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AN EMPIRICAL APPROACH TO DESIGN A PIFA ANTENNA

Sami. M. Sharif, Iman D. Abdalla

Dept. of Electrical and Electronic Eng. Faculty of Eng. University of Khartoum
Khartoum, Sudan
(E-mail: smsharif@uofk.edu, Iman.da@postgrad.uofk.edu)

Abstract: A parametric study is performed on a Planar Inverted F Antenna (PIFA) that operates at the frequency of 900 MHz The effect of the variation of the parameters on the bandwidth (BW) is analyzed. The study is performed using the Finite Element Method (FEM) numerical technique and the High Frequency Structural Simulator (HFSS) software.

Regression analysis is applied on the data obtained from the simulation to present a mathematical model that estimates the fractional bandwidth FBW. An empirical equation that predicts the FBW of the PIFA is introduced. The equation uses the effective design parameters; substrate material thickness and ground plane dimensions as predictors. A comparison between the results calculated by the equation and the results obtained via simulation is carried out for validation purposes. The results are found to be very close except for the values corresponding to substrate thicknesses above 6mm. Moreover, a second simulator using a different numerical technique is used for further verification.

A PIFA that operates at the 900 MHz frequency is fabricated. The results obtained from the physical measurement are compared with the results calculated by the empirical equation and the results obtained from the simulation. Close compatibility is observed.

Keywords: *PIFA, FBW, Resonant frequency.*

1. INTRODUCTION

Planar inverted F antenna is a rectangular micro strip antenna MSA that resonates at quarter wavelength. It is a development of the conventional half-wavelength MS antenna where the size is reduced. It consists of a radiating element on top of a ground plane with a short plate or pin connecting the radiating element to the ground plane, a substrate material filling the gap between the planes and a feeding mechanism. Its shape resembles the letter F when inverted [1].

Planar Inverted-F Antenna PIFA is one of the strongest candidates for most modern wireless applications; especially hand held devices due to its compact size, multiband operation capability, omni-directional radiation pattern and low Specific Absorption Rate (SAR) value among other properties [2, 3].

However, the design of PIFA remains a big challenge and an area of continuing research owing to the very narrow BW nature of the PIFA (around 1-2%), complex structure and lack of analytical models that can evaluate the performance and BW precisely. The study of PIFA has attracted the attention of researchers with the bandwidth BW being a major research area.

Many of the researches carried out parametric studies of PIFA and explained how the design parameters affect the BW and other performance characteristics [4-6]. Most of the studies have been used to develop new designs with enhanced BW or multiband capability [7-9]. Few papers presented developed mathematical models or equations that predict antenna characteristics like resonant frequency or input impedance [10, 11]. A development for an analytical model for PIFA analysis based on the conventional transmission line model and the cavity model is presented in the works of [12-13].

These models gave good formulas for evaluating the electric and magnetic fields and the input impedance of the PIFA, but they Lacked the accuracy due to Assumptions used such as infinite ground plane which is not the case in most applications, limited substrate height (<0.01λ), micro Strip or coaxial feed configurations only. This paper presents a parametric study on a PIFA antenna that operates on the 900 MHz frequency band. An empirical equation that can estimate a prediction of the fractional bandwidth (FBW) of the PIFA is introduced. The equation is based on the design parameters, thus it simplifies the evaluation of the performance and aids in the design process.

2. ANTENNA STRUCTURE

An initial model of a PIFA antenna that operates at the 900 MHz frequency band is designed to perform the parametric study. The basic structure consists of a radiating patch, ground plane, substrate material and a feeding mechanism. Micro-strip feed type with the standard 50 ohm transmission line is used, since it is one of the most widely used feeding techniques and it is easy to model and fabricate [14]. Substrate RT/Duroid 5880 with dielectric constant ε_r = 2.2 and loss tangent = 0.0009 is assumed because it has a low dielectric constant. The substrate thickness used is 1.574mm. The patch is located at the edge of the ground plane since this gives better BW [15]. The following equation is used to determine the initial values for the dimensions of the radiating patch [16].

$$L_{P}+W_{P}-W_{sh}-h=\lambda/4 \qquad (1)$$

Where λ is the wavelength, L_p = patch length, W_p = patch width, W_{sh}=short plate width and h=substrate height

$$\lambda=c/f_r\sqrt{\varepsilon_r} \qquad (2)$$

Where f_r= resonant frequency, c= speed of light, ε_r is the dielectric constant.

