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Demirdag et al.

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(54) **CHARGE COMPARATOR WITH LOW INPUT OFFSET**

(58) **Field of Classification Search**
USPC 341/172, 161, 155
See application file for complete search history.

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(73) Assignee: **Kenet, Inc.**, Reading, MA (US)

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(21) Appl. No.: **12/322,658**

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Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **7,173,558**
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Appl. No.: **11/175,994**
Filed: **Jul. 6, 2005**

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U.S. Applications:

(60) Provisional application No. 60/585,611, filed on Jul. 6, 2004.

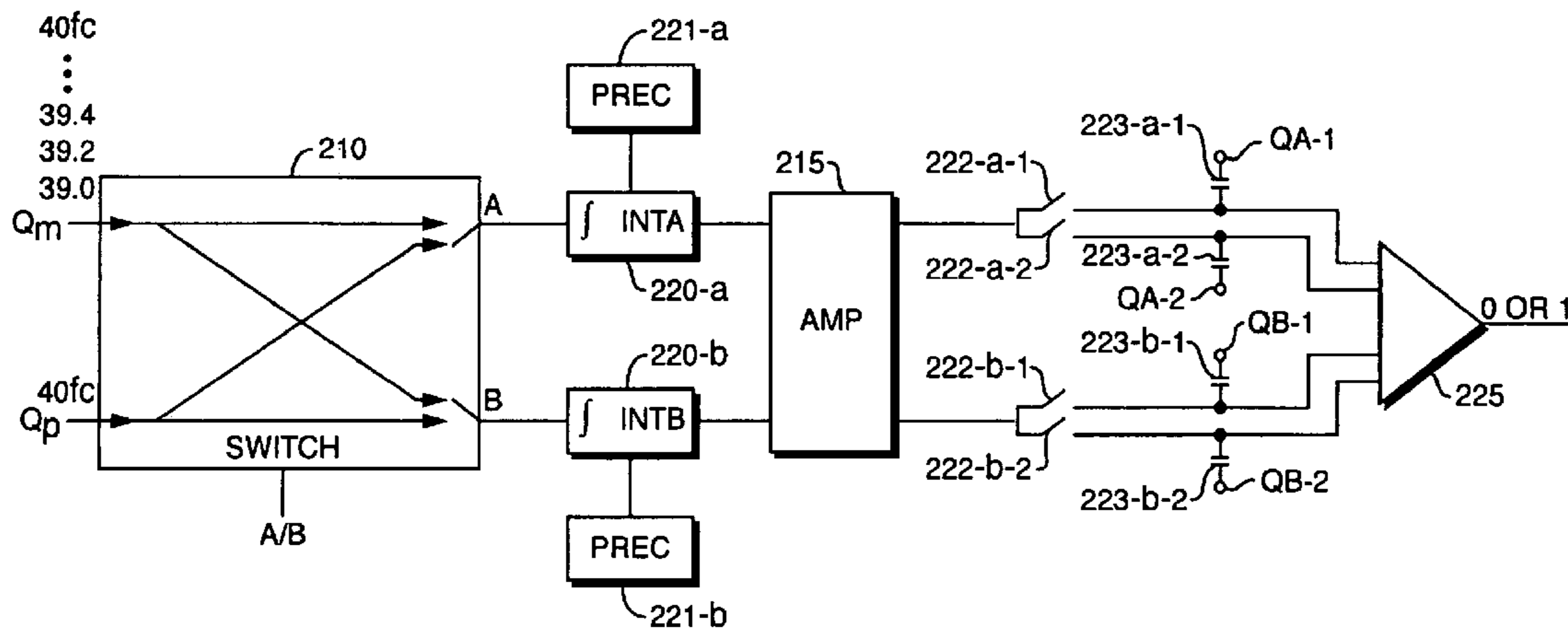
(57) **ABSTRACT**

A Direct Current (DC) charge comparator that provides low input offset by feeding complimentary plus and minus charge inputs to a single amplification path via an alternate input path switch. Multiple sample and hold circuits at the output of the amplification path permit comparison of the result when each of the charge inputs travels down each of the paths, to determine a correction.

