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Journal of Unmanned System Technology

Analysis of Vivaldi, Rectangular, Bow-tie, and Quasi-Yagi Antenna Performance for S-Band FMCW-SAR on UAV Platform

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Abstract— Frequency Modulated Continuous Wave (FMCW) radar uses continuous signal that can change its frequency along the measurement in its detection process. The developed FMCW radar will be combined with Synthetic Aperture Radar (SAR) technology that uses signal processing algorithm to improve the resolution of the output image beyond the limitation of physical antenna and will be mounted on the Unmanned Aerial Vehicle (UAV). On this paper, the performance of Vivaldi, rectangular, bow-tie, and quasi-Yagi antenna will be analyzed to determine which antenna is best used in the developed system. The developed FMCW-SAR radar has an operating frequency of 2.4 GHz (S-Band) and requires an operating bandwidth of 80 MHz to send and receive the continuous signal. The required beamwidth of antenna is 18o in order to illuminate the target perfectly. All of the developed antennas are made using FR4 Epoxy material with permittivity of 4.3 and height of 1.6 mm and each of it was able to meet these specifications. For the developed FMCW radar system, rectangular antenna will be chosen to be improved with consideration of the available space for installation of the antenna.

Keywords— microstrip antenna, Vivaldi antenna, rectangular antenna, bow-tie antenna, quasi-Yagi antenna, FMCW radar, SAR, aerial surveillance, UAV.

DOI: 10.21535/just.v5i3.976

I. INTRODUCTION

RADAR antenna illuminates the target with a microwave signal, which is then reflected and picked up by receiving device [2]. Microwave signal that illuminated by Frequency Continuous Wave (FMCW) radar transmits continuously and modulated in frequency or phase that can change its operating frequency during the measurement. Possibilities of radar measurements through runtime measurements are only technically possible with these changes in the frequency or phase [1]. The developed FMCW radar will process the reflected signal sequentially and then finally applies some mathematical methods to generate a high resolution image of the radar target using synthetic aperture radar (SAR) technology. SAR technology is the improvement of side looking radar that uses signal processing to improve the resolution of the backscattering signal translation beyond the limitation of the physical antenna aperture [3]. The developed FMCW radar will use Unmanned Aerial Vehicle (UAV) as a platform and can be modeled by side-looking airborne radar that shown in Figure 1 [1].

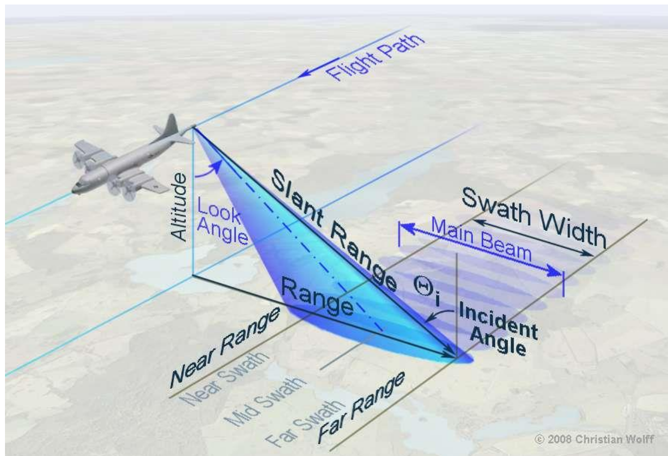

Figure 1 Side looking airborne radar [1]

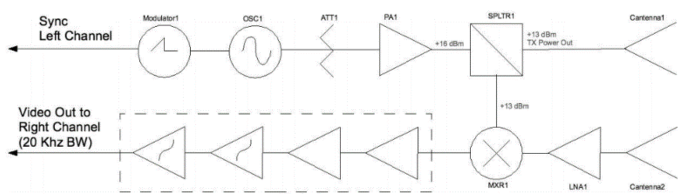

Figure 2 A block diagram of the developed FMCW radar [4]

