

Curved Rectangular Patch Array Antenna Using Flexible Copper Sheet for Small Missile Application

Jessada Monthasuwan, Charinsak Saetiauw, Chanchai Thongsopa

Abstract—This paper presents the development and design of the curved rectangular patch arrays antenna for small missile application. This design uses a 0.1mm flexible copper sheet on the front layer and back layer, and a 1.8mm PVC substrate on a middle layer. The study used a small missile model with 122mm diameter size with speed 1.1 Mach and frequency range on ISM 2.4 GHz. The design of curved antenna can be installation on a cylindrical object like a missile. So, our proposed antenna design will have a small size, lightweight, low cost and simple structure. The antenna was design and analysis by a simulation result from CST microwave studio and confirmed with a measurement result from a prototype antenna. The proposed antenna has a bandwidth covering the frequency range 2.35-2.48 GHz, the return loss below -10 dB and antenna gain 6.5 dB. The proposed antenna can be applied with a small guided missile effectively.

Keywords—Rectangular patch arrays, small missile antenna.

I. INTRODUCTION

THE demands of wireless communication systems are rapidly growing. Future wireless systems will provide various services such as broadband multimedia and high speed access. Especially, the application of military radio technology has become an important topic for microwave communication. In recent years, the increasing interest in antennas and propagations research is an application in military communication devices [1]. The communication link for a missile and military weapons communication devices used to be a wireless network system. Military wireless network system was used for monitoring and tracking of rocket or missile. The communication on missile or rocket was differs from the convectional radiofrequency and wireless communication technologies. The antenna designed for missile needs a bandwidth covered both receive and transmit signals of the missile including some bandwidth because of effect of missile's speed from Doppler Effect. The speed of small missile was about Mach 2 [2]. So, the antenna resonance frequency will be changed when it's used on the missile or military weapons. The essential equipment for their wireless communication systems is the antenna which is used for transmitting and receiving a signal. There are many types of antenna applied for the appropriate function and system. But one of the major requirements of a missile and weapons tracking application is a compact and extremely wideband antenna covering the spectrum frequency.

The microstrip patch antenna is better option for military weapons tracking application. Due to their exhibit small size, light weight, low manufacturing cost and easy fabrication. However, frequency shifts where there moving very high

speed [3]-[5] because the center frequency will be changed when it's moved with very high speed around 2 Mach. Recent antenna for missile application development tends to focus on small planar antennas such as bow-tie, elliptical, slot and array antennas [6], [7].

This paper presents a design and analysis of curved rectangular patch array antenna for small missile application. A thin and flexible copper sheet antenna was attached a part of cylindrical PVC substrate. This antenna was designed on small missile model by cylindrical metal object and antenna analysis was conducted by using the CST microwave studio program [8]. The frequency of a designed antenna was used in ISM frequency band at 2.4 GHz. The proposed antenna is realized and experimentally examined, since it has small size, light weight, easy fabrication and low manufacturing cost. In this paper, the antenna will have return loss lower than -10 dB which covered frequency standard of 2.4GHz ISM Band. The average gain achieved in the antenna is more than 6.5 dB over the operating frequency. The advantage of the proposed antenna is that it can be used to small missile for military application.

II. ANTENNA DESIGN AND SIMULATION RESULT

The advantages of the microstrip antennas are small size, and lightweight, conformable to planar and non planar surfaces. They are simple and cheap to manufacture using technology. Ideal for installation on guided missile designed to be small.

However, substrate is also important; we have to consider the temperature and other environmental ranges of operation. Thickness of the substrate has a large effect on the resonant frequency and bandwidth of the antenna. Bandwidth of microstrip antenna will increase with increasing of substrate thickness but with limits, otherwise the antenna will stop resonating.

The purposed antenna is designed from calculations and consists of two parts: the patch microstrip antenna and the matching microstrip line at center frequency 2.4 GHz.

