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A New Approach to Realize Variable Gain Amplifiers

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Abstract. A new methodology to develop variable gain amplifiers is developed. The methodology is based on a feedback loop to generate the exponential characteristic, which is required for VGA circuits. The proposed idea is very suitable for applications that require very low power consumption, and as an application, a new current mode variable gain amplifier will be shown. The gain is adapted via a current signal ranges from -7.5 μA to $+6.5$ μA. Pspice simulations based on Mietec 0.5 μm CMOS technology show that the gain can be varied over a range of 29.5 dB, with bandwidth of 3 MHz at maximum gain value. The circuit operates between ±1.5 V and consumes an average amount of power less than 495 μW.

Key Words: variable gain amplifiers

1. Introduction

A variable gain amplifier can be characterized by the following equation

$$V_{out} = GV_{in} \tag{1}$$

where G is the gain, which is required to be an exponential function of a control signal V_c, i.e., G is defined as

$$G = \exp(\alpha V_c) \tag{2}$$

where α is a constant.

Although it is simple to realize the exponential relation using bipolar transistors, there is no straightforward way to do the same job using CMOS transistors. However several approximations are reported in the literature [1–7].

One of the common approaches is to use the relation:

$$G = \frac{1 + \frac{\alpha}{2}X_c}{1 - \frac{\alpha}{2}X_c} \tag{3}$$

where X_c is the control signal.

Several realizations of this function are reported [1–7], but it is noted that these realizations consume an amount of power that is not suitable for very low power applications and use many transistors which may consume large area and may give rise to significant noisy output.

2. Proposed Methodology

A simple method is proposed here to overcome the above problems.

Figure 1 shows a feedback system, where X_I is an input signal and X_O is the output signal. Analyzing the circuit gives that

$$\frac{X_O}{X_I} = \frac{A}{1 - AB} \tag{4}$$

The relation could be useful in realizing the required exponential function if one takes

$$A = \frac{\alpha}{2}X_c \tag{5}$$

$$B = 1 \tag{6}$$

where α and X_c have their same values as in equation (3).

However, as the control signal X_c varies between negative and positive values, the system encounters negative and positive feedback respectively.

To ensure stability for positive values of X_c for which the system turns out to be positive feedback, the following equation must be satisfied

$$L < 1 \tag{7}$$

where L is the loop gain given by:

$$L = AB = \frac{\alpha}{2}X_c \tag{8}$$

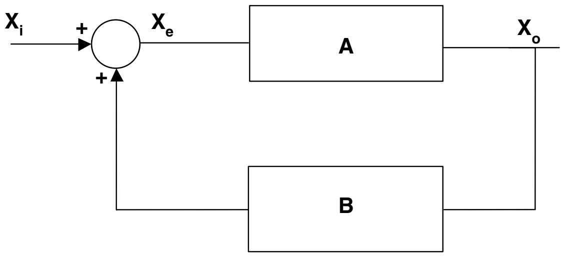

Fig. 1. Basic feedback loop.

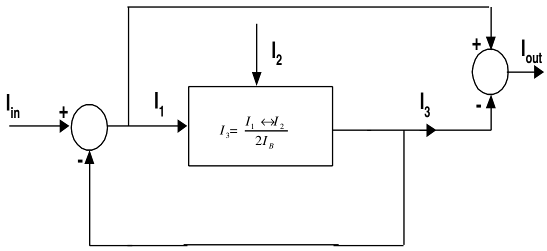

Fig. 3. The block diagram of the proposed current mode VGA.

From a different point of view, it can be shown that the quantity $|\alpha X_c/2|$ should be less than 0.7 to ensure a good approximation to the original exponential function. Therefore, the two limiting factors are consistent with each other.

With the above choice of A and B in equations (5), and (6); equation (4) becomes:

$$\frac{X_O}{X_I} = \frac{\frac{\alpha}{2}X_c}{1 - \frac{\alpha}{2}X_c} \tag{9}$$

Adding X_O and X_e leads to:

$$X_{out} = X_O + X_e = \frac{1 + \frac{\alpha}{2}X_c}{1 - \frac{\alpha}{2}X_c}X_i \tag{10}$$

where X_e is the signal taken directly after the summer as shown in Fig. 1.

