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DUAL BAND SECTORIAL SLOT PAC-MAN ANTENNA BY USING POLYPROPYLENE SUBSTRATE

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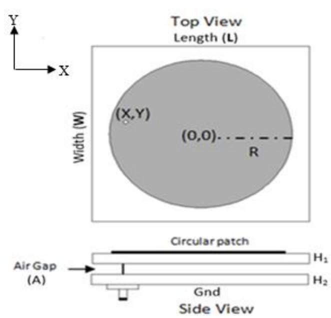
Graphical abstract



Abstract

In this paper, sectorial and circular slot Pac-man antenna for dual band frequency, 1.7 GHz for indoor wireless personal communications and 2.45 GHz Industrial science and medical (ISM) was proposed by using polypropylene (PP) flat pressed temperature con-trolled method. The method and material was chosen to reduce the overall cost and proposed new substrate with density =0.9gcm-3, dielectric constant = 2.57 and loss tangent = 0.0352.The dual band operation was distributed by sectorial slot design with, small circular slot to control and tuning the operating frequency. The back to back comparison between normal circular patch with Pac-man antenna using proposed substrate are dis-cussed and overall result distributed that there is no significant changes for gain, directivity, efficiency, vswr and physical size even though the proposed Pac-man antenna perform for dual band operation hence it is al-so improve the bandwidth of 17% compared to normal circular patch. The final Pac-man design fabricated using proposed polypropylene substrate (PP100) was then analyzed by using OTA-500 ATENLAB anechoic chamber.

Keywords: Pac-man antenna, polypropylene substrate, flat pressed method

1.0 INTRODUCTION

Polymers or plastic are popular lately to be used in high frequency substrate due to the material is cost effective, low density and easily to be integrate with others bio-composite to form high temperature bio-composite material substrate [1]. Polymer is no more a greenhouse issue since it can be recycle and reusable on other purposes with just heating the polymer according to its melting point temperature. On this re-search project scope, the antenna design was fabricated with polypropylene polymer due to high thermal conductivity (λ=0.708 w/m.k) compared to other polymer material. The melting point for polypropylene was reported about 180°C [2] with thermal diffusivity (a=0.47x10-6 m2/s) by using polypropylene substrate noted as PP100.The ability of the material to handle high temperature due to antenna radiation is crucial since it will expand the physical thickness of the material, hence it also change the value of the dielectric constant (εr). The changes of the εr value, will degrade the overall performance of the antenna structure design since there is a huge difference on simulation and real design application and make the resonant frequency to shift a little bit from the desired operating frequency. It has been demonstrated previously[3]-[4], that adding the slot to the antenna design will improve some of the band-width , control the operating frequency and also, reduce the size of the antenna due to the reduction of effective area and excited surface current paths of radiating element. In this paper, the sectorial slot was proposed to enhance the bandwidth hence, provide dual band operating frequency. The comparison between normal circular patch antennas [5] and proposed antenna was also demonstrated briefly to reveal the relevancy of adding the sectorial slot by maintaining the existing physical dimension of normal circular patch antenna. The application of this research was expect to cover the indoor wireless personal communication at 1.7GHz and wireless body area network (WBAN) at 2.45GHz industrial, science and medical (ISM). The proposed fabricated process for PP100 polypropylene substrate was briefly discuss in [6] including dielectric and loss tangent value for specific frequency.

2.0 ANTENNA DESIGN

Most of the basic antenna design parameter was given in Table 1.

Table 1 Basic Antenna Design Parameter

Design parameter	Value
Substrate thickness	1.6 mm
Desired frequency	1stBand = 1.7 GHz 2ndBand = 2.45 GHz
Copper thickness	0.4 mm

The pacman structure polypropylene material substrate and the hot and cold press fabrication method was used due to simplest fabrication pro-cess. The setting of hot and cold flat press method was given in Table 2 below was fabricated on top of

Table 2 The setting of hot and cold flat press method

Hot Press Setting	Cold Press Setting
Temperature: 180°C	Temperature : 20°C
Pressure: 1000 psi	Pressure: 500 psi
Duration: 330 seconds	Duration: 120 seconds
Venting : 2 seconds	Venting : 2 Seconds

Oven process 110⁰C (1 Hours) for discard moisture after final substrate fabricated (size substrate 150 x150 x 1.6 mm) (ASTMD570-98)

