A Slotted Planar Inverted-F Antenna (PIFA) with Capacitive Loaded at 960 MHz

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Abstract: **A slotted planar inverted-F antenna (PIFA) with additional of shorting pin and capacitive loaded was designed and analysis in this paper. This antenna is feed by a 50Ω coaxial feed and covers the GSM900 frequency range with return loss value less than -10dB. A substrate of low dielectric constant, ε_r equal to 4.7, thickness of 1.6 mm and tangent loss of 0.019 was selected to obtain a desired radiating pattern that meets the demanding bandwidth specification. The design was verified using Computer Simulation Tool (CST) Microwave Environment software 2011. The slotted PIFA antenna is measured using Vector Network Analyzer (VNA). Both the simulation and experimental results are compared and analyzed from the return loss value, gain improvement, radiation pattern, bandwidth enhancement and voltage standing ratio (VSWR) value. The simulation and measurement result was resemble as nearly omni-directional radiation pattern characteristic, improved antenna gain, improved back lobe, bandwidth and return loss.**

Keywords: **PIFA antenna, slots, capacitive loading, low frequency applications**

I. INTRODUCTION

The modern mobile wireless communication systems require the antennas for different systems and standards with characteristics like miniature and compact size, broadband, multiple resonant frequencies and high gain to create an effective communication link. Because of many attractive features such as easy fabrication, low manufacturing cost and simple structure [1], Planar Inverted F Antenna (PIFA) have attracted many researcher to study about this antenna.

PIFA can be designed in a variety of shapes in order to enhanced gain and bandwidth for multiband frequency application dependent of the operating frequency. Fig. 1 shows the basic structure of PIFA antenna. The basic PIFA antenna consists of a ground plane, a radiating patch, a feed wire attached the ground plane and radiating patch, and a shorting plane connected between the ground and the radiating patch. The planar inverted-F antenna has advantages when dealing with the shortfalls of the $\lambda/4$ monopole antenna in mobile communication applications [2]. The antenna also has a high degree of sensitivity to both vertically and horizontally polarized radio waves, thus making the Planar Inverted-F Antenna ideally suited to mobile applications. In addition, PIFA's can reduce the possible electromagnetic energy absorption by the mobile handset user's head, because of relatively smaller backward radiation toward the user and reasonably efficient and free of excessive radiation illuminating the user's head (low SAR value) [3].

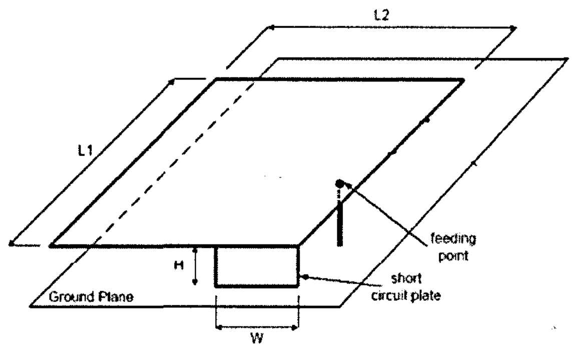


Fig.1: Geometry of the proposed PIFA [4].

II. PROBLEM STATEMENT

A compact PIFA antenna is very attractive for mobile handset due to its small and low-profile structure, simple design, and ease of fabrication. There are several miniaturization techniques used to have compact antennas, for example, the slots insertion in the radiation element to create new resonances, to lengthen the electric lengths and to create new resonators [1]. It create a capacitive effects distributed all around the slot. These effects can reduction the frequency of the resonators operating modes.

But some major drawbacks of PIFA such as large volume at low frequency, lower gain and narrow bandwidth have limited PIFA applications. In order to overcome this drawbacks, many techniques have been proposed to achieved wideband or multiband of PIFA such as introducing slots, capacitive loaded, additional shorting pin and loading a dielectric material with high permittivity [5]. The common point of all these actions is to create capacitive effects distributed all around the slot. These effects are taken into account in the reduction in frequency of the resonators operating modes [6]. Furthermore, it is found that a little adjustment of the shape can make it work in the demanded resonant frequencies [3].

