A Simple 2-Transistor Transresistor[*]

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Abstract - **A simple transresistance amplifier is introduced that is both linear and compact. It consists of only two transistors and a current source. Despite its simplicity, its linearity properties are attractive when compared to existing transresistance structures. Simulation results comparing the performance of the new structure with several other single-ended and balanced structures are presented along with experimental results.**

I. INTRODUCTION

Transresistance amplifiers convert signal currents into signal voltages. Fig. 1 contains the block diagram of an ideal transresistance amplifier. It produces an output voltage that is equal to the product of the transresistance gain, H, and the input current, Iin.

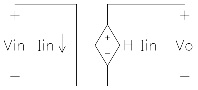

Fig. 1. Ideal transresistance amplifier

Real transresistance amplifiers only approximate the characteristics of an ideal transresistance amplifier. Important concerns when evaluating or designing these circuits are the input and output impedances, achievable transresistance gain, circuit complexity, frequency response, and linearity. Because the voltage swing at the input is proportional to the input impedance, to be compatible with low voltage processes, a low input impedance is essential. Furthermore, because requirements for large-signal swings at the output are typical, in most applications the linearity of the circuit is of importance.

Resistors are often used to convert a current to a voltage. However, they are not preferred for many monolithic applications for several reasons. Due to the low sheet resistance of polysilicon, integrated resistors require a large die area. The nonlinear behavior of diffusion layer resistors excludes them from many applications. The post-fabrication value of the resistance exhibits wide variability and its value is not correlated with other process parameters such as circuit capacitances, transconductances, or channel conductances. Trimming and/or tuning schemes are often required to compensate for process variability. Finally, resistors are not well suited for low voltage applications because, unlike a transresistor which has a low input impedance and therefore small voltage swings at the input, the input impedance is large. As a result, large voltage swings occur on the same node where the variable input current is applied.

Over the years, a great deal more research was performed in the area of linear transconductance amplifiers than on transresistance amplifiers. Fortunately we can utilize the existing knowledge to our advantage because it is easy to convert a transconductance to a resistance using the technique depicted in Fig. 2.

To circumvent some of the disadvantages associated with integrated resistors, MOS based circuits are often used to implement transresistance amplifiers and resistors. For large signal swings, the MOS transistor, is not a very linear device. Therefore, elaborate circuitry is often employed to *linearize* the circuit response. Although some linearization techniques utilize the characteristics of MOS transistors operating in saturation [6][7], most reported techniques rely on the characteristics of the MOS transistor operating in the linear region of operation [1][3][4][5][8][11].

Because analysis with more accurate models quickly becomes intractable, designers have been forced to develop linearization schemes using the existing simple analytical device models. Many techniques that highly attenuate or completely cancel circuit nonlinearities using these device models have been reported. Unfortunately, the simple analytical device models used do not accurately represent the nonlinearities present in a real-world device. For example, as pointed out in [10] and acknowledged in [2], the simple device models used for hand analysis assume the mobility is constant. This is probably an acceptable approximation for small signal variations but not for large signal variations such as those present at the output node of a transresistor. As a result of the model inaccuracies, even those reported schemes that promise complete cancellation of the nonlinear terms do not perform well in practice.

In this paper, a new transresistance amplifier that outperforms most existing structures on many of the key performance parameters is introduced. It is highly linear, very compact, and very simple.

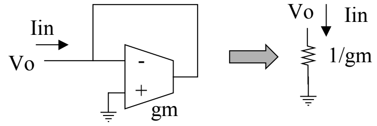

Fig. 2. Transforming a transconductance amplifier into an effective resistance

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II. PROPOSED CIRCUIT

The proposed transresistance amplifier is shown in Fig. 3. It consists of two MOS transistors and a current source. The input current is applied to the drain of M1 and the output voltage is obtained at the source of M2. The configuration ensures that M1 operates in the linear region of operation at all times while M2 remains saturated for typical process parameters for M1 and M2.

