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Beamwidth Optimization of Corner Reflector for RF Energy Harvesting from Solar and GPS L1 Satellite

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Abstract—Radio waves energy harvesting is interesting research in recent times. Development of antenna as the instrument to catching radio waves is fascinating research in energy harvesting system. The paper presents the design of corner reflector for radio wave energy harvesting with GPS L1 working frequency with gain 9.69, return loss -11.19 dB, beamwidth 47.3 degrees that can accommodate north-south solar movement in a year around and bandwidth 52.512 Mhz.

Keywords: Antenna; Beamwidth; Corner Reflector; Energy Harvesting

I. INTRODUCTION

The development of antennas for RF energy harvesting has been very popular in recent times. The antenna that can receive radio waves become one interesting part of the research. Radio waves that catched from source converted into other energy such as DC power.

Some source of radio waves that can be converted are the sun and GPS L1 satellite. Sun radiates radio waves [1] and some cases the radio waves from sun interfere with communication in the earth [2] and positioning of GPS L1 [3-6].

The sun seems to move relative 23.45^{o} towards north from and vice versa while earth rounding the sun. It means the sun moves relatively 46.9^{o} north-south all year around.

Corner reflector antenna is an instrument that can be used to catch radio waves from source before radio waves convert into other energy.

In previous research, a microstrip antenna at GPS L1 frequency had been developed [7]. That microstrip antenna will be used as feed antenna in this paper. There also been beamwidth optimization with parasitic element, flat reflector [8], using array [9-12], enlarge aperture [13], particle swarm optimization [14] and using parabolic reflector [15]. Corner reflector in recent research been used to modify radiation pattern [16] and change the directivity [17].

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This paper will present design a corner reflector that works for GPS L1 satellite at 1.575 GHz with 46.9^{o}beamwidth to accommodate north-south sun movement throughout the year. This work emphasizing optimization result process for solar which also works for GPS L1.

II. CORNER REFLECTOR DESIGN

2.1. Characteristic of Feed Antenna

Feed antenna that used in this paper is large aperture microstrip antenna that been developed before [7]. The antenna using FR-4 substrate and use air gap between patch and ground plane that has function to increase the gain, bandwidth, and VSWR. The microstrip antenna uses a circular patch to obtain suitable bandwidth. Table 1 shows parameters of antenna and the geometry of antenna is shown in Figure 1.

Table 1. Antenna Feed's Parameter

Parameters	Simulation	Measurement
VSWR	1.54	1.3237
Return Loss	-13.449 dB	-17.119 dB
Bandwidth	101 MHz	128 MHz
Impedance	50 Ω	38.535 – j4.5651 Ω
Polarization	Unidirectional	Unidirectional
Gain	9.002 dB	9.61 dB

Table 2. Summary of The Antenna Parameters

Parameters	Value (mm)
Length of the substrate (*lg*)	205 (1.0765λ)
Width of the substrate (*wg*)	275 (1.44375λ)
Patch radius (*a*)	40.8 (0.2142λ)
Distance from feed to the center of the patch (*L*)	72 (0.378λ)
Width of microstrip line (*W*)	6.8 (0.0357λ)
Thickness of cooper	0.035 (0.00018375λ)
Thickness of FR4	1.6 (0.0084λ)
Air gap (*g*)	11 (0.06 λ)

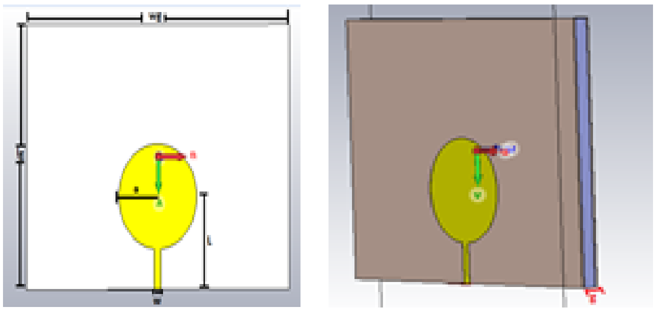

Figure 1. Geometry of Feed Antenna

2.2. Geometry of Corner Reflector

Figure 2 shows the proposed design of the corner reflector. The aperture of corner reflector (*Da*) designed using 2 approaches, that is formula approach Half Pass Beamwidth (HPBW) of horn antenna (1) and the other one using approach HPBW of dish antenna (4) that adopting from previous research [18]. With the desired beamwidth is 46.9°, aperture of corner reflector (*Da*) with horn approach is 315.025 mm (3) and with dish approach, generated Da about 283.61 mm (6). Equations to define length of reflectors (Lgl), width of reflector (Wd) and space between feed and reflector (Hf) are in Table 3 [19]. Corner reflector in this research using copper with 1 mm thickness. Where relative permeabilityof copper is 0.99991.