In this paper, a slotted PIFA antenna with capacitive loading is proposed to enhance gain and broaden bandwidth was designed to operate at the frequencies of GSM900 using CST Microwave Studio simulation software. By introducing slots on the patch, miniaturization of the PIFA is achieved [1].

Among other types of radiators, PIFA Antennas have been utilized in diverse areas of communication systems, exhibiting low profile structure and flexibility in impedance matching [7].

III. ANTENNA DESIGN

PIFA is generally a λ/4 resonant structure achieved by short-circuiting its radiating patch to the antenna's ground plane using a shorting plate. Their structure is similar to a shorted rectangular microstrip patch antenna with air as dielectric [8]. They can resonate at a much smaller patch size for fixed operating frequency compared to the conventional patch antenna. The parameters of PIFA can be adjusted by varying the dimensions with respect to other [8]. TABLE 1 summarizes the effects of different PIFA design parameter on its characteristics [9].

TABLE 1: THE EFFECT OF PIFA PARAMETERS ON ITS CHARACTERISTICS.

PARAMETER	EFFECT
Height	Control bandwidth. An increase in h widens the bandwidth.
Width	Control impedance matching
Length	Increase inductance of the antenna and determine resonant frequency
Width of shorting pin	Affect on the anti-resonance and increase bandwidth
Feed position from shorting pin	Affect on the resonance frequency and bandwidth

PIFA can be made to operate in multiband with etched slot on the radiating element [8]. The slot in the radiating element gives a more compact design for the antenna and thus reduces the volume occupancy. For a standard, coax-fed, quarter-wave microstrip patch antenna, the operating frequency can be approximately determined from the length of antenna patch as follows:

$$L_1 \approx \frac{\lambda_d}{4} = \frac{1}{4} \cdot \frac{c}{f\sqrt{\varepsilon_r}} \qquad \text{..................(1)}$$

$$L_2 = \frac{c}{4f}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad \text{..................(2)}$$

$$f = \frac{1}{4}\left(\frac{c}{L_1 + L_2}\right) \qquad \text{..................(3)}$$

Where,

c = free space velocity of light, 3×10^8 m/s
f = frequency of operation
(L1+L2) = total length, x

$$x = \frac{c}{4f}$$

Where λd is the wavelength inside the substrate. The lengths L1 and the width L2 can be subsequently optimize to obtain an improved frequency match by do optimization procedure through experimental trials. In designing a PIFA antenna, the following formula was implemented as an outline in designing procedures. The width and the length, L1 and L2 of the patch that can be calculated as equation (3),

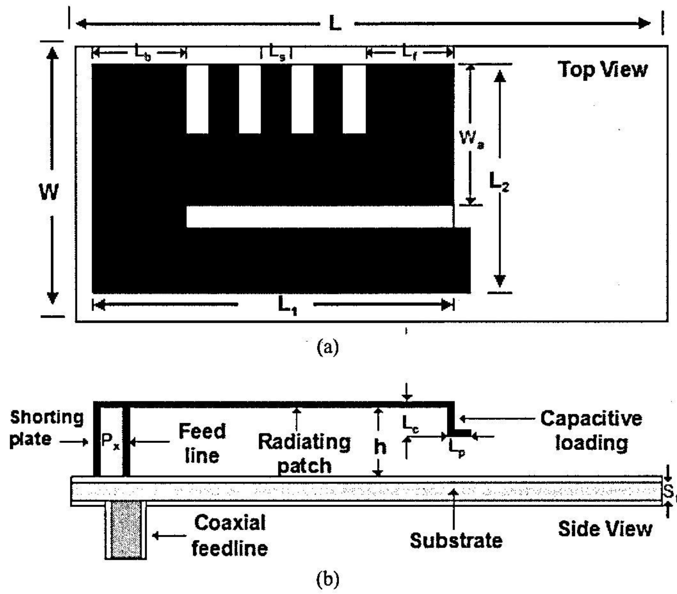


Fig. 2: PIFA structure for a) Top view of the antenna
b) Side view of the antenna

From formula (3), the proposed configuration of PIFA is design such as Fig. 2 above. W=32mm and L=100mm represent the width and the length of substrate respectively, and St is the thickness of the substrate. L1=53mm and L2=30mm represent the width and length of the radiated patch at the top. A ground plane with same size of substrate covers all part of the substrate. The patch and the ground plane are connected by a shorting plane with a height of h=10mm. The detail parameters are shown in TABLE 2 below.

