International Journal Of Electronics Engineering (Issn: 0973-7383)
Volume 10 • Issue 2 pp. 323-328 June 2018-Dec 2018 www.csjournals.com

Dual Band Tunable Circular Microstrip Antenna for GPS and Radar Applications

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Abstract: This paper presents a novel design and development of stub and slot loaded dual band tunable circular microstrip antenna (DBTCMSA) for GPS and radar applications. The DBTCMSA has two symmetrical stubs with two diagonal slots, placed in second and fourth quadrant of a circular patch. In the obtained dual bands for directional GPS the resonant frequency appears at 1562 MHz lies in the GPS bandwidth (1583-1550 MHz) used for outdoor positioning system and second band has an application for radar because the operating band lies at X-band frequency range having resonant frequency of the band is at 8.8 GHz. Usually the minimum requirement of bandwidth for GPS is 20MHz and for radar is 200 MHz. If the GPS system is operating below 1585 MHz, the separate antenna has to be designed where the antenna size becomes bulky at lower frequencies. Hence, this can be avoided by simply changing the dimensions of the stubs used in the proposed DBTCMSA and the same antenna may be used to any frequency band below 1585 MHz due to its tunable property. The maximum virtual size reduction of 53.9% is achieved in this case. The antenna has been designed by using low cost modified glass epoxy substrate material of thickness 1.6mm and permittivity of 4.2. The antenna gives peak gain of 4.9 dBi and 3.97 dBi for first and second tunable bands respectively. The antenna gives broadside radiation pattern.
Keywords: AGPS, CGPS, DBTCMSA, DGPS, GPS, Stub and Slot.

Introduction

The GPS is first used in USA for military applications and later for public use in the year 1980. But now –a-days, civil global positioning system (CGPS) has become very popular and it has many applications. With latest technological advances such as differential GPS (DGPS), assisted GPS (AGPS), Civil GPS receivers are able to locate themselves with an error of 1-3 meters at outdoor and it is very successful in outdoor areas. However, in case of indoor, it is hard to decode GPS signals due to the additional losses caused by the heighted buildings. The accuracy of GPS is with 15 meters where as for DGPS it is within 10 centimeters. The DGPS is most useful in between two defined points but it has demerits for open area where directional GPS is useful . The most current GPS receivers only operate at a resonant frequency of 1575 MHz. The basic operating band width requirement for the GPS antenna is of 20 MHz [1] at L band and the operating band width of 200 MHz for radar applications at X-band frequency range. For these two operating bands the antenna are designed separately. In view of this a novel geometry of DBTCMSA has been proposed. This single antenna operates for dual bands and satisfies the basic requirements and also provides the feature of tuning facilities for both the bands by simply changing the dimension of the stubs used in the antenna.

Description of the antenna geometry

The conventional circular microstrip antenna (CMSA) is designed using low cost modified glass epoxy substrate material of thickness h=1.6mm with relative permittivity $\varepsilon_r = 4.2$. The antenna is fed using simple microstripline feeding. This feeding has been selected because it can be simultaneously fabricated along with the antenna element. The radius of this antenna is calculated using equation (1) [2].

$$a = \frac{K}{[1+(2h/\pi\epsilon_r k)\{ln(\pi k/2h)+1.7726\}]^{-1/2}} \qquad .....(1)$$

where, $k = \frac{8.794}{f\times\epsilon_r{}^{1/2}}$

$$a_e = a\left\{1 + 2h/\pi\ \epsilon_r\ a\left[ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2}$$

Figure 1 shows top view of geometry of CMSA in which W_f, L_f, W_t and L_t are the width and length of microstripline feeding and width and length of quarter wave transformer respectively. Figure 2 shows the variation of return loss versus frequency of CMSA. From this figure it is seen that the antenna resonates very close to the designed frequency of 3 GHz which validates the design concept of CMSA.

