

Conformal bandpass filter with $\lambda_g/4$ short-circuited stubs using defected ground structure

LI Rong-zheng, HUA Chang-zhou*

(Faculty of Electrical Engineering & Computer Science, Ningbo University, Ningbo 315211, China)

Abstract: A conformal bandpass filter with $\lambda_g/4$ short-circuited stubs using defected ground structure (DGS) is described in this paper, which effectively solves the problem that the width of $\lambda_g/4$ short-circuited stubs is too large to be realized in realizing medium or narrow bandpass filters. The filter is designed basing on high impedance termination to reduce the width of the low characteristic impedance lines, and then two sections of $\lambda_g/4$ impedance transformer are used at input and output of the filter to match to $50\ \Omega$ system. DGS is applied to increase the width of the high characteristic impedance lines in the filter. This planar special filter can adopt a flexible dielectric-slab and is easy to conform to material surface. Finally, a 13 orders bandpass filter working at 20 GHz is designed, fabricated, and measured. In addition, the flexibility of the filter is also tested. Experimental results and full wave simulated ones are compared and the proposed design method is verified.

Key words: defected ground structure (DGS); high characteristic impedance; $\lambda_g/4$ short-circuited stubs; bandpass filters

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1 Introduction

Bandpass filter with $\lambda_g/4$ short-circuited stubs is one of very common planar bandpass filters in microwave integrated circuits design. Moreover, it can also be found as an automated guided design module in Keysight Advanced Design System (ADS). Engineers can easily realize the design of such filter in ADS without much calculation. However, this kind of bandpass filter generally achieves a fractional bandwidth of 0.4 to 0.7. When the design goal of bandwidth is less than 0.4, especially at higher microwave frequencies where the width of transmission line is comparable to the line's quarter wavelength, one would always find that it becomes impossible to realize

a bandpass filters with $\lambda_g/4$ short-circuited stubs because the width of the short-circuited stub becomes too wide.

Other filter structures such as interdigital filters, combline filters and hairpin filters are commonly used to realize narrow bandwidth bandpass filter. Tapped type coupling structure^[1] at the input and output of filter can be used to expand the bandwidth. However, due to the limitation of coupling level, those filters can hardly achieve a medium bandwidth.

If we increase the impedance of termination of bandpass filters with $\lambda_g/4$ short-circuited stubs, the characteristic impedance of the short-circuited stubs would increase and the width of line could be reduced to be realized. However, on the other hand, the characteristic impedance of the high characteristic

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第一作者: 李荣正(1989-), 男, 河南濮阳人, 在读硕士研究生, 主要研究方向: 微波毫米波器件及电路. E-mail: li457324@163.com

*通信作者: 华昌洲(1984-), 男, 浙江杭州人, 副教授, 主要研究方向: 微波毫米波天线及电路. E-mail: huachangzhou@nbu.edu.cn

impedance transmission line in the filter becomes higher, which corresponds to narrow line width. Therefore, increasing the impedance of termination of filter would increase the insertion loss. Moreover, the width of high characteristic impedance transmission line could become too thin to be realized^[2]. One solution for this is to implement DGS in the filter.

Research on the DGS has been reported with various configurations in microwave and millimeter frequency-band applications. The DGS with periodic or non-periodic arrays provides a rejection band in some frequency range due to the increase of the effective inductance of transmission line^[3-4], and the DGS is applied to many different circuits such as filters, antennas, couplers, power dividers, and amplifiers, etc^[5-10].

In this paper, DGS is used to realize bandpass filters with $\lambda_g/4$ short-circuited stubs basing on high termination impedance. Because DGS could increase the effective inductance of a transmission line, it could be used to realize the high characteristic impedance microstrip lines in the filter. In the following sections, design of non-conformal and conformal bandpass filters with $\lambda_g/4$ short-circuited stubs based on high termination impedance and DGS will be presented. In these designs, substrate is chosen to be Rogers RT/duroid 6002 with a relative dielectric constant of 2.94 and a thickness of 0.127 mm, which have good toughness and can be very easily to conform to the surface of the carrier.

2 Design of bandpass filter with quarter-wave length short stubs

2.1 Theoretical analysis

Equivalent network of an n order (n is odd number) bandpass filters with $\lambda_g/4$ short-circuited stubs is shown in Fig. 1. The filter consists of $(n-1)/2$ connecting lines and $(n-1)/2+1$ shunt short stubs. All of the lines and stubs are $\lambda_g/4$ length. For a given filter with degree n , the characteristic of the bandpass filter with $\lambda_g/4$ short stubs is strongly dependent on the characteristic admittances

of the short stub lines denoted by Y_i ($i=1$ to n) and the characteristic admittances of the connecting transmission lines denoted by $Y_{i,i+1}$ ($i=1$ to $n-1$)^[2,11].

