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ACTIVE FILTERS: A RELIABILITY AND PERFORMANCE ANALYSIS

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ABSTRACT

This paper demonstrates the reliability and performance aspect of the active filters. The active filters are the very important circuitry that is used in most of the electronic and electrical systems for desired response. The active filters are made by active and passive elements and their reliability and performance directly depends on the reliability of active and passive elements. In this work, the reliability and performance of various active filters based on different combinations of resistors and capacitors have been considered. The reliability and performances of active filters are analyzed for various RC combinations based on empirical prediction method.

Key words: Reliability, Active filters, Failure rate, RC network

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1. INTRODUCTION

In the Morden era of the electronic systems, the most challenging issue is the reliability and performance of the active filter under various operating conditions. Therefore, numerous efforts have been made by the research community to improve the performance and reliability of the electronic components and systems. The basic components of the active filters are resistors, capacitors, and operational amplifier, and the overall performance of the systems directly depends on the reliability of these components. Furthermore, the reliability is the key factor to evaluate the performance of the components, which is calculated by the failure rate of the components over the prescribed time period of use under various operating conditions. Moreover, the reliability of these components is varying by the selection of composition of the material as well as fabrication process. The reliability prediction (RP) is measured during the design and development phase, and the operation and maintenance phase at various system levels in order to evaluate, determine and improve the dependability of the component.

To get the highly reliable active filters, various electronic industries are still struggling in the selection of reliable components. In this paper, we have analyzed the different types of resistors and capacitors to evaluate the reliability and performance of the low pass active filters based on the empirical prediction method.

Rest of manuscript is organized as follows. The basic circuit of Butterworth filter and Chebyshev filter are demonstrated in Section 2. The information of reliability of various components, those are required for design of an active filter is provided in section 3. Reliability analysis of RC based Active filter and the comparative reliability analysis are also given in Section 3. The performance analysis of Butterworth filter and Chebyshev filter shows in Section 4. The conclusion of the manuscript is given in Section 5.

2. LOW-PASS BUTTERWORTH AND THE CHEBYSHEV FILTERS

The Butterworth and Chebyshev filters is the most common active filter which is generally used in the signal processing to get the flat frequency response (no ripple) and zero roll of response in the stop band. These filters are also used in design of digital filters for the motion analysis and audio circuits. An active filter gives the fast response and very simple in use to understand the frequency response and filtering application for various electronic systems.

Figure 1 shows the circuit diagram of first-order Butterworth low pass filter which consists of the resistors and capacitors, and it is designed for various combinations of resistors and capacitors.

