

Coplanar Stripline Loaded Reconfigurable Loop Antenna for WLAN and WiMAX Applications

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Abstract—In this paper, a loop antenna loaded with coplanar strip (CPS) line is proposed as a multiband antenna. The CPS line is added with two switches to vary the antenna perimeter to cover seven different bands. The CPS line introduced into the loop is not only useful in reconfiguring antenna dimensions but also provides stationary radiation patterns for the all the covered bands. The proposed antenna works in single and dual-band modes. When the proposed antenna works as a single band antenna, it produces a band from 4.2GHz to 5.7GHz. Under dual-band operation, it produces bands from 3.75GHz to 4.7GHz and from 6.4GHz to 7.8GHz. The other dual-band mode ranges from 3.5GHz to 3.8GHz and from 5.58GHz to 7.4 GHz. The simulated and measured results are in good agreement and the proposed antenna can be used satisfactorily for W-LAN and WiMax applications. The proposed technique can also be used for size reduction of loop antennas.

Keywords—coplanar stripline; loop antenna; multiband; wideband; wavelength

I. INTRODUCTION

UWB band allocation ranges from 3.1GHz to 10.6GHz. There are 12 different bands, each 528MHz wide [1]. The center frequency of each band from [1] is used as reference below. The electrical behavior of the wire loop antenna is examined in [2]. For a fixed radius of the loop, the impedance of the antenna depends on the wire thickness. The relation between the wire thickness and loop radius is referred to as thickness factor (Ω). The thickness factor is defined in (1):

$$\Omega = 2\ln(2\pi r/b) \quad (1)$$

where Ω is the thickness factor, r is the radius of the loop in meters and b is the wire radius in meters, used to construct the loop antenna. The impedance variation of the loop as a function of the thickness factor and the loop circumference can also be seen in [2]. As the thickness factor decreases, antenna impedance also decreases. Therefore by varying thickness of the loop antenna, the impedance of the antenna can be varied easily. The loop antenna is categorized as thin or thick loop. The thin antenna has $\Omega > 9$ and resonates at more than one frequencies [2]. The thick antenna is capacitive in nature with the advantage of almost uniform resistance. The loop antenna is also categorized as small or large loop antenna. When the circumference of the loop is equal to or larger than the

operating wavelength, the loop is called a large loop and small otherwise. In general, the small loop antenna has a circumference less than $\lambda/10$, where λ is the wavelength at which the antenna is designed. The small loop is a poor radiator while the large loop antenna is a good radiator as shown in [2]. The loop antenna resonates at a wavelength equal to the circumference of the loop. The circumference of the loop is calculated using (2) and (3):

$$C = 2\pi r = \lambda \quad (2)$$

$$\lambda = c/f \quad (3)$$

where C is the circumference of the loop antenna (m), r is the radius of the loop (m), c is the speed of light in free space (m/s), f is the design frequency of the loop (Hz).

A multiband antenna should operate at different frequencies with stable radiation patterns. Since a thin and large loop antenna resonates at different frequencies [2], it can be used to operate at different frequencies. It is observed that the pattern at a smaller wavelength is different from the pattern at a larger wavelength for the specified band of operation. This happens due to the variation in the current distribution along the loop due to variation in the operating wavelength. A thin loop with $\Omega=12$ resonates at $C/\lambda=1.1$ i.e. $C=1.1\lambda$ or $C=2.2\lambda$. The second resonant wavelength is twice the first. Therefore we can design a loop to have the two desired bands using (2). But this technique suffers from poor stability in radiation patterns. Figure 1 explains this very well. A simple wire loop whose circumference is $C=\lambda$ radiates normal to its plane as shown in Figure 1(a). When the same loop is excited at a wavelength double to that of the previous case, then the pattern does not remain the same (Figure 1(b)). The radiation pattern at 2λ is too random. Such an antenna cannot be claimed as a multiband antenna. A simple solution to this problem is that the circumference of the loop should vary in accordance with the desired wavelength. This arrangement will keep the circumference $C=\lambda$ or near to λ .

