Electronically Tunable First Order All-Pass Filter using Synthetic Inductor

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Abstract An electronically tunable first order all-pass filter structure using a Multiplication Mode Current Conveyor (MMCC) building block is presented. The control voltage (V) of the MMCC tunes the desired phase (θ) while the time constant (τ) can be adjusted by the CFA-based synthetic lossless grounded inductor (L). When the circuit is analyzed taking into account the device non-idealities, low active sensitivity of the design is observed. The effects of port transfer error (ε) have also been studied. The circuit is implemented using readily available AD-844 type Current Feedback Amplifier (CFA) elements. The circuit has been successfully tested for electronic θ-tunability, upto about 250 KHz by PSPICE simulation and with hardware experimentation.
Keywords: MMCC; All pass filter; Synthetic inductor; CFA;

1 INTRODUCTION

All-pass filters are special purpose function circuits which provide variable phase response [1-4] while delivering constant gain in a certain frequency band. Such filters find wide application in communication systems as phase/delay equalizers, phase injector for stability improvement [5], in phase lock loop (PLL) and in voltage controlled oscillator (VCO) design. Provision of electronic tunability of such circuits enhances its functional versatility. In the present work it has been proposed that the Multiplication Mode Current Conveyor (MMCC) building block [6] may be used for this purpose if its control voltage terminal is utilized. MMCC device application for implementation of all-pass filters has been previously reported [7]. The control voltage here may be directly fed ensuring circuit simplicity and suitability for integration. In the present design, a four-quadrant multiplier [8,9] device (ICL-8013 or AD-534) had been coupled at the front end of the MMCC device implementation while its back end is fabricated with AD-844 CFA element [10-12].

The phase selective component is a CFA based synthetic lossless grounded inductor (L); Design of synthetic inductors using the ideal op-amp with infinite gain formulation as well as using op-amp with single pole roll-off model had been reported earlier. Subsequently synthetic inductance simulation circuits using different active elements such as, Current Conveyors (CCs) [13-16], Current Controlled Conveyors (CCCIIs), Current Feedback Operational Amplifiers (CFOAs), Current Differencing Buffered Amplifiers (CDBAs), Current Differencing Transconductance Amplifiers (CDTAs), and Operational Transconductance Amplifier (OTA) have been reported in the literature. In the present circuit the synthetic inductor has been is connected to the current source

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x-terminal of the MMCC yielding a first order all-pass filter.

With an ideal device, the port transfers are unity ($\varepsilon = 0$) and the parasitic capacitances at the current source nodes are extremely low ($C_{p,\ z} \approx 0$); this leads to a lossless grounded-L. However at relatively high frequencies these parasitics become dominant and the usable range of frequency may be limited for the circuit.

2 CIRCUIT ANALYSIS AND DESIGN

The implementation scheme is indicated in Figure 1 The MMCC block is realized with ICL-8013 (and also AD-534 as a variant) and AD-844 CFA as indicated in Figure 2.

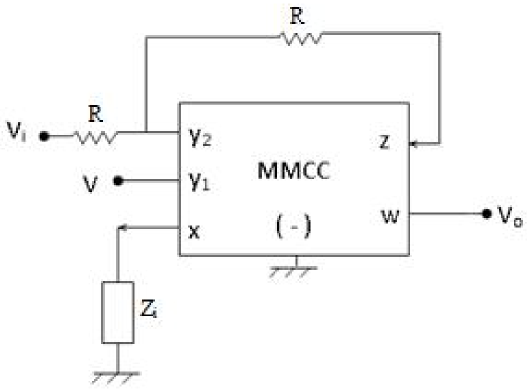

Fig. 1. Implementation of the first order all pass filter.

The nodal relations of the MMCC are $V_x=V_{y1}V_{y2}$, $i_z=i_x$ and $I_{y1,2}=0$. The control voltage (V) is applied at y_1 terminal and input signal V_i is applied at y_2 terminal. k (=0.1/volt) is the multiplication constant.

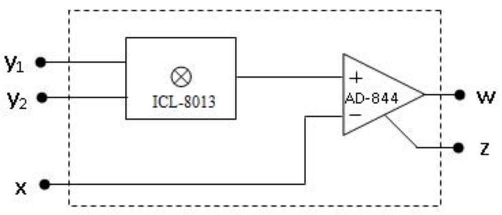

Fig. 2. Realization of MMCC block using AD 844 (CFA) and multiplier ICL 8013.

The CFA (implemented using AD 844) nodal equations can be described by following matrix:

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} . \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix} \text{ and } V_O = V_Z \qquad (1)$$

The port relations taking the non idealities into account are:

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta & 0 & 0 \\ 0 & \pm\alpha & 0 \end{bmatrix} . \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix} \text{ and } V_O = \delta V_Z \qquad (2)$$

The port transfer ratio in terms of error coefficients is

$$\alpha = 1 - \varepsilon_i, \beta = 1 - \varepsilon_v, \delta = 1 - \varepsilon_z \ .$$

According to available literature report [17, 18] these tracking errors are extremely small $0.01 \le \varepsilon_{i,v,z} \le 0.004$.