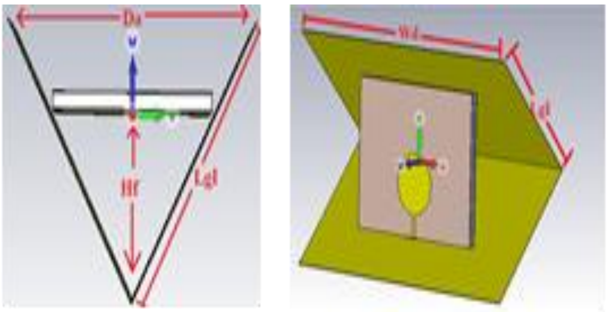

Figure 2. Geometry of Corner Reflector

Table 3. Summary of The Corner Reflector's Geometry

Symbol	Explanation	Equation
Da	Aperture	Equation (1) and (2)
Hf	Feed antenna's space with reflector	$\lambda/3 \leq Hf \leq 2\lambda/3$
LgI	Reflector's Length	Lg≃ 2Hf
Wd	Reflector's Width	1.2Lg ≤ Wd ≤ 1.5Lg

$$HPBW_H = 78^0 \frac{\lambda}{Da} \quad (1)$$

$$Da = \frac{78^0 \times 190.4254}{46.9^0} \quad (2)$$

$$Da = 315.025 \text{ mm} \quad (3)$$

$$w_d = \frac{70^0\lambda}{Da} \quad (4)$$

$$46{,}90 = \frac{70^0 x 190{,}4254}{Da} \quad (5)$$

$$Da = 283.61 \quad (6)$$

where: $HPBW_H$ = Half Pass Beamwidth Horn Antenna

Bw_d = Beamwidth of Dish Antenna

Da = Aperture of Corner Reflector

Booth of corner reflector approach will be simulated using CST Studio 2016, optimized, and compared which approach gives the most optimal result.

III. RESULTS AND DISCUSSION

Simulation and optimization of corner reflector antenna have been analyzed using CST Microwave Studio 2016. Some of the most optimal simulations results of corner reflector are shown in Figure 3 until Figure 6. The graphic in Figure 3 and Figure 4 shows the Wd effects on gain, beamwidth and VSWR where Hf = 126.95 mm (0.6667λ) and LgI = 247.55 mm (2Hf) constant with horn approach. Wd effects on gain, VSWR and beamwidth where Hf = 88.865 mm (0.4667λ) and LgI=204.389 mm (2.3Hf) constant with horn approach are shown in Figure 5 and Figure 6. Simulation results are not yet optimal and not according to specification and need to optimize.

Graph in Figure 3 descript the decreasing dimension of Wd resulting the sharpening the beamwidth, decreasing the VSWR and increasing the gain. Based on the trend, the corner reflector can be optimized with decreasing dimension of Wd. The optimization results show in Figure 7 and Figure 8.

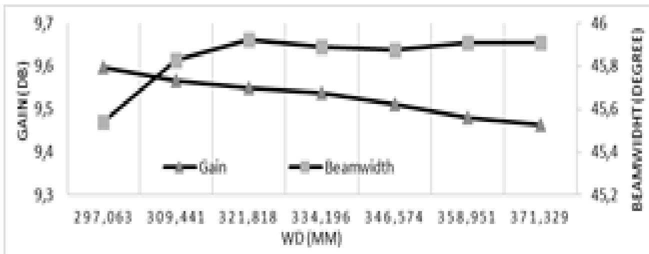

Figure 3. Wd effects on Gain and Beamwidth With Horn Approach Where Hf = 126.95 mm (0.6667λ) and LgI = 247.55 mm (2Hf) Constant.