II. RESEARCH METHOD

Since mechanical changes in the entire structure of the antenna are not possible to hold $C=\lambda$ true for different wavelengths, the loop structure in Figure 2 is proposed. The proposed loop is square in shape and a coplanar strip (CPS)

line is added to it. The CPS line is added with multiple electronic switches that can be turned ON and OFF to change CPS line length. The change in the CPS line length finally changes the overall circumference of the loop.

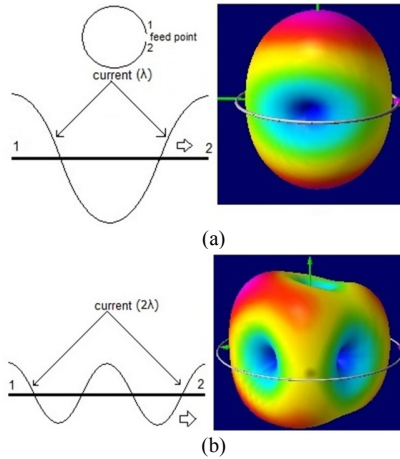


Fig. 1. The loop antenna showing radiation patterns at (a) λ , (b) 2λ .

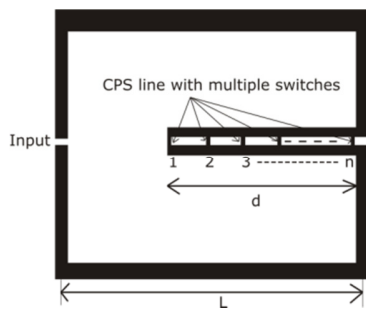


Fig. 2. Proposed loop antenna with CPS line along with the arrangement of switches.

The total length of the loop is $4 \times L$, L representing the arm length of the loop. When switch 1 is closed and the others are open, the length of the loop is $4 \times L + 2d$, where d is the length of the CPS line. Therefore, the loop length can be varied from $4 \times L$ to $4 \times L + 2d$. The loop length can be varied in small steps if the switches are placed close to each other. It is known that the transmission line only carries electrical energy from one point to another but does not radiate significantly. Therefore the four sides of the loop are the only radiating components of the proposed structure. The role of the CPS line is to only vary the overall length of the structure and eventually the generation of multiple bands. This structure ensures that the current distribution along the radiating portion will remain the same, therefore uniform radiation pattern is expected. A square loop of 16mm outer length and 0.7mm and 1mm width is simulated using CST Studio software in order to know the availability of possible bands with the corresponding antenna impedance as shown in Figure 3. It can be observed in Figure 4 that the antenna behaves differently for the two widths. There can be two bands available only after proper impedance matching. The larger width ensures larger bands since the antenna impedance is uniform. It can be observed in Figure 5 that the width of the loop antenna affects its impedance. When antenna width is

0.7mm, the loop resonates at 4.55GHz. The resistance at this frequency is about 125Ω . The resistance drops to about 96Ω for 1mm width. The loop with 1mm width shows minimum reactance at 5.1GHz and the resistance at this frequency is about 176Ω . The loop resistance is more than 270Ω for the same frequency when the width is 0.7mm. The antenna impedance for these frequencies is larger than the reference impedance of 50Ω , therefore there is poor reflection coefficient at these frequencies (Figure 4). Since the magnitude of the reflection coefficient is more than -8dB at the lower frequency, the band availability cannot be ignored. Another possible location for the availability of the band is at 7.6GHz and 7.9GHz for a loop with width 0.7mm and 1mm respectively. The reactance is larger at these frequencies. The loop with 1mm width has less variation in reactance than the loop with 0.7mm width.

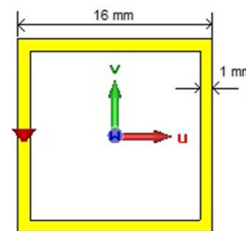


Fig. 3. Proposed loop antenna with CPS line along with the arrangement of switches.

