

BIAS SENSING IN DRAM SENSE AMPLIFIERS

Background of the Invention

This invention relates to bias sensing in DRAM (dynamic random access memory) sense amplifiers. More particularly, this invention relates to improving the refresh performance of DRAM devices.

As a result of charge leakage from DRAM memory cells, sense amplifier devices sense (or sample) and restore electrical charge within each of the memory cells of a given DRAM device. In order to sense and restore the electrical charge of a memory cell that is connected to a particular digit line, a sense amplifier compares the bias voltage on a "reference" digit line with the bias voltage on the digit line connected to the memory cell that is accessed (i.e., read).

If a logic "1" is stored in the accessed memory cell capacitor, upon accessing the memory cell, stored electrical charge from the capacitor is shared with the digit line. This slightly raises the voltage on the memory cell digit line relative to the reference digit line bias voltage. The sense amplifier detects this voltage change and applies a suitable voltage (e.g., V_{cc}) to the memory cell digit line such that the memory cell is recharged and restored to a full level of electrical charge.

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If a logic "0" is stored in the memory cell capacitor, upon accessing the memory cell, the absence of stored electrical charge in the capacitor causes some electrical charge present on the biased digit line to be shared with the memory cell. This slightly reduces the voltage on the memory cell digit line relative to the biased reference digit line. The sense amplifier detects this voltage change and applies a ground (GND) signal to the memory cell digit line so that the accessed memory cell is fully discharged (i.e., logic "0").

The refresh time or interval between sensing (i.e., reading) and restoring the electrical charge within memory cells is limited to the bias voltage level applied to the reference digit lines. For example, a DRAM memory cell holding an electrical charge representative of a logic "1," is sensed after a finite time interval (refresh time). The sense amplifier then determines that a logic "1" is stored in the memory cell and restores its electrical charge to full value. However, if this refresh duration is too long, the electrical charge stored within this memory cell will degrade too much. When this occurs, the sense amplifier erroneously determines that a logic "0" is stored in the memory cell. Thus, it does not restore the memory cell electrical charge to its full value (i.e., logic "1").

Therefore, for a memory cell storing a logic "1," the refresh time must occur before the voltage on the sensed memory cell digit line drops below the reference digit line bias voltage. Otherwise, the DRAM device erroneously detects a logic "0." To avoid this, the interval between refresh times must be reduced. However, by reducing the interval between refresh times, the power dissipation within the DRAM device undesirably increases. This becomes progressively

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problematic as DRAM memory arrays increase in memory capacity as their physical dimensions decrease. By reducing the reference digit line bias voltage, the time interval between the refresh operation (refresh time) increases as a result of providing an increased margin for electrical charge degradation in the memory cell. However, some known memory devices, such as disclosed in Lee et al. U.S. Patent No. 5,701,268, drive the voltage on both the reference and sensed memory cell digit lines to a higher potential.

It is also known that by including dummy memory cells on the digit lines of DRAM memory devices, the bias voltage for any particular reference digit line can be reduced to improve the refresh performance. By reducing this bias voltage (threshold level), the probability of logic "1" detection increases (increasing reliability), and therefore, the required time between refresh operations increases.

However, the inclusion of dummy cells inefficiently uses fabrication area, which is particularly undesirable in light of the trend towards smaller DRAM array devices with increased memory capacity. For example, Eto et al. U.S. Patent No. 6,169,701 discloses the use of such dummy cells.

In view of the foregoing, it would be desirable to provide improved refresh performance in DRAM memory devices by varying the threshold or bias voltage used in the sensing operation.

Summary of the Invention

It is an object of this invention to provide improved refresh performance in DRAM memory devices by varying the threshold or bias voltage used in the sensing operation.