Hence in Figure 2 one gets $i_z=i_x$,$V_x=kVV_{y2}$ and $V_w=V_z$ which is an additional voltage source output node, not usually depicted in conventional current conveyor; with ± V one gets a ±MMCC block.The first order all pass filter realization has been depicted in Figure 1 wherein the grounded impedance Z_i is being implemented by the input impedance Z_i of Figure 3.The analysis is first carried out assuming ideal MMCC and CFA building blocks, i.e. parasitics are negligible and port errors are insignificant. The first order AP function (H) is

$$H = \{ s\tau - 1 \} / \{ s\tau + 1 \} \qquad (3)$$

where $\tau = L/kRV$ The input impedance of the circuit given in Figure 3. is:

$$Z_i = sCR_1R_2 \quad , L= CR_1R_2 \qquad (4)$$

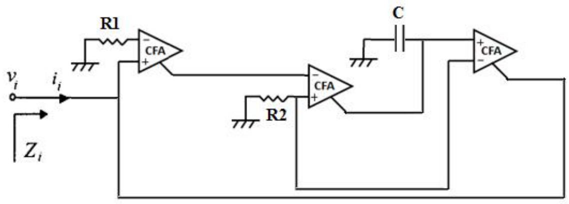

Fig. 3. Inductance Simulation Topology.

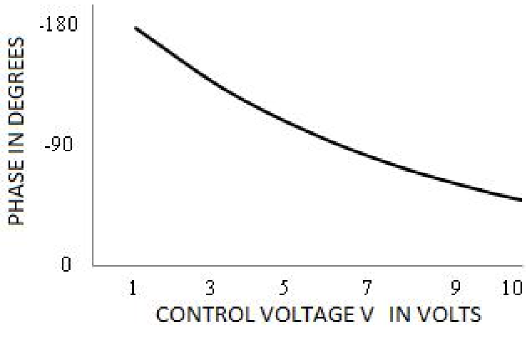

Fig. 4. Phase variation at 200kHz with L=0.4mH, R1=R2=R=1kΩ , C= 0.4nF: ϴ-variation with Contral Voltage.

The select frequency is $\omega_0=1/\tau$ and the phase is $\theta = -2\ arctan\left(\omega/\omega_O\right)$. Thus the select frequency and the phase response are electronically tunable by the control voltage (V) in a range $0 \le \theta \le \pi$.

3 EXPERIMENTAL RESULT

The MMCC based all-pass filter has been designed as in Figure 1 The aspect of electronic tuning of the variable phase (θ) is achieved by simple adjustment of control voltage (1V.d.c.≤ V≤10V.d.c) of the MMCC block. This tuning procedure had much convenient than that used in some previous work [19, 20] where additional current control circuitry would be needed for g_m- variation. The phase selective element is the synthetic lossless-L. The MMCC device implementation in hardware had been obtained using the AD-844 CFA chip along with a multiplier ICL-8013 (or AD-534) chip.

The phase response was measured using both PSPICE simulation and by hardware test; the parasitic capacitor values are measured to be $C_p \approx$ 4.5 pF and $C_z \approx$ 6 pF at $V_{cc} = \pm$ 15V.d.c. Satisfactory θ-tuning is obtained upto about 250KHz by varying V while transmission gain was observed at unity in this band. The test results are shown in Figure 4. and Figure 5. The nominal components are chosen such that R<< $r_{p,z}$ and C >> $C_{p,z}$ so as to minimize the effects of the parasitic.

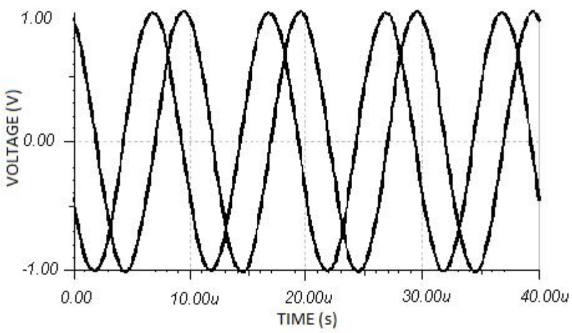

Fig. 5. Quadrature wave response of the All-pass filter at 100kHz.

4 CONCLUSION

The proposed all pass filter can be controlled through external DC voltage V. The building blocks are implemented with readily available multiplier and CFA IC-chips. Compared to other such schemes [19, 20], here no additional current control circuitry is needed since electronic tuning is achieved by simply applying V to the MMCC control-node. This is an advantage in view of less hardware complexity and avoiding additional quiescent power dissipation leading to easy integrability. The effects of device non idealities have been thoroughly analyzed. It is seen that port errors (ε) cause insignificant deviations on phase. However, the parasitics introduce some deviations on θ–characteristics and reveal certain limits on the maximum usable frequency. The synthetic inductor used does not require any passive component matching to obtain desires value of inductance. The circuit has been verified by hardware circuit fabrication and also with PSPICE simulation. Expected range of tunability of phase variation is obtained in a frequency band of upto 250 KHz.

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