ANALYSIS OF DEBOO INTEGRATOR USING CFA

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ABSTRACT

This paper deals with analysis of parameters of non-inverting "Deboo" integrator using current feedback amplifier (CFA). Basic structure and active compensated structure are mentioned and compared.

1 INTRODUCTION

Integrators are basic building blocks for synthesis of universal multiple-feedback frequency filters. Current feedback amplifier (CFA) has better performance then classical voltage feedback amplifiers (VFA) in the frequency domain. CFA has a greater frequency bandwidth, which isn't dependent on set gain. Application of CFA is limited by some factors, which are resulting from its circuit construction. Especially, it is not possible to place a capacitor directly between its output and inverting input. Deboo [1] is one of useful structures of integrator, which satisfy this rule.

The simple integrators using only one operational amplifier have problems with restriction on low frequencies. This main error is caused by its finite value of gain and other non-ideal parameters of used CFA. It is possible to eliminate it by active compensation, which exploits the matching of dual op-amp. The limitation of one device is compensated by the very same limitation of other.

2 ANALYSIS OF BASIC STRUCTURE

The program SNAP has been used for symbolical analysis of the circuit (Fig. 1). If the ideal amplifier is mentioned, value of transipedance Z_T is infinite, input impedance R_Y is infinite, input impedance R_X is zero and output impedance R_O is zero. Then the transfer function has a common form

$$K(p) = \frac{R_2\left(R_F + R_G\right)}{-R_1 R_F + R_2 R_G + pCR_1 R_2 R_G}. \quad (1)$$

It is acceptable to use simplification $R_F = R_G = R_{FG}$, $R_1 = R_2 = R$ and $C_1 = 2C$.

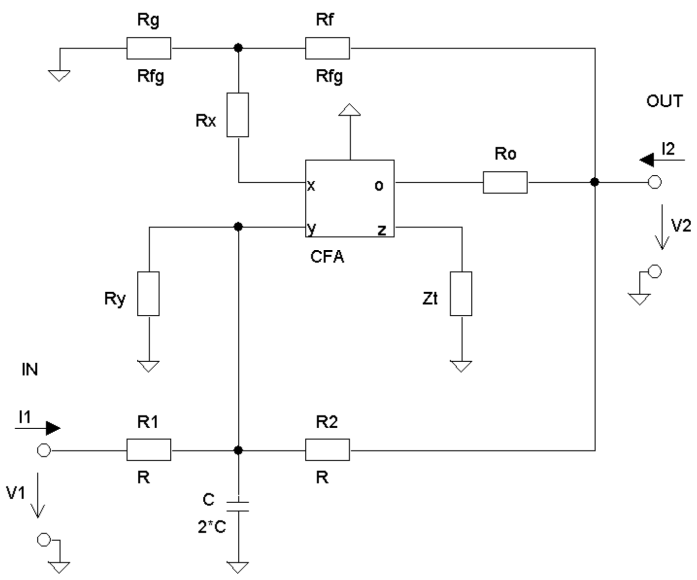

Fig. 1: *Non-inverting integrator Deboo using CFA*

Modified form directly matches the simple transfer function of ideal non-inverting integrator. The pole lies in the origin of complex plane ($p_0 = 0$) and ω_0 (or f_0) is frequency of unity-gain.

$$K = \frac{1}{pCR} = \frac{1}{j\omega CR} \approx \frac{1}{j\frac{\omega}{\omega_0}} \Rightarrow \omega_0 = \frac{1}{CR} \quad , \quad f_0 = \frac{1}{2\pi CR} . \qquad (2)$$

If the finite value of CFA's transimpedance Z_T is mentioned, there is a big difference between new and ideal equation. The transfer function is

$$K(p) = \frac{\frac{1}{CR} \cdot \frac{Z_T}{Z_T + R_{FG}}}{p + \frac{1}{CR} \cdot \frac{R_{FG}}{Z_T + R_{FG}}} . \qquad (3)$$

The equation has changed from ideal (2), now $p_0 \neq 0$. The pole p_0 is moved from origin to the left side of complex plane. Common expression could be

$$K = \frac{\omega_0}{p + p_0} \qquad (4)$$

Comparison of equations (3) with standard (4) gives separate parameters:

$$\omega_0 = \frac{1}{CR} \cdot \frac{Z_T}{Z_T + R_{FG}} \quad , \quad Z_T >> R_{FG} \quad \Rightarrow \quad \omega_0 \approx \frac{1}{CR} , \qquad (5)$$

$$p_0 = \frac{1}{CR} \cdot \frac{R_{FG}}{Z_T + R_{FG}} \approx \omega_0 \frac{R_{FG}}{Z_T + R_{FG}} = \omega_0 \Delta . \qquad (6)$$

When the error term in equation (6) goes to zero ($\Delta \to 0$), then the limitation on low frequencies is small and the integrator is approximately ideal.