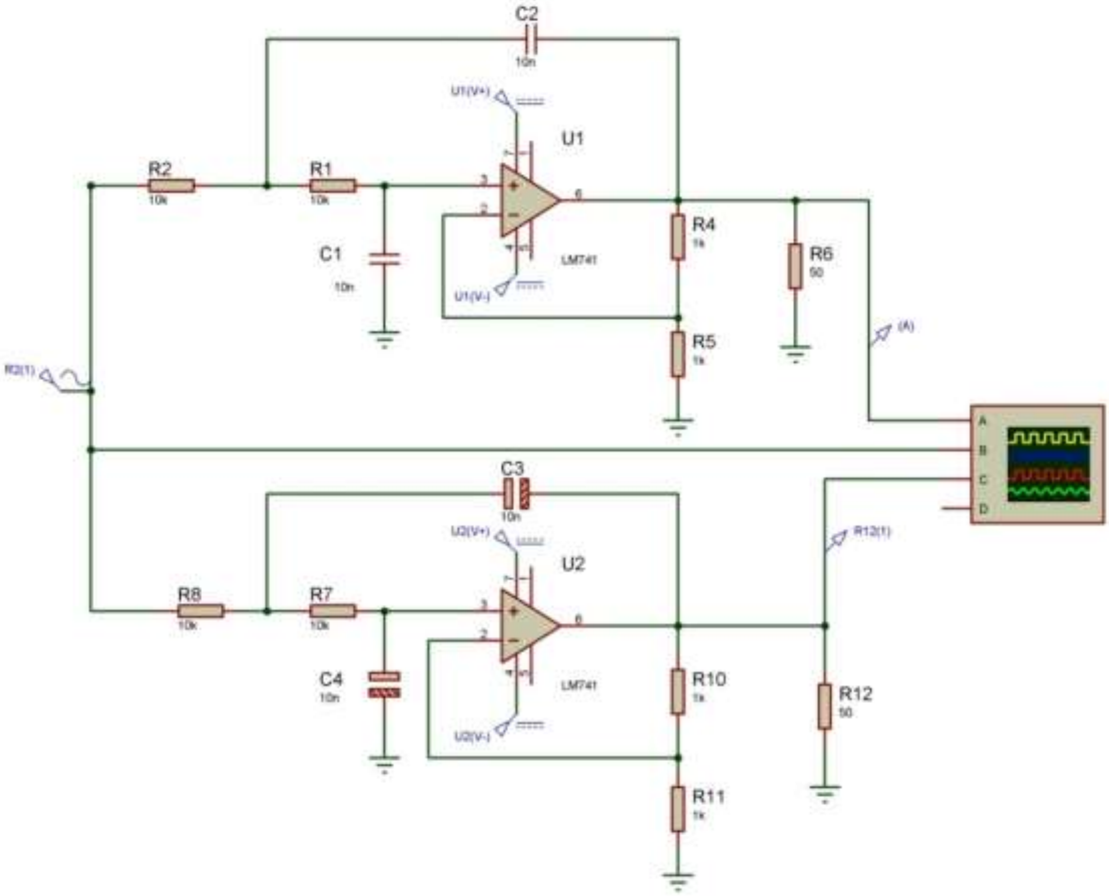

Figure 1 Circuit design of the Butterworth low pass filter

In the figure 1, there are two simple low pass Butterworth filters where only the material composition of resistors and capacitors are changed. The upper part of circuit is made by the wire wound type resistors and ceramic type of capacitors and lower part of circuit is made by metal film resistor and electrolyte type but values of resistors and capacitors are considered same. The schematic circuit diagram of Butterworth active filter is designed using the Proteus 8.7 software and simulation results are plotted for comprehensive analysis of their performances.

Furthermore, figure 2 shows the circuit diagram of first-order Chebyshev low pass filter which consists of the resistors and capacitors circuit with the various combination of the resistors and capacitors. The upper circuit as shown in figure 2 have wire wound type resistors and ceramic type of capacitors while lower circuit has metal film resistor and electrolyte type of capacitors of the same values.

