Low-Sensitivity, Low-Noise, Band-Rejection and All-Pass Active-RC Filters

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Abstract— **In this paper we introduce a new design procedure for low-sensitivity and low-noise filter biquads which have a symmetrical bridged-T passive-RC network. They are also low-power circuits, in that they use only one operational amplifier (opamp). The new design concept is based on the recently introduced "impedance tapering" method which was applied to allpole filters in [1], whereas in this paper it is extended to the design of filters with finite zeros. Thus, it is applied to two commonly used filter sections suitable for the realization of band-rejection and all-pass filters with low and medium pole-Q factors. In the new design procedure, the topology and component count remain the same; we just judiciously select the component values in order to reduce component tolerance sensitivity and improve noise performance. The sensitivity analysis is examined analytically and double-checked using PSpice Monte Carlo runs. In the PSpice noise analysis, a macro-model of the uA741 opamp is used. It is found that the minimum-sensitivity and minimum-noise filters coincide.**

I. Introduction

In this paper we present low-sensitivity and low-noise design procedures for two commonly used 2nd-order active-RC single-opamp filter sections suitable for the realization of band-rejection (BR) and all-pass (AP) transfer functions (TF). Both are described in [2][3] and contain a physically symmetrical passive-RC sub-network (known as "bridged-T"). One is used for the realization of medium pole-Q values ($2<q_p<20$) ([3] pp. 60-61 for AP and pp. 62-64 for BR), while the other is used for low pole-Q values ($q_p<2$) ([3] pp. 48-49 for AP and pp. 50-51 for BR).

The new design method presented in this paper was first introduced in [1]. It is based on the appropriate impedance scaling of the filter components. It reduces the sensitivity to the passive components and improves the noise performance. The recently introduced design concept in [4], in which one half of a symmetrical passive-RC network is impedance scaled (by which the symmetrical passive-RC network becomes "potentially symmetrical"), is also investigated.

II. 2ND–order Band-Rejection and All-Pass Biquads

Consider two very common 2nd- order BR and AP filters: the "medium-Q" biquad in Fig. 1 and the "low-Q" in Fig. 2. A classification of single-amplifier biquads was introduced in [2] and expanded in [5]. There, a 2nd-order active-RC filter as shown in Fig. 1 is called differential input (or type II), dual feedback (DF), class 4 (or "BP in the positive feedback loop"), which is designated by II-DF-4. Note that a ladder-RC network realizes the BP characteristics in the positive feedback loop, while in the signal forward path there is a "bridged-T" network. Recall that the bridged-T has the TF characteristic of the frequency-rejection network (FRN).

According to the classification in [5] the filter circuit in Fig. 2 is the II-SF-3 filter (type II or differential input, SF or single feedback, and class 3 or "FRN in the negative feedback loop"). It has a bridged-T in the negative feedback loop, and a ladder-RC network in the signal forward path. We can see thet some kind of duality exists between filters in Fig 1 and Fig 2. The former combines a BP positive-feedback loop with constant negative feedback, while the latter has only an FRN-negative-feedback loop. A proper complementary transformation [6] applied to the circuit in Fig. 1 would have produced constant positive feedback

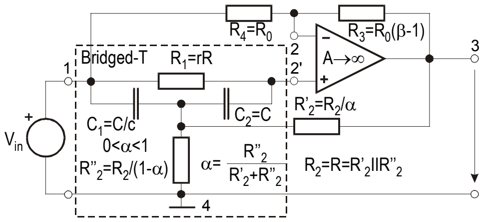

Figure 1. 2nd-order BR and AP "medium-Q" active-RC filter with bridged-T section in the positive feedback and scaling factors *r* and *c*.

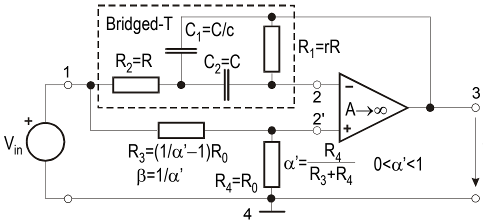

Figure 2. 2nd-order BR and AP "low-Q" active-RC filter with bridged-T section in the negative feedback and scaling factors *r* and *c*.

in the circuit in Fig. 2, too. But because the latter filter is low-Q (and therefore single-feedback) it has no constant positive feedback. In spite of that, the two circuits are very closely related to one another and, in fact, the optimization conditions for the one are identical to those of the other.

