

Capacitive Gap Loaded Dual, Triple and Wide Band Loop Antenna

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Abstract

In this paper, a printed loop antenna with current reconfiguration technique is proposed to improve the usability of the loop as a multiband antenna for UWB applications ranging from 3.1 GHz to 10.6 GHz. The current reconfiguration is achieved using a capacitive gap along the circumference of the loop antenna. The shift in the location of the capacitive gap changes the current distribution in the antenna and new bands are generated. It is found that using a single capacitive gap along the loop, the antenna can be operated as a wide band antenna whose frequency ranges from 6 GHz to 10.8 GHz with % bandwidth of 57. The proposed loop can also be used as dual and triple band antenna in the frequency range from 6 GHz to 10.8 GHz by simply switching ON and OFF the switches. The proposed antenna generates the highest numbers of bands at the minimum expense of switches. The proposed loop without capacitive gap is capable of covering only 24% out of the 3.1 GHz-10.6 GHz range. The range of band can be varied from 24% to 57% using the switches. The proposed antenna very well rejects the WLAN and WiMAX bands.

Keywords

Capacitive Gap, Current Reconfiguration, Loop Antenna, Multiband, Wide Band

Introduction

Reconfigurable antennas are required for the better selectivity of the desired band of operation. These are also used to have desired radiation pattern at different frequencies of operation. The reconfigurability in any antenna is achieved by introducing physical changes in the antenna structure. These changes in antenna structure bring change in antenna current distribution which changes antenna impedance. The performance of antenna changes as the antenna impedance changes. There are several techniques to achieve reconfigurability features in antenna. These techniques use electronic switches, optical, mechanical and electromechanical switches (Mohamed Nasrun Osman et.al, 2015). The change in current is introduced either in the antenna itself or in the ground plane (DGS: defected ground structure) as shown in (Mohammed Al-Husseini et. al., 2010) and (Xuelin Liu et. al., 2015). The structural modification in the antenna is used to control the orientation of the current in the antenna to generate different bands (Sonia Sharma and Chandra C. Tripathi, 2015).

Limitations and Solution to the Existing Multiband Loop Antenna

It is shown (S. P. Shastri, R. R. Singh, K.V. Ajetroa, 2018) that a printed loop antenna can be used to generate multiple bands to cover various bands under UWB applications ranging from 3.1 GHz to 10.6 GHz. Figure 1 is reproduced from (S. P. Shastri, R. R. Singh, K.V. Ajetroa, 2018) to show the multiband printed loop antenna. The loop is fed with a compact BALUN which is a compact size BALUN. This leads to the reduction in the overall dimension of the loop antenna. The loop antenna is interfaced with a printed BALUN and is simulated using CST STUDIO. The material used is DUROID 5880 with a thickness of 0.787mm.

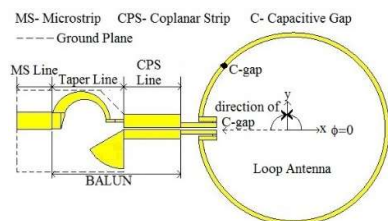


Figure 1: The Printed Loop Antenna Interfaced with a BALUN Transformer

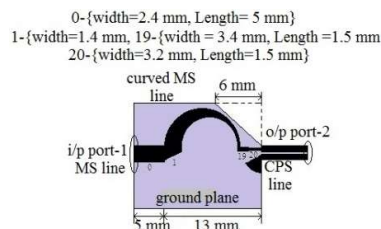


Figure 2: Dimensional Details of the Compact Printed BALUN Transformer

The loop radius is 13.2 mm with a width of 0.6 mm. This dimension of the loop is taken to cover the least frequency of UWB band which is 3.1GHz. The dimensional information of the BALUN is shown in Figure 2. The electrical characteristics of the loop are shown in Figure 3. The antenna generates three distinct bands from 3.1 GHz to 11 GHz.

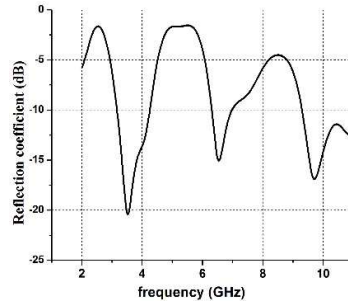


Figure 3: Reflection Coefficient v/s Frequency of Loop Antenna without Capacitive Gap

In order to claim the multiband property of the antenna, it is important to analyze the radiation patterns of the loop antenna at the claimed bands. The first band is available from 3.1 GHz to 4.2 GHz. The second band is available at 6.6 GHz with a bandwidth of 528 MHz. The last two bands are available at 9.77 GHz and 10.3 GHz with same bandwidth. It can be observed in Fig. 4 (a) and (b) that out of the three bands, the radiation patterns of the first band are uniform in θ -plane and are orthogonal to the plane of the loop, Figure 4(a).