Because the capacitor is placed between the non-inverting input Y of CFA and the ground, it is necessary to study the effect of finite CFA's input impedance. It could be represented by resistor R_Y (fig. 1). Transfer function for finite Z_T and finite R_Y is

$$K(p) = \frac{\dfrac{1}{CR} \cdot \dfrac{Z_T}{Z_T + R_{FG}}}{p + \dfrac{1}{CR} \cdot \dfrac{Z_T R + 2R_{FG} R_Y + R_{FG} R}{2R_Y \left(Z_T + R_{FG}\right)}} . \qquad (7)$$

The unity-gain frequency is like (2) and the pole is approximately

$$p_0 \approx \omega_0 \left(\frac{R_{FG}}{Z_Y} + \frac{R}{2R_Y} \right) = \omega_0 \Delta . \qquad (8)$$

The bad effects of finite Z_T and finite R_Y are added. It is necessary to chose small value R (value of resistors R_1 and R2) and use CFA with high input resistance to minimize the error term Δ.

Next basic parasitic parameters, non-zero resistance R_X of inverting input and non-zero output resistance R_O, have not sizable effect.

3 ANALYSIS OF ACTIVE COMPENSATED STRUCTURE

The active compensation improves the features of integrator on low frequencies. The limitation of amplifier is then particularly suppressed.

The transfer function of active compensated Deboo integrator (fig. 2) using CFAs with finite transipedance is

$$K = \frac{\dfrac{1}{CR} \cdot \dfrac{Z_T^2 + Z_T R_{FG}}{Z_T^2 + Z_T R_{FG} + R_{FG}^2}}{p + \dfrac{1}{CR} \cdot \dfrac{R_{FG}^2}{Z_T^2 + Z_T R_{FG} + R_{FG}^2}} . \qquad (9)$$

The comparison of this equation with (4) appears that the unity-gain frequency is approximately equal to term (2). The pole is drifted to

$$p_{0C} = \omega_0 \frac{R_{FG}^2}{Z_T^2 + Z_T R_{FG} + R_{FG}^2} = \omega_0 \Delta_C . \qquad (10)$$

The error term of compensated structure Δ_C is much smaller then without compensation Δ (6). It matches to second power

$$\Delta = \frac{R_{FG}}{Z_T + R_{FG}} \quad \Rightarrow \quad \Delta_C \approx \Delta^2 . \qquad (11)$$

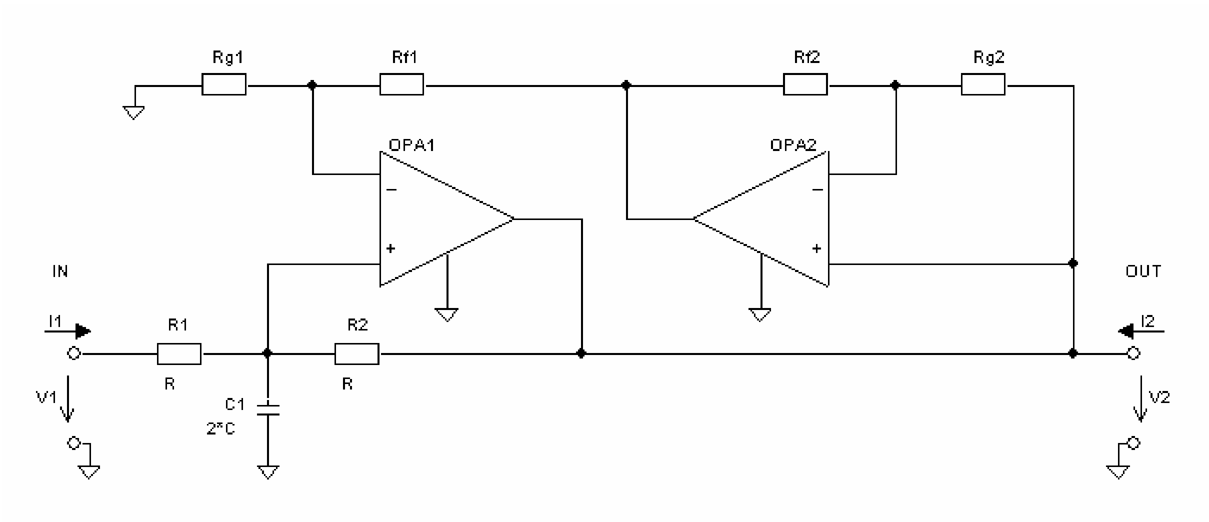

Fig. 2: *Active compensated non-inverting integrator Deboo*

When the finite input resistance of both CFAs is simultaneously mentioned, the transfer function is

$$K = \frac{\dfrac{1}{CR} \cdot \dfrac{Z_T^2 R_Y + Z_T R_{FG}}{Z_T^2 R_Y + Z_T R_{FG} R_Y + R_{FG}^2 R_Y}}{p + \dfrac{1}{CR} \cdot \dfrac{Z_T^2 R + Z_T R_{FG} R + R_{FG}^2 R + 2 R_{FG} R_Y}{Z_T^2 R_Y + Z_T R_{FG} R_Y + R_{FG}^2 R_Y}} . \qquad (12)$$

The unity-gain frequency stills same as (2). Frequency of pole is approximately

$$p_{0C} \approx \omega_0 \frac{R}{2R_Y} = \omega_0 \Delta_C . \qquad (13)$$

The error term would be composed of two parts in full expression like (8). But the error cased by finite transimpedance of CFAs (10) is much smaller then the error caused by finite input resistance. Finite non-ideal value of R_Y has the major effect there.