The voltage TF of the circuits in Figs.1 and 2 is given by:

$$T(s)=\frac{V_{out}}{V_{in}}=K\frac{s^2+b_1 s+b_0}{s^2+a_1 s+a_0}=K\frac{s^2+(\omega_z/q_z)\cdot s+\omega_z^2}{s^2+(\omega_p/q_p)\cdot s+\omega_p^2}, \qquad (1)$$

where the pass-band gain K, coefficients a_i and b_i (i=0,1), pole and zero frequencies ω_p, ω_z and Q-factors q_p, q_z are given, as functions of components of the circuit, in Table 1. Note that

$$\beta=1+R_3/R_4 \qquad (2)$$

represents the gain factor ($\beta\geq1$), and $\alpha=R_2''/(R_2'+R_2'')$ an attenuation in the positive feedback ($0\leq\alpha\leq1$) in "medium-Q" circuits. In the "low-Q" circuit we have an attenuation α' (given in Table 1). Note that $\alpha'=1/\beta$ [where β is given by (2)]. Note, also, that if we turn an opamp off, then we include zero as the gain β value into expressions for pole and zero Qs, we obtain the passive Q factor, $\hat{q}$, of the bridged-T (given in Table 1—we use the symbol "^" above any passive-network parameter). The zero Q, q_z, of the bridged-T is also given in Table 1.

In what follows we shall demonstrate that impedance scaling upwards of the resistors R_1 and C_1 is a suitable design for the filters in Fig. 1 and 2. Therefore we introduce impedance-scaling factors r and c defined by

$$R_1=rR,\ C_1=C/c,\ R_2=R,\ C_2=C. \qquad (3)$$

A. Sensitivity Analysis of a Medium-Q Band-Rejection Filter

First we present the step-by-step design of the filter circuit in Fig. 1. To realize desired pole and zero frequency ($\omega_z=\omega_p$ in

TABLE I. SECOND-ORDER FILTER COEFFICIENTS, POLE-ZERO FREQUENCY AND Q PARAMETERS IN TERMS OF COMPONENT VALUES.

Filter circuit	K	$a_0=\omega_p^2$	$a_1=\omega_p/q_p$	$\omega_p=\omega_z$	q_p
Medium-Q (Fig. 1)	1	$\frac{1}{R_1R_2C_1C_2}$	$\frac{R_2(C_1+C_2)+R_1C_2(1-\alpha\beta)}{R_1R_2C_1C_2}$	$\frac{1}{\sqrt{R_1R_2C_1C_2}}$	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)+R_1C_2(1-\alpha\beta)}$
Low-Q (Fig. 2)	$\alpha'=\frac{R_4}{R_3+R_4}$	$\frac{1}{R_1R_2C_1C_2}$	$\frac{C_1+C_2}{R_1C_1C_2}$	$\frac{1}{\sqrt{R_1R_2C_1C_2}}$	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)}$
Filter circuit	$\hat{q}=\hat{q}_{\text{Bridged-T}}$	$b_0=\omega_z^2$	$b_1=\omega_z/q_z$	$q_{z\text{Bridged-T}}$	q_z
Medium-Q (Fig. 1)	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)+R_1C_2}$	$\frac{1}{R_1R_2C_1C_2}$	$\frac{R_2(C_1+C_2)+R_1C_2(1-\beta)}{R_1R_2C_1C_2}$	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)}$	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)+R_1C_2(1-\beta)}$
Low-Q (Fig. 2)	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)+R_1C_2}$	$\frac{1}{R_1R_2C_1C_2}$	$\frac{R_2(C_1+C_2)+R_1C_2(1-1/\alpha')}{R_1R_2C_1C_2}$	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)}$	$\frac{\sqrt{R_1R_2C_1C_2}}{R_2(C_1+C_2)+R_1C_2(1-1/\alpha')}$