It is clear now that the required approximation function is obtained, the overall block diagram is shown in Fig. 2.

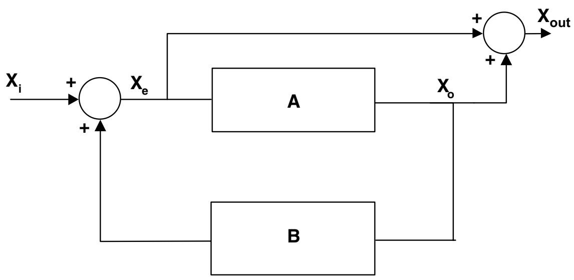

Fig. 2. Proposed idea to realize VGA.

3. Circuit Description

The described methodology can be applied to voltage mode circuits as well as current mode circuits, as an application, a current-mode variable gain amplifier is developed based on the block diagram of Fig. 3.

The block A can be synthesized as linearly controlled current amplifier, and if one choose the control signal (X_C) to be a current signal then block A is synthesized as a four quadrant current mode multiplier, with one of its inputs as the control current signal.

An efficient four quadrant current mode multiplier is reported in [8], and is employed here to demonstrate the methodology, the multiplier is shown in Fig. 4 and is characterized by the following equation:

$$I_3 = \frac{I_1 I_2}{2I_B} \tag{11}$$

where I_3 is the output current, I_1 and I_2 are input currents, I_B is an internal bias current shown in Fig. 4.

Pspice simulations of the multiplier are shown in Fig. 5 and Fig. 6, where the bandwidth is over 20 MHz and the input referred noise equals to 1.39 pA/$\sqrt{\text{Hz}}$.

Applying the above methodology to the multiplier gives the following equations:

$$X_C = I_2 \tag{12}$$

$$\alpha = \frac{1}{I_B} \tag{13}$$

$$\frac{I_{out}}{I_{in}} = G = \frac{1 - \frac{I_2}{2I_B}}{1 + \frac{I_2}{2I_B}} \tag{14}$$

where X_C, α and G have the same meanings as in equation (10).

The overall circuit is shown in Fig. 7, where $-2I_3$ is added to I_{in} to realize the feed-forward path of block

