TRANSACTIONS ON ELECTRICAL AND ELECTRONIC MATERIALS
Vol. 18, No. 2, pp. 62-65, April 25, 2017

Regular Paper

pISSN: 1229-7607 eISSN: 2092-7592
DOI: https://doi.org/10.4313/TEEM.2017.18.2.62
OAK Central: http://central.oak.go.kr

An Efficient Design of a DC-Block Band Pass Filter for the L-Band

Avneet Kaur† and Jyoteesh Malhotra
Department of Electronics & Communication Engineering, Guru Nanak Dev University-Regional Campus, Jalandhar 144009, India

In this paper, three DC Block designs are presented which efficiently meet the need of modern-day compactsize wireless communication systems. As one of the important parts of a complete system design, the proposed microstrip-based DC block with coupled transmission lines efficiently attenuates unwanted frequencies that cause damage to the system. The compact-sized DC block structures are created by incorporating an extended coupled-line section with a radial stub, an enveloped coupled-line section, and using alternate up-down meandering techniques. The structures are analyzed for the L-Band using a high-resistive silicon substrate. At a resonating frequency of 1.575 GHz, the designed DC Block structures have a return loss better than -10 dB, an insertion loss of around -1 dB, and also possess wide pass-band characteristics.

Keywords: Radial stub, High-resistive silicon, Coupled-line section, Up-down meanders

1. INTRODUCTION

The DC Block is a widely used passive microwave component suitable for various RF/microwave circuit applications such as antennas, mixers, amplifiers and switches. DC Blocks prevent unwanted microwave frequencies from causing severe damage to and errors in microwave and millimeter systems, while allowing the required RF signal to pass through them at minimal loss [1]. At microwave frequencies, both a capacitor and coupled-line DC Block has been used in many applications for preventing dc current flow while permitting the RF (radio frequency) power to flow through the circuit. However, capacitors are attractive only at lower microwave frequencies where they are considered as lumped-element components. At higher frequencies, they behave as distributed elements, and thus produce unwanted parasitic elements [2]. So, at microwave frequencies, distributed coupled networks, i.e. a coupled-line DC Block, acts as an ideal band-pass filter for microwave signals [3].

The importance of DC Blocks in wireless communication systems arises from the fact that they have the capability of providing dc blocking, power division, and impedance matching, if used in an arrangement called as “two-way” DC Block [4]. Also, in power distribution systems for antenna feeding arrays, they are necessary for completely separating the high dc power applied to phase-shifters from other components, in order to avoid crosstalk among the output ports, while allowing a wide range of RF signals to pass through them [5].

With the changing technology employed to provide wireless communication services, a tremendous effort is placed on enhancing the electrical performance of these systems while maintaining a compact size. Thus, miniaturized DC Block designs are needed because dc-blocking is an important front-end component connecting other components of the wireless system, and so, its size effects the overall size of RF/microwave device. Thus, in order to meet the present day demand for miniaturized components, this paper presents three novel compact-sized DC-Block designs, which are created by employing extended coupled-line sections with a radial stub; enveloped coupled-line sections, and alternate up-down meanders. All these designs are aimed at reducing the size of the device, in comparison to the conventionally available long line-length DC Blocks reported in literature [6], while improving its RF-performance. The first two designs can be categorized as DC Blocks having double line coupling structures, whereas the third design structure with alternate up-down meanders is an example of a DC Block with a three-line coupling structure. The designed structures are simulated on a high-resistive

† Author to whom all correspondence should be addressed:
E-mail: avneetkaur.53@gmail.com

silicon substrate (ρ>8 kΩ, h=675 μm, tanδ=0.001 and εr=11.8) for a center frequency of 1.575 GHz. All the structures are designed keeping in mind their compatibility with the designed dual-band Hilbert curve-based Wilkinson Power divider [7] for the overall system implementation. Keeping in the mind the near future fabrication and substrate availability in foundries, Si has been chosen as the potential substrate. Well established and documented treatment and fabrication processes allow the integration of the electronics on the same substrate. Moreover, silicon wafers are extremely flat and accept coatings and additional thin-film layers for building micro structural geometries or conducting transmission lines. From a structural point of view, Si is an ideal material having almost the same Young's modulus as steel (about 2 × 105 MPa) along with lightness almost comparable to aluminium. This makes it an ideal candidate for design and manufacture of such devices in comparison to other substrate materials. Moreover, the same substrate wafer can also be used for the fabrication of CMOS structures which may or may not be a part of the device. This allows us to create multiple uses of the same silicon wafer, thereby, considerably reducing the cost factor for the complete system design incorporating the designed DC Block. Based on these factors of cost and multiple uses of the silicon wafer, we chose this substrate.