Component of FMCW radar system include a modulator, an oscillator, RF power amplifiers, a mixer, a power splitter, a low noise amplifier (LNA), a video amplifier, a control and processing computer, and antennas. A block diagram of the developed radar is shown in Figure 2 [4]. The function of the antennas is to convert electrical signals to radio waves to be transmitted to the radar target, and then to also detect and receive the same radio waves to be converted back into electrical signal. The antenna of the FMCW radar affects the signal-to-noise ratio (SNR), system resolution, and range and azimuth ambiguities. The purpose of this work is to make the antennas that can meet the specification of the FMCW system

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This paper was submitted on October 12, 2017; revised; and accepted on December 30, 2017.

will be developed and to decide the most suitable antenna should be improve to enhance the performance of the system [3]. The developed FMCW radar requires a bandwidth of 80 MHz, beamwidth of 18o, and works on a 2.4 GHz frequency (S-Band). FR4 Epoxy material with permittivity of 4.3 and height of 1.6 mm was chosen to develop the antennas, because it is easy to find and cheaper than other materials.

For the developed radar system, microstrip antenna is chosen with consideration of the weight, because as mentioned before, the radar will be brought by UAV that has a very limited load. Performance of commonly used antennas, such as Vivaldi, rectangular, bow-tie, and quasi-Yagi will be analyzed and compared to find the most suitable antenna. The developed antennas are made in the small size, so that the simulation and measurement process can be simpler and faster. The enhancement of the antenna will be done when the most suitable antenna has been chosen.

The performance of the developed FMCW antennas will be analyzed from some antenna parameters, such as reflection coefficient (S_{11} Parameter), gain, bandwidth, beamwidth, dimension, and weight. Then the antenna to be enhanced will be selected based on these parameters.

II. ANTENNA DESIGN

A. 2×1 Vivaldi Array Antenna

The Vivaldi antenna is created in 2×1 array so its gain is not too small, compare to other antennas. Figure 3Figure 3 shows the dimension of the developed Vivaldi antenna and its realization [5].

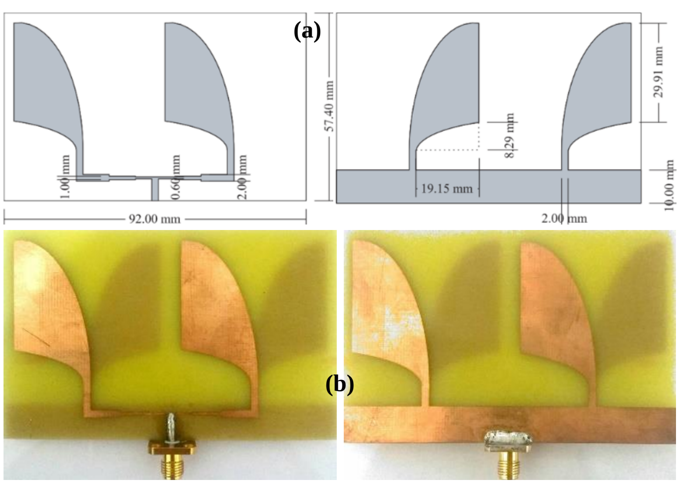

Figure 3 2×1 Vivaldi array antenna: (a) configuration design; (b) antenna realization

B. 2×2 Rectangular Array Antenna

As with the Vivaldi antenna, the rectangular antenna is also created in its array version so that the gain is not too small to compare with other antennas. Figure 4 shows the dimensions of the developed rectangular antenna and its realization [6]. The back side of antenna is a full ground (not etched PCB board), so it is not displayed.