Table 1) we calculate passive elements in the passive-RC network [i.e. R_i and C_i (i=1,2)]. We choose the capacitor C_2 value, the capacitor ratio c and the resistor ratio r, and then calculate the value of resistor R_2 using

$$R_2=(2\pi f_p C_2)^{-1}\cdot\sqrt{c/r}\ , \tag{4}$$

where $f_p=\omega_p/2\pi$. In the next step, to realize the desired zero-Q factor, q_z we have to calculate the required gain β using

$$\beta=1+(c^{-1}+1)\cdot r^{-1}-q_z^{-1}\cdot 1/\sqrt{rc}\ , \tag{5}$$

and, finally, to realize the desired pole-Q factor, q_p, we calculate the required positive feedback attenuation α from

$$\alpha=1-\beta^{-1}(q_p^{-1}-q_z^{-1})\cdot 1/\sqrt{rc}\ . \tag{6}$$

Note that equations (5) and (6) readily follow from Table 1 and (3). In the design procedure, we distinguish two main cases:

(*i*) to design a BR filter, we choose an infinite zero-Q value, q_z in (5) and (6) and obtain:

$$\beta=1+(c^{-1}+1)\cdot r^{-1}\ ,\ \alpha=1-(\beta\cdot q_p)^{-1}\cdot 1/\sqrt{rc}\ . \tag{7}$$

(*ii*) to design an AP filter, we choose the zero-Q value equal to the negative pole-Q value, i.e. $q_z=-q_p$ in (5) and (6) and obtain:

$$\beta=1+(c^{-1}+1)\cdot r^{-1}+q_p^{-1}\cdot 1/\sqrt{rc}\ ,\ \alpha=1-2\cdot(\beta\cdot q_p)^{-1}\cdot 1/\sqrt{rc}\ . \tag{8}$$

In what follows we investigate the sensitivity of the BR case of the filter in Fig. 1 to the passive component tolerances. The relative sensitivity is defined in [1]. We obtain the relative *coefficient-to-component sensitivities* of coefficient a_0 to all passive components, which are equal to -1. There is nothing that can be done that will affect the component sensitivity of a_0. Only the sensitivities of a_1 are dependent on the realization of the filter circuit, and can be reduced by non-standard circuit design.

TABLE II. SENSITIVITY OF COEFFICIENT a_1 TO COMPONENT VARIATIONS IN A 2ND-ORDER BAND-REJECTION FILTER.

x	$-(1/q_p)\cdot S_x^{a_1}$		
R_1	$\sqrt{\frac{R_2C_1}{R_1C_2}}+\sqrt{\frac{R_2C_2}{R_1C_1}}$	$\frac{1}{\sqrt{rc}}+\sqrt{\frac{c}{r}}$	1
R'_2	$\alpha(1-\beta)\sqrt{\frac{R_1C_2}{R_2C_1}}$	$\alpha(1-\beta)\sqrt{rc}$	$\alpha(1-\beta)\left(\frac{1}{\rho}+1\right)$
R''_2	$(1-\alpha)\sqrt{\frac{R_1C_2}{R_2C_1}}$	$(1-\alpha)\sqrt{rc}$	$(1-\alpha)\left(\frac{1}{\rho}+1\right)$
C_1	$\sqrt{\frac{R_2C_2}{R_1C_1}}+(1-\alpha\beta)\sqrt{\frac{R_1C_2}{R_2C_1}}$	$\sqrt{c/r}+$ $(1-\alpha\beta)\sqrt{rc}$	$1/(1+\rho)+$ $(1-\alpha\beta)(1/\rho+1)$
C_2	$\sqrt{\frac{R_2C_1}{R_1C_2}}$	$\frac{1}{\sqrt{rc}}$	$\frac{\rho}{1+\rho}$

Therefore, they are presented in the first column of Table 2, where x represents each of the passive components.

By "non-standard" design we mean the "impedance tapering" design procedure of low-sensitivity allpole active-RC filters, which was first introduced in [1]. In the filter examples in this paper we perform impedance tapering using (3), and we obtain the sensitivities in the second column of Table 2.

