 shows the antenna gain performance result of the UWB monopole antenna with U-shaped SRR. Figure 13 shows the radiation pattern of the UWB monopole antenna with U-shaped SRR at first resonant frequency at 6.272 GHz (0^0 and 90^0) and second resonant frequency at 7.82 GHz (0^0 and 90^0).

Table 5.
Performance of UWB Monopole Antenna with Modified U-shaped SRR Performance (Design *E*)

Frequency (GHz)	Return loss (dB)	Gain (dB)
Band-notch frequency, 5.624	- 3.639	0.251
Resonant frequency, 6.272	- 25.91	1.763
Resonant frequency, 7.82	- 26.165	3.213

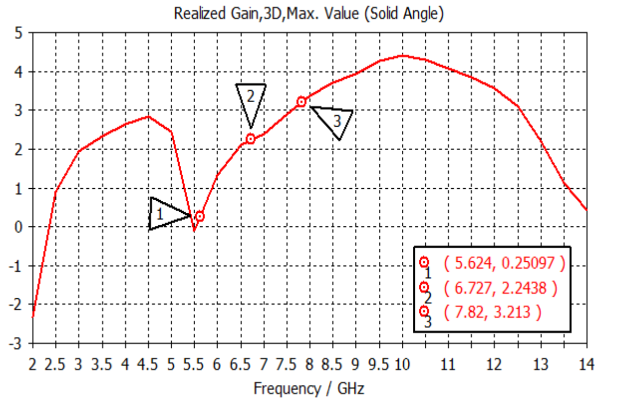

Figure 12: Antenna gain performance result of the UWB monopole antenna with U-shaped SRR

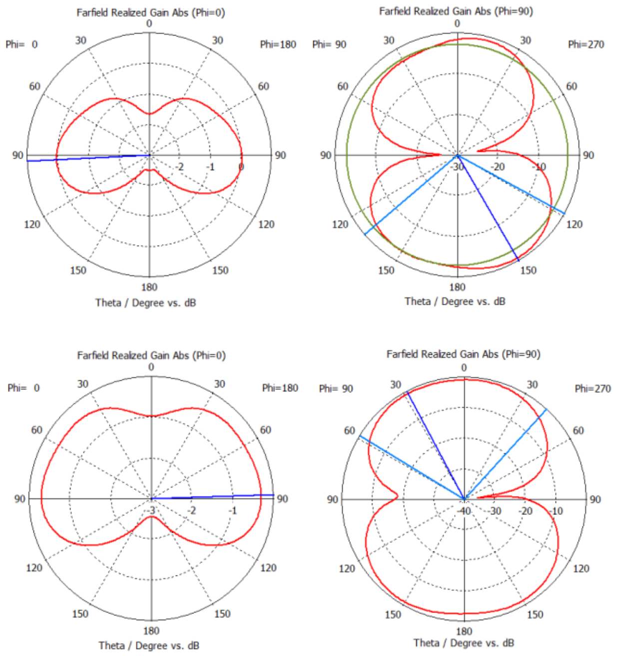

Figure 13: Radiation pattern of the UWB monopole antenna with U-shaped SRR, (a) first resonant frequency at 6.272 GHz (0^0 and 90^0), (b) second resonant frequency at 7.82 GHz (0^0 and 90^0)

Figure 14 represents the comparison of return loss for of UWB monopole antenna with modified U-shaped SRR (Design *A*, *B*, *C*, *D* and *E*). The location of SRR and other types of slot at the patch affected the location of the resonant frequency and band-notch frequency. It also affects the bandwidth performance and the gain of the antenna.

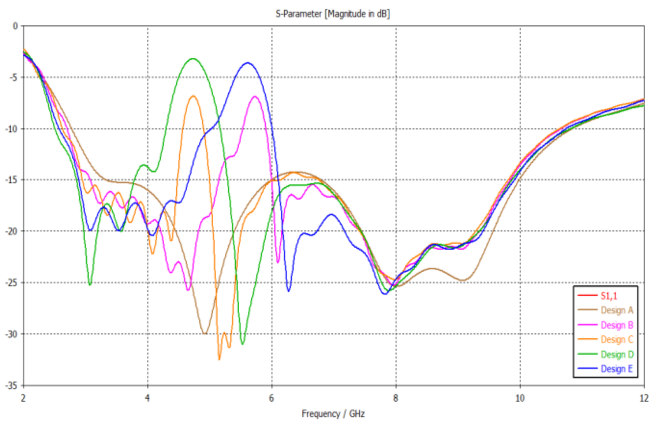

Figure 14: Comparison of return loss for of UWB monopole antenna with modified U-shaped SRR (Design *A*, *B*, *C*, *D* and *E*)

IV. CONCLUSION

The UWB monopole antenna with U-shaped SRR design had been done with several parametric studies works at SRR structure. The UWB effect had been done by the partial ground at the back part of the antenna. The increment and the reduction in the size of the SRR structure had been in effect to shift the location of the resonant frequency of the antenna. This technique also had a capability to control the size of the antenna by adjusting the patch antenna after the reduction or the increment of the resonant frequency. The important thing in this work is to create the band-notch frequency of the antenna, effect from the embedded of the SRR structure at the patch antenna.

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