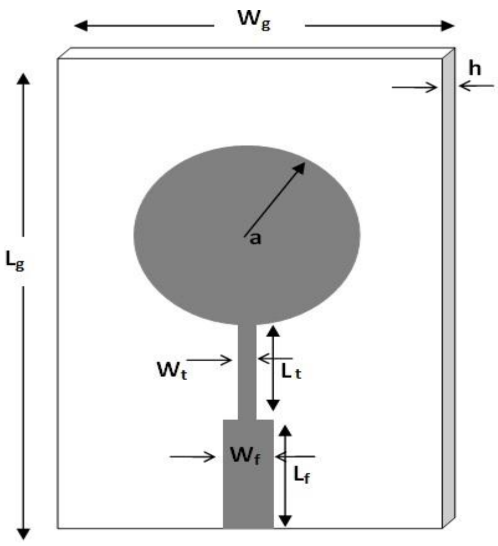

Figure 1. Geometry of CMSA

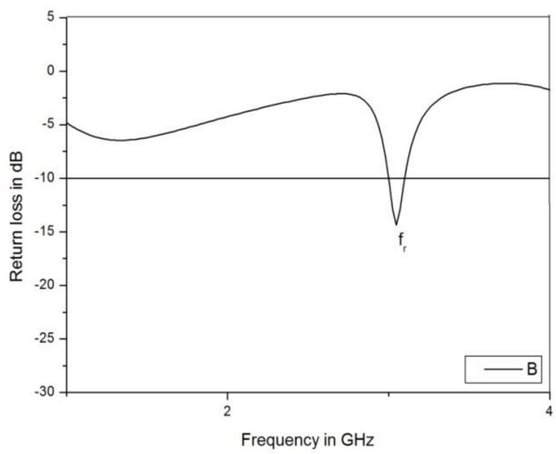

Figure 2. Variation of return loss verses frequency of CMSA

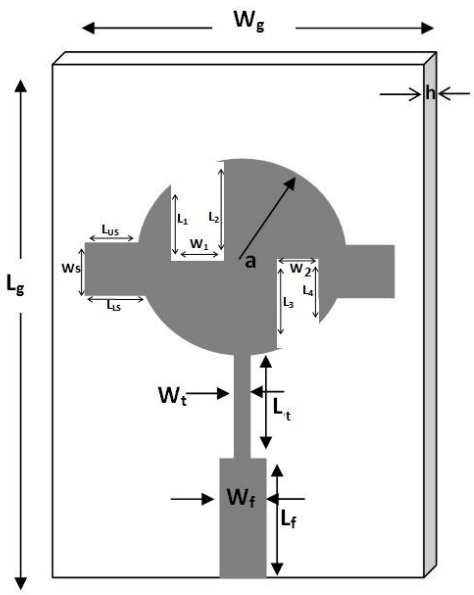

Figure 3. Geometry of DBTCMSA

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Volume 10 • Issue 2 pp. 323-328 June 2018-Dec 2018 www.csjournals.com

Figure 3 shows top view of geometry the DBTCMSA. This antenna is having the same basic design as that of conventional CMSA as shown in Figure 1. The radius of patch and dimensions of microstripline feed and quarter wave transformer are remains same. For CMSA has been modified into DBTCMSA by adding two identical stubs along its axis and two diagonal slots [3-5], which are placed in second and fourth quadrant over the surface of the patch. The Table 1 and 2 gives the design parameters of DBTCMSA. In Figure 3 the dimensions of stubs L_{US} and L_{LS} have been varied from 0.59 to 1.04 and 0.79 to 1.24 respectively to tune the GPS band. Similarly to tune the X-band the L_{US} and L_{LS} have been varied from 0.59 to 0.94 and 0.79 to 1.15 cm respectively as shown in Table 1 and 2 respectively.