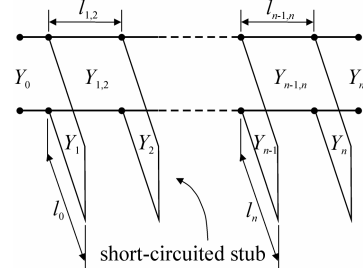


Fig. 1 Bandpass filter with $\lambda_g/4$ short stubs

The design equation for determining the characteristic admittances of each stub and connecting lines described in [2] are given by

$$\begin{aligned} \theta &= \pi(1 - W_f/2)/2, \\ J_{1,2}/Y_0 &= g_0\sqrt{2g_1/g_2}, \\ J_{n-1,n}/Y_0 &= g_0\sqrt{2g_1g_{n+1}/(g_0g_{n-1})}, \\ J_{i,i+1}/Y_0 &= 2g_0g_1/\sqrt{g_ig_{i+1}}, \quad i=2, \dots, n-2, \\ N_{i,i+1} &= \sqrt{(J_{i,i+1}/Y_0)^2 + (2g_0g_1 \tan \theta/2)^2}, \\ &\quad i=1, \dots, n-1, \\ Y_1 &= Y_0(N_{1,2} - J_{1,2}/Y_0) + g_0Y_0(1-h/2)g_0 \tan \theta, \\ Y_n &= Y_0(N_{n-1,n} - J_{n-1,n}/Y_0) + \\ &\quad Y_0(g_ng_{n+1} - g_0g_1h/2) \tan \theta, \\ Y_i &= Y_0(N_{i-1,i} + N_{i,i+1} - J_{i-1,i}/Y_0 - J_{i,i+1}/Y_0), \\ &\quad i=2, \dots, n-2, \\ Y_{i,i+1} &= Y_0(J_{i,i+1}/Y_0), \quad i=1, \dots, n-1, \end{aligned} \quad (1)$$

where g_i are the element values of a ladder-type low-pass prototype filter and W_f is the fractional bandwidth.

Bandpass filter with $\lambda_g/4$ short stubs is capable to realize the fractional bandwidth between 0.4 and 0.7. The narrower fractional bandwidth of the filter, the larger Y_i (and the width of the stub) will be. At microwave frequencies, if the fractional bandwidth is smaller than 0.4, the width of the stub would be too wide to be realized. We could design the filter with higher impedance termination to decrease the values of Y_i . Meanwhile, using DGS will increase the width of the connection line, which is greatly decreased because all of the impedance levels are increased due to the high impedance termination.

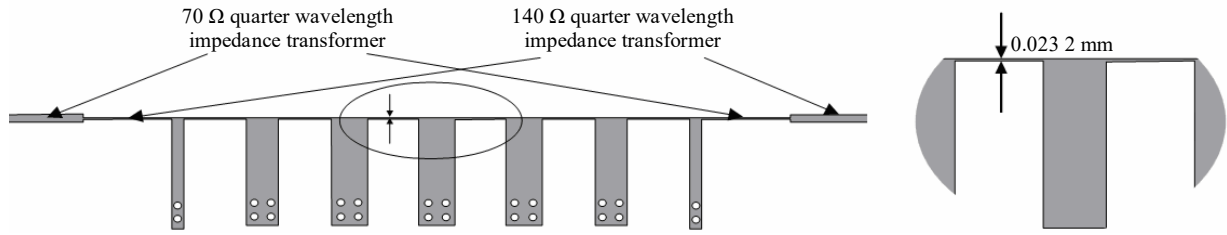


Fig. 2 The geometry of filter with 200 Ω impedance termination

2.2 Filter design

An example filter with 25% fractional bandwidth is designed to show the proposed design idea. The central frequency of the filter is $f_0=20$ GHz (17.5–22.5 GHz). The filter is a 13 orders Chebyshev filter with ripple of 0.1 dB.

At first, we choose the termination impedance of the filter to be 200 Ω . The characteristic impedance of every shunt short-circuited stub and connecting line can be calculated by equations (1)–(3). The filter is designed with the help of ADS, and the layout of the filter is shown in Fig. 2.

In order to get a good impedance matching to 50 Ω , two impedance transformers are added to the input and output port of the filter. Each impedance transformer consists of two sections of quarter wavelength transmission line impedance transformer. The characteristic impedance of the two quarter wavelength lines is 140 Ω and 70 Ω , respectively.

