BAND–PASS FILTER DESIGN USING CURRENT CONVEYORS

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ABSTRACT

This paper presents procedures leading to the construction of an ARC band-pass filter employing the UCCX device i.e. a universal eight-port current conveyor suitable for analog signal processing. The filter design is based on RLC prototype, and thus the filter is naturally operating in the voltage mode.

1 RLC FILTER DESIGN

Owing to the set of PAL TV standards (FM bands), filter properties were chosen as follows:

- Center frequency f_o = 4,43 MHz,
- Pass-band width B_p = 200 kHz (geometrical configuration),
- Maximum pass-band gain K_0 = –6 dB (due to the RLC prototype),
- Maximum pass-band attenuation A_{max} = 0,3 dB,
- Stop-band width B_s = 350 kHz,
- Minimum stop-band attenuation A_{min} = 56 dB,
- Cauer approximation, 2nd type (with imaginary frequency zero points).

Using tables and graphs [1], [2], passive normalized low-pass RLC prototype and real band-pass RLC filter were proposed. Two complementary passive band-pass filters are available, see Fig. 1. Source and load resistances were set to $R_1 = R_2 = 600\ \Omega$. Observing the first variant, passive element parameters are obtained:

$L_1 = 711{,}4$ nH, $L_3 = 485{,}3$ nH, $L_5 = 802{,}4$ nH, $C_1 = 1{,}814$ nF, $C_3 = 2{,}660$ nF, $C_5 = 1{,}609$ nF, $L_2^+ = 4{,}279$ µH, $L_2^- = 4{,}853$ µH, $L_4^+ = 1{,}595$ µH, $L_4^- = 1{,}731$ µH, $C_2^+ = 266{,}0$ pF, $C_2^- = 301{,}6$ pF, $C_4^+ = 745{,}7$ pF, $C_4^- = 809{,}5$ pF.

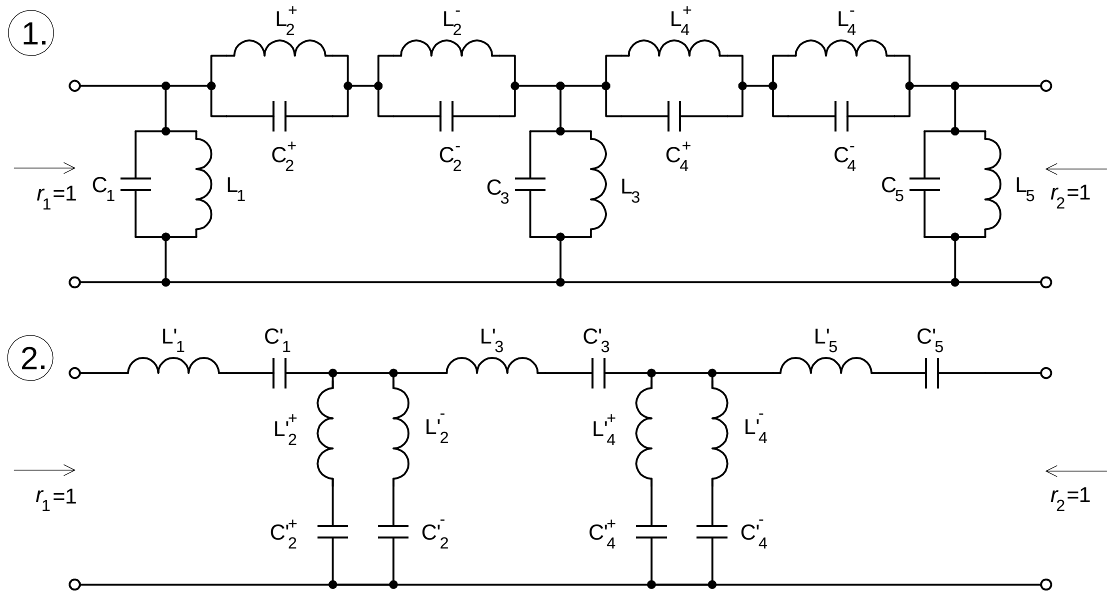

Fig. 1: *Cauer RLC band-pass filters, 5^{th} order*

Fig. 2a shows how the frequency magnitude responses are affected by the change of the coil quality factor. The same holds up for frequency phase responses in Fig. 2b.

