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Digital Radio Broadcasting Frequency Chebyshev CLF and HPF Designs Using ROGER 4003C

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Abstract—**The development of the frequency bands in microwave range filter play an important role in many RF or microwave applications. Filters are two port networks used to control the frequency response in an RF or microwave system by allowing transmission at frequencies within the passband, and attenuation within stopband of the filter. This research project consists of the elementary principle of microwave theory, the elementary knowledge of microwave filter design as well as fabrication and performance evaluation of Chebychev bandpass filters. The purpose of the research project is to compare the characteristic performance of different microstrip filter designs i.e coupled line (CLF) and hair pin filters (HPF). The designs were fabricated on the same type of material i.e FR4. Insertion loss method has been used in the design to produce the parallel coupled quarter wavelength resonator filters. The compatible filter in this project was able to filter out the required frequency for Digital Radio Broadcasting in the range of 1.452 GHz to 1.492 GHz. The designs were implemented using Microwave Office 2003 (V6.01) simulation software. The two filter designs were fabricated based on the Chebychev filter. The Chebyshev response is more selective than the Butterworth response at the expense of the insertion loss and greater group delay. The filters were tested using Advantest R3767CG Network Analyser. The entire filter designs and the performance of the substrate were evaluated. It was found that the HPF has better performance compared with CLF design in terms of bandwidth, matching impedance and quality factor.**

Index Terms— **Chebychev, microstrip, couled line, hairpin filter, digital radio broadcasting.**

I. INTRODUCTION

The rapid growth in the application of microwave technology particularly in communication system such as mobile telephony, data, and television transmission has made the frequency bands in microwave range became more limited. It has to be shared and filters are used to select or confine the RF or microwave signal within the assigned spectral limits. Hence, microstrip filters are deployed in many RF or microwave applications. Emerging applications such as wireless communications continue to challenge RF microwave filters with ever more stringent requirements, higher performance, smaller size, lighter, and lower cost.

The aim of the research is to design a microstrip filter that operates in L-Band frequency spectrum from (1 GHz- 2 GHz) based on coupled line filter design using two different types of copper-clad boards.

The scope of the research covers parts that determine the filter dimension, dielectric material characteristics, correspond of impedance criterion, and obtain the application frequency range. Microwave Office 2003 (Version 6.01) application software was used to design the microstrip filter layout. It was fabricated in the PCB Fabrication Laboratory and the testing was carried out using network analyzer.

II. MICROWAVE APPLICATION

Microwave application is very extensively used in broadcasting and Digital Radio Broadcasting (DRB) is the next generation of radio. It is a new way of broadcasting radio via a network of terrestrial transmitters. The DRB frequency range is from 1452 MHz to 1492 MHz which is in the microwave frequency range. It is designed to provide CD quality sound in a mobile reception environment, the flexibility to interact with other media and the opportunity to deliver data casting. In this research the microstrip filter design was designed to operate at DRB frequency range

A. Microstrip Filter Structure

Filters are two port networks used to control the frequency response in an RF or microwave system by allowing transmission at frequencies within the passband of the filter, and attenuation within stopband of the filter. This research work was carried out based on Chebyshev filter response. It was chosen because of its selectivity compared with Butterworth response. The general structure of microstrip is illustrated in Figure 1. A conducting strip (microstrip line) with a width W and a thickness t is on the top of the dielectric substrate that has a relative dielectric constant e_r and a thickness h, and the bottom of the substrate is a ground (conducting) plane.

