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Low passive filters applications in naval engineering

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Abstract. In this paper one analyses different low passive filters that are used successfully in naval engineering applications. Filters are successfully used in marine control systems, supply systems on board or for reduction of harmonic distortion. The advantages and disadvantages of the filters were also presented. Using Matlab and Simulink the filters electrical circuits (3^{rd} and 5^{th} order passive filters Chebyshev and Elliptical are considered in this paper) were analysed.

1. Introduction

Filters are electrical circuits and by using them the undesirable signals are avoided and only the required ones will pass. Filters can be designed using many methods that have their respective advantages and disadvantages [1]. In general, filters are designed by either passive components (resistors, inductors and capacitors) or active components (transistors, FETs and Op-amps). There are many applications of filters in the field of Telecommunication, Digital Signal Processing, etc. [2].

When a measurement is performed, the part of the measured values which is noise, that does not characterize the phenomena being measured, must be removed so that the obtained data expresses the characteristics of the system being tested. Data filtering is very important because without it the measurements and the derived values often depict physical phenomena that are virtually impossible. In order to choose and analyze a filter in a time domain system it is important to determine their characteristics: stability, attenuation, time-lag and distortion [3].

There are various filters that are successfully used in the marine applications. For example: VHF-band pass filters, X band high pass filter's highly specialized tasks, VHF Band LC Low Pass Filter, Low pass filters etc. [4].

The passband frequency of the VHF- bandpass filter can be between 30MHz and 300MHz. They can be a combination of both a low pass filter and a high pass filter. In general, they permit only a particular frequency (either wide or narrow) band and impedes every remaining frequency. These filters are used for long range data communication up to several tens of kilometers with radio modems and marine communications. These types of filters are the least to be affected by the atmospheric noise and interference from other electrical equipment than with other frequency bands. VHF multiplication traits are ideal for short-distance communication, with a range that's somewhat farther than line-of-sight from the transmitter.

The X band high pass filter can make the submarines or radars that detect enemy aircraft to work effectively. Moreover, X-band frequency is also applied in marine radar, coastal surveillance radar, and weather radar [4]. The frequency ranges from 8 to 12 GHz and to ensure that only the approved frequencies “pass” within this range, X band high pass filters are used. They have a very low impedance at high frequencies, and a very high impedance at low frequencies.

The VHF Band LC Low Pass Filter is used successfully in many applications one of them being the marine communications. The VHF range require that the layout of the LC filter should be laid out carefully. To minimize the inductive and capacitive coupling, the inputs and outputs of the LC filter should be kept apart. The VHF low band filters work precisely to output frequencies of between 30MHz to 300MHz.

The easiest manufactured low pass filter can be made by connecting a single inductor with a single capacitor. The order of a low pass filter is determined by the number of inductors and capacitors that form the filter. This filter also provides a much smoother form of a signal, eliminating any short-term fluctuations and leaving the long-term trend. The main applications of low pass filters are made evident in audio amplifiers to direct the lower frequency signals to larger bass speakers or to lower any high frequency [5].

In some areas the large number of marine radars present simultaneously above the horizon makes the mutual interference a very likely event [6]. In the radar target track data always a mass of noise signal can be found. The noise disturbs the target identification in the display screen, which causes the illusion the target is fluttering. Many filter techniques to resolve this problem were used but all the information needed was difficult to acquire or was inaccurate [7], [8].

The different antennas used onboard are influenced by the total clutter. This clutter has a finite frequency spectrum caused by echoes from the sea and is not stationary with respect to the antennas. Also, different fluctuations are introduced by the antenna itself – for example, her rotational scanning. In [9] is stated that combinations of passive filters, used to eliminate DC components from echo signals received from fixed targets, can successfully improve the frequency response of an MTI (moving-target-indicator) radar canceler.

The filters used in ship’s construction must function properly in all propulsion settings and grid configurations and they must not lead to increases in voltage or current. This is verified through measurements during the sea trial [10].

Filters are very useful for reduction of harmonic distortion and are the ideal solution to ensure good power quality in the supply systems on board.