a)

b)

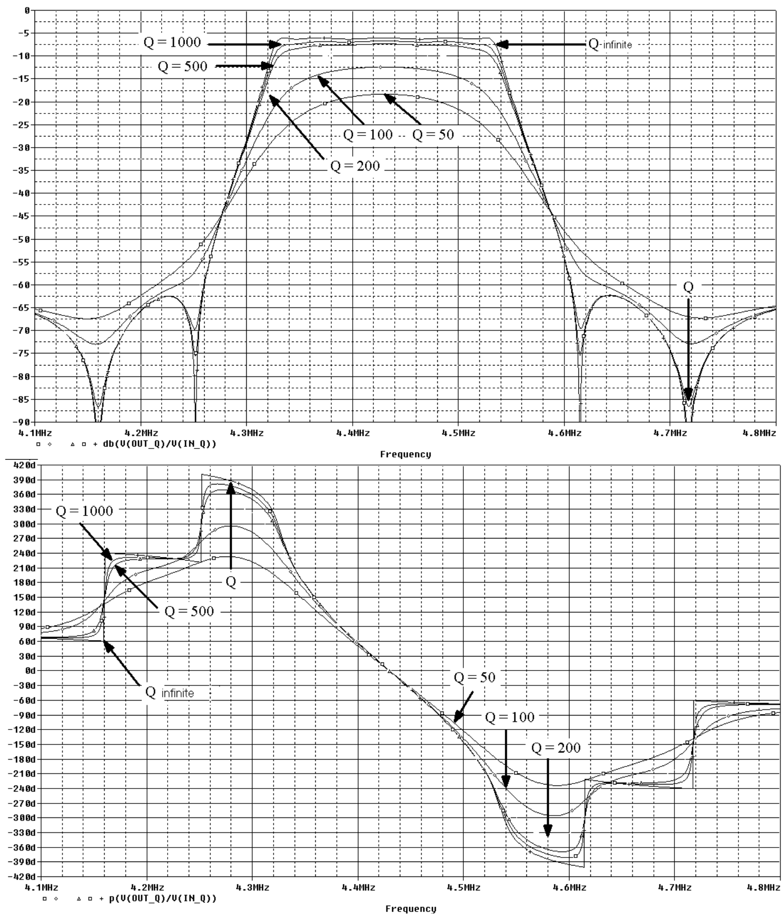

Fig. 2: *Magnitude a) and phase b) frequency responses of the RLC band-pass filter*

2 ARC BAND-PASS FILTER WITH THE UCCX DEVICE

The gyrator as the imittance inverter [3] can be modeled using dual current conveyor denoted as UCCX0349 **Chyba! Nenalezen zdroj odkazů.**4], see fig. 3.

