New active diode with bulk regulation transistors and its application to integrated voltage rectifier circuit

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ABSTRACT

This paper describes new active diode with bulk regulation transistors and its application to the integrated voltage rectifier circuit for a biological signal measurement system with smartphone. The conventional active diode with BRT has the dead region which causes leak current, and the output voltages of the application (e.g. voltage rectifier circuit) decrease. In order to overcome these problem, we propose new active diode with BRT which uses the control signal from the comparator of active diode to eliminate the dead region. Next we apply the proposed active diode with BRT to the integrated voltage rectifier circuit. The proposed active diode with BRT and voltage rectifier circuit were fabricated using 0.6 μm standard CMOS process. From experimental results, the proposed active diode with BRT eliminates the dead region perfectly, and the proposed voltage rectifier circuit generates + 2.86 V (positive side) and - 2.70 V (negative side) under the condition that the amplitude and frequency of the input sinusoidal signal are 1.5 V and 10 kHz, respectively, and the load resistance is 10 kΩ.

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1. INTRODUCTION

Improving the quality of life and increasing healthspan is become global concern and challenges, therefore, measuring the own vital data is necessary for management of health on a daily basis. Many researchers focus on realizing the biological signal measurement systems [1]-[7]. Our research group tries to realize the battery less measurement system for biological signals by using a smartphone. This system positively use the function of a smartphone, which are the earphone output and the microphone input with A/D converter. In detail, the conditioning of the biological signal is done by an amplifier and filter, and this signal is inputted through the microphone terminal of the smartphone. This analog signal is converted to digital signal by A/D converter built-in a smartphone and this signal is analyzed by the application program on the smartphone. On the other hand, the outer circuits for conditioning the analog signal are needed the supply voltage. The supply voltages are generated by the smartphone as follows. The sinusoidal signals are generated by application program on the smartphone and its signals are outputted through the earphone terminal. These sinusoidal signals (AC signals) are converted to DC voltages using a voltage rectifier circuit designed by our research group. The voltage rectifier circuit consists of diodes, and in many cases, the parasitic diodes of MOSFET are used for integrated version. In this way, the proposed system can be connected to signal conditioning circuits through the earphone and microphone terminals only. However, the conventional voltage rectifier circuit has disadvantages. The diodes have a potential barrier which is approximately 0.7 V, therefore, using parasitic diodes is difficult to apply for the low voltage applications. Furthermore, in the case of using the parasitic diodes of MOSFET, the bulk terminal of MOSFET should be connected to V_{SS} (or lowest voltages of the circuit), however, since the input of the parasitic diodes of MOSFET is sinusoidal signal in many cases, the polar of the input signal is changed every second. In order to these problems, the active diode with bulk regulation transistors (BRT) was proposed [8]-[10]. However, the conventional active diode with BRT has the dead region that the output voltage is indeterminate value. Therefore, the leak current is occurred in the conventional active diode with BRT. As the results, the performance of the application circuit using the conventional active diode with BRT such as the operation range, current consumption etc degrades.

In this research, we propose new active diode with BRT firstly. The proposed active diode with BRT can be realized adding an inverter to conventional one and has no dead region. Next, we propose the new integrated voltage rectifier circuit using the proposed active diode with BRT. The proposed circuits were implemented by using 1-poly, 3-metal, single n-well, 0.6 μm CMOS process. The effectiveness of the proposed circuits are shown in this paper through the experimental results.

2. CONVENTIONAL ACTIVE DIODE WITH BRT

Figure 1 shows the circuit schematic of conventional active diode with BRT which is consisted of three MOSFETs and one comparator [8]-[10]. The operation of the active diode with BRT shown in Figure 1 is different in the two voltage ranges that are $V_A > V_B$ and $V_A < V_B$, where V_A is terminal voltage of A and V_B is terminal voltage of B.

In the case of $V_A > V_B$, the terminals A and B are become the source and drain terminals respectively. As the results, the output of comparator becomes high, then M_1 turns off, and M_2 and M_3 turn on and off respectively. Therefore the terminal C is connected to terminal A (it is indicated the bulk of M_1 connect to own source terminal). In the case of $V_A > V_B$, the terminals A and B are become the drain and source terminals respectively. As the results, the output of comparator becomes low, then M_1 turns on, M_2 and M_3 turn off and on respectively. Therefore, the terminal C is connected to own source terminal.

From the above explanation, the terminal C, which is bulk terminal of M_1, is always connected to own source terminal. In this way, the leak current through the bulk terminal (the parasitic diodes of M_1) can be prevented. That is to say, the conventional active diode with BRT behaves like a diode with the threshold voltage of 0 V.

