A High Efficiency Variable Gain Amplifier Circuit with Controllable
Transconductance Amp

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A novel power reduction technique for a variable gain amplifier (VGA) with a two-stage operational amplifier is proposed. The technique improves the power consumption of a VGA by optimizing the bandwidth and the phase margin dynamically on all gain range of the VGA through controlling the input transconductance of opamp. A VGA utilizing the proposed technique shows 40% reduction of power consumption against a conventional VGA at the best condition of VGA gain range.

Keywords: CMOS, Variable Gain Amplifier (VGA), Switched-Capacitor, low-power

1. Introduction

Variable gain amplifiers (VGAs) are used in CCD imaging system, telecommunication systems and others for adaptive control of signal amplitudes. In an analog front end of CCD imaging system, switched-capacitor techniques are used to implement digitally programmable gain in general (1). A switched-capacitor VGA has a high-gain amplifier with a capacitor network feedback. The VGA gain can be controlled by changing the feedback factor of the capacitor network. The change of the feedback factor results in changes of the bandwidth and the phase margin with a conventional opamp (2). Therefore, a VGA circuit has to be designed to cover required bandwidth and phase margin even at the worst case in changes of those two parameters. Such design results in excessive performances and power at all conditions except for the worst case. A technique to stabilize bandwidth constant through switching compensation capacitor in the opamp (3) is reported. However the phase margin is not constant with the reported method. Thus, still there is room for optimization.

This paper proposes a new power optimization technique for a VGA. The technique utilizes an opamp with controllable input transconductance to make the bandwidth and the phase margin constant on all gain range. A constant bandwidth and a constant phase margin get rid of excessive performances and lead to efficient power consumption.

2. Circuit Description

The block diagram of the proposed VGA is presented in Fig.1. The VGA consists of two-stage opamp with negative feedback. The feedback factor (\( \beta \)) is controlled to define the VGA gain. Assuming that the dominant pole frequency of two-stage opamp is much lower than

\[ \omega_1 = \beta \frac{g_{m1}}{C_c} \]

\[ \omega_2 = \frac{g_{m2}}{C_P + C_L + C_P C_L} \]

\[ \phi_{PM} = \cos^{-1} \left( 1 + \frac{\omega_2^2}{\omega_1^2} \right)^{\frac{1}{2}} \]

the frequency of second pole and the transconductance of second stage is large, the bandwidth (\( \omega_1 \)), the second pole(\( \omega_2 \)) and the phase margin(\( \phi_{PM} \)) of VGA are approximately given by

where \( g_{m1} \) and \( g_{m2} \) are the transconductance of the first stage and the second stage, \( C_P \) and \( C_L \) are the parasitic capacitor and the load capacitor, respectively. Designing \( g_{m1} \) controllable and controlling it to be inversely proportional to \( \beta \) make \( \omega_1 \) constant on all gain range(1). \( \omega_2 \) is obviously unchanged by any control of \( \beta \). A circuit schematic to achieve controllable \( g_{m1} \) is shown in Fig.2. The first stage is constructed of the switchable opamp, connected in parallel. The switchable opamp operates while each \( \text{ctl} \) is high. The variable \( g_{m1} \) is achieved by controlling those switches.

A comparison of VGA key parameters between the proposed technique and the conventional method using a switched compensation capacitor is shown in Tab.1. In order to change the gain of VGA from 0 to 18dB, the value of \( \beta \) is controlled from 1 to 1/8. In this table, \( g_{m_{\text{conv}}} \) and \( C_{\text{conv}} \) are the input transconductance and

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the size of compensation capacitor respectively, to satisfy a system requirement with the conventional VGA at $\beta = 1/8$. The $\omega_1$ and $\phi_{PM}$ are the bandwidth and the phase margin required by system specification respectively.

The proposed VGA has controllable $g_{m1}$ which is inversely proportional to $\beta$, when the conventional has controllable $C_C$, which is proportional to $\beta$. Thus both VGAs have constant $\omega_1$, equals to $\omega_{1s}$. In addition to constant $\omega_1$, the $\phi_{PM}$ of the proposed VGA keeps constant value $\phi_{PMs}$, while the $\phi_{PM}$ of the conventional VGA is not constant, because $\omega_2$ depends on $C_C (1)/(2)$. This means the proposed VGA has optimized phase margin on all gain range. The slew rate of VGA is calculated by the ratio between the tail current of the first stage and the $C_C$. In the proposed circuit, the tail current of the first stage is proportional to $g_{m1}$. Thus the slew rate of the proposed VGA takes maximum value at $\beta = 1/8$ and is inversely proportional to $\beta$. This change of slew rate depend on $\beta$ is exactly same as conventional VGA, because conventional VGA controls $C_C$ to be proportional to $\beta$. The required implementation area is determined by a sum of maximum $C_C$ and maximum $g_{m1}$. Then, the proposed VGA can be implemented in smaller area than the conventional VGA. The power consumption is proportional to $g_{m1}$. Therefore the proposed VGA reduces power consumption at all gain range except for the $\beta = 1/8$ case.

### 3. Simulated Results

The simulated results of the proposed VGA over the entire gain range (from 0dB to 18dB) is shown in Fig.3. The bandwidth is depicted in Fig.3, and the phase margin is in Fig.3. Both the bandwidth and the phase margin are constant on all gain range. Figure 3 shows power consumption, normalized by the power consumption at $\beta = 1/8$. A 40% improvement of the power consumption is achieved at $\beta = 1$.

### 4. Conclusion

The power reduction technique for a VGA is proposed. The technique achieves constant bandwidth and constant phase margin on all VGA gain range, by means of two stage opamp which has controllable input transconductance. Therefore the VGA with the proposed technique can reduce excessive performances and excessive power consumption. The proposed VGA achieves 40% power reduction at the best condition of VGA gain range.

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