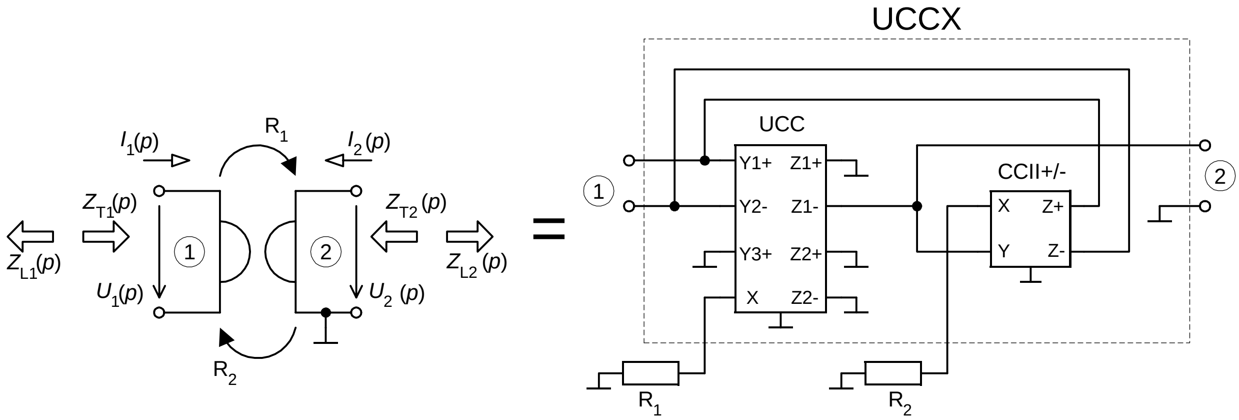

Fig. 3: *Current conveyor UCCX acting as positive gyrator*

Input impedances $\mathbf{Z}_{L1}$, $\mathbf{Z}_{L2}$ are transformed in output impedances

$$Z_{T1}(p)=(Z_{L2}g_{m1}g_{m2})^{-1},\ Z_{T2}(p)=(Z_{L1}g_{m1}g_{m2})^{-1}. \tag{1}$$

Utilizing UCCX double current conveyor, we obtain

$$Z_{T1}(p)=(R_1R_2)/Z_{L2},\ Z_{T2}(p)=(R_1R_2)/Z_{L1}. \tag{2}$$

Using two-port or multiple-port immittance transformations [5] in Fig. 4, the filter topology was modified into the version seen in Fig. 5.

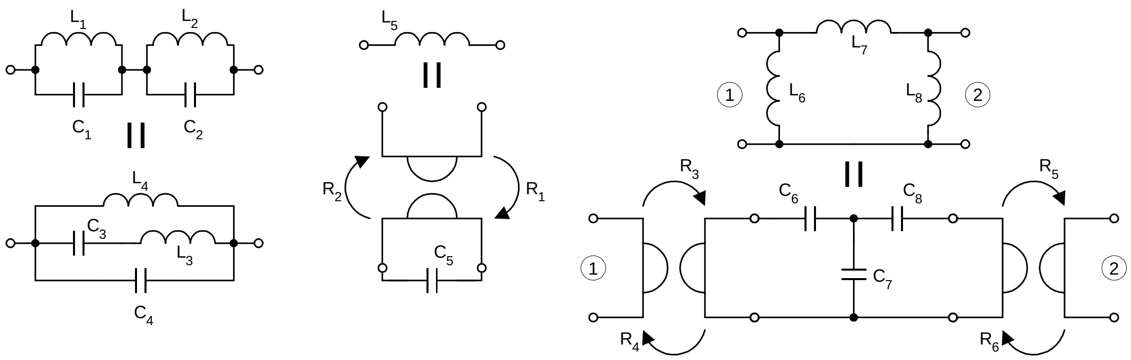

Fig. 4: *Passive and active circuit transformations*

The transformation relations are

$$L_4=L_1+L_2,\ C_4=C_1C_2/(C_1+C_2),\ L_3=C_1C_2L_1L_2/(C_3L_4C_4),\ C_3=(L_4)^{-1}(L_1C_1+L_2C_2-L_3C_3-L_4C_4),$$
$$C_5=L_5/R_1R_2,\ R_G^2=R_3R_4=R_5R_6,\ C_6=L_6/R_G^2,\ C_7=L_7/R_G^2,\ C_8=L_8/R_G^2. \tag{3}$$

Simulating two Π sections of coils it is needed to replace L_3 in fig. 1 with parallel connection of two identical coils L'_3 and L''_3 with double inductance. Thus one of the six UCCX conveyors can be omitted. Final ARC filter topology is presented in fig. 5.

