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Compact Tunable and Dual band Circular Microstrip Antenna for GSM and Bluetooth Applications

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ABSTRACT: A Circular Microstrip Antenna with slot cut in it for tunable and dual band operation has been presented. The existence of an electrically small slot along the feed axis or the perpendicular axis changes the resonant frequency of the patch leading to tunability. If both slots co-exist and are of comparable lengths, which equals to greater than half of the radius, dual frequency operation is obtained. A design has been proposed for obtaining dual band operation for GSM 1800/1900 - Bluetooth 2450 MHz. Experiments have been performed to validate the theoretical results.

INDEX TERMS: slotted circular microstrip antenna, tunable microstrip antenna, dual band microstrip antenna, dual band operation

I. INTRODUCTION

Tunable microstrip antennas (MSAs) are used for changing to another nearby frequency for a specific application, wherein instantaneous bandwidth of the antenna is not very large. Likewise, dual band antennas are used largely as they eliminate the need for a separate antenna for two frequencies and at the same time provide good isolation. Frequency tuning in the single layer MSA is achieved by various methods such as; placing electrically small stub on the patch, using shorting posts between patch and the ground plane, using varactor/PIN diodes etc [1-9]. These methods, for tuning the resonance frequency, are also widely used with modifications for achieving dual frequency response and also tuning these two frequencies [2-4, 10-15]. Among all the methods used for tuning the resonance frequency and obtaining the dual band operation, the stub loading technique is widely used. Though, good tuning range and dual band operation is obtained using

stub/stubs loading method, it has an inherent disadvantage. The stub protrudes out from the periphery of the patch, leading to increase in the size of the patch, which limits its application where compact tunable or dual frequency antennas are required. Slot being a complementary structure of the stub, cutting slot/slots inside the patch also gives frequency tuning and dual frequency operation. Slot loaded MSAs have been reported to achieve frequency tuning and also dual band operation [16-22].

In this paper, new configurations of tunable and dual band operation have been proposed by cutting slot either on the axis containing the feed or the axis perpendicular to it in circular microstrip antenna (CMSA). The presence of electrically smaller slot along either of the axes results in change in the resonance frequency of the antenna. The perpendicular slot is located at the position of the current maximum along the periphery of the CMSA. Thus a larger change on the resonance frequency has been obtained. If both the slots of comparable lengths are used simultaneously, for lengths greater than half the radius, dual frequency operation is observed. A practical design for the GSM 1800 MHz-Bluetooth 2.45 GHz has been proposed. The radiation patterns at both the frequencies are in the broadside direction. The simulations have been carried out using IE3D software [23].

II. FREQUENCY TUNABLE CMSA USING SINGLE SLOT

A CMSA with slot placed along the feed axis is shown in Figure 1(a). An axial small slot of length l is placed at the voltage maximum

points or the current minimum point. The dimensions of the CMSA has been chosen as R = 25 mm, and slot width d = 2 mm on glass epoxy substrate with $\varepsilon_r = 4.3$, thickness h =1.59 mm and $tan\delta = 0.01$. The length of the slot is varied and the corresponding resonance frequency is noted. The slot length is increased from 2 mm to 14 mm, the corresponding resonance frequency changes from 1.668 GHz to 1.676 GHz, giving frequency variation of only 8 MHz. This is because open ended small slot at voltage maxima has almost negligible effect on current distribution. The overall effective ε_r decreases with decrease in the effective area of the patch because of increase in slot dimension. Therefore, the resonance frequency of the CMSA structure increases slightly. The increase in frequency occurs only till a slot length of 14 mm, beyond which the effect is not significant. The feed point xremain at 8 mm for all the slot lengths.

Similar dimensions have been chosen for studying the effect of slot on the perpendicular axis of the CMSA. A slot is made of length *l* as shown in Figure 1(b).



Figure 1 CMSA with (a) an axial slot, (b) a perpendicular slot

As the length of perpendicular slot increases from 2 mm to 26 mm, the resonance frequency decreases from 1.660 GHz to 1.042 GHz as shown in Figure 2.