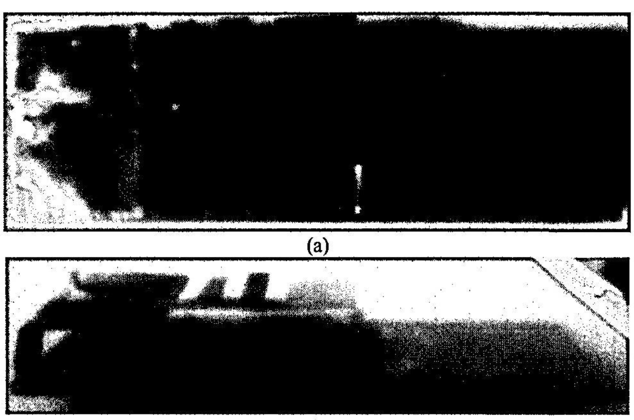
TABLE 2: PARAMETER AND THEIRS VALUE

Parameter	Value (mm)	Parameter	Value (mm)
[illegible]	100	[illegible]	19
W	32	Py	15
L1	53	Px	3
L2	30	Lb	20
Ld	35	Lf	16
[illegible]	4	Lc	4
[illegible]	7	Lp	2.5
Ls	4	h	10
[illegible]	9		

The essential parameter specifications for the design of the rectangular planar inverted F antenna are: Dielectric constant = 4.7, substrate (FR4) thickness (St) 1.6mm, loss tangent = 0.019. The coaxial feed line is designed so as to have a characteristic impedance of 50Ω and is symmetrically located under the metallization of the copper plate ground plane. One method of reducing PIFA size is simply by shortening the antenna with adding a shorting pin. The shorting pin of size W=6 and L=10mm respectively consists of a vertical conducting strip and it used not only to connect between the patch and ground, but also to support the whole antenna. The 50 Ω coaxial probes has a radius of 0.55mm are fed near the shorting pin. The shorting pin is positioned at the corner of the planar element to yield a maximum reduction in the antenna's size [4]. The narrower the shorting plate, W the lower the resonant frequency of the PIFA [3]. Even though this approach affects the impedance at the antenna terminals such that the radiation resistance becomes reactive as well. This can be compensated with capacitive top loading. The capacitive loaded of size 7mm x 2.5mm are added at the right corner of the radiating patch as shown in Fig. 2 to reduces the resonance length from λ/4 less than λ/8 at the expenses of bandwidth and good matching [10]. It is formed by folding the open end of the PIFA toward the ground plane and adding a plate (parallel to the ground plane) to produce a parallel plate capacitor for the load.

IV. RESULT AND ANALYSIS

The design procedure of proposed antenna is started with a classical PIFA design techniques using CST simulator, aiming the best impedance matching of 50Ω and return loss less than -10dB with operation frequency of 960MHz. An optimization process must consider the location and size of shorting plate, feeding point, capacitive loaded and number of slot. After an optimized design was obtained, the proposed antenna was fabricated on an FR-4 substrate with copper as radiating patch and then fed by a SMA connector to connect to the Rohde & Schwarz ZVA40 VNA 10M-40GHZ for measurement process. Fig. 3 shows the fabricated of slotted PIFA antenna.



(a)

(b)

Fig. 3: A fabricate slotted PIFA structure for a) Top view of the antenna, b) Side view of the antenna

The first objective is to compare the simulation result of different number of slots at radiating patch in terms of return loss, VSWR, gain, frequency and bandwidth. Simulated results for each number of slots are tabulated in TABLE 3. From TABLE 3, the best simulation result with improved gain, VSWR, bandwidth and miniature size is by using 5 slots.

