Original Article

ISSN: 2349 - 4891

International
Journal of Recent Research and Applied Studies

Resonant Frequency Estimation of Single and Double Slot Loaded Multiband Antenna

A. Beno

Associate Professor, ECE Department, Dr. Sivanthi Aditanar College of Engineering, Tiruchendur, Tamilnadu, India.

Received 30th June 2014, Accepted 30th July 2014

Abstract

A single and double slot loaded microstrip antenna is designed to analyze for frequency miniaturization. The antenna is designed with FR4 substrate on a ground plane with dielectric permittivity 4.4. The radiating patch has a dimension of 25 mm × 30 mm fed by a microstrip line feed. The surface current is increased with the slits achieving frequency miniaturization of 60%. A resonant frequency estimating formula for calculation and optimization on single and double slot loaded multiband antenna is presented. The resonant frequency values are found to be in good agreement with calculated, simulated and tested results. The antenna works in multiband covering the major wireless bands.

Keywords: Microstrip Antenna, Resonant Frequency, Parallel Slot, Multiband, Miniaturization.

Introduction

The field of communication has grown past with the developments in the field of electronic industry. In competition the development of the antenna design is also reaching its edge in miniaturization. Among the different methods of miniaturization presented [1] slot antenna is an attractive candidate [2]. The introduction of the slots on radiating patch helps to achieve frequency miniaturization with different shapes and sizes [3-7]. The resonant frequency estimate for dual band antenna is presented for slot perturbated antenna structures [8-12]. The antenna with slots helps to achieve miniaturization and multiband [13-15]. The effects on inducing slits in the radiating patch enable the antenna to operate at further lower frequencies with meandering effect [16-17]. This work presents the slot loaded multiband antenna and its resonant frequency determination using relations for lower and higher bands. The antenna design also exhibit the effect of inserting slots on the patch having variable lengths, width and similar slot arrangements for achieving miniaturization.

Design of Slot Loaded Patch

The rectangular patch antenna is designed to operate at a resonant frequency of 2.4 GHz with a dimension of 27.1 mm × 37.9 mm. It is designed and fabricated with FR4 dielectric as substrate having height h = 2.4 mm on a ground plane having a dimension of 44.1 mm × 54.9 mm using formulas [18]. The antenna achieved a reflection coefficient of -23.03 dB with an impedance bandwidth of 4.9% as given in Figure 1.

Correspondence
A.Beno,
E-mail: beno_csi@yahoo.com, Ph. +9194434 53030

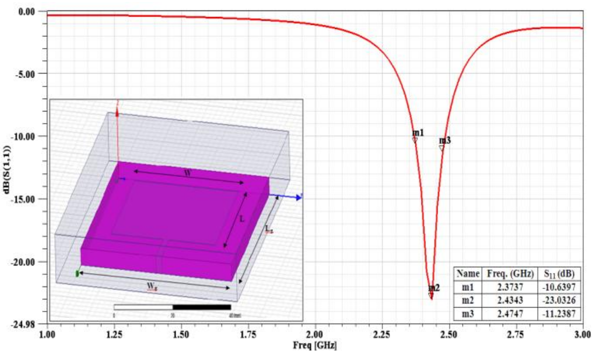

Figure 1. Microstrip Fed Patch Antenna and S_{11} *vs* Frequency Characteristics

The designed structure is introduced with a single slot parallel to the length of the antenna with a width of 1.5 mm and length 15 mm. The antenna structure with the specific dimension is given in the Figure 2.

