New Topologies for OTRA Based Programmable Precision Half-Wave and Full-Wave Rectifiers

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***Abstract*—This paper presents new topologies for programmable precision rectifiers designed using Operational Trans-Resistance Amplifiers (OTRA). Topologies for Half-Wave Rectifiers (HWR), and Full-Wave Rectifiers (FWR) working in both positive and negative rectification modes are proposed. The variation of the voltage transfer curves (VTC) with change in the bias voltage, and the ability to set the gain by reworking the resistor values are included. The functional verification of proposed circuits is carried out using Cadence Virtuoso tool using SCL's 180nm technology. Effect of process corner and temperature variations was also studied, and it is observed that the circuits are resilient.**

***Keywords*–OTRA; Precision Rectifiers; Programmable Rectifiers; Half-Wave; Full-Wave**

I. Introduction

Programmable precision rectification finds various applications in the industry, [1] from AC Voltmeters, to detection circuits like sample and hold circuits, polarity detectors, AM wave detectors, to instrumentation. Diodes are at a disadvantage when it comes to such applications under [2] low voltage conditions, as they have an inherent cut-in voltage of around 0.7V, which renders them unusable with the range of -0.7V to 0.7V.

Op-Amps are the traditional choice of active blocks for making precision rectifiers. However, Op-Amps have a limited slew rate due to their voltage-mode processing, which hinders usability in high-frequencies. In general, current mode processing is considered to be faster, more linear, and more dynamic. [2] It inherently has a high bandwidth of operation, which makes current-mode blocks like OTRA a desirable choice in modern circuitry. Also, the pole of the OTRA [3] is much higher than the pole of a generic Op-Amp, which makes it favourable for high-frequency applications. Many applications of OTRA as an active block have emerged recently [4], [5], [6], which detail the usefulness of the active block OTRA.

A detailed review shows that many precision rectifier circuits employing current-mode blocks exist in literature. The circuits detailed in [7] , [8], and [9] use diodes, which make them unusable for low voltage applications. The circuits in [10] employ BJT-based current mirrors, along with active block Current Conveyor-II. The full-wave circuits of [11] employ an excessive number of active blocks, which makes them energy and area inefficient. The circuits of [8], [12], [13] and [14] provide current-mode outputs, which need to be converted to voltage-mode for practical purposes, increasing the total number of devices. The circuit proposed in [15] lack rail to rail output capabilities and does not have programmability. [16] presents a simple precision rectifier design composed of two current conveyors, two diodes, two DC voltage sources and one DC current source. This design is aimed for only small amplitude signal rectification.

This paper proposes new topologies for programmable precision HWRs and FWRs, operating in both positive and negative modes, based on the active block OTRA which gives us advantages as stated earlier. The circuits in [17] are programmable current limiters. Parallels can be drawn from the basic idea of [17] to implement programmability in the current work.

II. The OTRA

The Operational Trans-Resistance Amplifier (OTRA) is a three-terminal device as shown in Fig. 1.

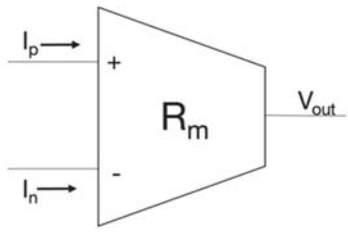

Fig. 1: OTRA Block Diagram

The OTRA amplifies the difference of the currents I_p and I_n and the output is the voltage V_{out} in accordance with port characteristics as expressed by (1). The R_m is known as the trans-resistance gain, and its value approaches infinity for an ideal OTRA, which in turn forces the input currents to be equal. For ideal operation, V_p and V_n should be zero. Also, V_{out} should not depend on the current drawn from the output terminal, i.e. I_{out}.

$$\begin{bmatrix} V_p \\ V_n \\ V_{out} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_{out} \end{bmatrix} \quad (1)$$

The output of an ideal OTRA reaches positive or negative saturation levels (V_{DD} or V_{SS}) if used in an open loop configuration as the R_m is infinite. Thus, for linear applications the OTRA must be used in a negative feedback configuration. The OTRA used in this work [3] is shown in Fig. 2. The transistor W/L ratios can be referenced from [3].