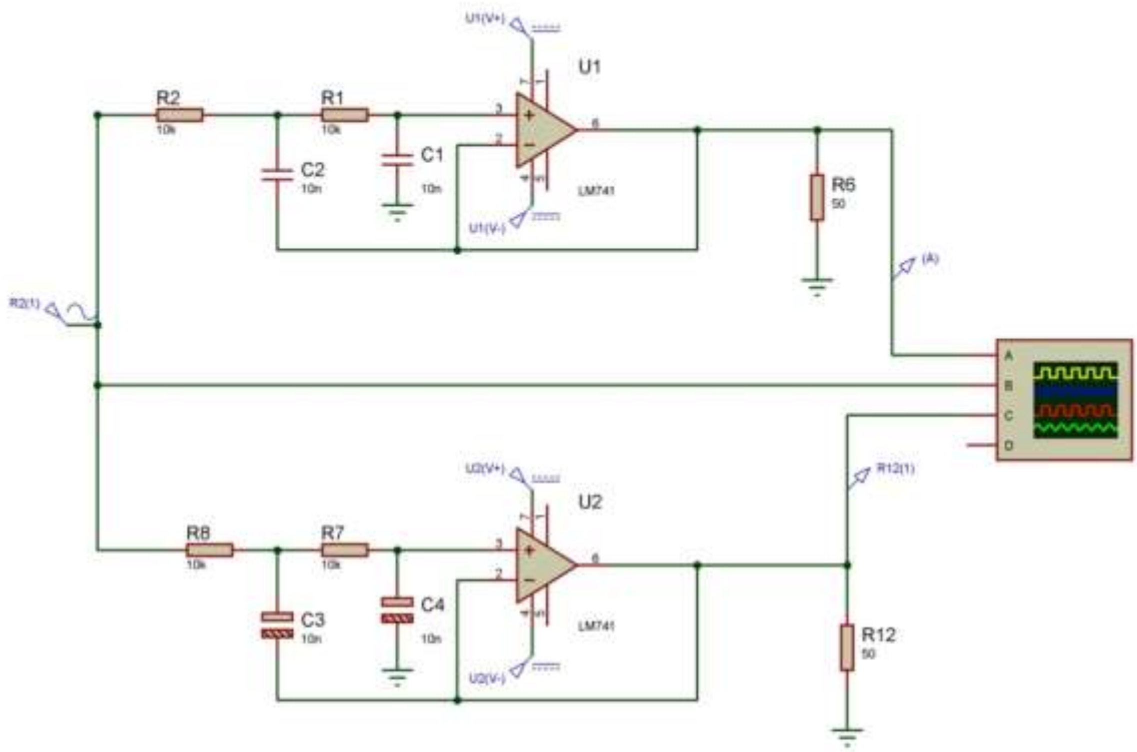

Figure 2 Circuit design of the low pass Chebyshev filter

3. RELIABILITY ANALYSIS

The performance of the system depends on the failure rate of the components which is varying with type of components. To develop the highly reliable filters, it is required to select the highly reliable combination of the components during the design process. There are several methods have been developed to calculate the reliability of the electronic system and components [1-5]. These categories are commonly three types, first is the empirical prediction method which is based on the experience of engineers and historical data, such as Military handbook (MIL-HDBK-217F) [6,7]. Second is physics of failure, which is based on the root cause analysis of the failure mechanism, failure modes, and stresses [8-14]. The third is the life testing method that is used to determine the reliability by testing a relatively large number of samples at their specified operation stresses and statistical model is used to analyze the data [15-20].

In this work, we have used the empirical prediction method which is based on models developed from the statistical curve fitting of historical failure data that are collected different engineering fields and manufacturers. This method is used to estimate the reliability for the similar or modified parts. The military handbook (MIL-HDBK-217F) [6-7] is the most common resource of the data of empirical prediction method. In this, the reliability R(t) of the component is given by:

$$R(t) = e^{(-\lambda t)}$$

where, λ is the failure rate of the component, which is calculated after 10^6 hours. Furthermore, the failure rate of the components depends on the temperature and various environmental operating conditions.

3.1. Reliability Calculation for Various Capacitors

The reliability of the capacitors is also calculated by the failure rate (λ). Table 1 shows the failure rates and corresponding reliability at different time for the various types of the capacitors and these data are taken from military handbook [6-7].

Table 1 Reliability calculation for the different composition of the capacitors

S. No.	Capacitor Type	Failure rate per 10^6 hours	Reliability (R) after t time	
			t= 168 hrs	t= 336 hrs
1	Electrolytic	0.00012	0.980	0.960
2	Ceramic	0.00099	0.846	0.717
3	Plastic film	0.00230	0.680	0.416

From table 1, it is seen that the maximum failure rate is found for plastic film capacitor and minimum for electrolytic capacitor.
The reliability for the various types of capacitors is plotted in figure 2.

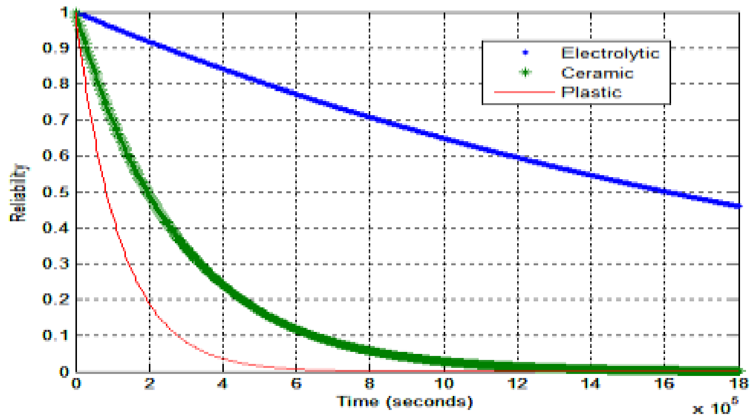

Figure 3 Reliability plot for the various types of capacitors

From the figure 3, it is also seen that the reliability of the electrolytic capacitor (blue color diamond symbol) which is found better as comparison to ceramic (green star symbol) and plastic film (red line) capacitors.

