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Novel Transformation to Design Dual-Band Filters

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Abstract: This paper introduces novel derived transformation equations to design dual-band filters. The design utilizes the approach adopted for dual-band bandpass filter design based on asymmetric half-wavelength resonator. The obtained optimized filter by this approach is used as a reference and the proposed transformation is applied to calculate the new filter design hardware parameters that satisfy its given specifications. Two dual-band filters are demonstrated by using this transformation. The reference dual-band filter is designed to have: bandwidths of 96 MHz and 185 MHz at the central frequencies 2.1 GHz and 5.6 GHz for UMTS/ Wi-MAX applications, respectively. Another two dual-band filters for GPS/WiLAN and GPS/Wi-MAX applications are illustrated to verify the transformation technique. The momentum simulations for these filters show that the specifications are: bandwidths of 85 MHz and 100 MHz at the central frequencies 1.575 GHz and 5.8 GHz for the first one while bandwidths of 95 MHz and 100MHz at the central frequencies 1.5 GHz and 3.8 GHz for the second filter, respectively. All the results are obtained using circuit and momentum simulation of the Agilent Design Simulator (ADS) package.

Keywords: Dual-band Filter, Microstrip Filter, Frequency Transformation, Shunt Open stubs or Asymmetric Resonator.

1. Introduction

Microwave bandpass filters act as the air interface of RF systems. Therefore, several types of microstrip dual-band filters have been developed to be utilized in wireless communication systems. Recently, microstrip filters deign approaches have been proposed. These methods include dual-band filter with meander-loop resonator and complement split-ring resonator (CSRR) defected ground structure (DGS) [1] that are operated for respective passbands. They have compact size, dual band and high selectivity but they have complex structures. Also there are dual-band filters that are based on conventional triangular dual-mode [2] that are characterised by compact structure and low insertion loss but they suffer also from complex structures. Other filters are based on half-wavelength resonators [3]. The main feature of these methods is that n or n + 1 transmission zeros can be generated for a structure composed of n resonators that can be demonstrated by two-pole microstrip hairpin filters. More transmission zeros and the maximum of attenuation in the stopband of transmission response can be obtained by utilizing open circuited stubs, parallel coupled-lines and cross-coupling. Another filters use asymmetric half-wavelength resonator structure [4-5] and shunt open stubs can be added to add extra passband to the filter so that a dual-band filter can be obtained by adding four shunt open stubs. Although, in asymmetric half-wavelength resonator [4-5], the condition for the total lengths of the microstrip lines of the filter and its bandwidths are derived, the initial lengths of these lines are guessed, while the final lengths are obtained by optimizer.

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This paper is organized as follows: the analysis and design steps of asymmetric half-wavelength resonators structure with shunt open stubs are illustrated in Section II. Equations of the filter lengths normalized to the guided wavelength, λ_g and the novel transformation technique are introduced in Section III.
The proposed systematic dual-band filter procedure is applied to implement two filters which desired specification and the obtained results are analysed in Section IV. The conclusions and comparison with others methods are given in Section V.

2. Filter Design based on asymmetric half-wavelength resonators structure

2.1 Filter Analysis

The structure of multi-band filter using asymmetric half-wavelength resonators with four shunt open stubs is shown in Fig. 1 [5]. It consists of upper section and lower section, where each section consists of microstrip lines L_1, L_2, L_3 and L_4 in addition to a coupling capacitor C_s. Note that L_1 includes the total length of $L_{\_1}$, L and the length of the diagonal of the microstrip bend between $L_{\_1}$ and L (L_d) as illustrated in Fig. 1. Similarly, L_2 is the total length of $L_{\_2}$, L and the length of the diagonal of the microstrip bend between $L_{\_2}$ and L (L_d). The length L_4 is the shunt open stub, which is connected to the resonator directly. The coupling between the two open ends of the resonators is simply expressed by the gap capacitance Cs.