The following dimensions are used: patch length L_p = 16.13 mm, patch width W_p = 40 mm, ground length L_g=120mm, ground width W_g= 40mm and the short plate width W_{sh}=1mm, see Fig 1.The distance between the feed plate and the short plate is varied to obtain impedance match.

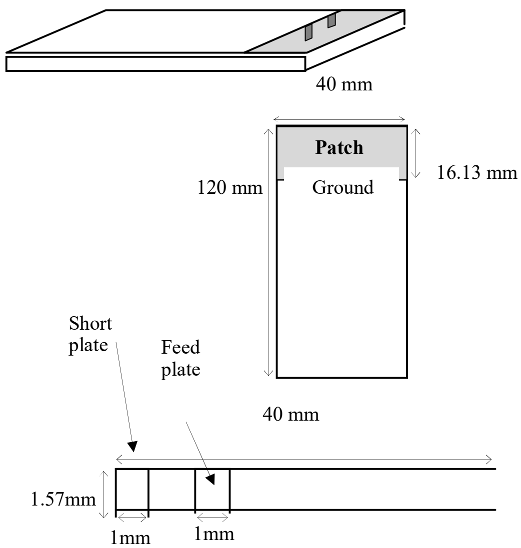

Fig .1. PIFA Antenna

3. Parametric Studies

A parametric study is performed on the parameters that have a significant effect on the BW with negligible effect on the frequency It is found from previous studies that the parameters with significant effect on the BW and negligible effect on the resonance frequency are the substrate height and the ground dimensions [17].

The parametric study is performed on these effective parameters to analyze their effect on the BW. FEM numerical technique is used via the HFSS simulation software. The procedure adopted for this study is that only one parameter is changed at a time while all other parameters are held constant. The substrate height is varied from 1mm to 10 mm, the ground width is varied from 40mm to 50mm and the ground length is varied from 100 to 150mm. Different sets of parameters are taken to form a large collection of data. (The value of obtained resonance frequency is in the range of 0.89 GHz and 0.91 GHz, and in very few runs it is around 0.92 GHz).

The BW is measured at the value where return loss = 10 dB. FBW is calculated using the following equation [16]:

$$FBW = BW/f_c \qquad (3)$$

Where f_c is the central frequency.

Figs 2 (a) and (b) show the effect of the substrate height h on the FBW for different values of ground dimensions. It is clear that the relation between FBW and h is linear, where FBW increases with increase in h. Figs 3 (a) and (b) represent a sample of the results of the variation of ground width W_g, it is also clear that a linear function represents the relation between the FBW and W_g, where FBW decreases with increase in W_g. Figs 4 (a) and (b) represent a sample of the results of FBW with the variation of ground length L_g for different values of ground width and substrate height. A polynomial relation between FBW and the ground length L_g is observed.

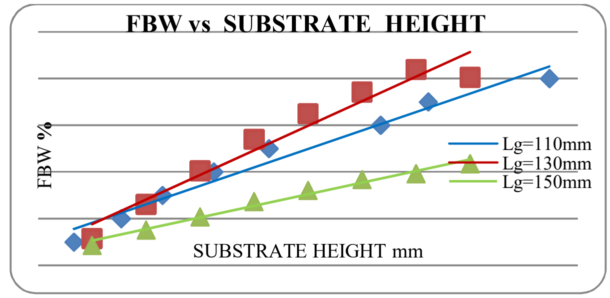

Fig .2. (a) FBW vs. Substrate Height (Various L_g values)