Remark 2: However, the ceramic-based capacitor shows low cost, small size, more stable and low inductance but high voltage coefficient whereas in case of an electrolytic capacitor, it is found that it has large values, high current and voltage and small size but there is a major problem of leakage and polarization.

3.2. Reliability Calculation for Various Resistors

The failure rate (λ) and corresponding reliability for the different time of the resistors are shown in table 2, which is taken from the MIL-HDBK-217F.

Table 2 Reliability calculation for the different composition of the resistors

S. No.	Resistor Type	Failure rate per 10^6 hours	Reliability (R) after t time	
			t= 168 hrs	t= 336 hrs
1	Carbon Composition	0.00230	0.679	0.461
2	Metal Film	0.00120	0.817	0.668
3	Wire-wound Composition	0.01400	0.095	0.009

From the table 2, it is clear that the maximum and minimum failure rates are found for the wire-wound and metal film resistors respectively.

The reliability plot for the different types of resistors (carbon, metal film and wire wound composition) with time is given in figure 4.

From the figure 4, it is clearly seen that the metal film composition based resistor (green color star) shows better reliability as compared to the carbon (blue color diamond) as well as wire wound (red line) composition based resistors.

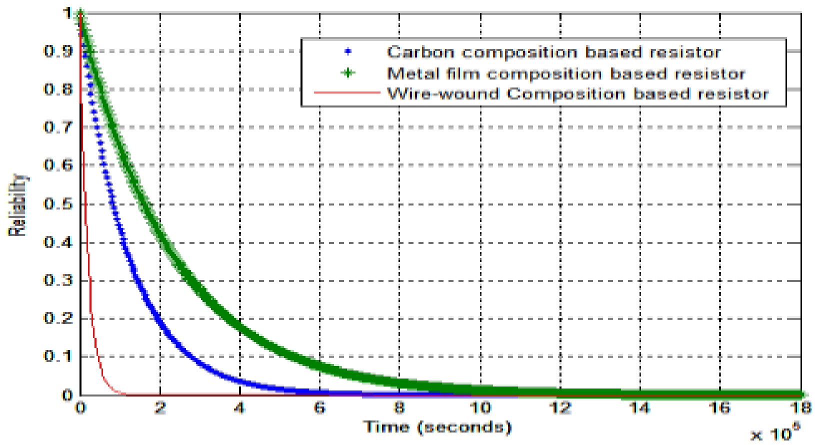

Figure 4 Reliability plot for various composition based resistors

Remark 1: The wire wound resistor shows worst reliability. Furthermore, the carbon composition based resistor show low cost, high power/small case size and applicable for wide range of values but its tolerance limit and temperature coefficient are quite poor whereas in case of wire-wound, it is found excellent tolerance and temperature coefficient but it is more expensive for large case size. The metal film resistor has good capability towards their tolerance and temperature coefficient and also lower cost.

3.3. Reliability Calculation of RC Based Active Filters

The basic unit of passive, as well as active filters is the RC network and designed structure of the filters may change by combination of resistors and capacitors in the RC network. Overall failure rate of the system is basically depends on the reliability of these discrete components that are used in the designing of active filters, which is a function of the failure rate of discrete components. Therefore, in case of RC based filters the final reliability of filters calculated as the cumulative sum of failure rates of capacitors and resistors.

The failure rate of the RC based filter is calculated as

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n$$

And over all reliability of the filter can be calculated using formula as $R(t) = e^{(-\lambda t)}$.

Table 3 shows the failure rates and corresponding reliability for different time periods for all possible combinations of resistors and capacitors that are used in active filters.