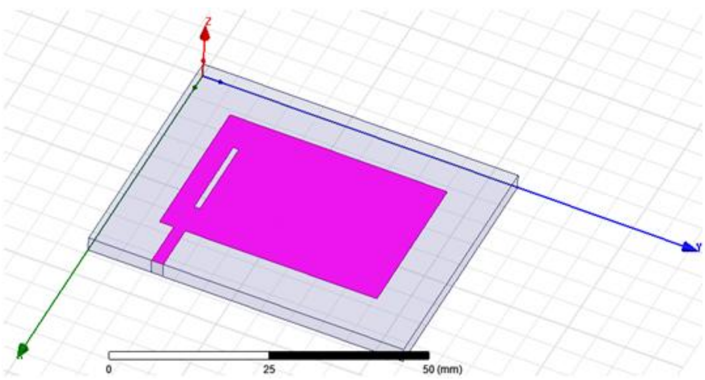

Figure 2. Single Slot MPA with S_L = 15 mm and Width S_W =1 mm

The insertion of the slot in the patch alters the surface current and changes the electrical length of the antenna. The insertion of the slot changes the reactance of the patch antenna influencing the new resonant frequencies. The multiband with new resonating bands is shown in the Figure 3. It resulted with six bands with the lower operating band having the center frequency shifting to 1.81 GHz with S_{11} -13.3 achieving a frequency miniaturization of 24.58%.

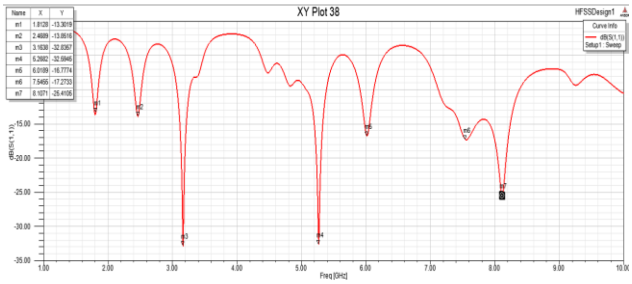

Figure 3. *S_{11} vs Frequency of* Single Slot MPA

Design Formula for Slot Loaded Antenna

A design model equation is derived to determine the lower band frequency and higher band frequency. The resonant frequency of an antenna is obtained using the formula given in equation

$$f_o = \frac{c}{L\sqrt{\varepsilon_r}}$$

where *L* is the length of the antenna. The slot on a patch alters the operating frequency of the antenna by changing the effective electrical length with surface current path. The length of the slot on a patch is usually chosen as half wavelength or quarter wavelength. Based on the length of the slot the antenna operates with new resonant frequencies resulting with dual or multiband characteristics. To estimate the multiband characteristics for the single slot antenna a formula is derived. The resonant frequency formula given in equation (1) is used to obtain the multiband formula including the slot length and width with two constants *n* and *a*. The formula is used to estimate the resonant frequency in the lower band covering till 5 GHz and upper band above 5 GHz.

The lower bands till 5 GHz of the antenna are calculated using the formula as given in equation (2).

$$f_{low} = \frac{c \times S_W}{(5-n) \times (S_L + .a) \times \sqrt{\varepsilon_r}}$$

Where "*c*" is the velocity of light, a constant 3 × 10^8, S_W is the width of the slot, S_L is the length of the slot, ε_r is the dielectric constant of the substrate, "*n*" represent the number of modes varying from 1,2,3,...for lower band and "*.a*" indicate the number of slots available on the radiating patch. To obtain accuracy and minimize the error between the calculated and simulated results the formula is modified to determine the modes of resonant frequency above 5 GHz for the multiband antenna as given by the equation (3)

$$f_{high} = \frac{c \times S_W}{(1+n) \times (S_L + .a) \times \sqrt{\varepsilon_r}}$$

Here "*n*" indicating the possible number of modes in the higher band for the selected slot length S_L and width S_W takes up the values in odd decimals varying as 0.1, 0.3, 0.5, 0.7, etc. and the variable, "*.a*" represents the number of slots available on the radiating patch.

The calculated values for the patch with single slot resulting in the lower and higher bands for the design with slot length S_L = 15 mm and S_W = 1 mm is given in the Table 1 and Table 2.

Table 1. Comparison of calculated and simulated resonant frequency of single slot

n value	f_{low} Calculated (GHz)	f_{low} Simulated (GHz)	% of Error
1	1.89	1.81	4.2%
2	2.36	2.46	4.06%
3	3.15	3.16	0.31%

Table 2. Comparison of calculated and simulated resonant frequency of single slot

n value	f_{high} Calculated (GHz)	f_{high} Simulated (GHz)	% of Error
.1	8.61	8.10	5.9%
.3	7.28	7.54	3.44%
.5	6.31	6.01	4.75%
.7	5.57	5.26	5.56%

The simulated results coincided close with the calculated values with minimum error. Similarly the antenna is introduced with another parallel slot with same dimension and its influence on the resonant frequency is considered for the analysis and estimation. The structure of the antenna with additional slot is given in the Figure 4.

