A Feedforward Technique with Frequency-Dependent Current Mirrors for a Low-Voltage Wideband Amplifier

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***Abstract*—A feedforward technique using frequency-dependent current mirrors for a low-voltage wideband amplifier is presented. In the conventional single-stage wideband amplifiers, the folded cascode structure is used. However, the common-gate transistor requires an additional $V_{DS\text{sat}}$ and reduces the available output voltage range. In this study the cascode structure is avoided; instead, a frequency-dependent current mirror, whose input impedance becomes higher for a higher frequency, is used to form the feedforward path from the input of the current mirror with a feedforward capacitor. This technique is effective to improve a 100 MHz–1 GHz frequency characteristic of the amplifier. The amplifier has been fabricated using the standard 0.8 μm CMOS process. The phase margin is improved from 46–66° without sacrificing the unity gain frequency of 133 MHz compared with the amplifier without this technique. The amplifier operates at 2.5 V power supply voltage and consumes 12 mW.**

I. Introduction

This paper describes a feedforward technique using frequency-dependent current mirrors and its application to a low-voltage wideband amplifier. A current mirror is advantageous for low-voltage applications compared with a folded cascode configuration, since the folded cascode configuration requires an additional $V_{DS\text{sat}}$ for the common-gate transistor. This $V_{DS\text{sat}}$ reduces the available output voltage range and is not negligible, especially for a low-voltage wideband circuit in which transistors conduct 1 mA to a few tens of mA current. Considering the frequency characteristic and output impedance, however, the current mirror produces a lower nondominant pole and a lower output impedance than a folded cascode configuration. Futhermore, reported improvements using feedforward techniques [2]–[4] have been based on the folded cascode configuration. The improvement of the high-frequency characteristic and the realization of high-output impedance are key issues in applying the current mirrors to a low-voltage wideband circuit. In this paper, the improvement of the frequency characteristic is described.

II. Feedforward Technique and a Wideband Amplifier

The feedforward approach on the conventional current mirror does not perform efficiently, because most of the high-frequency (HF) component of an input current flows through the diode-connected input transistor due to its low-input impedance and little bypasses the current mirror via a feedforward capacitor. To efficiently bypass the current mirror for high frequencies, the input impedance of the current mirror should be large while the input impedance should be small for low frequencies and DC. Therefore, a frequency-dependent current mirror (FDCM) is required for effective feedforward. The structure of the high-speed current mirror [1], which was recently reported, is used to realize the FDCM.

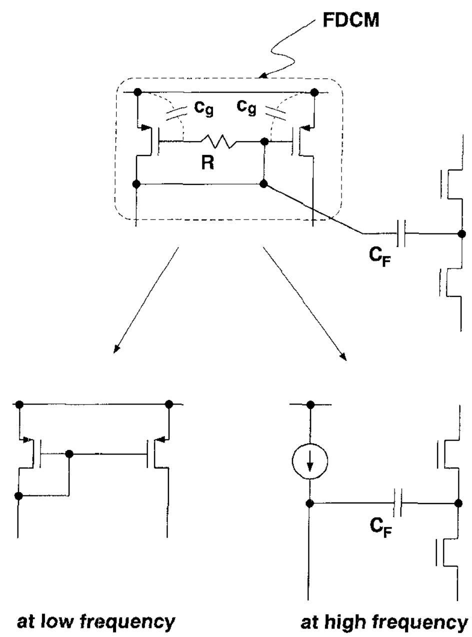

Fig. 1. Operation of FDCM with feedforward capacitor.

A resistor R is connected between the drain and the gate nodes and forms a low pass filter (LPF) with a gate-source capacitance c_g of the input transistor in the FDCM. Fig. 1 shows the operation of the proposed feedforward technique with FDCM. For low frequencies and DC, the input impedance of the FDCM is low since the low-frequency (LF) and DC components pass through the LPF. The FDCM operates as a conventional current mirror and the LF and DC components do not flow into the feedforward capacitor. For frequencies higher than the cut-off frequency $1/Rc_g$ of the LPF, the input impedance becomes higher since the drain-gate path is cut by the LPF. The input transistor of the current mirror operates like a cur-