For class-4 circuits, the method of minimizing the sensitivity of the pole Q, q_p, with respect to the positive feedback β, is known. They have the BP TF in the positive feedback loop, with pass-band gain, passive pole Q and frequency denoted by ω_k, $\hat{q}$ and ω_0, respectively. Then the pole Q of the filter has a form given by:

$$q_p=\hat{q}\cdot(1-\beta\cdot\hat{q}\cdot\omega_k/\omega_0)^{-1}\ . \tag{9}$$

The sensitivity of the pole Q, q_p (or a_1), to the gain β readily follows from (9), and it is given by:

$$S_\beta^{q_p}=-S_\beta^{a_1}=q_p/\hat{q}-1\ . \tag{10}$$

According to (10) the sensitivity is reduced as the value of the passive pole Q, $\hat{q}$, increases [e.g. by increasing impedances R_1 and C_1 as in (3)]. Will the decrease in sensitivity in (10) really reduce the sensitivity to the tolerances of the two positive-feedback resistors R_3 and R_4? The gain β sensitivity to the resistors R_3 and R_4 readily follows from (2), and it is given by

$$S_{R_3}^\beta=-S_{R_4}^\beta=1-1/\beta\ . \tag{11}$$

Finally, the relative variation of pole Q, q_p, due to variations in resistors R_3 and R_4, is given by:

$$S_{R_3}^{q_p}=-S_{R_4}^{q_p}=S_\beta^{q_p}\cdot S_{R_3}^\beta=(q_p/\hat{q}-1)\cdot(1-1/\beta)\ . \tag{12}$$

If we express the gain β from (9) and substitute it into (12) we have the following form of the sensitivity:

$$S_{R_3}^{q_p}=-S_{R_4}^{q_p}=q_p\cdot(1/\hat{q}-\omega_k/\omega_0)-1\ . \tag{13}$$

Introducing (3) into (13) we obtain the sensitivity in the form:

$$S_{R_3}^{q_p}=-S_{R_4}^{q_p}=q_p\left(1/\sqrt{rc}+\sqrt{c/r}\right)-1\ . \tag{14}$$

Note that the sensitivity in (13) [or (14)] and all sensitivities in Table 1 are proportional to the pole Q, q_p. This is the characteristic of "medium-Q" filters [2]. This means that one does well to select the filter type yielding the lowest pole Q, for a given specification.

A glance at the sensitivity in (14), and those in the second column of Table 2, shows that some of them are partially proportional[1] to the capacitive scaling factor c, but exclusively inversely proportional to the resistive scaling factor r. Other expressions, which include terms $(rc)^{1/2}$, will be small since they

[1] By "partial proportionality" we mean that c will appear partially in the numerator, partially in the denominator of the sensitivity expressions.

are multiplied by the small quantities $\alpha(1-\beta)$, $(1-\alpha)$ and $(1-\alpha\beta)$ (note that the gain β will generally be between unity and, say, 2.5 and α less than unity). Thus, resistive impedance scaling with equal capacitors (c=1 and r>1) reduces the coefficient sensitivities to all passive filter components. To check the above conclusions regarding sensitivity, we design filters with various resistance (r) and capacitance (c) ratios in the following example.

Example: Let's realize a BR filter having 1kHz center frequency and pass-band range of 200Hz. To obtain this selectivity we need a pole-Q factor of $q_p=\omega_0/B=5$. The magnitude of the TF characteristic is shown in Fig 3.

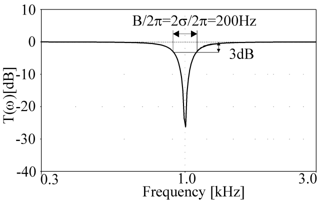

Figure 3. The 2nd-order filter BR TF magnitude (f_0=1kHz, q_p=5).

When we build filters using integrated circuit technology, we must calculate resistors and capacitors in such a way that we do not exceed the upper limit of total capacitance $C_{TOT}=C_1+C_2$. With the total capacitance C_{TOT} given, we choose the capacitor ratio c [according to (3)] and calculate C using

$$C=C_{TOT}\cdot(1+1/c)^{-1}\,. \quad (15)$$

For the example of total capacitance value C_{TOT}=300pF, which is realizable on the chip, we obtain the component values of the filters in Table 3. In addition, in the last two columns of Table 3, pole- and zero-Q factors of the passive bridged-T sub-network are given. Corresponding Monte Carlo (MC) runs with 1% Gaussian distribution, zero-mean resistors and capacitors were carried out using PSpice and presented in Fig. 4.

TABLE III. COMPONENT VALUES OF 2ND-ORDER BR FILTERS WITH VARIOUS SCALING FACTORS (RESISTORS IN [KΩ], CAPACITORS IN [PF]).