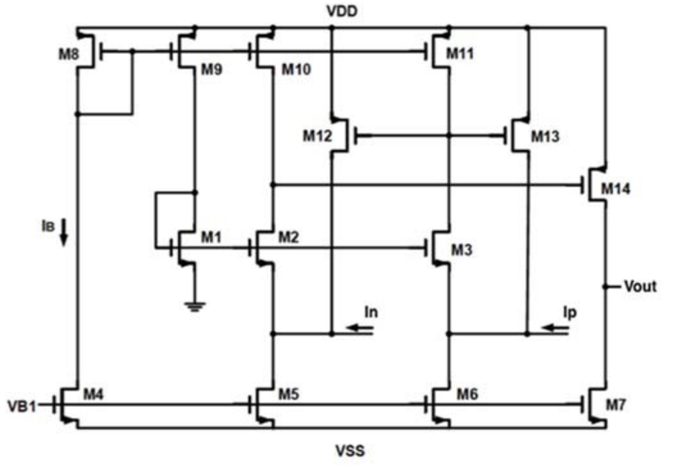

Fig. 2: OTRA CMOS Circuit [3]

III. Half-Wave Rectifiers

The proposed circuits for the positive and negative HWRs are shown in Figs. 3 and 4 respectively.

The OTRA 1 is connected in open-loop configuration, and acts as a Comparator. It is used to compare the input voltage with the bias voltage, and provides inputs to the digital logic.

The digital logic is basically a CMOS inverter working between the rails of V_{DD} and V_{SS}, with W/L ratio of both PMOS and NMOS taken as 1µ/0.5µ. It is used to generate the control signals needed to drive the analog multiplexer based on transmission gates, with W/L Ratios as 10µ/0.5µ.

The analog multiplexer in case of positive HWR lets the difference between V_{source} and V_{bias} pass to the output if it is positive, else the output is maintained at 0V. Similarly, in negative rectifier, the difference is passed on to the output if the difference is negative and the output is maintained at 0V otherwise.

The OTRA 2 acts as a non-inverting amplifier for Fig. 3 and 4. The magnitude of the gain of these amplifier configurations may be expressed as

$$gain = \left|\frac{R_f}{R_{in}}\right| \qquad (2)$$

Based on the values of the discrete components it can either simply buffer the input, or provide a gain as per (2).

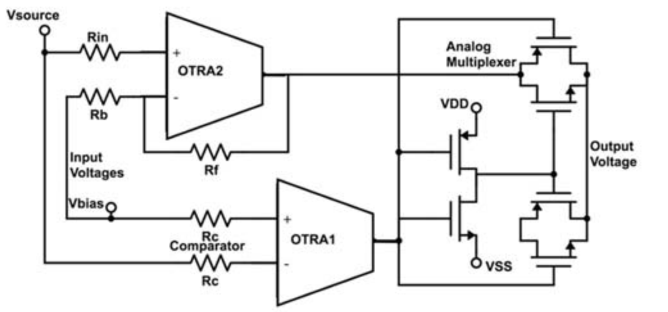

Fig. 3 Schematic of Positive HWR

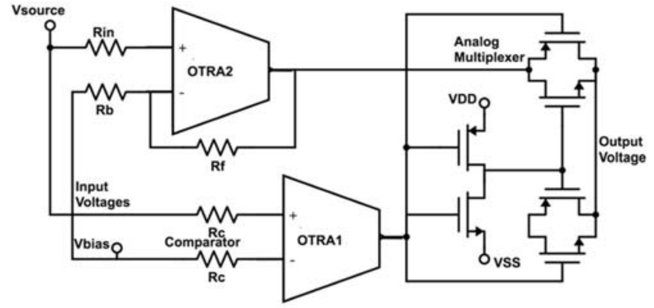

Fig. 4: Schematic of Negative HWR

IV. Full-Wave Rectifiers

The circuits for the positive and negative FWRs are as shown in Figs. 5 and 6 respectively.

