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LOW OFFSET COMPARATORS
BASED ON CURRENT COPIERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 This disclosure relates generally to comparators, and in particular, to comparators and circuits based on current copiers.

2. Description of the Related Art

10 In some comparators such as a standard differential pair comparator, input device threshold mismatch and transconductive parameter mismatch causes voltage offsets. Comparators using current mirrors have such voltage offsets, since current mirror load contributes to offset and must be adjusted for accurate operation. Offset voltages are often
15 stored on capacitors and subsequently subtracted from input signals to adjust for the offset. The storage and subtraction process may be slow, since comparators are generally placed in a closed feedback loop arrangement during the offset cancellation process. In use with analog-
20 to-digital (A/D) and digital-to-analog (D/A) converters, such slow adjustment for offset limits the speed of the conversion process.

25 In some comparator circuits which adjust for offset effects, currents may be stored so as to be proportional to a reference, with an input signal being fed to an input device, and clock feedthrough suppressed. However, such comparators are also subject to such slow adjustment of offset. Offset adjustment is also required for other circuits such as flash converters and the like. It would be
30 advantageous to reduce or cancel offset effects as well as increase comparison processing speed without closed loop calibration and without direct switch charge injection at the input of the comparator.

SUMMARY

35 An integrated circuit including a comparator having

reduced offset and based on current copiers is disclosed, including an input node; a reference node; an input device for receiving a reference signal from the reference node during a first comparison cycle, for receiving an input
5 signal from the input node during a second comparison cycle, and for converting the input signal and the reference signal to an input current and a reference current, respectively; and a current copier for storing the reference current during the first comparison cycle, and for generating a
10 comparison signal from the stored reference current and the input current during the second comparison cycle.

The current copier may include a switch for closing during the first comparison cycle; and a transistor which responds to the closing of the second switch for storing the
15 reference current during the first comparison cycle. An adjustment circuit, coupled to the input device and the current copier, is included for generating an underestimate current as a first portion of the reference current; and the current copier responds to the underestimate current to
20 storing a second portion of the reference current to reduce an offset in the generation of the comparison signal.

An amplifier may be included for enhancing a gain associated with the generation of the comparison signal. The amplifier may include a plurality of transistors in a
25 cascode arrangement between the input device and the current copier to enhance the gain. The comparison functional output is produced at the node connecting the input device and current copier. The voltage at this node rises when the current stored in the current copier is larger than that
30 generated by the input device, if no other path for charge flow exists at this node.

An improved flash converter is also disclosed using the disclosed comparators.

BRIEF DESCRIPTION OF THE DRAWINGS

35 The features of the disclosed low offset comparators

and flash converters and method of operation based on current copiers will become more readily apparent and may be better understood by referring to the following detailed description of an illustrative embodiment of the present invention, taken in conjunction with the accompanying drawings, where:

FIG. 1 illustrates a block diagram of the disclosed comparator;

FIG. 2 illustrates an exemplary circuit of the disclosed comparator;

FIG. 3 illustrates clock pulse signals;

FIG. 4 illustrates an inverter;

FIG. 5 illustrates resistor strings of a flash converter;

FIG. 6 illustrates an alternative embodiment of a comparator;

FIG. 7 illustrates a variable threshold inverter; and

FIG. 8 illustrates a differential comparator.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now in specific detail to the drawings, with like reference numerals identifying similar or identical elements, as shown in FIG. 1, the present disclosure describes low offset comparators and flash converters based on current copiers. In these disclosed devices, the offset associated with mismatch of input devices in a comparator is eliminated by using only one input device which is time-shared between the two input signals. The input device converts each signal in succession into a current. A current copier stores one of these signals while the input device produces the other signal, and the two currents are then compared.