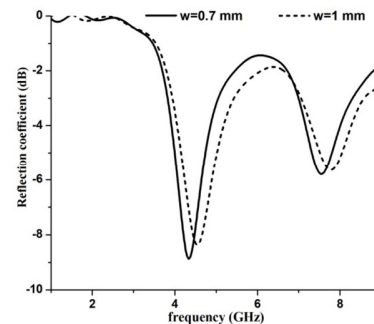


Fig. 4. Frequency v/s reflection coefficient of the loop antenna for different widths.

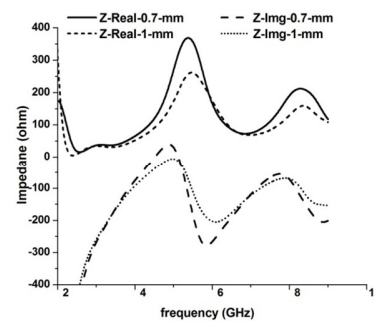


Fig. 5. Loop impedance as a function of width and frequency.

In order to solve the impedance mismatch problem, a printed BALUN transformer can be used to feed the antenna. The inclusion of the BALUN increases antenna size and if possible should be avoided. Here, we are providing a simple

solution to bring antenna impedance down to the reference impedance of 50Ω. Above, it was demonstrated that the loop impedance can be varied by varying the loop width. Therefore, instead of having a uniform width the loop can be made to have non uniform width. The proposed loop antenna contains non uniform width which changes gradually from 1mm to 1.5mm and then to 2mm towards feed end. Since there is no standard technique to introduce nonlinearity in the loop antenna, the dimension for the different arms of the loop is chosen only after multiple simulations. The different dimensions are given to the loop for reducing antenna impedance so that the loop can be directly fed with a 50Ω source. The dimensional information of the loop is shown in Figure 6. The feed is connected to the broader width of the antenna since it offers low impedance while the narrow width offers high impedance. Here the broader width helps converting loop antenna to a thick antenna which has low resistance with high capacitive reactance. The narrow dimension of the loop is present at the opposite of the feed and is 1mm wide. The narrow dimension of the loop converts the loop to a thin antenna which has high resistance and inductive and capacitive reactance. Therefore this combination brings overall antenna impedance to a uniform level. Finally, a folded coplanar strip line (CSP) feed is added to the loop. The folded CSP feed not only helps in lowering antenna impedance to 50Ω but also it saves the onboard space as most of the part of the folded CSP is within the loop area as shown in [1]. The proposed feed can be useful in feeding the antenna directly with a coaxial feed. The dimensional details of the folded CSP line are shown in Figure 7.

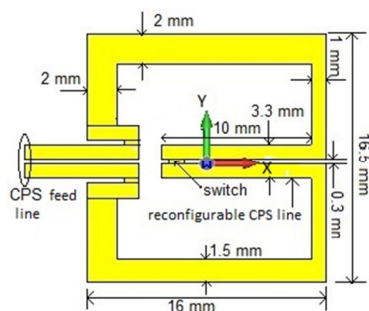


Fig. 6. The proposed loop with dimensional details.

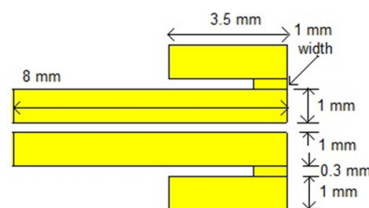


Fig. 7. The dimensional details of the feed.

The CSP line not only plays important role in the transformation of impedance but also converts an unbalanced coaxial cable to balanced feed [3]. The proposed loop is added with additional CSP line of 10mm length exactly opposite to the feed as shown in Figure 6. Therefore the inclusion of the CSP line can increase the length of the loop by 20mm. The CSP length can be increased or decreased by turning ON and

OFF the switches and the overall length of the loop can be varied to obtain different frequencies.