In accordance with the invention, a DRAM device is provided that has a plurality of digit lines and a plurality of sense amplifiers, where each sense amplifier is coupled to an adjacent pair of digit lines. Each adjacent pair of digit lines includes first and second digit lines. The DRAM

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device also includes a first voltage coupling/decoupling device having an output coupled to the first digit line and a second coupling/decoupling device having an output coupled to the second digit
5 line. The first voltage coupling device capacitively couples a voltage onto the first digit line and the second voltage coupling device capacitively decouples a second voltage from the second digit line, wherein the first digit line is an "active" digit line and the
10 second digit line is a "reference" digit line.

This embodiment preferably operates as follows in accordance with the invention: an electrical bias voltage is applied to the first and second digit lines. Electrical-charge within the memory cell is
15 accessed such that electrical-charge sharing occurs between the memory cell and the first digit line, generating a first digit line bias voltage. After the memory cell is accessed, voltage is capacitively decoupled from the second digit line, causing a
20 reduction in bias voltage. The DRAM sense amplifier is then fired in order to restore the electrical charge in the memory cell to its designated charge value (logic "1" or logic "0").

A second embodiment of a DRAM device in
25 accordance with the invention has first and second digit lines, first and second transistors, sense amplifiers, and first and second voltage coupling/decoupling devices. The first and second digit lines have a line connection. The first and
30 second transistors each have a first and second terminal. The second terminal of the first transistor couples to the line connection of the first digit line, and the second terminal of the second transistor couples to the line connection of the second digit
35 line.

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Each sense amplifier has a first and second sensing connection, wherein the first sensing connection couples to the first terminal of the first transistor, and the second sensing connection couples to the first terminal of the second transistor. Each of the first and second voltage coupling/decoupling devices has an output, wherein the first coupling/decoupling device output couples to the first sensing connection and to the first terminal of the first transistor, and the second coupling/decoupling device output couples to the second sensing connection and to the first terminal of the second transistor.

This second embodiment preferably operates as follows in accordance with the invention: a voltage is applied to the first and second digit lines. Electrical-charge within the memory cell is accessed such that electrical charge sharing occurs between the memory cell and the first digit line, generating a first digit line bias voltage. After the memory cell is accessed, the first isolation transistor is switched ON so that the first sensing connection couples to the first digit line, and the second isolation transistor is switched ON so that the second sensing connection couples to the second digit line. The first and second isolation transistors are then switched OFF so that the first and second sensing connections are electrically isolated from the first and second digit lines. Following the isolation of the sense amplifier connections from the digit lines, a second voltage is capacitively decoupled from the second sense amplifier connection, thus reducing its bias voltage. The DRAM sense amplifier is then fired in order to restore the electrical charge in the memory cell to its designated charge value (logic "1" or logic "0").

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Brief Description of the Drawings

The above and other objects and advantages of the invention will be apparent upon consideration of the following detailed description, taken in
5 conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

FIG. 1 is a circuit diagram of a first embodiment of a DRAM memory circuit according to the
10 invention;

FIG. 2 is an electrical representation of a first embodiment of a coupling network according to the invention;

FIG. 3 is a circuit diagram of a second embodiment of a DRAM memory circuit according to the
15 invention;

FIG. 4 is an electrical representation of a second embodiment of a coupling network according to the invention;

FIG. 5 is a timing diagram illustrating various signal voltages corresponding to the refresh operation of a DRAM memory sense amplifier according to the invention;
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FIG. 6 is a timing diagram illustrating applied signal voltages for coupling and decoupling voltages from digit lines during the sensing of a memory cell according to the invention; and
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FIG. 7 is a block diagram of a system that incorporates the invention.

Detailed Description of the Invention
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The invention provides DRAM sense amplifier devices with improved bias sensing. These sense amplifiers include additional devices for either capacitively decoupling voltages from "reference" digit
35 lines, capacitively coupling voltages onto "active"

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digit lines, or both. Note that a digit line attached to an accessed memory cell is designated as being the "active" digit line. A digit line adjacent to the "active" digit line and sharing the same sense amplifier is designated as the "reference" digit line. Therefore, "active" and "reference" digit lines dynamically change based on which of the two digit lines is coupled to an accessed memory cell. By decoupling voltage from a reference digit line, or by coupling voltage onto an active digit line, or by both coupling and decoupling voltage onto and from these digit lines, bias (threshold) voltage sensing by the sense amplifiers is improved.