To compensate for offset, the comparator of the present disclosure uses a single input device, switched between the input signal and a reference, and a similarly switched

sampling circuit. In an exemplary embodiment, as shown in FIG. 1, the comparator 10 receives an input signal 12 which is switched by switch 14 to an input device or circuit 16. This circuitry is typically incorporated in an integrated circuit (IC). The input device 16 converts the input signal 12 to a current which is stored by a sampling circuit 18 operatively connected to the input device 16. In operation, the comparator 10 uses the switch 14, the input device 16, and the sampling circuit 18 to generate an output 20 as the comparison signal of the input signal 12 with a reference signal. The comparator 10 may include or may be operatively connected to a controller 22 for controlling the switch 14 and the sampling circuit 18. Such a controller 22 may be incorporated in a control mechanism of an integrated circuit including or connected to the comparator 10 in a manner known in the art.

The comparator 10 of FIG. 1 may optionally include an adjustment circuit 24 connected to the input device 16 and the sampling circuit 18 to underestimate a reference signal to improve the adjustment for offset by the comparator 10. The comparator 10 may also include an amplifier 26 to enhance gain during a comparison phase.

In the exemplary embodiment of the comparator 10 shown in FIG. 2, the comparator 10 receives an input voltage V_{IN} and a reference voltage V_{REF} as input signals 12 for comparison. The input signals 12 are switched by switches 32, 34, respectively, of switch 14. Such switches 32, 34 may be embodied as transistors such as metal oxide semiconductor field effect transistors (MOSFETs) which respond to clocking pulses to drive the input device 16. It is understood that other types of transistors and equivalent circuits may be employed in a manner known in the art.

The switched input signals 12 are applied to the input device 16 which may be, for example, a MOSFET operatively connected to a drain voltage V_{dd} 28 and a source voltage V_{ss}

30. The input device 16 is operatively connected to the sampling circuit 18 and the output 20. In an exemplary embodiment, the sampling circuit 18 is a current copier, as described in S.J. Daubert et al., "Current Copier Cells",
5 ELECTRONICS LETTERS, VOL. 24, NO. 25, Dec. 1988, pp. 1560-1562. The current copier 18 includes a MOSFET 36 and a switch 38. In the exemplary embodiment, the gate capacitance of the MOSFET 36 is sufficient for operation of the current copier 18; otherwise, a capacitor 40 may be
10 provided in the current copier 18.

The devices 50, 52, if present, enhance the performance in a manner to be described. If not present, that is, with a short circuit replacing the drain to source path of each, the comparator 10 still operates.

15 In operation, the controller 22 or, alternatively, an independent clock source, provides clocking pulses to switches 32, 34, 38, as illustrated in FIG. 3. The switch 38 of the current copier 18 receives pulse 54, labelled C_1 , while switches 34, 32 receive pulses 56, 58, respectively,
20 which are labelled C_2 , C_3 , respectively. In particular, when a pulse is high or active, the corresponding switch is closed (i.e. conducting).

When C_1 and C_2 are active, i.e. switches 38, 34, respectively, are closed, the input device 16 generates a
25 current flowing through MOSFET 36 approximately given by

$$I_{REF} = k_1 \left(\frac{W}{L} \right)_1 (V_{REF} - V_{T1})^2 \quad (1)$$

where k is a constant, and W and L are the width and length of the channel, respectively, and V_{T1} is the threshold voltage of the MOSFET. When C_1 goes low, the gate voltage of the MOSFET 36 corresponding to the above current is
30 stored by the capacitor 40. Switch 32 may then be opened; i.e. when C_2 goes low.

When C_3 goes high while C_1 is low, as in FIG. 3, the

input device 16 generates a current having magnitude

$$I_{IN} = k_1 \left(\frac{W}{L} \right)_1 (V_{IN} - V_{T1})^2 \quad (2)$$

The two currents from the input device 16 and the MOSFET 36 are thus in conflict, and the voltage at the output 20 indicates which of these two currents is larger.

- 5 If the reference voltage V_{REF} is higher than the input voltage V_{IN} , the output voltage rises and is interpreted as a logic decision.

Both of the compared currents are generated successively by the same input device 16, and so $k_1 W/L$ and
10 V_{T1} cancel. When the comparator 10 is operated fast enough to allow junction leakage to be neglected, the comparator 10 suffers no significant source of offset other than that created by switch 38.