In some cases, because there are many possible configuration alternatives, the design may be difficult. The use of filters ensures high efficiency and trouble-free operation and, in many cases, they guarantee the compliance with the main power quality specification. Filters eliminate the risk of equipment breakdown due to harmonic pollution and at the same time they allow reactive power compensation and load balancing, thus contributing to a reduction in the running costs [11], [12].

Some of the vessels have very strict underwater noise requirements, typically several decades dB below normal levels for other applications. Using filtering and reduction of vibrations techniques one can ensure that the ship motors will be feasible also for high demanding applications [13].

Filters are also used for the reconstruction of non-measured data. For many applications important process states are not measured because no convenient sensors exists or the costs to install a sensor are too high. In such cases model-based filtering techniques can be applied. The unmeasured signals are reconstructed, and the filtering is performed before the signals are used in a feedback control system. [13]

Filters have successfully been used in marine control systems since the 1970s and they are in a continuous development. For example, into all future ship designs developing technologies, such as the power electronic building block architecture (it consists of an array of power electronics switches, sensors, microcontrollers, filters, etc.), are incorporated.

2. Filter analysis

In this paper we decided to analyze low passive filters - made up of inductors, capacitors, and resistors. In general, the resistors in the filter are the source and load impedances. Resistors might exist in the circuit as separate resistor components or they might be an inherent feature of the amplifier that provides the signal and the amplifier that receives the output of the filter.

As stated, the design of filters can be various, and each design has his own advantages and disadvantages. For example, a lower number of element order can make the frequency response sloping and can worse the selectivity. By contrast, the higher the number of filter element order (greater than 5), the steeper the frequency response is, and it results bigger filter dimensions [4].

The first filter is a Chebyshev low pass filter. One of the reasons that we chose this filter is that it has a response that is easily realized with few components and offers a good selectivity with one of the steepest roll-off responses of the group [14].

The Chebyshev response is a mathematical strategy for achieving a faster roll-off by allowing ripple in the frequency response. Chebyshev filters can be analog or digital filters. There are two types: Chebyshev Type-I and Chebyshev Type-II. Chebyshev Type-I has steeper roll off and more passband ripple - they are all pole filters. Chebyshev Type-II (in some cases are called inverse Chebyshev filters) have ripple only in the stopband – their transfer functions contain zeroes as well as poles. Chebyshev filters minimize the error between the idealized and the actual filter characteristics over the range of the filter, but with ripples in the passband [2], [7]. Due to this property Chebyshev have a ripple less response in passband and more irregular response in stopband [2].

One of the advantages of this filter by comparison with others, for example Butterworth, is that has a better rate of attenuation beyond the passband even if it has ripples and it usually leads to a lower-order polynomial to accomplish the same result [3].

The other filter is an elliptic one. The difference between the two filters can be seen in Fig. 1 [15].

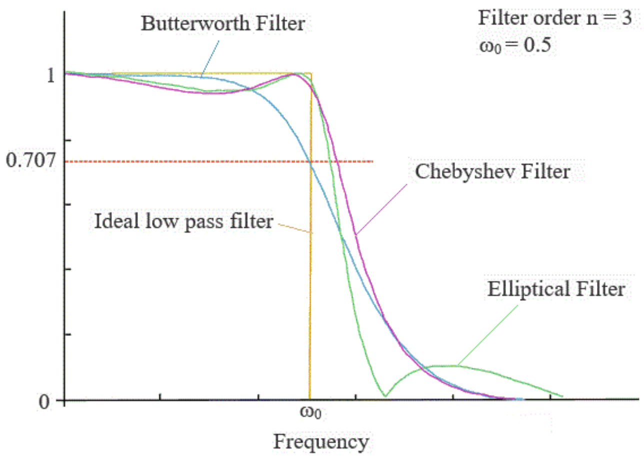

Fig. 1. Different filters frequency response

The elliptic filter is used in many applications where a very fast transition between the passband and stopband frequencies is required. The filter exhibits gain ripple in both passband and stopband.

The amount of ripple in each band is independently adjustable [16]. Because it allows ripple in both the stop band and pass band has a shorter transition region than the Chebyshev filter [3].

