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VRATISLAV MICHAL, KAREL HAJEK, JIRI SEDLACEK
UNIVERSITY OF DEFENCY, BRNO UNIVERSITY OF TECHNOLOGY, CZECH REPUBLIC

ACTIVE FILTERS BASED ON GOAL - DIRECTED LOSSY RLC PROTOTYPES

Abstract

The ARC filters based on RLC ladder prototypes exhibit some advantages as low sensitivities. On the other hand there are disadvantages which are coupled with ARC simulation of ideal inductors of LC ladder prototypes what brings higher sensitivities to real parasitic properties of ARC simulation. Usage of new principle of goal – directed losses RLC ladder prototypes enables to design ARC realizations with optimized parameters and minimized influence of real active elements. In paper here are new possibilities of ARC filter optimization in some practical examples presented.

Introduction

By classical filter design there are usually single or double – sided termination RLC filter prototypes used. In many catalogues are these standard LC ladder prototypes which are using ideal loss – les reactive L and C elements wide tabled. Here the terminals resistances are transformed to the internal structure and dumped the LC circuit to realize the required transfer function.

In [2] was described a new method how to optimize resulting active filter structures based on classical ladder prototypes using goal – lossy filter prototype design, where the losses are dispersed to the whole ladder structure. It was shown that the performances of these filters designed with the lossy structures - like sensitivities, components ratio etc, may be better than the synthesis based on the classical loss – les RLC ladder prototypes.

Theoretically can be used goal lossy ladder prototypes with losses dispersed to the all branches of network. In the practice there are most often used structures, where losses are dispersed to all parallel (see Fig.1b) or to all serial branches of filter structure (Fig.1c) what corresponds with resulting parameters of active elements

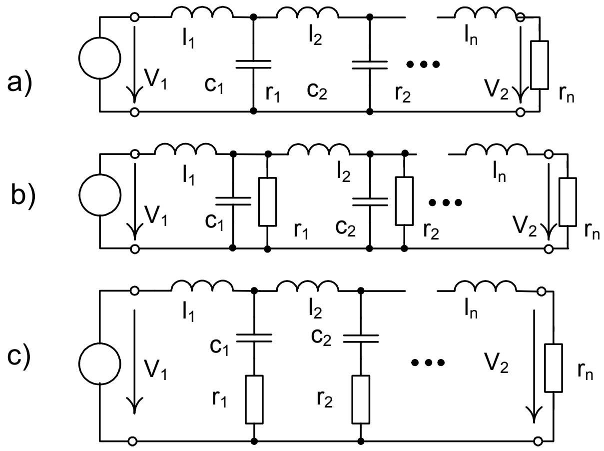

Fig. 1 – RLC ladder filter prototype a) ideal, b) with parallel losses, c) with serial lossy resistors

simulating passive ladder elements (inductors, FDNR) . In [2],[3], the design algorithm of these goal – lossy ladder prototypes with parallel lossy resistors (Fig.1b) was described and special software to goal – lossy filter synthesis was presented, main possible network goal – lossy filter value elements was presented for standard types of approximations in form of tables too. However for many cases the width of approximation types or parameter ranges is not sufficient , requirement of special software is also some disadvantage for many designers. Therefore a new method how to designe the goal – lossy filter structures was developed.

2 A new method of goal – directed lossy filter synthesis

Generally, the algorithm of filter synthesis can be leaden to compute lossy ladder structure:

- with required quality factor of passive elements,
- with required resistor value.

In the above mentioned literature the first process was preferred. In the present time there are at disposal many analysis software products [4],[5] which can be used generally by a process of network optimization. These products can be used also directly to synthesis of goal – directed lossy structures without requirement of the special numerical algorithm implementation or software. The software blocks called usually network optimizers and allow to compute (in many cases by selected numerical method) all values of network elements with aims to reach the prescribed (ideal) transfer network characteristic. A principle and process of a new synthesis method is briefly given as rough draft in Fig 2.