The proposed designs have satisfactory RF-performance with a return loss better than -10 dB and an insertion loss of around -1 dB. The design methodology of the proposed DC Block is detailed in Section II. Results pertaining to RF-performance of the designed dc-blocking filters are discussed in Section III, and conclusions are given in Section IV.

2. DESIGN METHODOLOGY

A DC Block is a section of symmetric quarter-wavelength coupled-lines which is generally used to pass on a certain range of microwave frequencies, without degradation while attenuating unwanted frequencies. These parallel coupled transmission lines with equal conductor widths are open circuited at one port and terminated with characteristic impedance, Z_0, at the other port, as shown in Fig. 1.

These coupled-lines can be realized in terms of their evenmode and odd-mode impedances by using the following relations, equations (1) and (2) [8]:

$$Z_{0e} = \sqrt{S}\left[1+\sqrt{1+\frac{1+\sqrt{1+\Omega^2}}{\Omega^2}\left(1-\frac{1}{S}\right)}\right]Z_0 \quad (1)$$

$$Z_{0o} = \sqrt{S}\left[-1+\sqrt{1+\frac{1+\sqrt{1+\Omega^2}}{\Omega^2}\left(1-\frac{1}{S}\right)}\right]Z_0 \quad (2)$$

where S is the Voltage Standing Wave ratio and Ω is the normalized bandwidth.

In order to compute the normalized bandwidth, it is necessary to know the values of relative bandwidth (Br) and cut-off frequencies (f_1, f_2). Therefore, using equations (3) and (4) below, the required value of Ω can be calculated.

$$B_r = 2\left(\frac{f_2 - f_1}{f_2 + f_1}\right) \quad (3)$$

$$\Omega = \cot\left[\frac{\pi}{2}\left(1-\frac{B_r}{2}\right)\right] \quad (4)$$

In our designs, for f_2 = 2.075 GHz and f_2 = 1.075 GHz (with center frequency of 1.575 GHz), the relative bandwidth is found to be 0.635, and thus Ω= 0.543. Thus, for a standard value of S and characteristic impedance of 50 Ω (Z_0), the even- and oddmode impedances of the coupled-line section are calculated to be Z_{0even} = 157.256 Ω and Z_{0odd}= 40.913 Ω. Upon substituting these values into ADS/Lincalc [9] along with the coupling coefficient, C=0.3, the optimized line-width and spacing obtained for the λ/4 coupled-line structure are 162.277 μm and 12 μm, respectively. The reason for setting the coupling coefficient to 0.3 is to maintain an adequate balance between fabrication difficulty and the frequency bandwidth of the device. Also, it helps in achieving perfect matching between the ports.

Since, the conventional coupled-line sections employed in DC Blocks are a quarter-wavelength long, the overall size of these blocks is quite large. In order to reduce their size and to improve the coupling between the coupled-lines, novel designs for DC Block are proposed in this paper using double-line and threeline coupling structures. DC Blocks having double-line coupling structure is explained by using two different designs, namely: Design A which makes use of a radial stub along with an extension of coupled-line structure in vertical direction, and Design B which incorporates enveloping of the extended coupled-line section. For the DC Block with a three-line coupling structure, a proposed Design C, makes use of alternate up-down meanders to reduce the overall size of the DC Blocks.

2.1 Design A

This DC Block design, incorporating a double-line coupling structure, reduces the size of conventional DC Blocks by miniaturizing the fixed line-length coupled-line section between input and output ports. This reduction is achieved by measuring a segment of the quarter-wavelength long coupled-line section from open-circuited ends in the upward and downward vertical direction. Also, to improve the RF-performance of this proposed DC Block, it is necessary to maximize the coupling content of the device. The increased coupling content is achieved by extending the similar size of segments from the impedance terminated ends of coupled-lines in parallel with the previous extensions. The measured segments have a line-length of 4 mm, with a proper line spacing of 0.012 mm between them. However, the open-circuited ends are a type of microstrip discontinuity which results in generation of surface waves that cause crosstalk and attenuation

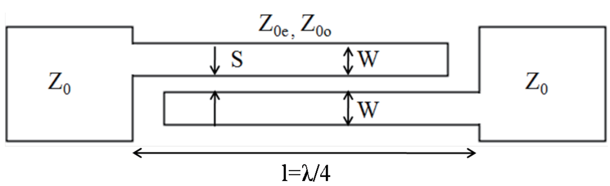

Fig. 1. Conventional circuit of DC block.