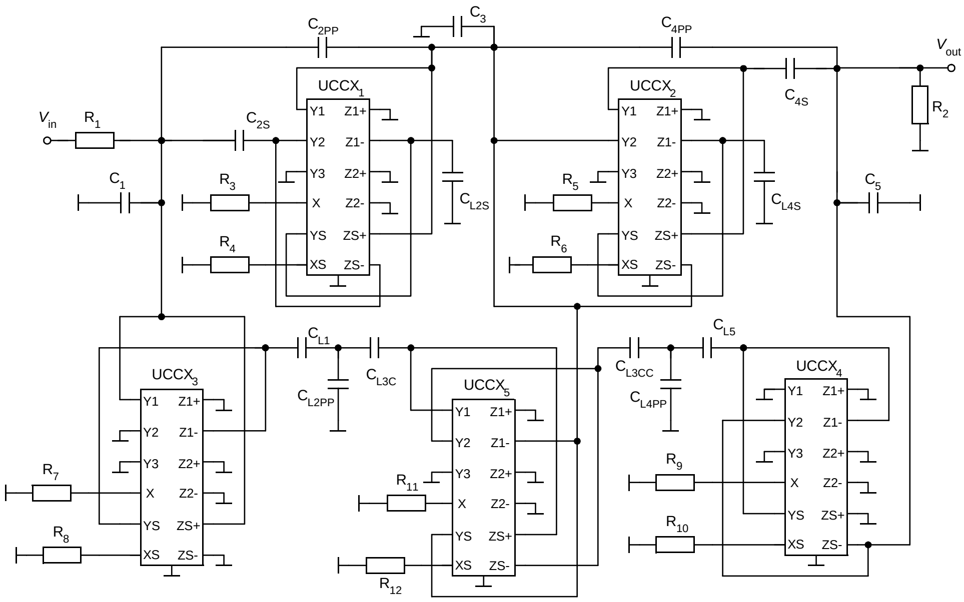

Fig. 5: *ARC Cauer 5th order band-pass filter containing the UCCX devices*

3 NUMERICAL RESULTS

The calculation of passive component parameters was done. Resistances R_3 to R_{12} should be chosen with respect to Y input voltage limits (approx. ±850 mV) and X port current limits (approx. ±1 mA) [4]. Impedance multiplication coefficient k_Z also changes impedance levels at several pins, thus adjusts voltage their levels. The maximum and minimum capacities were optimized, which is illustrated in Fig. 6 and 7.

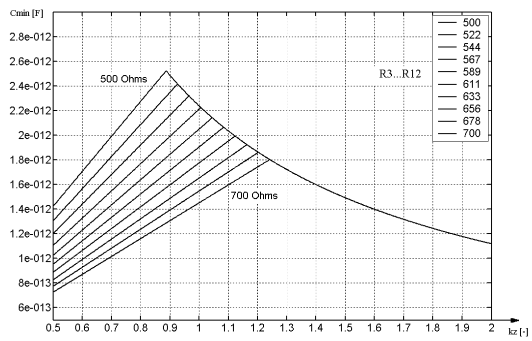

Fig. 6: *Minimum capacity vs. impedance multiplication coefficient*

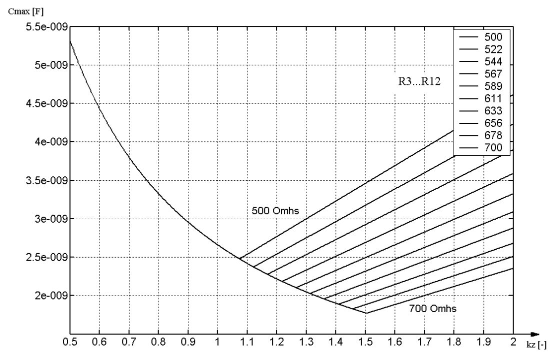

Fig. 7: *Maximum capacity vs. impedance multiplication coefficient*

The absolute minimum value of C_{max}/C_{min} ratio equals 1189. Fig. 6 shows resistances R_3 to R_{12} (chosen to equal 620 Ω) having the tendency to fall right to reach the limit $C_{min} \approx 2$ pF. This contrasts with the need for reducing currents flowing through X ports of UCCX devices. From fig. 7 it is evident that C_{max} is not limiting (up to 2,5 nF). When impedance multiplication coefficient k_z was determined to equal 1,13, then the R_1 and R_2 resistances are 678 Ω.