Table 1: Design parameter of DBTCMSA for tuning GPS band

For constant stub width Ws=0.8 cm and fixed lengths of Diagonal slots L_1=0.82cm , L_2=1.34cm , L_3=1.30cm , L_4= 0.99cm and widths W_1= 0.8cm , W_2= 0.6 cm .			
Variation of stub length L_{US} and L_{LS} in cm	**Resonant frequencies in MHz**	**Return loss in dB**	**Impedance bandwidth in %**
L_{US}=0.59 & L_{LS}=0.79	$f_{r1=}$1585	13.41	1.67
L_{US}=0.64 & L_{LS}=0.84	$f_{r2=}$1562	14.49	2.10
L_{US}=0.74 & L_{LS}=0.94	$f_{r3=}$1540	16.08	1.94
L_{US}=0.84 & L_{LS}=1.04	$f_{r4=}$1472	13.22	1.64
L_{US}=0.94 & L_{LS}=1.15	$f_{r5=}$1450	10.62	1.07
L_{US}=1.04 & L_{LS}=1.24	$f_{r6=}$1382	10.81	1.19

Table 2: Design parameter of DBTCMSA for tuning X-band (Radar)

For constant stub width Ws=0.8 cm and fixed lengths of Diagonal slots L_1=0.82 cm, L_2=1.34cm, L_3=1.30cm , L_4= 0.99cm and widths W_1= 0.8cm,W_2= 0.6 cm .			
Variation of stub length L_{US} and L_{LS} in cm	**Resonant frequencies in GHz**	**Return loss in dB**	**Impedance bandwidth in %**
L_{US}=0.59 & L_{LS}=0.79	$f_{r1=}$8.83	13.04	4.07
L_{US}=0.64 & L_{LS}=0.84	$f_{r2=}$8.875	22.36	3.29
L_{US}=0.74 & L_{LS}=0.94	$f_{r3=}$8.80	25.36	3.57
L_{US}=0.84 & L_{LS}=1.04	$f_{r4=}$8.58	16.14	5.66
L_{US}=0.94 & L_{LS}=1.15	$f_{r5=}$8.92	15.13	5.8

Results and discussion

Figure 4 shows the variation of return loss verses frequency of DBTCMSA. When antenna is constructed having L_{US}=0.59cm and L_{LS}=0.79cm, the resonant frequency appears at f_{r1} = 1585 MHz as shown in Table 1. Similarly for L_{US}=0.64 cm and L_{LS}=0.84cm, L_{US}=0.74 cm and L_{LS}=0.94 cm, L_{US}=0.84 cm and L_{LS}=1.04 cm, L_{US}=0.94 cm and L_{LS}=1.15cm, and L_{US}=1.04cm and L_{LS}=1.24cm, the resonant frequencies appears at f_{r2}, f_{r3}, f_{r4}, f_{r5} and f_{r6} respectively as shown in Figure 4. The corresponding impedance bandwidths in percentages are 1.67, 2.1, 1.94, 1.64, 1.07 and 1.19 respectively. The operating band width of GPS is 33 MHz (1583-1550 MHz). The resonant frequency of f_{r2} as shown in Figure 4 lies in this frequency range and hence this band can be used successfully for GPS application. Further, it is noted that the minimum requirement for GPS band range is 20 MHz, however the proposed antenna DBTCMSA gives 33 MHz which is more than required bandwidth [6-8]. The DBTCMSA also gives a gain of 4.9dBi in its operating band having a resonant frequency of f_{r2} as shown in Figure 4. Again from Figure 4 it is seen that, by changing the length of stubs of DBTCMSA the operating bandwidth can be tuned to lower frequency side. The resonant frequency f_{r1} is tuned to f_{r6} by changing the dimension of stubs in the proposed antenna. This gives a highest virtual size reduction of 53.9 % which avoids the design of larger size antenna required at lower frequencies [9]. The impedance bandwidth and virtual size reduction is calculated by using the equations (2) and (3).

$$\text{Impedance bandwidth (\%)} = \frac{f_H - f_L}{f_c} x100 \quad \text{.................(2)}$$

$$\text{Virtual size reduction in (\%)} = = \frac{Fc - Ft}{Fc} \times 100 \quad \text{………. (3)}$$