(51) **Int. Cl.**
H03M 1/12 (2006.01)

(52) **U.S. Cl.**
USPC 341/172; 341/161

21 Claims, 4 Drawing Sheets



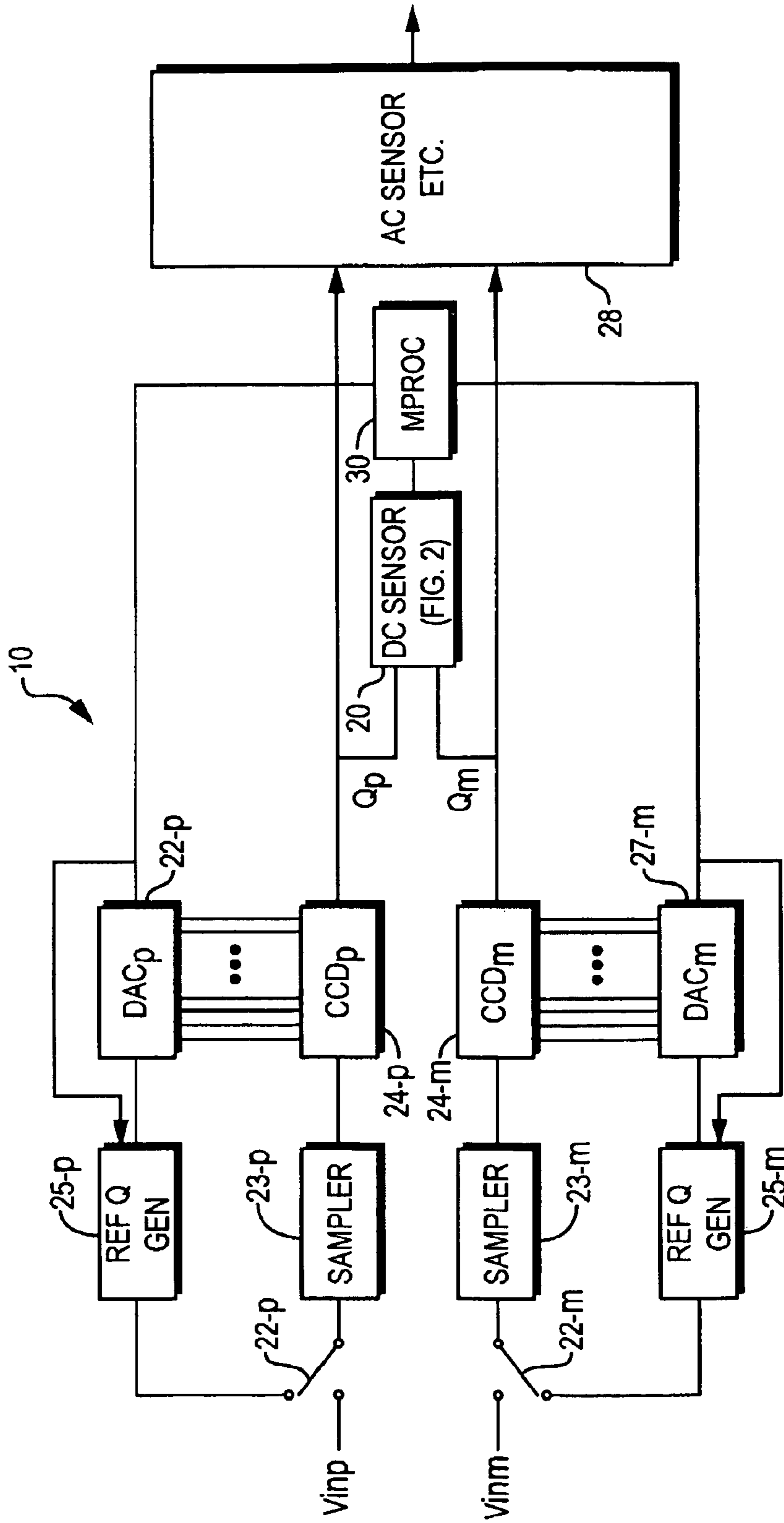


FIG. 1

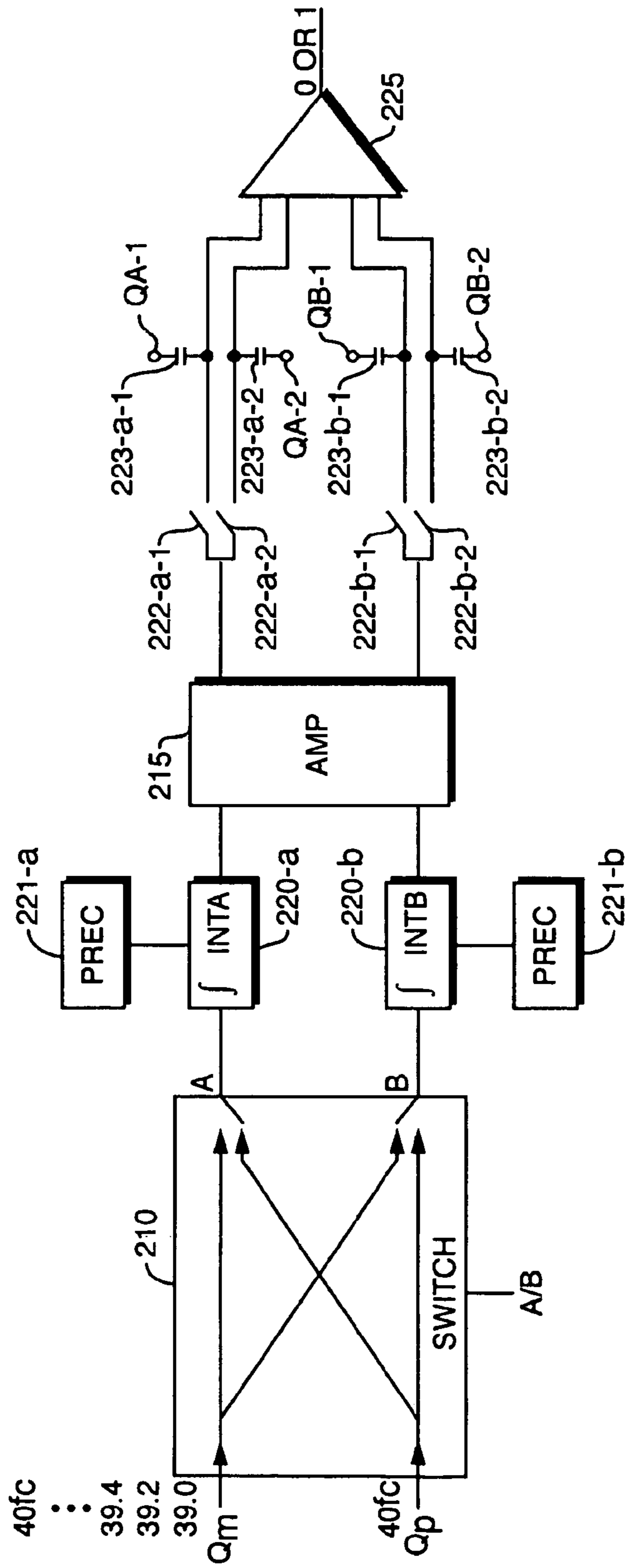


FIG. 2

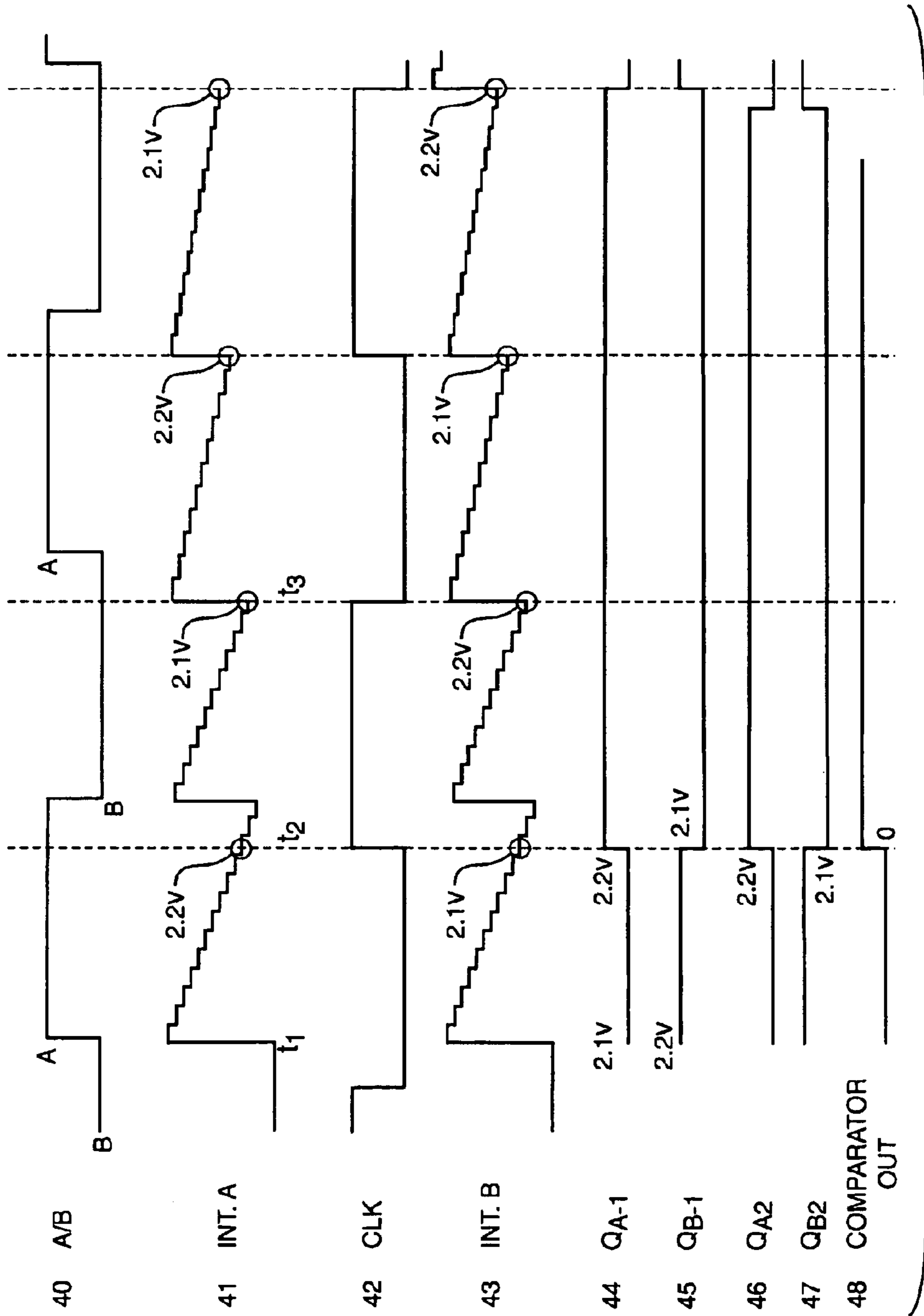


FIG. 4

CHARGE COMPARATOR WITH LOW INPUT OFFSET

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/585,611, filed on Jul. 6, 2004, the entire content of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to charge comparators, especially those which may be used with Charge Coupled Device (CCD) pipeline-based structures.

Circuits for performing signal processing functions are now common in numerous consumer devices such as digital cameras, cellular telephones, wireless data network equipment, audio devices such as MP3 players, video equipment such as Digital Video Disc (DVD) players, High Definition Digital Television (HDTV) equipment and numerous other products. It is well known that Charge Coupled Devices (CCDs) circuits may be used to implement many of the signal processing functions required in such products.

One circuit, called a Charge to Digital (QDC) converter, is used to convert an input analog voltage to digital data. One way to implement a QDC is as a successive approximation type converter that includes a number of charge storage stages arranged as a serial pipeline register. The input signal voltage is typically represented as a pair of complimentary charges which are processed in positive (plus) and negative (minus) signal paths. In this type of converter, the complimentary input charges pass from stage to stage down respective pipelines dedicated to processing the plus and minus signals.

One critical component of a QDC is the reference charge comparator used at each stage. The reference charge comparator compares an input charge amount to a reference charge amount, and then optionally adds a reference charge amount to each charge as it travels through the stage.