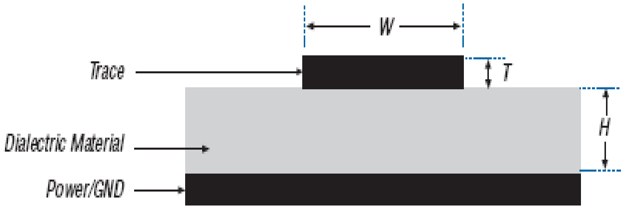


Fig. 1. Microstrip Structure

B. Design Parameter

The filter was design based on the following parameters.

i) **Microstrip Filter Parameter**

Frequency Range	(1.452 – 1.492) GHz
Attenuation Response	30 dB
Equal Ripple Response	3.0 dB
Insertion Loss	3.0 dB
Impedance (Z_o)	50 Ω
Filter Type	Bandpass Chebyshev

ii) **Frequency Range**

Lower Frequency Range, f_L = **1.452 GHz**

Upper Frequency Range, f_U = **1.492 GHz**

iii) **Center Frequency**

$$f_O = \frac{f_U + f_L}{2} = \left(\frac{1492 + 1452}{2}\right) \text{MHz} = 1.472\text{GHz}$$

iv) **Bandwidth, BW**

$$BW = f_U - f_L = (1492 - 1452)\text{MHz} = 40\text{MHz}$$

v) **Fractional Bandwidth, FBW**

$$\Delta = \frac{w_U - w_L}{w_O} = \frac{2\pi(1.492\times10^9) - 2\pi(1.452\times10^9)\text{Hz}}{2\pi(1.472\times10^9)\text{Hz}}$$

$$= 0.02714$$

vi) **Normalized Frequency; Ω**

$$\Omega = \frac{w_0}{w_2 - w_1}\left(\frac{w_x}{w_0} - \frac{w_0}{w_x}\right)$$

$$A = \left(\frac{2p \times 1.5165 \times 10^9}{2p \times 1.472 \times 10^9} - \frac{2p \times 1.472 \times 10^9}{2p \times 1.5165 \times 10^9}\right)$$

$$\Omega = \frac{(2p \times 1.472 \times 10^9)}{(2p \times 1.492 \times 10^9) - (2p \times 1.452 \times 10^9)} A$$

$$\Omega = 2.192355$$

vii) **Ripple Factor, a_m**

$$IL = 10 \log_{10}(1 + a_m^2)$$

$$3.0 \text{ dB} = 10 \log_{10}(1 + a_m^2)$$

$$0.3 = \log_{10}(1 + a_m^2)$$

$$1.99526 = (1 + a_m^2)$$

$$a_m^2 = 0.99526$$

$$a_m = 0.997628$$

III. DESIGN PROCESS

Two different types of filters were designed and fabricated using photolithography process on the same FR4 copper board as illustrated in Table I.

TABLE I. THE PCB MATERIAL SPECIFICATION FOR FR4

Material Specification Parameter	FR4 (Fire Retardant)
Relative Dielectric Constant, (Er)	4.25
Substrate Thickness, (H)	1.6 mm
Conductor Thickness, (T)	0.035 mm
Loss Tangent of Dielectric, (Tand)	0.0200
Substrate Material	Epoxy based glass

A. PCB Material Selection

FR4 (Fire Retardant) PCB material was used in this research work. It is the most commonly used PCB material in many microwave filter fabrications. The specification of the material is shown in Table 1.

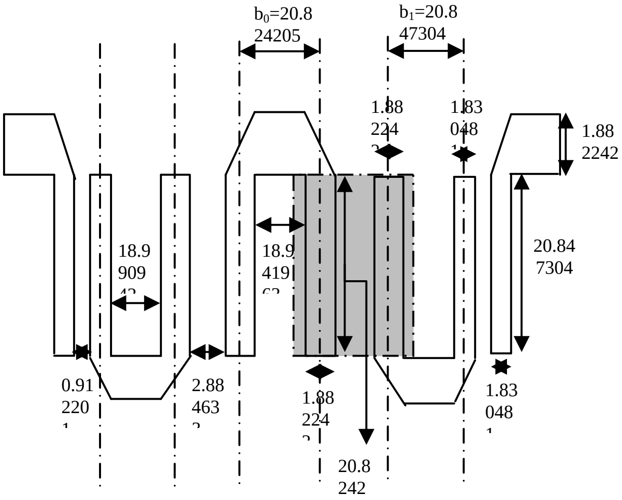


Fig. 2. The resonators are bent at the slide factor area to produce the hairpin resonator structure.