FIG. 1 shows a DRAM sense amplifier circuit 100 within a DRAM array, wherein sense amplifier 100 is connected to a pair of adjacent digit lines 102, 104 through a pair of isolation transistors 106, 108. Sense amplifier 100 is coupled to digit line 104 through isolation transistor 108 and coupled to digit line 102 through isolation transistor 106. Isolation transistor 108 has terminals 109a, 109b, wherein terminal 109b connects to digit line 104, and terminal 109a couples to sense amplifier 100. Isolation transistor 106 has terminals 107a, 107b, wherein terminal 107b connects to second digit line 102, and terminal 107a couples to sense amplifier 100.

Both isolation transistors 106 and 108 are controlled by a multi-level gate driver 110 that simultaneously applies suitable drive voltages to respective terminals 112, 114 of isolation transistors 106 and 108. The drive voltages switch the isolation transistors 106, 108 ON or OFF to control the electrical isolation between digit lines 102, 104 and sense amplifier 100. A plurality of memory cells such as memory cells 116 and 150 are connected respectively

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to digit lines 104 and 102. For clarity, only memory cells 116 and 150 are shown in FIG. 1.

Memory cell 116 includes a transistor 118 and a capacitor 120, wherein the gate of transistor 118 connects to a wordline 122 (WL) within the DRAM array. Terminal 124 of transistor 118 connects to one end of capacitor 120, wherein the other end of capacitor 120 is grounded. The other terminal 126 of transistor 118 connects to digit line 104, at node 128.

10 A first voltage coupling/decoupling device 130 is also connected to digit line 104. Voltage coupling device 130 includes a coupling/decoupling capacitor 134 and a signal driver device 132. Capacitor 134 connects to the output of signal driver 132 at node 136 and connects to digit line 104 at node 138. Node 138 is the output of voltage coupling/decoupling device 130.

A second voltage coupling/decoupling device 140 is connected to digit line 102. Voltage coupling device 140 includes capacitor 144 and a second signal driver device 142. Capacitor 144 connects to the output of signal driver 142 at node 146 and connects to digit line 102 at node 148. Node 148 is the output of voltage coupling/decoupling device 140.

25 Sense amplifier device 100 includes an N-sense and a P-sense amplifier. The P-sense amplifier includes a cross-coupled PMOS transistor pair having a first PMOS transistor 158 and a second PMOS transistor 160. The N-sense amplifier includes a cross coupled NMOS transistor pair having a first NMOS transistor 162 and a second NMOS transistor 164. The first PMOS transistor 158 and the first NMOS transistor 162 share a common connection 178 that couples to digit line 102 through node B and isolation transistor 106. Second PMOS transistor 160 and second NMOS transistor 164 share a common sensing

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connection 180 that couples to digit line 104 through node A and isolation transistor 108. A common node connection 166 between NMOS transistor pair 162, 164 is normally biased at $V_{cc}/2$ (half the supply rail). The
5 N-sense amplifier is "fired" or activated by connecting common node connection 166 to ground via turned ON transistor 168. This effectively pulls the common node connection 166 from $V_{cc}/2$ to ground (0V).

Similarly, a common node connection 170
10 between PMOS transistor pair 158, 160 is normally biased at about 0V (ground). The P-sense amplifier is "fired" or activated by connecting common node connection 170 to V_{cc} (supply rail) via turned ON transistor 172. This effectively pulls the common node
15 connection from 0V to V_{cc} .

During the sensing and restoring operation, both the N-sense and P-sense amplifiers are fired sequentially, with the N-sense amplifier "fired" first, followed by the P-sense amplifier.

20 Note that for illustration purposes only, digit line 102 is designated the "reference" digit line 102 and digit line 104 is designated the "active" digit line. Voltage coupling/decoupling device 140 decouples a percentage (or fraction) of voltage from
25 the "reference" digit line 102 to reduce the bias voltage on this line. Voltage coupling/decoupling device 130 may (optionally) couple a percentage (or fraction) of voltage onto the "active" digit line 104 to increase the bias voltage on this line.

