TELKOMNIKA, Vol.16, No.5, October 2018, pp. 2032~2039
ISSN: 1693-6930, accredited **A** by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v16i5.8669

The Design of Capacitive Slit on Improving the Antenna Gain of Binomial Double Strip Hexacula Omnidirectional Broadband Antenna

Syahrial*[1], Safwan[2], Rizal Munadi[3], Roslidar[4]
[1,3,4]Electrical Engineering and Computer Department, Syiah Kuala University, Banda Aceh, Indonesia
[2]Informatics Department, Aceh Polytechnic, Banda Aceh, Indonesia
*Corresponding author, e-mail: syahrial@unsyiah.ac.id

Abstract

The capacitive slit is a method of making the impedance value to be resistive. To achieve this goal is a challenge in addition to the slit antenna and gives impact to gain as one of the important parameters in antenna design. The antenna gain in a particular direction is defined as 4π times the ratio of radiation intensity in that direction to the power received by the transmitter antenna. In this research, the proposed capacitive slit method was tested on the hexacula omnidirectional broadband antenna operating on frequency 0.85-3 GHz and gain 4.8 dBi. The testing was conducted to obtain the gain improvement of the hexacula omnidirectional broadband antenna. The placement of the capacitive slit was implemented on a double strip antenna with 4 times experiments. The best experiment result was obtained when three capacitive slits were placed on different strips. The capacitive slit was designed by analyzing the average value of input impedance before calculating the dimension of the capacitive slit that applied to the antenna. The experiment result shows that the best value of the antenna gain is 7.196 dBi. The gain increment is linear to the number of capacitive slits applied to the antenna.

***Keywords**: antenna, broadband, gain, impedance, capacitive slit*

1. Introduction

Today, the use of technology and wireless applications shows tremendous growth. Various wireless technologies are available on the market and offer ease of use and installation. To connect between wireless communication devices, this role is handled by a part called an antenna. The antenna is a transition structure of free space structure and a waveguide device that transmit and receive the electromagnetic wave at radio frequency [1]. Generally, one antenna is being used for only one application [2]. This type of antenna has narrow bandwidth and usually called as a narrowband antenna. Narrowband antennas are often based on resonant configurations. Because of resonance, the electromagnetic field in a narrowband antenna decays very slowly in time and varies drastically as a function of frequency [3]. Narrowband antenna can be used for several applications, but the antenna has to be added according to the number of applications. This type of antenna is called a broadband antenna. The broadband antenna is required in miniaturizing the radio communication, cognitive radio, and decreasing the handover in mobile radio [2]. This antenna can be used also as Radar Cross Section antenna [4].

One of the broadband antennas that is being used for many applications is binomial double strip hexacula omnidirectional antenna. Unlike other antennas, this antenna has dielectric with different materials and all the materials are household waste. The utilization of the household waste as the antenna dielectric reduces the production cost of the antenna and contributes to the recycling waste utilization for technology. This antenna works in the range of ultrahigh-frequency (UHF) and has a bandwidth of 2.67 GHz working frequency, in the UHF range (0.85 GHz - 3 GHz) [5] and a gain of 4.8 dBi. Availability of bandwidth must be considered in channeling information to the destination. Bandwidth must be provided so that transmission quality is not reduced. In terms of bandwidth, for example, one of the studies conducted by [6] the application of microstrip-to-coplanar stripline balun transitions is intended to achieve wide bandwidth and its performance. Another result in bandwidth perspective, a coupled shorting

Received January 22, 2018; Revised April 22, 2018; Accepted June 28, 2018

strip for compact patch antenna has the stable performance for wideband satellite navigation applications [7].