The total length of one resonator is given by [5]:

$$L_1 + L_2 + 2\,L_3 = \lambda_g/2 \qquad (1a)$$

$$L_1 > L_2 \qquad (1b)$$

$$L_1 < \lambda_g/4,\ L_2 < \lambda_g/4,\ L_3 < \lambda_g/4,\ L_4 < \lambda_g/4 \qquad (1c)$$

Where λ_g is the guided wavelength at fundamental resonance frequency, f_r, which is calculated as:
For a dual-band filter with resonance frequencies lower, f_L and upper, f_U, f_r is calculated as:

$$f_r = \frac{f_L + f_U}{2} \qquad (2)$$

So the guided wavelength, λg is calculated as:

$$\lambda_g = \frac{v_p}{f_r} \quad and\ v_p\ is\ the\ phase\ velocity$$

$$where,$$

$$v_p = \frac{c}{\sqrt{\varepsilon_{eff}}} \quad and\ c\ is\ the\ speed\ of\ light \qquad (3)$$

$$and\ \varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} * \frac{1}{\sqrt{1 + 12\frac{h}{W}}}$$

In this design example: f_r = 3.85 GHz and λ_g = 56.76 mm.
The two transmission zeros on both sides of the first passband, f_{r1} are f_1 and f_2 that can be obtained as [5]:

$$f_1 = \frac{c * n * \arccos(\sin \beta L_1 * \cos \beta L_3 * \tan \beta L_4)}{2\pi * \sqrt{\varepsilon_{eff}} * (L_1 + L_3)} \qquad (4a)$$

$$f_2 = \frac{c * n * \arccos(\sin \beta L_2 * \cos \beta L_3 * \tan \beta L_4)}{2\pi * \sqrt{\varepsilon_{eff}} * (L_2 + L_3)} \qquad (4b)$$

Where β is the propagation constant, Z_0 the characteristic impedance of the resonator, ε_{eff} is the effective dielectric constant, n is the mode number.
The Band Width, BW_1 the first passband, f_{r1} is calculated as:

$$BW_1 = f_2 - f_1 \qquad (4c)$$

The other two transmission zeros on both sides of the second passband, f_{r2} are f_3 and f_4 can be obtained as [5]:

$$f_3 = \frac{c * n * \arccos(-\cos \beta L_2 * \sin \beta L_3 * \sin \beta L_4)}{2\pi * \sqrt{\varepsilon_{eff}} * (L_1 + L_3 + L_4)} \qquad (4a)$$

$$f_4 = \frac{c * n * \arccos(-\cos \beta L_1 * \sin \beta L_3 * \sin \beta L_4)}{2\pi * \sqrt{\varepsilon_{eff}} * (L_2 + L_3 + L_4)} \qquad (5b)$$

The Bandwidth, BW_2 the second passband, f_{r2} is calculated as:

$$BW_2 = f_4 - f_3 \qquad (5c)$$

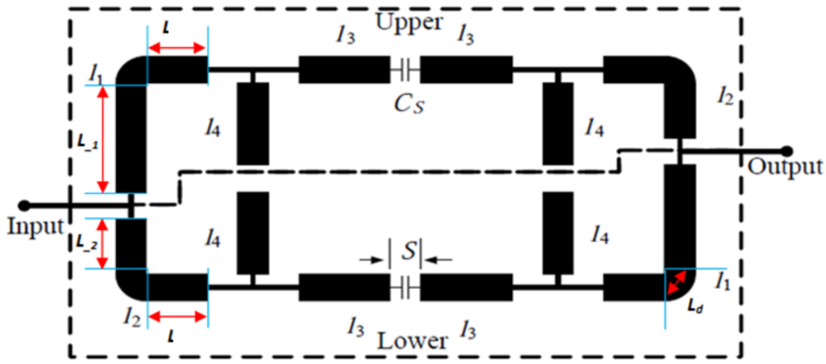

Fig. 1 The dual-band filter using asymmetric half-wavelength structure with four shunt open stubs

2.2 Dual-band Filter Design

Filter Specifications:

It is desired to design a dual-band filter with resonance frequencies, f_{r1} = 2.1 GHz and f_{r2} =5.6 GHz. The bandwidths are required to be: $BW_1 \geq$ 60 MHz and $BW_2 \geq$ 150 MHz for UMTS / Wi-MAX applications. It is also desired that this filter has the return loss, S_{11} to be better than 10 dB and the insertion loss, S_{21} to be better than -0.5 dB.