30 Thus, an increase in the voltage difference between "reference" digit line 102 and "active" digit line 104 can be accomplished by either decoupling voltage from "reference" digit line 102, coupling voltage to "active" digit line 104, or both decoupling
35 voltage from "reference" digit line 102 and coupling voltage onto "active" digit line 104. The voltage

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coupling or decoupling function of voltage coupling/decoupling devices 130, 140 depends on whether their corresponding digit lines are designated as being an "active" digit line or a "reference" digit line.

5 FIG. 2 shows an electrical representation of the voltage coupling/decoupling device of FIG. 1 (device 130 or 140). The digit line capacitance 204 is denoted by $C_{\text{digitline}}$ and is electrically represented as a capacitor having a first connection to digit line 206
10 and a second connection to ground. The digit line capacitance is not a fabricated component such as coupling/decoupling capacitor 210. It is an existing parasitic effect and is therefore not included in the circuit diagram of FIG. 1.

15 Coupling/decoupling capacitor 210 has first and second connection terminals 212, 214, wherein first connection terminal 212 receives a coupling/decoupling drive voltage signal (V_{CSL}) from a voltage driver device or signal source. Second connection terminal 214
20 connects to digit line 206 and thus to the first connection of the digit line capacitance 204. A capacitive network is therefore formed between coupling/decoupling capacitor 210 and digit line capacitance 204. By applying a suitable
25 coupling/decoupling drive voltage signal (V_{CSL}) to connection terminal 212, voltage can be decoupled from, or coupled to, digit line 206. This is also shown in equation (1) below:

$$\Delta V_{\text{NODE}} = \frac{C_c}{C_c + C_{\text{digitline}}} \times \Delta V_{\text{CSL}} \quad (1)$$

where ΔV_{NODE} is the change in voltage on digit line 206,
30 C_c is the capacitance of coupling/decoupling capacitor 210, $C_{\text{digitline}}$ is the capacitance 204 of digit line 206, and ΔV_{CSL} is the voltage switching magnitude

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generated by the coupling/decoupling drive voltage signal (V_{CSL}). FIGS. 5 and 6 illustrate the coupling and decoupling process in more detail.

Comparing the electrical representation of
5 FIG. 2 with coupling/decoupling devices 130, 140 in
FIG. 1, coupling/decoupling capacitor 210 is equivalent
to coupling/decoupling capacitors 134 and 144. Also,
 V_{CSL} is generated by each signal driver device 132, 142,
wherein signal driver device 132 generates a first
10 drive voltage signal (V_{CSL1}) and signal driver device 142
generates a second drive voltage signal (V_{CSL2}). The
voltage switching magnitude ΔV_{SCL} generated by both
drive voltage signals (V_{SCL}) provides the necessary
signaling for coupling or decoupling voltage onto or
15 off of corresponding digit lines 102 and 104. The
capacitance ($C_{digitline}$) 204 of digit line 206 is
equivalent to the parasitic capacitance of digit
lines 102 and 104. The signal driver devices (132
or 142) apply the coupling/decoupling drive voltage
20 signals (V_{CSL}) onto signal lines 136, 146, where the
drive voltage signals (V_{CSL}) are received by
coupling/decoupling capacitors 134, 144, respectively.
The switching transition direction (low-to-high or
high-to-low) of the voltage switching magnitude ΔV_{CSL}
25 determines whether voltage is coupled onto or off of
the digit line. Thus, the change in voltage on the
digit line (ΔV_{NODE}) depends on whether a voltage is
coupled to the digit line (increasing its bias
voltage), or whether a voltage is decoupled from the
30 digit line (reducing its bias voltage).