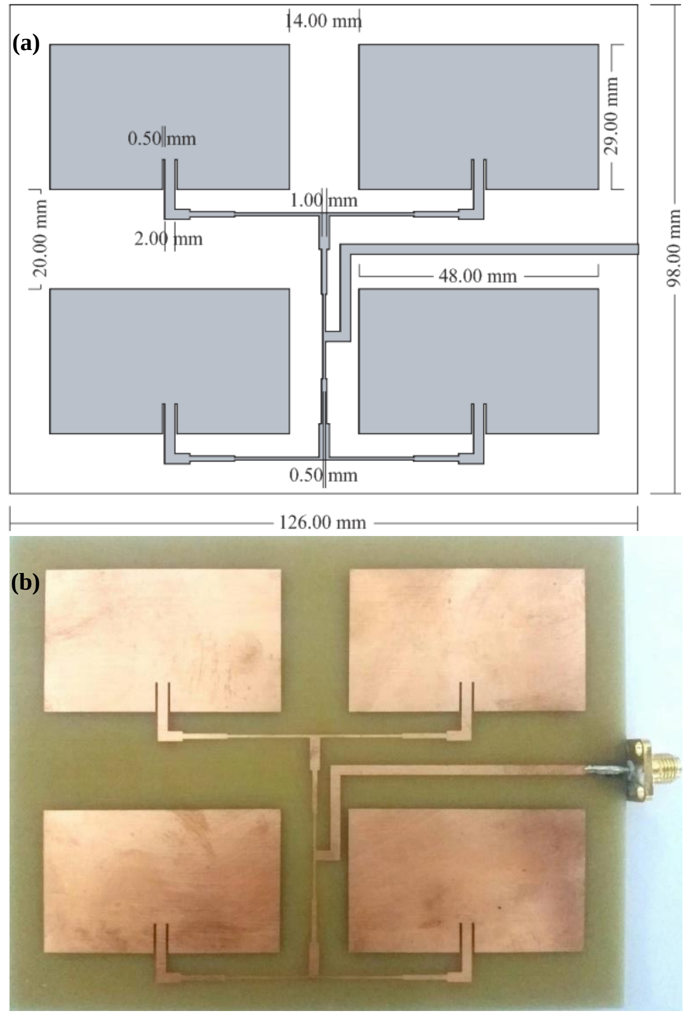

Figure 4 2×2 rectangular array antenna: (a) configuration design; (b) antenna realization

C. Bow-tie Antenna

The Bow-tie antenna is created in single version because the gain of a single version is big enough to compare with others antenna. Figure 5 shows the dimension of the developed bow-tie antenna and its realization [7].

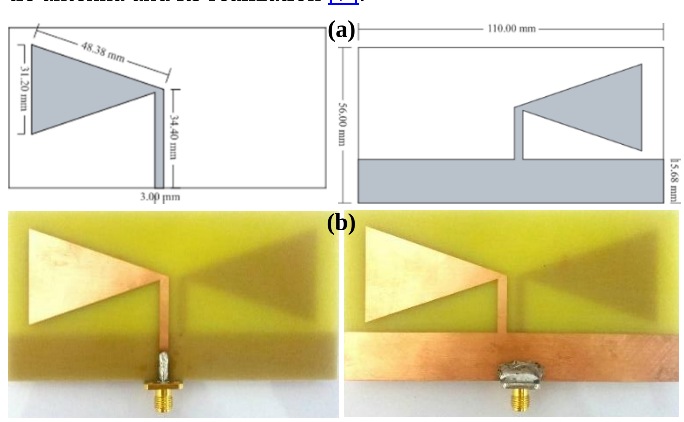

Figure 5 Bow-tie antenna: (a) configuration design; (b) antenna realization

D. Quasi-Yagi Antenna

As with bow-tie antenna, single version of quasi-Yagi antenna is created. Figure 6 shows the dimension of the developed bow-tie antenna and its realization [8].