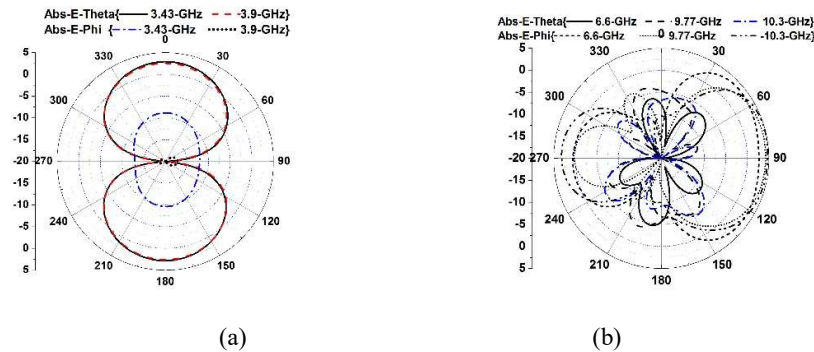


Figure 4: Radiation Pattern of Loop at 3.43 GHz, 3.96 GHz, 6.6GHz, 9.77 GHz, and 10.3 GHz.

But, the radiation patterns available for the last two bands are uniform in ϕ plane, Figure 4(b). Therefore the antenna can be claimed to have only dual band property. In order to increase the number of the bands and to claim the multiband feature of the antenna, a capacitive gap is introduced along the circumference of the loop as shown in Figure 1. The capacitive gap changes the current distribution along the loop. This change in the current along the antenna changes the input impedance of the antenna. A loop antenna of circumference equals to one wavelength is shown with input point marked as 1 and 2 in Figure 5(a). Figure 5(b) shows the current distribution in the same antenna at wavelength λ . It can be observed that a current maximum occurs at the feed points 1 and 2. Figure 5(c) shows the same antenna with a capacitive gap opposite to the feed point i.e. at the mid of the antenna. The current distribution throughout the antenna changes when excited at the wavelength λ . A current minima exists at the capacitive gap and the current is distributed in such a way that the current minima exists at the feed points. This leads to poor antenna impedance. This shows that the introduction of a capacitive gap at different locations, along the circumference of the loop, will lead change in the antenna impedance and this technique can be used to generate different bands from the loop antenna.

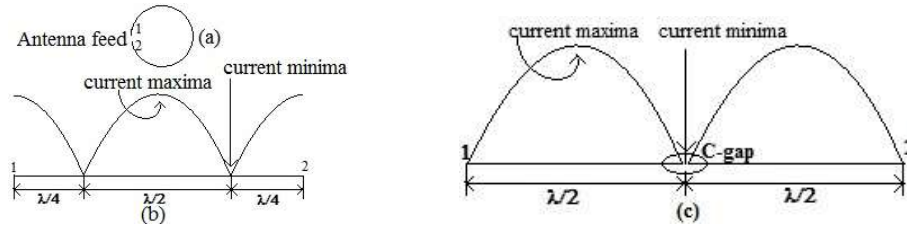


Figure 5: (a) Loop Antenna with Feed Point, (b) Current Standing Wave Along Loop with No Capacitive Gap, and (c) Current Standing Wave Along Loop with Capacitive Gap

Research Method

In order to generate more bands with a stable radiation pattern, a capacitive gap is added to the loop antenna and its impact on reflection coefficient and the radiation pattern is analyzed. The capacitive gap can be created by switching a diode ON or OFF at desired locations. In this paper the capacitive gap is realized using short and open circuit along the circumference of the loop. The capacitive gap is added to the loop from feed end and the location of the feed is augmented by 10° as shown in Figure 1. There is no useful band available till 40° , therefore, the electrical characteristic and the radiation patterns are not taken into consideration. Figure 6 shows that when the gap is created at 45° , the antenna generates a very wide range of frequency. This band ranges from 6.23 GHz to 10.2 GHz with a % bandwidth of 48.