Antenna performance improvement is a challenge and encourages investigation to produce optimal power improvements on the receiving antenna side. One approach to improve antenna performance is by improving antenna gain. Antenna gain is the ratio of maximum radiation intensity of an antenna to the radiation intensity of the comparison antenna with the maximum power equal to the efficiency factor. The antenna gain is related to the directivity and efficiency of the antenna where the antenna gain is equal to the antenna directivity if the antenna has efficiency factor, η, equal to one (isotropic) [1]. There are many ways that can be done to make an antenna that suits our needs by using the technique of slit, strip, and loop loading. A study involving a combination of the three techniques is applied to the antenna slot to reduce the resonant frequency [8]. A measurement of a modified circular ring slot that was adopted to enhance cross-polarization performance has improved gain, cross-polarization level, and bandwidth[[9]. Another investigation of the addition of gaps in the microstrip triangle antenna was proposed for the implementation of C band communication and the results obtained gave a better performance impact [10]. Another research in satellite communication for Ka-band has implemented a log-periodic dipole arrays bands to achieve high gain result [11]. A study of a modified circular ring slot that was adopted to enhance cross-polarization performance has improved gain, cross polarization level, and bandwidth. The use of certain materials and techniques has been carried out such as the proposed addition of slabs of split-ring resonator unit cells into the orthogonal plane of the antenna substrate [12], the application of a dielectric partial loading technique uses a small lens into the aperture on horn antenna type that works in the range 1-18 GHz [13].

One of the methods to increase the antenna gain is by applying capacitive slit. The capacitive slit is a method for making reactive impedance to be resistive. Resistive impedance will have an impact on antenna parameters, one of them is antenna gain. The hexacula omnidirectional antenna of the binomial double strip to be designed here is an antenna that has a transmit pattern in all directions (omnidirectional) and a broadband one. This binomial double strip Hexacula omnidirectional broadband antenna is principally a multilevel adapter of impedance characteristic in the air toward the terminal impedance [14]. One way to get a large antenna gain and a transmitting pattern that spreads in all directions are by radially coupling some antennas.

Many methods to improve antenna gain and mostly these methods make the new model of the antenna not adding a component to exist antenna form to improve antenna gain. These methods such as cylindrical shell-shaped superstrate [15] and cylindrical ring dielectric resonator [16]. In this paper, we discuss the impact of adding the slit antenna on the antenna gain of binomial double strip hexacula omnidirectional broadband antenna. The goal is to analyze the gain increase when the capacitive slit is applied to the binomial double strip hexacula omnidirectional broadband antenna. The implementation of the capacitive slit is done only up to three double strip antennas because the initial strip is the input impedance of the antenna.

2. Research Method

2.1. The Objective and Flowchart

The research method here is an experiment using antenna software simulation. The study objective is to analyse the addition of capacitive slit based on gain improvement for the hexacula omnidirectional broadband antenna of the binomial double strip. Then the process of this research is desribed into some stages as shown in Figure 1.

The minimum limit of antenna gain value is required to achieve the optimum result. The specification of the designed antenna as follows: operating frequency range of the antenna: 0.3-3 GHz, VSWR ≤ 1.5, antenna gain ≥ 7 dBi, omnidirectional radiation pattern. UHF frequency is chosen because of many applications in telecommunication work at this frequency range. The VSWR ≤ 1.5 will enable power transmission more than 90%. The gain value has to be more than 7 dBi to make the radiation pattern reaches further compared to binomial hexacula omnidirectional without the capacitive slit.

As shown in Figure 1, the first step is to study antenna gain and efficiency. Then, it follows by determining the specification and dimension of the antenna. Based on the proposed antenna specification, the simulation process is run to get the expected result. In order to get the dimension of the capacitive slit, the average value of input impedance of the antenna has to be analyzed first. Every applied capacitive slit is being observed to figure out the increasing value of the antenna gain. This step is repeated by increasing the second and third capacitive slits on the antenna strip.