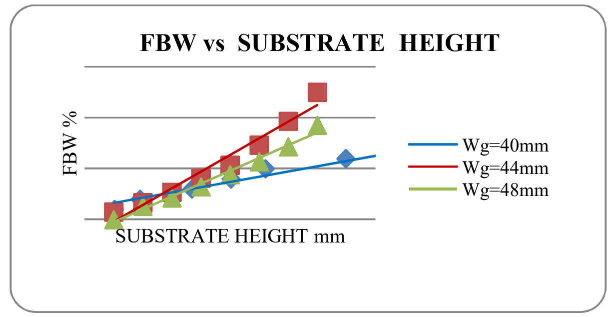

Fig. 2. (b) FBW vs. Substrate Height (Various W_g values)

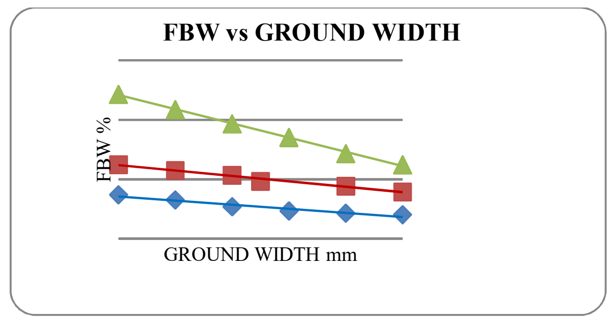

Fig .3. (a) FBW vs. Ground Width (Various h values)

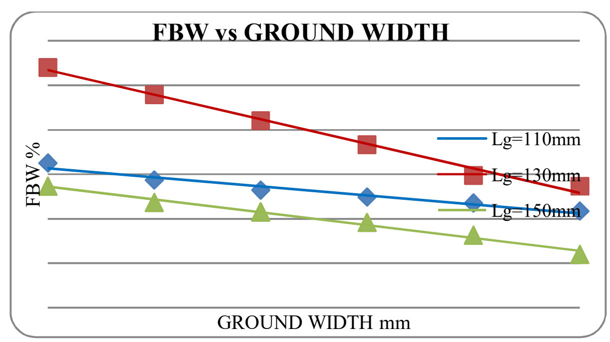

Fig .3. (b) FBW vs. Ground Width (Various L_g values)

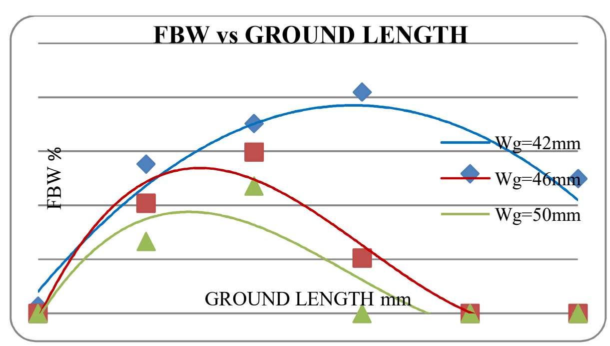

Fig .4. (a) FBW vs. Ground Length (Various W_g values)

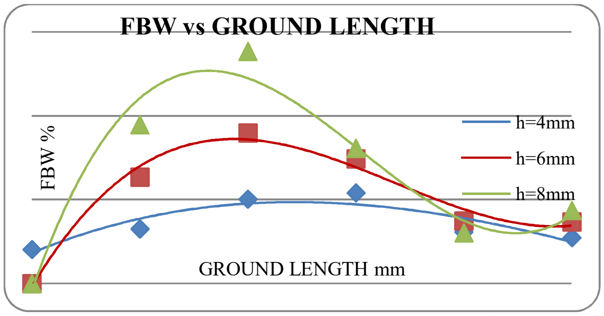

Fig .4. (b) FBW vs. Ground Length (Various *h* values)

4. Empirical Equation

Regression analysis is applied on the generated data to build the mathematical model. FBW represents the dependant response variable to be predicted, the substrate height, ground width and ground lengths represent the independent predictors or regressors.