Design Procedure:

The RT 5880 substrate is utilized in this design. These substrate parameters are: thickness, h = 0.78 mm, dielectric constant, ε_r = 2.2 and loss tangent, δ = 0.001.
The layout of dual band filter using asymmetric half-wavelength resonators structure with four shunt open stubs is shown in Fig. 2.

Using the filter specification, calculate f_r using Eq. (2), λ_g using Eq. (3), and then start the simulation with initial guess for L_1, L_2 and L_3 that satisfy Eq. (1) and the lengths L and L_4 are also chosen. As W is 2.4 mm, so L_d is 1.9 mm .Apply the parametric analysis till obtaining the best filter performance that meets the filter specification. The optimized filter parameters are shown in Fig. 3 and listed in Table 1. The designed filer performance parameters are shown in Fig.4, The momentum simulation results are illustrated in Fig. 4 and listed in Table 2.

Table 1 The optimized parameters of dual-band filter for UMTS and Wi-MAX.

Length	L_1	L_2	L_3	L_4	L_c	S	W
Value (mm)	13.4	3.2	5.8	6	4.5	0.43	2.4

Table 2 The optimized performance parameters of dual-band filter for UMTS and Wi-MAX.

Parameter	At resonance frequency f_{r1}= 2.1 GHz			At resonance frequency f_{r2} =5.6 GHz		
	S_{11} (dB)	S_{21} (dB)	BW_1 (MHz)	S_{11} (dB)	S_{21} (dB)	BW_2 (MHz)
Value	-28.755	-0.414	100	-19.349	-0.489	185

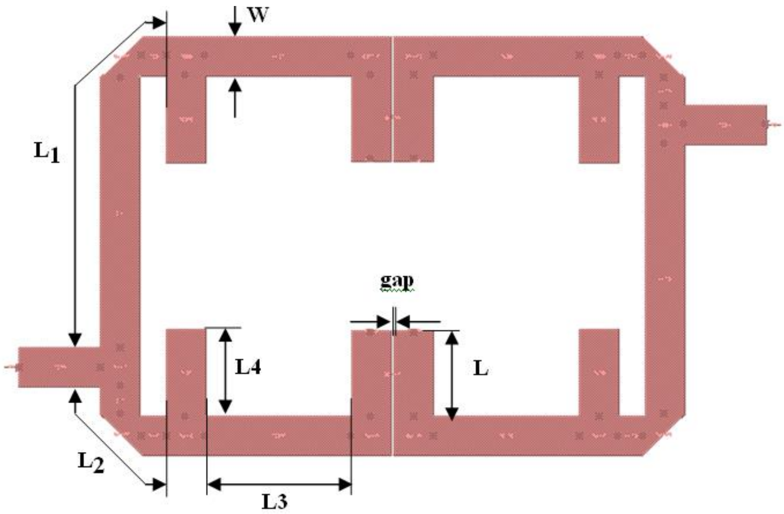

Fig. 2 Layout of dual-band filter using asymmetric half-wavelength structure with four shunt open stubs.

