

## Bidirection True Analogue Switch Based on Two CCIIIs Easy for Measuring Load Power

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### Abstract

A bidirection true analogue switch based on two third-generation current conveyors (CCIIIs) easy for measuring the load power is proposed. The proposed switch takes advantages over the previous current conveyor switches in view of the true bidirection operation, the current and voltage transfer, and the outputs for measuring the load power. Using the supply voltage of  $\pm 1.5$  V in the SPICE simulation, the proposed switch yields an operation range between  $-300$  mV and  $300$  mV with the error of lower than 1%. Moreover, the simulation shows the switching of a 1 MHz sine wave and the cutoff frequency of about 90 MHz.

**Keywords:** analogue switch, current conveyor, wattmeter

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## 1. Introduction

It has already proved in (Premont et al. 1998) and (Monpapassorn 2002) that the current conveyor analogue switches are better than the conventional analogue switches in view of the good voltage transfer, the good current transfer, and the high frequency operation. In 1998, Premont et al. originally presented an analogue switch based on two second-generation current conveyors (CCII+s) as shown in Fig. 1(a). The technique is to control the bias current of the CCII ( $I_c$ ),  $I_c = 0$  for turning-off the switch and  $I_c =$  a fixed current for turning-on. For this switch, only the voltage buffer action from node Y to node X is used, thus the switch only transfers the voltage with bidirection operation (using two CCII+s). The author further presented an analogue switch using one CCII- (Monpapassorn 2002) with transferring both the voltage and the current as shown in Fig. 1(b). However, this switch operates like one direction switch, it has been noted in (Monpapassorn 2002) that, for the precise operation, the high impedance load must be applied to B and the low impedance load must be applied to A, where A and B are the switch poles.

In this paper, the author shows that two CCIIIs can operate as an analogue switch with the improved drawbacks of the previous switches, namely, the proposed switch is the bidirection switch to be able to transfer both the voltage and the current, and the load can be connected to pole A or B. Additionally, the necessary outputs for measuring the load power are given.

## 2. Proposed switch

A CCIII was introduced by Fabre (Fabre 1995) with the voltage and current relations at nodes X, Y and Z

$$\left. \begin{aligned} I_Y &= -I_X \\ V_X &= V_Y \\ I_Z &= I_X \rightarrow \text{CCIII} + \\ \text{or} \\ I_Z &= -I_X \rightarrow \text{CCIII} - \end{aligned} \right\} \quad (1)$$

A proposed CCIII analogue switch is shown in Fig. 2 in which consists of one CCIII+ and one CCIII-. In this switch, both CCIIIs are controlled the bias current for turning-on and turning-off by one current through the current mirrors. Node Y of the CCIII+ is connected to node X of the CCIII-, the other nodes X and Y are also connected. From the above operation of the CCIII, the CCIII+ is used for transferring the voltage and current from A to B and the other is used for transferring those from B to A. Nodes Z of two CCIIIs are also connected so that the combination of their currents is the current flowing through the switch (load current), which is useful for measuring the load power. The other useful output for measuring the load power is the load voltage that can be obtained from A or B for a high input impedance wattmeter. If the input impedance of the wattmeter is low, a voltage buffer is required; we may use the buffer technique for transferring the voltage from node Y to node X of the CCII if it is easy in the CCIII process. A block for measuring the load power using the proposed switch is shown in Fig. 3. The opposite direction (positive and negative) of the load current is not the problem because this current has to be changed to the absolute current by a full-wave rectifier. In the same way, the load voltage must be changed to the absolute voltage. For the floating load, a voltage

subtractor has to be used additionally to detect the voltage across the load to supply to the wattmeter. The load power is the product between the absolute voltage and current. This voltage and current multiplier is easy to realize by using an operational transconductance amplifier (OTA).