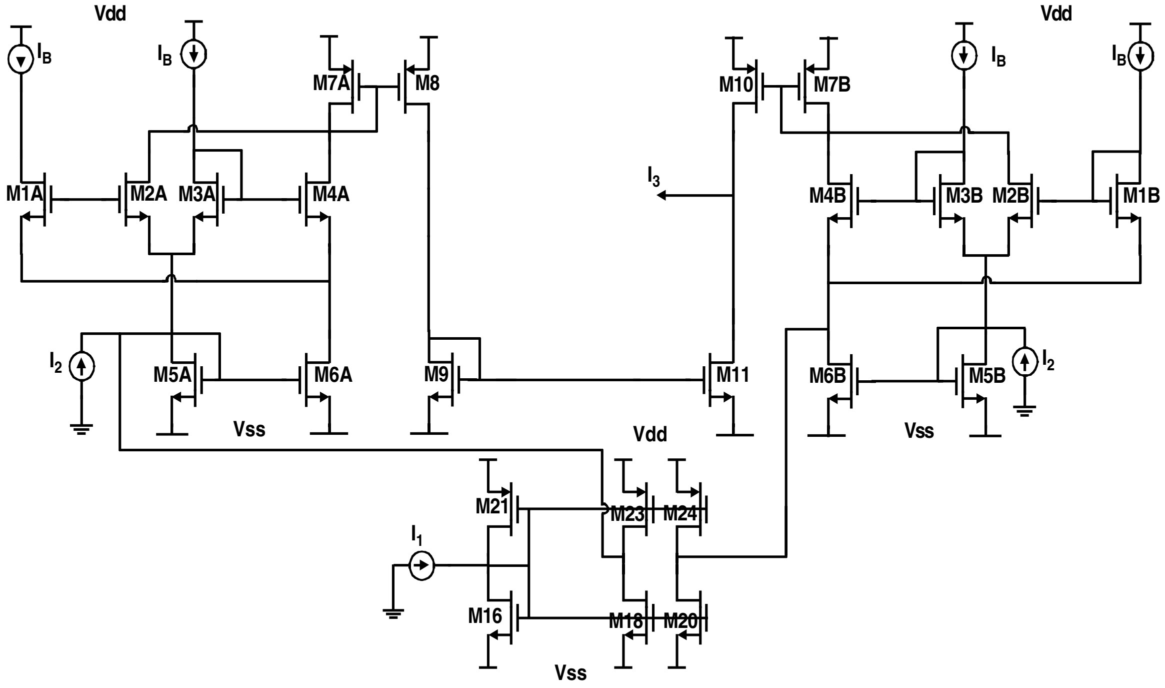

Fig. 4. The multiplier circuit introduced in [8].

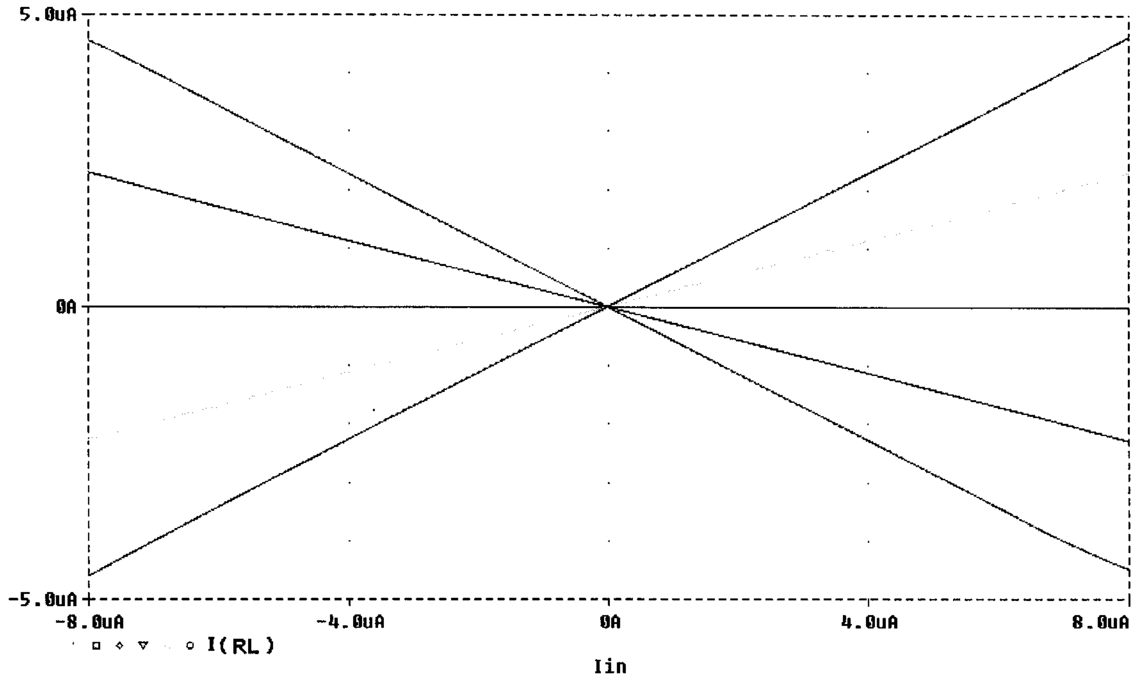

Fig. 5. DC simulation of the multiplier.