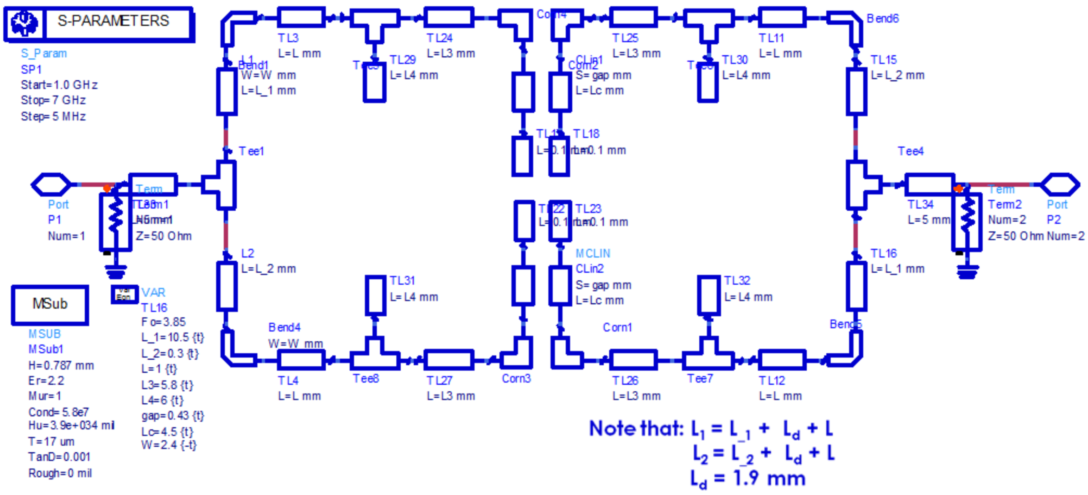

Fig. 3 The optimized design of dual-band filter for UMTS and Wi-MAX.

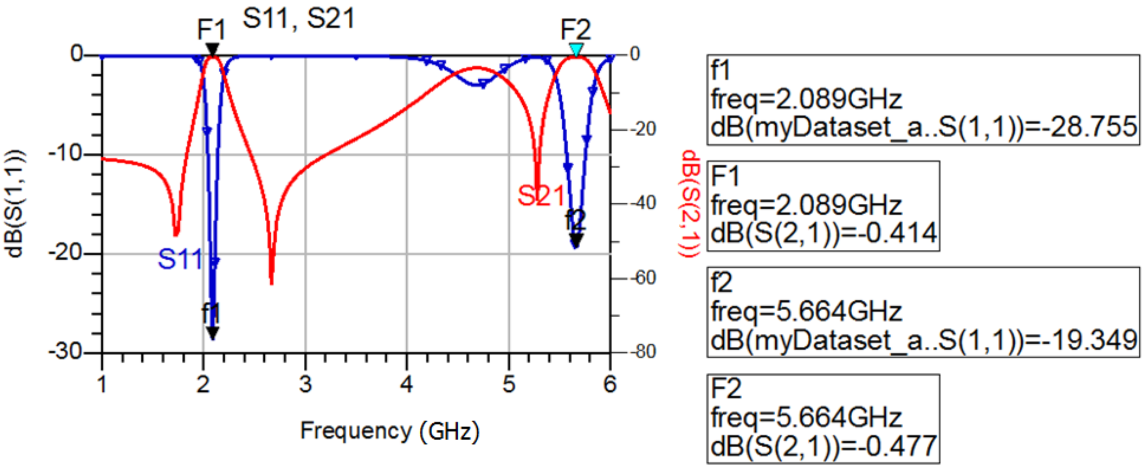

Fig. 4 The momentum simulation of dual-band filter for UMTS and Wi-MAX.

3. Generic Transformation for Dual-band Filter

Section II illustrates an optimized dual-band structure based on asymmetric half-wavelength resonators structure with four shunt open stubs proposed in [4-5]. The obtained results shown in Fig. 3, Fig. 4, Table 1 and Table 2 satisfy the desired filter design specification. Therefore, we will take this design as reference and then derive generic transformation equations to be utilized to design any other dual-band filter with arbitrary specifications.