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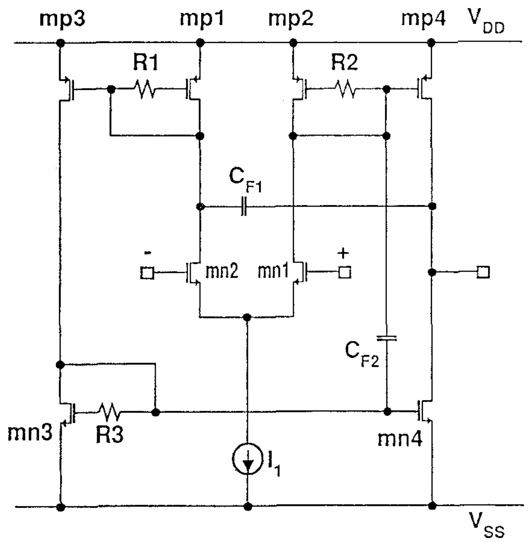

Fig. 2. Wideband amplifier with feedforward technique.

rent source. Therefore, the HF components flow through the feedforward capacitor C_F. To reduce the loss due to the gate-source capacitance c_g of the output transistor in the FDCM, the feedforward capacitor C_F is, for example, 10 times larger than the gate-source capacitance c_g.

In a 100 MHz–1 GHz circuit, large-size transistors are used to conduct 1 mA to a few tens of mA current. The gate-source capacitance c_g is around 0.5–2.0 pF depending on the process technology. Then, using R of 100 Ω–1 kΩ, the HF component of 100 MHz–1 GHz successfully bypasses the FDCM, while the resistors of 100 Ω–1 kΩ do not generate any significant noise.

Fig. 2 shows a single-stage wideband amplifier using this feedforward technique with the FDCM's. The HF component of the output current of *mn*2 is fed forward to the output node directly via C_{F1} and bypasses two current mirrors (*mp*1, *mp*3 and *mn*3, *mn*4). The HF component of the output current of *mn*1 is fed forward to the input of another FDCM via C_{F2} and is amplified. In the conventional amplifier, a channel length of the transistors used in the current mirrors should be sufficiently short or minimal for shifting the parasitic poles to higher frequencies with sacrificing gain. This technique with FDCM's is expected to show greater improvement when the channel length is long and the gate-source capacitance is large. Here, however, the minimum channel length is applied for the FDCM's to demonstrate the effectiveness even in the extreme case.

III. Experimental Results

Amplifiers with and without the proposed feedforward technique were fabricated using the standard 0.8 μm CMOS process with a load capacitor of 7 pF. The amplifiers operate at 2.5 V power supply voltage. Two source followers are also integrated for each amplifier on the same chip; one follows the amplifier and operates as an output buffer for driving the 50 Ω input of the network analyzer, and the other is used for calibration and cancelation of the frequency characteristic of the source follower. A micrograph is shown in Fig. 3.

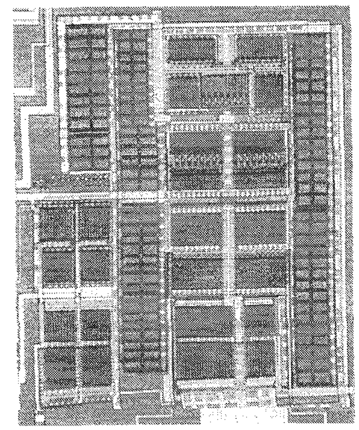

Fig. 3. Micrograph of wideband amplifier.

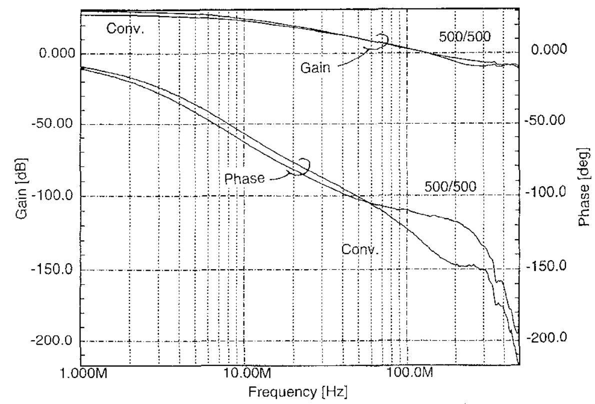

Fig. 4. Open-loop characteristics.