Considering Figure 2 and 3 in the previous section it is clear that there is a linear relation between the FBW and the two parameters; substrate height and ground width, so a linear regression model is used. Figure 4 shows a polynomial relation between FBW and the ground length L_g. Polynomials can be expressed as linear regression models as well. The method of least squares LSM is used to estimate the values of the regression coefficients. The following equation is obtained:

$$FBW = \left(-8.757 + 0.15624h + 0.1738L_g - 0.02847W_g - 0.00069{L_g}^2\right)^{1/0.348813} \quad (4)$$

The equation is valid in the following intervals:

Substrate height 1mm< h <10mm

Ground length 100mm< L_g <150mm

Ground width 40mm< W_g <50mm

A comparison between the predicted and the simulated values of FBW is shown in the following line plots. Fig. 5 shows the line plots of FBW vs. the substrate height. The equation is very accurate with smaller substrate heights, at h >7mm the equation is less accurate. At the higher substrate heights the feed position affects the return loss and the BW, and causes a relatively significant shift in the resonant frequency, while at lower substrate heights the feed position affects the return loss only, see Fig 6.

The feed position is a parameter that affects BW at higher substrates. When running simulation tests variable values of feed position were used (to implement the impedance match), but these variations were not included in the equation, because they affect the frequency as well. This explains the difference between FBW values obtained from the simulation and the ones calculated by the equation.

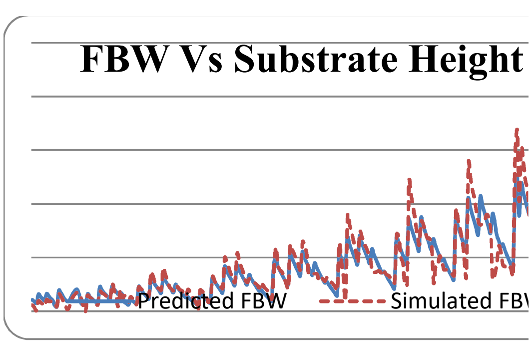

Fig .5. Comparison bet. Predicted FBW and Simulation FBW

A new set of simulation tests is performed using a different simulator; Computer Simulation Technology (CST). CST uses a numerical technique named Finite Integration Technique (FIT) which is based on the FDTD numerical technique. The tests covered the intervals where resonance is accurately achieved and where the empirical equation is accurate i.e. where substrate height *h* is less than 7mm.

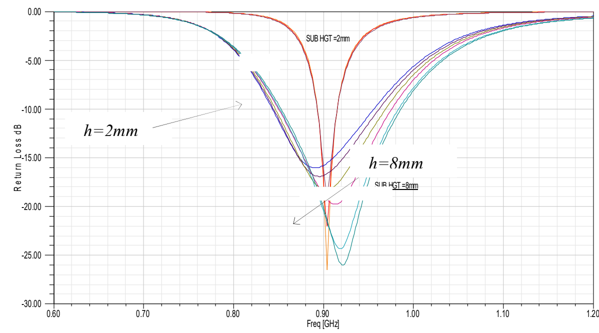

Fig .6. Effect of the Feed Position

Fig 7shows a comparison between the results obtained by the simulation software HFSS and CST and the results predicted by the empirical equation. The three line plots show high similarity, which adds validation to the mathematical model.

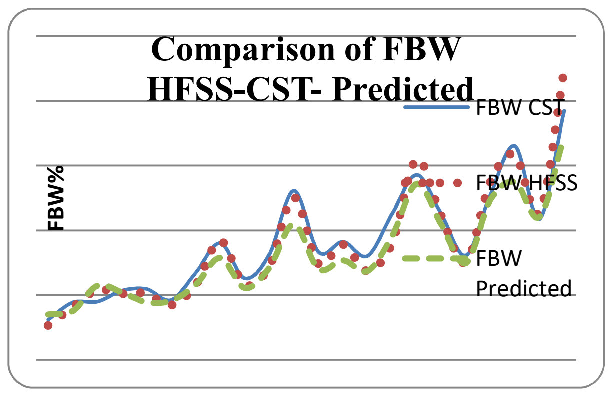

Fig .7. Comparison between Predicted FBW, HFSS FBW and CST FBW

5. FABRICATION

The physical implementation was limited by the availability of the substrate type. The only available substrate was FR4_epoxy with thickness 1.6 only. The mathematical model was built using substrate RG Duroid 5880 which has a dielectric constant of 2.2, while the substrate FR4_epoxy has a dielectric constant of 4.4.