The CCIII circuit used in this work is shown in Fig. 4. MOSs M1, M3, M4 and M6 have the same characteristics and the drain currents  $I_{DM1}$  and  $I_{DM4}$  are equal to  $I_C$  by mirroring of M11, M12, M14 and M15 as well as M1 and M13, the voltage at node Y is thus followed to node X (Bruun 1993), this makes  $V_X = V_Y$ . MOSs: M7, M8 and M17; M11, M12 and M13; M9, M10 and M18; M14, M15 and M16 operate as current mirrors. The current at node X is mirrored by M7, M8, M14, M15 and M9, M10, M11, M12 to the drains of M12 and M15 that are connected to node Y, resulting in  $I_Y = -I_X$ . The current at node X is also mirrored by M7, M17 and M9, M18 to the drains of M17 and M18 (node Z+), causing  $I_Z = I_X$ . In addition, this node X current is mirrored by M7, M8, M14, M16 and M9, M10, M11, M13 to the drains of M13 and M16 (node Z-), causing  $I_Z = -I_X$ . The circuit of the CCIII+ has no M13 and M16 and that of the CCIII- has no M17 and M18. The M2 and M5; closely matched to M1, M3, M4, and M6; may be used to follow the node Y voltage to the low input impedance wattmeter.

Because the proposed switch operates by transferring the voltage from node Y to node X, the minimum and maximum input voltages are

$$\left. \begin{aligned} V_{in(max)} &= VDD - \left| V_{eff3} \right| - \left| V_{eff7} \right| - |V_{TN}| - |V_{TP}| \\ V_{in(min)} &= VSS + \left| V_{eff6} \right| + \left| V_{eff9} \right| + |V_{TN}| + |V_{TP}| \end{aligned} \right\} \quad (2)$$

where  $V_{eff} = V_{GS} - V_T = \sqrt{2I_D / \mu C_{OX} (W/L)}$ :  $V_{GS}$  is the gate to source voltage,  $V_T$  is the threshold voltage,  $I_D$  is the drain current,  $\mu$  is the mobility of

carriers,  $C_{ox}$  is the gate capacitance per unit area,  $W$  and  $L$  are the channel width and length. The operation voltage range is  $V_{in(max)} - V_{in(min)}$ , the equation shows that the operation range depends on the supply voltage, namely, if the high supply voltage is used, the operation range will widen. Since the load ( $R$ ) is connected at node X of the operating CCIII, the load current is the current at node X that is  $V_{in}/R$ . We consider node X as the output of a voltage source, the internal resistance of the good source has to be very low, for the used CCIII, this resistance depends on the bias current  $I_C$  (Bruun 1993), i.e., if the high  $I_C$  is used, the resistance will be low. However, to consume low power, if the high resistance load is applied, the  $I_C$  can be the low current. Theoretically, the -3 dB bandwidth is equal to

$$f_{cutoff} = (R_x + R_y) / R_x R_y C_y \quad (3)$$

where  $R_x$  and  $R_y$  are the internal resistance at nodes X and Y, and  $C_y$  is the internal capacitance at node Y, of the CCIII.

The proposed switch can operate as the multiplier or divider circuit by connecting a voltage-controlled grounded resistor at node A or B of the switch, the other node of the switch as  $V_1$ , the voltage-controlled-resistor node as  $V_2$ , the load current node as  $I_{out}$ . Because of  $I = E / R$ , if the characteristic of the voltage-controlled resistor is  $R = KV_2$ , where  $K$  is the constant of the resistor, the load current will be the divider result of two voltages. On the other hand, if the characteristic of the resistor is  $R = K/V_2$ , the load current will be the multiplier result.

### 3. Simulation results

To verify the theoretical design, the proposed switch was simulated by using the parameters extracted from its layout; these parameters include the parasitic capacitance. The 0.5  $\mu\text{m}$  MOS technology of AMI was selected and its level 49 model was obtained through MOSIS. The supply voltage is  $\pm 1.5$  V. The constant current source ( $I_C$ ) for turning-on the switch is 20  $\mu\text{A}$  and for turning-off is 0  $\mu\text{A}$ . One CCIII was tested at the frequency below 5 MHz for finding the internal parasitic resistant. The results: for turning-on,  $R_y \approx R_z \approx 100 \text{ k}\Omega$ ,  $R_x \approx 350 \Omega$ ; and for turning-off,  $R_y \approx R_x \approx 10 \text{ M}\Omega$ ,  $R_z \approx 1 \text{ G}\Omega$  were found. From the switch configuration, when the switch turns on, the very high  $R_y$  and the very low  $R_x$  are preferred. The very low  $R_x$  can be obtained by using the high  $I_C$  for turning-on as already described; however, the load resistance should be considered to set the suitable  $I_C$  to obtain the low power consumption. The very high  $R_y$ , from the tested results, is achieved when the CCIII turns off. Thus, one way to obtain the very high  $R_y$  is turning-off the unused CCIII, but this method needs an additional  $I_C$  controlling circuit to separate each CCIII operation.