Table 3 Reliability Active Filter for various combinations of Resistors and Capacitors

S. N.	Resistor Type	Capacitor Type	Failure rate(λ) per 10^6 hours	Reliability (R)after t time	
				t= 168 hrs	t= 336 hrs
1	Carbon Composition	Ceramic	0.00329	0.575	0.331
2	Carbon Composition	Electrolytic	0.00219	0.665	0.443
3	Carbon Composition	Plastic film	0.00460	0.461	0.213
4	Metal Film	Ceramic	0.00219	0.692	0.479
5	Metal Film	Electrolytic	0.00132	0.800	0.641
6	Metal Film	Plastic film	0.00350	0.555	0.308
7	Wire-wound Composition	Ceramic	0.01499	0.0805	0.0065
8	Wire-wound Composition	Electrolytic	0.01412	0.093	0.0087
9	Wire-wound Composition	Plastic film	0.01630	0.065	0.0042

From the table 3, it is clear that the failure rate is found worst and less reliable for combination of wire-wound resistor and plastic film capacitor and it is suggested that the such material based combination of resistors and capacitors is not preferred for design of active filters whereas for combination metal film resistor and an electrolytic capacitor, the reliability of the active filter is found very good which is more desirable combination of resistors and capacitors. In this case the failure rate for the metal film resistor and electrolytic capacitor combination is 0.00132 and reliability is estimated as 0.8 at 168 hours and 0.641 at 336 hours which is good as compared to other combination of RC network based active filter.

Furthermore, the reliability plots for different combination of resistors and capacitors for active filter circuit are shown in figure 5.

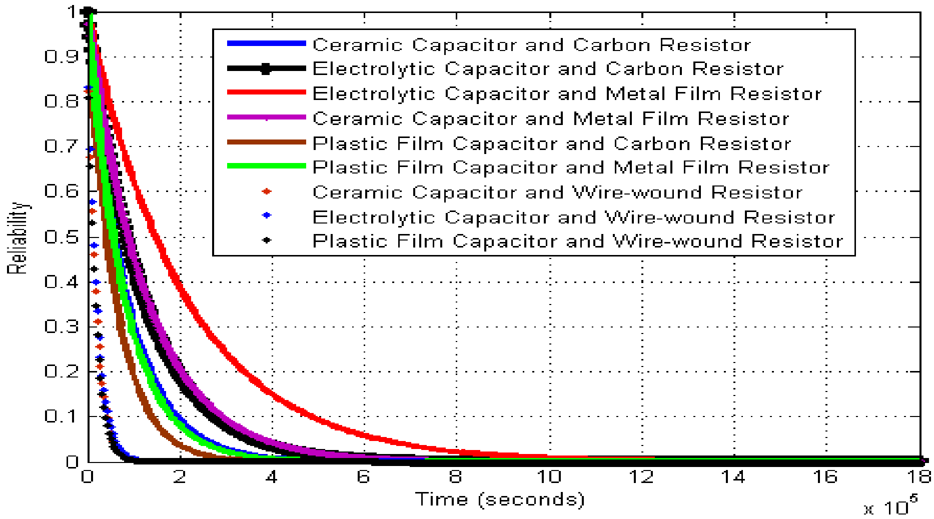

Figure 5 Reliability plot for different combination of RC network for Active Filters

From the figure 5, it is also clear that the best reliability curve is found for the combination of metal film resistor and electrolytic capacitor as compared to other combinations of RC network for the design of active filters.

4. RESULT AND DISCUSSIONS

In this section the performance of first order low pass Butterworth and Chebyshev filters are given. The frequency response of the first order Butterworth low pass filter with the cut off frequency of 1 kHz is shown in figure 6, where the open black circle shows the response for the combination of ceramic type capacitor and wire wound type resistor, and the solid red circle shows the response for the combination of the electrolytic type of capacitor and metal film type of resistor.