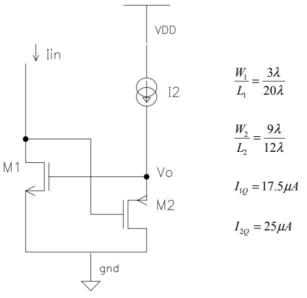

Fig. 3. Newly proposed transresistor

A detailed analytical analysis of the nonlinear behavior has not been included because the simple analytical models required to make the analysis tractable are not sufficient to accurately predict the performance of the real circuit. Rather, we rely on more accurate predictors of circuit performance - computer simulations using BSIM3 models and experimental results. Ultimately, even these simulated results will be in error because the device models were not developed to accurately represent the nonlinearities deep in the triode region of operation.

The new transresistor has some attractive performance attributes. First, as will be demonstrated in the next section, the circuit is more linear than other reported linear transresistance circuits in both the single-ended and balanced configurations. Second, a wide range of transresistance gains is achievable by varying the W/L ratio of M1. The circuit can be modified to make the transresistance gain voltage controllable by placing a triode region NMOS transistor in between M1's source and ground. Thirdly, the new transresistor has good high-frequency performance with the location of the pole determined mainly by the choice of I2 and the size of the capacitive load to be driven. Finally, the new circuit may be suitable for applications that formerly required specialized trimming and tuning because the value of the transresistance gain may be correlated with other process parameters such as MOS transconductance.

III. PERFORMANCE COMPARISON

The proposed circuit and several other MOS resistive circuits were simulated with HSPICE using BSIM3 (Level 49) models for a 0.35µ process. Because applications exist for both single-ended and differential signals, both single-ended and balanced structures were simulated. In an effort to avoid obscuring the true characteristics of the structures, ideal components were used for all supporting circuitry such as current sources, voltage sources, and amplifiers.

The most popular reported single-ended structures are the grounded resistors introduced by Babanezhad [1] and Wyszynski [11]. Their circuits are depicted in Figures 4 and 5 respectively. For comparison purposes, the devices were chosen to obtain a transresistance gain of approximately 28 kΩ.

Fig. 6 shows a comparison of the simulated transfer characteristics of both the new structure and the existing structures over the range of ±17.5uA from their respective Q-points.

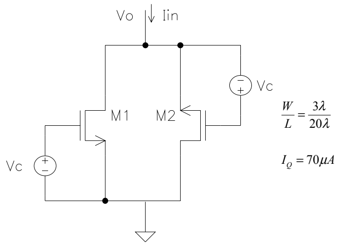

Fig. 4. Grounded resistor concept by Babanezhad [1]

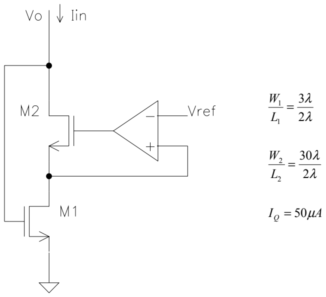

Fig. 5. Grounded resistor concept by Wyszynski [11]

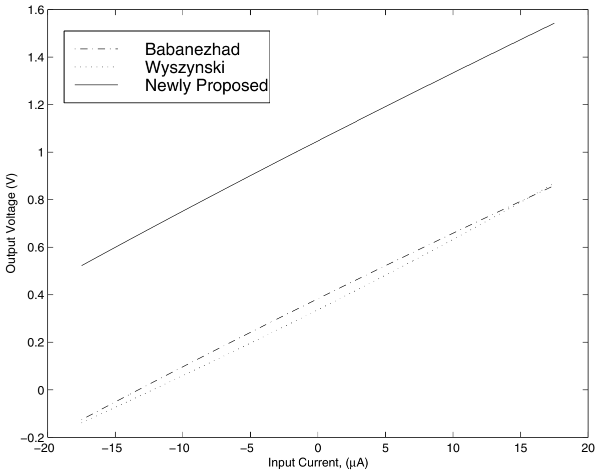

Fig. 6. Simulated transfer characteristics of the single-ended structures shown in Figures 3, 4, and 5