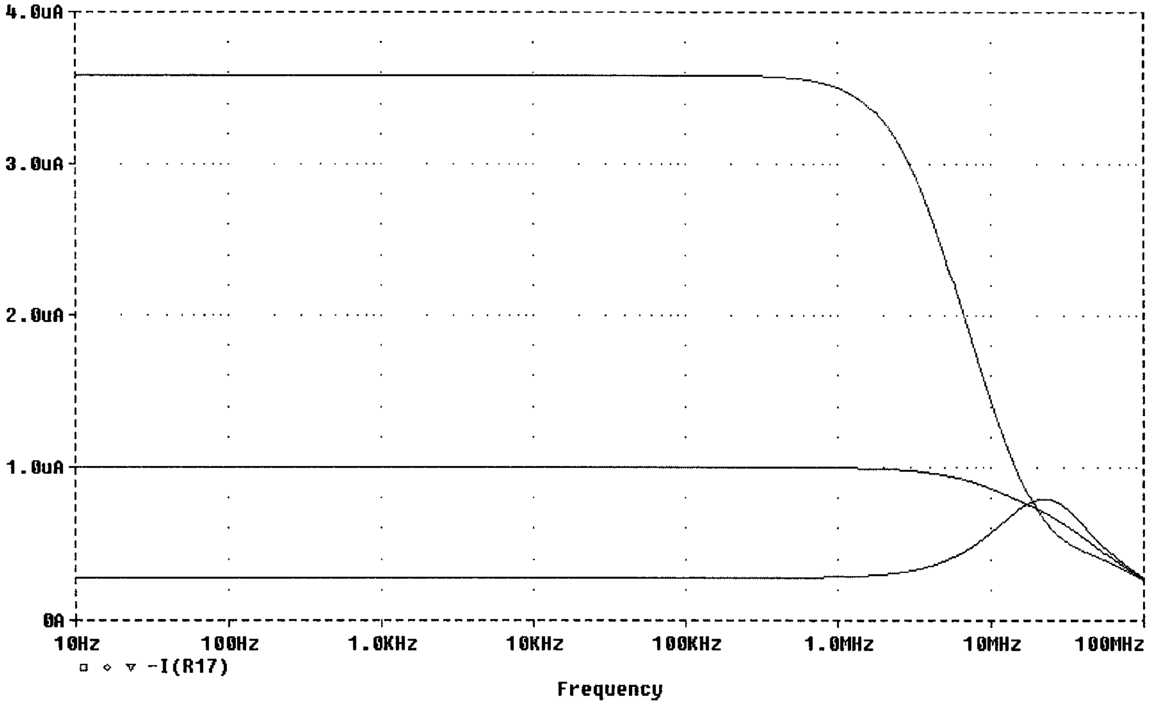

Fig. 6. Frequency response of the multiplier for three values of I_2.