The operation range of the proposed switch using the load of 100  $\text{k}\Omega$  is ranged from  $-300$  mV to 300 mV with the error of lower than 1 %, as described, this error can be decreased by increasing the  $I_C$ , leading to higher power consumption. The author supplied a sine wave (1 MHz, 100 mV<sub>peak</sub>) both to A, B connected to the grounded-load, and to B, A connected to the grounded-load. The operations of the switch in both cases are the same. The operation in the first case is shown in Fig. 5. Increasing the frequencies was

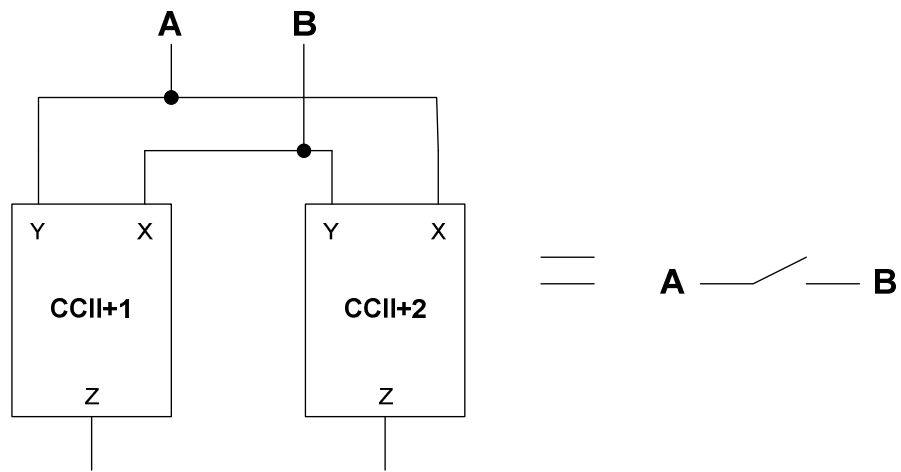
performed; the author found that the proposed switch could operate with the  $-3$  dB bandwidth of about 90 MHz.

### 4. Conclusion

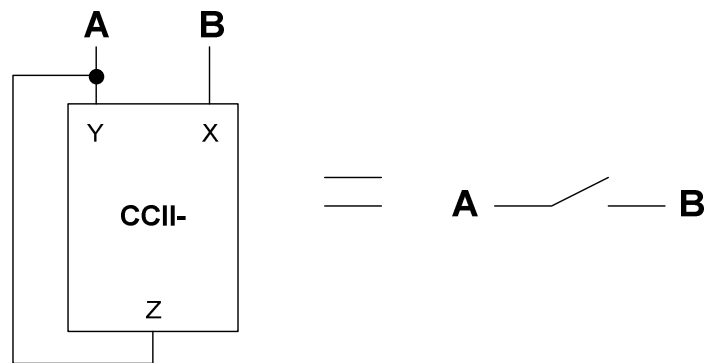
In this paper, the author has reported a bidirection true analogue switch based on two CCIIIs, which is easy for application to measure the load power. The proposed switch can transfer both the voltage and the current. The load is free to connect to pole A or B. The load voltage and current outputs are given. The proposed switch can operate as the multiplier or divider circuit by adding a suitable voltage-controlled grounded resistor. The proposed switch is suitable for applications needing the high operation linearity and frequency.