The circuits act as FWRs working at the tipping point of V_{bias}. The positive FWRs let the absolute value of the difference between V_{source} and V_{bias} pass to the output. The negative FWRs let the negative of the absolute value of the difference between V_{source} and V_{bias} pass through to the output.

OTRAs 1 and 3 are used to generate the VTCs that the output will be following in the cases where V_{source} is greater than V_{bias}, and when V_{source} is less than V_{bias} respectively. In Fig. 5, OTRA 1 is acting as a non-inverting amplifier, and OTRA 3 as an inverting amplifier. In Fig. 6, OTRA 1 is acting as an inverting amplifier, and OTRA 3 as a non-inverting amplifier.

The discrete components connected to them in input and feedback provide gain by (2). It must be noted that the R_{in} and R_f connected to OTRAs 1 and 3 must have the same values respectively to get equal gain for both half-cycles.

The same scheme of comparison as detailed in the previous section is used for FWRs as well, with OTRA 2 connected in open-loop configuration and acting as a comparator. The only difference is that when V_{source} is less than V_{bias}, the output follows an appropriate VTC from OTRA 3 instead of being grounded. Control signals for the analog multiplexer are also generated in the same manner, with an inverter operating between the rails of V_{DD} and V_{SS}.

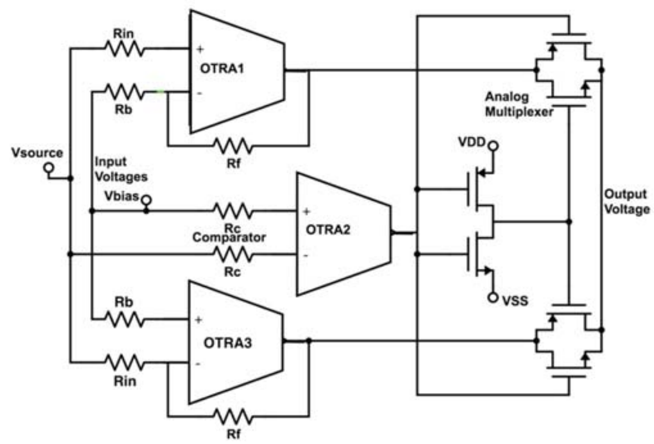

Fig. 5: Schematic of Positive FWR

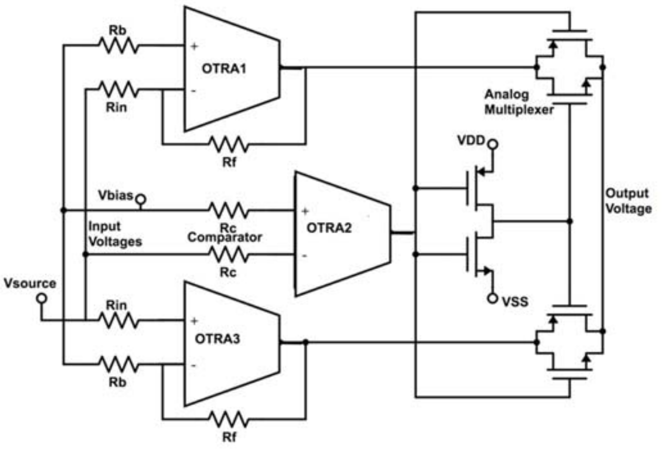

Fig. 6: Schematic of Negative FWR

V. SIMULATION RESULTS

The functional verification of proposed circuits is carried out on Cadence Virtuoso tool using SCL's 180nm technology node. V_{DD} was taken as +2V and V_{SS} as -2V globally.

The VTCs for the positive and negative HWRs under various V_{bias} voltages are shown in Figs. 7 and 8 respectively. The resistance values taken were all 100KΩ, and bias voltage V_{bias} varied from -1V to +1V. The input voltage V_{source} was DC swept from -2V to +2V.

It may be observed that no dead-zone appears in the VTCs, thus verifying the suitability of the proposed circuits even for voltages in the range -0.7to 0.7V, where conventional diode-based circuits fail to operate.