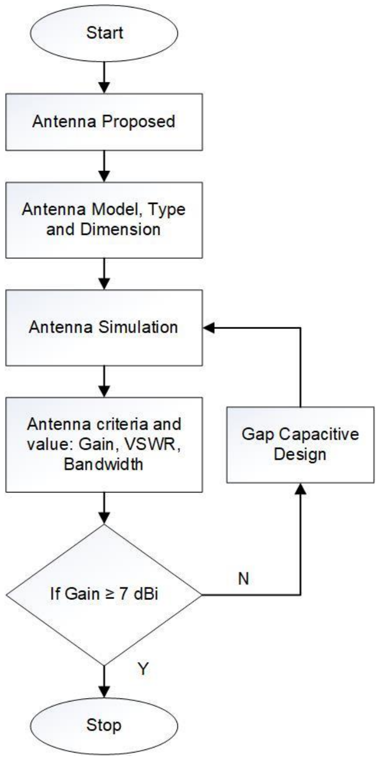

Figure 1. Flowchart of capacitive slit design

2.2. Design Method

In designing the capacitive slit, the method using here is collecting the data of antenna gain and reactive impedance of the simulation result. After the binomial double strip hexacula, the omnidirectional broadband antenna is designed, the simulation is conducted to obtain the value of antenna gain and the reactive impedance. If the antenna gain never reaches the expected value, then the average value of input impedance is considered as the standard to determine the capacitive slit dimension. The capacitive slit is placed at the beginning of the antenna strip. The simulation is repeated. If the expected antenna gain value is not achieved after this step, then another slit will be added to the other strip. This process is repeated until the antenna gain ≥ 7dBi. After the expected value of the antenna gain is obtained, then a graphic of antenna gain that shows the relation to the number of applied capacitive slits is drawn. This result is analyzed to find the trend of the increased gain value to the number of applied capacitive slits on the antenna.

2.3. Physical Dimension of the Antenna

The binomial double strip hexacula omnidirectional broadband antenna has physical dimension consisting of six branches of double strip arranged radially to get the omnidirectional radiation pattern. The processes of designing the antenna physical dimension are as follow: determining the level of the antenna using the binomial method, figuring out the impedance of each level, defining the antenna dielectric for each level, setting the length of each level, adjusting the distance between the strip, calculating the monochronic dimension. The design process of the antenna physical dimension aims to achieve the expected specification that previously defined. All of this physical dimension design processes are calculated manually.

Figure 2 shows the structure of a broadband antenna with six branches of the line using the binomial method of the single capacitive slit. This antenna consists of six double strips and six binomial levels. The objective of using the binomial method is to minimize the deviation of the air impedance and the input impedance so that the input or output signal will not be reflected.

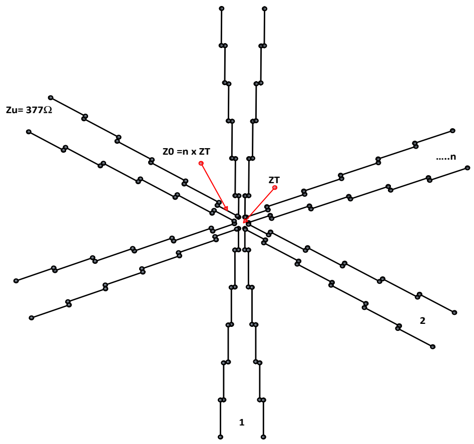

Figure 2. Antenna structure

The first step is determining the antenna level using the following equation [1]:

$$BW = \frac{\Delta f}{f_o} = 2 - \frac{4}{\pi}\cos^{-1}\left[\frac{1}{2}\left(\frac{\Gamma m}{|A|}\right)^{\frac{1}{N}}\right] \quad (1)$$

The equation (1) is used to calculate the number of the binomial levels applied to the antenna that enables the impedance transition reducing the return loss. The impedance of each antenna is found using equation (2) [2].

$$\ln Z_{01} = \ln Z_{01} + 2^{-N} C_0^N \ln \frac{Z_u}{Z_o} \quad (2)$$

This equation shows that there are changes in impedance value for each level. The changing value of the impedance will give influence to the return loss and power transfer of the antenna which finally will improve the antenna performance. After the impedance of each level is determined, then the average input impedance of the antenna is analyzed. The impedance of each level is set to be different to reduce the transition value at each impedance level. The more binomial level (N), the smaller the antenna impedance displacement value which minimizing the return loss and finally indicates the improvement of the antenna bandwidth. Each level of the binomial antenna has different lengths according to its dielectric value and its binomial level of wavelength. Equation (3) is used to determine the length of each antenna level $\lambda/4$.