B. Couple Line Filter Design

Figure 3 shows the schematic designs for coupled line filter design using the FR4 material. The substrate material specification and the elements parameter are based on the calculation explained in section Design Parameter. Figure 3 shows the typical third order edge coupled microstrip filter with its n+1 coupled section and Figure 4 shows the hairpin filter design. It has compact structure configuration by cascading several coupled line sections, each represents a quarter wavelength filters. Since the maximum coupling occurs over a quarter wave long coupling region, to achieve resonance, each resonator element is nearly half wavelength long at the center frequency and kept open at both ends. The filter is terminated at the input and output lines with characteristic impedance Z_0. The width and spacing of the lines determine the filter characteristics, with narrow spacing being required for broad pass bands. Narrow pass bands thus require larger spacing which results in less coupling between the elements and thus increased loss. Other filtering structures are possible based on coupled line arrangements where low loss or narrow bandwidths are required.

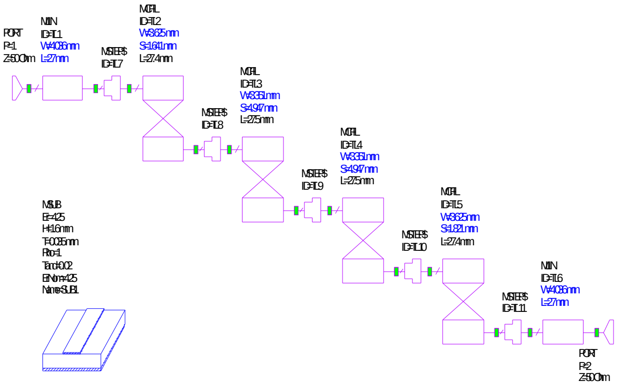


Fig. 3. Schematic designs for coupled line bandpass filter (CLF).

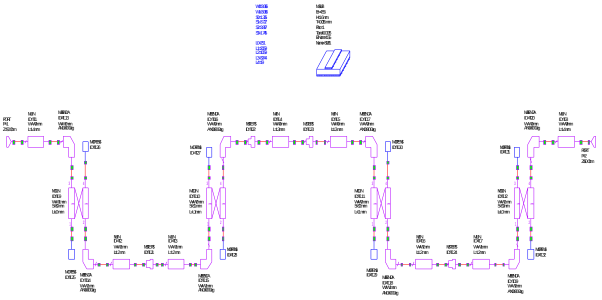


Fig. 4. Schematic designs for hairpin line bandpass filter (HPF).

The two filter designs were simulated in real time tuning which all the variables of the dimension (width, spacing and length) been adjusted and changed in order to get the yield of the project specification. After the real time tuning the layout design is generated as shown in Fig. 4.

C. Microwave filter fabrication

The circuit patterns of Fig. 4 are realized by the photolithographic process. A mask of the circuit to be realized is drawn at a suitable scale and placed on top of a photoresistive layer board. The structure is then exposed to ultraviolet radiation, which reaches the photosensitive layers through the mask openings. The exposed parts are removed by the photographic development, and the metal cover is etched away from the exposed area. It is also possible to deposit metal by evaporation or sputtering upon a bare dielectric substrate. In this research project the testing process was carried out using the R3765/67G series network analyzer. A network analyzer makes measurements of S-parameter S11 and S21, SWR, Smith Chart for impedance matching and etc.

IV. RESULT AND ANALYSIS

This section discusses about all the results and analysis based on the result obtained using Microwave Office 2003 (Version 6.01) simulation software, and testing equipment "R3765G/67G-Series" vector network analyzer. The outcome of each microwave filters are determined; analysis is referred to the structure of the designs and also the scattering parameters which are obtained from the simulation software and network analyzer.

A. The layout of microstrip band pass filter designs

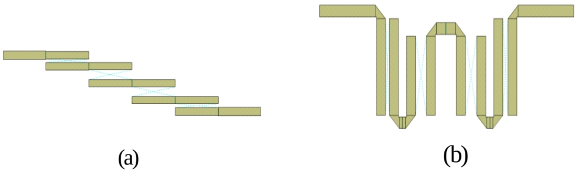


Fig. 5. FR4 material microstrip filter layout in 2D and 3D mode. (a) Coupled line design layout (b) Hairpin line design layout.