III. LOOP RESPONSE ANALYSIS

In this section, the proposed reconfigurable loop is analyzed for different switching conditions of the switches along CSP line. The ON state of the switch is realized by the short circuit and the OFF state by the open circuit. The switch is operated from the left of the CPS line towards the thin arm of the loop and the response of the loop is tabulated in Table I. It can be observed from Table I that there are two distinct modes of antenna operation: single and dual band modes. The antenna works as dual band antenna when the switch at locations 0mm and 3mm is ON from the left end of the CPS line. The bands covered are Band-6, Band-7, and Band-2, Band-8 respectively. Only one switch is ON at a time while the others are OFF.

TABLE I. BANDS GENERATED UNDER SWITCH ON STATE

Mode	Switch Location	f_1 - f_2 10dB BW (GHz)	Available band [1]	Center frequency (GHz)	% Band-width
A	0mm	3.5-3.8	No Band	3.65	8.2
		5.6-6.85	Band-6, 7	6.23	20
B	3mm	3.7-4.5	Band-2	4.1	19.5
		6.8-7.43	Band-8	7.12	9
C	8mm	4.17-5.9	Band-3, 4, 5	5	34.4
D	All Off	4.2-5.75	Band-3, 4, 5	4.975	31.2

A, B = dual band and C, D = single band, f_1 and f_2 are the lower and upper cut-off frequency respectively. The switch location is measured from the left of the CPS line shown in Figure 6.

It can be observed in Table I that when the switch at 8mm (near to the thin arm of the loop), is ON, the loop generates a wider band from 4.17GHz to 5.9GHz. The loop produces Band-3, Band-4 and Band-5 for this particular position of the switch. The loop generates the same bandwidth when all the switches present along the CPS line are OFF. Therefore to get the maximum number of bands at the minimum expense of switches, switch at location 8mm can be discarded. If we operate the switch at 0mm, and 3mm, we can easily get 7 different bands. It is also observed that the loop antenna generates larger bandwidth when it is operated under single mode (mode C and mode D). The maximum % bandwidth under C mode, CPS line is almost completely removed from the loop as the switch is closed. The lowest frequency observed under this mode of operation is 4.17GHz. When the switch at 0mm is ON, complete CPS line is added in series with the loop. The lowest frequency under this mode, i.e. mode A, is 3.5GHz. Since the area occupied by the proposed antenna is the same for the two frequencies, this technique can also be used to reduce antenna size. The different bands under the influence of the operating switches are shown in Figure 8, which gives a good idea of how well the proposed technique covers a wider band from 3.5GHz to 7.43GHz. In order to check the stability of the radiation pattern for claiming multiband operation, the radiation pattern at the center frequency of each band listed in Table I is analyzed. The radiation patterns are orthogonal to the plane of the loop and are shown in Figures 9(a) and 9(b). The patterns are plotted at the center frequencies of each obtained band listed in Table I. The plane of the proposed loop is aligned with X-Y plane for all radiation patterns. An antenna

having such a stable radiation pattern for different frequencies must have a uniform current distribution.

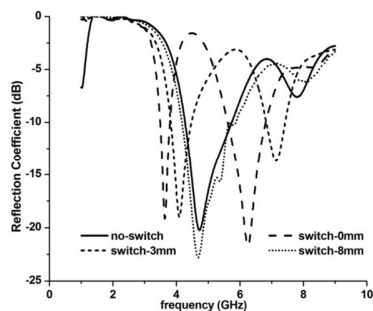


Fig. 8. The reflection coefficient v/s frequency for different switches.