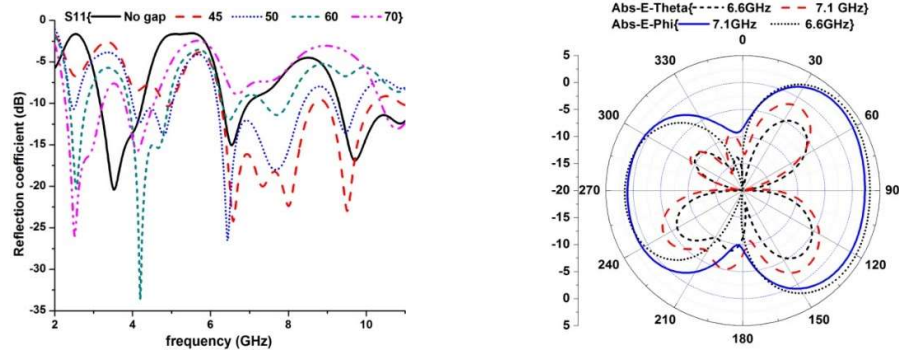


Figure 6: Reflection Coefficient v/s Frequency of the Loop Antenna Without and With Capacitive Gaps at Different Locations

The radiation patterns for this band are analyzed in order to verify the availability of the wide range of the frequency. It can be observed in Figure 7 that the radiation pattern is uniform for $\theta=90^\circ$ and $\Phi=0^\circ$ which is the plane of the loop as shown in the Figure 1. So a wideband operation can be claimed when the capacitive gap is introduced at 45° .

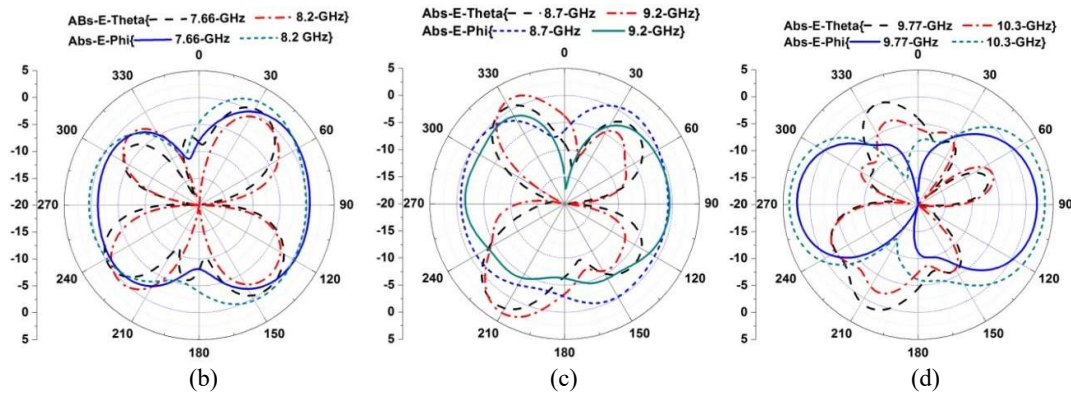


Figure 7: Radiation Pattern of Loop at (a) 6.6 GHz and 7.1 GHz, (b) 7.66 GHz and 8.2 GHz, (c) 8.7 GHz and 9.2 GHz, (d) 9.77 GHz, and 10.3 GHz for Capacitive Gap at 45° .

The loop responds in a similar way when it is added with a capacitive gap at 50° with a little drop in the reflection coefficient from 8.6 GHz to 8.9 GHz. The loop produces a new band from 4 GHz to 5 GHz. But a better response is observed for a capacitive gap at 60° as shown in Figure 6. The new bands available are from 2.36 GHz to 2.83 GHz, 3.8 GHz to 4.95 GHz and 7.34 GHz to 8 GHz. In order to verify the multiband operation of the loop with a capacitive gap at 60° , the radiation patterns are analyzed. It can be observed from Figure 8 that the radiation pattern at 2.4 GHz is orthogonal to the plane of the loop and is little inclined at 4.48 GHz since the two electric fields are comparable with each other. The radiation at 7.66 GHz is oriented in the horizontal direction. Therefore it can be claimed that when there is no gap and when gap is at 60° , there are total 3 bands with radiation patterns orthogonal to the plane of the loop. The first band is available at 2.4 GHz, the second is at 3.6 GHz and the third is at 4.2 GHz. The same antenna can be used to cover other 3 bands with the first band at 6.5 GHz, the second at 7.66 GHz and the third band at 10 GHz. The radiation for these bands are in the plane of the loop and is oriented at $\Phi = 0^\circ$. Therefore even though there are six distinct bands available for when the loop is operated with a capacitive gap (C-gap) at 60° and the loop with no C-gap. Therefore, only three bands can be claimed, i.e., three bands below 6 GHz or three bands above 6 GHz.

