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Design of Wideband Microstrip Bandpass Filter for S-Band Application

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ABSTRACT

This paper describes the design of wideband parallel coupled microstrip bandpass filter (BPF) for S-Band application. S-Band is the range of frequency from 2 GHz to 4 GHz which is a part of microwave system and a partly combination between Ultra High Frequency (UHF) and Super High Frequency (SHF) which including Wireless Local Area Network (WLAN), *High-Speed Downlink Packet Access* (HSDPA), Bluetooth, Worldwide Interoperability for Microwave Access (WiMAX) and *Long Term Evolution* (LTE) applications. In order to satisfy the needs for many applications to be used at once, S-Band microstrip bandpass filter is proposed as it functions to remove out other frequencies from the passband using planar microstrip transmission topologies. To design the prototype, certain constraints had to be identified, the lumped element works well in low frequencies but at high frequency problems arises which the inductor and capacitors are only available for a limited range of values and the distance between the filter components at microwave frequency is not negligible. Hence, the microstrip transmission line is used in the design as it capabilities handling wide band of fabricated. The BPF will be designed using a parallel coupled line method which will be simulated using Advanced Design System (ADS) software, fabricated using FR4 substrate and analyzed using a network analyzer. The design is compared between ideal case design (lumped element) and parallel coupled line method for insertion loss, S_{21} and return loss, S_{11} The results is acceptable between simulation and measures values which -4.89 dB and -14.591 dB for S_{21} and S_{11} respectively.

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INTRODUCTION

Bandpass filter is an electronic device that is used in both transmitted and received signals which have to be filtered first at a certain center frequency between two specific frequencies, bandwidth (Stephen A. Maas, 1998). It plays a major significant role in these wireless communication systems, since the transmitted and received signals need to be filtered as center frequency with a specific bandwidth. In realization of this system, a new transmitter and receiver are indeed to be completed. To design the system, the choice of transmission line technology is important to provide a good parameters measure of the efficiency of the design which achieve the minimal insertion and return loss. Microstrip is preferable since the technology of a microstrip transmission line is most extensively used planar transmission line in Radio Frequency (RF) application, (Stephen A. Maas, 1998). Compared to conventional circuit and coaxial lines, printed planar transmission lines are widely used, having a broadband in frequency, provide compact circuit and light in weight, and generally economical to produce since they are readily adaptable to hybrid and monolithic integrated circuit fabrication technologies at RF and microwave frequencies (Mudrik Alaydrus, 2010).

There are many types of transmission line like waveguide which has the advantages of high power-handling capability and low loss but is bulky and expensive. The other one is coaxial line which has very high bandwidth and is convenient for test applications, but is a difficult medium in which to fabricate complex microwave components (Leo G. Maloratsky, 2009). The conventional circuit or lumped circuit which is conceptually a helpful starting point to see how various designs can be realized. But in synthesizing the circuit in this manner, the implicit symmetries of a lumped circuit element only have a single mode of propagation and length scales characterizing the element are small compared to a wavelength which must be respected over the required design band. Also, the circuit can only be characterized by a single parameter. In this case, the transmission line is realized since it is characterized by two or more parameters. Such differences in dimensionality between idealized and physically achievable components in the lumps circuit can lead to a breakdown in applicability of simple circuit based synthesis approaches (David M. Pozar, 2005). In this limit, planar transmission line models are

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realized and full wave analysis approaches are required to simulate the response. Planar transmission lines are divided into four topologies; co-planar waveguide, Strip line, Slotted line and microstrip line. In this paper, microstrip line is chosen as it fulfills the requirements of the wideband bandpass filter design which is operating at S-Band (2-4GHz) frequency.

Microstrip is well confined for large line width over substrate height ratios and is well suited for realizing elements with low characteristic impedance and radiation loss. Slot line on the other hand has a poor field confinement and can be susceptible to radiative loss. Microstrip filter is preferable since the technology of a microstrip transmission line is mostly used planar transmission line in RF application (Stephen A. Maas, 1998). It is based on printed circuit board (PCB) and offers easy and cheap in production compared to conventional circuit and coaxial lines (Mudrik Alaydrus, 2010). Table 1 shows the previous work related to microstrip bandpass filter design.

Table 1: Previous Work on BPF Design.