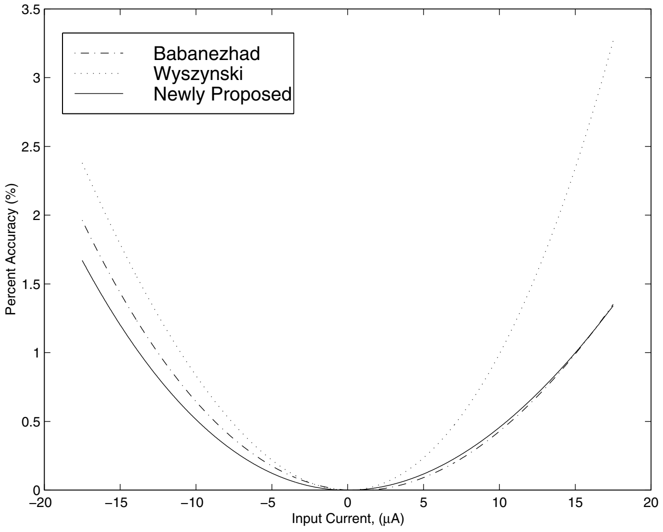

Fig. 7. Percent accuracy relative to full scale deviation for the single-ended structures in Figures 3, 4, and 5

Fig. 7 shows a comparison of the percent accuracy relative to full scale for the three structures. The new circuit offers modest improvements in linearity over the existing structures.

Balanced versions of the proposed transresistor, Wyszynski's circuit, and an alternative circuit based on work by Czarnul [3] and Song [9] were simulated as well. Balanced structures will perform better than the corresponding single-ended structure because they inherently cancel even-ordered nonlinearities. The schematic of the Czarnul/Song circuit is shown in Fig. 8. Theoretically, using a simple analytical model, this circuit facilitates cancellation of all nonlinearities but as observed by Vidal [10] and supported by the simulation results presented here, the circuit does exhibit nonlinearities due, in part, to mobility degradation.

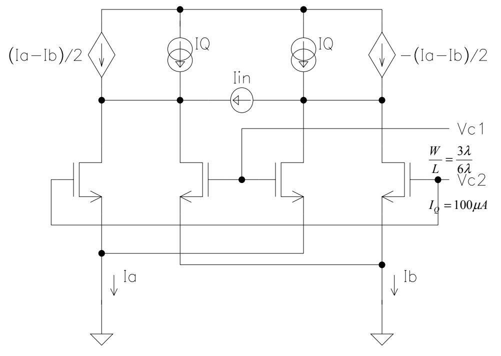

Fig. **8.** Grounded resistor based on concept by Czarnul/Song [3][9]

Fig. 9 shows a comparison of simulated transfer characteristic of the balanced structures over the range of ±35uA differential input current. The Wyszynski circuit and the newly proposed transresistor compare quite favorably while the Czarnul/Song circuit, in spite of its added complexity, is visibly nonlinear.

Fig. 10 contains a plot of the percent accuracy relative to the full-scale deviation for the three balanced structures. As for the single-ended case, the proposed circuit exhibits the most linear response of the three considered.

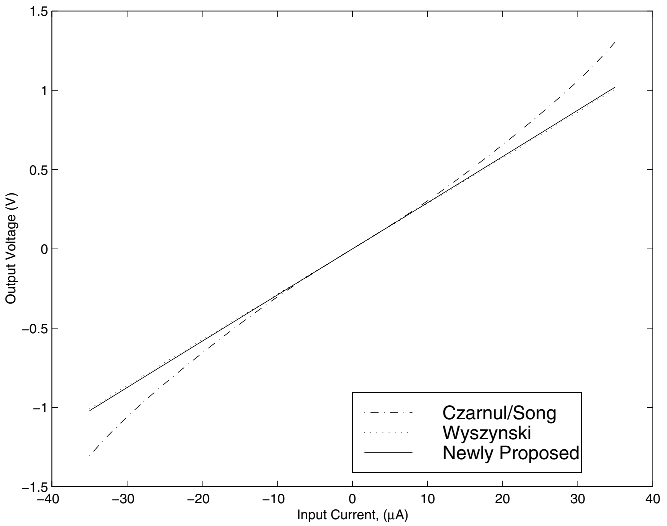

Fig. 9. Simulated transfer characteristics of the balanced versions of the structures shown in Figures 3 and 5 and the circuit shown in Fig. 8