Consider, Fig. 1 shows a rectangular microstrip patch antenna of length L , width W resting on a substrate of height h . the length of the patch must be slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium and equal to $\lambda_0 / \sqrt{\epsilon_{\text{reff}}}$ where λ_0 is the free space wavelength.

From Fig. 1, patch antenna can be design with a given resonance frequency f_0 , the effective length is given by [9] as:

$$L_{\text{eff}} = \frac{c}{2f_0\sqrt{\epsilon_{\text{reff}}}} \quad (1)$$

where the expression for ϵ_{reff} is given by Balanis [10] as:

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$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \quad (2)$$

For efficient radiation, the width W is given by Balmain and Barta [11] as

$$W = \frac{c}{2 \sqrt{\epsilon_r + 1}} \quad (3)$$

Next, we introduce a simple and most commonly used feed technique which is the microstrip transmission line. Microstrip transmission line is connected directly to the patch to induce excitation. The main advantage is that the feed line and the patch can be printed on the same substrate layer.

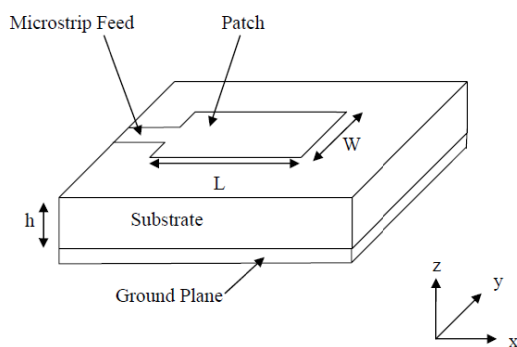
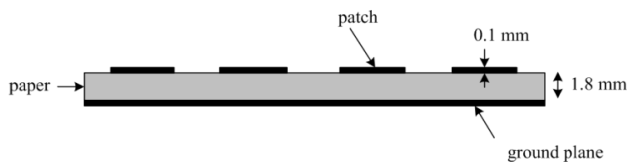
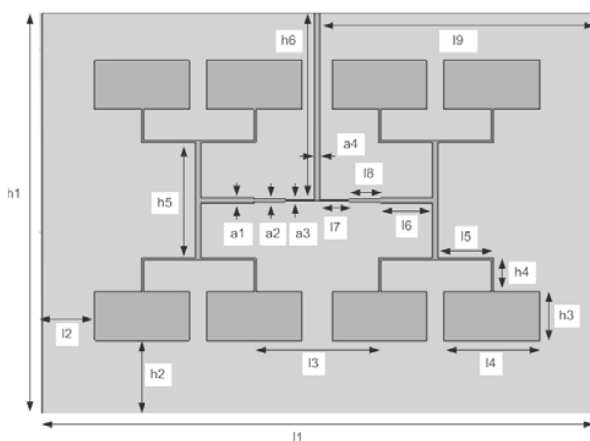


Fig. 1 Microstrip Patch Antenna



(a) Top view



(b) Front view

Fig. 2 Schematic of proposed antenna (Straight)

Three types of feed network were used: tapered lines to match 100Ω patch elements to a 50Ω input; combination of 100Ω, 50Ω and 70Ω lines; and a corporate-feed network loaded with multiple-section quarter-wave length

impedance transformers. The technique was chosen for this design because it presented better simulation results in impedance matching and antenna response. The input port of antenna was fed into the center of strip line of the antenna. The size of the microstrip line was calculated on the center frequency at 2.4 GHz with 50Ω, 70Ω and 100Ω impedances as shown in Fig. 2.

The patch array antenna was designed appropriately for an application of small cylinder missile. Center-to-center spacing between the patches is more than 0.5λ in order to obtain a proper balance between antenna gain and radiation main lobe shape. The proposed antenna model used the thin copper 0.1 mm. For the patch array [7] on front layer and ground layer at the back of the PVC substrates with a thickness of 1.8 mm. Fig. 2, with the parameters in Table 1.