Even though, the elliptic filters possess a weakness of having the most nonlinear phase response over their pass band, compared with other filters, the elliptic filter requires the lowest order filter – e.g. in some cases a 3rd order elliptic order can replace a 5th order Chebyshev filter [17] - [19].

The advantages of this filter are that it has, by comparison of other ladder filters, the faster transition between the passband and the stopband, for the given values of ripple (whether the ripple is equalized or not).

The elliptic filter has very sharp filter cutoff characteristics, the cut off is sharper than the Chebyshev, but has a reduced stopband performance [20]. This is done at the expense of a very nonlinear group delay. Also, they are much harder to design, and their numeric evaluation is difficult. But the fact that they provide the sharpest transition between the passband and the stopband accounts for their widespread use [21], [22].

In safety critical marine applications a sudden drop-out of the control system may lead to dangerous situations, if not an adequate signal substitution will take place. If for some period of time a model-based filters are applied, the measured signal can be replaced. From the most used conventional analog and digital filters, and model-based filters used in control system design one can mention: the class of linear time invariant systems for lowpass filtering where the most known are Chebyshev, Bessel and Elliptic filters; and the infinite impulse-response class filters where the most known are Chebyshev, Elliptic and Butterworth [13]. This is one of the reasons why in this paper the two filters, Chebyshev and Elliptical, were chosen.

Also, the Chebyshev filter is useful for determine the wave-induced component and the whipping component of the stress record onboard - ship structures are prone to fatigue cracking due to fluctuating loads caused by the seaway [23].

The Chebyshev filter is, as well, successfully used in wireless power transmission. As stated in [24] the used filters have two main functions. They can limit the frequency of the incoming rf signals and they can prevent the reradiation of higher order harmonics produced by different electronics components (for example a rectifying diode).

3. Matlab models

As stated earlier the elliptic filters are considerably more complex compared to Chebyshev filters. We decided to make Matlab simulations in order to verify if the differences between the two filters are significant. We chose a 3rd and 5th order Chebyshev filter and an 3rd and 5th order elliptical filter. The filters were realized using passive components such as series inductors and shunt capacitors with Cauer topology. In figures 2 and 3 are presented the schematics. In these representations, some of the measuring devices were eliminated in order to better see the electrical diagram.