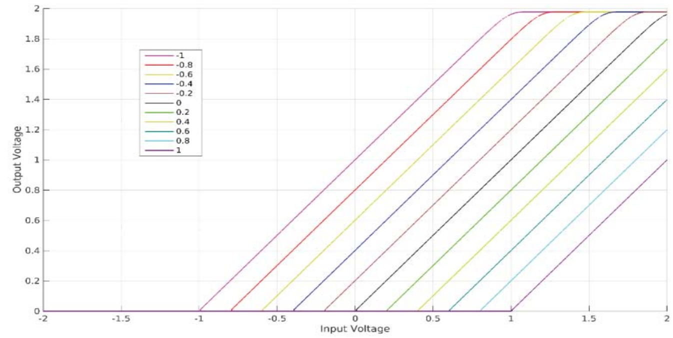

Fig. 7: Positive HWR VTCs

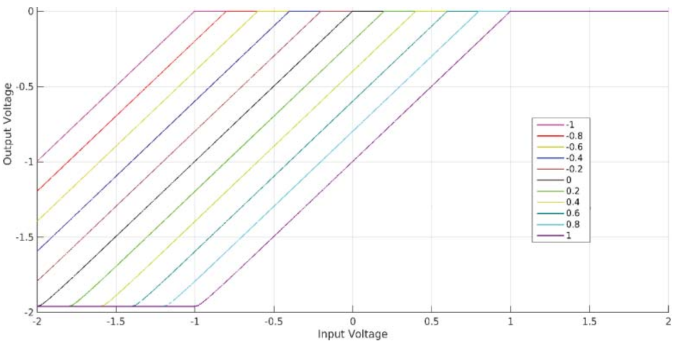

Fig. 8: Negative HWR VTCs

For Transient analysis, the values for R_{in} and R_c were set to 100KΩ, and R_f varied from 100KΩ to 500KΩ. The input voltage chosen was a 300mV amplitude sinusoid at 1KHz frequency. Transient responses of the positive and negative rectifiers for various values of gains are shown in Figs. 9 and 10 respectively.

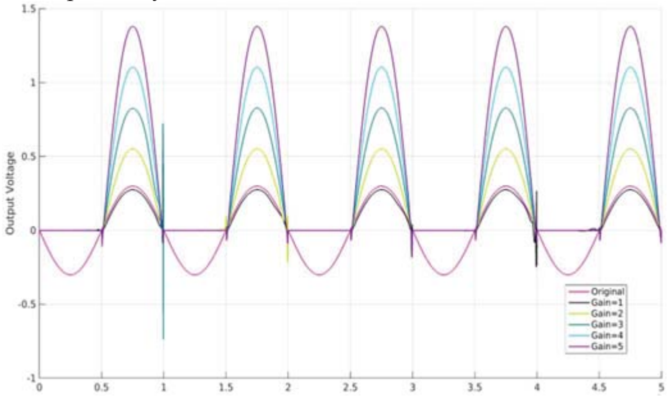

Fig. 9: Positive HWR Transient Response

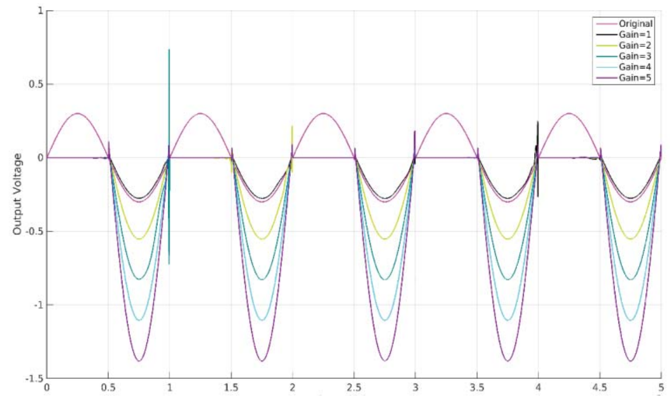

Fig. 10: Negative HWR Transient Response

Figures 11 and 12 respectively show the VTCs for the positive and negative FWRs under various V_{bias} voltages. For verification of their functionality, the resistance values taken were all 100KΩ, and bias voltage V_{bias} varied from -1V to +1V. The input voltage V_{source} was DC swept from -2V to +2V. In these curves also, no dead-zone is observed thus verifying the theoretical propositions.