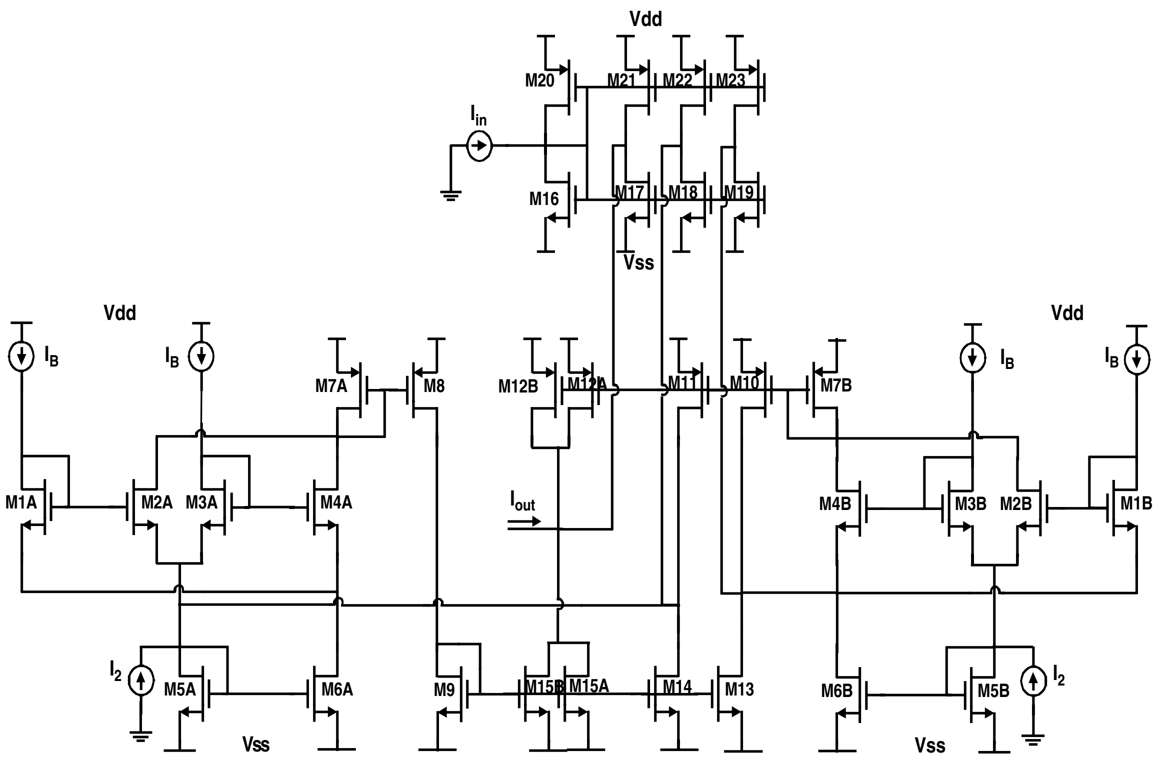

Fig. 7. The complete current mode VGA.

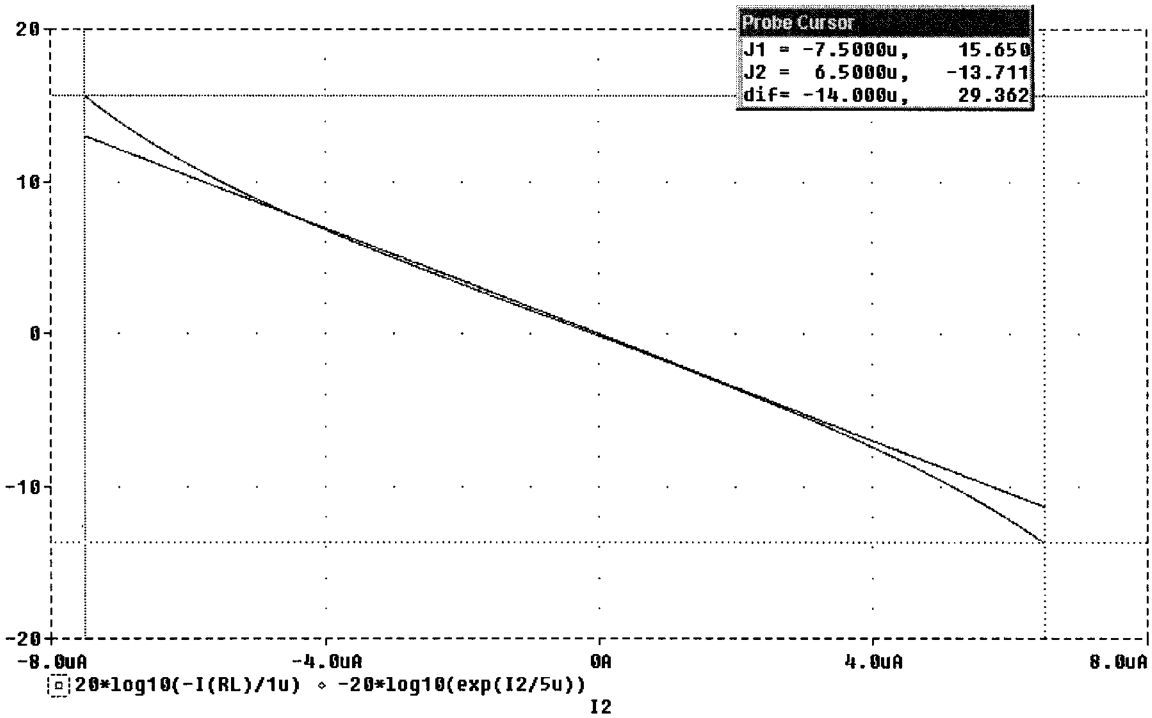

Fig. 8. Gain of the proposed VGA and ideal exponential gain versus I_2.