Fig. 3 shows the full wave simulated results of the filter shown in Fig. 2. It shows that because the widths of the connection lines are very thin (0.0232 mm, corresponding to $Z_0=168 \Omega$), the insertion loss is more than 3 dB at the center frequency of the passband. Except for the high insertion loss, filter shown in Fig. 2 is difficult to be fabricated with standard printed circuit board (PCB) technologies since the width of connection lines are only 0.0232 mm.

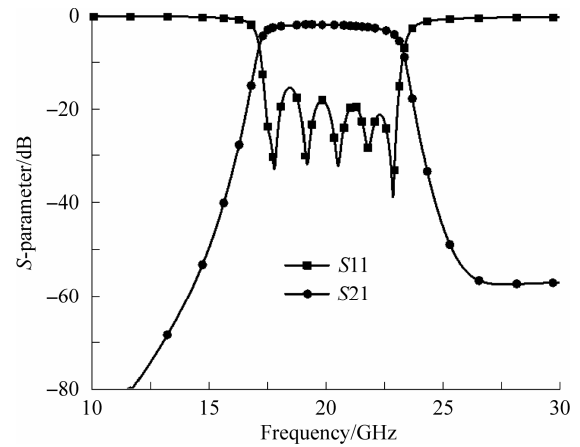


Fig. 3 Simulated results of the filter in Fig. 2

To solve the problem that connection lines are too thin, DGS is applied to the filter, as shown in Fig. 4. The DGS is realized by removing an area of metal under the connection line, on the back side of the substrate. Therefore, a slot window is created under the microstrip line. The shape of the slot is rectangular, whose length is equal to the length of connection line, and width is 1 mm. Because the filter will be placed on a shielded metal base, a cuboid cavity which has the same shape of slot and depth of 2 mm is created on the metal base.

By removing the metal under the connections line, the distance between the connecting line and ground is increased. Therefore, the capacitance of the connection line to ground is decreased and characteristic impedance is increased. For the same width of line, a very high

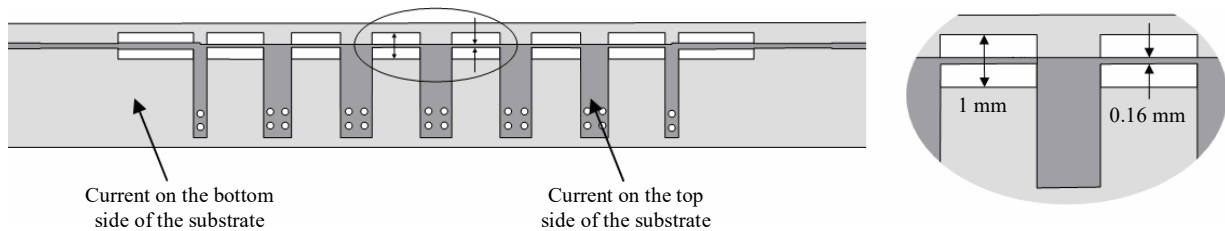


Fig. 4 The geometry of the filter with DGS

characteristic impedance transmission line could be achieved by using DGS, which is impossible to be realized without DGS.

The characteristic impedance of connecting line with DGS can be obtained from electromagnetic simulation. Fig. 5 shows the simulated characteristic impedance of the connecting line with and without DGS versus the width of line, where substrate and DGS size is described above. From Fig. 5 we can see that, to realize a high impedance transmission line, the width of line with DGS is much larger than the one without DGS. Without DGS, the width of $Z_0=168\ \Omega$ microstrip line is 0.023 2 mm; with DGS, the width of microstrip line is increased to around 0.16 mm.

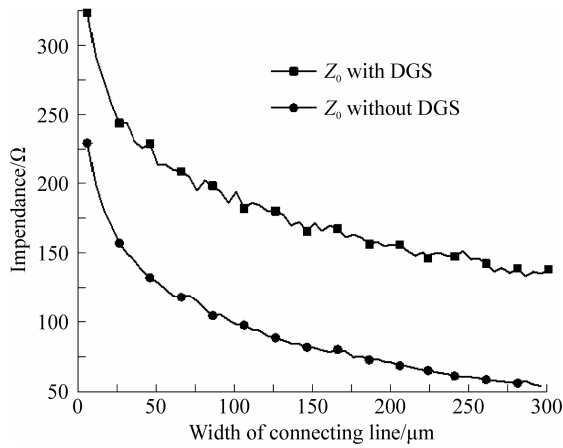


Fig. 5 Characteristic impedance of the connecting line with and without DGS versus width of line

2.3 Design results

Fig.6 shows the fabricated filter with DGS and the shielded metal base of the filter.