4 THE COMPARISON OF BASIC AND COMPENSATED STRUCTURE

The final terms for drifted pole of both structures are (8) and (13). The input resistance of CFA has major effect there. Basic structure has more one term including ratio of feedback resistor's and transimedance's value.

The difference has been compared by simulation in PSpice using extended models of CFAs. Basic real parameter has been mentioned, namely transimpedance Z_T (its DC value Z_0), frequency of its dominant pole f_{pZ} and input resistance R_Y. Resistance of inverting input R_X and output resistance have minor effect on frequency characteristics of tested integrators.

Concrete, the typical values has been used [2] – $Z_0 = 500$ kΩ, $f_{pZ} = 500$ kHz and $R_Y = 500$ kΩ. The integrator has been designed for unity-gain frequency $f_0 = 1$ MHz. It has been chosen C = 500 pF, then it is R = 318,3 Ω. CFA's feedback resistors are $R_{FG} = 500$ Ω.

Fig. 3 shows the resultant frequency module and phase characteristics. The pole of basic integrator is about $p_0 = 1{,}5$ kHz. It is the same like result of equation (8). The pole of compensated integrator is about $p_{0C} = 330$ Hz. The result of (13) confirms it. The deformation of curve on higher frequencies is caused by finite bandwidth of used CFAs.

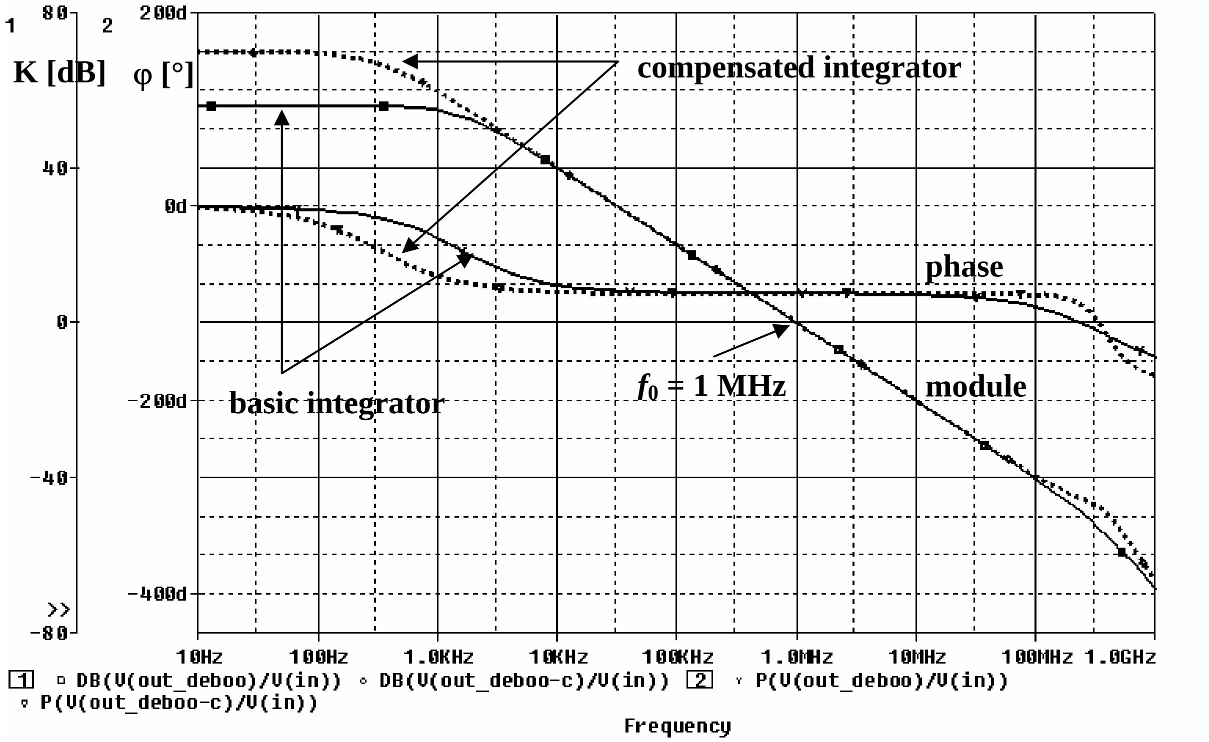

Fig. 3: *Frequency characteristics of basic and compensated Deboo integrator*

5 CONCLUSION

The compensated Deboo integrator has better much better parameters then basic structure. The frequency of pole is mainly affected by value of its input resistance.

ACKNOWLEDGEMENT

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