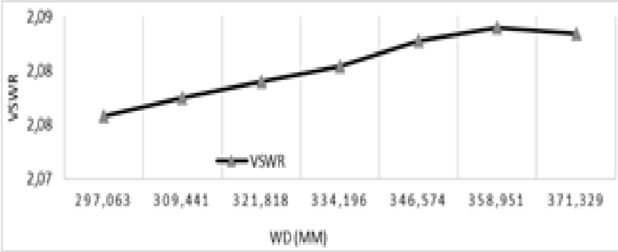

Figure 4. Wd effects on VSWR With Horn Approach Where Hf = 126.95 mm (0.6667λ) and LgI = 247.55 mm (2Hf) Constant.

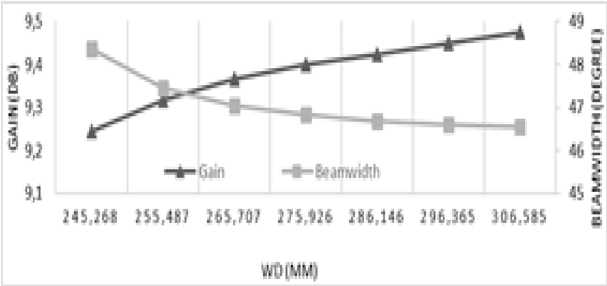

Figure 5. Wd effects on Gain and Beamwidth With Horn Approach Where Hf= 88,865 mm (0,4667λ) and LgI=204,389 mm (2,3Hf) Constant.

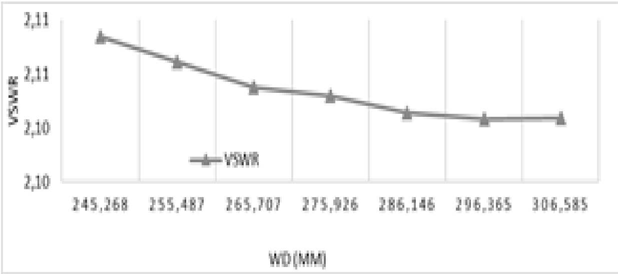

Figure 6. Wd effects VSWR With Horn Approach Where Hf= 88.865 mm (0.4667λ) and LgI=204.389 mm (2.3Hf) Constant

Another case with graph in Figure 5 and Figure 6. The graph shows that increasing dimension of Wd leads trend of increasing gain, narrowing beamwidth and lowering the VSWR. Based on the trend, corner reflector can be optimized with increasing dimension of Wd. Results are shown in Figure 9 and Figure 10.

Decreasing dimension of Wd in the graph on Figure 7 and Figure 8 effectingsharpening the beamwidth, decreasing VSWR and increasing the gain. But the trend having saturation at Wd ≤ 235.17 mm (Wd ≤ 0.85LgI) as shown in Figure 4. The most optimum result in this optimization part is Wd = 222.79 mm (0.8LgI).

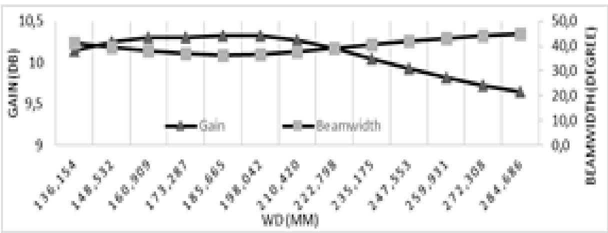

Figure 7. Decreasing of Wd Dimension effects on Gain and Beamwidth

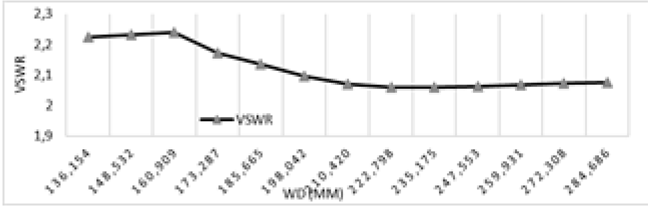

Figure 8. Decreasing of Wd Dimension effects on VSWR

Figure 9 and Figure 10 shows that increasing of Wd give a trend of increased gain and sharpening the beamwidth also lowering the VSWR. But the trend is saturated withWd ≥ 357.901 mm (1.75LgI). The most optimal result at Wd = 357.682 mm (1.70LgI).