The measured and simulated results of the processed bandpass filter with DGS are presented in Fig. 7. It can be seen from the figure that the insertion loss of the filter (including the connectors) is less than 2.3 dB, and the return loss of filter in the pass band is better than 20 dB, the measured results have a great agreement with the simulated ones.

The proposed filter is compared with some previously published designs^[12-14] in Table 1. Obviously from the table, the proposed filters exhibit the smallest circuit size with identical or even improved in-band

performances.

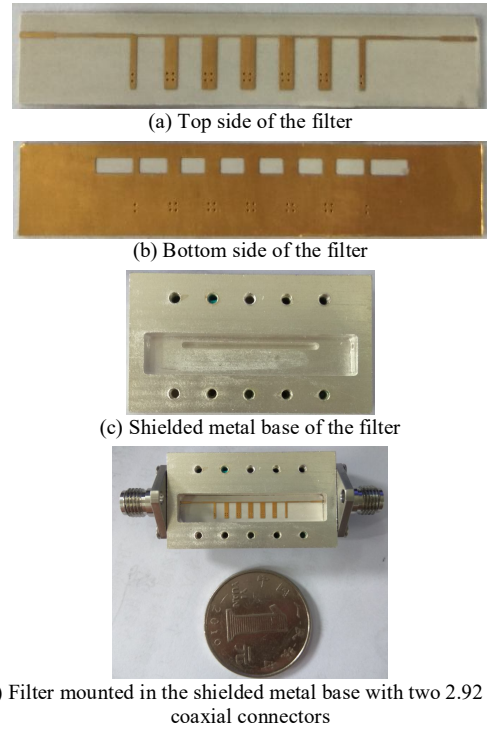


Fig. 6 Fabricated filter with DGS and the shielded metal base

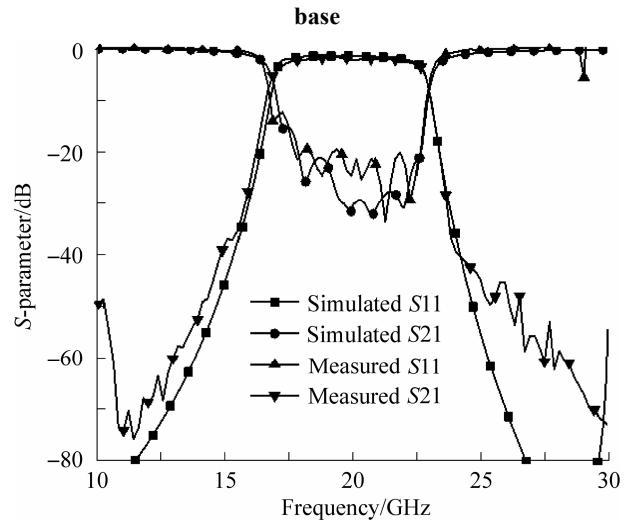


Fig. 7 Simulated and measured S -parameters of the filter

Table 1 Performance comparison with some reported BPFs with $\lambda_g/4$ short-circuited stubs

Scheme	f_0/GHz	$W_t/\%$	I_L/dB	Filter orders	Circuits size λ_0^2
[12]	4.15	50.6	0.6	5	2.1×2.1
[13]	2.46	5	1.6	3	0.32×0.25
[14]	2	10	1.5	5	0.25×0.27
This work	20	25	2.3	13	2.3×1.3

3 Design of conformal bandpass filter

Because the designed filter is required to be mounted in the flexible electronic equipment, a bend test is necessary to ensure practical availability. Fig. 8 shows the simulated return loss when the designed filter is bended in different radius. It can be seen from the figure, the larger the radius, the better the return loss. When the radius is less than 15 mm, the return loss will deteriorate rapidly. Finally, in order to test the performance of the bended filter, a filter whose bend radius is 20 mm was processed. The filter is affixed to the surface of an arc-shaped metal block with a radius of 20 mm. The conformal filter with DGS is fabricated as shown in Fig. 9. To facilitate measurement, two 2.92 mm coaxial connectors are attached to the two ports of the filter.