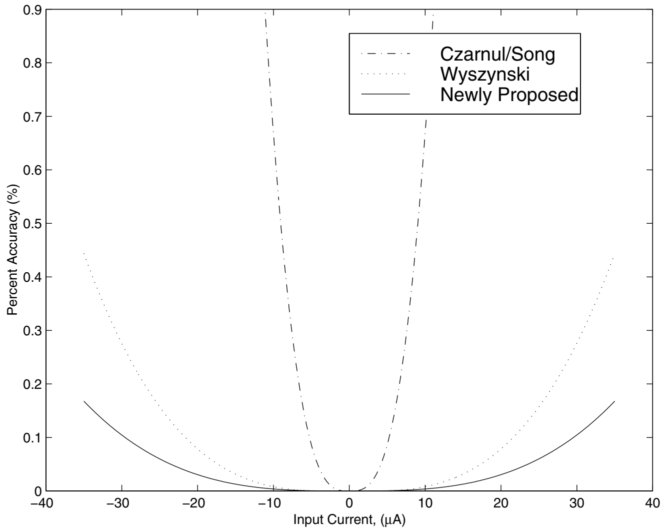

Fig. 10. Percent accuracy relative to full scale deviation for the balanced versions of the structures in Figures 3 and 5 and the circuit shown in Fig. 8

IV. EXPERIMENTAL RESULTS

A single-ended test circuit for the proposed structure of Fig. 3 was constructed using transistors from a prefabricated transistor array (*Electronic Technology Corporation MST2*). No attempt was made to optimize the individual or relative device sizes.

The measured transfer characteristics are plotted along with a best-fit line in Fig. 11. Fig. 12 contains a plot of the percent accuracy relative to full-scale. The experimental results indicate an accuracy of ±0.2% over a voltage swing of 1.65 Vpp. A balanced structure would exhibit even more linear behavior and simulations suggest that even better performance could be achieved by optimizing the relative device sizes.

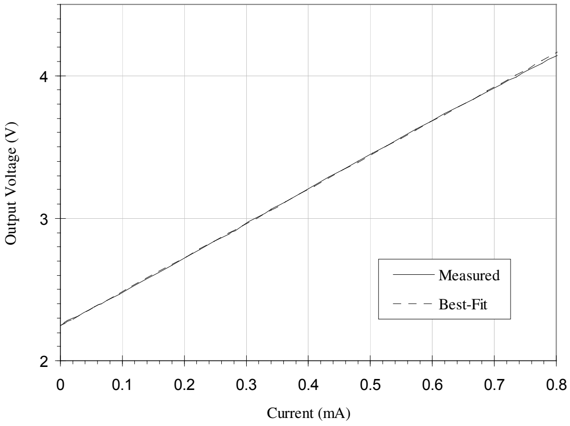

Fig. 11. Measured transfer characteristic of the single-ended version of the newly proposed transresistor

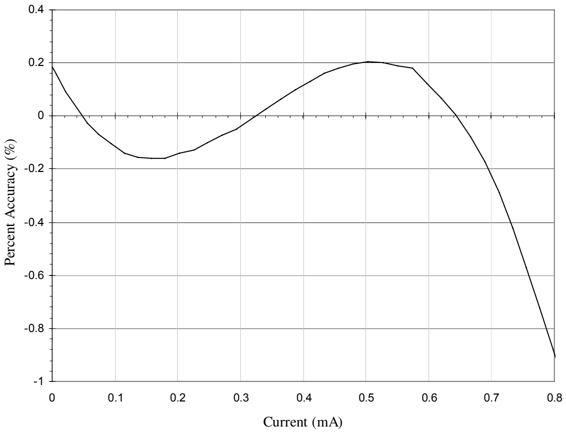

Fig. 12. Percent accuracy relative to full scale deviation for the experimental circuit

SUMMARY

A simple, new, two-transistor transresistor that offers attractive linearity characteristics and transresistance density has been introduced. Simulation results using BSIM3 models show that it is more linear than other popular structures.

Experimental results for the new transresistor implemented in a 2μ CMOS process were presented. For a single-ended non-optimized structure built from prefabricated transistor arrays, linearity of ±0.2% over a voltage swing of 1.65 Vpp was measured. Significant improvements in performance can be obtained by optimizing the structure or by implementing a balanced version of the circuit.

V. REFERENCES

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