The increase of the dielectric constant shifts the resonant frequency to a lower value, so the dimensions of the antenna were modified in order to obtain resonance at 900 MHz frequency.

The same design of the antenna where the patch width is the same as the ground width was maintained, so the patch width was kept fixed at 40mm and the PIFA modification was applied by decreasing the patch length only.

Table 1. Comparison between Measured Results and Simulation Results.

	Experiment	HFSS
BW	16.07 MHz	16 MHz
Frequency	884 MHz	888.7 MHz
Return Loss	-24.638 dB	-29 dB
FBW	1.82%	1.8%

An antenna with the following dimensions was fabricated

Patch width=40mm

Patch length=6mm

Short plate width=1mm

Ground width =40mm

Ground length=120mm

The Substrate material FR4-epoxy with dielectric constant=4.4 and substrate thickness 1.6mm was used. Copper plates with thickness 35 µm were used for the patch and ground planes.

A vector network analyzer was used to test the antenna and take the measurements of the return loss, BW and the resonant frequency. Accordingly the values of the FBW were calculated.

The following results were obtained from the measurement:

BW= 16.07 MHz

Freq= 884 MHz

Return Loss= -24.638 dB

The above antenna was simulated by HFSS simulator; Fig 8 shows the results of the return loss. Table 1 presents a comparison between results obtained from the simulation and the results obtained from the measurement.

From the Table 1 it is clear that the fabricated antenna has very close results with the simulated results. The small difference in the resonant frequency and return loss is expected, it is due to the impedance matching techniques.

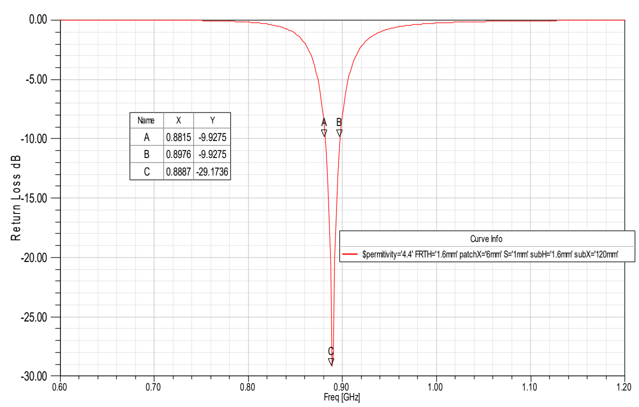

Fig .8. Return Loss

The results of the FBW are compared with the predicted FBW that is calculated by the empirical equation. The results are listed below:

FBW predicted by the equation = 2%

FBW obtained via HFSS simulator = 1.8%

FBW via experimental measurement = 1.82%

The results are quite close despite using a different substrate material and a different patch length, the reason is that a very small substrate height is used; with small substrate heights the effect of patch length and dielectric constant on BW is insignificant.

6. CONCLUSION

A parametric study has been performed on a PIFA antenna that operates at the low frequency band 900 MHz, using FEM numerical technique and HFSS simulation software.

An empirical equation that predicts the FBW of the PIFA antenna has been introduced. The equation is expressed in terms of the substrate height and ground dimensions. A comparison has been performed between the results obtained via simulation and the results calculated by the equation. The equation was found to be highly accurate with substrate heights up to 6 mm, having a difference of approximately no more than 1% between simulated and calculated values of FBW. At higher substrate heights the equation has been less accurate due to the absence of the other parameters that have not been included in the model. These latter parameters have an effect on the BW at higher substrate heights only. Another set of analysis has been performed using a different numerical technique (FIT) and a different simulator (CST simulation software). The results of the CST simulator were compared with the results of the empirical equation and the results of the HFSS simulator for verification. Very good agreement has been recorded between the three sets of results. The designed PIFA was fabricated, and the measured results were compared with results obtained via simulation and results calculated by the empirical equation, close agreement was observed between all results.

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