Accurate comparison of the charge input to each stage is therefore an extremely important part of assuring overall QDC accuracy. Unfortunately, Direct Current (DC) and/or Analog Current (AC) offset input errors can be introduced into these charge comparator circuits quite easily.

In a differential QDC, if a different input offset is introduced in the plus path than in the minus path, this can also result in erroneous results. Even a slight offset in the amount of a reference charge comparison result can thus have a ripple effect as the charges pass down multiple pipeline stages.

SUMMARY OF THE INVENTION

The invention is a Direct Current (DC) charge comparator that provides low input offset. Low offset is achieved through a single final amplification path using an alternate path switch and a track and hold input circuits.

More particularly, the two complimentary charge inputs are each first fed to a cross point switch. In a first state, the switch sends the input plus signal charge down a first path to first output and the minus signal charge down a second path to a second output. This is called the "non-inverted" condition. After a time, the state of the switch is swapped, so that the plus

charge travels down a path to the second output, and so that the minus charge down a path to the first output. This is called the "inverted" condition of the switch.

The charges appearing at each switch output are then integrated, and the integrated outputs are then sampled and stored, such as by storage capacitors. The storage capacitors can be precharged to a preset voltage before the switch state is swapped and the output sampled and stored again. These outputs are preferably tracked by a sample and hold circuit, to avoid spikes close to the comparator decision times.