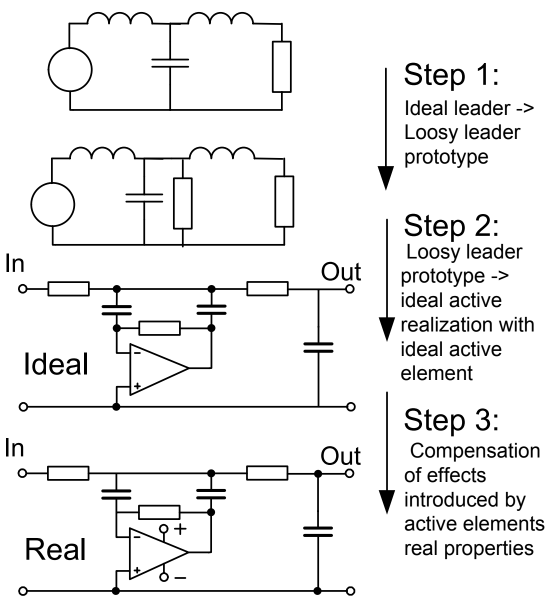

Fig. 2 – Process of active filter design and final filter optimization

The main procedures of filter component computing can be divided to these main steps:

- lossy network analysis – analysis of lossy structure behaviour and investigation of maximum lossy values or determination of limiting lossy parameters.
- Generation of required transfer function table (transfer ratio value versus frequency),
- Final optimization of passive ladder network,
- Final optimization of active network with regard to real active element performance.

3 Synthesis of goal – directed lossy prototypes with parallel resistors

The procedure of filter synthesis can be leaden to compute lossy ladder structure: a) to obtain the required quality factor of passive elements, b) to reach the transfer function with required resistor value. While in the above mentioned literature the first process was chosen, in presented new method the second possibility was selected.

The accuracy of goal lossy ladder prototype transfer response with comparison to transfer response of ideal loss-less ladder can be in a case of 3rd order ladder RLC filter analysis demonstrated. Transfer function of LP filters from Fig.1a) can be written as:

$$H_{(s)} = \frac{1}{a_0 + a_1 s^1 + a_2 s^2 + ... + a_n s^n} \quad , \qquad (1)$$

where a_0-a_n are coefficients of denominator and s the complex frequency jω. The voltage transfer of goal -lossy structure from Fig.1b) is given:

$$H_{(s)} = \frac{1}{a_0 + (a_1 + k_1)s^1 + (a_2 + k_2)s^2 + ... + a_n s^n} , \qquad (2)$$

where $k_{1,2}$ are the parts which are inserted due to losses. By comparison of this two equation, we can observe, that the exact solution of problem (transfer function of goal lossy prototypes with parallel dumped resistors which is equivalent with ideal transfer response) evidently can be (in limited range of parameters) found.

Applying above mentioned method by usage of software TINA optimizer [5] were calculated parameter values of two most often used standard approximation types - Butterworth and Tchebyschev. The values (normalized to frequency ω=1) of parallel goal –lossy ladder prototypes for 5th to 9th filter order were ordered in table 1. The presented values can be directly to filter design of low – pass filters with FDNR active elements (as filter from Fig.5) or high – pass filters with active inductors in case of high – pass filters successfully used.

4 Synthesis of goal – directed lossy prototypes with serial resistors

The synthesis of goal – lossy network with serial resistors (Fig.1b) brings more problems. Transfer function of 3rd order mentioned filter network with serial lossy resistors can be expressed as:

$$H_{(s)} = \frac{r_n + r_1 r_n c_1 s}{r_n + (r_1 r_n c_1 + l_1 + l_2)s + (r_1 l_1 + r_1 l_2 + r_n l_1)c_1 s^2 + l_2 c_1 l_1 s^3} \qquad (3)$$

However by comparison with eq.(1), it is clear, that exact solution (equivalent transfer function by lossy structure) cannot be found. The nominator of transfer function(3) of goal - lossy RLC ladder prototype with serial dumped resistors exhibit inserted zeros of transfer with time constant $r_n c_n$. It means that from frequency $\omega = 1/r_n c_n$ is the slope of transfer function reduced by -20dB . Therefore for this network structures the range of possible filter solutions is limited.

By proper network value parameters can be successfully found solution with allowable difference of transfer function from ideal required transfer response, how declare example of transfer function of Tchebyschev goal – lossy prototype of 5th filter order from Fig.3. From comparison of transfer responses is evidently seen effect influence of parasitic pole for RLC lossy structure with serial resistors with effect of slope degradation in the stop-band. The computed characteristic are agree with ideal up to -80dB what is in practice fully acceptable in more cases.

The active realization of serial lossy structures can be used for one op-amp synthetic elements with serial losses. This realizations can exhibit some advantage in better properties in the stop-band (absence of transfer zeros).