The antenna dielectric is defined using the following equation [1].

$$\lambda_{\varepsilon 0N} = \frac{\lambda_u}{4\sqrt{\varepsilon_{r0N}}} \quad (3)$$

Because of the different value of the impedance of each level, the dielectric of the antenna for each level is not the same. Based on this dielectric value, this result becomes a reference in specifying the antenna material to be used.

The capacitive slit is determined by counting the antenna impedance (Za) that consists of resistive (R) and a reactive component (Xc/Xl) as written in equation (4). The reactive component is expressed by capacitive reactance (Xc) and inductive reactance (Xl). The width of the capacitive slit is calculating using the equation as follows [1].

$$Z_a = R \pm iX_c/X_l \tag{4}$$

$$C = \frac{1}{2\pi f X_c} \tag{5}$$

$$C = \frac{\varepsilon_0 . \varepsilon_r . A}{d} \tag{6}$$

The result of antenna dimension calculation based on the literature study is presented in Table 1. This antenna is constructed of chopper plate as the conductor and household waste as the dielectric material, which can be plastics, carton, or other household waste. In Table 2, the value of antenna dielectric, impedance, and the length of each binomial level are desribed. The antenna is designed based on the specification provided in Table 2. Figure 3 is the result of the antenna design using the parameter value from Table 2. After the design process, the simulation using antenna software is executed to figure out the expected antenna gain.

Table 1. Antenna Dimension

Dimensional of antenna	Size
Length of copper plate	24,404 cm
Width of copper plate	0,551 cm
The distance between 2 plate	3,132 cm
High of monophonic	2,911 cm

Table 2.The Calculation Result of Antenna Dielectric, Impedance, and Length

N	Z $_{0N}$	ε_{r0N}	$\frac{\lambda_{\varepsilon 0N}}{4} (cm)$
1	301,07 Ω	$\varepsilon_{r01} = 1{,}57$	$\frac{\lambda_{\varepsilon 01}}{4} = 3{,}633\text{cm}$
2	307,564 Ω	$\varepsilon_{r02} = 1{,}5025$	$\frac{\lambda_{\varepsilon 02}}{4} = 3{,}708\text{cm}$
3	324,42 Ω	$\varepsilon_{r03} = 1{,}3504$	$\frac{\lambda_{\varepsilon 03}}{4} = 3{,}911\text{cm}$
4	348,34 Ω	$\varepsilon_{r04} = 1{,}17132$	$\frac{\lambda_{\varepsilon 04}}{4} = 4{,}212\text{cm}$
5	367,43 Ω	$\varepsilon_{r05} = 1{,}05277$	$\frac{\lambda_{\varepsilon 05}}{4} = 4{,}431\text{cm}$
6	375,356	$\varepsilon_{r06} = 1{,}00878$	$\frac{\lambda_{\varepsilon 06}}{4} = 4{,}525\text{cm}$