From Fig. 2 and Fig. 3, the filter deign parameters are: the transmission lines using of the asymmetric half-wavelength structure (L_1, L_2 and L_3), the coupling parameters (L_c and S) and the length of each of the four shunt open stubs (L_4).

Analysing the obtained results shown in Fig. 3, Fig. 4, Table 1 and Table 2, we can deduce that the relations of the lengths L_1, L_2 and L_3 with respect to the guided wavelength λg can have the form:

$L_1/\lambda_g = 0.24$
(6a)

$L_2/\lambda_g = 0.06$
(6b)

$L_3 / \lambda_g = 0.10$
(6c)

λ_g is the guided wavelength at fundamental resonance frequency, f_r which are calculated using Eq. (2) and Eq. (3).

In this design example: L_1 = 13.4 mm, L_2 = 3.2 mm and L_3 = 5.8 mm.

Similarly, the coupling parameters, L and S are given by:

$L_c / \lambda_g = 0.08$
(7a)

$S / \lambda_g = 0.0075$
(7b)

In this design example: L = 4.5 mm and S = 0.43 mm.

In the same manner, the length of each of the four shunt open stubs, L_4 is calculated as:

$L_4 / \lambda_g = 0.12$
(8a)

In this design example: L_4 = 6 mm.
Define a ratio; R_{ref} represents the ratio between resonance frequencies: upper, f_U and lower, f_L as:

$$R_{ref} = \frac{f_U}{f_L}$$
(9)

This ratio will be considered as a reference to normalize the corresponding ratios when designing any other desired filters as will be illustrated in the following section.

3.1 Design Procedure to design any desired Dual-band Filter

In order to design any desired Dual-band Filter with resonance frequencies: upper, f_{Udesr} and lower, f_{Ldesr}, apply the following procedure:

Calculate the desired resonance frequency, f_{rdesr} from Eq. (2) as:

$$f_{rdesr} = \frac{f_{Ldesr} + f_{Udesr}}{2}$$

Then calculate the desired wavelength λ_{gdesr} corresponding to f_{rdesr} using Eq. (3).

After that the ratio between resonance frequencies: upper, f_{Udesr} and lower, f_{Ldesr} is calculated from Eq.(9) as:

$$R_{desr} = \frac{f_{Udesr}}{f_{Ldesr}}$$

Then calculate the ratio between R_{desr} to R_{ref} which we define as design ratio R as:

$$R = \frac{R_{desr}}{R_{ref}}$$

And the normalized wavelength λ_{gnorm} is then calculated as:

$$\lambda_{gnorm} = R * \lambda_g$$

Using the equation deduced Eq. (6), Eq. (7) and Eq. (8) to calculate the filter hardware parameters as:

$L_1 \approx 0.24\ \lambda_{gnorm}$ $L_2 \approx 0.06\ \lambda_{gnorm}$ $L_3 \approx 0.1\ \lambda_{gnorm}$

$L_c = 0.08\ \lambda_{gnorm}$ $S = 0.0075\ \lambda_{gnorm}$ $L_4 = 0.12\ \lambda_{gnorm}$

Finally, Simulate using the obtained filter design parameters and then tune using L_4 and L to move the two center frequencies left and right to adjust the required frequencies. Also optimize the response with slight tune in lengths and gap of coupled line (S) to have good response.

4. Applications

4.1 Dual-Band Filter Design for GPS and WiLAN Applications

In order to design a dual band filter for GPS and WiLAN applications with desired resonance frequencies: f_{Ldesr} = 1.575 GHz and f_{Udesr} = 5.8 GHz using substrate of the reference filter. Apply the previous design procedure:

$$f_{rdesr} = \frac{f_{Ldesr} + f_{Udesr}}{2} = 3.691 GHz$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} * \frac{1}{\sqrt{1 + 12\frac{h}{W}}} = 1.87$$

$$v_p = \frac{c}{\sqrt{\varepsilon_{eff}}} = \frac{3*10^8}{\sqrt{1.87}} = 0.219*10^9\ m/s \qquad \lambda_{gdesr} = \frac{v_p}{f_{rdesr}} = 59.2\ mm$$

$$R_{desr} = \frac{f_{Udesr}}{f_{Ldesr}} = 3.68 \qquad R = \frac{R_{desr}}{R_{ref}} = 1.38 \qquad \lambda_{gnorm} = \lambda_{gdesr} R \approx 84\ mm$$