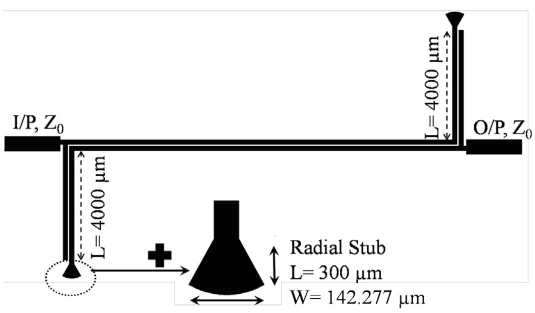

Fig. 2. Design A of DC block with radial Stub.

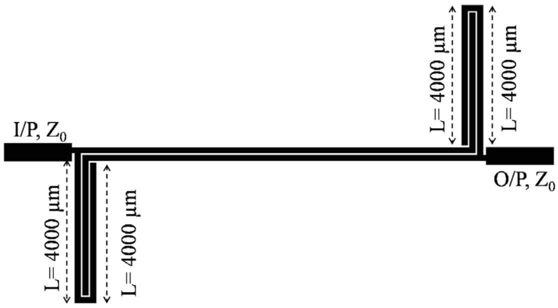

Fig. 3. Design B of DC block.

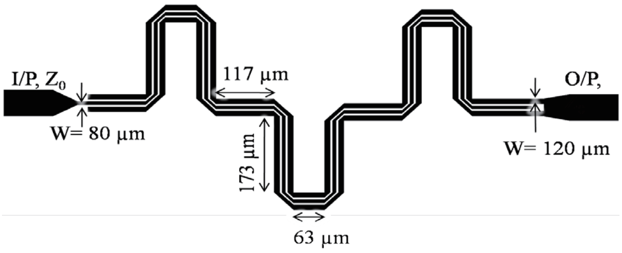

Fig. 4. Design C of DC block.

in microstrip devices. Generation of these unwanted waves can be prevented by increasing the circuit inductance which will result in leak out of these waves to ground.

To increase the inductance of the device without affecting the filter pass-band response, a radial stub is incorporated at the open end of upward and downward coupled-line extensions, as shown in Fig. 2. A radial stub is a useful element for providing a clean (i.e. no spurious resonances) broadband short circuit impedance stub, which shorts the unwanted radiation to ground, thus, improving the overall performance of the DC Block. The physical dimensions of width, length and angle of the employed stub are 0.142 mm, 0.3 mm and 60° respectively. Thus, in this design, parallel coupled transmission-lines are terminated by a characteristic impedance (Z_0) at one port and a radial stub at other port, with additional extensions in parallel to improve the coupling content. The total cross-sectional area of this proposed design is 18.47×9 mm^2.

2.2 Design B

This DC Block design with a double-line coupling structure is a modified version of Design A. It incorporates enveloping of the extended coupled-line section of Design A to increase the coupling content between the transmission lines. The vertical segments extended out from the open-circuited ends of the coupled-line section are encased by segments measured from the coupled-line section terminated with the characteristic impedance. This enveloping is done by chopping off an extra 4 mm from the quarter-wavelength long coupled-lines in addition to the 4 mm portions which were taken out from the total linelength of the coupled-line section in Design A. Thus, the total line-length of the envelope is 8 mm, with an adequate spacing of 0.012 mm between the transmission lines. This enveloping of extended segments results in increased coupling between the transmission-lines, and also reduces the length of the doubleline coupling structure between input and output ports. This improves the performance of the DC Block by improving its return loss, removing the harmonics and decreasing its insertion loss. Also, the overall cover area of this design is 14.57×8.59 mm^2, which is approximately 40.44 mm^2 less than that of Design A.