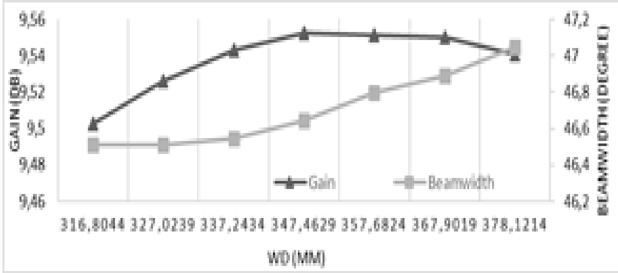

Figure 9. Increasing of Wd Dimension effects on Gain and Beamwidth.

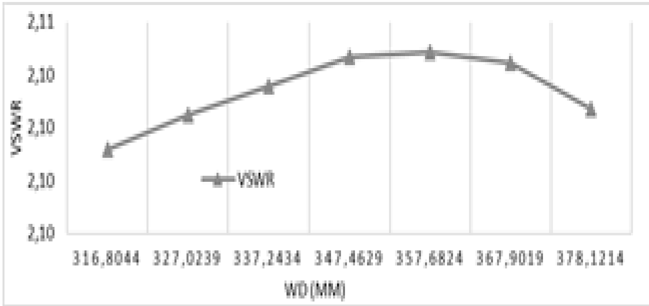

Figure 10. Increasing of Wd Dimension effects on VSWR

Both of most optimal result is compared. Geometry gives best result is Wd = 222.79 mm (0.8LgI), Hf = 126.95 mm (0.6667λ), LgI = 247.55 mm (2Hf) with VSWR = 2.07, Return Loss = -9.15 dB, gain = 10.27dB, but beamwidth to accommodate north-south = 37.678^{o} and not according antenna specification.

According to previous research [7], decreasing the air gap at the microstrip antenna which used as feed effects the decreasing VSWR and gain. This optimization part is changes the dimension of the air gap from 13 mm into 11 mm and 7 mm and this change is expected resulting decreasing VSWR of Corner Reflector. The graph in Figure 11 and Figure 12 shows the effect of the air gap changes on gain, beamwidth, and VSWR of corner reflector with various feed's air gap.

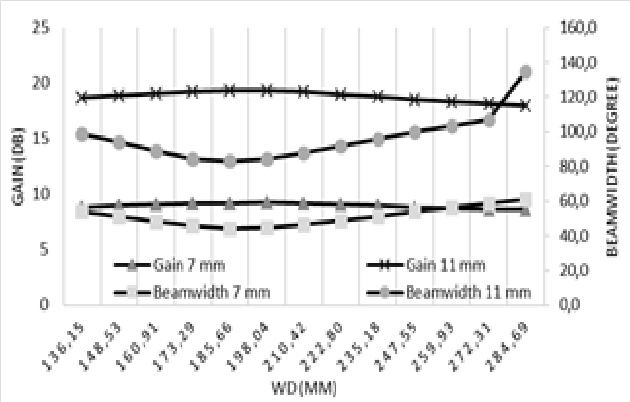

Figure 11. Decreasing of Wd Dimension effects on Gain and Beamwidth With Various Feed's Air Gap

Figure 14 and Figure 15 are shows beamwidth with 7 of mm air gap is more sharpen compare to beamwidth 11 mm of the air gap. Gain with 7 mm is lower than gain 11 mm air gap. Antenna corner reflector with 11 mm of air gap has higher VSWR than 7 mm of the air gap. The best result based on the graph is Wd= 198.04 mm where the air gap of antenna feed is 11 mm. But beamwidth result is not yet according to the desired specification.

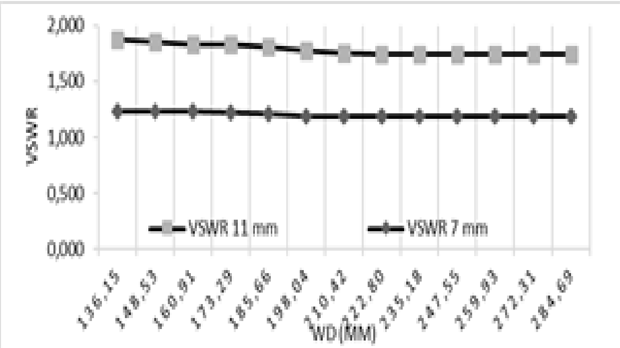

Figure 12. Decreasing of Wd Dimension effects on VSWR With Various Feed's Air Gap

Next optimization step is changing the angle of the corner reflector's plane without changing the aperture of the corner reflector (Da). In other words, changing the plane's angle equivalent changing the length of the reflector (LgI) and changing the reflector distance to the feed antenna. The results of the simulation are shown in the graph in Figure 13 and Figure 14.