Figure 5 shows the schematic design of coupled-line and hairpin line microstrip bandpass filter using the FR4 material. The substrate material specification and the elements parameter is based on the calculation. The hairpin filter configuration is derived from the coupled line filter. To improve the aspect ratio, the resonators are folded into a "U" shape.

B. The comparison for the different design patterns on the same material.

Table 2 is the hairpin line microstrip filter layout dimensions using FR4 material for the design after the real time tuning results with the supported variable or equation syntax value. Based on layout dimensions comparison from the simulation software for the hairpin line microstrip bandpass filter design, which use the same type of substrate material (FR4), had shown that the width and gap of the transmission lines CLF design were greater than that of the HPF design.

TABLE II. THE HAIRPIN LINE LAYOUT DESIGN DIMENSIONS

Element	**FR4 HPF**
TLn (W0)	3.0660
TLn (W1)	3.0660
TLn (S0)	1.3350
TLn (S1)	3.7270
TLn (S2)	3.8970
TLn (S3)	1.7450
TLn (L0)	**25.1000**
TLn (L1)	**20.5900**
TLn (L2)	**1.0590**
TLn (L3)	**3.2440**
TLn (L4)	19.0000

Note:
TLn is the transmission line elements from the schematic design. The (**Wn**, **Sn** and **Ln**) is the variable or equation syntax for the transmission line width, spacing and length respectively.

Table III. The coupled-line layout design dimensions

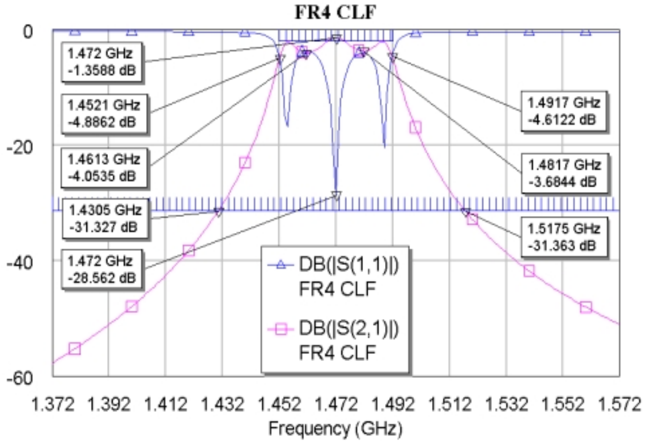
Element	**FR4 CLF (mm)**
TL1 (W)	4.0360
TL1 (S)	**27.0000**
TL2 (W)	3.6250
TL2 (S)	1.6410
TL2 (L)	**27.4000**
TL3 (W)	3.3510
TL3 (S)	4.9470
TL3 (L)	**27.5000**
TL4 (W)	3.3510
TL4 (S)	4.9470
TL4 (L)	**27.5000**
TL5 (W)	3.6250
TL5 (S)	1.8210
TL5 (L)	**27.4000**
TL6 (W)	4.0360
TL6 (L)	**27.0000**

Note:

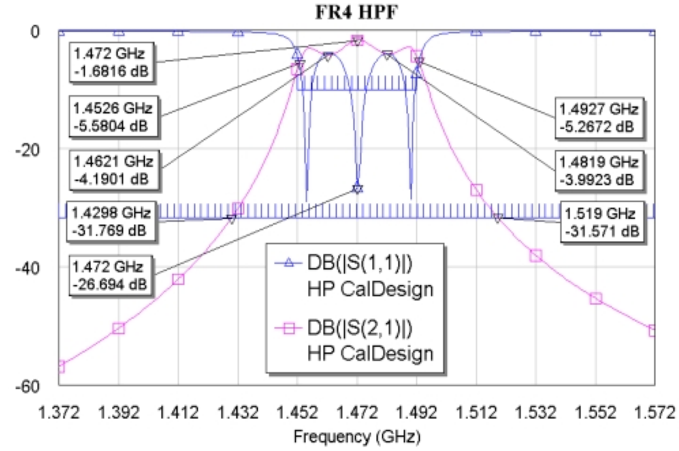
TLn is the transmission line elements from the schematic design.**W** is the width for the transmission line. **S** is the spacing in between two coupling transmission line.**L** is the length for the transmission line.