2.1 And Normal Circular Patch Antenna

The basic design of the antenna is based on the circular type patch antenna with coaxial feed through type. Even though there is a success regarding the circular patch design using others feeding and matching technique [7], the coaxial feed through type was chosen, since there is a freedom to the antenna designer to apply the air gap technique to enhanced the antenna gain and provide more bandwidth, hence there are some others physical parameter to adjust the resonant frequency instead of only the dimension circular size. The single circular patch antenna were given in Figure 1 and proposed sectorial slot Pac-man antenna is shown in Figure 2. The design of the circular patch was distributed by the equation (1) and equation (2) below. The only parameter that can be adjusted to shift the desired frequency up and down rely on the thickness of Air gap and the Radius (R) of the circular patch dimension. On most of the previous research [7], the feeding point situated, near end of the circular patch, this is due to edge effect distribute high surface current compare to other area. The coordinate position of the feeding was given as (X, Y) whereby the center of the patch was labeled at coordinate (0, 0). It also note that ε_r (Dielectric constant of Substrate), fr (Resonant Frequency in Hz) and h (Height of the substrate in cm).

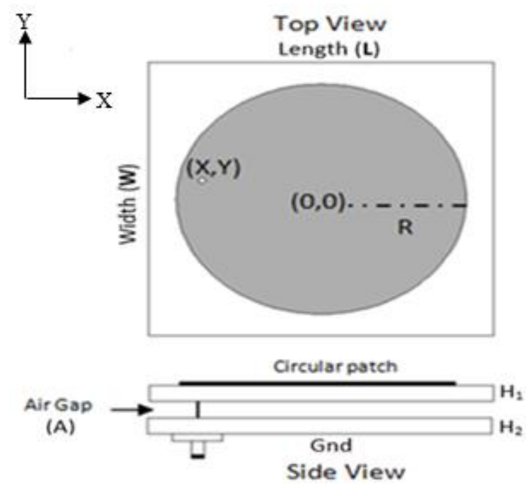


Figure 1 Circular Patch Antenna

$$R = \frac{F}{\sqrt{1 + \frac{2h}{\pi\varepsilon_r F\left[In\left(\frac{\pi F}{2h}\right) + 1.7726\right]}}} \quad (1)$$

Where

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

2.2 Sectorial Slot Pac-man Antenna

The proposed sectorial slot Pac-man antenna was inspired by equation (1) and equa-tion (2) and with modification from the idea of circumference mathematical model-ling equation (1)-(2), the equation can used to predict the operating frequency of the 1st and 2nd resonant frequency by using equation (3) and equation (4). The idea of modelling the sectorial slot section, was rely by replacing the sector slotted circular patch by two equivalent circular patches of circumferences $C_1$and C_2. The circum-ference of C_1 is the total perimeter of the circular patch with sector slot and its corresponding resonance frequency would be fr_1, the lower resonance frequency of the proposed design. Similarly the circumference of C_2 is the length of the major arc of the sector-slotted circular patch and its resonant frequency would be fr_2, the second resonance of the proposed design .The general equation with c is the speed of light, ε_{reff} is the effective permittivity by two layered of circular patch.

$$f_{r1} = \frac{1.841 * C}{P_e\sqrt{\varepsilon_{reff}}} \quad (3)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r \varepsilon_{r1}(h+h_1)}{\varepsilon_r h_1 + \varepsilon_{r1} h} \quad (4)$$

The effective circumference of the equivalent circular C1 (sectorial) and C2 (big cir-cular) is given by equation 5.

$$p_e = p_1 \sqrt{1 + \frac{2h}{\pi R \varepsilon_{re}(In\frac{\pi R}{2h} + 1.7726)}} \quad (5)$$

Where

$$i = \begin{bmatrix} 1 \rightarrow P_1 = C_1 = R(2\pi - \alpha) + 2R \\ 2 \rightarrow P_2 = C_2 = R(2\pi - \alpha) \end{bmatrix} \quad (6)$$

R is the radius of patch, while α is slot angle of the Pac-man antenna, C_1 is small circumference (sectorial) and C_2 is the other side of circumference.