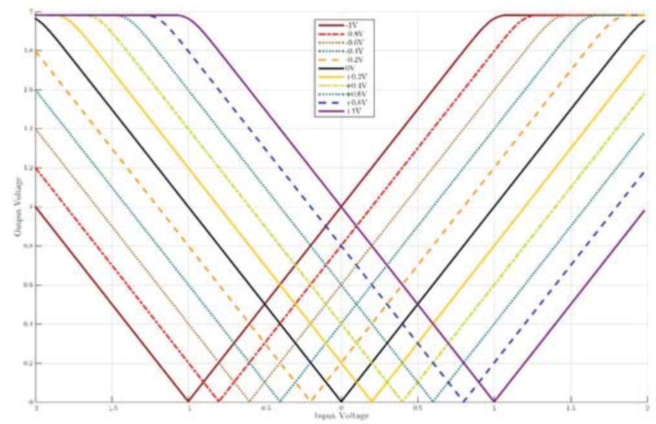

Fig. 11: Positive FWR VTCs

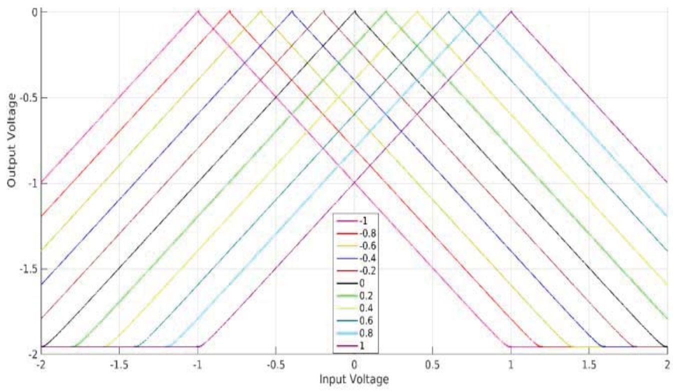

Fig. 12: Negative FWR VTCs

Transient analysis of the positive and negative FWRs is also carried out for which the values for R_{in} and R_c were taken to be 100KΩ, and R_f was varied from 100KΩ to 500KΩ to get programmable output. The input voltage was a 300mV amplitude sinusoid at 1KHz frequency. Transient analysis of the rectifier for various values of gains are as shown in Figs. 13 and 14. They show that complete full-wave rectification, both positive and negative, is achieved by the proposed circuits.

The proposed positive FWR is used to test the operation of the proposed circuits under PVT Variations. The process corners were varied for all 5 usual combinations, i.e. Typical, Fast-Fast, Fast-Slow, Slow-Fast, and Slow-Slow. The temperature was varied from -20ºC to +70ºC.

Fig. 15 shows that any process corner skew will not affect their operation and we can infer from Fig. 16 that the circuits can be operated from -20ºC to +70ºC safely.

