OTRA based half wave rectifier

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Abstract

Precision rectifier finds application in a number of measurement and instrumentation systems. Earlier op-amps were used to implement precision rectifiers by connecting diodes in their feedback loops. Due to very high gain those circuits were capable of rectifying voltages even in millivolts. However in high frequency regions op-amps would not be a good choice because of their finite slew rates. The operational transresistance amplifier (OTRA) can be used as an alternate active block for low voltage rectification in high frequency range. This paper presents an OTRA based half wave rectifier (HWR). Its operation is validated through SPICE simulation, wherein OTRA is implemented using current feedback operational amplifier (CFOA) which is commercially available as AD844 IC. The simulation results are in conformation with the proposed theory.

1. Introduction

DC power supply is an important part in most of the electrical, electronic and instrumentation systems. Rectifier is the most essential part of any DC power supply which converts AC supply into equivalent DC voltage. The rectifier converts bi-polar waveform to uni-polar one. Rectifiers also find applications in AC voltmeters, signal polarity detectors, averaging circuits, peek value detectors, and amplitude modulated signal detectors.

In general the pn junction diodes are used for rectification [1]. However because of their cut-in voltage limitation (0.7V for Silicon, 0.2V for Germanium), they cannot rectify signals below cut-in voltages. Therefore for signals having excursions smaller than diode cut-in voltage, simple diode based rectifier would not be an appropriate choice. For low voltage rectification Precision rectifiers are used. Conventionally precision rectifiers are implemented with diode connected in the feedback loop of op-amp [2, 3]. Due to very high gain of opamp these circuits are capable of rectifying small voltages. However in high frequency regions op-amps would not be a good choice because of their finite slew rates.

In past few decades current mode processing have gained attention of designers due to some of their very attractive attributes such as wider bandwidth, low voltage operation, and absence of parasitic capacitances. The Operational Trans Resistance Amplifier (OTRA) is one of the current mode processing blocks [4]. It is a current input voltage output device with input and output, both impedances being low. The OTRA also has a very high transresistance gain, ideally infinite. The input terminals of OTRA are virtually grounded, so both the terminals are free from parasitic capacitance. Due to this OTRA becomes eventually free from slew rate limitation.

A number of precision rectifiers designed using various current mode building blocks are available in literature [5-16] which provide either current [5-10] or voltage [11-16] output. Most of practical circuits are voltage driven therefore the circuits which provide current outputs cannot be used directly to feed the voltage mode circuits. The current signal need to be converted to voltage signal thus increasing the number of active blocks.

The circuits detailed in [11-16] are designed using active block Current Conveyor or its variant. These structures provide voltage output but at high output impedance level, which is not suitable for impedance matching purpose.

This paper presents OTRA based HWR which provides voltage output at appropriate impedance level and may be used for low voltage and high frequency applications.

2.Proposed Circuit

The OTRA is a high gain current input voltage output analog building having its bandwidth virtually independent of closed loop gain. The circuit symbol of OTRA is given in Fig.1. and the terminal behaviour of OTRA can be represented by the matrix given in (1)
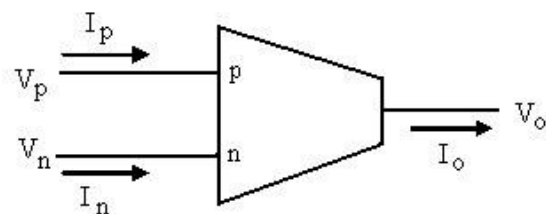

Fig.1: Symbol of OTRA

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

The circuit for half wave rectifier is shown in Fig.2. This circuit consists of two OTRAs and an NMOS switch. The OTRA1 is configured as inverter and OTRA2 as a comparator. The Output of OTRA1 is connected to the source of NMOS whereas that of OTRA 2 is connected to gate of NMOS. The NMOS conducts for negative half cycle of the input waveform as the output of comparator is positive during this cycle. Thus only half cycle is available at the drain of transistor thus providing the rectification. Similarly the rectification of positive half cycle may also be obtained if NMOS is replaced by PMOS switch.
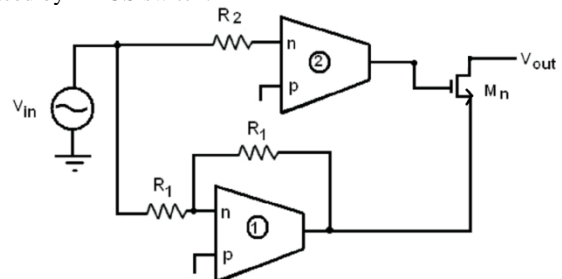

Fig.2: OTRA based precision Half Wave Rectifier

The current differencing property of the OTRA makes it possible to implement the resistors connected to the input terminals of OTRA, using MOS transistors with complete non linearity cancellation [4]. Each resistor can be implemented using two matched n-MOSFETs connected in a manner as shown in Fig. 3.
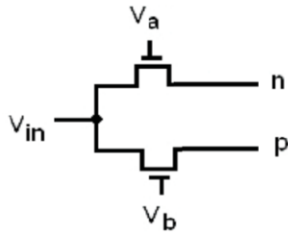
Fig.3 MOS Based Resistor