Using the design equations: Eq. (6), Eq. (7) and Eq. (8) to calculate the filter hardware parameters as:

$L_1 \approx 0.24\ \lambda_{gnorm}$ = 0.24 * 84 = 20.1 mm $L_2 \approx 0.06\ \lambda_{gnorm}$ = 0.06* 84 = 5.04 mm

$L_3 \approx 0.10\ \lambda_{gnorm}$ = 0.1* 84 = 8.4 mm $L_c = 0.08\ \lambda_{gnorm}$ = 6.7 mm

$S = 0.0075\ \lambda_{gnorm}$ = 0.63 mm $L_4 = 0.12\ \lambda_{gnorm}$ = 10.1 mm

The optimized filter parameters are shown in Fig. 5 and listed in Table 3. The designed filer performance parameters are shown in Fig.6 and the results momentum simulation is illustrated in Fig. 6 and listed in Table 4.

Table 3 The optimized parameters of dual-band filter for GPS and Wi-LAN.

Length	L_1	L_2	L_3	L_4	L_c	S	W
Value (mm)	20.1	5.8	8.8	5	5.5	0.25	2.4

Table 4 The optimized performance parameters of dual-band filter for GPS and Wi-LAN.

Parameter	At resonance frequency f_{r1}= 1.575 GHz			At resonance frequency f_{r2} =5.8 GHz		
	S_{11} (dB)	S_{21} (dB)	BW_1 (MHz)	S_{11} (dB)	S_{21} (dB)	BW_2 (MHz)
Value	-21.705	-0.374	85	-19.945	-0.956	63