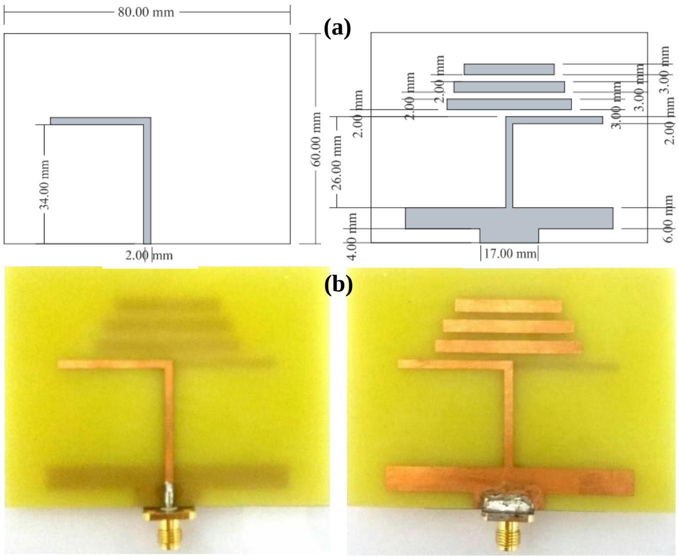

Figure 6 Quasi-Yagi antenna:
(a) configuration design; (b) antenna realization

III. Result and Discussion

As mentioned before, the performance of the developed FMCW antennas will be analyzed from some antenna parameters, such as reflection coefficient (S_{11} Parameter), gain (G), bandwidth, beamwidth, dimension, and weight. Reflection coefficient (S_{11}) and gain (G) of developed antennas respectively shown in Figure 7 and Figure 8. These parameters are based on the simulation result of the antenna simulator software. To make the antennas parameter easier to analyzed, the Table 1 shows the detail information about the developed antennas. All the simulation results parameters shown in the Table 1 are calculated at the operating frequency of 2.4 GHz.

Practically, the antenna will operate properly at its operating frequency if at that frequency, the S_{11} parameter value is below -10 dB [6]. The smaller value of S_{11} parameter gives the better quality factor (Qa) of the antenna [6]. Based on the result, all the developed antennas have worked well at the operating frequency of 2.4 GHz. It can be seen from the value of its S_{11} parameter that worth much less than -10 dB. However, it can be seen that Vivaldi antenna has the best quality factor compared to other developed antennas. But, it does not mean that the Vivaldi antenna is the best antenna that suitable to the SAR system will be developed because the other parameters also have to be considered.

The bandwidth of antenna shows the frequency range where antenna can operate properly. As mentioned before, antenna will work properly if the S_{11} parameter value is -10dB, so the bandwidth is measured by subtracting the highest frequency when the S_{11} value is -10 dB by the lowest frequency when the S_{11} value is -10 dB around the operating frequency [6]. As can be seen on the Table 1, bandwidth required by the system has also been achieved by all antennas. However, Vivaldi antenna has the widest bandwidth that reaches 1.03 GHz than others antennas. Therefore, if the bandwidth of the system wants to be upgraded, then this antenna will be suitable to be developed to be an array form.

Gain of antenna shows how well the antenna converts input power into radio wave in the specific direction. It measured by using some parameter of the antenna, such as input power, received power, and system losses [6]. Gain of all developed antennas are not too high because the antennas are still in single form or simple arrays. However, it will be easier to develop a bow-tie antenna to increase the gain. That's because its single antenna alone can provide a large enough gain. The gain of the antenna will increase as the antenna is made in the form of an array. Theoretically, the larger form of the array will give the higher gain. There is something to be considered when this bow-tie antenna chose to be upgraded into array form. It is because the bow-tie antenna has an end fire type, where the direction of radiation pattern is parallel to antenna arrangement, the thickness of the array will depend on one of the dimension of the antenna. In this case is about 56 mm, so it need more space on the platform that will carry the radar system. If we choose broadside antenna type to be upgraded, the thickness of the array can be same as the single antenna thickness. In this case is 1.6 mm, so it save much more space on the platform.