TABLE 3: TABULATED RESULTS OF SIMULATED RETURN LOSS, FREQUENCY, VSWR, GAIN AND BANDWIDTH

Num of slot	Parameter				
	Return [illegible]	Freq [illegible]	[illegible]	Gain [illegible]	[illegible]
[illegible]	-42.54	0.9816	1.015	2.733	112.32
[illegible]	-35.03	0.9744	1.036	2.748	105.6
[illegible]	-42.29	0.9696	1.015	2.759	102.24
[illegible]	-42.35	0.9677	1.015	2.781	99.36
[illegible]	-40.25	0.9648	1.019	2.794	96.48
[illegible]	-30.51	0.96	1.061	2.811	92.16

Based on simulation results, it indicates that each slot designs has return loss value less than -10dB at resonant frequency around 960MHz to 980MHz. As the number of slot is increasing, the gain is averagely increased up to 0.013dB and reach up to 2.811dB for 5 slot PIFA antenna. The result of proposed slotted PIFA antenna with more slot shows that antenna gain is improved compared to conventional antenna and less slotted antenna. The return loss of -30.51dB, gain of 2.81dB and operated at low frequency of 960MHz is achieved by using 5 slots PIFA antenna. This proposed antenna shows that the gain is increased by 0.078dB from 2.733dB of conventional PIFA antenna. High gain antennas is preferred because it have the benefit of longer range and signal quality is better compared to low gain. Since PIFA antenna radiates an omni-directional radiation pattern, it emits radiation with about the same power in all direction. This gain value is accepted because of PIFA antenna generate a small value of gain. From TABLE 3, the return losses versus frequency graph are plotted to compare each number of slots for proposed PIFA antenna and presented in Fig. 4.

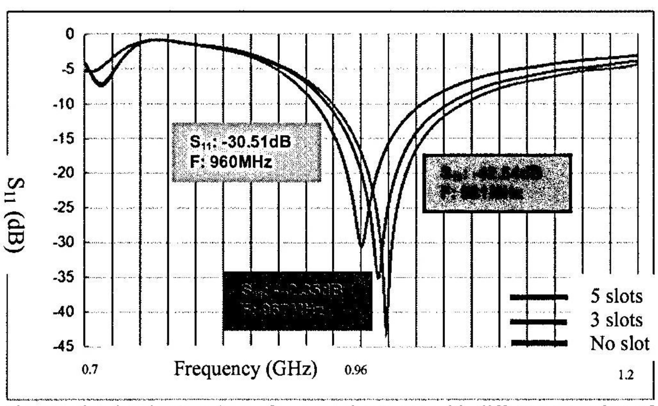


Fig. 4: Simulated return loss of proposed antenna with difference number of slots

From Fig. 4, it shows that a compact PIFA antenna can be achieve by manipulating a slot at radiating patch. The gain and bandwidth also improved with addition of slots. However it suffers the return loss result since it has a smallest return loss value compared to other patch with fewer slots.

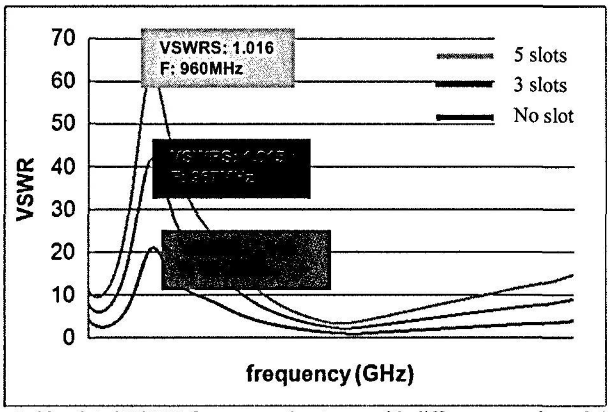


Fig. 5: Simulated VSWR for proposed antenna with difference number of slots

Voltage Standing Wave Ratio (VSWR) is an important parameter that determines the quantity of power delivered to an antenna. An antenna with small value of VSWR show that it matched to the transmission line and the more power is delivered to the antenna. The minimum value of VSWR is 1.0, in which case none of the power is reflected, which is the ideal case. From the Fig.5, it is observed that the smallest VSWR is 1.015 operated at 981.6MHz, 969.6MHz and 967.7MHz. But the best simulated VSWR results of proposed slotted PIFA antenna is 1.061 which slightly higher than the lowest VSWR value. However it is accepted since it is still in VSWR range.