However, the conventional active diode with BRT shown in Figure 1 has a problem in the switching operation of M_2 and M_3. Because Vin is AC signal (sinusoidal wave), M_1 and M_3 operate not only stable states of ON and OFF but also in the transitional region (dead region) which is not ON and OFF states. That is to say, the voltage of terminal C (V_C) is an indeterminate value in the dead region and the dead region is depend on the threshold voltage of MOSFET (V_T).

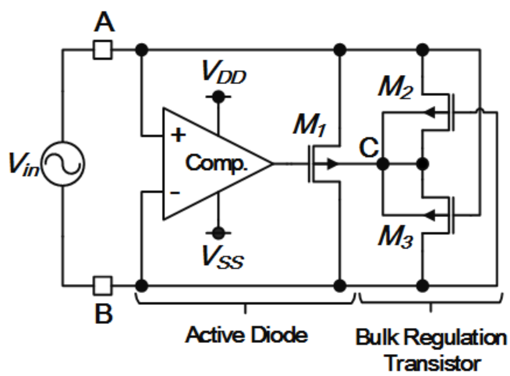

Figure 1. Conventional active diode with BRT

3. PROPOSED ACTIVE DIODE WITH BRT

Figure 2 shows the circuit schematic of the proposed active diode with BRT. In order to overcome the dead region, the output of the comparator (V_{comp}) is used for the switching signal of M_2 and M_3 because

Vcomp does not output a voltage in the dead region but outputs the digital signal of High (V_{DD}) or Low (V_{SS}). In the actual design, an inverter is added for the switching control of M_2, as shown in Figure 2.

The operation of the proposed active diode with BRT is almost same with conventional one. The differential of the operation of the proposed and conventional circuits is switching of BRT. V_{comp} is a digital signal, therefore the gate voltages of M_2 and M_3 are also digital signal. As the results, M_2 and M_3 turn ON or OFF in the moment. In this way, we can overcome the dead region problem.

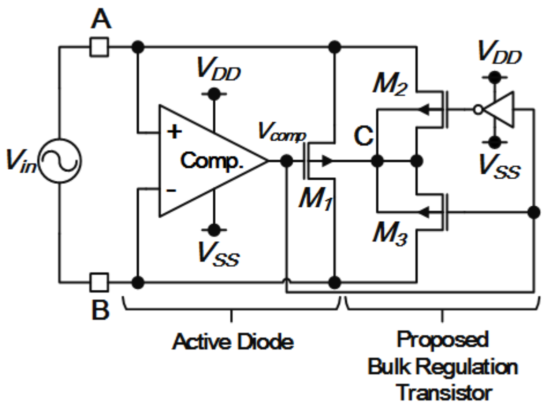

Figure 2. Proposed active diode with BRT

4. APPLICATION TO INTEGRATED VOLTAGE RECTIFIER CIRCUIT

Figure 3 shows the cisrcuit schematic of the conventional voltage rectifier circuit [8]-[10]. This circuit has two functions; one is conversion of the AC voltages to the DC voltages and the other is voltage doubler. Therefore, the output voltage of this circuit becomes the twice DC voltage of the amplitude of the input sinusoidal signal ideally. As shown in Figure 3, the circuit consists of four diodes and four capacitors. This circuit operates as follows. D_1 and C_2 constitute the well-known half-wave voltage rectifier circuit. The voltage rectifier circuit with voltage doubler can be realized by adding to D_2 and C_1. By adding D_2 and C_1, in the negative half cycle of the input sinusoidal signal, C_1 is charged and in the next positive half cycle, C2 is charged with adding the voltage of C_1. As the results, the positive voltage doubler can be achieved. In the same way, the circuit of the bottom side in the voltage rectifier circuit shown in Figure 3 also operates as the negative voltage doubler because the circuit has complementary structure of the upper side one. However, the output voltage of this circuit is decrease because the diodes has a threshold voltage. Furthermore, the problems of the stable operation and leak currents remain even if the conventional active diode with BRT is employed in stead of diode shown in Figure 3.

Figure 4 shows the circuit schematic of the proposed voltage rectifier circuit. In the Figure 4, the proposed active diode with BRT is employed in order to overcome the above problems. The voltage rectifier circuit is realized by replacing four diodes with the proposed active diode with BRT and the conventional active diode with BRT. Because the proposed circuit is designed by using single n-well process, the proposed active diode with BRT is applied to D_2 and D_3 and the conventional active diode is applied to D_1 and D_4. On the other hand, the proposed circuit can be divided to two circuit blocks as mentioned previously; positive and negative voltage doublers. Therefore, we can reduce the number of the comparators because the output signals of comparators can be shared since the circuit blocks of positive and negative voltage doublers have complementary structure each other. This contributes the reduction of the chip area and power consumption.