The dimensions of the microstrip filter layout design depend on the material specifications in term of the dielectric constant values that affect the length size of the design, which mean that the greater the dielectric constant values, the smaller will be the length. For the substrate thickness material specification it is proportional to the layout design width and gap sizes. The decrease in the substrate thickness will reduce the transmission lines width and gap. These circumstances had been proved by the calculation work in previous section.

C. The frequency response of the designs



(a) CLF line design response



(b) HPF design response

Fig. 6. Chebyshev bandpass response for microstrip filter design using FR4 material

According to the simulation results from Fig. 6 (a) and (b), it is the Chebyshev bandpass filter response which designed in fractional bandwidth of 2.7174 percent and all the results shown the rejection levels at the response dips or roll-off are better than -50dB. The insertion loss (S21) signal for the entire designs is less than -2dB, while the return loss (S11) signal response is more than -25dB. It can be observed that all the simulation bandpass filter responses have a good agreement in both the passband and stopband. There are 3 ripples occurred on top of the insertion loss signal (S11). These Chebyshev passband ripples response is equal to the order and number of reactive elements in the Chebyshev prototype as shown in Table IV.

TABLE IV. THE 3DB RESPONSE RESULT FOR THE ENTIRE MICROSTRIP FILTERS DESIGN

Type of Design	**Lowest Ripple Point (dB)**	**Highest Ripple Point (dB)**	**3dB Ripple Response (dB)**
FR4 CLF	4.0535	1.3588	2.6947
FR4 HPF	4.1901	1.6816	2.5085

From the table, HPF has the highest ripples point, with better selectivity.

D. 3dB cut-off frequency response

Two normal definitions for the cutoff of Chebyshev filters are often used. Some contributors have defined the cutoff attenuation as 3 dB, and others define the cutoff attenuation as the passband ripple value, with the latter perhaps somewhat more generally accepted.

TABLE V. THE ENTIRE DESIGNS RESULT OF 3DB CUT-OFF FREQUENCY RESPONSE

Type of Design	**Insertion Loss (S21) Peak Point (dB)**	**Lower Cut-off Frequency Point (dB)**	**3dB Cut-off Frequency Response (dB)**
FR4 CLF	1.3588	4.8862	3.5274
FR4 HPF	1.6816	5.5804	3.8988

Table V shows the 3dB cut-off frequency response for all designs is beyond 3dB value. However, Chebyshev bandpass filter allows the user to specify any attenuation equal to or greater than the ripple attenuation as the cutoff. Any of the cutoff attenuation greater than the ripple may be specified for the Chebyshev response.

E. 3dB bandwidth response

The 3dB bandwidth is typically reference to the 3 dB bandwidth points of a bandpass filters passband. Table 6 notices that all the microstrip filters design has the 3dB bandwidth quite close to the design specification which is 40MHz.

TABLE VI. THE 3DB BANDWIDTH RANGE OBTAINED FROM THE DESIGNS

Type of Design	**Lower Frequency (GHz)**	**Upper Frequency (GHz)**	**3dB Bandwidth (MHz)**
FR4 CLF	1.4521	1.4917	39.6000
FR4 HPF	1.4526	1.4927	40.1000

F. The comparison of the Smith chart results for the designs

The Smith chart is a graph that allows all passive impedances or admittances to be plotted in a reflection coefficient chart of unit radius. For this measurement the resonator only needs one port which means that S11 parameter is taking into consideration. The beauty of this measurement is a perfect circle that the measured reflection coefficient, plotted on a Smith chart, describes as a function of frequency. If there is no any perfect circle, than it is something wrong with the reference position.