Note, from Equation (1) that by increasing
both the capacitance value of coupling/decoupling
capacitor 210 and the voltage switching magnitude ΔV_{CSL} ,
a higher percentage (or fraction) of coupling or
35 decoupling can be achieved. For example, to
decouple 10% of the bias voltage from the digit line,

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the coupling/decoupling capacitance should be approximately one tenth (1/10), or ten percent of the digit line capacitance. However, if the digit line capacitance is relatively large, the

5 coupling/decoupling capacitor must be proportionally increased, which results in the fabrication of larger capacitor devices at the expense of reducing DRAM memory capacity per device size.

The voltage switching magnitude (ΔV_{SCL})

10 generated by the signal driver device (132 or 142) is normally between ground and the supply rail (V_{CC}) in order to maximize the coupling/decoupling fraction. Note that the voltage switching magnitude (ΔV_{SCL}) can be varied (increased or decreased) between a first and

15 second voltage by the signal driver device (132 or 142) in order to vary the coupling/decoupling fraction. Both the first and second voltage generated by the signal driver device (132 or 142) are controllably variable. Also note that more than one

20 coupling/decoupling capacitor may be connected between any given digit line and signal driver device.

In describing the sensing operation of sense amplifier 100, memory cell 116 is considered to hold electrical-charge corresponding to a stored logic "1."

25 As previously indicated, during accessing (i.e., reading), sensing, and restoring the charge within memory cell 116, digit line 104 is considered the "active" digit line, and adjacent digit line 102 is considered the "reference" digit line. Also, both

30 digit lines are pre-biased at $V_{CC}/2$ (half the supply rail) prior to firing the N-sense and P-sense amplifiers.

In order to access electrical-charge stored within memory cell 116, suitable voltage is applied to

35 the gate of transistor 118 by means of word line (WL) 122. Once the gate voltage is applied and

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transistor 118 is fully turned ON, a low impedance electrical connection is established between terminals 124 and 126 of the transistor 118. This effectively connects one side of capacitor 120 directly
5 to digit line 104 such that electrical-charge sharing occurs between capacitor 120 and digit line 104. Due to the electrical-charge from capacitor 120 discharging onto "active" digitline 104, there will be a slight increase in "active" digit line bias voltage compared
10 with the bias voltage on adjacent reference digit line 102. Therefore, a detectable voltage difference (ΔV) occurs between digit lines 104 and 102.

Once memory cell 116 is accessed, gate driver 110 applies a gate voltage to gate terminal 114
15 and to gate terminal 112 of isolation transistors 108, 106, respectively. This causes both isolation transistors 106, 108 to fully turn ON. With isolation transistor 106 in the ON state, an electrical connection is established between node B and
20 "reference" digit line 102. Sensing connection 178 of sense amplifier 100 connects to node B and therefore to "reference" digit line 102. Similarly, with transistor 108 in the ON state, an electrical connection is established between node A and "active"
25 digit line 104. Sensing connection 180 of sense amplifier 100 connects to node A and therefore to "active" digit line 104. Thus, the voltage on "active" digit line 104 is received by the sense amplifier's sensing connection 180, and the voltage on "reference"
30 digit line 102 is received by the sense amplifier's sensing connection 178. Once the isolation transistors are in the OFF state, sense amplifier connections 178 and 180 are isolated from respective digit lines 102, 104. However, the voltages on digit
35 lines 102 and 104 remain stored on nodes A and B and sensing connections 178, 180.

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The voltage difference between "active" digit line 104 and "reference" digit line 102 is relatively small. By increasing this voltage difference, both the sensing and the refresh performance of the DRAM device can be improved. In terms of the sensing operation, for example, there will be less probability of sense amplifier 100 erroneously allocating or not allocating the appropriate electrical charge to an accessed memory cell. Also, as the voltage difference between "active" digit line 104 and "reference" digit line 102 increases, the time interval between necessary refresh operations advantageously increases. This is due to the bias voltage on "reference" digit line 102 having a lower voltage threshold, which in turn allows the electrical-charge in accessed memory cell 116 to further deteriorate without becoming undetectable. This means that once the deteriorated electrical-charge in memory cell 116 is accessed, the bias voltage on "active" digit line 104 is still higher than reference digit line 102. However, in accordance with the correct operation of the invention, if no charge is present in accessed memory cell 116 (i.e., logic "0" stored), the bias voltage on "active" digit line 104 must have a lower bias voltage value than that of "reference" digit line 104.