Figure 2 Frequency variation of CMSA with the length of the perpendicular slot.

Here the change in resonance frequency is much larger, as the slot is placed at the current maximum point. Inclusion of the slot at this point alters the current distribution, causing perturbation in the current path. The effect of placing the slot is equivalent to the elongation of surface current path length. Thus, a reduction in the resonance frequency of the antenna is observed. The effect of the perpendicular slot is more profound than the axial slot. Therefore, lower frequency of operation can be obtained by using smaller antenna size, leading to the design of compact antennas.

The width of the slot, for both the cases, does not play major role in the frequency tuning. In the entire tuning range, the effective BW (VSWR ≤ 2) of both the above tunable antenna configurations remains same around 14 MHz. For higher perpendicular slot lengths, the feed point x = 10 mm needs to be increased slightly by 1 mm for proper impedance matching. The radiation pattern of these tunable CMSA configurations has been found to be in the broadside direction at all the above frequencies.

III. DUAL BAND CMSA WITH SLOTS

It has been found through simulation of tunable configurations that for the smaller



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perpendicular slot a small loop in the input impedance loci at higher frequency is formed, which is not observed for a single axial slot cut in CMSA. The presence of the loop at higher frequency f_2 in the input impedance loci indicates the excitation of another resonant mode in the configuration. However, even if the length of the single perpendicular slot is increased, the loop size does not increase appreciably, leading to improper impedance matching at the two dual band frequencies. For a proper dual band operation two slots; axial as well as perpendicular, are essential. One slot is placed on the feed axis and the other slot is placed on the perpendicular axis as shown in Figure 3(a).

Initially, for smaller slot lengths, impedance matching is not obtained at the higher frequency. Also, the frequency of the additional resonance for the smaller length of the slots is greater than the second harmonic frequency of the circular patch [4]. For the dual bands to occur, it is imperative that the two slots are of comparable lengths. If the lengths vary by a large margin then the CMSA does not exhibit proper matching at dual frequency operation. The two slot length higher than $l_1 = l_2 = R/2$ gives matching at both the dual frequencies. The lengths of the two equal slots were varied from 15mm to 23mm. At the lower resonance f_1 current crowding around the perpendicular slot takes place, indicating that the surface current is circulating along this slot. Thus, the surface current path length corresponding to the lower resonance frequency depends on the perpendicular slot dimensions. At the higher resonance frequency f_2 , the current is pushed away from this slot so that the surface current path length of this mode is almost independent of the perpendicular slot parameters. The resonance frequency f_2 of this mode is primarily decided by the patch dimensions and to some extent the dimensions of the axial slot.

For some cases, with two perpendicular equal length slots, very good matching (Return Loss in excess of -20 dB) is not achieved at both the frequencies. The introduction of the third perpendicular slot, as shown in Figure 3 (b), with small length, considerably improves the matching at both the frequencies.



Figure 3 (a) Double slot CMSA, (b) Double slot CMSA with the third tuning slot

The effect of the third slot can be understood by comparing the Return loss plots of the antenna as shown in Figure 4. The third smaller length slot also provides minor tuning of f_2



Figure 4: Return loss without and with the third slot, $l_1 = 20$ mm, $l_2 = 22$ mm, $l_3 = 8$ mm and feed point x = 8 mm



To demonstrate the frequency tuneability of the dual band operation length of the two slots are kept equal $(l_1 = l_2)$ and varied from 15mm to 23mm and the length of the third slot is kept constant at $l_3 = 10$ mm, as shown in Figure 3(b). The feed point of the patch, for all the slot length remained within x = 8 + 0.5



mm. The variations of the two frequencies as

a function of $l_1 = l_2$ are plotted in Figure 5.