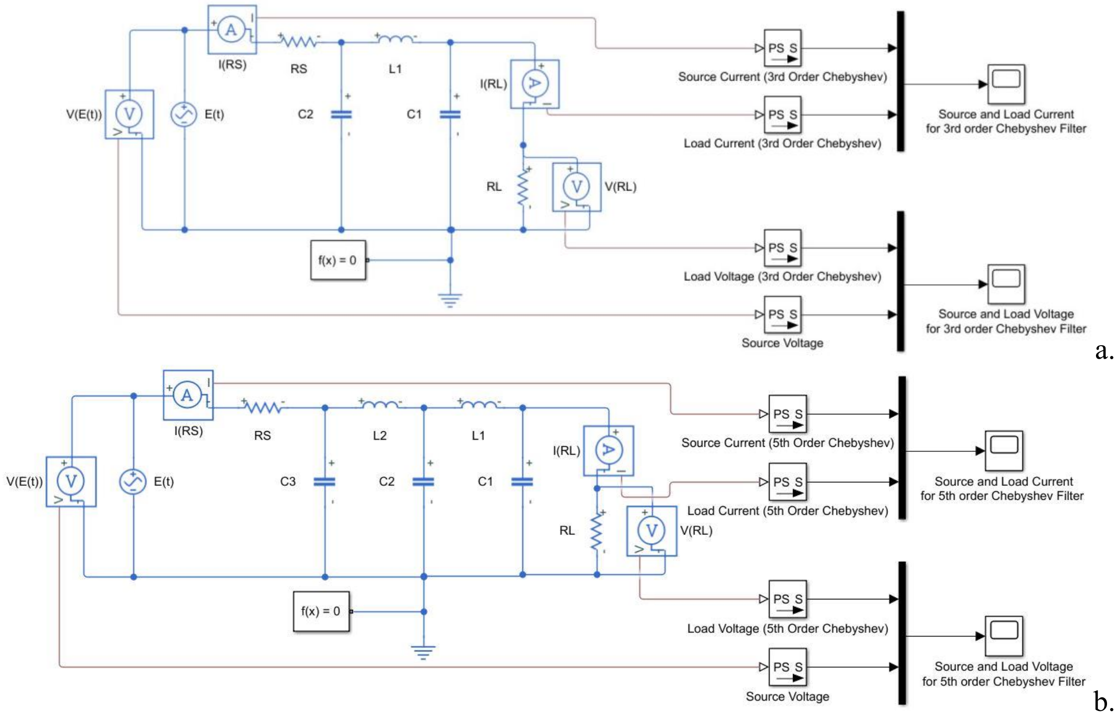

Fig. 2. Matlab diagram of the a. 3rd and b. 5th order Chebyshev filter

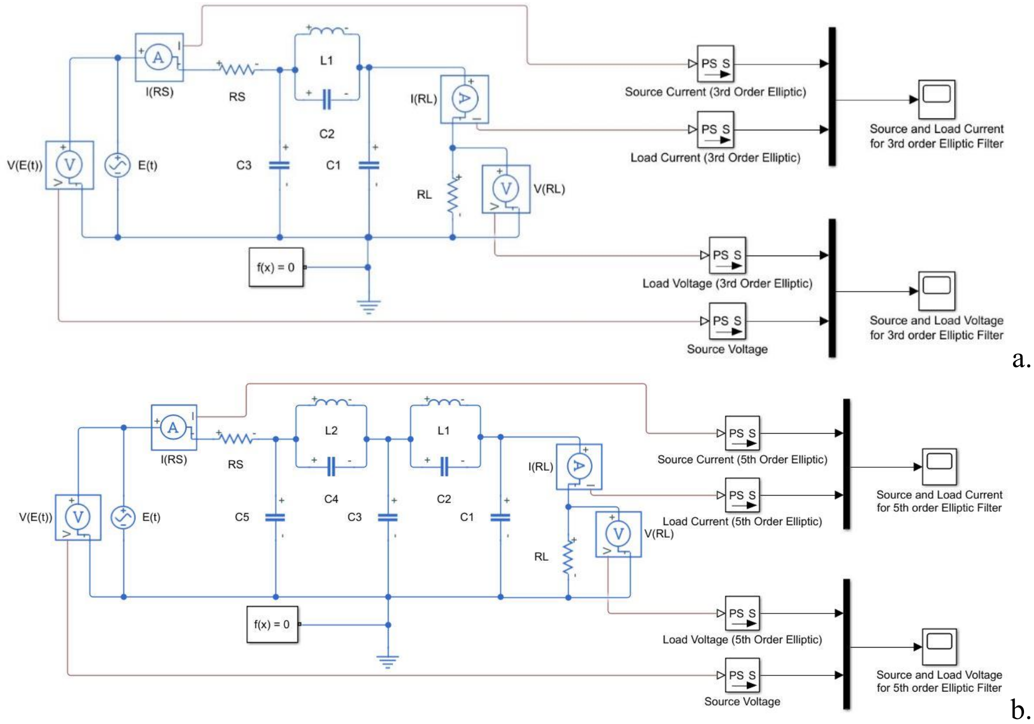

Fig. 3. Matlab diagram of the a. 3rd and b. 5th order Elliptical filter

In order to try to cover the different filter frequencies used in naval applications the simulations were made for three different frequencies (150 Hz, 100 kHz and 50MHz). The effective value for the source e (t) is 100V. The following figures show the variation graphs of the input and output voltage and the attenuation of the output signal.