No.	r	c	R_1	C_1	R_2	C_2	α	β	$\hat{q}$	q_z
1)	1	1	1061	150	1061	150	0.933	3.0	0.333	0.5
2)	4	4	2652	60	663	240	0.962	1.312	0.190	0.8
3)	1	4	1326	60	1326	240	0.956	2.25	0.222	0.4
4)	4	1	2122	150	530	150	0.933	1.50	0.333	1.0

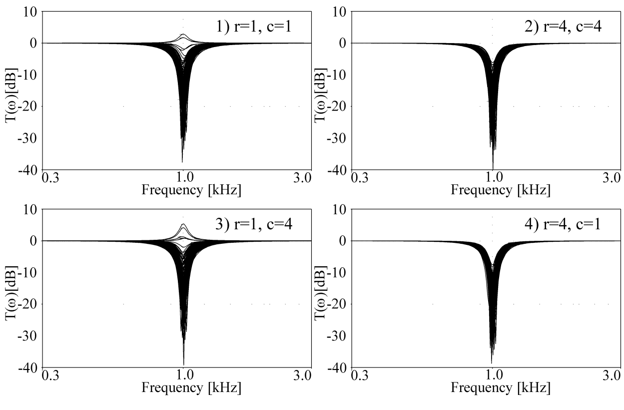

Figure 4. MC runs of imp.-tapered 2nd-order BR filters given in Table 3.

We can see that filter no. 4 with equal capacitors (c=1) and resistor ratio r>1 has minimum sensitivity. In [3] are given design procedures for min.-GSP biquads (the GSP gives a measure of a filter's magnitude sensitivity to the open-loop opamp gain (A) variation). The optimum trade-off in the design of the filter circuit in Fig. 1 is to choose resistor ratio r>1 thus reducing passive sensitivity, and to calculate capacitor ratio c for min. GSP (from [3] p. 63), which provides a circuit with reduced active sensitivity, as well.

Note that for the BR filter case the coefficient b_1 in (1) does not exist. For the AP filter case, b_1 exists, and the sensitivities of the coefficient b_1 to the components are calculated. Those sensitivities have very similar form to the a_1 sensitivities in Table 2, and therefore, will not be presented. Additionally, the sensitivity of the AP filter has been analysed by MC runs, and it can be concluded that the same design strategies applied in the BR filter design can efficiently be extended to the AP filter design.

B. Noise Analysis of a Band-Rejection Filter

We demonstrate that band-rejection active-*RC* filters that are designed for minimum sensitivity to component tolerances are also superior in terms of low output and input thermal noise. Noise effects are calculated with the simulation program PSpice with a macro-model of operational amplifier uA741 and with the circuit elements at their *nominal* values.

Figures-of-merit such as *dynamic range* and *noise factor* will not be calculated; instead the curves that represent the *output* and *input* noise spectral densities will be observed and compared. We recall that with lower output noise level we obtain higher dynamic range, and with lower input noise level we obtain lower noise factor.

To analyze noise contributions we use the same examples, given in Table 3. The corresponding output and input noise spectral densities are shown in Fig. 5.

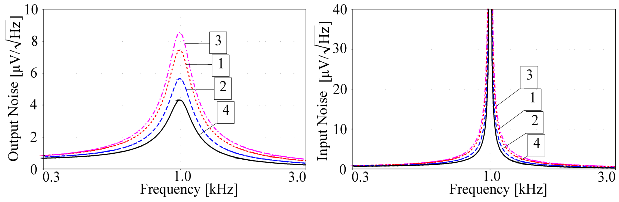

Figure 5. Output and input noise spectral density of impedance-tapered 2nd-order BR filters given in Table 3.

Observing the noise spectral density curves in Fig. 5, we conclude that the filter with the lowest noise is filter no. 4, which has minimum sensitivity as well.

Sensitivity performance are dependent only on the values of the component ratios and the gain β, while noise is dependent on the resistor values in the circuit and the operational amplifier itself. It is luck that the min. sensitivity design procedure of the BR active-RC filter in Fig. 1 provides min. noise performance, as well.

C. Sensitivity Reduction using Potential Symmetry

In the design concept introduced recently in [4], instead of general scaling factors r and c [as in (3)] we apply impedance scaling to the symmetrical passive-RC network; it becomes "potentially symmetrical". Therefore we use scaling factor ρ:

$$R_1=(1+\rho)R;\ C_1=C;\ R_2=\rho/(1+\rho)R;\ C_2=C/\rho. \quad (16)$$

Note that by increasing the impedance-scaling factor ρ of one half of a symmetrical passive RC-network, we increase its pole-Q factor, $\hat{q}$, towards the upper limit of (never accessible) 0.5 (see [2]), while the zero-Q factor, q_z, of the bridged-T is always equal to unity regardless of the ρ value.