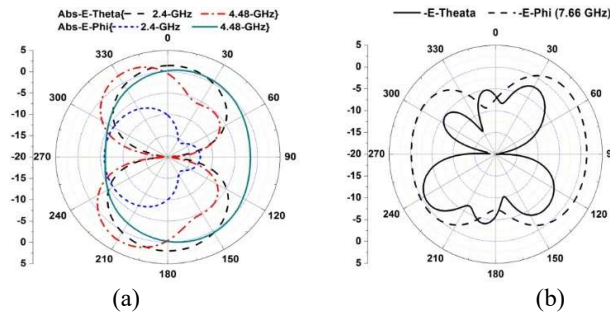


Figure 8: Radiation Pattern of Loop at (a) 2.4 GHz, 4.48 GHz and (b) 7.66 GHz for Capacitive Gap at 60° .

There is no fruitful result when the capacitive gap is at 70° , 80° and 90° . When a capacitive gap is created at 100° and shifted at 110° , the response of the antenna is almost the same for both the cases but is better when the C-gap is at 110° . The new bands generated under this case are from 7.27 GHz-8.5 GHz, and from 8.97 GHz to 10 GHz. So it can be concluded that the loop for this particular case works as dual band antenna. Therefore, when the loop loaded with a capacitive gap at 110° and the loop with no gap are considered, a total of four bands are generated to cover six different bands at 7.66 GHz, 8.2 GHz, 9.2 GHz and 6.6 GHz, 9.7 GHz and 10.3 GHz respectively. But the second band from the loop with C-gap at 110° and the first half of the second band from the loop with no C-gap are overlapped therefore the antenna can be claimed to cover only three bands. The details of the electrical and radiation pattern characteristics are shown in Figure 9 and Figure 10.

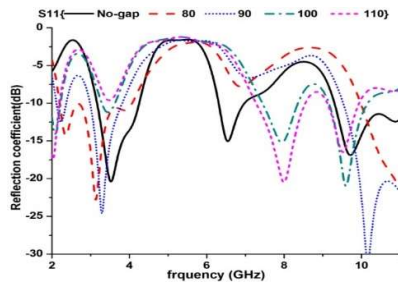


Figure 9: Reflection Coefficient v/s Frequency of the Loop Antenna without and with Capacitive Gaps at Different Locations.

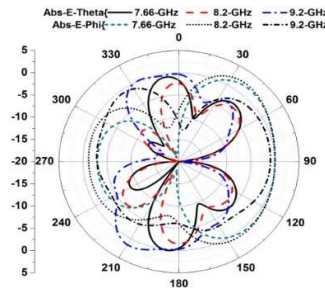


Figure 10: Radiation Pattern of Loop at 7.66 GHz, 8.2 GHz and 9.2 GHz for Capacitive Gap at 110° .

The capacitive gap is further shifted till 310° with a step shift of 10° and the reflection coefficient for all the cases are compared in Figure 11. It can be observed that there is no new band available for any of the cases. Nevertheless, the two cases of the capacitive gap at 130° and 250° are worth to consider as these cases generate a wide band, ranging from 6.4 GHz to 8.4 GHz. Out of these two cases, the reflection coefficient is better for when the gap is at 130° . Once again the antenna with C-gap at 130° and with no gap can be used as triple-band loop antenna covering a band from 6.2 GHz to 8.3 GHz and from 9 GHz to 10.6 GHz as observed in Figure 12.