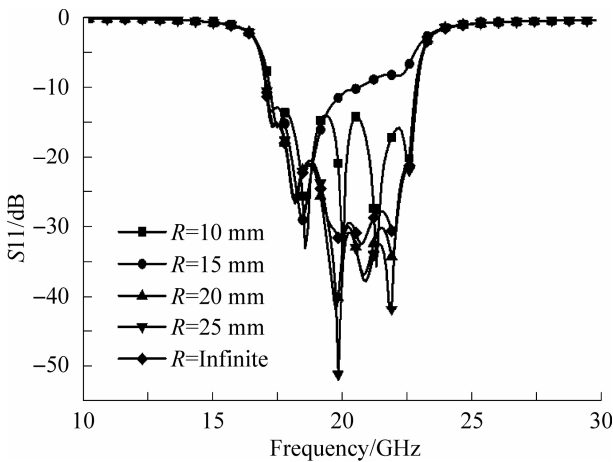


Fig. 8 Simulated return loss of the filter bended in different radius

Fig. 10 shows measured results of the processed conformal bandpass filter with the DGS compared with simulated ones. The S -parameters of the filter were measured using an Agilent N5230A network analyzer. It can be seen that, the insertion loss of the filter (including the connectors) is less than 3 dB, and the return loss of filter in the pass band is better than 15 dB. The simulated fractional bandwidth is 25.0% (17.5–22.5 GHz), while the measured one is 27.8% (17.0–22.5 GHz) at the center frequency of 19.75 GHz with the ripple of ± 0.7 dB. The measured bandwidth is slightly wider than the simulated one, which may be caused by the

fabrication error of the filter and the arc-shaped metal block.



Fig. 9 Photograph of the fabricated conformal filter

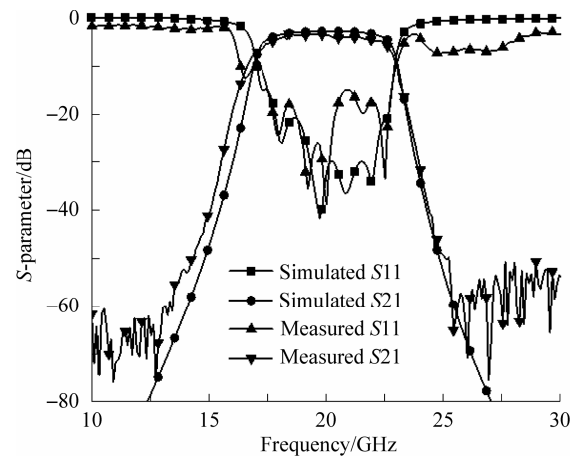


Fig. 10 Simulated and measured results of the conformal filter with DGS compared with simulated ones

4 Conclusion

In this paper, a conformal bandpass filter with $\lambda_g/4$ short-circuited stubs basing on high impedance termination and using defected ground structure has been proposed for medium fractional bandwidth bandpass filter. The design method of this kind of filter is described. To demonstrate it, a 25% fractional bandwidth 13 orders bandpass filter with $\lambda_g/4$ short-circuited stubs has been designed. Measured results of the designed filter agree with predicted ones. Then, the flexibility of the filter is tested. From the results, the filter also demonstrates good flexibility.

Although the DGS has been widely used in various configurations in microwave and millimeter frequency-band applications, we have not seen it used in the filter with $\lambda_g/4$ short-circuited stubs. This method expands the fractional bandwidth range that the filter with $\lambda_g/4$ short-circuited stubs can be realized and it has an

important effect on the application of this kind of filter in a wider field.

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基于缺陷地结构的共形四分之一波长短截线带通滤波器

李荣正, 华昌洲*

(宁波大学 信息科学与工程学院, 浙江 宁波 315211)

摘要: 在原有的四分之一波长短路短截线带通滤波器的基础上加入缺陷地结构, 可以有效的解决在设计中等带宽或窄带带通滤波器的时候, 四分之一波长短路短截线太宽而无法实现的问题. 此四分之一波长短路短截线带通滤波器在较高的终端阻抗下设计, 较高的终端阻抗使阻抗较低的四分之一波长短路短截线宽度减小. 在滤波器的输入输出端用两级四分之一波长阻抗变换器把较高的终端阻抗匹配到 50Ω , 然后用缺陷地结构增大滤波器中高阻抗线的宽度以便于物理实现. 该种平面结构滤波器可以很好地适用于多种介质基板且易于和材料表面共形. 最后, 一个中心频率为 20 GHz 的 13 节四分之一波长短路短截线滤波器被设计、加工和测量, 同时也测试了该滤波器的灵活性. 经过仿真和实测数据的对比, 证明了该方法的有效性.

关键词: 缺陷地; 高特性阻抗; 四分之一波长短路短截线; 带通滤波器

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