### 5. References

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(a)



(b)

Fig. 1 Previous current conveyor analogue switches:

(a) proposed by Premont et al. and (b) proposed by Monpapassorn

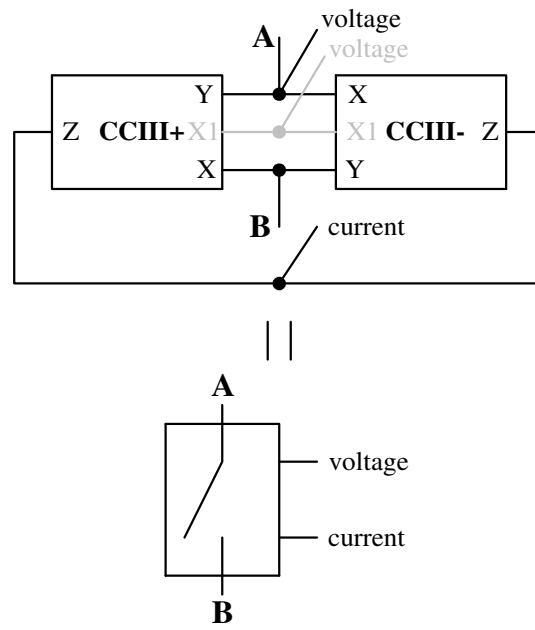


Fig. 2 Proposed CCIII analogue switch