With (16) we obtain the sensitivity relations given in the third column of Table 2. Furthermore, introducing (16) into (13) we obtain the sensitivity of the positive feedback gain β to the resistors R_3 and R_4 in the form:

$$S_{R_3}^{q_p}=-S_{R_4}^{q_p}=q_p-1\,. \quad (17)$$

A glance at the sensitivity in (17), and those in the third column of Table 2, shows that increasing the scaling factor ρ reduces the sensitivities to the passive component tolerances very slightly, and to the feedback resistors R_3 and R_4 not at all. In contrast, in the case of "Split-Feedback FRN" in [4], increasing the ρ reduces the sensitivity. From this we conclude that the potential symmetry can effectively be used only in the design of few filter circuits. To double-check the above conclusions we designed the filter in Fig. 1, with two values of ρ. The component values of the resulting filters are in Table 4, MC runs are in Fig. 6, and noise analysis is in Fig. 7.

TABLE IV. COMPONENT VALUES OF 2ND-ORDER BR FILTERS WITH POTENTIALLY SYMMETRICAL BRIDGED-T.

No.	ρ	R_1	C_1	R_2	C_2	α	β	$\hat{q}$	q_z
1)	1	2122	150	530	150	0.933	1.50	0.333	1.0
2)	4	3316	240	530	60	0.911	1.80	0.444	1.0

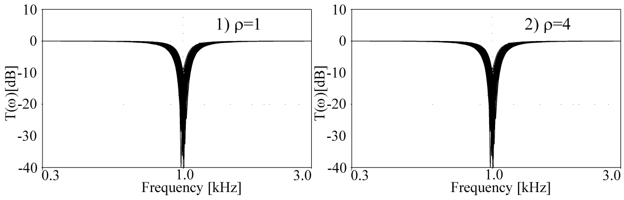

Figure 6. MC runs of imp.-tapered 2nd-order BR filters given in Table 4.

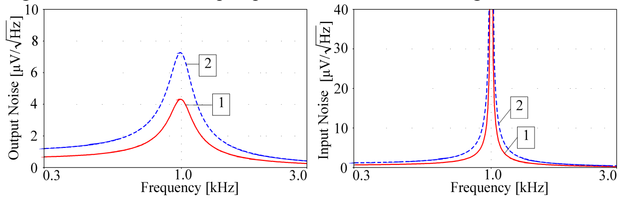

Figure 7. Output and input noise spectral density of impedance-tapered 2nd-order BR filters given in Table 4.

It appears that as ρ increases, the sensitivities in Fig. 6 do not change substantially. Furthermore, filter no. 1 which has ρ=1 and a symmetrical bridged-T network has lower noise and is therefore preferable. Incidentally, it is identical to filter no. 4 with minimum sensitivity in Table 3.

III. LOW-Q 2ND–ORDER BR AND AP BIQUAD

In what follows we design the filter circuit of Fig. 2. In the first step we realize the desired value of pole Q, q_p. We choose a capacitor ratio c, and then calculate a resistor ratio r using

$$r=q_p^2\cdot(2+c^{-1}+c)\,. \qquad (18)$$

Next, to realize the desired pole and zero frequencies ω_p and ω_z, we calculate the passive elements in the bridged-T network using (4) above. Finally, to realize the desired zero-Q factor, q_z (see q_z in Table 1), we have to find the resistors $R_3/R_4=1/\alpha'-1=\beta-1$. In the design procedure, we distinguish between the two main cases:

(*i*) to design a band-rejection (BR) filter, we calculate β from (7) and then $R_3/R_4=\beta-1$.

(***ii***) to design an all-pass (AP) filter, we calculate β from (8) and then $R_3/R_4=\beta-1$.

Example: Let's realize a BR filter having 1kHz center frequency and pass-band range of 500Hz, i.e. the pole Q $q_p=\omega_0/B=2$. The magnitude of the TF characteristic is shown in Fig. 8a. Filter component values with three values of c are presented in Table 5, and corresponding MC runs are in Fig. 8b-d. The output and input noise spectral densities are shown in Fig. 9.