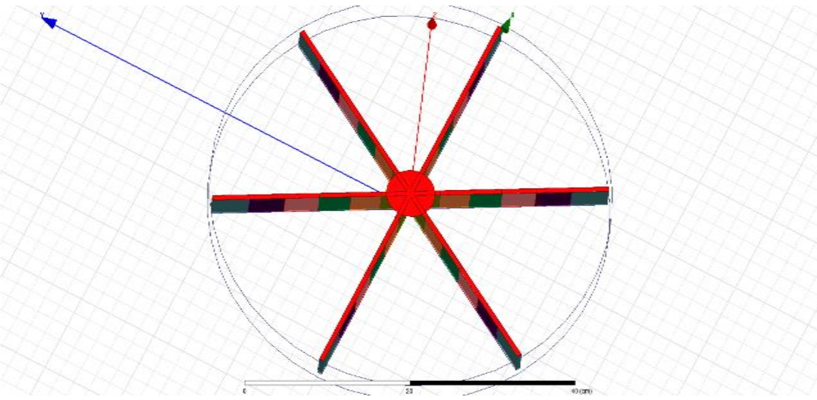

Figure 3. The binomial double strip hexacula omnidirectional antenna

3. Results and Analysis

As the design process is completed, then software simulation for the antenna design is executed in four phases which are applying none capacitive slit to the antenna, one capacitive slit to the antenna, two capacitive slits to the antenna, and three capacitive slits to the antenna respectively. The purpose of these phases is to collect data for finding out the correlation of antenna gain with the number of capacitive slits applied to the antenna.

The first phase of the simulation is simulating the antenna gain for double strip binomial hexacula omnidirectional antenna without the capacitive slit. The result of the simulation is shown in Figure 4.

Figure 4 illustrates the graph of antenna gain and the radiation pattern. The distinct in color shows the value of the antenna gain, the highest antenna gain value is represented by red while the lowest gain value in blue. The highest gain is 2.762 dB + 2.41 dBi = 5.172 dBi which is not in the expected range that is ≥ 7 dBi. Figure 4 also presents the radiation pattern of the first phase antenna design simulation that is omnidirectional.

The second phase of simulation is applying one capacitive slit to the antenna of binomial double strip hexacula omnidirectional. The result simulation displayed in Figure 5 shows the graph of antenna gain and the radiation pattern of the antenna with one capacitive slit. The red area represents the highest gain. The value of the highest gain is 4.144 dB + 2.41 dBi = 6.554 dBi which means that the result is not satisfied with the expected value yet (≥ 7 dBi). The radiation pattern shown in Figure 5 is omnidirectional.

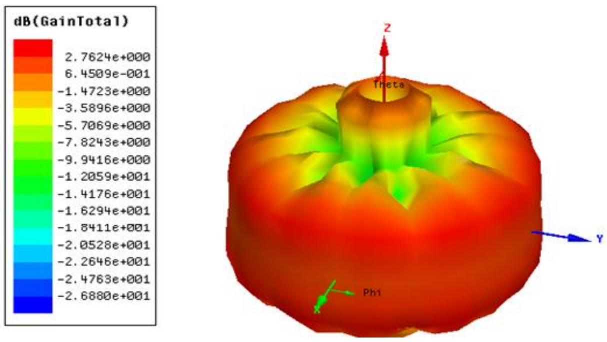

Figure 4. The Gain of binomial double strip hexacula omnidirectional antenna without a capacitive slit

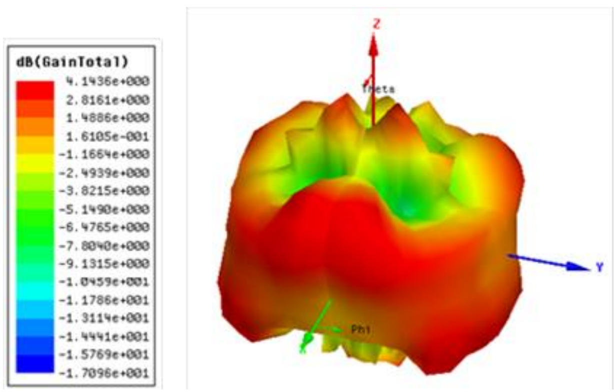

Figure 5. The gain of binomial double strip hexacula omnidirectional antenna with one capacitive slit

The third phase is executing the simulation for the antenna with three capacitive slits. The result simulation of the binomial double strip hexacula omnidirectional antenna with two capacitive slits is presented in Figure 6. This image shows the antenna gain and the radiation pattern of the simulation on the antenna with two slits. The highest antenna gain here is 4.217 dB + 2.41 dBi = 6.657 dBi. This result is still under the expected gain value which is ≥ 7 dBi. While the radiation pattern is omnidirectional.