Figure 5 Frequency variation of CMSA with length of the equal slots

As the length of the two slots increase from 15mm to 23mm, the first frequency f_1 decreases from 1.410 GHz to 0.954GHz, offering 33% of frequency tuneablity with respect to the initial frequency of the slotted CMSA, whereas comparatively less variation is observed at the higher resonant frequency f_2 . The higher frequency deceases from 1.482GHz to 1.312GHz. With increase in the length of the slots, the separation between the two bands also increases from 72 MHz to 358 MHz. Frequency separation of the dual band operation can be further increased by slightly changing the lengths of two slots l_1 and l_2 . However, for good matching at both the frequencies, the length difference between two slots should not be more than 20%.

The effect of slot width on the resonance frequencies has also been investigated. The changes in slot width yields very limited tuneablity at f_1 and f_2 .

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IV. DESIGN OF DUAL BAND CMSA ANTENNA FOR GSM 1800/1900 AND BLUETOOTH 2450 MHz FREQUENCY BANDS

With the insight of the data generated for dual band CMSA in the previous section, a practical design for a dual band CMSA antenna operating at the GSM 1800/1900 MHz and the Bluetooth frequency bands of 2.45 GHz has been put forth. For the lower band, the antenna has been designed for an intermediate frequency of 1.85GHz. By altering the slot dimensions l_1 and l_2 , the frequency can be increased to 1.9 GHz (GSM 1900) or decreased to 1.8 GHz (GSM 1800). The Bluetooth band of the antenna is designed at 2.45 GHz (Bluetooth band is from 2.4 GHz to 2.48 GHz). The configuration has been designed on substrate with $\varepsilon_r = 4.2$ and thickness of dielectric as h = 1.59 mm and $tan\delta = 0.01$. The radius of the patch has been optimized as 14 mm. Lengths of the slots l_1 and l_2 have been chosen slightly unequal. The lengths of the axial and perpendicular slots are $l_{1=}$ 13 mm and $l_{2=}$ 11.75 mm, respectively. The length of the third tuning slot is optimized as $l_3 = 3$ mm. The optimized feed point was x = 7 mm.

fabricated The antenna was and measurements were carried out for input impedance and VSWR. These results are compared in Figure 6. The measured frequencies are 1.86 GHz and 2.45 GHz against the simulated values 1.85 GHz and 2.46 GHz, respectively. The percentage error between experimental and theoretical values of dual band frequencies is 0.5% at first frequency and 0.4% at second frequency. There is agreement between measured and simulated values of input impedance loci and VSWR plots. Both the frequency bands displayed impedance match with measured VSWR of 1.7 and 1.6 for GSM and Bluetooth bands, respectively against the respective simulated values of 1.05 and 1.15 as shown in Figure 6. The discrepancies between theoretical and experimental parameters are due to variation in the parameters of the

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commercial grade substrate and fabrication errors.



Figure 6 Dual band response of a slotted CMSA with $l_1 = 13$ mm, $l_2 = 11.75$ mm, $l_3 = 3$ mm and feed point x = 7 mm (a) Smith Chart (b) VSWR Plot

The antenna has a broadside gain of 2.5 dB and 4.5dB at GSM and Bluetooth bands, respectively. Figure 7 represents the theoretical radiation patterns of the slotted CMSA antenna at two frequencies. The main beam at both the frequency bands is along the broadside direction. The cross polar level is around -14.5 dB in both the planes at f_1 . There

is slight shift in maxima at f_2 because of asymmetry in the configuration. For the same reason, the cross polar level is higher at -12 dB for the H-plane and -12.2 dB in E-plane at f_2 .



The resonance frequency of the original CMSA without slot is much higher (2.6 GHz) than either of the dual band frequencies. Thus a smaller sized antenna has been designed for lower frequency of operation, which would have required a much larger patch antenna.

V. CONCLUSION

The effects of slots on the circular patch antenna have been studied for frequency tuneability and dual band operation. The dual band GSM-Bluetooth circular patch antenna has been fabricated and tested. The theoretical and practical results are in agreement. The introduction of slots does not add to the physical dimensions of the antenna structure, leading to a compact design for realization of frequency tunable and dual band antennas.