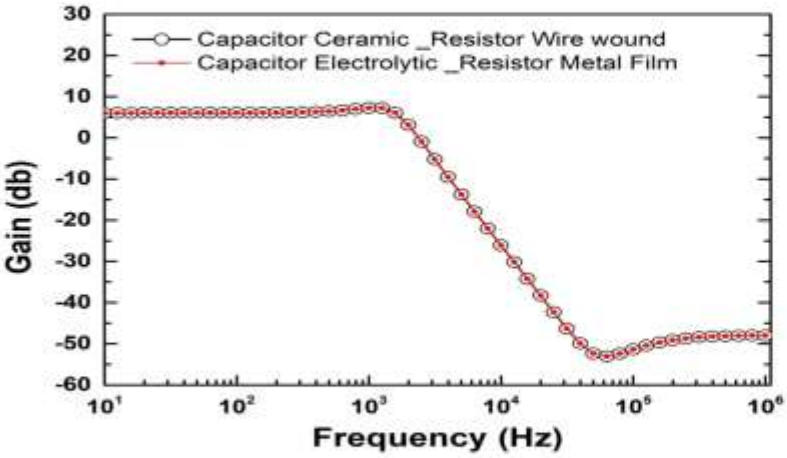

Figure 6 The frequency response of the Butterworth low pass filter for the two different combinations of the resistors and capacitors

From the figure 6 it is clear that, the initial frequency response is found to be same for both the combinations with -20 dB/decade.

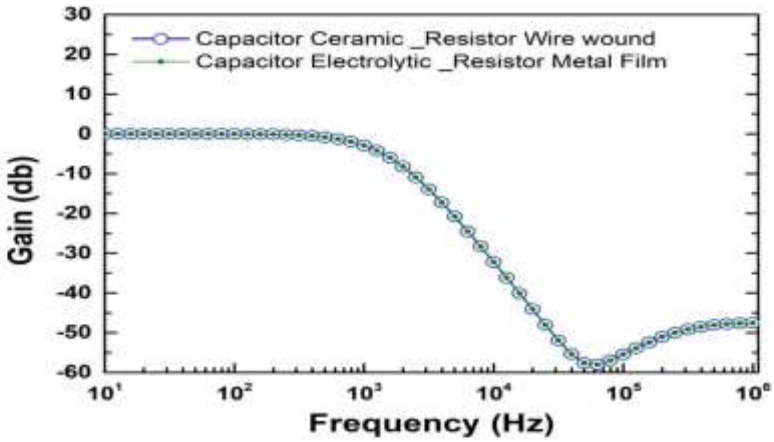

Figure 7 The frequency response of the low pass Chebyshev filter for the two different combinations of the resistors and capacitors

Similarly, Figure 7 shows the frequency response of the first order Chebyshev filter with the cut off frequency of 1 kHz. In this figure, the open black circle shows the response for the combination of ceramic type capacitor and wire wound type resistor, and the solid green circle shows the response for the combination of the electrolytic type of capacitor and metal film type of resistor.

From the above analysis, it is clearly noticed from the table 3 that the maximum and minimum failure rates are found for the wire wound resistor and plastic film capacitor and metal film resistor and electrolytic capacitor combinations respectively. Apart from this, the performance of the Butterworth and Chebyshev filters are estimated for various combinations of resistors and capacitors, those are used in the design of filters. Moreover, from the figure 5, it is clear that the reliability of Butterworth and Chebyshev filters is found best for the combination of an Electrolytic capacitor and Metal film resistor, and worst for the combination of a wire-wound resistor and plastic film capacitor.

5. CONCLUSIONS

The paper highlights the reliability and performance of the active filter. In this work, various combinations of resistors and capacitors have been included to analysis of reliability and performances of Butterworth and Chebyshev filters. The failure rate (λ) is calculated on the empirical prediction method with data available in military handbook (MIL-HDBK-217F) for all the combinations of resistors and capacitors for design of the active filters. The better reliability is observed for the combination of electrolytic capacitors and metal film resistors as compared to other combination of resistors and capacitors while worst reliability is found for the combinations of wire-wound resistors and plastic film capacitors. This concludes the metal film resistor and electrolytic capacitor combination is the highly reliable combination for the Butterworth and Chebyshev filters.

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