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

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Abstract

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 the stopband of the filter. This research project consist 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 Chebyshev response is more selective than the Butterworth response at the expense of the insertion loss and greater group delay. The purpose of the research project is to design, fabricate, test and evaluate the performance of microstrip filter based on coupled line filter (CLF) and hair pin filter (HPF) designs on the ROGER 4003C substrate material.

The insertion loss method was used to produce the parallel coupled quarter wavelength resonator filters. The compatible filter mentioned 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 filters were designed and simulated using Microwave Office 2003 (V6.01). Prototype of Chebychev bandpass hairpin line and coupled line filters were then fabricated on ROGER4003C material. The entire filter designs and the performances of the substrate material to the designs are contrast. The filters were tested using Advantest R3767CG Network Analyzer. From the test results it was found that for the specified 3 dB bandwidth of 40 MHz, CLF performed 50.6052 MHz, and HPF 45.0936 MHz. Center frequency (1.4720 MHz), CLF performed 1.4298 MHz, HPF 1.4755 MHz. Load quality Q (36.8), CLF performed 36.614, HPF 28.2540 and the specified matching impedance of 50 Ω, CLF performed 51.587 and HPF 42.078.

Keywords: Chebychev, microstrip, coupled line, hairpin filter, digital radio broadcasting

1. Introduction

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 ROGER 4003C 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.

2. 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 ε_r and a thickness h, and the bottom of the substrate is a ground (conducting) plane.

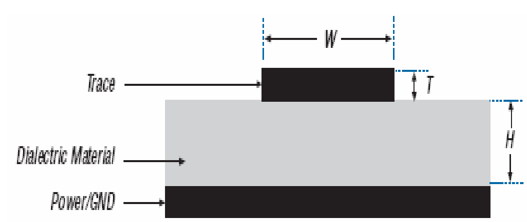

Figure 1. Microstrip structure

2.1 Design Parameters

The filter was designed based on the following parameters.

2.1.1 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

2.1.2 Frequency Range

Lower Frequency Range, f_L = 1.452 GHz

Upper Frequency Range, f_U = 1.492 GHz

2.1.3 Center Frequency

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

2.1.4 Bandwidth, BW

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

2.1.5 Fractional Bandwidth, *FBW* (Δ)

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

$$= 0.02714$$

2.1.6 Normalized Frequency; Ω

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

$$\Omega = \frac{(2\pi\times1.472\times10^9)}{(2\pi\times1.492\times10^9) - (2\pi\times1.452\times10^9)}\left(\frac{2\pi\times1.5165\times10^9}{2\pi\times1.472\times10^9} - \frac{2\pi\times1.472\times10^9}{2\pi\times1.5165\times10^9}\right)$$

$$\Omega = 2.192355$$

2.1.7 Ripple Factor, a_m

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

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

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

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

$$a_m^2 = 0.99526$$

$$a_m = 0.997628$$

3. Design Process

The design process includes the use of MWO software for generating the schematic diagram of both designs and simulation, and selection of fabrication material.

3.1 PCB material selection

ROGER 4003C PCB material was used in this research work. The ROGER 4003C was chosen for its better performance in higher operating frequency. The specification of the material is shown in Table 1.

Table 1. The result of the calculation microstrip lines dimension (ROGER4003C material ε_r = 3.38).

Coupled Line, j_n	Length (mm), l_n	Width (mm), w_n	Space (mm), S_n
0	31.270955	1.830481	0.912201
1	31.236307	1.882242	2.884633
2	31.236307	1.882242	2.884633
3	31.270955	1.830481	0.912201

3.2 Microwave filter fabrication

The CLF and HPF designs were derived from the basic coupled line band pass filter layout as shown in Fig. 2. The circuit patterns are realized into a finish product shown in Figure 3 on ROGER 4003C material by the photolithographic process. The testing was carried out using the R3765/67G series network analyzer as shown in Figure 4. A network analyzer makes measurements of S-parameter S11 and S21, SWR, Smith Chart for impedance matching and etc.