Author	BPF	Substrate	F_C (dB)	S_{21} (dB)	S_{11} (dB)
(Leo G. Maloratsky, 2009)	Microstrip Parallel Coupled	RO TMM10	3.2	-7.5	-15
(K. U-yen et al., 2011)	Microstrip Parallel Coupled with Stub Loader Resonator	RT/Duroid 6010	3.0	<1.0	< -10
(Shivam Tapar et al. 2011)	Microstrip capacitive coupled Resonator	RO 3010	2.5	-4	-16
(S. Prabhu and J.S. Mandeep, 2007)	Microstrip Parallel Coupled	-	2.3	-2.13	-23

2. Design Methodology:

Basically, the design of BPF filter is based on the insertion loss method. The perfect filter would have a zero insertion loss in the passband, infinite attenuation in the stopband and a linear phase response to avoid signal distortion in the passband. This method allows filter performance to be improved in a straightforward manner, at the expense of a higher order filter. There are four main steps of BPF design which including a design specification, low pass prototype design, scaling and conversion and implementation. Table 2 shows the BPF specifications. All the BPF specifications are important in order to determine the order filter, N. It involves with the frequency transformation from the low pass prototype filter to band pass prototype filter and normalized frequency. A low pass prototype filter is defined as the low pass filter whose element value are normalized to make the source resistance or conductance equal to one, denoted by $g_0 = 1$ and the cutoff angular frequency to be unity, denoted by $w_C = 1$ rad/s. The low-pass prototype elements values obtained can be represented either prototype beginning with the shunt element or series element.

Table 2: BPF Specifications.

Specification	Value
Passband	2-4 GHz (S-Band)
Frequency Center, f_o	3GHz
Bandwidth	2GHz
Substrate	FR4
Insertion Loss, (S_{11})	<-15dB
Return Loss, (S_{21})	0dB
Low pass, f_{cutoff}	4GHz
No. of Filter order	7
Implementation	Lump Element & Parallel Couple

Low pass prototype filters were normalized designs which having cutoff frequencies of 1 rad/s and 1 Ω source and load terminations. Therefore, to obtain a practical filter response for band pass, that prototype can be scaled in terms of impedance and frequency. For the impedance scaling, a source of Ro can be obtained by multiplying the impedances of the prototype design by Ro. In principle, applying that scaling has no effect on the response shape. However, the frequency transformation will have an effect on all the reactive elements accordingly but no effect on the resistive elements.

For the implementation of BPF, lumped element and transmission line (microstrip) is used. However, lumped element such as inductor and capacitors are generally available only for a limited range of values and are difficult to implement at microwave frequency. In addition, at microwave frequency the distances between filter components is not negligible. Richard’s transformation is used to convert lumped elements to transmission line sections, while Kuroda identities can be used to separate filter elements by using transformation line section. The low-pass filter consists of series and parallel branch, *J*-inverter is used to convert low pass filter to bandpass filter with only shunt branch. Based on the even and odd characteristic impedance, the dimensions (width, length, and spacing) of the coupled lines can be obtained using ADS Line Calculator, LineCalc. The length of coupled line is quarter wavelength, λ/4 long. The dimensions computed using LineCalc is assumed to be lossless and have not taken discontinuity and losses into consideration. Therefore slight tuning is required to optimize the filter response.

Result and Analysis:

The simulation of BPF is started from the calculation to determine the order of the filter and element values of the low pass prototype. It followed by obtained the schematic of implementation using lumped element and parallel couple. The performances of filter design can be analysis with based on S-parameter where S21 (dB) referred to insertion loss of the filter. While input and output return loss of the filter are depending on S11 (dB) and S22 (dB). The lumped element of the bandpass filter was designed using an insertion loss method which designed in various orders to see the difference between the lower order and the higher order practically from N=5 to N=10. The Chebyshev prototype 0.5 dB ripple response is used where Chebychev is sharper than using Butterworth at the stopband.