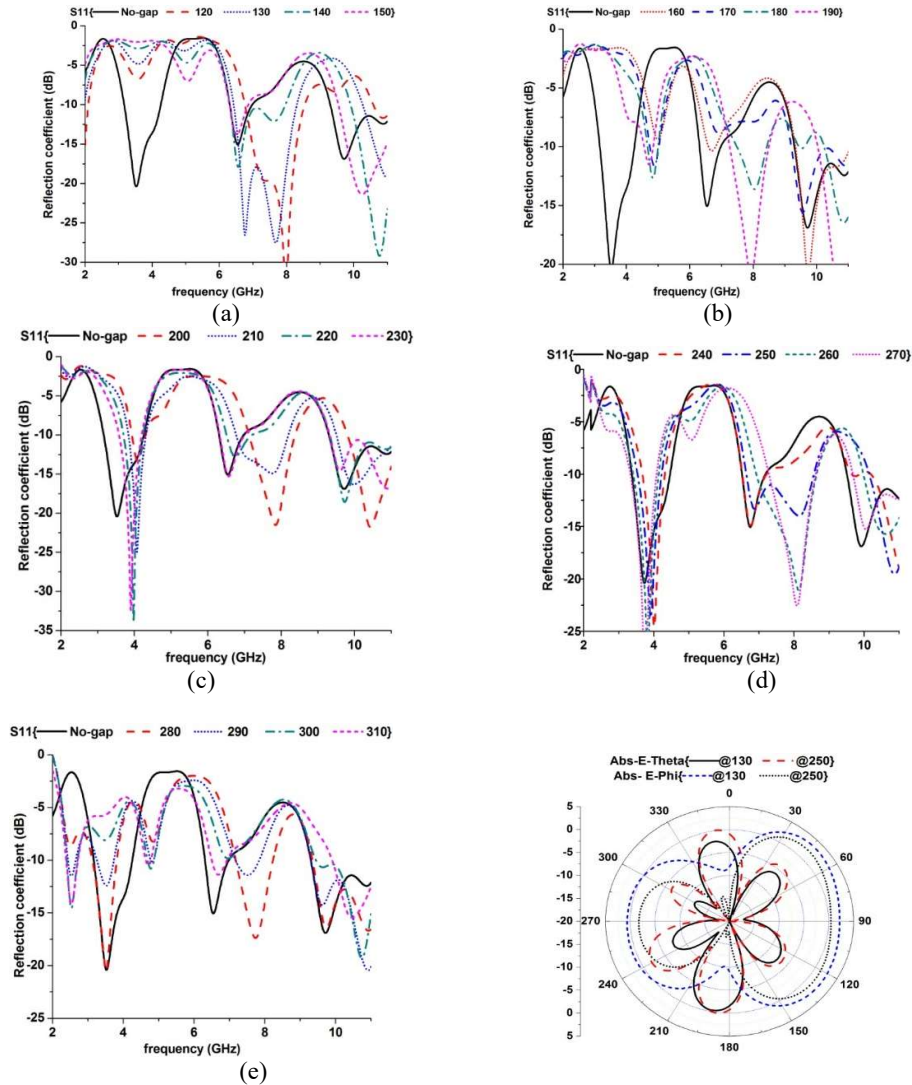
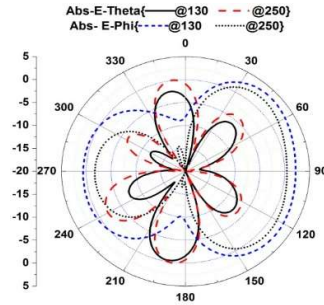


Figure 11: Reflection Coefficient v/s Frequency of the Loop Antenna without and with Capacitive Gaps at Different Locations

Figure 12: Radiation Patterns at 7.1 GHz for Capacitive Gaps at 130° and 250°.



It can be concluded that the capacitive gap introduced in the loop antenna by using a switch, reconfigures the antenna bands. The orientation of the radiation pattern of the loop can be categorized as orthogonal and parallel to the plane of the loop antenna. It is observed that the antenna radiates in the orthogonal direction when the frequency is less than 6 GHz and it is parallel to the plane of the loop and uniform along $\Phi=0$ direction above 6GHz. Table 1 summarizes the significant characteristic of multiband operations using a capacitive gap. The loop antenna with no capacitive gap generates three bands. The introduction of capacitive gap along the circumference of the loop generates new bands listed in Table 1. f_c is the center frequency of the listed band.

Gap Location	No gap		45°	60°		110°	130°/250°
f_c GHz	3.6	6.5, 10	6.2-10	2.4, 4.48	7.66	8, 9.5	7.6
Number of bands	1	2	Single wide band	2	1	2	Single wide band
Orientation of Radiation	Orthogonal to loop plane	Along the loop plane	Along the loop plane	Orthogonal to loop plane	Along the loop plane	Along the loop plane	Along the loop plane

Table 1: Summary of Different Bands Generated Using Capacitive Gap at Different Locations

The maximum number of bands is available when the switch is placed at 110° . The loop with no C-gap and gap at 110° together generates three distinct bands and covers BAND-7, BAND-9-10 and BAND-12-13-14 as shown in Figure 13. Thus the loop can cover 6 different bands using a single switch.