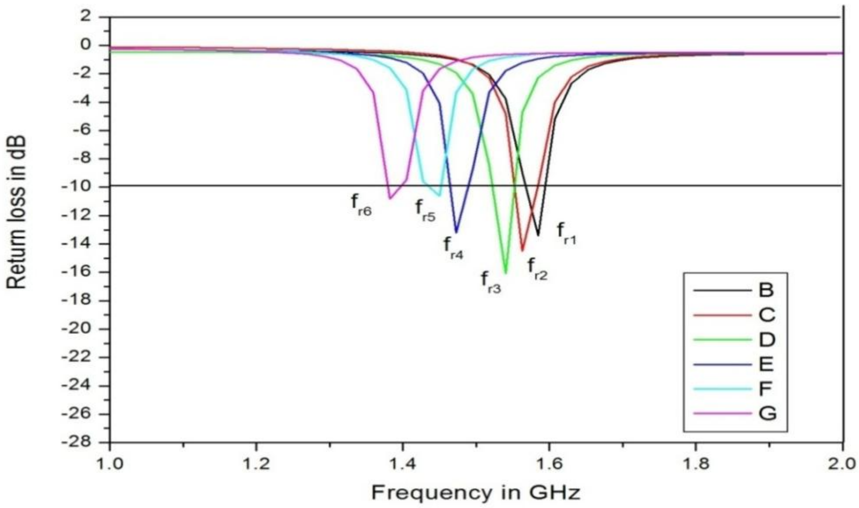

Figure 4. Variation of return loss verses frequency of DBTCMSA.

Figure 5 shows the variation of return loss verses frequency of DBTCMSA. When antenna is constructed having L_{US}=0.59cm and L_{LS}=0.79cm, the resonant frequency appears at f_{r1} i.e. 8.83 GHz. This resonant frequency can be tuned on either side of the X-band by changing the dimensions of stubs listed in Table 2. For L_{US}=0.64cm and L_{LS}=0.84cm, L_{US}=0.74cm and L_{LS}=0.94cm, L_{US}=0.84cm and L_{LS}=1.04cm and L_{US}=0.94 L_{LS}=1.15cm, the resonant frequencies appears at f_{r2}, f_{r3}, f_{r4} and f_{r5} respectively. It is seen that by changing the dimensions of stubs the resonant frequency of the operating band decreases from f_{r1} to $f_{r4,}$ that is from 8.8 GHz to 8.58 GHZ and thus the total tuning range is 11.65%. However by changing the dimension of stub L_{US}=0.94, L_{LS}=1.15cm the resonant frequency of the band increases towards the higher frequency side of X-band i.e. appears at f_{r5}=8.92GHz shown in Figure 5. This property of antenna also finds an application at X-band (13). The corresponding impedance bandwidths of operating bands shown in Figure 5 are 4.07, 3.29, 3.57, 5.66, and 5.8 percentage respectively. The operating band of frequency having resonant frequency of 8.8GHz has an impedance bandwidth of 3.57% (band width of 300 MHz) and gain of 3.97dBi. The Band width of 300 MHZ of proposed antenna is more than 200 MHz required for radar applications. [10-15]