If the center frequency (F_0) is located at the center of the Smith chart, then the magnitude $|\Gamma|$ is plotted as a radius ($|\Gamma| \leq 1$) from the center of the chart, and the angle $q(-180° \leq q \leq 180°)$ is measured from the right-hand side of the horizontal diameter. Any passively realizable ($|\Gamma| \leq 1$) reflection coefficient can then be plotted as a unique point on the Smith chart.

TABLE VII. SMITH CHART RESULTS FOR IMPEDANCE MATCHING

Type of Design	**Magnitude (Ohm)**	**Angle (q)**
FR4 CLF	50.4190	4.2345°
FR4 HPF	50.0880	-0.1695°

Table VII shows the result of impedance matching obtained from the Smith Chart. It was found that FR4 HPF has better impedance matching compared with the FR4 CLF.

G. Test results

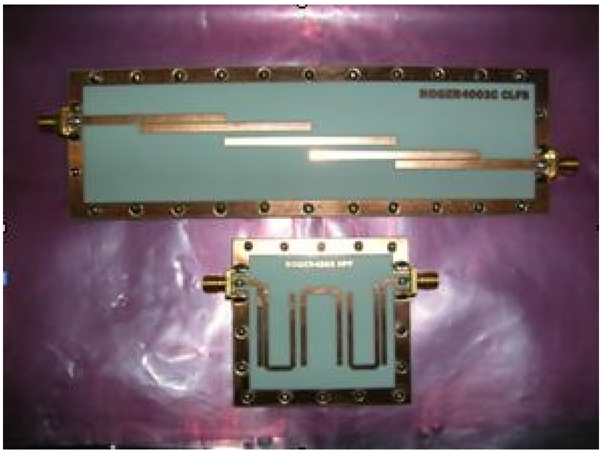


Fig. 7. The coupled line and hairpin line microstrip filter with the full grounding condition.

Fig. 8. Testing process using Advantest R3767CG Network Analyzer.

The bandwidth simulation results were tabulated in Table 8. The FR4 HPF has better bandwidth response compared with CLF.

TABLE VIII. LOG MAG RESULTS FOR 3DB BANDWIDTH RESPONSE OF MICROSTRIP FILTERS DESIGN USING FR4 MATERIAL.

Type of Design	F0 (GHz)	differ	Differ %
Specification	1.4720		
FR4 CLF	1.4600	-0.0120	0.8152
FR4 HPF	1.6038	0.1318	8.9538

Type of Design	BW(MHz)	differ	Differ %
Specification	40.0000		
FR4 CLF	43.6716	3.6716	9.1790
FR4 HPF	40.9496	0.9496	2.3740

Type of Design	Q factor	differ	Differ %
Specification	36.8000		
FR4 CLF	33.4310	3.3690	9.1549
FR4 HPF	39.1650	2.3650	6.4266

TABLE IX: THE INSERTION LOSS AND RETURN LOSS FOR THE FR4 CLF AND HPF DESIGNS IN BETWEEN THE MEASURED AND SIMULATION RESULTS

Type of Design	**Measurement**		**Simulation**	
	(S21) Insetion Loss (dB)	**(S11) Return Loss (dB)**	**(S21) Insertion Loss (dB)**	**(S11) Return Loss (dB)**

FR4 CLF	-11.1290	-7.7640	-1.3588	-28.5620
FR4 HPF	-20.6920	-8.5570	-1.6816	-26.6940

The center frequency output result is quite close to the desired frequency, it is just 0.8152 % different with the specification frequency. The bandpass response is shifted 12 MHz to the lower range. Seem the bandwidth is greater than the specification bandwidth of 3.6716 MHz, so the Q factor value is less than the specification as well as simulated Q factor values. Subsequently, the bandpass response showed that the 30dB attenuation response for the rejection level has a good agreement with the desired specification.

From the test it was found that there were no ripples at the passband response because of high insertion loss (S21) and small return loss (S11) response.