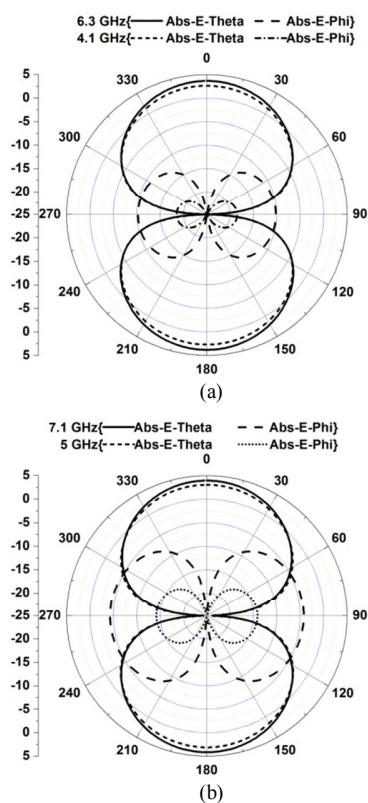


Fig. 9. The simulated radiation patterns at the center frequency of the bands listed in Table I.

In order to verify this relation, current distribution for all the plotted radiation patterns is reproduced and analyzed in Figure 10. The current distribution in the proposed antenna can be divided into two parts: a) Current in vertical arms, parallel to Y-axis and b) Current in horizontal arms, parallel to X-axis. The variation in the magnitude of current along the antenna is shown with a dashed line and the direction of current is shown with a continuous line (Figure 12(a)-(b)). It can be observed that the current distribution along Y-arms is in phase, while out of phase along X-arms. X-arms radiations are mutually canceled. On the other hand, the current from Y-arms contributes to radiation. The inclusion of the CPS line is completely justified here, as it only helps in reconfiguring the

antenna dimension and keeps the current distribution uniform along the loop for all the frequencies. A comparison of the proposed loop is done with other recent existing reconfigurable antennas. The summary of the comparison is shown in Table II.

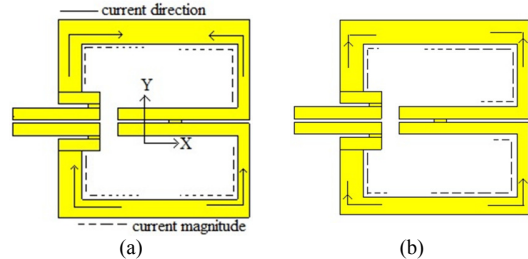


Fig. 10. The current distribution along the loop for different center frequencies. (a) $f=3.9\text{GHz}$, (b) $f=7.1\text{GHz}$

TABLE II. PROPOSED ANTENNA COMPARATIVE ANALYSIS

Reference	Bands	Frequency (GHz)	Number of switches	Number of antennas
[4]	2	1.8, 2.4	8	1
[5]	2	8.2, 10.4	1, MEM capacitor	1
[6]	2	15.95, 17.1	1, MEM capacitor	1
[7]	2	2.4, 5.8	Motor	2
[8]	3	1.58, 2.38	2	1
	5	1.51, 2.28	4	1
[9]	5	2.16-9	4	1
[10]	3	2.4, 3.5, 5.2	6	1
[11]	4	2.45, 3.49, 5.13, 5.81	2	1
Proposed	7	3.9-7.4	2	1

The antenna given in [4] generates two distinct bands centered at 1.8GHz and 2.4GHz. These two bands are generated using eight different switches. The antennas proposed in [5, 6] are multiband antennas generating two bands at 8.2GHz, 10.4GHz and 15.95GHz, 17.1GHz respectively. Both antennas use MEM switch for reconfiguration. There are four antennas proposed in [7]. The two antennas are used to generate two different bands and the others are used to change pattern and polarization. The two antennas used to generate different bands are selected using a rotating mechanism so the reconfiguration is controlled mechanically. The antenna proposed in [8] is operated with two switches and depending on the ON and OFF states of diodes, the antenna generates three different bands from 1.58GHz to 2.38GHz. When the same antenna is added with four diodes and is made ON or OFF in a particular sequence then it generates five different bands from 1.51GHz to 2.28GHz. The antenna proposed in [9] uses 4 switches and depending on the ON and OFF state of switches, it is operated as single, double and triple band antenna generating a total of 5 different bands. The antenna proposed in [10] uses 3 pairs of the diode and generates six different bands under single, dual and triple band modes. A single monopole antenna with two optical switches generates four different bands in [11]. The proposed antenna uses only two switches and can be operated as single and dual band antenna. When both switches are OFF, the loop works as a wideband antenna. The total bands generated by the proposed antenna are seven and is higher than all the antennas compared

in Table II. The proposed antenna uses a lesser number of switches. Other than this the antenna profile is very compact.