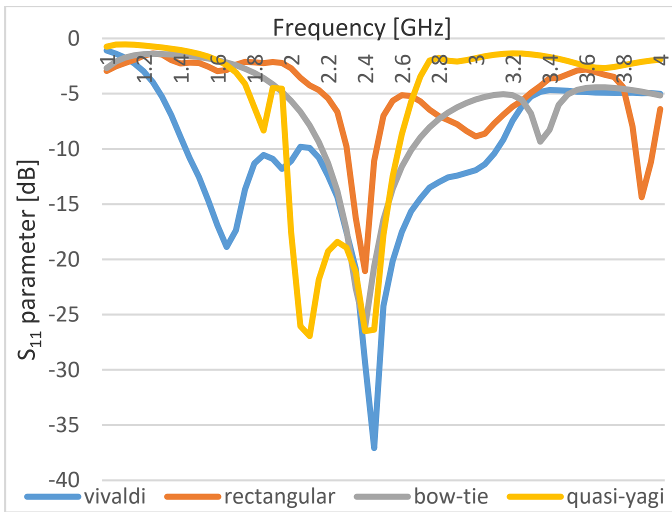

Figure 7 S_{11} parameter of the developed antennas

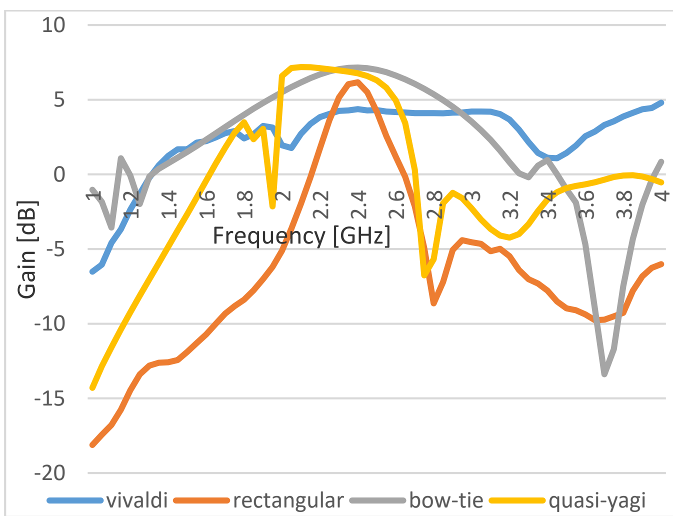

Figure 8 Gain of the developed antennas

Table 1 Comparison of the developed antennas

	Vivaldi	Rectangular	Bow-tie	Quasi-Yagi
S_{11} [dB]	-29.325	-21.064	-26.201	-26.490
Bandwidth [MHz]	1,030	150.8	482.7	611.4
Gain [dB]	4.370	6.166	7.153	6.767
Beam width [deg]	176.8	67.1	118.2	111.8
Antenna type	end fire	broad side	end fire	end fire
Dimension [cm×cm]	9.2×5.7	12.6×9.8	11×5.6	8×6
Weight [gr]	20	47	23	18

Radar system generally requires a small beam width of antenna radiation to make signal processing easier and more accurate. The developed SAR system, required 18° beam width of the antenna. All the developed antennas have large value of beam width. This can be handled by creating antennas in the form of arrays. The more the number of elements in the array, the beam width will be smaller. Of all the developed antenna, the rectangular antenna has the smallest beam width. Therefore, this antenna becomes the most easily developed to obtain small beam width.

Based on dimensions and the weights, the quasi-Yagi is the most compact antenna. However, it should be consider again that the end fire antenna type need more space to be mounted on the platform when it is created at the array version, unless it is made in the form of serial array only.

The above solution is more promising to make the antenna in the form of arrays, but actually change the antenna material can also be a solution to change the parameters of the antenna. Materials with low dielectric constants tend to have the ability to radiate radio waves better but tend to have lower bandwidth. Therefore, the material selection must be tailored to the needs of the desired SAR system.

IV. Conclusion

All the antennas that have been created have met the desired FMCW radar specifications, with 80 MHz bandwidth and 2.4 GHz operating frequency, except the 18o beam width. However, to improve the performance of radar systems and to fix the required beam width, the antenna should be developed in the form of larger arrays. Basically, all the antennas have been created can be improved according to the radar system requirements. For the next generation of FMCW radar system that will be created, rectangular antenna will be chosen to be developed with consideration of the available space for installation of the antenna on the UAV. The material used remains FR4 Epoxy because this material has a dielectric constant that is not too high or too low so it is more easily developed in terms of bandwidth and gain. Besides that, as mentioned before it is easy to find and cheaper than other materials.

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