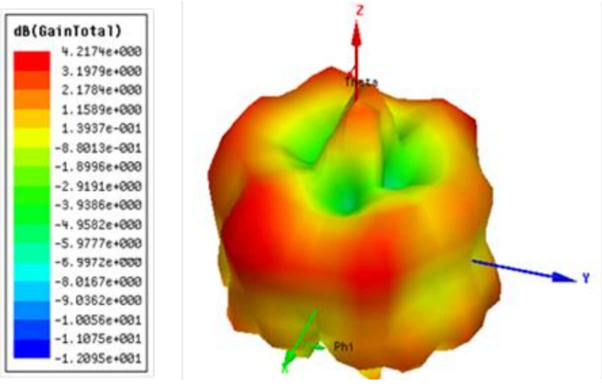

Figure 6. The gain of binomial double strip hexacula omnidirectional antenna with two capacitive slits

The last phase is doing the simulation on the binomial double strip hexacula omnidirectional antenna with three slits. The result simulation is depicted in Figure 7. Figure 7 shows the graph of the antenna gain and the radiation pattern of the antenna simulation. The highest gain obtain is 4.786 dB + 2.41 dBi = 7.196 dBi. This is exactly the gain that is stated in the antenna specification which is ≥ 7 dBi. Figure 7 also sketches the radiation pattern of the antenna that is omnidirectional. The graph shown in Figure 7 is the best result of antenna simulation with three capacitive slits which is antenna gain ≥ 7dBi with omnidirectional radiation pattern.

Figure 8 shows the graph of antenna gain correlation with the number of capacitive slits applied to binomial double strip hexacula omnidirectional antenna. The highest gain is 7.196 dBi achieved when three capacitive slits are applied to the antenna with the highest antenna efficiency 99.03%. The threshold line drawn in Figure 8 represents the gain threshold specified to the designed antenna. It can be analyzed that antenna gain is linearly related to the number of capacitive slits applied to binomial double strip hexacula omnidirectional antenna. The radiation pattern resulted from all simulation phases is omnidirectional.

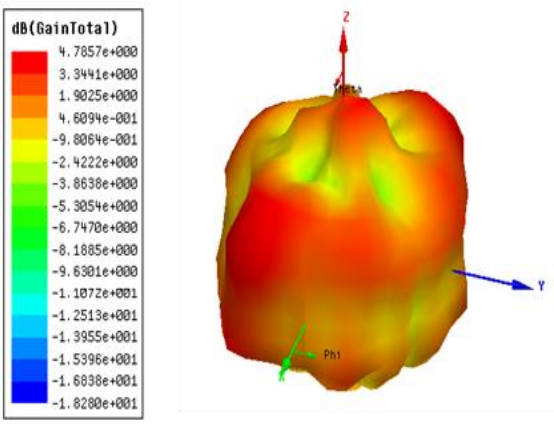

Figure 7. The gain of binomial double strip hexacula omnidirectional antenna with three capacitive slits

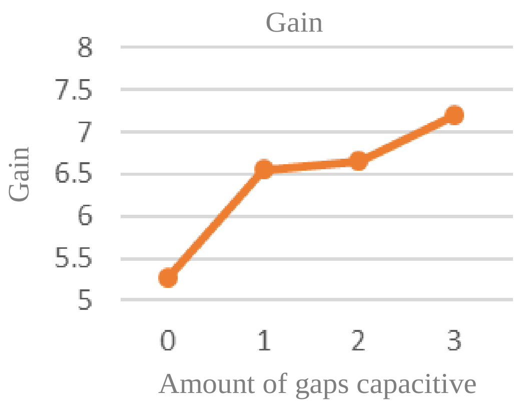

Figure 8. The correlation of antenna gain and the number of capacitive slits applied to double strip binomial hexacula omnidirectional antenna

4. Conclusion

The design and simulation of antenna binomial double strip hexacula omnidirectional antenna have successfully conducted. The simulation is done in four phases with the best result given by the antenna designed with three capacitive slits. The increment of the gain is linear to the number of capacitive slits applied to the antenna. The antenna with three capacitive slits has gain 7.196 dBi which corresponds to the specification of an expected gain of the antenna. While the uniformly distributed gain is given by the antenna of binomial hexacula omnidirectional without capacitive slits.