IV. RESULTS AND ANALYSIS

The proposed reconfigurable antenna is manufactured and tested using Vector Network Analyzer N9926A. A photograph of the entire four proposed antennas is shown in Figure 11. A comparison between the simulated and measured reflection coefficient is shown in Figure 12.

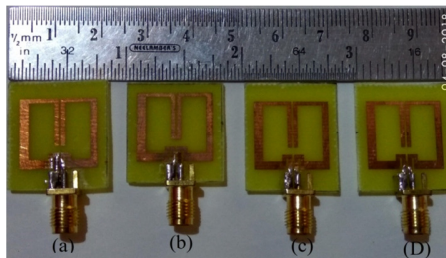


Fig. 11. Photograph of the reconfigurable square loops for (a) no switch, (b) switch at 0mm, and (c) switch at 3mm and (d) switch at 8mm.

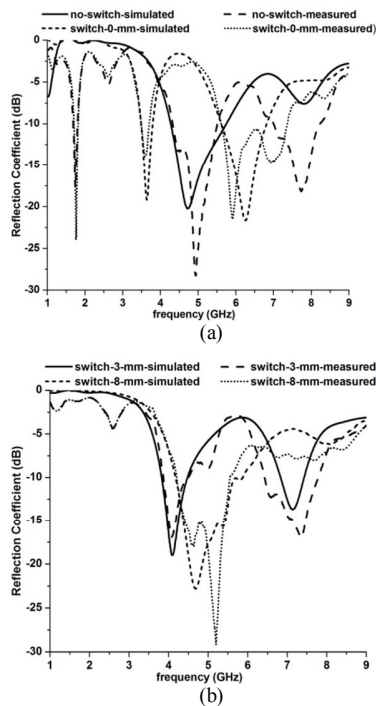


Fig. 12. Comparison between simulated and measured reflection coefficient.

TABLE III. SIMULATED AND MEASURED RESULT COMPARISON

Switch Location	Simulated f_1 - f_2 (GHz)	Measured f_1 - f_2 (GHz)	Bands Available	Center frequency (GHz)
0 mm	3.5-3.8	3.5-3.8	No Band	3.65
	5.6-6.85	5.58-7.4	Band-6,-7	6.23
3 mm	3.7-4.5	3.75-4.7	Band-2	4.1
	6.8-7.43	6.4-7.8	Band-8	7.12
All Off	4.2-5.75	4.2-5.7	Band -3, -4,	4.975
		6.8-8.3	-5	7.55

f_1, f_2 lower and upper cut off frequencies respectively

The simulated and measured results are in good agreement and are summarized in Table III. Measured results justify the importance of folded CPS feed and the role of the non-uniform loop arms with inner CPS line for frequency reconfigurability. It also shows that the inclusion of two switches is sufficient to cover seven different bands.

V. CONCLUSION

The proposed structure shows that a loop antenna can be designed to have multiple bands. The included CPS line within the antenna ensures the reconfigurability in antenna structure to get multiple bands with uniform radiation pattern. Since the CPS line does not contribute to radiation, the patterns generated for different lengths of CSP line have the same orientation. The proposed loop can be operated as single and dual band antenna and generates a total of seven bands using minimum number of switches. Since the proposed antenna covers Band-2, Band-3, Band-4, Band-5 Band-6, Band-7 and Band-8 ranging from 3.5GHz to 7.8GHz, it can be useful in WLAN 802.11 a/n and WiMAX applications. The proposed structure has the smallest dimensional profile. The proposed technique can be used for size reduction of the loop antenna.

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