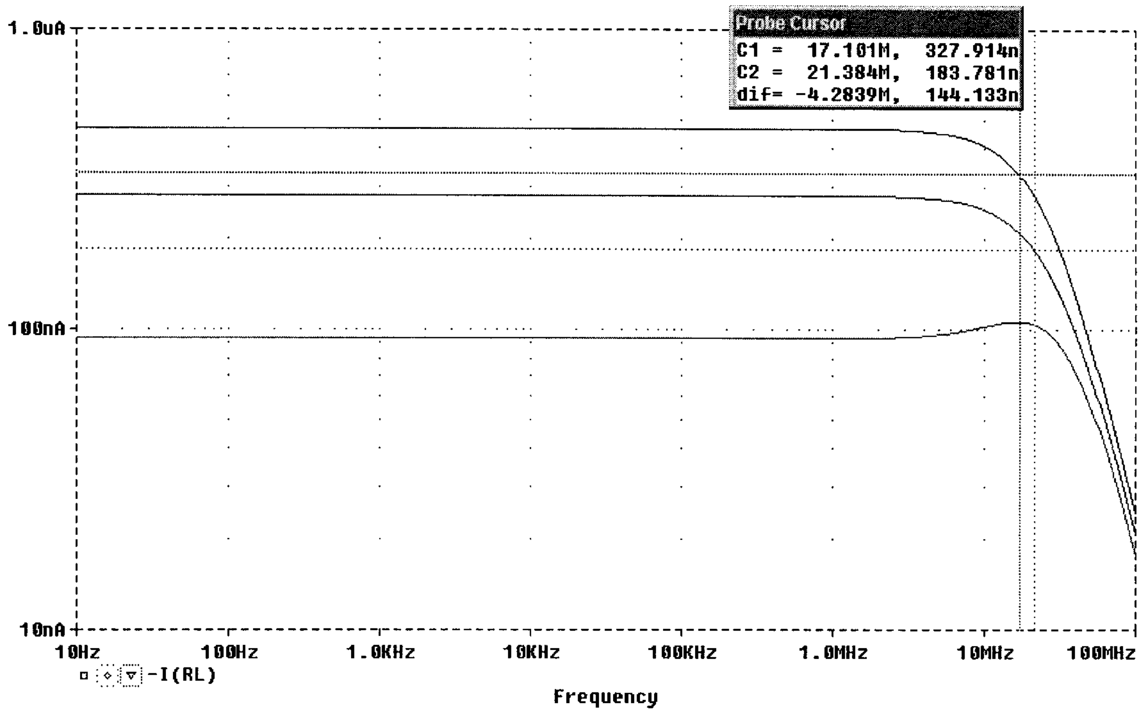

Fig. 9. The frequency response of the proposed VGA for different value of I_2.