TABLE I
DIMENSIONS PARAMETER OF PROPOSED ANTENNA

Parameter	Size(mm)	Parameter	Size (mm)
l1	300	h1	220
l2	28.5	h2	41
l3	68	h3	27
l4	52	h4	18
l5	29.75	h5	63
l6	29	h6	102
l7	15.75	a1	3
l8	17	a2	2
l9	148.5	a3	1
a4	3	a4	3

Designing an antenna for small missile, bandwidth needs to cover both receiving and transmitting signals including bandwidth from Doppler Effect. The speed of small missile is around 2 Mach at the frequency of 2.4 GHz and result from Doppler Effect is ± 11.07 GHz which can be calculated by (4).

$$f_d = \frac{v f_0}{c} \quad (4)$$

where

f_0 is the transmit frequency (Hz)

v is the speed of missile (m/s)

c is the speed of light (m/s)

f_d is the signal frequency Doppler Effect (Hz)

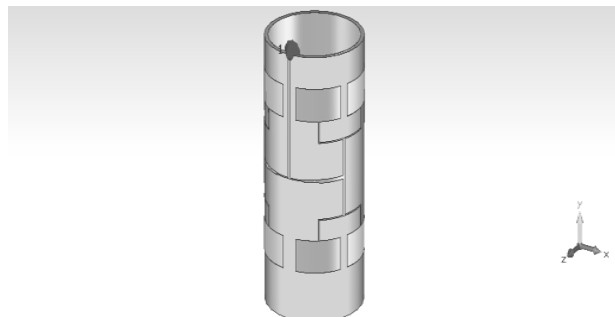


Fig. 3 Model of proposed antenna curved on cylindrical PVC tube

However, when we curved patch array on PVC tube at 130 mm diameter as shown in Fig. 3, the simulation result shows that the antenna is not working at the same center

frequency 2.4 GHz. So, we have a modification of the parameters of the antenna to adjust the frequency resonance back to 2.4 GHz as shown in Fig. 4. The result of simulation shows that we can adjust l_4 equal to 52mm to make a resonant frequency 2.4 GHz.

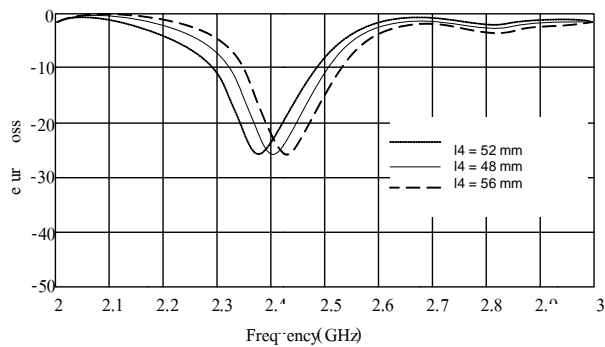


Fig. 4 Reflective coefficient (S_{11}) of patch array antenna curved on PVC tube with difference l_4