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REFERENCES

- M. Du Plessis and J. H. Cloete, "Tuning stub for Microstrip patch Antenna," in Proc. IEEE Antennas Propagat. Symp., June 1993, pp. 964–967.
- [2] R. James and P. S. Hall, Handbook of Microstrip antennas, Peter Peregrinus Ltd., London, England, vol.1, 1989.
- [3] G. Kumar and K. P. Ray, "Broadband microstrip antennas", Artech House, Boston, 2003.
- [4] K. P. Ray and Girish Kumar, "Tunable and Dual-Band Circular Microstrip Antenna with Stubs," Transactions on Antennas And Propagation, Vol. AP-48, pp. 1036 – 39, 2000
- [5] M. Sanad, "Effect of shorting posts on short circuit microstrip antennas," *IEEE AP-Symposium Digest*, pp.794 - 797, June 1994.
- [6] R. B. Waterhouse, "Small microstrip patch antenna", *Electron. Lett.*, Vol. 31, pp. 604-605, 1995.
- [7] I. J. Bahal and P. Bhartia, "Frequency agile microstrip antennas," Microwave J., pp. 67-70, October 1982.
- [8] E. H. Bhuiyan, et. al., "Active tuning and miniaturization of microstrip antenna", *IEEE AP-Symposium Digest*, pp.10 13, June 2002.
- [9] A. S. Daryoush et. al., "Optically tuned patch antenna for phased array pplication", *IEEE AP-Symposium Digest*, pp. 2229 2232, June 1992.
- [10] S. E. Davidson, S. A. Long, and W. F. Richards, "Dual band microstrip antenna with monolithic reactive loading," Electron. Lett., vol. 21, pp. 936–937, Sept. 1985.
- [11] W. F. Richards, et al., "Dual band reactively loaded microstrip antenna", *IEEE Trans. Antennas and Propagat.*, pp. 556-561, May 1985.
- [12] A. E. Daniel and G. Kumar, "Tunable dual and triple frequency stub loaded rectangle

microstrip antenna," in Proc. IEEE Antennas Propagat. Symp., June 1995, pp. 2140–2143.

- [13] Kin-Lu Wong et. al., "Compact microstrip antenna with dual frequency operation", *Electron. lett.*, Vol. 33, No. 8, pp. 646-647, April 1997.
- [14] S. C Pan. and K. L. Wong, "Design of Dual frequency Microstrip Antenna using shorting pin Loading", *IEEE AP. Symposium Digest*, pp. 312 – 314, 1998.
- [15] Chia- Laun Tang, et.al., "Small circular microstrip antenna with dual frequency operation", *Electron. Lett.*, Vol. 33, No.13, pp. 1112-1113, June 1997.
- [16] Lu, J., H., "Single feed dual frequency rectangular microstrip antenna with a pair of step slots" *Electron. Lett.*, Vol. 35, pp. 354-355, March 1999.
- [17] K. L. Wong, "Compact dual frequency microstrip antenna with a pair of bent- slots" *Electron. Lett.*, Vol. 34, pp. 225 -226, February 1998.
- [18] S. Maci, and G. B. Gentili ., "Dual frequency patch antenna", *IEEE Antennas* and Propgat Magz., Vol. 39, No. 6, pp. 13-20, December 1997.
- [19] S. Maci,, et. al., "Dual-Band slot loaded patch antenna", *IEE proc. Microwaves Antennas and Propagat.*, Vol. 142, No. 3, pp. 225-232, June 1995.
- [20] Y. X. Guo, et al., "Dual-band slot loaded short- circuited patch", *Electron. lett.* Vol. 36, No. 6, pp. 289-290, February 2000.
- [21] A. E. Daniel and R. K. Shevgoankar," Slot loaded rectangular microstrip antennas for tunable dual band operation", *Microwave Opt. Tech. Lett.*, March 2005 pp. 441-444.
- [22] Kin-Lu wong and Wen-Shan Chen, "Slot-loaded bow-tie microstip antenna for dual frequency operation", *Electron. Lett.*, Vol. 34, No. 18, pp. 1713-74, September 1998.
- [23] IE3D 9.0, Zeland Software, Freemont, USA