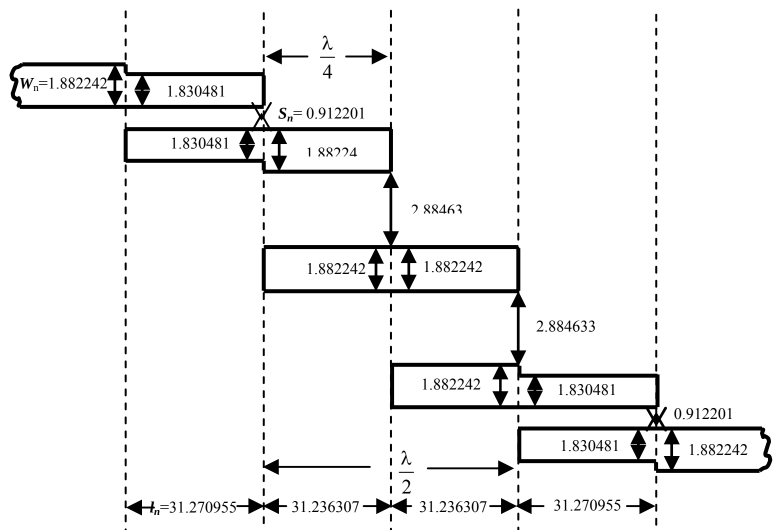

Figure 2. Coupled line bandpass filter layout.

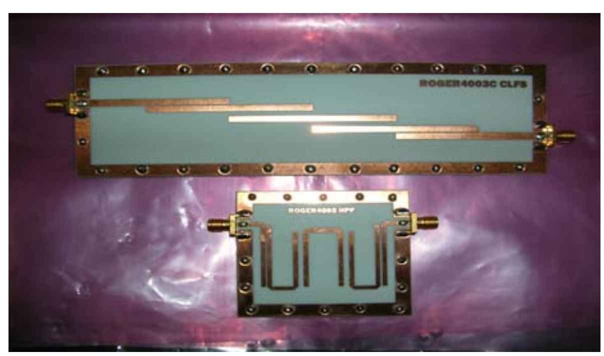

Figure 3. The coupled line and hairpin microstrip filter with the full grounding

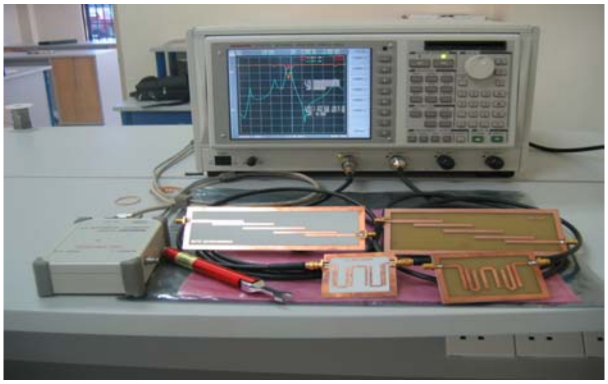

Figure 4. Testing process using Advantest R3767CG Network Analyzer

4. Result and Analysis

This section discusses about 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.

From the simulation results shown in Fig. 5 and Fig. 6 the Chebyshev bandpass filter shows 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.

4.1 3dB ripple response of the designs

Referring to Fig. 5 and Fig. 6 there are 3 ripples occurred on top of the insertion loss signal (S21). These Chebyshev passband ripples response is equal to the order and number of reactive elements in the Chebyshev prototype which had been specified earlier. The 3dB ripples response of the ROOGER 4003C coupled line filter was found to be 2.5417. Compared with filter, but with improved selectivity.

4.2 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 3dB, and others define the cutoff attenuation as the passband ripple value, with the latter perhaps somewhat more generally accepted. The 3dB cut-off frequency response for both CLF and HPF designs is beyond 3dB value i.e. 3.0506 and 4.0733 respectively. 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.