Generally, the practical insertion loss measurement are higher than the insertion loss obtained from the simulation designs. This is due to the imperfection of the filter structure or microstrip line and the roughness of the microstrip surface cause of losses. The I/O port of the SMA connector also contributes to the insertion loss and also the testing apparatus such as coaxial cables and the connectors of the network analyzer introduces high losses to the physical designs.

The difference of bandwidth is caused by the inaccuracy of fabrication process causing the measurement of the microstrip lines to differ from the actual design. The narrowing of the spacing causes the bandwidth to increase and vice versa. The major factor that contributing to the varying of the bandwidth is the imprecision of the equipment used for fabrication processes which only has the sensitivity up to ±0.5mm.

TABLE X. THE IMPEDANCE MATCHING RESULTS FOR THE ENTIRE DESIGNS

Type of Design	**Impedance Matching, S11 (Ohm)**	**Specification Z_0 (Ohm)**	**% Difference**
FR4 CLF	87.218	50	74.436
FR4 HPF	107.567	50	115.134

The impedance matching is 87.218 Ohm for the CLF design with the difference of 74.436 percent to the required value. While the HPF designs the impedance matching is much bigger 107.567. Therefore the load is not matched to the Z_0 of the line and the structures will consequence the reflection on the circuit. So the insertion loss is high and the bandwidth is widened. Analysis shows that the mismatch is mainly due to the deviation of the value of the coupling capacitors between the resonators created in fabrication. Loss is due both to the finite conductivity of the metal and to the dissipation of the dielectric material used to construct the line. The frequency dependence of these effects and the change in electromagnetic field distributions with wavelength together give rise to dispersion.

In order to produce a good design the consideration of the impedance matching just as with the source, if Z_0 transmission line drives a load of Z_0 there is no reflection, hence no standing wave pattern, maximum power is transferred, and measurements are greatly simplified. Thus to minimize reflections and maximize measurement accuracy, microwave instruments have test port impedances equal to the characteristic impedance of microwave coaxial cable and connectors (Z_0 = 50 Ohm).

TABLE XI. SWR MEASURED VALUES FOR THE ENTIRE DESIGNS

Type of Design	**SWR**	**Reflection Coefficient**	**Return Loss (dB)**
FR4 CLF	2.395	0.4109	7.7253
FR4 HPF	2.185	0.3721	8.5878

Table XI shows that the SWR and reflection coefficient of the FR4 CLF and FR4 HPF. It is found that FR4 CLF has higher SWR and therefore lower return loss compared with the FR4 HPF. Hence, it affected the circuit design become mismatch, this will increase the reflection and the filter will have the problem to filter the desired signal into the passband. The SWR due to the standing wave within the transmission line is often used to quantify how well a part is impedance matched. Always expressed as a ratio to unity, a SWR of 1.0:1 indicates perfection (there is no standing wave). A SWR of 2:1 means the maxima are twice the voltage of the minima. A high SWR such as 10:1 usually indicates the system have problem, such as a near open or near short circuit. The mismatched occurrence at the designs is mainly due to the deviation of the value of the coupling capacitors between the resonators created in fabrication.

V. CONCLUSION

The photolithography fabrication results out of the designated dimensions. Care is required in the fabrication to ensure proper circuit operation. Meanwhile, micromachining technology should be introduced to produce microstrip filter devices with higher performance.

The accuracy of the entire microstrip filters compared to the actual parameter was acceptable and the mcirostrip filters had successfully produced the bandpass response. In term of the scattering parameters S11 for return loss and S21 for insertion loss measurements, the CLF filter design obviously given lower insertion loss than HPF.

Based on the results of the tests of the two different types of designs, on overall the HPF has better performance than the CLF. This is based on the coefficient of reflection and return loss. However in some expect, CLF has got some advantage, especially on the impedance matching S11. The FR4 material has a bigger Q but lower bandwidth. The Q factor is considered as an important factor when judging the performance of the microwave filter. For a good microwave filter, a large Q factor and a small bandwidth are desirable where the larger the Q factor, the better the selectivity of a microwave filter.

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