Observing the MC runs in Fig. 8, we conclude that filter no. 2 with equal capacitors (c=1) has slightly (almost negligibly) lower sensitivity than the other two filters, 1 and 3. This very small sensitivity reduction, obtained by varying impedance scaling factors c and r, is characteristic of the "low-Q" circuits (see [7]). In addition, filter no. 2 has minimum component spread (resistor ratio). Recall that the function $f(c)=c+c^{-1}$ reaches its min. value of 2 when the value of c=1. In that case, (18) reaches its minimum and simplifies into $r=4q_p^2$. This is another reason for choosing equal capacitors. Note the characteristic proportionality of the component spread to the squared pole Q, q_p, by "low-Q" circuits [7]. And finally, observing the curves in Fig. 9, we conclude that the filter with the lowest noise is again filter no. 2,

TABLE V. COMPONENT VALUES OF 2ND-ORDER LOW-Q BR FILTERS WITH VARIOUS SCALING FACTORS.

No.	r	c	R_1	C_1	R_2	C_2	α	$\hat{q}$
1)	25	1/4	6631	240	265	60	0.833	0.333
2)	16	1	4244	150	265	150	0.888	0.222
3)	25	4	6631	60	265	240	0.952	0.095

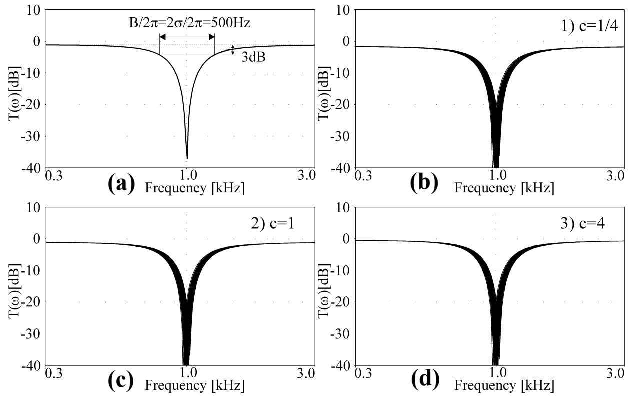

Figure 8. **(a)** 2nd-order BR filter magnitude with f_0=1kHz, q_p=2. **(b)-(d)** MC runs of impedance-tapered filters given in Table 5.

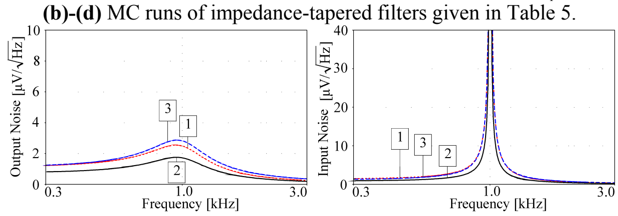

Figure 9. Output and input noise spectral density of impedance-tapered 2nd-order BR filters given in Table 5.

which we obtain by keeping the capacitor values equal. Thus, the design strategy for the 2nd- order low-Q filter shown in Fig. 2 appears to be straightforward.

IV. CONCLUSIONS

Our new design procedure is based on the recently introduced "impedance tapering" method, which was applied to the design of low-sensitivity *allpole filters* in [1]. In this paper it was demonstrated that the method can efficiently be applied to the design of low-sensitivity *filters with finite zeros*. Therefore, we present the design procedure of optimal BR and AP 2nd-order single-opamp commonly-used medium- and low-pole-Q active-RC biquads [3][5]. By appropriate choice of component values, low-sensitivity and low-noise filters are provided. We apply the same design strategies for desensitization in both BR and AP TF characteristics. The results of the analytical analysis and PSpice simulation suggest that the optimum design of both filters regarding sensitivity and noise is to choose equal capacitors $C_1=C_2$ and the resistor ratio $R_1/R_2>1$. Additionally, for the medium-Q filter, GSP product can be minimized (and both passive and active sensitivities reduced) by choosing $R_1/R_2>1$ and calculating C_2/C_1 for min. GSP (see [3]). Finally, from the point of view of the recently introduced design in [4] of *potentially symmetrical* bridged-T, it is suggested that the passive-RC sub-network (i.e. bridged-T) of the filters considered here, be kept *symmetrical* ($C_1=C_2$).

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