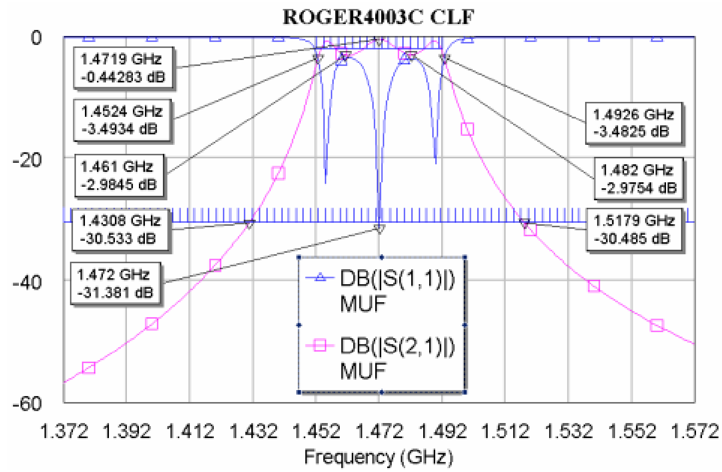

Figure 5. Chebyshev bandpass response for CLF design

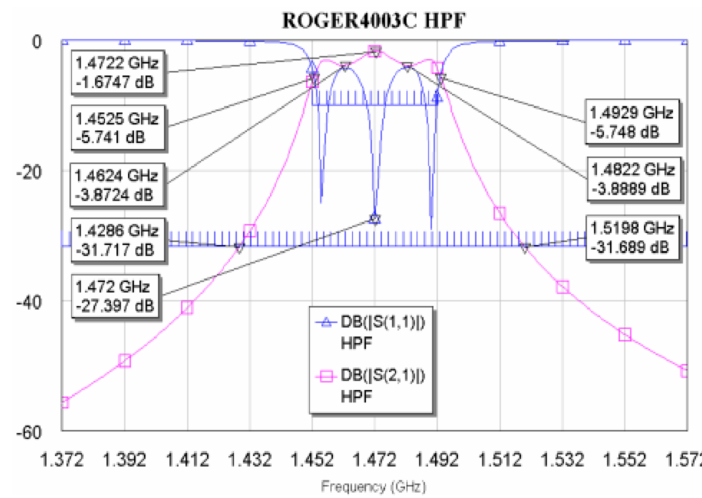

Figure 6. Chebyshev bandpass response for HPF design Using ROGER 4003C

4.3 3dB bandwidth response

The 3dB bandwidth is typically reference to the 3dB bandwidth points of a bandpass filters passband. Table 2 shows the simulation result of all the microstrip filter designs that the 3dB bandwidths are quite close to the design specification which is 40MHz.

Table 2. The 3dB bandwidth range obtained from the designs

Type of Design	Lower Freq. (GHz)	Upper Freq. (GHz)	3dB Bandwidth (MHz)
ROGER4003C CLF	1.4524	1.4926	40.2000
ROGER4003C HPF	1.4525	1.4929	40.4000