The designed with the higher the order, produces a larger circuit. Hence in order to choose a suitable circuit, the design should not be too large and must produce a very good response for S12 and S21. Table 3 shows the comparison of BPF design using lumped element. The higher the order of the filter produces a sharper cut off and better result for the insertion loss and return loss without any tuning or optimization towards the circuit design. The higher order, the bigger the circuit size. Hence, N=7 is taken as the desired bandpass filter prototype since it has a good agreement towards desired responses furthermore the circuit is not too large. The response of BPF using lumped element for N = 9 is shown in Fig. 1. The lumped element design discussed in the previous sections generally works well at low frequencies practically. Meanwhile, two problems arise at microwave frequencies such as the inductors and capacitors are generally available only for a limited range of values and are difficult to implement at microwave frequencies, but must be approximated with distributed components. In addition, at microwave frequencies the distances between the filter components is not negligible.

The implementation of BPF using parallel couple can be achieved by calculating the even and odd characteristic impedance (Z0e and Z0o). The dimensions of each coupled lines can be obtained using LineCalc. The physical dimension of the coupled lines, which is computed by LineCalc is shown in Table 4. The layout of 7th order parallel-coupled bandpass filter is shown in Fig. 2.

Table 3: Comparison between Nth order of Lumped Element Design.

N_{th} Order	S_{11}(dB)	S_{21}(dB)
5	-2.724	-3.317
6	-9.391	-0.531
7	-10.283	-0.427
8	-8.998	-0.585
9	-0.498	-9.665

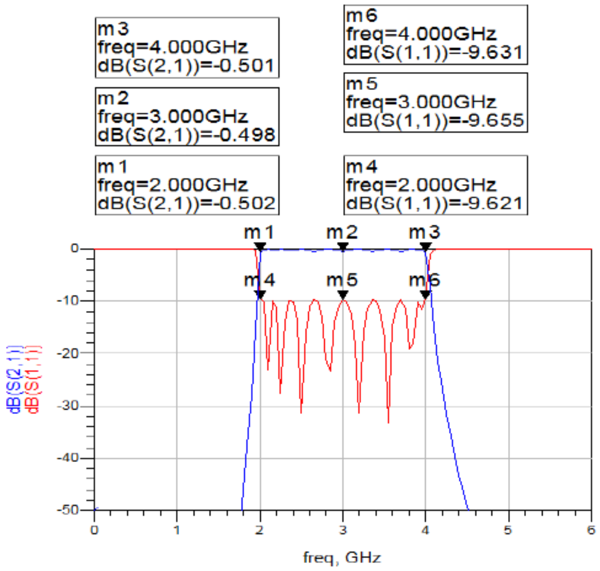

Fig. 1: S11 and S21 values for N=9.

Table 4: Microstrip Design Parameters of the 7th Parallel-Coupled Half-Wavelength Resonator Filter (Tuned Values) for spacing < 0.5mm.

Coupled Line	Width, W (μm)	Spacing, S (μm)	Length, L (mm)
1	718.853	168.109	15.1156
2	818.985	100.242	14.6534
3	775.058	141.041	14.6968
4	839.713	109.974	14.3012
5	860.49	136.379	14.6159
6	778.745	106.191	13.7772
7	762.297	102.977	15.1675
8	549.587	195.901	13.8547

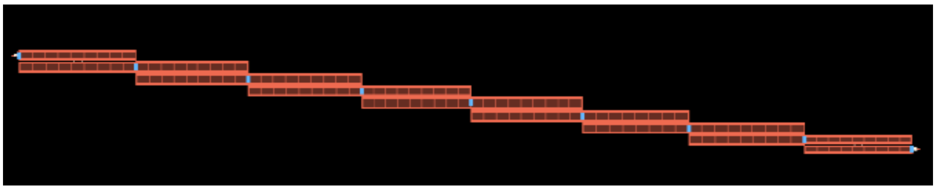

Fig. 2: The layout for the Parallel Coupled lines BPF.

The insertion loss and return loss are shown in Fig.3 and Fig. 4 respectively. From the simulation result, the insertion loss (S21) and return loss (S11) values, shows a good achievement towards the expected result value which the insertion loss is near to 0 dB at the resonance frequency and the return loss is less than -10 dB. The lower cut off frequency shows a delayed attenuation and getting better after 0.1GHz. For the upper cutoff frequency there is an early attenuation at 3.8 GHz. The result is highly acceptable and the bandwidth of the passband covered is still higher than 1.9 GHz.