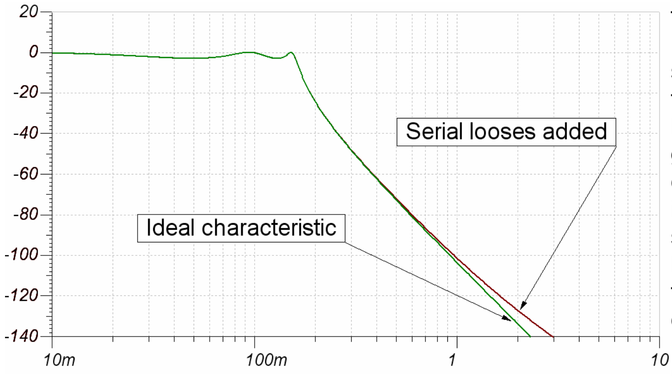

Fig. 3 – The influence of inserted transfer zeros in case of network with serial lossy resistor prototype

	R_p	l_1	c_1	c_2	c_2	l_3	c_3	l_4	c_4	l_5
BUTTERWORTH 5th ord	-	**1.5400**	**1.6900**	**1.3800**	**0.8940**	**0.3089**	-	-	-	-
	6	1.1040	2.1440	1.2400	1.0290	0.3336	-	-	-	-
	4	0.9630	2.3700	1.1590	1.0980	0.3450	-	-	-	-
	2	0.6928	3.0570	0.9805	1.2820	0.3726	-	-	-	-
	1	0.4370	4.4430	0.7501	1.6500	0.4112	-	-	-	-
BUTTERWORTH 7th ord	-	**1.5900**	**1.800**	**1.6600**	**1.4000**	**1.0500**	**0.6550**	**0.2220**	-	-
	6	0.9751	2.5700	1.2700	1.1800	0.9382	0.7628	0.2422	-	-
	4	0.8167	2.9500	1.1400	2.0100	0.8876	0.8132	0.2507	-	-
	2	0.5438	4.1200	0.8605	2.6100	0.7593	0.9585	0.2725	-	-
	1.5	0.4428	4.9000	0.7406	3,0000	0.6905	1.0500	0.2588	-	-
BUTTERWORTH 9th ord	-	**1.5600**	**1.8400**	**1.7800**	**1.6200**	**1.400**	**1.1400**	**0.8410**	**0.5150**	**0.1730**
	6	0.8628	2.9200	1.2000	2.3500	1.0800	1.4800	0.7567	0.6009	0.1869
TSCHEBYSEV 5th ord	-	2.1500	1.3000	2.6200	1.2500	1.7400	-	-	-	-
	6	0.8225	2.0080	2.3880	1.5428	2.6329	-	-	-	-
	4	0.5053	2.8621	2.2035	1.6660	3.0700	-	-	-	-
TSCHEBYSEV 7th ord	-	**2.1800**	**1.3300**	**2.7100**	**1.3600**	**2.6700**	**1.2700**	**1.7600**	-	-
	6	0.3768	3.5100	2.0600	2.0600	2.5300	1.4700	3.0600	-	-
	4	0.2207	5.7500	1.5700	2.3800	2.2200	1.5900	3.8100	-	-
	2	0.0842	14.980	0.7258	3.9600	1.4500	2.2100	5.4800	-	-
TSCHEBYSEV 9th ord	-	**2.2000**	**1.3400**	**2.7400**	**1.3800**	**2.7600**	**1.3700**	**2.6900**	**1.2700**	**1.7700**
	6	0.1887	6.4000	1.6500	2.4900	1.8900	1.9000	2.6800	1.4300	3.7300
	4	0.0928	12.790	1.0600	3.1200	1.4600	2.3500	2.3900	1.6000	4.9300
	2	0.0550	21.540	0.7133	4.0800	1.1700	2.8700	2.0500	1.8200	5.9300

Table 1 - The prototypes of Tschebyschev and Butterworth single terminated RLC ladder filter (Fig. 1b), normalized to ω=1 with terminal resistor r=1Ω

5 The compensation of active elements real properties

Most important advantage of goal - directed lossy frequency filter design is the possibility to realize the active equivalent of the passive RLC ladder network with simple (non – ideal) synthetic function block, like FDNR, GIC or synthetic inductors with minimized numbers of active elements [2]. The AC transfer response of filter designed from the RLC ladder prototype should exactly correspond with the required AC transfer response only if the ideal Op-amp or other active elements are used. The real frequency response of active elements caused shifting of the cut-of frequency and quality factor of filter. This fact is dominant by all active realizations (e.g.

cascade realization etc.), if dominant real parameters of active elements are not taken in to account during the design procedure.