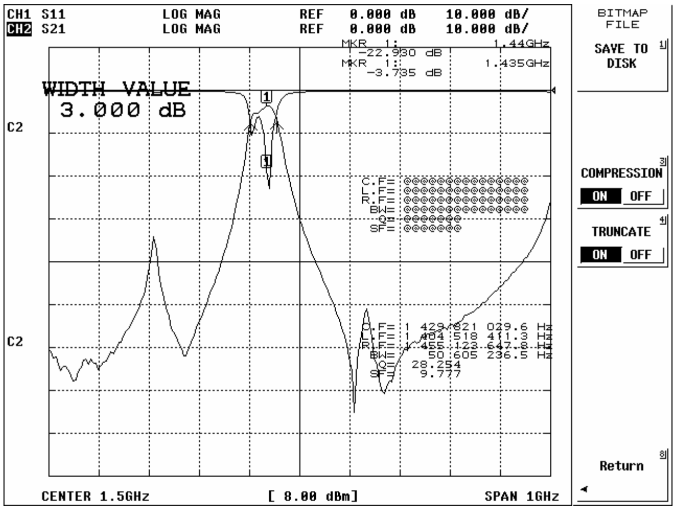

Figure 7. Test result for Chebyshev CLF bandpass using ROGER 4003C

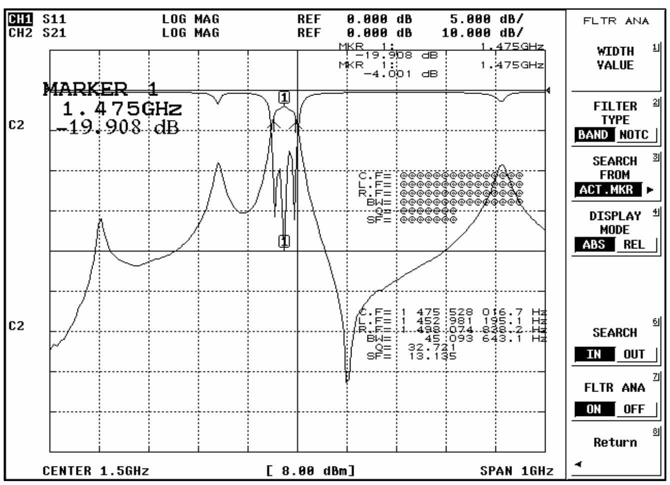

Figure 8. Test result for Chebyshev Hairpin filter bandpass using ROGER 4003C

Table 3. LOG MAG results for 3dB bandwidth response of microstrip filters design using ROGER4003C material.

Type of design	F_0 (GHz)	BW(MHz)	Q Factor
Specification	1.4720	40.0000	36.8000
ROGER CLF	1.4298	50.6052	28.2540
ROGER HPF	1.4755	45.0936	32.7210

Table 3 shows the result obtained from the test. The center frequency, bandwidth and Q-factor of the Roger 4003C HPF was found to be very close to that of the specification.

Table 4. The impedance matching

Type of Design	Impedance Matching, S11(Ohm)	Specification Z_0 (Ohm)	Insertion Loss S21 (dB)
ROGER4003C CLF	51.587	50	-3.7350
ROGER4003C HPF	42.078	50	-4.0010

Table 5. The SWR of the designs

Type of Design	SWR	Reflection Coefficient	Return Loss (dB)
ROGER4003C CLF	1.154	0.0715	-22.9300
ROGER4003C HPF	1.229	0.1027	-19.9080

From Table 4 and 5, the insertion loss (S21) for CLF and HPF designs was found to be -3.735 and -4.0010 and the return loss (S11) was -22.9300 and -19.9080 respectively. The CLF design has shown better impedance matching as compared with HPF design. The matching was reflected in a lower return loss of -3.7350 dB.

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 maximum 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.

5. Conclusions

Based on the data analysis on this project, it was found that the accuracy of the entire microstrip filters compared to the actual parameter was acceptable and the micro strip filters had successfully produced the required bandpass response. Microstrip filter can also be designed and fabricated on other than ROGER 4003C material such as FR4. Generally the performance of the design using ROGER 4003C is much better compared with that of FR4 and significantly decreased the final sizes of the filters. Both the scattering parameters S11 (return loss) and S21 (insertion loss) of CLF filter design using the ROGER4003C are better that that of the HPF.

Based on the practical design for the two different types of micro-strip filter design the hairpin line design is better than the coupled line design, though in regard of size, the hairpin line design is smaller than the coupled line design. While in term of bandwidth and quality factor (Q), obviously the hairpin line design had a narrower bandwidth and bigger Q factor value than the coupled line design. The Q factor is considered as an important factor when judging the performance of the microwave filter. In good microwave filter, a large Q factor or quality 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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