The output of the sample and hold circuit is then typically amplified before further processing.

The circuit thus provides a pair of outputs, in each of two different states. One pair of output represents the amplified and sampled plus and minus inputs in the non-inverted switch state, and another pair of outputs represents the amplified and sampled plus and minus inputs in the inverted switch state.

These outputs are then compared, preferably by using a differential difference amplifier, so that the response to a plus input in the non-inverted condition (that is, due to the plus charge traveling along one path) is compared to the response to a plus input in the inverted condition (that is, due to the plus charge traveling along the other path). The minus charges are similarly compared.

Since the input offset is amplified in the same way for both the inverted and non-inverted switch conditions, the input offset is effectively cancelled by the difference amplifier. As a result, any input charge differences are more accurately determined.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. 1 is a high level diagram of a Charge to Digital (QDC) converter that may use a DC sensor according to the present invention.

FIG. 2 is a more detailed block diagram of the DC sensor.

FIG. 3 is a detailed circuit diagram of portions of the DC sensor.

FIG. 4 is a timing diagram for the DC sensor.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

A description of preferred embodiments of the invention follows.

FIG. 1 is a block diagram of device 10 that may use a Direct Current (DC) sensor 20 according to the present invention. The illustrated device 10 is a Charge to Digital converter (QDC), but it should be understood that the DC sensor 20 may be used in other types of circuits adopted for processing charge packets.