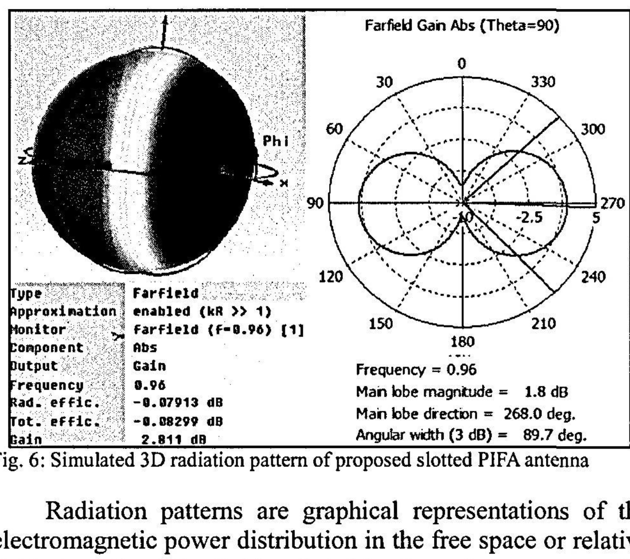


Fig. 6: Simulated 3D radiation pattern of proposed slotted PIFA antenna

Radiation patterns are graphical representations of the electromagnetic power distribution in the free space or relative field strength of the field radiated by the antenna represented in 3D graph or polar. This graph shows the main lobe, side lobe and back lobe of the design antenna. The simulated far-field radiation pattern as shown in Fig. 6 indicate the value of gain and the forward directional pattern of proposed slotted PIFA antenna. From the far-field radiation pattern above, it can be observed that this antenna produced a nearly omni-directional radiation pattern with front to back ratio equally to 1. The front-to-back ratio of an antenna is the proportion of energy radiated in the principal direction of radiation to the energy radiated in the opposite direction. A high front-to-back ratio is desirable because this means that a minimum amount of energy is radiated in the undesired direction.

TABLE 4: SIMULATION RESULT FOR VARIED SIZE AND HEIGHT OF CAPACITOR LOADED

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5 mm	-14.47	0.93	2.883	76.23
7 mm	-30.51	0.96	2.811	92.16
9 mm	-24.23	0.97	2.758	113.57
[illegible]				
(2 x 5) mm^2	-37.1	0.96	2.798	126.73
(2.5 x 7) mm^2	-30.51	0.96	2.811	92.16
(4 x 8) mm^2	-26.78	0.95	2.819	89.93

The second objective is to analyze the effect of capacitor loaded size and height from upper ground of slotted PIFA antenna. TABLE 4 above shows the simulation results for varied size and height of capacitor loaded. The tabulated results show that the capacitor loaded size and height plays an importance role in optimization process. The lower height of capacitor loaded position is suitable for reconfiguring low frequency antenna (higher gain but lower return loss and bandwidth). Meanwhile higher position of capacitor loaded generates a higher resonant frequency, wider bandwidth but decrease in gain value. The size of capacitor loaded also influent the simulation result. A smaller size of capacitor loaded increased return loss value and bandwidth but decreased the gain value. However by choosing a bigger size of capacitor loaded, the value of gain improved but it suffer from lower value of return loss and bandwidth. So a smart choice toward all antenna parameter is needed to optimize and design a best slotted PIFA antenna.

The measured result of return losses of the proposed slotted PIFA antenna compared with the simulation is shown in Fig. 7 below. As mentioned before, the simulation result indicates that the proposed antenna has operation frequency at 960MHz and return loss of -30.51dB. It can be seen that the measured frequency response fall at two resonant frequencies which is 745MHz and 898MHz. It occurs because of the slots on the radiating patch. The measured result shows that the return loss value shifted 6.5% to the left with reduced value by 34% to -19.98dB. Even though this measurement result still showing that this antenna have a wide bandwidth about 85dB.