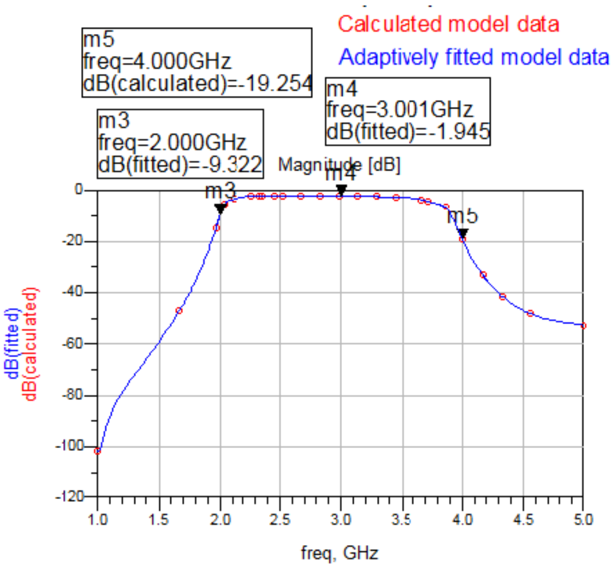

Fig. 3: Simulated Graph for Insertion Loss, S_{21}

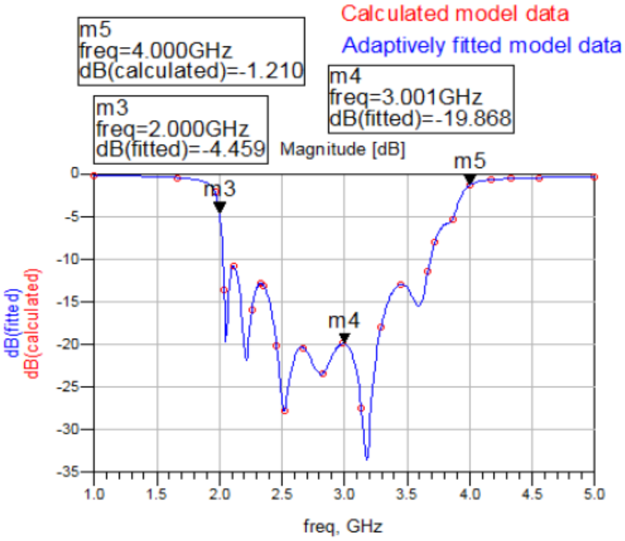

Fig. 4: Simulated Graph for Return Loss, S_{11}

From an optimization process of the parallel coupled using spacing ≥ 0.5mm, the output result is seen that less accurate as the parallel coupled with spacing less than 0.5mm. The spacing affects the bandwidth of the design, since the bandwidth covered in this design decreased to 1.2 GHz. The value for the S21 at the operating frequency is less affected and only increased about -1dB and the value for S11 at the operating frequency is found to be lesser at -20.304 dB compared to the parallel coupled design with spacing less than 0.5 mm which is at -19.868 dB. The parallel coupled with spacing less than 0.5 mm is still found to be giving a better performance compared to the parallel coupled with spacing higher than 0.5mm. The parallel coupled design with spacing ≥ 0.5mm had to be chosen as the design to be fabricated.

Fig. 5 show the fabricated of parallel couple line BPF. From the measurement result in Fig. 6 and Fig. 7, show that there are slight changes in the S21 and S11 response compared to the simulated result of the same parallel coupled design. The values for S21 and S11 at the operating frequency are -4.4903 dB and -14.59 dB respectively, compared to the simulation results which are -2.832dB and -20.304 dB. Several losses may due to the soldering effect, the bending of the coaxial connector wire and also towards the tangent loss of the substrate itself. The result is acceptable, and the bandwidth for the measured result is maintained as the simulation result.

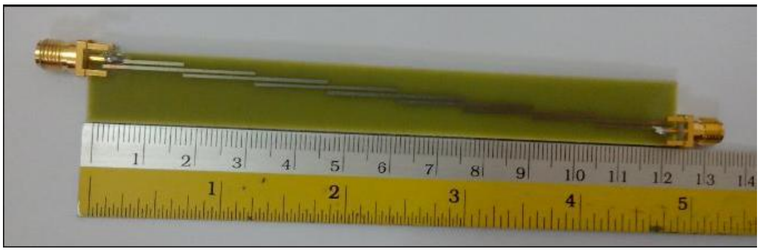

Fig. 5: Fabricated Parallel Couple Line.