2.3 Design C

In this design, alternate up-down meandering is done to the coupled-line structure, which significantly reduces the length and therefore, the overall size of the DC Block. The coupled-line structure used in this design is a three-line coupling structure. These structures are preferred over double-line coupling structures because they are capable of generating stronger coupling between the coupled-line sections employed in the design [10]. Also, these DC Block filters have the advantage of wider bandwidth and more compact size. To obtain a three-line coupling structure, a single transmission line is generated from the input port, whereas two parallel lines are generated from output port. These parallel lines are 120 µm wide and have a gap of 80 µm between them. The transmission line from the input port, having a width of 80 µm, is totally encased by the parallel lines generated from the output port. The spacing between the parallel lines with respect to the transmission-line generated from input port is 40 µm. For size reduction, alternate up-down meandering is done while maintaining a proper gap between the fingers of meander. The height of each meander is 0.173 mm and their width is 0.063 mm, and the spacing between alternate meanders is 0.117 mm. With the incorporation of these alternate up-down meanders, there is a 29% shrinking of the proposed design in comparison to the conventional fixed line-length DC Block. However, further shrinking of the design will lead to cross-coupling between the walls of employed meanders that will introduce distortion and cause degradation in the return loss. This design has a total cover area of 12.5×4.5 mm^2 which is smaller than Designs A and B by 109.98 mm^2 and 68.9 mm^2, respectively. Therefore, this design provides us with the most compact DC Block design among all the proposed designs.

3. RESULTS AND DISCUSSION

All of the proposed DC Block designs were analyzed using a commercially available FEM solver [9] that provides a more refined result due to the entire 3D structure under analysis. The structures are simulated for a high resistive silicon substrate (ρ>8 kΩ, h=675 µm, tanδ=0.001 and εr=11.8) for a center frequency of 1.575 GHz in the L-Band. Thin substrates with high dielectric constant are very effective in minimizing undesired radiation, which also considerably reduce the size of the structure, thereby, making silicon a highly preferred choice for the DC Block filter designs. The RF performance of all the proposed designs are shown in Fig. 5, with their comparative performance summarized in Table 1.

Considering the RF performance of the proposed DC Block designs, from Fig. 5(a), it can be concluded that Design A meets the targeted RF performance, i.e. the return loss is better than -10 dB and insertion loss is around -1 dB. However, its return loss graph also shows the presence of harmonics in the range 2~2.5 GHz, which is not desired. This undesired feature of Design A is very effectively overcome in Design B, which is Design A's modified version. The return loss for Design B, Fig. 5(b), has a maximum value

Table 1. Performance of all the proposed DC Block designs.

Para-meters	Return loss (dB)	Insertion loss (dB)	f_{LCF} (GHz)	f_{UCF} (GHz)	B.W. (GHz)	Size (mm^2)
Design A	-40.276	-0.988	0.600	2.70	2	18.47 × 9
Design B	-54.148	-0.921	0.500	2.50	2	14.57 × 8.59
Design C	-35.595	-0.028	0.765	4.00	3	12.5 × 4.5

f_{LCF}= lower cut-off frequency; f_{UCF}= upper cut-off frequency; B.W.= bandwidth

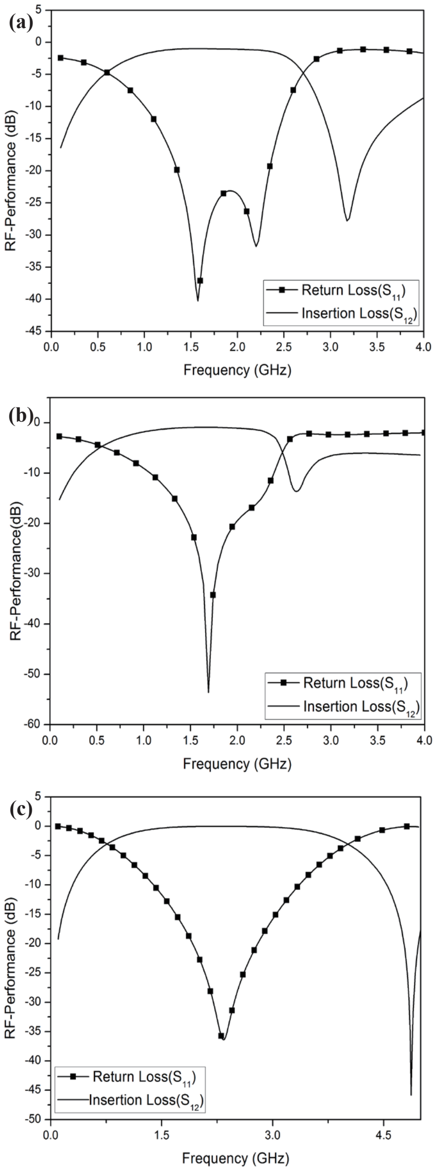

Fig. 5. (a) RF-performance of design A, (b) RF-performance of design B, and (c) RF-performance of design C.