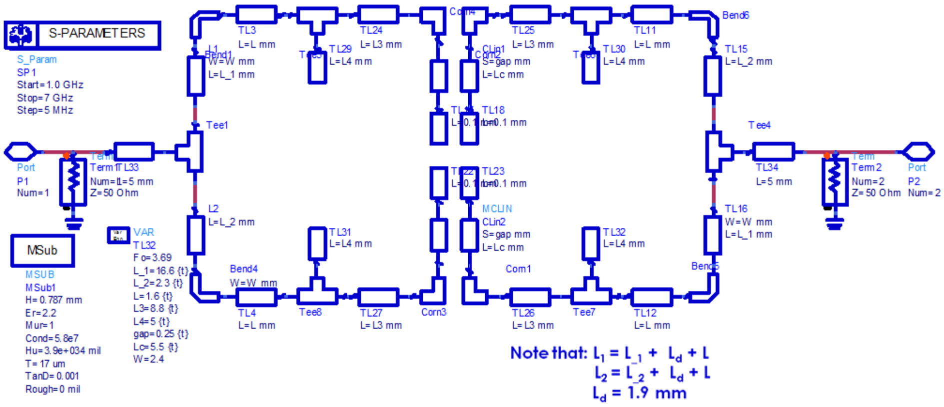

Fig. 5 The optimized dual-band filter for GPS and Wi-LAN Applications

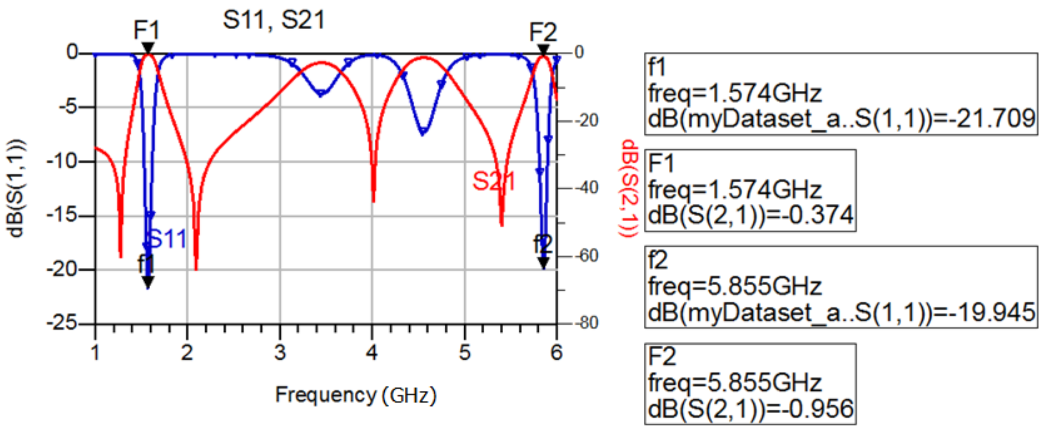

Fig. 6 The momentum simulation of dual-band filter for GPS and WiLAN applications

4.2 The Dual-band Filter design for GPS and WiMAX Applications

In order to design a dual band filter for GPS and WiMAX applications with desired resonance frequencies: f_{Ldesr} = 1.5 GHz and f_{Udesr} = 3.8 GHz using substrate of the reference filter. Apply the previous design procedure:

$$f_{rdesr} = \frac{f_{Ldesr} + f_{Udesr}}{2} = 2.65\ GHz$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} * \frac{1}{\sqrt{1 + 12\frac{h}{W}}} = 1.87$$

$$\lambda_{gdesr} = \frac{v_p}{f_{rdesr}} = 82.5\ \ mm$$

$$v_p = \frac{c}{\sqrt{\varepsilon_{eff}}} = \frac{3 * 10^8}{\sqrt{1.87}} = 0.219 * 10^9\ \ m/s$$

$$R_{desr} = \frac{f_{Udesr}}{f_{Ldesr}} = 2.53 \qquad R = \frac{R_{desr}}{R_{ref}} = 0.95 \qquad \lambda_{gnorm} = \lambda_{gdesr} R = 78.4\ \ mm$$

Using the equation deduced Eq. (6), Eq. (7) and Eq. (8) to calculate the filter hardware parameters as:

$L_1 \approx 0.24\ \lambda_{gnorm}$ = 0.24 * 78.4 = 18.8 mm

$L_2 \approx 0.06\ \lambda_{gnorm}$ = 0.06* 78.4 = 4.7mm

$L_3 \approx 0.10\ \lambda_{gnorm}$ = 0.1* 78.4 = 7.8 mm

$L_c = 0.08\ \lambda_{gnorm}$ = 6.3 mm

$S = 0.0075\ \lambda_{gnorm}$ = 0.59 mm

$L_4 = 0.12\ \lambda_{gnorm}$ = 9.4 mm

The optimized filter parameters are shown in Fig. 7 and listed in Table 5. The designed filer performance parameters are shown in Fig. 6 and the results momentum simulation is illustrated in Fig. 8 and listed in Table 6.

Table 5 The optimized parameters of dual-band filter for GPS and Wi-MAX.

Length	L_1	L_2	L_3	L_4	L_c	S	W
Value (mm)	18.6	4.9	7.9	9.5	8.8	0.35	2.4

Table 6 The optimized performance parameters of dual-band filter for GPS and Wi-MAX.