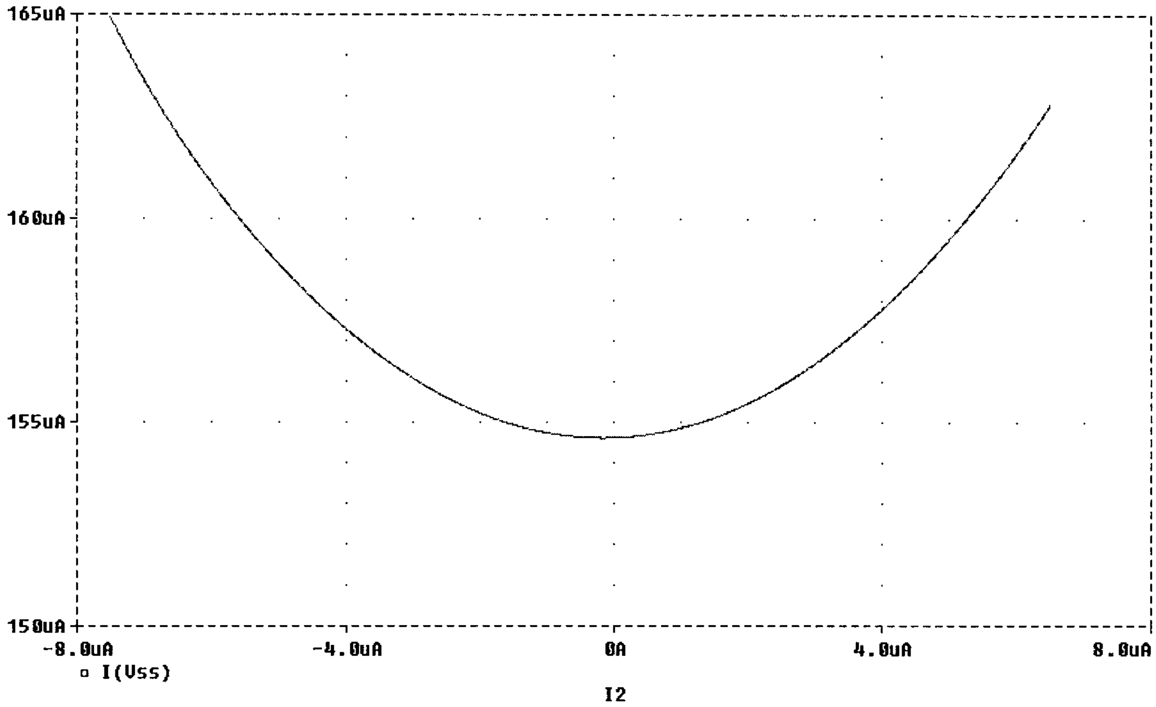

Fig. 10. Supply current versus control current I_2.

diagram of Fig. 3 i.e.,:

$$I_{out} = -2I_3 + I_{in} = 2\frac{-\frac{I_2}{2I_B}}{1+\frac{I_2}{2I_B}}I_{in} + I_{in}$$
$$= \frac{1-\frac{I_2}{2I_B}}{1+\frac{I_2}{2I_B}}I_{in} \quad (15)$$

Meanwhile another version of I_3 is fedback to be added to I_{in} at the multiplier input. Figure 7 and Fig. 8 show the overall circuit performance using Pspice.

The power consumption is less than 495 μW, bandwidth of 3 MHz at maximum positive gain (15 dB) and the input referred noise current equals to 0.14 pA/$\sqrt{\text{Hz}}$.

The method is recommended for applications that require very low power consumption. That is because unlike conventional methods [2] that generate exponential function separately and use a multiplier to multiply the input signal by the gain and thus consume power in the exponential generating circuit and the multiplier, the proposed solution offers only a multiplier circuit to achieve the required response.

Table 1. Aspect ratios of the transistors of the complete VGA shown in Fig. 7.

Transistors	Aspect Ratios (W μm/L μm)
M1A,M1B,M2A,M2B	5/5
M3A,M3B,M4A,M4B	5/5
M5A,M5B,M6A,M6B	10/5
M7A,M7B,M8,M10,M11,M12A,M12B	5/5
M9,M13,M14,M15A,M15B	2.5/5
M20, M21,M22,M23	5/5
M16,M17,M18,M19	2.5/5

4. Conclusions

A new methodology to implement VGA is presented and a new current mode VGA is introduced which has very low power consumption and employ only a few number of transistors. This gives superior noise figure of the circuit and also small area, the circuit may be used in applications which require very low power consumption.

References

1. Harjani, R., "A low power CMOS VGA for 50 Mb/s disk drive read channels." *IEEE Trans. on Circuits and Systems* 42(6), pp. 370–376, June 1995.
2. Motamed, A., Hwang, C. and Ismail, M., "A low voltage low power wide range CMOS VGA." *IEEE Trans. on Circuits and Systems II* 45(7), pp. 800–811, July 1998.
3. Green, M. and Joshi, S., "A 1.5 V CMOS VGA based on pseudo-differential structures." *IEEE International Symposium on Circuits and Systems,* Geneva, Switzerland, pp. 461–446, 2000.
4. Huang, P., Chiou, L. and Wang, C., "A 3.3 V CMOS wide band exponential control variable gain amplifier," in *Proceedings of IEEE International Symposium on Circuits and Systems.* Monterey, CA, USA, 1998, pp. 285–258.
5. Brannen, R., Elwan, H. O. and Ismail, M., "A simple low voltage all MOS linear-dB AGC/Multiplier circuit," in *Proceedings of IEEE International Symposium on Circuits and Systems.* Orlando, FL, USA, 1999, pp. 318–321.
6. Elwan, H., Ismail, M., Gao, W. and Sadkowski, R., "A CMOS digitally programmable class AB OTA circuit," in *Proceedings of International Conference on Microelectronics.* Kuwait, 1999, pp. 51–54.
7. Ibrahim, M., Elwan, H., Kramer, B. and Embabi, S., "A 110 MHz 70dB CMOS VGA," in *Proceedings of IEEE International Symposium on Circuits and Systems.* Orlando, FL, USA, 1999, pp. 628–631.
8. Ismail, M. and Fiez, T., *Analog VLSI Signal and Information Processing.* McGraw Hill, New York, 1993, Chapter 6.