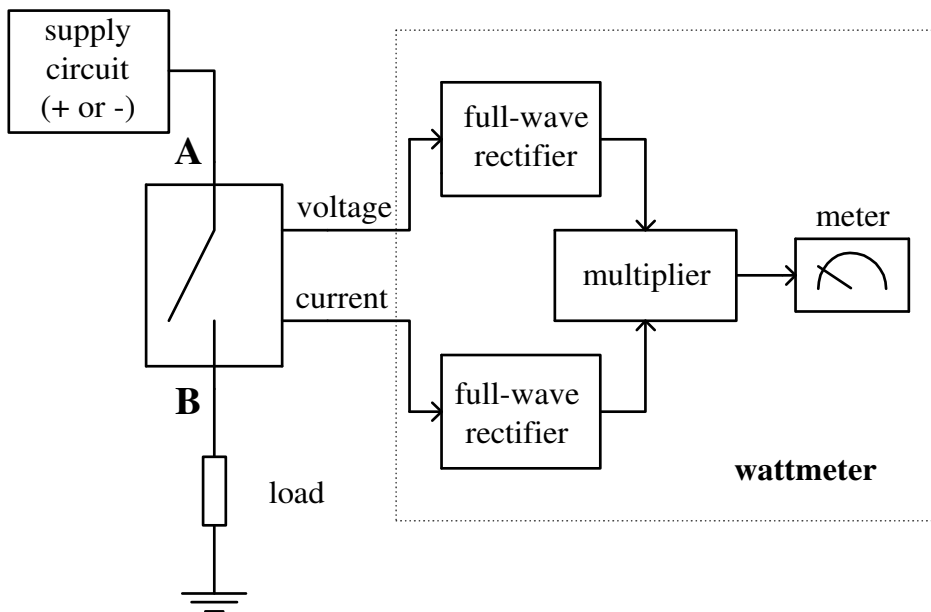


Fig. 3 Measuring the load power using the proposed switch

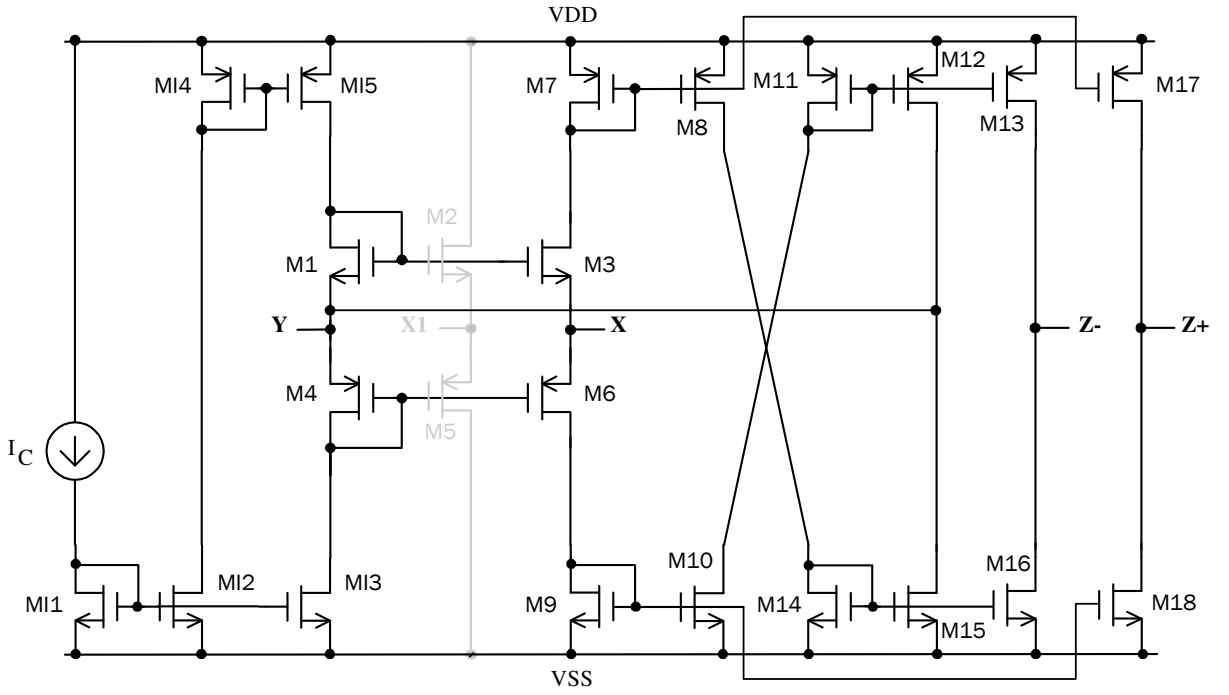


Fig. 4 CCIII circuit used in this work

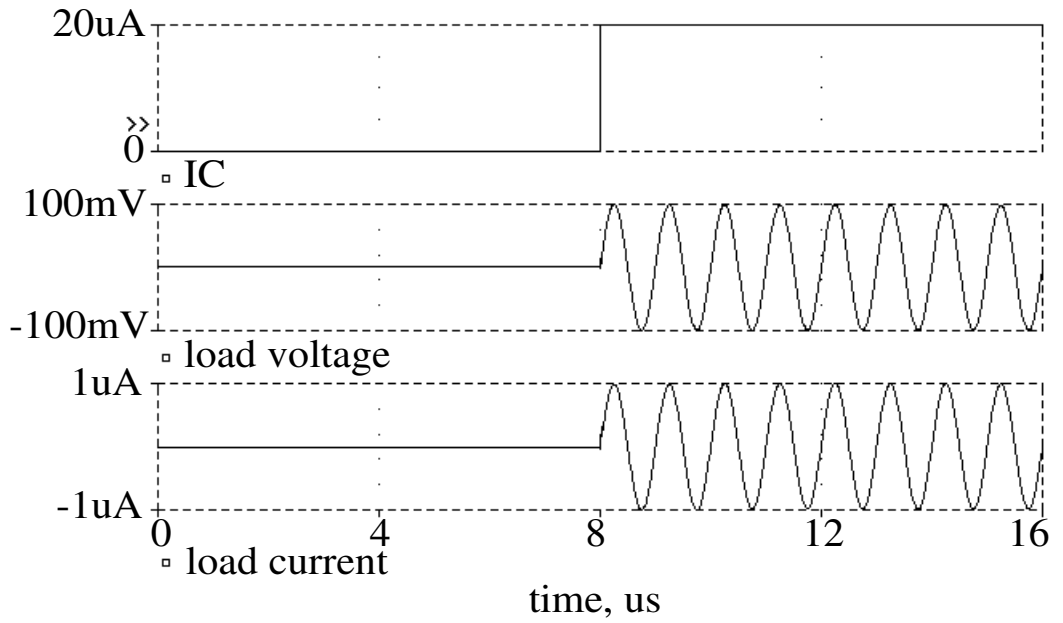


Fig. 5 Operation of the proposed analogue switch