Feedthrough from switch 38 of the current copier 18
15 introduces an error in the current stored in the current copier 18. The drain current of MOSFET 36 is:

$$I_2 = \beta_2 (V_{sg2} - V_{T2})^2 \quad (3)$$

and the drain current of the input device 16 is:

$$I_1 = \beta_1 (V_{gs1} - V_{T1})^2 \quad (4)$$

The charge feedthrough of switch 38 results in a change in the source-gate voltage of MOSFET 36 equal to ΔV ,
20 resulting in an offset which may be calculated as:

$$V_{OFFSET} = \Delta V \sqrt{\frac{\beta_2}{\beta_1}} \quad (5)$$

which is input-referred.

In the disclosed comparator 10, offset is minimized by minimizing the ratio β_2/β_1 by adjusting the parameters W and

L of the input device 16 and the MOSFET 36.

In an alternative embodiment, to avoid excessive V_{sg2} , an adjustment circuit 24 may be included, as shown in FIG. 2. The adjustment circuit 24 is operatively connected to the input device 16, the current copier 18, and the output 20 by connection 42. The adjustment circuit 24 includes a MOSFET 44 coupled to the V_{REF} , and a pair of MOSFETs 46, 48, with the drain of MOSFET 48 operatively connected to the input device 16, the sampling circuit 18, and the output 20. The adjustment circuit 24 operates such that the current i_x flowing through connection 42 from MOSFET 48 is an underestimate of the current I_{REF} , and the MOSFET 36 carries the remainder; i.e. $I_{REF} - i_x$. The adjustment circuit 24 does not provide an additional source of offset when i_x is less than I_{REF} . If i_x is a large fraction of I_{REF} , the parameters of the input device 16 and MOSFET 36 may be determined to minimize β_2/β_1 . In this exemplary embodiment, the comparator 10, including the adjustment circuit 24 shown in FIG. 2, does not have the same drain currents at the input device 16 and the MOSFET 36, so the offset voltage is:

$$V_{OFFSET} = \Delta V \frac{g_{m2}}{g_{m1}} \quad (6)$$

Therefore, both of the factors:

$$\sqrt{\frac{\beta_2}{\beta_1}} \quad \text{and} \quad \sqrt{\frac{I_{d2}}{I_{d1}}} \quad (7)$$

contribute to the reduction in offset by the current copier 18 using switch 38.

In the above exemplary embodiments, the source of the input device 16 and the MOSFET 44 of the adjustment circuit are connected to the common source voltage V_{ss} 30. In another exemplary embodiment, bias conditions may be

established by including a source of bias current between the sources of MOSFETs 16, 44 and V_{ss} , to provide a tail current I_{BIAS} . The tail current I_{BIAS} allows for independent control of V_{REF} and I_{REF} with no additional offset effects.

5 When so included, the equations (1)-(2) are modified, but equations (5)-(7) remain valid.

In alternative embodiment to the comparator 10 in FIG. 2 including the adjustment circuit 24, the current copier 18 may be a bidirectional current copier, which does not
10 require that i_x is less than I_{REF} .

Other gain-enhancement techniques known in the art may be employed as the amplifier 26 to increase amplification during the comparison stage; i.e. when C_j is high. In an exemplary embodiment shown in FIG. 2, the amplifier 26 is a
15 pair of MOSFETs 50, 52 forming a cascode circuit, with the output 20 connected to the sources of MOSFETs 50, 52, and the sources of the input device 16 and the MOSFET 36 connected to the drains of MOSFETs 50, 52, respectively.

In another alternative embodiment shown in FIG. 4, a
20 comparator circuit 60 employs the arrangement of a current copier 18 and switched inputs with switches 32, 34, 38 as described above for reducing offset, as well as a cascode arrangement of MOSFETs 62, 64 for gain enhancement. Input device 16 and MOSFET 36 perform an inverter function, and
25 another inverter 66 connects the cascode arrangement to the output 68. In an exemplary embodiment, the MOSFETs 62, 64 are low threshold devices, but alternatively the gate of MOSFET 64 may be connected to an independent bias voltage source. MOSFET 70 provides means by which the reference
30 current may be controlled, in a manner to be described in conjunction with the circuit shown in FIG. 5.