In the proposed circuit, two diodes can be replaced with the proposed active diodes with BRT, however, the remain two diodes cannot be replaced as mentioned previously. Therefore, the output voltage of the proposed rectifier circuit is slightly decrease compared with the ideal output. However, the output voltage of Figure 4 is drastically improved as compared with that of Figure 3.

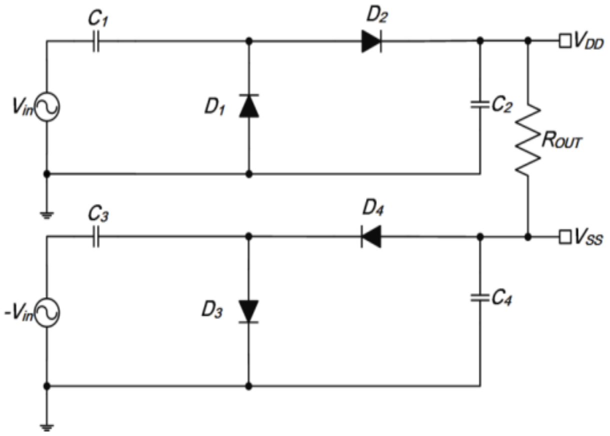

Figure 3. Conventinal voltage rectifier circuit

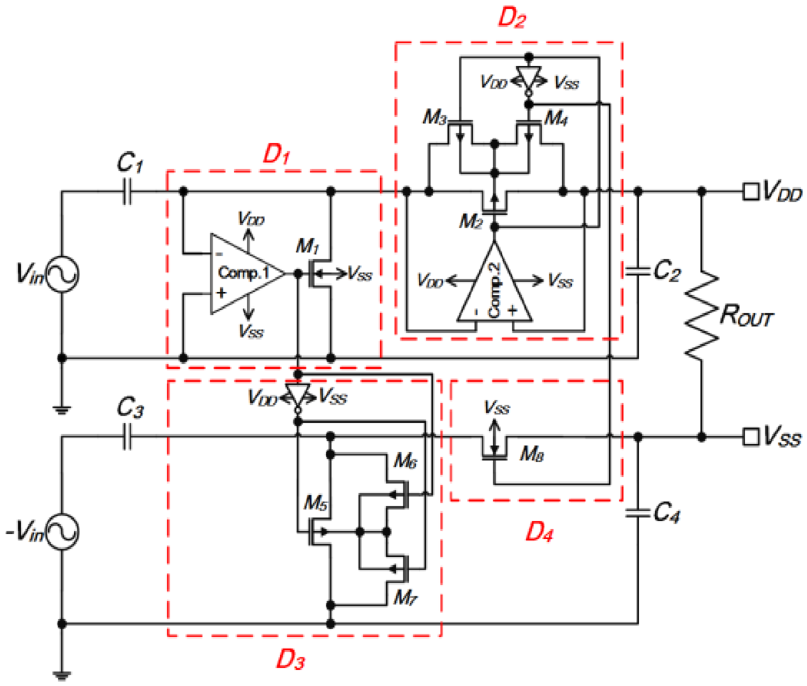

Figure 4. Proposed voltage rectifier circuit

5. SIMULATION AND EXPERIMENTAL RESULTS

The proposed active diode with BRT shown in Figure 2 and the proposed rectifier circuit shown in Figure 4 were designed and fabricated by using 1-poly, 3-metal, single n-well, 0.6μm CMOS process. The design parameters are listed in Table 1.

Table 1. Design Value of Each Devices

Item	Value
Channel Width (μm) / Channel Length (μm) of M_1, M_2, M_5, M_8	40 / 1 (10*)
Channel Width (μm) / Channel Length (μm) of M_1, M_2, M_5, M_8	10 / 1 (2*)
$C_1 - C_4$ (μF)	4.7
V_{DD} (V)	2.5
V_{SS} (V)	-2.5
Amplitude of V_{in} (V)	1.5
Frequency of V_{in} (kHz)	10

* This value means the number of parallel connection of MOSFET.