The voltages at the drain and the source terminals for both MOSFETs are equal as both p and n terminals of OTRA are virtually grounded. On taking the difference of the currents flowing in the two transistors, the non linearity gets cancelled out. The value of the resistor realized, can be computed using following equation

$$R = \frac{1}{K_N(V_a - V_b)} \tag{2}$$

Where

$$K_N = \mu_n C_{ox}(W/L) \tag{3}$$

The K_N needs to be determined for the transistors being used to implement the resistors. The value of resistance can be electronically tuned by varying V_a or V_b. The MOS realization of the proposed circuit is shown in Fig. 4.
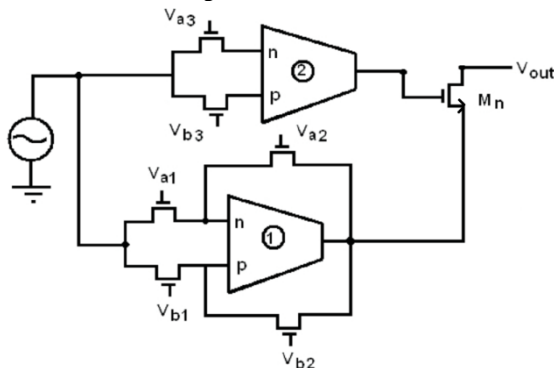

Fig. 4 The MOS realization of the proposed circuit.

3. Realization of OTRA and Simulation Results

To proposed structure is validated through SPICE simulation. For simulation the OTRA is realized using two AD844 CFOA ICs as shown in Fig. 3.
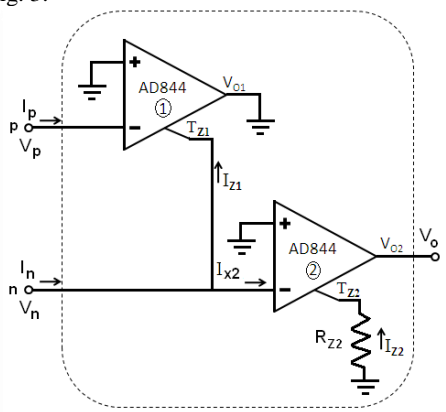

Fig. 3 The AD844 based realization of OTRA [17]

Various currents can be evaluated as

$$I_{z1} = I_p \tag{4}$$
$$I_{x2} = I_n - I_{z1} \tag{5}$$
$$I_{z2} = I_{x2} \tag{6}$$

From (4) and (5), the current through z_2 terminal can be calculated as

$$I_{z2} = I_n - I_p \tag{7}$$

The voltages at various ports may be written as

$$V_p = V_{1-} = V_{1+} = 0 \tag{8}$$

$$V_n = V_{2-} = V_{2+} = 0 \tag{9}$$
$$V_o = V_{z2} = -I_{z2}R_{z2} = (I_p - I_n)R_{z2} \tag{10}$$

Ideally the input resistance at the "x" terminal of CFOA is zero and at the Z terminal it is infinite. Practically, for AD844 CFOA the value of input resistance R_x is around 50Ω and Rz is around 3MΩ.

The SPICE schematic of the circuit is shown in Fig 4. Supply voltages of ±15 volts are used for simulation purpose. The input signal and the corresponding inverted signal at the output of OTRA inverter is shown in Fig 5(a) and the rectified output is shown in Fig. 5(b).
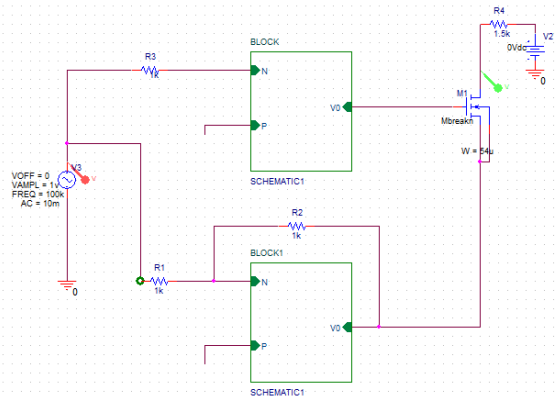

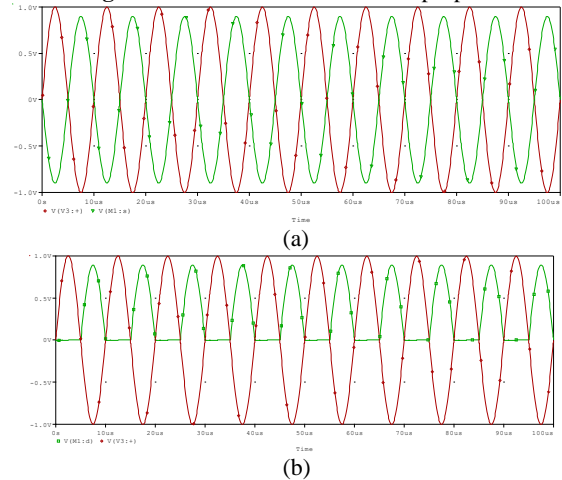**Fig. 4** The SPICE schematic of the proposed circuit

(a)

(b)

Fig. 5. Input waveform and (a) output of OTRA inverter (b) output waveforms of Half Wave Rectifier

4. Conclusions

Rectifiers are one of the important requirements in instrumentation measurement and number of other electronic systems. Conventionally rectifiers are designed using diodes. Due to cut in voltage requirement of the diode, the low voltage rectification is done with precision rectifiers designed using op-amp and diodes. However, these op-amp based circuits are not suitable for high frequency applications due to their slew rate limitations.

In this paper a precision half wave rectifier is proposed using OTRA and MOS as a switch. The resistances used in the circuit can also be realised using MOS transistor for the integration purpose. The proposed circuit is validated through SPICE simulations and results are in close approximation with proposed theory.

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