of -54.148 dB at the resonating frequency of 1.575 GHz, without any presence of harmonics, thus, showing improved RF performance in comparison to Design A. However, in terms of operational bandwidth, Design A using a radial stub having lower and upper cut-off frequencies as 600 MHz and 2.7 GHz, has a pass-band range of approximately 2 GHz. Similarly, for the enveloped DC Block design, the frequency band obtained has a bandwidth of 2 GHz, therefore, both designs provide similar pass-band ranges for desired microwave frequencies. For Design C, the return loss is -35.595 GHz and the insertion loss is less than -1 dB, which is an important feature of this design. Also, Design C, with upper and lower cut-off frequencies of 765 MHz and 4 GHz, has a pass-band range of nearly 3 GHz, which is more than the other two designs. Therefore, it is clear that our DC Block designs offer a wide pass-band, covering the L and SBands, for desired microwave frequencies.

4. CONCLUSIONS

In this paper, one of the major concerns of modern day wireless communication systems of having a compact size DC Block is addressed. All the proposed designs have a total cover area much smaller than conventional DC Blocks. Of all the proposed designs, Design C, which uses a three-line coupling structure, has the smallest cross-sectional area of 56.25 mm^2, which is 109.98 mm^2 and 68.9 mm^2 smaller than other two DC Block designs having double-line coupling structures, respectively. Also, Design C has a wider pass-band range for the desired microwave signal frequencies. Therefore, we can say that the DC Block with a three-line coupling structure has the advantage of wider bandwidth and more compact size with moderate RF performance. Overall, for an RF signal, compact size with high return loss and low insertion loss is desirable for DC Blocks. Our analyses have shown that all our designed DC Blocks, having return loss better than -10 dB and insertion loss around -1dB at center frequency, satisfy the above constraints.

REFERENCES

[1] D. M. Pozar, *Microwave Engineering* (3rd Edition) (John Wiley & Sons, New York, 2005).

[2] D. L. Combe and J. Cohen, *IEEE Trans. Microwave Theory Tech.*, **MTT-20**, 555 (1972). [DOI: https://doi.org/10.1109/TMTT.1972.127808]

[3] S. H. Choi, J. Y. Lee, and K. B. Lee, *Proc. Asia-Pacific Microwave Conference* (Bangkok, Thailand, 2007). p. 1. [DOI: https://doi.org/10.1109/apmc.2007.4554778]

[4] S. Srivastava, S. R. Panchal, D. R. Gandhi, P. Bharadhwaj, and S. Singh, *Proc. IEEE International Microwave and RF Conference (IMaRC)* (Hyderabad, India, 2015). p. 56.

[5] T. Ji, H. Yoon, J. K. Abraham, and V. K. Varadan, *IEEE Transactions on Microwave Theory and Techniques*, **54**, 1131 (2006). [DOI: https://doi.org/10.1109/TMTT.2006.869721]

[6] H. R. Ahn and T. Itoh, *IEEE Transactions on Microwave Theory and Techniques*, **58**, 2463 (2010). [DOI: https://doi.org/10.1109/TMTT.2010.2058936]

[7] A. Kaur, H. Singh, and J. Malhotra, *Trans. Electr. Electron. Mater.*, **17**, 257 (2016).

[8] D. Kajfez and B. S.Vidula, *IEEE Trans. Microwave Theory Tech.*, **MTT-28**, 974 (1980). [DOI: https://doi.org/10.1109/TMTT.1980.1130205]

[9] Advanced Design System (ADS) 2011- Agilent Technologies.

[10] J. T. Kuo and E. Shih, Proc. *IEEE Microw. Antennas Propag.*, **149**, 243 (2002). [DOI: https://doi.org/10.1049/ip-map:20020572]