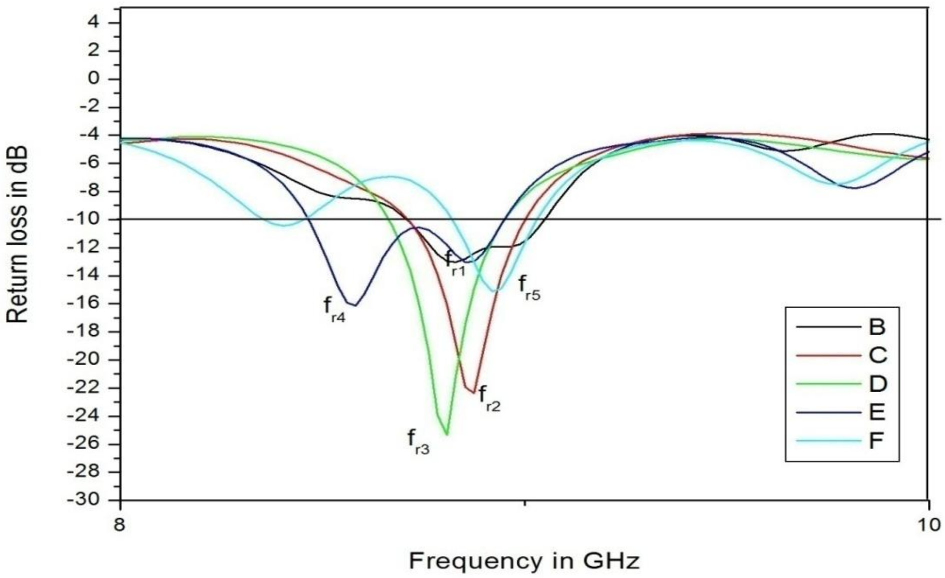

Figure 5. Variation of return loss verses frequency of DBTCMSA

International Journal Of Electronics Engineering (Issn: 0973-7383)
Volume 10 • Issue 2 pp. 323-328 June 2018-Dec 2018 www.csjournals.com

Figure 6 and 7 shows typical radiation pattern of DBTCMSA measured at 1562 MHz and at 8.80 GHz respectively. The radiation patterns are broadsides and linearly polarized in both E and H plane.

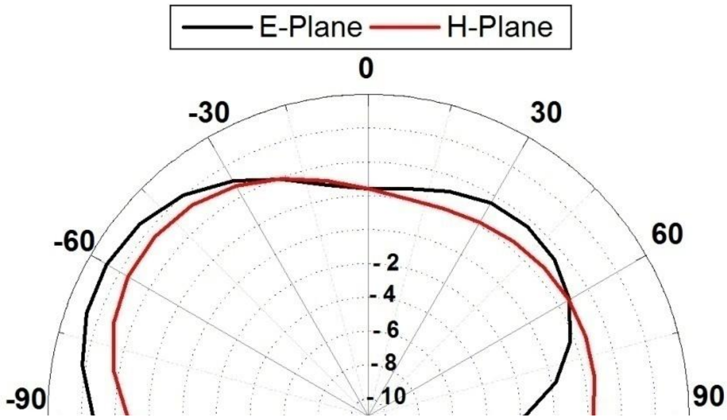

Figure 6. Typical radiation patter of DBTCMSA found at 1562 MHz

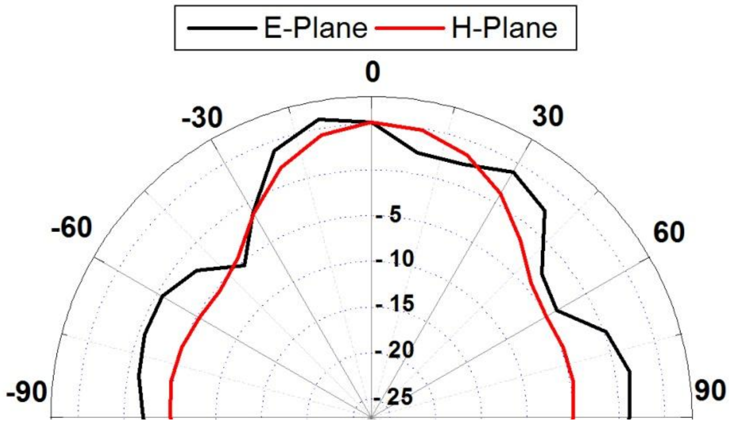

Figure 7. Typical radiation patter of DBTCMSA found at 8.80 GHz

Conclusion

From the detailed study of design and development of DBTCMSA, it is concluded that, the dual band tunable circular microstrip antenna can be realized by using new structure realized from conventional CMRSA. The DBTCMSA has been constructed by using low cost modified glass epoxy substrate material having less complex geometry. The antenna is quite efficient for GPS and radar applications. A single antenna is capable to operate for two band of frequency satisfying the minimum frequency range and gain. The operating bands of this antenna can be tuned for the desired frequency range by simply changing the dimension of stubs used in DBTCMSA. This new concept avoids the design of separate and larger size antenna to operate for lower frequency. The antenna gives a highest virtual size reduction of 53.9%. The antenna gives broadsided and linearly polarized radiation pattern in its operating bands. The two operating bands lies at L and X-band frequency ranges and they are far away from each other which also avoid unwanted signal interference between the bands.

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