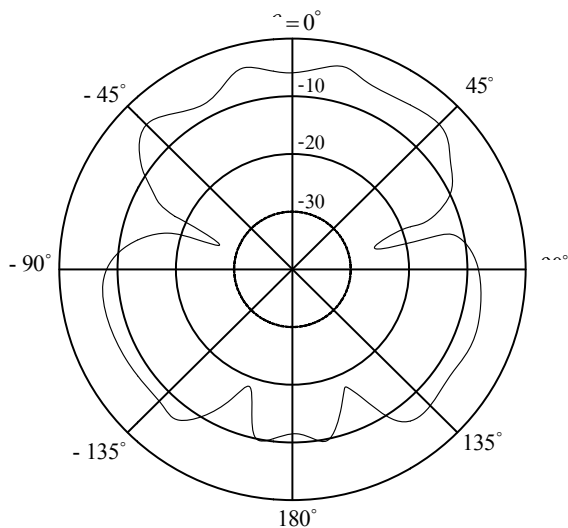


Fig. 5 Simulation result of E-field radiation pattern

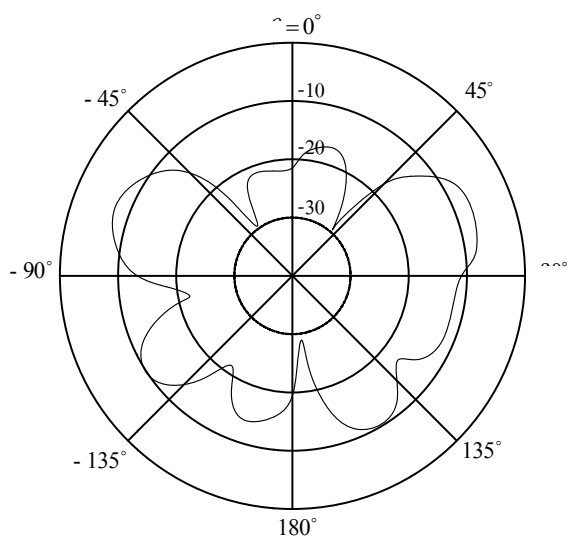


Fig. 6 Simulation result of H-field radiation pattern

The E-field and H-field radiation patterns of curved patch array antenna were shown on Figs. 5 and 6, respectively. The plan of the electric field direction shown in Fig. 5 has about 7 dB directional gain.

III. MEASUREMENT RESULT

The prototype antennas were fabricated from flexible copper sheet with the same dimension parameters and electrical properties as simulation model and shown in Table I except l_4 as we had explained previously. The prototype antenna made from flexible copper sheet and curved on PC tube as shown in Fig. 7. The prototype antennas are characterized in terms of return loss and radiation pattern using an Agilent HP8722D Microwave Vector Network Analyzer, is performed in the anechoic chamber. The result of simulation compared with a measurement of prototype with resonant frequency at 2.4 GHz as shown in Fig. 8.

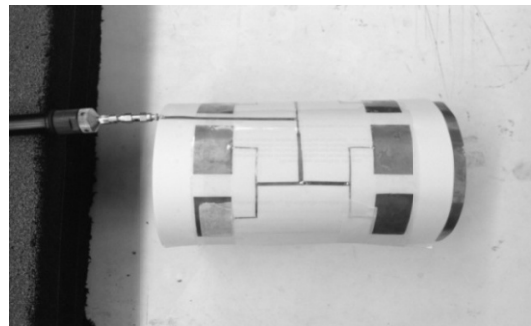


Fig. 7 Prototype of patch antenna arrays curved on PVC Tube

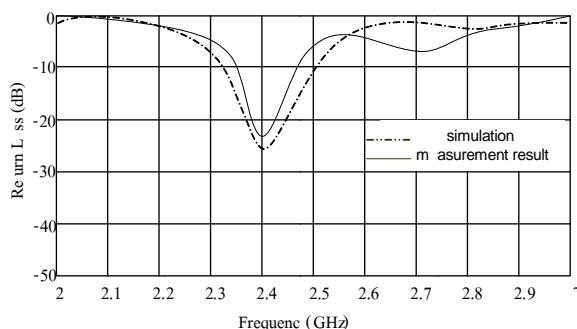


Fig. 8 Reflective coefficient (S_{11}) of proposed antenna compared between simulation and measurement result

The antenna is laid on XY-plane and curved in XZ-plane. The E-fields and H-fields radiation patterns of curved patch array antenna were measured and shown on Figs. 9 and 10, respectively.

The plane of the E-field radiation pattern shown in Fig. 9 has about 6.5 dB directional gain. This measurement result agrees with simulation result of curved patch array antenna has a radiation pattern as omnidirectional, a frequency band width is 2.35-2.48 GHz and average gain in all direction is 6.5 dB. This was enough to use for a satellite application.