As described above in conjunction with FIG. 3, as switches 34, 38 close, the gates of the n-channel MOSFETs 16, 64 are connected to the reference voltage V_{REF} and the
35 current is copied to MOSFETs 36, 62 in the current copier

18. The inverter 66 buffers the output. As switch 32 closes, the input signal V_{IN} is connected to the gates of MOSFETs 16, 64, and the load at the output 68 retrieves the copied current stored in the current copier 18. A
5 comparison of V_{IN} with V_{REF} is then made with reduced offset. As the magnitude of V_{REF} increases the current stored may become excessive. The p-channel device 70 with its gate connected to V_{BIAS} enables this current to be controlled.

The disclosed use of current copiers and switched input
10 signals to reduce offset has further applications. For example, in a flash converter 2^N comparators are used to obtain n-bits of resolution, and the comparators should be simple and fast. As shown in FIG. 5, flash converters use strings 72, 74 of resistors to produce multiple reference
15 levels as reference voltages V_{R1} , V_{R2} , V_{R3} , V_{R4} . Such resistor strings cause variation in a copied current over a wide range of current values, especially as the current is related to the square law characteristics of the MOSFETs.

The variations of current may be avoided using
20 complementary metal oxide semiconductors (CMOS), such as a series combination of a pair of complementary devices 76, 78 as shown in FIG. 5. In the exemplary embodiment, two resistor strings 72, 74 are used which are current biased, and MOSFETs 80, 82 provide that the currents in the input
25 devices of each comparator in the flash converter are approximately the same within a matching accuracy. The pairs 76, 78 of FIG. 5 may then be used as the input device including MOSFETs 16, 70 in FIG. 4 to operatively connect multiple comparators embodied in FIG. 4 as a flash
30 converter.

For comparators connected to, for example, a first resistor string 72, low threshold devices are not essential for cascoding since a second resistor string 74 is available for biasing the cascode devices. Taps from the second
35 resistor string 74 may be used to obtain cascode bias

voltages. In a further alternative embodiment, the comparator 84 in FIG. 6 provides complementary loading, so it may be used for higher reference level values of V_{REF} approaching V_{dd} in FIG. 5.

5 In another alternative embodiment, as illustrated in FIG. 7, a class AB push-pull version 86 of the current copying comparator is disclosed. With both of switches 92, 104 closed, transistors 90, 96 perform the equivalent function of transistors 16, 36, respectively, in FIG. 6. At
10 the same time, complementary transistors 88, 98 perform the same function. When switch 94 is closed, the comparison occurs and an output is obtained at output node 102 through the inverter 100 as a buffer. An optional capacitor 106 may be included, as shown in FIG. 7.

15 In a further alternative embodiment, a differential comparator 108 having low offset is shown in FIG. 8 which connects reference voltages V_{rp} , V_{rn} (positive and negative, respectively), and input voltages V_{inp} , V_{inn} (positive and negative) to switches 110-116, respectively, where switches
20 110, 112 are clocked by pulse C_2 in FIG. 3, and switches 114, 116 are clocked by pulse C_3 . Switches 110-114 are connected to input devices 118, 120, to current copiers including switches 122, 124 which are clocked by pulse C_1 , and MOSFETs 126, 128, with an optional capacitor 130 and
25 current bias 132. Output nodes 134, 136 are positive and negative outputs of the differential comparator 108.

While the disclosed low offset comparator and method have been particularly shown and described with reference to the preferred embodiments, it is understood by those skilled
30 in the art that various modifications in form and detail may be made therein without departing from the scope and spirit of the invention. Accordingly, modifications such as those suggested above, but not limited thereto, are to be considered within the scope of the invention.



CLAIMS:

1. An integrated circuit (IC) including a comparator comprising:

- an input node;
- 5 a reference node;
- an input device for receiving a reference signal from the reference node during a first comparison cycle, for receiving an input signal from the input node during a second comparison cycle, and for converting the input signal and the reference signal to an input current and a reference current, respectively; and
- 10 a current copier for storing the reference current during the first comparison cycle, and for generating a comparison signal from the stored reference current and the input current during the second comparison cycle.
- 15

2. The integrated circuit of claim 1 wherein the current copier includes:

- a switch for closing during the first comparison cycle;
- 20 a transistor, responsive to the closing of the second switch, for storing the reference current during the first comparison cycle.