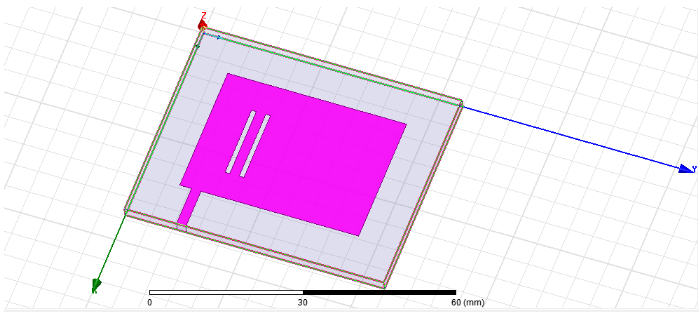

Figure 4. Dual Slot MPA with S_L = 15 mm and Width S_W =1 mm

The added slot again changes the current path on the radiating patch altering the electrical length and influence new modes. The new resonant frequency of the antenna shifts to a lower frequency of 1.77 GHz with a S_{11} of -14.56 dB and results with multiband consisting of six bands as shown in the Figure 5. The parallel slots achieves a frequency miniaturization of 26.25%

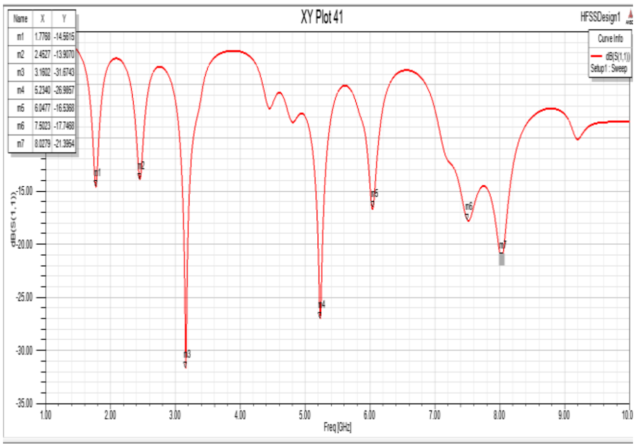

Figure 5. *S_{11} vs Frequency of* Dual Slot MPA

The formula in equation 1 and equation 2 is used to estimate the lower and higher band frequencies. The values of the calculated and simulated are listed for the lower and higher bands of frequencies and given in the Table 3 and Table 4.

Table 3. Comparison of calculated and simulated resonant frequency of dual slot

n value	f_{low} Calculated (GHz)	f_{low} Simulated (GHz)	% of Error
0	1.88	1.77	5.85%
1	2.35	2.45	4.08%
2	3.13	3.16	0.94%

Table 4. Comparison of calculated and simulated resonant frequency of dual slot

n value	f_{high} Calculated (GHz)	f_{high} Simulated (GHz)	% of Error
.1	8.55	8.02	6.19%
.3	7.23	7.50	3.6%
.5	6.27	6.04	3.66%
.7	5.53	5.23	5.42%

Conclusion

The antenna is designed with the fundamental frequency of 2.4GHz and inserted with slots with specific length and width to achieve frequency miniaturization. The antenna inserted with single and double parallel slot antennas is used to analyze the resonant frequency of the antenna. The effect of surface current and electrical length variation helped to achieve multiband operation. The antenna resonant frequency is achieved using a mathematical formulation and error % between the simulated and calculated values were determined. This helps to formulate designs with earlier estimation on resonant frequency.