The above described usage of network optimizers can be used also to final correction of the active filter performance with real models of active elements. The process of the optimization must correspond with the principle of the filter synthesis. As the main optimized parameter in the non-cascade realization was found cross-impedance of sub-blocks (with the generator switched off). In the case of cascade filter realization was successfully used as optimized parameters AC voltage transfer function.

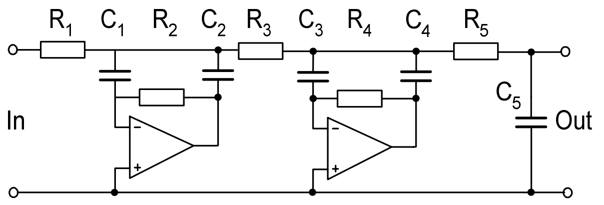

Fig. 4 Low - pass frequency filter of 5 th order with parallel lossy FDNR used for optimization

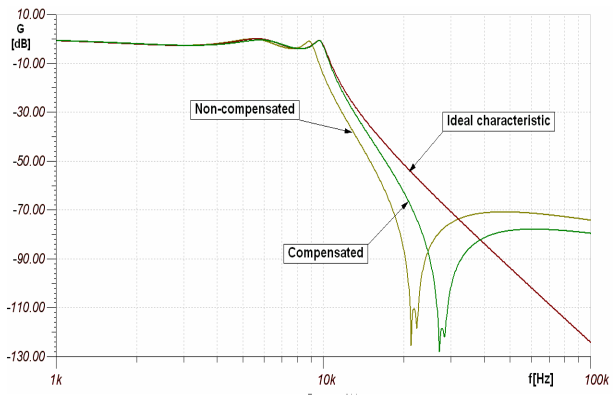

Fig. 5 Transfer responses obtained by optimization method in case of LP filter from Fig.4

As an example of optimization method the 5th order (10 kHz) low-pass RCD structure filter was designed from the passive RLC lossy ladder prototype (Fig.4, Tab.3). Using the Bruton´s transformation [1], the equivalent component values has been computed. In the Fig.5 we can observe the ideal characteristic (with ideal operational amplifier) and the characteristic obtained with real two-pole operational amplifier model LM741. From curves is very good seen the cut-of frequency shift due to the real properties of the operational amplifier. The above presented compensation method (using Tina optimizer) was used to optimize the final network, as best goal function the cross – impedance of each block was found. Each active block was optimized separately, what increased the speed of optimization. The final optimized characteristic is shown in Fig. 5.

During optimization process as most important part was identified procedure to determination of goal ideal AC transfer function (in tabled form) used by optimization procedure. This goal function must be specified in the transfer area, where are not presented the other parasitic effects of active elements. Therefore in the case of presented example of optimization process, the stop frequency of AC transfer function table was the cut-off frequency of filter, it means 10kHz.

Conclusion

In the paper was prescribed a new method which brings further possibility to improve filter design and optimization in area passive as well active filters. Here described method allows wider expansion of the filter synthesis based on goal – directed lossy filter prototypes. The presented method of compensation of active element influences can be widely used for all active elements like VFA,CFA, OTA, CCII etc. The great advantage of method is that enable to optimize resulting active filters by usage of usually accessible software for network analysis without requirement of special numerical programs what brings new possibility for many designers in area of filter design and optimization.

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[4] PSPICE design software (http://www.orcad.com/)

[5] PC Simulator Tina 6 pro (www.**tina**.com)

Pof.Ing. Karel Hajek, MILITARY ACADEMY Brno,
Kounicova 65, 623 00 Brno, Czech Republic
Tel. (+420) 79344 2550 Fax (+420) 79344 2550
E-mail: karelhajek@unob.cz

Doc.Ing.Jiri Sedlacek,CSc.,
Ing.Vratislav Michal
BRNO UNIVERSITY OF TECHNOLOGY,
Kolejni 4, 612 00 Brno, Czech Republic
Tel. (+420) 541149520 Fax (+420) 541149512
E-mail: sedlacj@feec.vutbr.cz
vratislav.michal@gmail.com

	R_1	C_1	R_2	C_2	R_3	C_3	R_4	C_4	R_5	C_5
Ideal	802,0	1,315n	241k	1,315n	4,224k	769p	440k	769p	4,256k	10n
Comp	833,54	490p	400,15k	1,791n	4,49k	458,1p	470,3k	1,109n	4,256k	9n

Tab 3 – ideal and optimized components values for 10kHz low pass filter (fig 4,5)