TABLE I
Measured Results

	Amp. with FDCMs and feedforward capacitors		Conventional Amp.
	500/500	700/300	
Min. power supply voltage	2.5 V	2.5 V	2.5 V
Power consumption	12 mW	12 mW	12 mW
Loop gain	30 dB	30 dB	30 dB
Unity gain frequency	134 MHz	141 MHz	133 MHz
Phase margin	66°	60°	46°

Open-loop characteristics of the proposed wideband amplifier and the conventional amplifier are shown in Fig. 4, where $R1 = R2 = R3 = 500\ \Omega$ for the proposed amplifier. The phase margin is improved from 46–66°, without sacrificing the unity gain frequency of 133 MHz. As summarized in Table I, the unity gain frequency is enhanced from 133–141 MHz with the phase margin of 60° for $R1 = R2 = 700\ \Omega$ and $R3 = 300\ \Omega$.

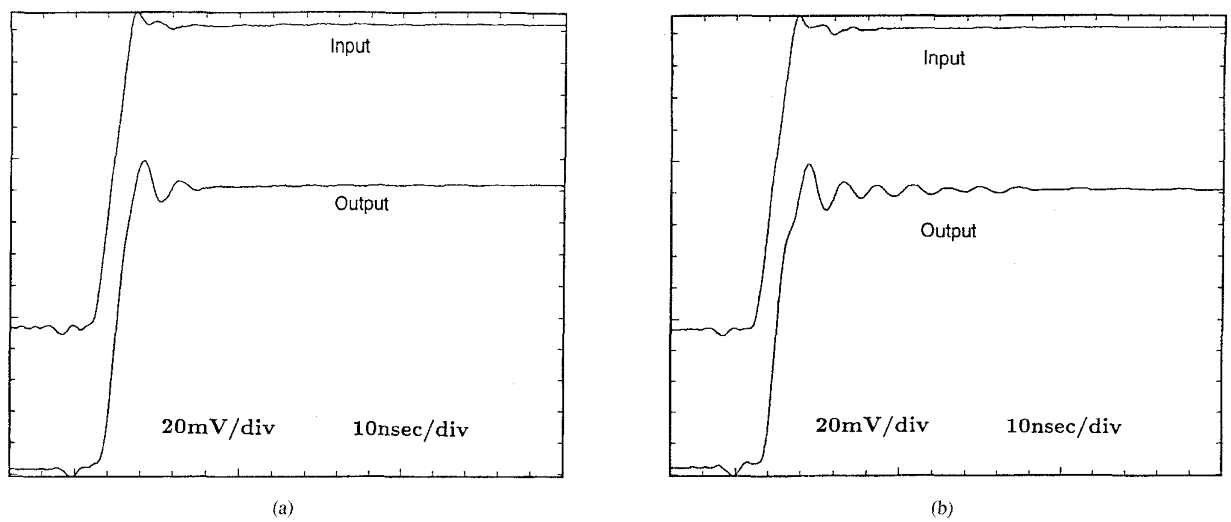

Fig. 5. Input and output waveforms. (a) Wideband amplifier with feedforward technique and (b) conventional amplifier.

The equivalent input noise voltage is 9 nV/$\sqrt{\text{Hz}}$ (@1 MHz) both for the proposed amplifiers and the conventional amplifier, and the added resistors in the proposed amplifiers cause little deterioration of the noise performance.

Fig. 5(a) and (b) show the input and output waveforms of the proposed amplifier and the conventional amplifier with the voltage follower configuration. The settling time of the proposed wideband amplifier is less than that of the conventional amplifier; this also indicates an improvement of the phase margin by the proposed technique.

IV. Conclusion

For a low-voltage wideband application, current mirrors are advantageous to achieve a wider output voltage range. To reduce the effect of the nondominant poles, the feedforward technique with the frequency-dependent current mirror has been proposed. This technique has been applied to a 2.5 V wideband amplifier. The proposed technique improved the phase margin from 46–66° without sacrificing the unity gain frequency. The increase of the phase margin reduces the settling time. The measured results indicate that this design approach is effective for the realization of a low-voltage wideband circuit. The obtained gain is insufficient for practical applications; improving the output impedance of the current mirror without sacrificing the output voltage range is a topic for further study.

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