References

1. David M.Pozar, Daniel H.Schoubert "Microstrip Antennas, The Analysis and Design of Microstrip Antennas and Arrays", John Wiley & Sons, 15 May 1995.
2. R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, London, 2001.
3. A. Beno. D. S. Emmanuel, "High Gain Inverted U Shaped Miniaturized Patch Antenna for Multiband Wireless Applications" *Microwave and Optical Technology Letters* , Vol. 55, No. 1, pp**.** 27-31, January 2013
4. C. Y. Chiu, C. H. Chan, and K. M. Luk, "Study of a small wide-band patch antenna with double shorting walls", *IEEE Antennas Wireless Propag. Lett.*, Vol. 3, pp. 230–231, 2004.
5. A. K. Shackelford, K. F. Lee, K. M. Luk, and R. Chair, "U-Slot patch antenna with shorting pin," *Electron Lett.*,Vol. 37, No. 12, pp. 729–730, 2001.
6. A. Beno, D. S. Emmanuel, "Diamond Shaped Symmetrical Slotted Miniaturized Microstrip Patch Antenna for Wireless Applications" *Journal of Theoretical and Information Technology*, Vol. 48, February 2013.
7. M. T. Islam, M. N. Shakib and N. Misran, "Broadband E-H Shaped Microstrip Patch Antenna For Wireless Systems", Progress In Electromagnetics Research, PIER 98, 163-173, 2009
8. Wang Ren, Zhiguo Shi*,Yu Li,and Kangsheng Chen, "Compact Dual-Band T-Slot Antenna for 2.4/5GHz Wireless Applications", Page No.2493-2497, IEEE 2006.
9. G.F.Khodaei, J.Nourinia, and C.Ghobadi, "A Practical Miniaturized U-Slot Patch Antenna with Enhanced Bandwidth", Progress in Electromagnetic Research B, Vol.3, 47-62, 2008.
10. Prabhakar H.V., U.K. Kummuri, R.M. Yadahalli and V. Munnappa, "Effect of various meandering slots in rectangular microstrip antenna ground plane for compact broadband operation", Electronics Letters, Vol. 43 No. 16, 2nd August 2007
11. A. Kaya, "Meandered Slot And Slit Loaded Compact Microstrip Antenna With Integrated Impedance Tuning Network", *Progress In Electromagnetics Research B, Vol. 1, 219–235, 2008*
12. W. Hu, Y.-Z. Yin, X. Yang, K. Song, Z.-Y. Liu and L.-H. Wen, "A Wide Open U-Slot Antenna with a Pair Of Symmetrical L-Strips For WLAN Applications", *Progress In Electromagnetics Research Letters, Vol. 16, 141-149, 2010.*
13. A. Beno. D. S. Emmanuel, "Quadra Square Edge Slotted Miniaturized Microstrip Patch Antenna for Multiband Applications", *International Journal of*

Wireless Communication, Vol.3, No.7, pp. 536-540, May 2011.

14. C.-J. Wang, Y.-J. Lee, and K.-C. Lee, "A Dual-Band CPW-Fed L-Slot Antenna With Both Linear And Circular Polarizations, *Progress In Electromagnetics Research C, Vol. 21, 229-241, 2011*.
15. Y.-C. Lee and J.-S. Sun, "Compact Printed Slot Antennas for Wireless Dual and Multi-Band Operations, *Progress In Electromagnetics Research, PIER 88, 289–305, 2008.*
16. Heng-Tung Hsu, Fang-Yao Kuo, and Ping-Hung Lu, "Design Of Wi-Fi/Wi-MAX Dual-Band E-Shaped Patch Antennas Through Cavity Model Approach", Microwave And Optical Technology Letters, Vol. 52, No. 2, pp-471-474, February 2010.
17. Mudar A. Al-Joumayly, Suzette M. Aguilar,Nader Behdad, and Susan C. Hagness, "Dual-Band Miniaturized Patch Antennas for Microwave Breast Imaging", IEEE Antennas And Wireless Propagation Letters, Vol. 9, 2010.
18. Vidya Sagar Chintakindi, Shyam.S.Pattnaik, O.P.Bajpal, Swapna Devi, Sastry V. R. S. Gollapudi and Patra.K.Pradyumna, "Parameters Calculations of Rectangular Microstrip Patch Antenna Using Particle Swarm Optimization Technique," IEEE, 2007.