The aforementioned increase in the voltage difference between "active" digit line 104 and "reference" digit line 102 is achieved by activating voltage coupling/decoupling device 140 such that a fraction or percentage of the existing reference digit line bias voltage (i.e., $V_{cc}/2$) is decoupled from reference digit line 102. Thus, the decrease in bias voltage on "reference" digit line 102, and the increase in bias voltage on "active" digit line 104 because of accessing memory cell 116, achieves this voltage difference increase. Because isolation

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transistors 106, 108 are still ON, the increase in bias voltage on "active" digit line 104 and the decrease in bias voltage on "reference" digit line 102 appear at nodes A and B, respectively.

5 The sense amplifier's sensing connections 180, 178 receive the respective bias voltages present on the "active" and "reference" digit lines from nodes A and B, respectively. Prior to "firing" the P- and N-sense amplifiers, isolation
10 transistors 106, 108 are turned OFF such that the P- and N-sense amplifiers are isolated from the parasitic capacitance of digit lines 102 and 104. Therefore, gate driver 110 removes the previously applied voltage from both isolation transistor gates 112, 114. This
15 turns both transistors 106, 108 OFF, resulting in the electrical isolation of nodes A and B and sensing connections 180, 179 from digit lines 104, 102.

 In the case of memory cell 116 (having a stored logic "1"), the increase in the active digit
20 line 104 bias voltage (also present at node A) relative to the reference digit line 102 bias voltage is detected when the N-sense amplifier is "fired." Once "fired," transistor 162 turns ON, connecting "reference" digit line 102 to ground (0V). The higher
25 bias voltage on "active" digit line 104 causes transistor 162 to start conducting prior to the conduction of transistor 164. Transistor 164 is thus held in the OFF state when transistor 162 turns ON.

 Once reference digit line 102 is grounded,
30 the P-sense amplifier is "fired." Upon "firing" the P-sense amplifier, transistor 160 turns ON and connects "active" digit line 104 to the supply voltage (Vcc) via connection 180 and node A. It will be appreciated that isolation transistor 108 must be turned ON again once
35 the charge voltage (Vcc) is applied to node A following the "firing" of the P-sense amplifier. This provides

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an electrical path between the charge voltage present at node A and "active" digit line 104. If the isolation transistor is OFF, the charge voltage is isolated from the "active" digit line 104.

5 With isolation transistor 108 turned ON, the charge voltage (Vcc) is supplied to "active" digit line 104. Also, with memory cell transistor 118 in the ON state (WL active), the charge voltage on "active" digit line 104 charges memory cell capacitor 120 to its
10 full capacity. Memory cell transistor 118 is then turned OFF by removing the gate voltage from word line 122. The charge on memory cell capacitor 120 is now restored and isolated from digit line 104.

If, for example, memory cell 116 stores
15 relatively no electrical-charge (i.e., logic "0"), once memory cell 116 is accessed, the charge sharing will conversely cause the "active" digit line 104 bias voltage to decrease relative to the "reference" digit line 102 bias voltage. Once isolation
20 transistors 106, 108 are turned ON, both the "active" digit line 104 bias voltage and the "reference" digit line 102 bias voltage are received by sensing connections 180, 178, respectively. Isolation
transistors 106, 108 are then turned OFF and the sense
25 amplifier is "fired." The decrease in the "active" digit line 104 bias voltage relative to the "reference" digit line 102 bias voltage is detected by sense amplifier 100. Therefore, following the "firing" of
sense amplifier 100, a ground reference signal is
30 applied (i.e., 0V) to the "active" digit line 104 via node A and isolation transistor 108 (which is ON). To restore memory cell 116 (to logic "0"), the cell must be accessed, thus, transistor 118 is fully ON.