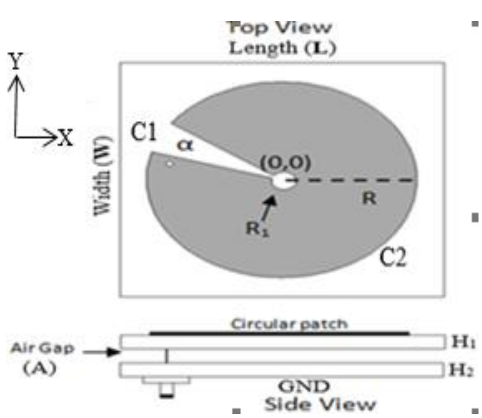


Figure 2 Proposed sectorial Pac-man antenna

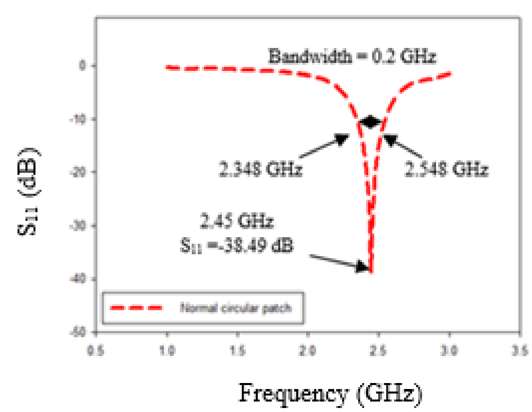
The design of the sectorial maintained the physical design of normal circular patch antenna like Figure 1. The reason was to see the possibility of sectorial slot to function as element to produce dual band characteristic while enhance the bandwidth. Besides that, the proposed of small circular slot (R1) to control the frequency to shift up and down depend on radius of the R1. In order to shift down the desired operating fre-quency the size of R1 must be reduced and vice versa. Each 0.5 mm increment of the size R_1 will increase the operating frequency about 180Mhz, this was due to decre-ment of surface area of the patch. Figure 2 above indicate the location of R1 at the center of the circular patch with notation coordinate of (0, 0). The design on both normal circular and proposed sectorial slot Pac-man patch antenna were revealed in Table 3, where ANT 1 (Normal circular patch) and ANT 2 (Sectorial slot Pac-man antenna).

(3) **Table 3** Antenna dimension

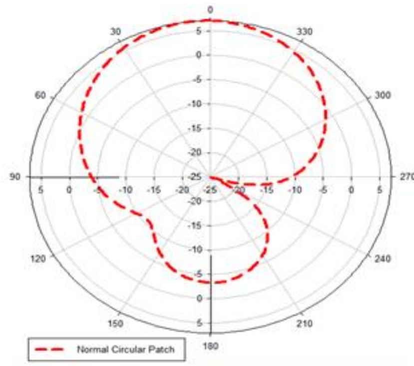
Parameter	ANT 1	ANT 2
Length (L)	66 mm	
Width (W(4))	66 mm	
Radius (R)	29.2 mm	
Thickness (H_1,H_2)	1.6 mm	
Air Gap (A)	5.2	
Feed point coordinate	(-23,3)	
Tuning radius (R_1)	0	2.8 mm
Slot angle (α)	0	18°

3.0 RESULT AND DISCUSSION

The overall design was based on circular patch antenna the addition of sectorial slot was to make the antenna perform as dual band, while the tuning small circle R1 was to perform as frequency adjuster or frequency tuner to fine tune the desired frequen-cy instead of adjusting the whole circular structure of the design. Figure 3a below show the simulated S11 result by using CST software, while Figure 3b indicate the radiation pattern of the design.



(a)



(b)

Figure 3 Normal circular patch antenna: (a) S_{11} (b) Radiation pattern

As shown on Figure 3a, the bandwidth was reported about 0.2 GHz with covered the frequency 2.348 GHz to 2.548 GHz at S11 below -10 dB. The centre frequency for this antenna was design at 2.45GHz with reported S11 value -38.49dB. For radiation pattern as shown on Figure 3b the Gain was reported about 7.9 dBi with main lobe direction is 359.0 degree. The side lobe level was at -10.2 dB. Only single band reported for nor-mal circular patch.