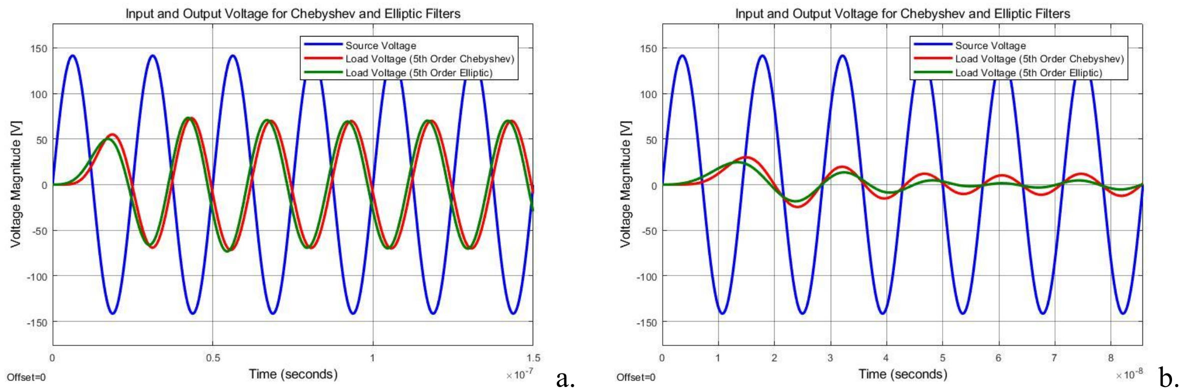

Fig. 4. Source and load voltage for a. 40MHz and b. 70MHz

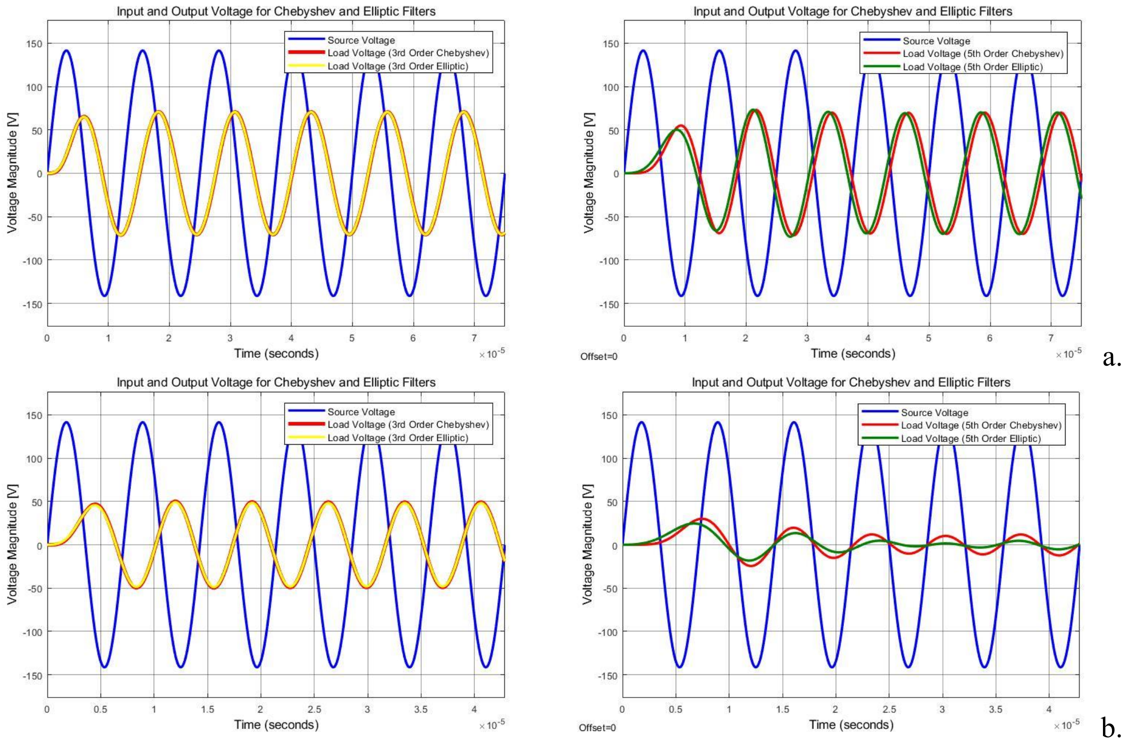

Fig. 5. Source and load voltage for a. 80 kHz and b. 140 kHz

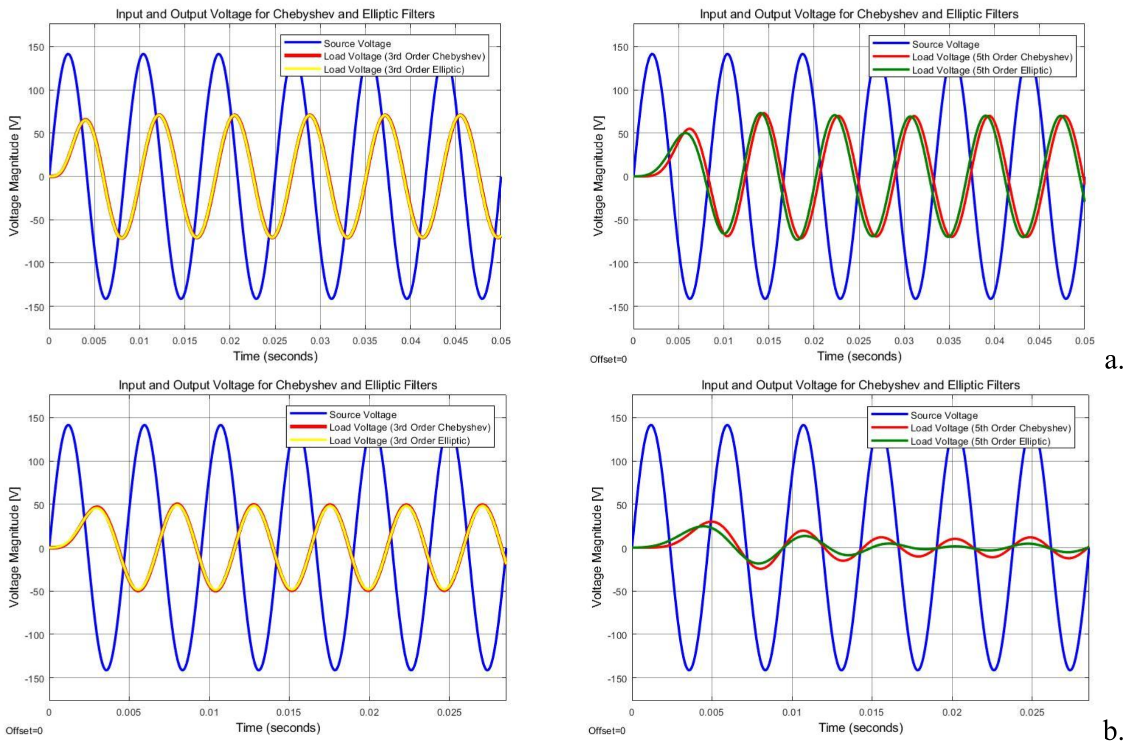

Fig. 6. Source and load voltage for a. 120Hz and b. 210 Hz

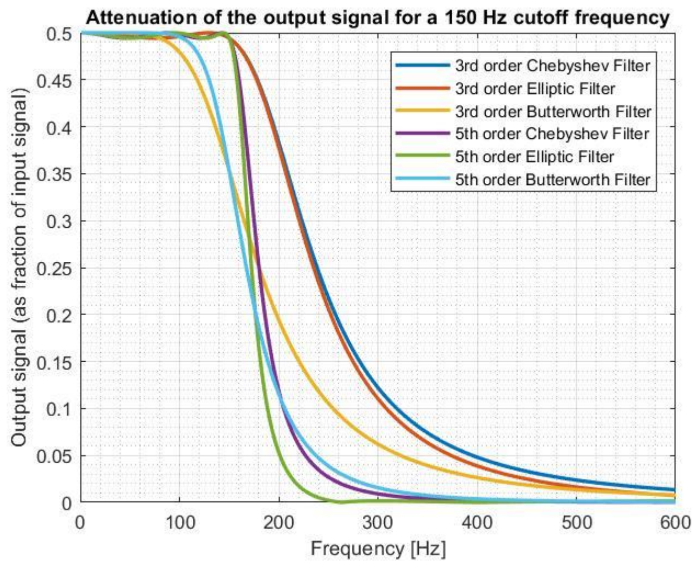

Fig. 7. Source and load voltage for 150Hz

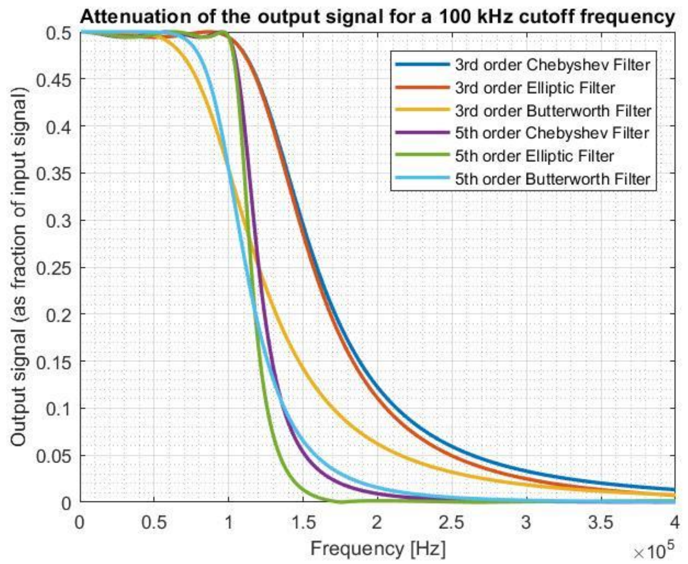

Fig. 8. Source and load voltage for 100kHz

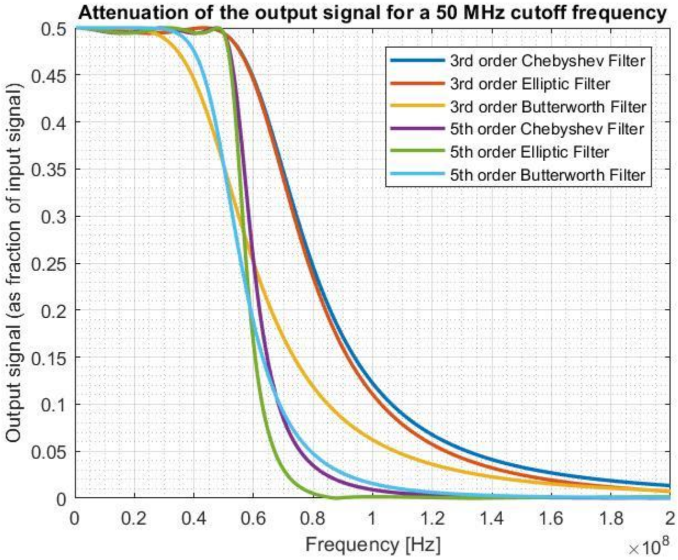

Fig. 9. Source and load voltage for 50MHz

Figures 4, 5, 6 show the differences between the voltage load for a frequency lower and higher than the cutoff frequency. For a frequency greater than the cutoff frequency the differences between the 5th order Chebyshev and Elliptic filter are better evidenced on the charts than those for the 3rd order