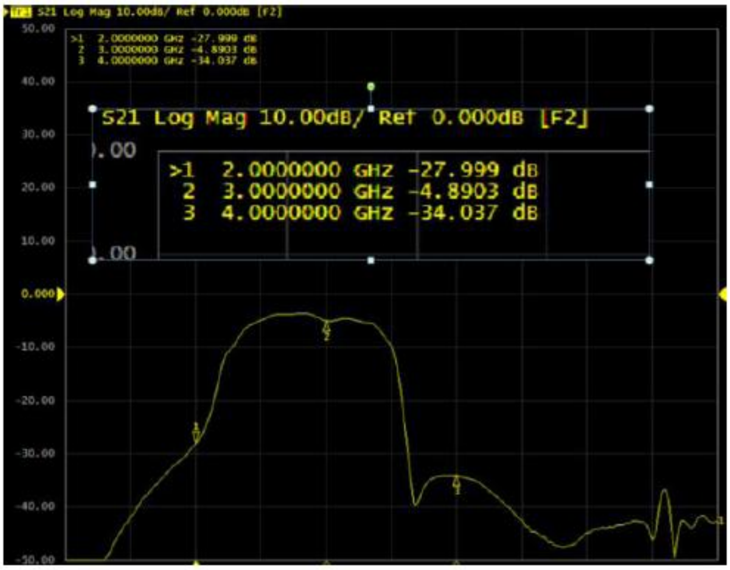

Fig. 6: Insertion Loss, S_{21}

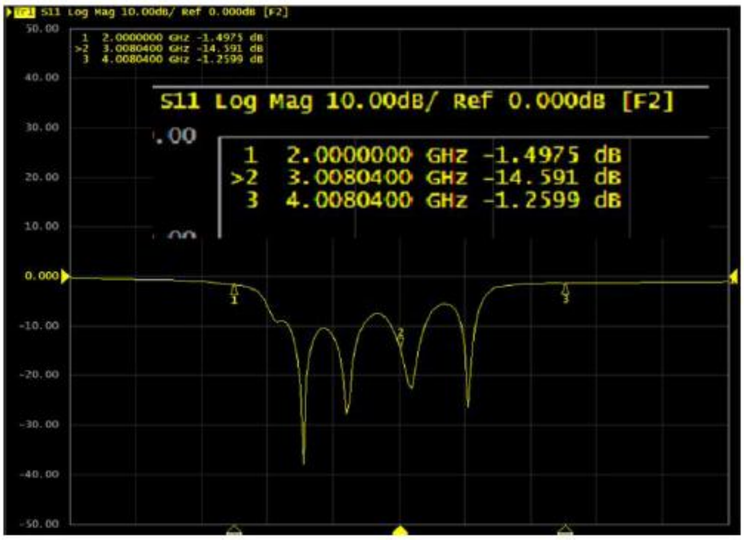

Fig. 7: Insertion Loss, S_{11}

Discussion:

Based on both designs, it can be seen that the parallel coupled line design in this research provides the good achievement among the other except for the ideal case in transmission loss, S21. The differences between the momentum simulation and measured were varied and still the results were acceptable and the loss were not more than 5 dB for S11 and S21 for both designs. Lumped element provides the lowest value for the S21, but still there is no eligible way to fabricate the design in this method. The parallel coupled design provides a better transmission loss, S21 and also a more stable return loss, S11 with a larger bandwidth for about 1.2 GHz which the good achievement between the simulation bandwidth and also much more better than [2] which only covers for about 500 MHz for the bandwidth. The loss acquired in the design might due to the soldering effect between the SMA connector and the FR-4 copper board, and also since the FR-4 board itself contains such losses due to its tangent loss.

Conclusion:

The microstrip S-Band bandpass filter for S-Band application using 7th order Chebyshev 0.5 dB Ripple prototype operating at 3.0 GHz was successfully designed, simulated, fabricated and analyzed. The circuit is designed using distributed elements and planar microstrip using a parallel coupled-line. For the future work, the performance of design the filter can improve by using a Defected Ground Structure (DGS) method (DGS), lower loss tangent substrate and compact microstrip bandpass filter.

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