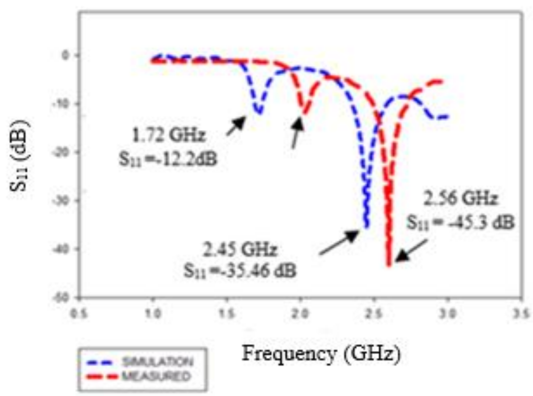
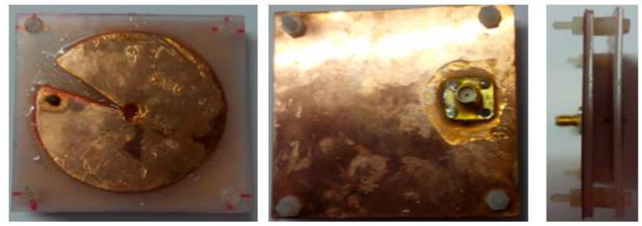


Figure 4 S11 result of Pac-man antenna

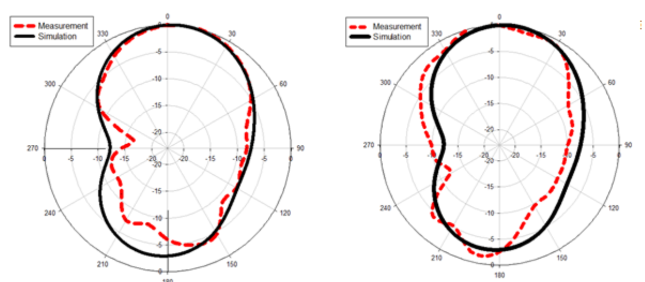
Figure 4 above show the S11 plot for proposed Pac-man antenna and from this plot the bandwidth obtain by the simulation on 2.45 GHz band was 0.234 GHz (2.354GHz -2.588 GHz) while for the 1.7GHz band the bandwidth reported was 0.048GHz (1.694GHz – 1.742GHz). Since the simulation result fulfil the desired re-quirement that function in dual band the antenna were then fabricated like Figure 5 below.



(a) (b) (c)

Figure 5 Proposed fabricated view Pac-man antenna design: (a) Front (b) Back/Ground (c) Side

The antenna like Figure 5 were then measure their S11 value and most of the result plot were shown in Figure 4. On the upper band the resonant frequency were reported at 2.56GHz with S11 value -45.3 dB. The bandwidth reported at this band was 0.229 GHz (2.71GHz -2.481GHz). The frequency reported resonant frequency seem to be shifted about 0.11GHz (2.56GHz -2.45GHz) to the upper frequency, while for the lower band the resonant frequency was seen at 2.1GHz with S11 value was -12.5dB. The bandwidths for lower band frequency appear to be 0.26 GHz (1.92 GHz – 2.18 GHz). The radiation pattern between simulation and fabricated antenna on both band were given in Figure 6a and Figure 6b.



(a) (b)

Figure 6 Radiation Pattern for Pac-man antenna at: (a) 2.45GHz (b) 1.75GHz

Most of the result for Pac-man antenna design were given in Table 4.

Table 4 simulation and measurement result

Parameter	Simulation Circular	Pac-man	Measurement Pac-man
Resonant Frequency (GHz)	2.45	1st Band =2.45 2nd Band =1.72	1st Band = 2.56 2nd Band = 2.1
S_{11} (dB)	-38.49	1st Band =-35.46 2nd Band =-12.2	1st Band =-45.3 2nd Band =-12.5
VSWR	1.05	1st Band =1.02 2nd Band =1.1	1st Band =1.01 2nd Band =1.08
Gain (dBi)	7.8	1st Band =4.2 2nd Band =7.9	1st Band =4.1 2nd Band =7.8
Directivity Gain (dBi)	8.26	1st Band =5.7 2nd Band =8.4	1st Band =5.3 2nd Band =8.2
Efficiency (%)	89.7	1st Band =67 2nd Band =89	1st Band =64.27 2nd Band =83.75

4.0 CONCLUSION

A new sectorial slot Pac-Man antenna with dual band operation 1.7 GHz (wireless personal communication) and 2.45GHz (WBAN) was simulated, fabricated and measured by using Polypropylene substrate. It has been simulated with CST cad simulation software, comparable with normal circular type patch antenna to see the significant of adding the sectorial slot angle (R) and also tuning small circle (R1) to enhance the design from single band to dual band operation with most of the physical design for normal circle patch antenna maintained. The air gap method was chosen since the design provide more bandwidth and gain. The target of the Pac-man design was to enhance the frequency band operation hence wider the bandwidth achieved by implemented the sectorial slot and tuning small circle at the center of the Pac-man antenna.

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