3. The integrated circuit of claim 1 further including:

- 25 an adjustment circuit, coupled to the input device and the current copier, for generating an underestimate current as a first portion of the reference current; and
- the current copier, responsive to the underestimate current, for storing a second portion of the reference current to reduce an offset in the generation of
- 30 the comparison signal.

4. The integrated circuit of claim 1 further



including:

an amplifier for enhancing a gain associated with the generation of the comparison signal.

5. The integrated circuit of claim 4 wherein the
5 amplifier includes:

a plurality of transistors in a cascode arrangement between the input device and the current copier to enhance the gain.

6. The integrated circuit of claim 1 wherein the
10 current copier generates a high comparison signal if the reference signal is greater than the input signal.

7. A comparator comprising:

a reference switch for connecting a reference node to an input device during a first comparison cycle;

15 an input switch for connecting an input node to the input device during a second comparison cycle;

the input device including an input transistor having a first and second conductive element, the input device for receiving a reference signal at the first
20 conductive element from the reference node during a first comparison cycle, for receiving an input signal at the first conductive element from the input node during a second comparison cycle, and for converting the input signal and the reference signal to an input current and a reference
25 current, respectively; and

a current copier including:

a copier transistor having a first and second conductive element, the first conductive element operatively connected to the first conductive element of the first
30 transistor; and

a copier switch for closing during the first comparison cycle and for opening during the second



comparison cycle, the copier switch for operatively connecting the first and second conductive elements of the second transistor during the first comparison cycle for storing the reference current, the second transistor
5 responsive to the opening of the copier switch to receive the input current, to generate a comparison signal, and to reduce an offset associated with the comparison signal from the stored reference and the input current during the second comparison cycle.

10 8. The comparator of claim 7 further including:
 an amplifier having:

 a first transistor operatively coupling the copier transistor to an output node;

 a second transistor in a cascode arrangement
15 with the first transistor and operatively coupling the output node to the input transistor; and

 wherein the first and second transistors respond to the input current and the stored reference current for enhancing a gain associated with the generation
20 of the comparison signal.

 9. The comparator of claim 7 wherein the current copier generates a high comparison signal if the reference signal is greater than the input signal, thereby generating an inverted signal of the input signal with reference to the
25 reference signal.

 10. The comparator of claim 7 wherein:
 the input device is time-shared between the input signal and the reference signal to convert each respective signal in succession to a corresponding current.

30 11. In an improved flash converter for converting an input signal, the flash converter having a series of



resistive elements for generating a plurality of reference voltages, having a plurality of comparators with each comparator associated with a respective reference voltage at respective reference nodes, the improvement comprising:

5 each comparator including:

 a first switch for switching between an input node and a reference node;

 an input device for receiving the reference voltage from the respective reference node during a first
10 comparison cycle, for receiving an input signal from the input node during a second comparison cycle, and for converting the input signal and the reference voltage to an input current and a reference current, respectively; and

 a current copier for storing the reference
15 current during the first comparison cycle, and for generating a respective comparison signal from the stored reference current and the input current during the second comparison cycle.

12. The improved flash converter wherein the
20 improvement further includes:

 the input device of each comparator including complementary metal oxide semiconductor (CMOS) transistors to reduce variation in copied reference currents.

13. A method for generating a comparison signal with
25 reduced offset comprising the steps of:

 receiving an input signal at an input node;
 receiving a reference signal at a reference node;
 receiving at an input device a reference input
signal from the reference node during a first comparison
30 cycle;

 generating a reference current from the reference signal;

 switching a copier switch during the first



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comparison cycle;

storing the reference current in a current copier during the first comparison cycle;

receiving at the input device an input signal from
5 the input node during a second comparison cycle;

generating at the input device an input current during the second comparison cycle; and

generating a comparison signal from the stored reference current and the input current during the second
10 comparison cycle to reduce offset thereof. *