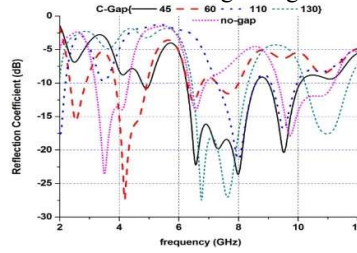


Figure 13: Various Bands Covered by C-Gap Loaded Loop Antenna

It can be observed in Figure 13 that the loop added with the capacitive gap covers all the bands from 3.1 GHz to 10.6 GHz. The band below 3 GHz is not taken into consideration. Figure 13 also shows that the antenna rejects WLAN and WiMAX bands. Figure 14 shows the band distribution for UWB band ranging from 3.1 GHz- 10.6 GHz as given in (S. P. Shastri, R. R. Singh, K.V. Ajetao, 2018) and is used here for reference purpose. The loop antenna added with C-gap at 45° produces a very wide band of frequency when compared with the other cases of the loop antenna added with C-gap. This technique can be used to enhance the bandwidth of the loop antenna. In order to verify this band enhancement technique, other loops with different dimensions are simulated and the bandwidth of each antenna is compared. A summary of the comparison is given in Table 2.

Location of C-gap	Radius of Loop (mm)	f_1 - f_2 (GHz)	% Bandwidth
45°	13.2	6.27-10	45.9
51°	19	3.5-5	35
65°	9.5	8.7-10.5	20
f_1 - f_2 - lower and upper cut off frequencies			
Table 2. Bandwidth Enhancement Using C-Gap			

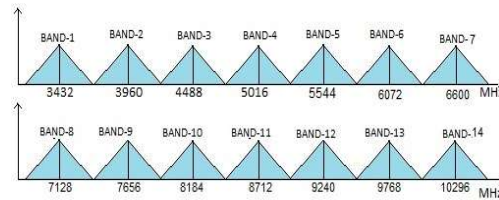


Figure 14. Band Allocation from 3.1 GHz - 10.6 GHz.

The bandwidth is larger for when the loop radius is of 13.2 mm and is minimum when the radius is 9.5 mm. The proposed technique is a simple technique to improve the antenna bandwidth. In order to find out the usefulness of the proposed technique, the result of the loop with capacitive gap is also compared with the loop with no capacitive gap and the comparison is shown in Figure 15. It can be observed that the center frequency of the obtained wide band using a capacitive gap is almost twice of the center frequency of the lowest band obtained when there is no capacitive gap for all the three cases compared in Table 2.

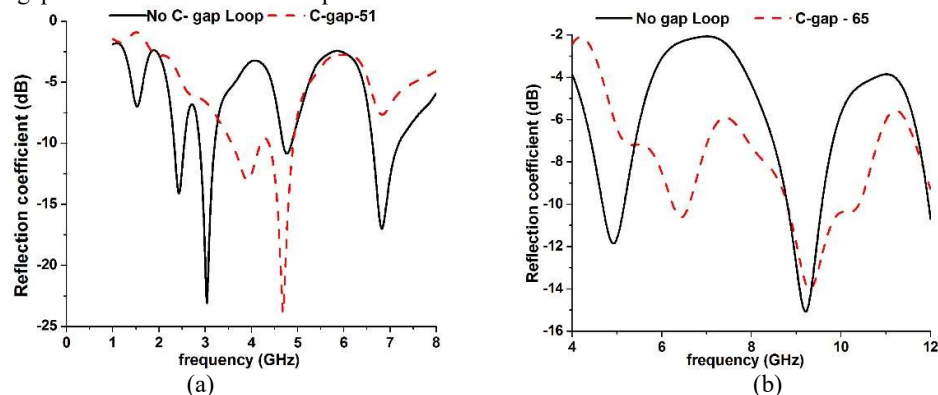


Figure 15. Reflection Coefficient of the Loop with C-Gap at (a) 51° and at (b) 65° for Loop with Radius 19 mm and 9.5 mm respectively.

Results and Discussion

In order to verify the proposed technique of generating different bands from a printed loop antenna, the antenna is manufactured and tested using VNA of series N9926A from Keysight Technologies. Figure 16 shows the photograph of the manufactured antenna.