For further research, the antenna simulation can be done by adding more capacitive slits according to the strip of the antenna, adjusting the slit size, and lengthening the antenna strip.

References

[1] Balanis, C.A. Antena Theory: Analysis and Design, 4th ed. Harper & Row Publ. Inc. New York. 2015.
[2] Gunnarsson R, Andersson P, Pettersson L. Design of wideband stepped-notch arrays using multi-section impedance transformer design rules. *IEEE Antennas Propag Soc AP-S Int Symp*. 2012;2-3.
[3] Balanis, C.A., Modern Antenna Handbook. John Wiley & Sons, 2011: 325.
[4] Mu J, Wang H, Wang H, Huang Y. Low-RCS and Gain Enhancement Design of a Novel Partially Reflecting and Absorbing Surface Antenna. *IEEE Antennas Wirel Propag Lett*. 2017;16:1903-1906.
[5] Juntunen JO, Nikoskinen KI, Heiska KJM. Binomial array as a multistate phase diversity antenna. *IEEE Trans Veh Technol*. 2000; 49(3):698-705.
[6] Wang H, Liu S, Chen L, Li W. Gain Enhancement for Broadband Vertical Planar Printed Antenna With H-Shaped Resonator Structures. *IEEE Transactions on Antennas and Propagation, August 2014*; 62(8): 4411-4415.
[7] Sun C, Zheng H, Zhang L, Liu Y. Analysis and design of a novel coupled shorting strip for compact patch antenna with bandwidth enhancement. *IEEE Antennas Wirel Propag Lett.* 2014;13:1477-1481.
[8] Haque SKM, Parvez KM. Slot antenna miniaturization using slit, strip, and loop loading techniques. *IEEE Trans Antennas Propag.* May 2017; 65(5):2215-2221.
[9] Chen C, Li C, Zhu Z, Wu W. Wideband and Low-Cross-Polarization Planar Annual Ring Slot Antenna. *IEEE Antennas Wirel Propag Lett.* 2017;16:3009–13.
[10] Sharma V, Sharma MM, Sharma B, Bhatnagar D. Circularly polarized broadband triangular microstrip antenna with slits for C band. *Int Conf Signal Propag Comput Technol ICSPCT*, July 2014;438–441.
[11] Zhai G. Gain enhancement of printed log-periodic dipole array antenna using an elliptical patch. *Proc 2015 IEEE 4th Asia-Pacific Conf Antennas Propagation, APCAP 2015*. 2016;54-55.
[12] Dadgarpour A, Kishk AA, Denidni TA. Gain enhancement of planar antenna enabled by array of split-ring resonators. *IEEE Trans Antennas Propag*. 2016; 64(8):3682-3687.
[13] Turk, A. S., Keskin, A. K. Partially Dielectric-Loaded Ridged Horn Antenna Design for Ultrawideband Gain and Radiation Performance Enhancement. *IEEE Antennas Wirel Propag Lett. 2012;11:921-924*.Safwan, Soetamso, Fahmi Arfianto. Rancang bangun antena Hexacula omnidirectional strip kembar binomial, 0,3 GHz - 3,0 GHz, VSWR ≤ 1,5, berterminal 50Ω SMA, bercatuan monokonik. *Jurnal IT Telkom.* 2009.
[15] Sharifian Mazraeh Mollaei M, Zanganeh E, Feshki Farahani M. Enhancement of Patch Antenna Gain Using Cylindrical Shell-Shaped Superstrate. *IEEE Antennas Wirel Propag Lett.* 2017;16:2570-2573.
[16] Feng, L.Y, Sun, Y, Leung, K W. Gain enhanced omnidirectional cylindrical ring dielectric resonator antenna. *IEEE Internasional Symposium on Antennas and Propagation (APSURSI).* 26 June-1 July 2016; 139-140.