FIG. 3 illustrates a second embodiment of the
35 invention. One difference between the embodiments of FIGS. 1 and 3 is that in FIG. 3 coupling/decoupling

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capacitors 134, 144 are connected to nodes A and B rather than directly to digit lines 104 and 102 as in FIG. 1.

As illustrated in FIG. 3, sensing
5 connection 180 of sense amplifier 100 connects to terminal 109a of isolation transistor 108 via node A. This connection between sense amplifier 100 and isolation transistor 108 is referred to as a first "gut-node" 300. Terminal 136 of coupling/decoupling
10 capacitor 134 connects to signal driver 132 (as in FIG. 1). Terminal 138 of coupling/decoupling capacitor 134 connects to "gut-node" 300 at node A.

Similarly, sensing connection 178 of sense
amplifier 100 connects to terminal 107b of isolation
15 transistor 106 via node B. This connection between sense amplifier 100 and isolation transistor 106 is referred to as a second "gut-node" 302. Terminal 146 of coupling/decoupling capacitor 144 connects to signal driver 142 (as in FIG. 1). Terminal 148 of
20 coupling/decoupling capacitor 144 connects to "gut-node" 302 at node B.

FIG. 4 shows an electrical representation of the coupling/decoupling device configuration used in FIG. 3. As described in the previous paragraph,
25 coupling/decoupling capacitors 134 and 144 are respectively connected to "gut-nodes" 300 and 302 as opposed to directly connecting them to the digit lines. "Gut-node" capacitance 404 is electrically represented as a capacitor having a first connection to the "gut-
30 node," and a second connection to ground. The "gut-node" capacitance is not a fabricated component, such as coupling/ decoupling capacitor 410. It is an existing parasitic effect and is therefore not included in the circuit diagram of FIG. 3.

35 Coupling/decoupling capacitor 410 has a first and second connection terminal, wherein the first

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connection terminal 412 receives a coupling/decoupling drive voltage signal (V_{CSL}) from a voltage driver device or signal source. Terminal 414 of coupling/decoupling capacitor 410 connects to the "gut-node" and thus to
 5 the first connection of "gut-node" capacitor 404. Therefore, a capacitive network is formed between coupling/decoupling capacitor 410 and "gut-node" capacitor 404, wherein by applying a suitable coupling/decoupling drive voltage signal (V_{CSL}) to
 10 terminal 412 of coupling/decoupling capacitor 410, voltage can be decoupled from, or coupled to, the "gut-node." This is also shown in equation (2) below:

$$\Delta V_{NODE} = \frac{C_C}{C_C + C_{gut-node}} \times \Delta V_{CSL} \quad (2)$$

where ΔV_{NODE} is the change in voltage on the "gut-node,"
 15 C_C is the capacitance of coupling/decoupling capacitor 410, $C_{gut-node}$ is the capacitance 404 of the "gut-node," and ΔV_{CSL} is the voltage switching magnitude generated by the coupling/decoupling drive voltage signal (V_{CSL}).

20 Comparing the electrical representation of FIG. 4 with coupling/decoupling devices 130, 140 in FIG. 3, coupling/decoupling capacitor 410 is equivalent to coupling/decoupling capacitors 134 and 144. Also, V_{CSL} is generated by the first or second signal driver
 25 devices 132, 142, wherein signal driver device 132 generates a first drive voltage signal (V_{CSL1}) and signal driver device 142 generates a second drive voltage signal (V_{CSL2}). The voltage switching magnitude ΔV_{CSL} generated by both drive voltage signals V_{CSL} provides
 30 the necessary signaling for coupling or decoupling voltage onto or off of corresponding digit lines 102 and 104. The "gut-node" capacitance ($C_{gut-node}$) 404 is a parasitic element. The signal driver devices (132

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or 142) generate the coupling/decoupling drive voltage signals (V_{CSL}) that are received by coupling/decoupling capacitors 134 and 144. The switching transition direction (low-to-high or high-to-low) of the voltage switching magnitude ΔV_{CSL} determines whether voltage is coupled to or decoupled from the digit line.