QDC 10 is a so-called successive approximation type converter that uses a number of charge storage stages arranged as a serial pipeline register. In this type of converter, generally speaking, an input source charge passes from stage to stage along the pipeline. A reference charge generator and a charge splitter connected to each stage generate a reference charge signal for that stage. The reference charge signal is then optionally added to the charge as it travels down the pipeline,

depending upon the comparison result. In the illustrated circuit there are actually two pipelines. That is, charges are carried in the circuit as complimentary pairs, which correspond to a complimentary representation of the input signals. In general, the overall operation of QDC **10** is similar to the QDC described in U.S. Pat. No. 5,579,007 issued to Paul.

It is desirable to be able to compare the charges at the outputs of the two pipelines. The present invention relates to an improvement in the accuracy of a charge comparison operation carried out within QDC **10**. Referring to FIG. **1** more particularly, an input voltage is presented as a complimentary pair of voltages, V_{inP} and V_{inM} , representing a positive (plus) and a negative (minus) version of the input signal to be converted. Switches **22-P** and **22-M**, one for each of the plus and minus paths, provide the selected input signal to a corresponding sampler **23-P** and **23-M**.

The samplers **23** each convert their respective input voltage to a charge. The charges output by the samplers **23** are then fed to an input stage of a respective charge pipeline **24-P**, **24-M**. The charge pipelines **24** may each use a Charge Coupled Device (CCD) analog shift register. The plus and minus paths through the converter **10** also have a respective Digital to Analog (DAC) ladder **27-P**, **27-M**. Although not pertinent to the present invention, it should be noted that each charge ladder **27** has a number of internal reference charge generators and a number of adjustable charge splitters.

The DC sensor **20** is used for comparing the output charge from plus CCD pipeline **24-M** to the output of minus CCD pipeline **24-P** calibrates the circuit **10** in such a way that a low input offset is provided. The basic idea is to provide a circuit that determines a difference between the charges provided in the complimentary charge paths, by periodically swapping the connection between the inputs and the comparison circuits.

FIG. **2** shows one embodiment of DC sensor **20** in more detail. In this embodiment, DC sensor **20** consists of an input cross point (A/B) switch **210**, integrators **220-A**, **220-B**, pre-chargers **221-A**, **221-B**, amplifier **215**, sampling switches, **222-A-1**, **222-A-2**, **222-B-1**, **222-B-2**, sampling capacitors **223-A-1**, **223-A-2**, **223-B-1**, **223-B-2** and output difference amplifier **225**. Positive and negative charges, Q_M , Q_P , such as may be provided by the CCD pipelines **24-P**, **24-M** are first received at the switch **210**. The charges may be input at a relatively high clock rate of, for example, 100 Megahertz (MHz) or higher.

The switch **210** allows for either the plus charge Q_M or the minus charge Q_P to be fed to the respective switch **210** output port A or B. Thus, in a first or "non-inverted" state, the switch **210** feeds Q_M to output A and Q_P to output B; in the other, or "inverted" state, switch **210** feeds charge Q_P to output A and Q_M to output B.

The A/B state or mode of the switch is changed at a rate which is somewhat slower than the input sample rate. In one embodiment, for example, the A/B toggle rate may be $1/48^{th}$ of the input charge sample rate.

The respective outputs of the switch **210** therefore are a series of charges that for a length of time correspond to the signal charges provided on input Q_M , followed by a series of the signal charges provided on input Q_P for a subsequent length of time, then followed again by a series of the charges on input Q_M , then the Q_P charges again, etc.

The switch outputs A and B can thus be thought of as having two states—a normal or "non-inverted" state when the switch **210** is in one position, and an inverted state when the switch is **210** is in the other position.

There is an integrator **220-A**, **220-B** associated with each of the A and B outputs. The integrators **220** are of the pre-

chargeable type such that they are recharged to a preset voltage by the respective pre-charger **221** before each cycle of operation.

An amplifier **215** provides amplified versions of the integrator outputs for further processing. In particular, the integrator outputs are amplified and then fed to a set of four sampling switches **222-A-1**, **222-A-2**, **222-B-1**, **222-B-2** and four sampling capacitors **223-A-1**, **223-A-2**, **223-B-1**, and **223-B-2**. There is a sampling switch **222** and corresponding capacitor **223** for storing each possible combination of switch state and input signal path—that is separate a sampling switch is provided for storing the integration result when (1) charge Q_P is coupled to switch port A, (2) charge Q_M is coupled to switch port B, (3) charge Q_P is coupled to switch port B, and (4) charge Q_M is coupled to switch port A.