Deviations may be partly due to the inaccuracies in measurement of antenna diameter; in antenna fabrication process such as during soldering and losses occurred because of the FR-4 board itself. However, the measured result still in accepted range since GSM900 range is (880MHz - 960MHz).

Return loss is one of the important parameters that indicate the difference between forward and reflected power measured at any given point in a wireless communication system. It should be as large a negative number as possible. The smaller value of return loss, the better it is. This is because to ensure that more than half power are transmitted to the destination. However the measured result shows and decreasing value of return loss compared to simulation value, but still below reference value of -10dB.

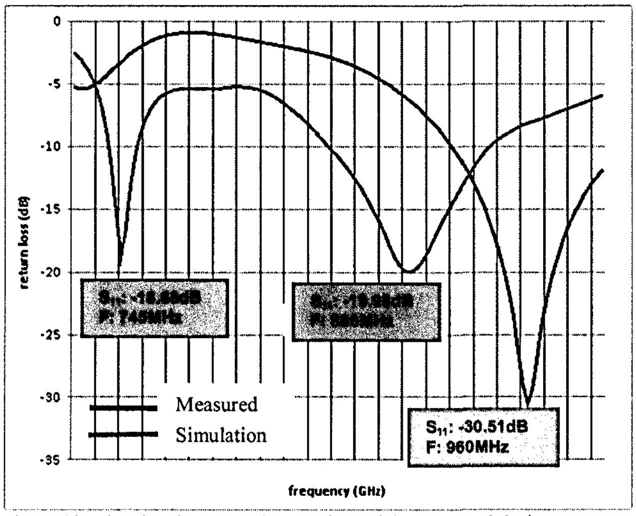


Fig. 7: Simulated and measured return loss of the proposed design antenna

Figure 8 shows a voltage standing wave ratio of measurement result. From Fig. 8, it shows that VSWR value increased to 1.2 compared to simulation value of 1.016. For the practical applications of microstrip antenna, VSWR = 2 is acceptable as the return loss would be -9.54dB or -10dB.

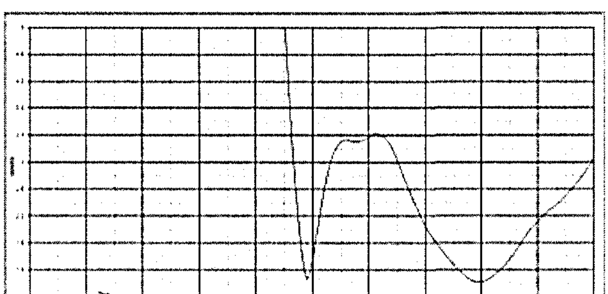


Fig 8: Measured VSWR of the proposed design antenna.

V. CONCLUSION

A slotted PIFA antenna with capacitor loaded has been presented for 960MHz. The simulation tool CST is utilized to perform the antenna design and optimization process. This antenna consists of slotted radiating patch, capacitor loaded and shorting pin. The effect of these three elements has been studies in improving gain, return loss, bandwidth and VSWR value. The best design of slotted PIFA antenna with capacitor loaded is with 5 slots at the radiating patch. With the appropriate design method, suitable material selection and strong theoretical knowledge, it is possible to design a slotted PIFA antenna with capacitor loaded at the designated operational frequency. No antenna is devoid of disadvantage. PIFA has disadvantages, but clearly its advantages outweigh the disadvantages. The result of proposed antenna shows that the radiating patch size is reduced; antenna performance is better compared to conventional PIFA antenna, improved gain and bandwidth of the antenna.

For future development, more techniques should be implies to improve the performance of this antenna such as adding an array of meta-materials on the upper ground plane.

ACKNOWLEDGMENT

The author would like to first thank her supervisor, Dr. Mohd Tarmizi b. Ali for his strong support and advices. Special thanks also to friends and members in Microwave Technology Centre (MTC), Universiti Teknologi Mara (UiTM) for their helps in completing this project.

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