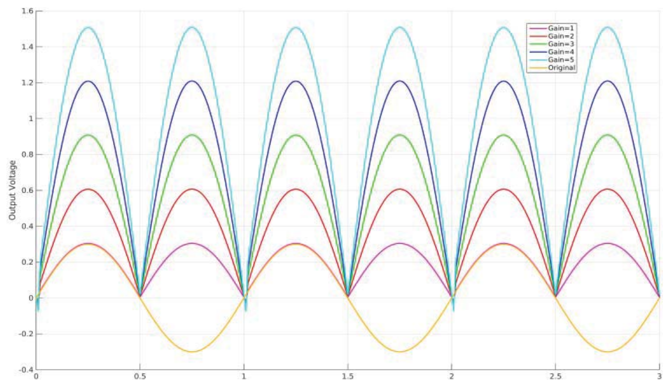

Fig. 13: Positive FWR Transient Response

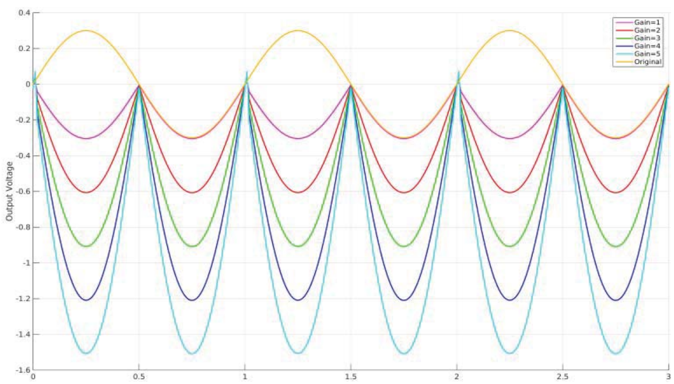

Fig. 14: Negative FWR Transient Response

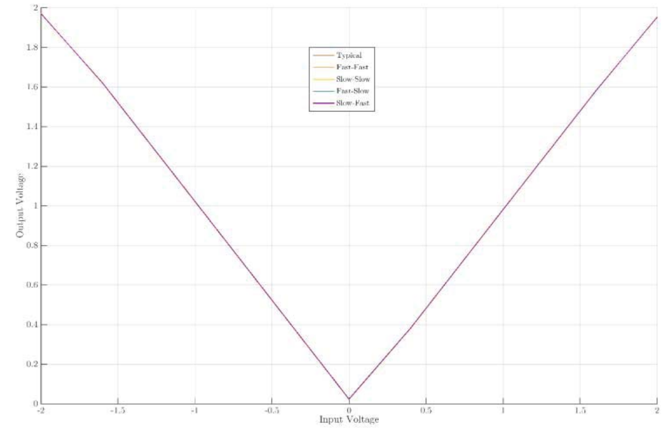

Fig. 15: Process Corner Variation for Typical, Slow-Slow, Slow-Fast, Fast-Slow, and Fast-Fast corners

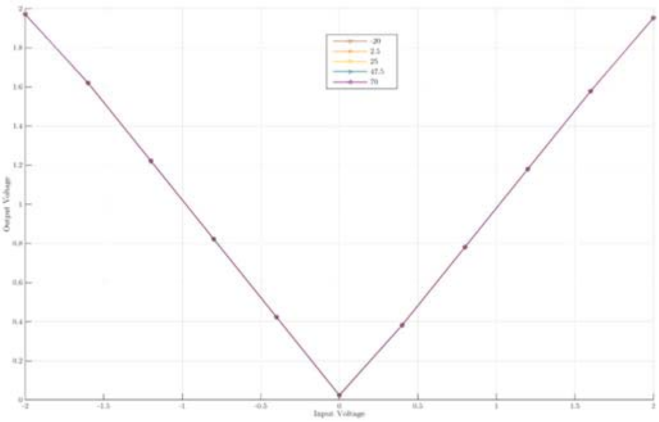

Fig. 16: Temperature Variation from -20ºC to +70 ºC

VI. CONCLUSIONS

In this work, new topologies for programmable precision half-wave and full-wave rectifiers have been proposed, which work in positive and negative rectification modes. OTRA gives us advantages like faster processing as it is current-mode, a much higher bandwidth, and a higher frequency of operation, apart from the advantages of an infinite Transresistance active block which can be applied to idealise the mathematical formulation, and obtain close practical mirroring of the hypotheses.

As detailed in [16] and [18], programmable precision rectifiers find many uses in the industry and in development of systems like low noise power supplies, AC voltmeters, linear function generators, RF demodulators, Watt meters and a multitude of non-linear analog signal processing circuits.

DC sweeps and transient analyses were performed. Simulation results of all the circuits on Cadence Virtuoso using SCL's 180nm technology node have been reported. The circuits were checked for process corner and temperature variations, and were found to be strongly resilient against these variations.

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