The resulting pair of differential, sampled charges (carried on the four capacitor outputs) are then compared using the differential difference amplifier **225**. Since the input offset is amplified the same way for both the inverted and non-inverted input charge conditions (i.e., for both modes of the switch **210**) any difference is effectively cancelled by the difference amplifier **225**. Therefore, only the input charges themselves end up being compared, and any input offset is cancelled.

The output of the difference amplifier, which may be a digital bit, can then be fed back to control circuits such as a reference charge input, or calibration circuits.

A more detailed circuit diagram of certain portion of the DC charge comparator **20** is shown in FIG. **3**. The input switch **210**, integrator pre-charge circuits **221**, integrating capacitors **223**, as well as a first stage of amplifier **220** are shown in much greater detail in this drawing. As shown the input charges Q_P and Q_M are fed to a respective portions of the input switch **210**. The input switch **210** consists of four transistors arranged in pairs. The first transistor pair **310-1** and **310-2** are coupled to receive the plus charge Q_P , and transistor pair **311-1** and **311-2** are arranged to receive the minus charge Q_M . In accordance with the state of the A/B input signal, the transistor pairs select their respective input charges to be passed along one of two outputs, either drain P1 or drain M1.

Thus, in a first mode where the A/B input is set to the A state, input charge Q_P will be fed to the drain P1 output and the input charge Q_M will be fed to the drain M1 output; when the input A/B is switched to the B mode, input charge Q_P is steered to the drain M1 output and input charge Q_M is steered to the drain P1 output.

A precharge circuit **221** is used to precharge the integrating capacitors. Specifically, precharge circuit **221** consists of a pair of transistors **313-1**, **313-2** that respectively receive the drain P1 and drain M1 signals. The gates terminals of these transistors **313** are controlled by a clock input K_{PCH} that determines the precharger state.

Integrating capacitors **314** are arranged to be fed to be coupled to the source terminals of respective transistors **313-1** and **313-2**. Although four (4) capacitors are shown (with a pair of capacitors being necessary to provide the required capacitance for each path) other configurations for capacitors **314** are possible.

The integrated signals are then fed to an amplifier **215** in the preferred embodiment they are first fed, however, through a preamplifier **318**. The preamplifier **318** consists of a pair of transistors **320-1**, **320-2** for amplifying each of the respective signal paths. A reference voltage may be provided to control these preamplifiers **318** via reference stages **322-1**, **322-2**.

The result is to provide a pair of voltages V_{IM1} and V_{IP1} to the amplifier **215** that represent the plus and minus signal paths after they have been sampled and held and after they

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have been subjected to the operation of the input switch **210**. In particular, signal V_{IM1} will for a period of time have a value associated with it that depends on the value of the input charge Q_P , and for a period of time then correspond to the value of input charge Q_M . Likewise, V_{IP1} will for a time have a value that depends upon input charge Q_M , and then take on a value for a period of time that depends on input charge Q_P .

FIG. 4 is a set of timing diagrams that further explain the operation of the DC charge comparator circuit **20**.

The top signal trace **40** represents the A/B state of the mode switch **210**.

Recall that a reference charge is fed to the input of the DC sensor **20**. For the sake of the following discussion, let us assume an example situation where there is a slight difference in the amount of the reference charge fed to the two signal paths. In the example scenario shown in FIG. 4, an input reference charge of about 40 femto-coulombs (fc) is provided to the plus charge path Q_P , but an input reference charge of only 39 fc is provided to the minus Q_M path.

The output of integrator A (**220-A**) is shown in signal trace **41**. With the switch set in the A mode, after being pre-charged at time **T1**, the integrator output will slowly ramp down as each successive charge is fed through the pipeline. Eventually, a time **T2** is reached that corresponds to the rising edge of a clock signal fed to the sampling switch **222**. At this point, the remaining charge on the integrator **220-A** is approximately 2.2 volts. This voltage will then be stored by the sampling capacitor **223-A-1** so that its output, Q_{A-1} , is also set to 2.2 volts, as shown in trace **44**.

In a similar operation, the integrator **220-B** for signal path B will be pre-charged at time **T1** and gradually reach a particular voltage at time **T2**. This final voltage will be different for the B path, at 2.1 volts for example, due to the difference on charge Q_M . This voltage will be stored in the capacitor **223-B-1** as output Q_{B-1} as shown in trace **45**.

When the state of the A/B switch **210** changes again, the input charges fed to paths A and B are also swapped. Thus, the outputs of the integrators will also have been swapped at time **T3**, the output of integrator **220-A** will be at 2.1 v, and the output of integrator **220-B** will be at 2.2 v.

These voltages will then be stored on the corresponding capacitors **223** as output Q_{A-2} shown in trace **46** and Q_{B-2} shown in trace **47**.