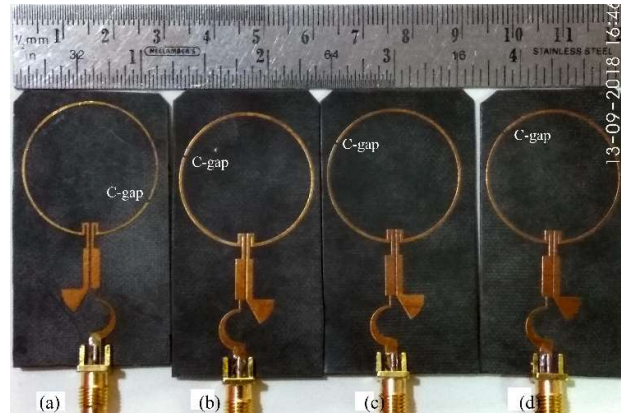
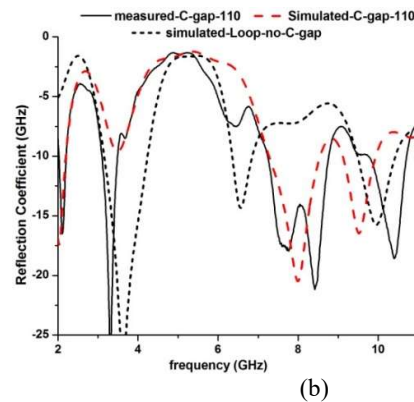
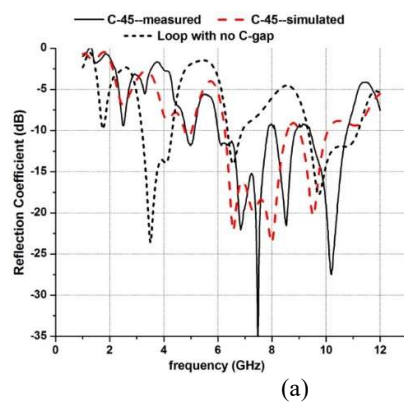


Figure 16. The Loop Antenna with C-Gap at: (a) 45° (b) 110°, (c) 120°, (d) 130°.

The measured result is compared with the simulated one and is shown in Figure 17. It can be observed that the measured results are in good agreement with the simulated result. The switch is realized using open and short circuit along the loop. The open gap is of 0.5 mm width and can be seen in Figure 16.

It can be observed here that the capacitive gap along the circumference of the loop indeed improves the usefulness of the loop as a multiband antenna. It can be observed in Figure 17 (a) that the loop, when added with the C-gap at 45°, produces a wide band from 6 GHz to 10.8 GHz. When there is no gap, the antenna covers an additional band from 3 GHz to 4.2 GHz. Therefore a total of two bands are available using a single switch. When the switch is at 110°, the antenna produces two distinct bands from 7 GHz to 8.4 GHz and from 10 GHz to 10.8 GHz. The loop with no C-gap already covers two different bands as shown in Figure 17 (b). When a single switch is used at 110°, the antenna produces total four distinct bands depending on the ON and OFF state of the switch. When the switch is at 120°, the antenna can produce three distinct bands as shown in Figure 17 (c). The performance of the loop loaded with C-gap at 130° is similar to the performance of the loop loaded with C-gap at 120° and is shown in Figure 17 (d). Since the radiation pattern of the loop is orthogonal to the plane of the loop below 6 GHz and along the loop plane above 6 GHz, the multiband can be claimed either for frequency below 6 GHz or above 6 GHz. The actual bands of operation using C-gap are listed in Table 3.



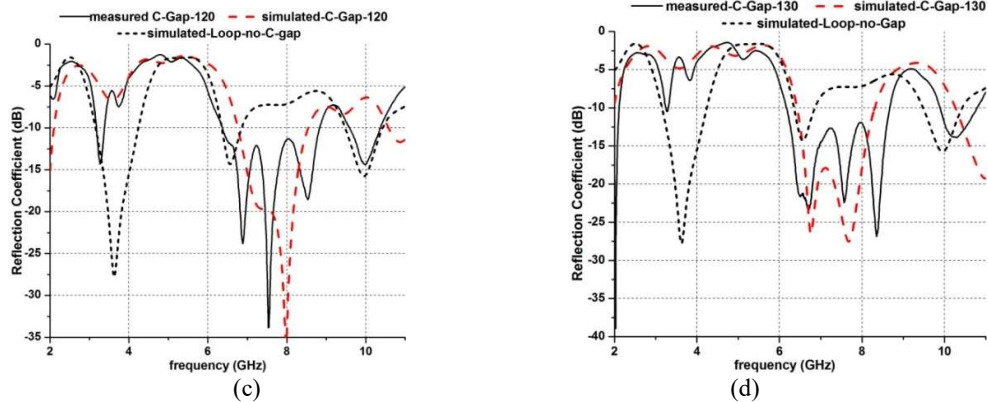


Figure 17. Proposed Loop Antenna with C-Gap at (a) 45° (b) 110°, (c) 120°, (d) 130°.