Figure 5 shows photograph of the proposed voltage rectifier. The area is 305 μm $\times$ 355 μm. Firstly, we confirmed the I-V characteristics of the proposed and conventional active diodes shown in Figure 1 and 2, respectively. As the results, we confirmed the threshold voltage of both circuits are the same and its value equals 0. Figure 6 shows the DC transfer characteristics of the the conventional and proposed active diode with BRT. In the Figure 6, the vertical and horizontal axes mean V_C and the input voltage V_{in}, respectively. From this experimental results, the dead region exist in the conventional circuits and its range is from -0.6 V to 0.6V. In contrast the results, we can confirmed that the dead region is perfectly eliminated in the proposed one. Figure 7 shows the oscilloscope photograph of the proposed voltage rectifier circuit In this experiment, the amplitude and frequency of V_{in} were 1.5 V and 10 kHz, respectively, and R_{OUT} = 10 kΩ. From this graph, we can find the proposed voltage rectifier circuit generate the positive and negative power supply voltages, and its values are +2.88 V and -2.72 V.

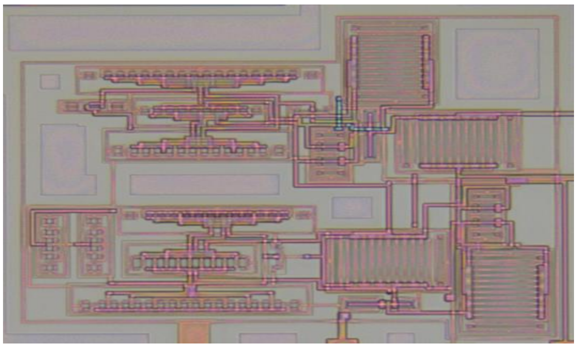

Figure 5. Photograph of the proposed voltage rectifier circuit

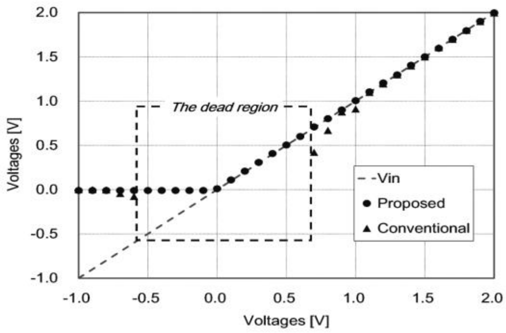

Figure 6. Relation between VC and Vin

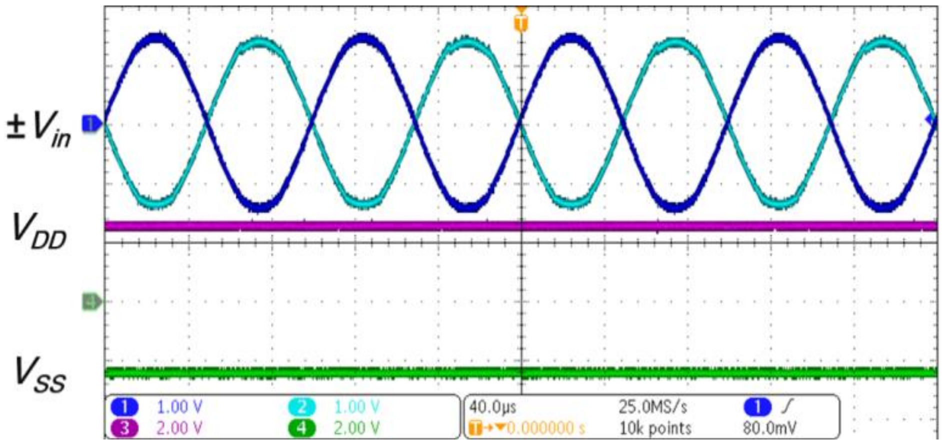

Figure 7. Oscilloscope photograph of the proposed voltage rectifier circuit

6. CONCLUSION

In this paper, new active diode with BRT and its application to integrated voltage rectifier circuit have been proposed. We could confirmed that the proposed active diode with BRT can eliminate the dead region perfectly. Additionally, its application to integrated voltage rectifier circuit can reduce the chip area and the power consumption by sharing the output voltage of comparator, furthermore, the chip area and the output voltage of the proposed voltage rectifier circuit are 305 μm $\times$ 355 μm and +2.86 V (positive side) and -2.70 V 7(negative side), respectively.

Future work is to apply the startup method for the proposed voltage rectifier circuit. In the experiment shown in Figure 7, external battery was used for power supply voltage of the comparator and inverter. However, our goal is to operate without external battery, therefore we should try to improve for the self-startup of the proposed voltage rectifier circuit.

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