Therefore, due to the difference in input charge Q_M and Q_P of only about one (1) femto-coulomb, the comparator output signal **48** will stay at a logic 1 or high logic state. The signal can then be fed back to the microprocessor **30** to effect an adjustment to the reference charge generators **25-P**, **25-M** to increase the level of Q_M . When Q_M is increased to a level larger than Q_P , the comparator output will switch to logic 0 or low state. In the illustrated example, it is suggested by FIG. 2 that adjustments will be made such that the charge Q_M is gradually increased from 39 fc up to 40 fc, eventually reaching a point where the two input charges are equal.

Since the input offset is amplified through the same path for both the inverted, and non-inverted switch states, it is effectively cancelled by the difference amplifier and only differences in the input charges are compared.

Among the novel aspects believed to exist with the present invention is the use of a redirecting switch or "chopper" to feed a pair of integrators, to compare the integrator result at a first time with that as of a second time.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various

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changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

What is claimed is:

1. A charge comparator comprising:

a switch connected to receive a pair of charge inputs as a plus charge input and a minus charge input, with the switch having a first state wherein the plus signal charge is coupled to a first output and the minus signal charge is coupled to a second output, and a second state wherein the plus charge input is coupled to the second output and the minus charge input is coupled to the first output;

a pair of charge integrators, connected to the first and second switch outputs, to provide a first integrated output signal and a second integrated output signal;

a pair of sample and hold circuits, connected to sample and hold respective ones of the first and second integrated output signals; and

a difference amplifier, coupled to the pair of sample and hold circuits, to determine a difference between the outputs of the sample and hold circuits.

2. A charge comparator comprising:

a switch connected to receive a pair of charge inputs as a plus charge input and a minus charge input, with the switch having a first state wherein the plus signal charge is coupled to a first output and the minus signal charge is coupled to a second output, and a second state wherein the plus charge input is coupled to the second output and the minus charge input is coupled to the first output;

a pair of charge integrators, connected to the first and second switch outputs, to provide a first integrated output signal and a second integrated output signal;

a pair of sample and hold circuits, connected to sample and hold respective ones of the first and second integrated output signals;

a difference amplifier, coupled to the pair of sample and hold circuits, to determine a difference between the outputs of the sample and hold circuits; and

a signal amplifier, connected to the output of the integrators, to provide an amplified output thereof.

3. A charge comparator as in claim 2 additionally comprising:

a second pair of sample and hold circuits, connected to cooperate with the first pair of sample and hold circuits, such that in a first mode, the first pair of sample and hold circuits stores respective integrated charge samples from the plus charge input and minus charge input, and such that in a second mode, the second pair of sample and hold circuits stores the plus signal charge and the minus signal charge, respectively.

4. A charge comparator as in claim 3 wherein the difference amplifier is connected to determine the difference between the output of the first pair of sample and hold circuits in a first mode and is connected to determine a difference in the outputs between the second pair of sample and hold circuit outputs in a second mode.

5. A charge comparator as in claim 2 wherein the charge integrators integrate the respective input charges over multiple clock periods prior to operating the sample and hold circuit.

6. A charge comparator as in claim 2 additionally wherein the difference amplifier compares a charge integrator result at a first time with a charge integrator result a second time, such that a plus charge input applied with the switch in one state is compared with the plus charge input with the switch compared in another state.

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7. A charge comparator as in claim 2 wherein the amplifier output in a non-inverted switch state is compared to an amplifier output in an inverted switch state, such that when fed to the differential difference amplifier any input offset is amplified in the same way for both the inverted and non-inverted switch conditions, to cancel an input offset.

8. A charge comparator as in claim 1 additionally comprising:

a second pair of sample and hold circuits, connected to cooperate with the first pair of sample and hold circuits, such that in a first mode, the first pair of sample and hold circuits stores respective integrated charge samples from the plus charge input and minus charge input, and such that in a second mode, the second pair of sample and hold circuits stores the plus signal charge and the minus signal charge, respectively.

9. A charge comparator as in claim 8 wherein the difference amplifier is connected to determine the difference between the output of the first pair of sample and hold circuits in a first mode and is connected to determine a difference in the outputs between the second pair of sample and hold circuit outputs in a second mode.

10. A charge comparator as in claim 1 wherein the charge integrators integrate the respective input charges over multiple clock periods prior to operating the sample and hold circuit.

11. A charge comparator as in claim 1 additionally wherein the difference amplifier compares a charge integrator result at a first time with a charge integrator result a second time, such that a plus charge input applied with the switch in one state is compared with the plus charge input with the switch compared in another state.

12. A charge comparator as in claim 1 wherein the amplifier output in a non-inverted switch state is compared to an amplifier output in an inverted switch state, such that when fed to the differential difference amplifier any input offset is amplified in the same way for both the inverted and non-inverted switch conditions, to cancel an input offset.