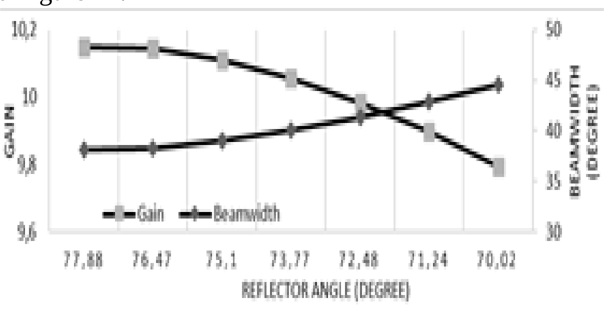

Figure 13. Reflector Angle Effects on Beamwidth and Gain

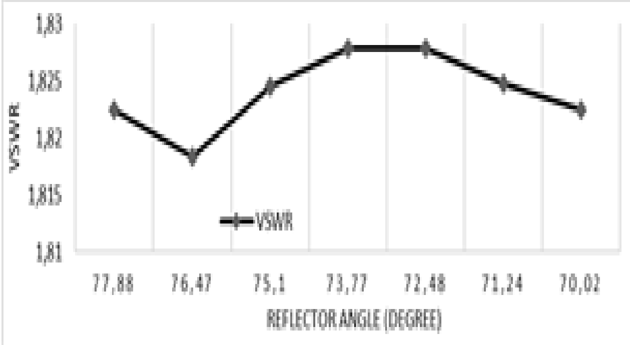

Figure 14. Reflector Angle Effects on VSWR

Decreasing of the reflector's plane angle causing decreasing beamwidth and increasing gain. Best angle's result is 76.47^{o} with lower VSWR than another angle. But beamwidth is not yet according to specification.

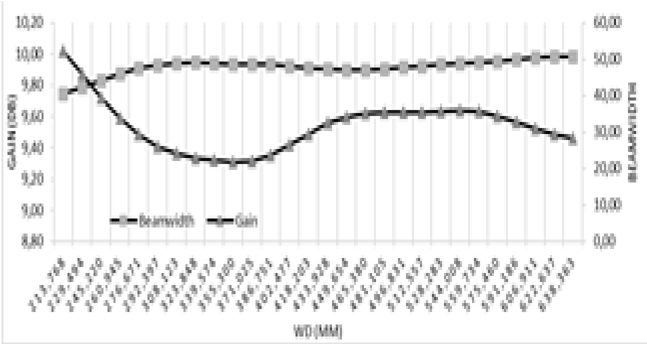

Figure 15. Wd Effects on Beamwith

To achieve 49.6^{o}beamwidth, optimization is done with enlarge Wd dimension. Decrement of Wd in this optimization step gives ups and down trend for beamwidth and gain also VSWR as shows in Figure 15 and Figure 16. The geometry that gives closest result to 49.6^{o}beamwidth is Hf = 136.95 mm with LgI = 255.33 mm and Wd = 481.10 mm. Simulation result with this geometry shows in Table 3. Radiation patterns of corner reflector antenna are shown in Figure 17 and Figure 18. VSWR graph is shown in Figure 19.

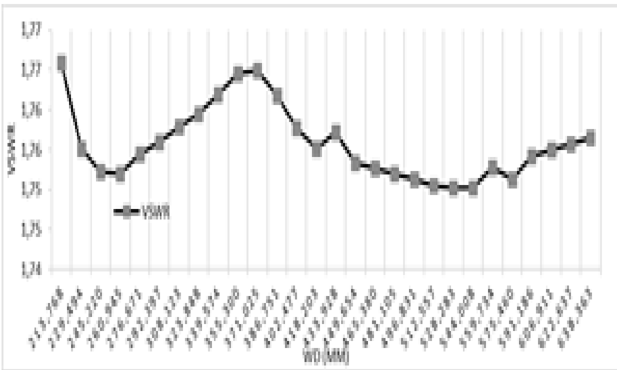

Figure 16. Wd Effects on VSWR

Antenna feed with 11 mm air gap without corner reflector and antenna feed integrated with corner reflector compared in Table 4. Based on the table, there is beamwidth changing when the corner reflector is used. Feed antenna beamwidth is 59.3° and with corner reflector beamwidth narrowing become 47.3°. Use of corner reflector sharpening feed antenna beamwidth. It means beamwidth of antenna corner reflector can accommodate solar movement from north-to-south all-around year.