A comparison of the proposed loop is done with the other recent existing reconfigurable antennas. The summary of the comparison is shown in Table 4.

Switch location	Switch State	Bands (GHz)	Application Band	Mode
45°	ON	6.27-7, 9.45-10.5	BAND-7, BAND-12-13	Dual or single wide band
	OFF	6-10.8	BAND-7-14	
110°	ON	6.27-7, 9.45-10.5	BAND-7, BAND-12-13	Triple
	OFF	7.2-8.8, 9.4-10.7	BAND-9-11, BAND-13-14	
120°	ON	6.27-7, 9.45-10.5	BAND-7, BAND-12-13	Dual
	OFF	6.2-8.8	BAND-8-10	

R	B	Frequency (GHz)	Number of switches	Number of Antenna
[6]	2	1.8, 2.4	8	1
[7]	2	8.2, 10.4	1, MEM capacitor	1
[8]	2	15.95, 17.1	1, MEM capacitor	1
[9]	2	2.4, 5.8	Motor	2
[10]	3	1.58, 2.38	2	1
	5	1.51, 2.28	4	1
[11]	5	2.16 - 9	4	1
[12]	3	2.4, 3.5, 2	6	1
[13]	4	2.45, 3.49, 5.13, 5.81	2	1
P	1	6-10.8	1	1
	2	6.27-7, 9.45-10.5	0	1
	2	6.27-7, 6.27-8.8, 9.45-10.5	1	1
	3	6.27-7, 7.2-8.8, 10-10.5, 9.45-10.5	1	1

R-Reference, B-number of bands, P-Proposed work

Table 3. Different Modes of Operation of C-Gap Loaded Loop Antenna

Table 4: Comparative Analysis of the Proposed Antenna with the Other Existing Antennas

The antenna given by authors in (P.Tilanth, P. C. Sharma, 2014) generates two distinct bands centered at 1.8 GHz and 2.4 GHz. These two bands are generated using eight different switches. The antenna proposed by the authors in (K. Topalli et.al., 2007, 2009) are multiband antenna generating two bands at 8.2 GHz, 10.4 GHz and 15.95 GHz and 17.1 GHz respectively. Both the antennas use MEM switch for the reconfiguration. There are four antennas proposed by authors in (F. Alsharif et.al., 2016). The two antennas are used to generate the two different bands and others are used to change pattern and polarization. The two antennas used to generated different bands are selected using a rotating mechanism so the reconfiguration is controlled mechanically. The antenna proposed by authors in (S. Sharma, C. C. Tripathi, 2015) is operated with two switches and depending on the ON and OFF state of diodes, the antenna generates three different bands from 1.58 GHz to 2.38 GHz. 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 1.51 GHz to 2.28 GHz. The antenna proposed by the authors in (X. Liu, X. Yang, F. Kong, 2015) uses 4 switches and depending on the ON and OFF state of switches, it is operated as single, double and triple band antenna and generates a total 5 different bands. The antenna proposed by authors in (H. I. Idris et.al., 2014) uses 3 pairs of the diode and generates three different bands under single, dual and triple band modes. A single monopole antenna with two optical switches generates four different bands as shown in (S.A.A. Shah et.al., 2017).

The proposed antenna uses a single switch and can produce up to three different bands. The number of bands listed in Table 4 also includes the bands generated by the proposed loop when there is no C-gap added to the antenna. It can be observed that the maximum number of bands obtained from a single antenna is five given in (S. Sharma, C. C. Tripathi, 2015) and (X. Liu, X. Yang, F. Kong, 2015) but there are four switches to generate these bands. The proposed antenna can generate three different bands using only a single switch. Though the bands generated are only three but are wide enough to cover every band given in Figure 14 from 6 GHz onwards. Therefore the proposed technique improves the usefulness of the loop antenna as a multiband loop.

Conclusion

A single loop antenna is not capable of generating multiple bands which restricts the wide application of loop antenna. The proposed method of current reconfiguration in the loop antenna using switches improves the number of bands. The proposed technique successfully demonstrates the enhancement of loop bandwidth using a single switch and can be extended to any dimension of the loop. It is also found that the antenna can be used as a dual or triple band antenna using a single switch at different locations. Therefore it can also be concluded that the location of the switch not only generates different bands but also influences the bandwidth of the produced bands. The proposed loop without a switch is capable of covering only 24% of the entire band of UWB ranging from 3.1 GHz to 10.6 GHz due to the unstable radiation pattern. The range of band can be varied from 24% to 57% using the switches.

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