13. An apparatus for converting an input charge to a digital value comprising:

a first charge pipeline for accepting a first pipeline charge input, and providing a first pipeline charge output;

a second charge pipeline for receiving a second pipeline charge input, and providing a second pipeline charge output;

the first and second charge pipeline inputs representing the input charge as a complimentary pair of input charges;

a first and second reference charge generator, for generating, respectively, a first and second reference charge representing a complimentary pair of reference charges;

a first and second charge domain digital-to-analog converter, coupled to respective ones of the first and second reference charge generators and coupled to respective ones of the first and second charge pipelines, to provide a first and second output charge representative of a complimentary pair of digital values; and

a charge offset sensor coupled to the first and second charge pipeline outputs, the charge offset sensor having a first sensor state wherein the first pipeline charge output is coupled to a first sensor output and the second pipeline charge output is coupled to a second sensor output, a second sensor state wherein the first pipeline charge output is coupled to the second sensor output and the second pipeline charge output is coupled to the first sensor output,

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a pair of charge integrators, connected to the first and second sensor outputs, to provide a first integrated output signal and a second integrated output signal and the charge sensor further determining a charge offset introduced by the apparatus by comparing the first integrated output signal provided in the first sensor state to the second integrated output signal provided in the second sensor state, and for also comparing the second integrated output signal provided in the first sensor state to the first integrated output signal provided in the second sensor state.

14. A method for charge comparison comprising:

receiving a complimentary pair of signal charge inputs as a plus charge input and a minus charge input;

in a first state, coupling the plus charge input to a first output and the minus charge input to a second output, in a second state, coupling the plus charge input to the second output and the minus charge input to the first output;

integrating the first and second outputs to provide a first integrated output signal and a second integrated output signal;

a first step of sampling and holding respective ones of the first and second integrated output signals in the first state, to provide first and second sample and hold output signals;

a second step of sampling and holding respective ones of the first and second integrated output signals in the second state, to provide third and fourth sample and hold output signals; and

determining a difference between the first and second sample and hold output signals and the third and fourth sample and hold output signals.

15. An apparatus for converting an input charge to a digital value comprising:

a first charge pipeline for accepting a first pipeline charge input, and providing a first pipeline charge output;

a second charge pipeline for receiving a second pipeline charge input, and providing a second pipeline charge output;

the first and second charge pipeline inputs representing the input charge as a complimentary pair of input charges;

a first and second reference charge generator, for generating, respectively, a first and second reference charge representing a complimentary pair of reference charges;

a first and second charge domain digital-to-analog converter, coupled to respective ones of the first and second reference charge generators and coupled to respective ones of the first and second charge pipelines, to provide a first and second output charge representative of a complimentary pair of digital values; and

a charge offset sensor coupled to the first and second charge pipeline outputs, wherein charge offset sensor further comprises:

a switch connected to receive a pair of charge inputs as a plus charge input and a minus charge input, with the switch having a first state wherein the plus signal charge is coupled to a first output and the minus signal charge is coupled to a second output, and a second state wherein the plus charge input is coupled to the second output and the minus charge input is coupled to the first output; and a pair of charge integrators, connected to the first and second switch outputs, to provide a first integrated output signal and a second integrated output signal.

16. An apparatus as in claim 15 wherein the charge offset sensor further comprises:

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a pair of sample and hold circuits, connected to sample and hold respective ones of the first and second integrated output signals.

17. An apparatus as in claim 16 wherein the charge offset sensor further comprises:

a difference amplifier, coupled to the pair of sample and hold circuits, to determine a difference between the outputs of the sample and hold circuits.

18. An apparatus as in claim 17 wherein the charge offset sensor further comprises:

a signal amplifier, connected to the output of the integrators, to provide an amplified output thereof.

19. An apparatus as in claim 17 additionally comprising: a second pair of sample and hold circuits, connected to cooperate with the first pair of sample and hold circuits, such that in a first mode, the first pair of sample and hold circuits stores respective integrated charge samples

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from the plus charge input and minus charge input, and such that in a second mode, the second pair of sample and hold circuits stores the plus signal charge and the minus signal charge, respectively.

20. An apparatus as in claim 19 wherein the difference amplifier is connected to determine the difference between the output of the first pair of sample and hold circuits in the first mode and is connected to determine a difference in the outputs between the second pair of sample and hold circuit outputs in the second mode.

21. An apparatus as in claim 19 wherein the difference amplifier compares a charge integrator result at a first time with a charge integrator result a second time, such that a plus charge input applied with the switch in one state is compared with the plus charge input with the switch compared in another state.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : RE44,410 E
APPLICATION NO. : 12/322658
DATED : August 6, 2013
INVENTOR(S) : Demirdag et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims:

In col. 7, line 26/27 should read:

tiple clock periods prior to operating the pair of sample and hold circuits.

Signed and Sealed this
Twenty-ninth Day of October, 2013



Teresa Stanek Rea
Deputy Director of the United States Patent and Trademark Office