Table 4. Comparation of Feed Antenna With 11 mm Air Gap and Corner Reflector

Parameters	Feed Antenna Simulation With 11 mm Air Gap	Corner Reflector Antenna Simulation
VSWR	1.40	1.76
Return Loss	-15.56 dB	-11.19 dB
Bandwidth	101 MHz	52.512 MHz
Beamwidth	59.3°	47.3°
Gain	8.95 dB	9.69 dB

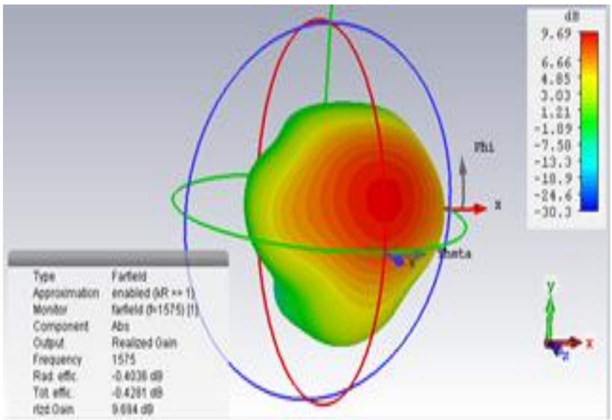

Figure 17. Gain of Corner Reflector Antenna

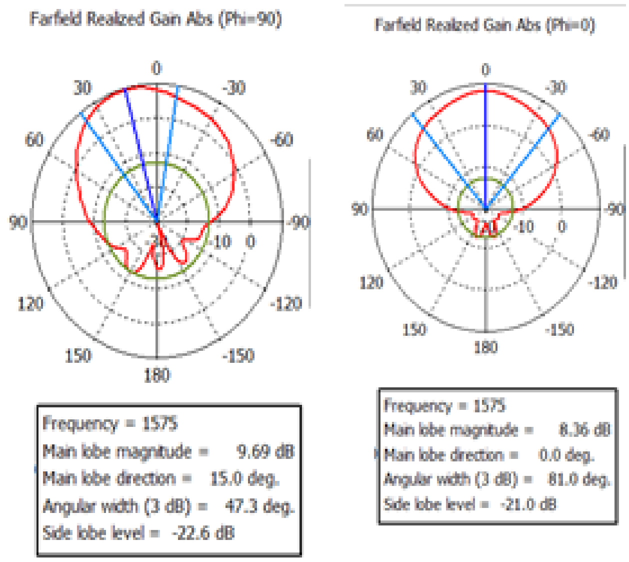

Figure 18. Radiation Pattern of Corner Reflector Antenna

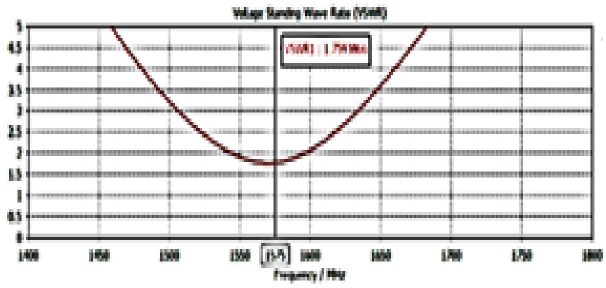

Figure 19. VSWR Graph of Corner Reflector Antenna

Used of corner reflector effect on gain. With corner reflector, feed's gain increasing about 0.74 dB from 8.95 to 9.68 dB. It means corner reflector effects increasing gain. Other than that, corner reflectors influence bandwidth become smaller from 101 MHz into 52.512 MHz and increasing VSWR from 1.4 to 1.76. After using corner reflector, the gain is slightly increasing followed by small increment of VSWR. Regardless, the main objective is to achieve the suitable beamwidth and hence this changes on VSWR can be neglected. After using corner reflector, gain increasing relatively low, and there increasing of VSWR, but main paramter of this work is to achieve 46.9°beamwidth.

IV. CONCLUSION

In this work, beamwidth of the corner reflector was optimized. The result shows the corner reflector aperture gives the best optimization result. This antenna design can be applied and implemented in RF energy harvesting system.

V. ACKNOWLEDGEMENT

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