Fig. 11 shows a range of bandwidth from the 2.38-2.435 GHz at -20 dB. This bandwidth covers the range of the missile which has 2 Mach of movement speed, calculated from the equation of the Doppler Effect.

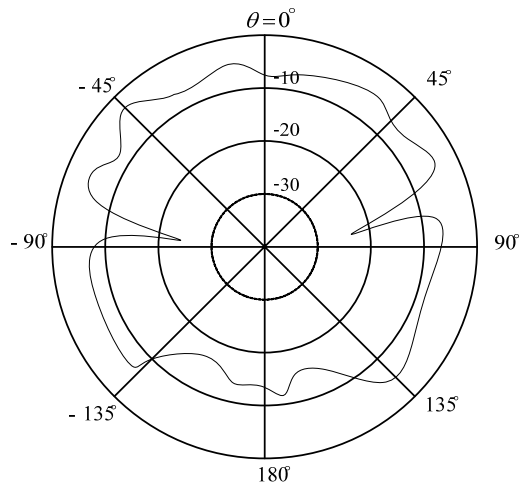


Fig. 9 E-filed radiation pattern from measurement

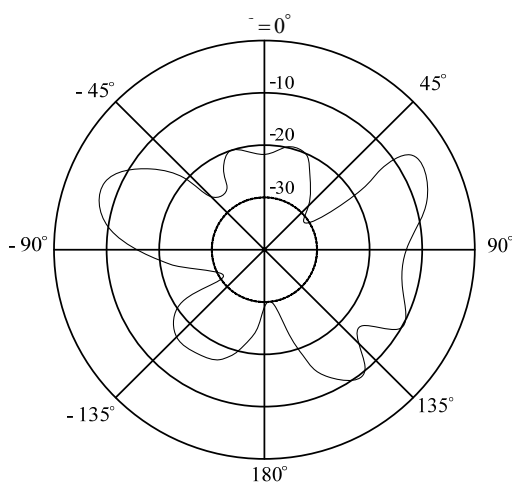
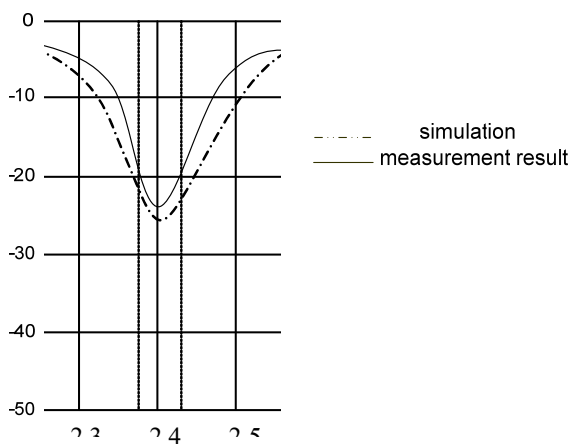


Fig. 10 H-filed radiation pattern from measurement

Fig. 11 Reflective coefficient (S_{11}) than -20 dB of purposed antenna compare between simulation and measurement result

IV. CONCLUSION

This paper presented the patch array antenna for a small missile application, which can be curved or bent along the cylindrical surface when it is installed on a small missile. The proposed antenna was designed with a cylinder PVC tube and antenna analysis was conducted by using the CST microwave

studio program. The ISM frequency of a designed antenna has center frequency at 2.4 GHz. In measurement, it is found that the proposed antenna has about 400 MHz (2:1 VSWR) frequency bandwidth which covered frequency range 2.35 - 2.48 GHz. The average gain achieved in the propose antenna is about 6.5 dB over the operating frequency. This antenna has Omni-directional radiation patterns at the center frequency of 2.4GHz and bandwidth covers all frequency effect on Doppler Effect (≈ 11.072 kHz). The advantage of the proposed antenna is that it can be used with small missile for military application.

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