Parameter	At resonance frequency f_{r1}= 1.5 GHz			At resonance frequency f_{r2} =3.8 GHz		
	S_{11} (dB)	S_{21} (dB)	BW_1 (MHz)	S_{11} (dB)	S_{21} (dB)	BW_2 (MHz)
Value	-33.041	-0.405	95	-19.87	-0.622	93

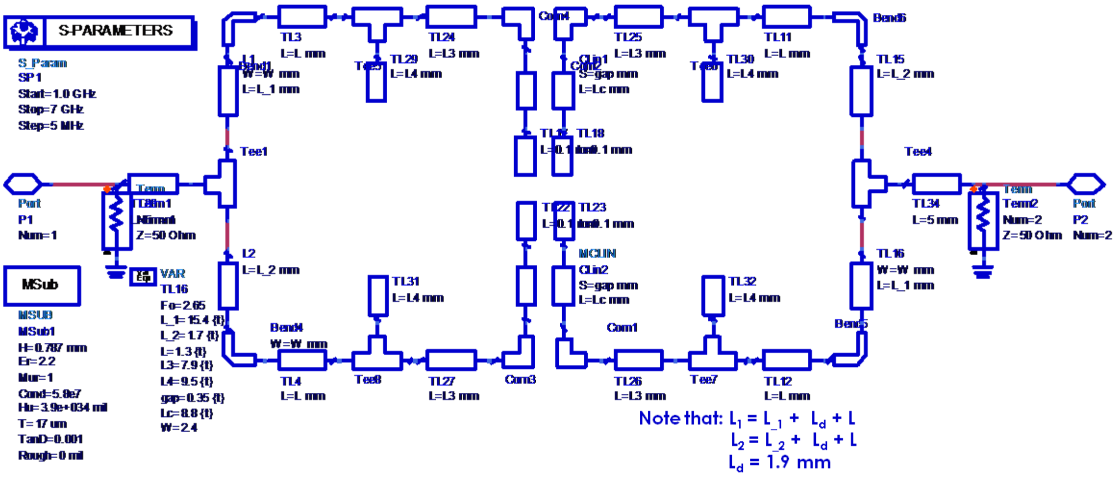

Fig. 7 The optimized dual-band filter for GPS and Wi-MAX Applications

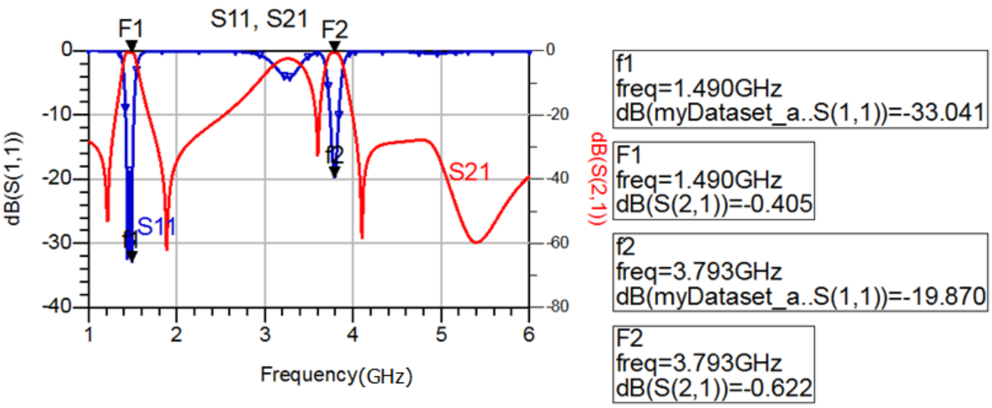

Fig. 8 The momentum simulation of dual-band filter for GPS and Wi-MAX Applications

5. Conclusion

In this paper, a novel generic transformation technique is proposed and the design equations are derived using theoretical analysis. The dual-band filter using asymmetric half-wavelength structure with four shunt open stubs is used to design a reference filter. Then this transformation is applied to transform any other desired filter specifications to the reference one for any desired ratio, $R_{desr} \geq 2.5$. To demonstrate the validity of this approach, two examples for dual-band typical filters, that are used indifferent wireless communication, are designed and implemented. The obtained momentum simulation results of designed dual-band filter indicate that this technique is easy, fast, generic and accurate.

6. References

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