The list of computed capacities is given below:

$C_1 = 1{,}605$ nF, $C_3 = 2{,}354$ nF, $C_5 = 1{,}424$ nF, $C_{2\mathrm{PP}} = 125{,}1$ pF, $C_{4\mathrm{PP}} = 343{,}5$ pF, $C_{2\mathrm{S}} = 1{,}98$ pF, $C_{4\mathrm{S}} = 2{,}31$ pF, $C_{\mathrm{L}1} = 2{,}09$ pF, $C_{\mathrm{L}3\mathrm{C}} = 2{,}85$ pF, $C_{\mathrm{L}3\mathrm{CC}} = 2{,}85$ pF, $C_{\mathrm{L}2\mathrm{PP}} = 26{,}8$ pF, $C_{\mathrm{L}4\mathrm{PP}} = 9{,}78$ pF, $C_{\mathrm{L}5} = 2{,}36$ pF, $C_{\mathrm{L}2\mathrm{S}} = 1{,}696$ nF, $C_{\mathrm{L}4\mathrm{S}} = 1{,}455$ nF.

Fig. 8 presents 100 runs of Monte-Carlo analysis of filter magnitude response. All passive elements have a common 1 % relative tolerance matching Gaussian distribution.

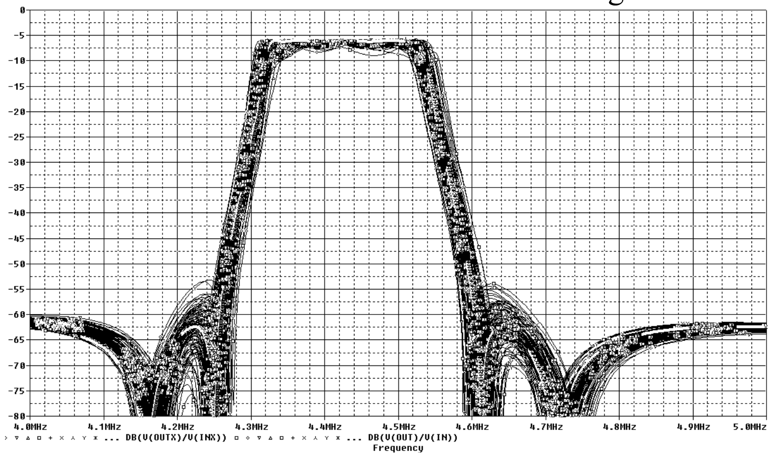

Fig. 8: *Monte-Carlo analysis of band-pass magnitude response*

4 CONCLUSION

The HF ARC band-pass filter design was based on the Cauer RLC prototype in voltage mode. Five Universal current conveyors denoted as UCCX0349 were involved to ensure high frequency transfer and immittance performances and assigned filter properties.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Zverev, A. I.: Handbook of Filter Synthesis, John Wiley & Sons, New York, 1967, ISBN 0-471-98680-1

[2] Saal, R.: Der Entwurf von Filtern mit Hilfe des Kateloges Normierter Tiefpasse, Telefunken GMBH, Backnang, West Germany, 1963

[3] Dostál, T.: Elektrické filtry (in Czech), Textbook FEEC BUT, Brno, 2004

[4] Koudar, I.: Realizace universálního proudového konvejoru, Doctoral thesis (in Czech). BUT Brno, 2002

[5] Hájek, K., Sedláček, J.: Kmitočtové filtry, BEN - technická literatura (in Czech), Praha, 2002, 1. vydání, ISBN 80-7300-023-7