filters. Also, the charts show that there are no big differences - at first glance the graphs for 3rd order Chebyshev and Elliptic filter seem to be overlapping. Checking the values, we could see that the differences between them are in the range from 0.4% to 3.57% - higher values were obtained for the Chebyshev filter. These differences are due to a small phase shift between signals - we can say that the amplitude reaches about the same value. In addition, these differences depend on the number of decimals of the electrical parameters, as well as on small calculation errors.

One can see that in the previous three figures we also analyzed a Butterworth filter. In theory using a lower-order polynomial Butterworth filter one can obtain the same result. One can see that this affirmation is not true because the Butterworth filter starts to attenuate the signal before the cutoff frequency.

Both Chebyshev and Elliptic filters are used successfully in various applications in the naval electrical systems - the elliptic filters are considerably more complex compared to Chebyshev filters so from the cost point of view the last ones are more desirable.

4. Conclusion

In this paper we presented 2 types of filters, Chebyshev filter and Elliptical filter, that are used successfully in many naval applications. We proved that the 2 filters are similar, and we presented the advantages and disadvantages of each of them. Is important when filter circuits are used for reactive current compensation, to pay attention to the reaction on the mean and peak value of the system voltage in case of frequency fluctuations and to the inadmissible effects on the voltage regulation of generators.

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