Equation (2) shows that by increasing the capacitance value of coupling/decoupling capacitor 410 and the voltage level change ΔV_{CSL} , a higher percentage (or fraction) of coupling or decoupling can be achieved. The advantage of connecting coupling/decoupling capacitors 134 and 144 to "gut-nodes" 300 and 302 is that a higher fraction or percentage of voltage coupling/decoupling can be achieved. This is due to the much lower capacitance value of "gut-nodes" 300 and 302. Referring to equation (2), it can be seen that for a given magnitude of voltage decoupling or coupling, the capacitance of coupling/decoupling capacitors 134 and 144 can be substantially less as a result of the relatively low capacitance of "gut-nodes" 300, 302. In the configuration of FIG. 1, where coupling/decoupling capacitors 134 and 144 are connected to respective digit lines 104 and 102, the relatively high capacitance ($C_{digitline}$) of digit lines 102 and 104 required that coupling/decoupling capacitors 134 and 144 also have a proportionally high capacitance as well. Therefore, the "gut-node" capacitance provides voltage coupling with the use of much smaller coupling/decoupling capacitors 134, 144. This advantageously enables the fabrication of physically smaller capacitors within a DRAM memory device. Also, for a given constraint in coupling/decoupling capacitor size, relatively more voltage coupling/decoupling is achievable in comparison to coupling/decoupling voltage directly from the digit line (as in FIG. 1). This

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results because $C_{\text{gut-node}}$ is considerably less (e.g., one tenth) than $C_{\text{digitline}}$. Referring to equations (1) and (2), for a constant value of coupling/decoupling capacitance (C_e), the smaller $C_{\text{digitline}}$ and $C_{\text{gut-node}}$, the higher the magnitude of generated voltage coupling or decoupling.

In order for the "gut-node" capacitance to be effective in the coupling and decoupling of voltage from the digit lines being sensed, when sense amplifier 100 is fired, both isolation transistors 106, 108 should be turned either fully OFF or partially OFF. If transistors 106, 108 are fully ON (i.e., in saturation), for each digit line, both the digit line capacitance and the "gut-node" capacitance will be electrically in parallel. Therefore, the total capacitance will be the sum of both the digit line capacitance and the "gut-node" capacitance, wherein the digit line capacitance is considerably higher than the "gut-node" capacitance. Referring to equation (1) or (2), the increase in total capacitance in the denominator will reduce the voltage coupling/decoupling fraction or percentage considerably. Thus, the advantage of exploiting the "gut-node" capacitance will be substantially diminished if the isolation transistors are fully ON. Both isolation transistors 106, 108 should be either OFF or partially OFF.

As previously indicated, the voltage switching magnitude (ΔV_{CSL}) generated by the signal driver device (132 or 142) is normally between ground and the supply rail (V_{CC}) in order to maximize the coupling/decoupling fraction. Note that the voltage level change value (ΔV_{CSL}) can be varied (increased or decreased) between a first and a second voltage by the signal driver device (132 or 142) in order to vary the coupling/decoupling fraction. Also note that more than

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one coupling/decoupling capacitor may be connected between any given digit line and signal driver device.

The operation of the embodiment of FIG. 3 will now be described with reference to the timing diagrams illustrated in FIG. 5. As shown in timing diagram 500, in order to access memory cell 116, at a time t_0 , a wordline voltage signal 502 (V_{ccp}) is applied to gate 122 of transistor 118. The magnitude of this voltage signal ensures that memory cell 116 is fully turned ON during the subsequent sense and restore operations.

As shown in timing diagram 504, at time t_0 , an ISO gate signal 506, is raised from $V_{cc}/2$ to V_{ccp} so that the gate voltages of isolation transistors 106 and 108 are raised above their threshold value. This turns isolation transistors 106, 108 ON such that the voltage on "active" digit line 104 and "reference" digit line 102 are received by respective "gut-nodes" 300 and 302, and are therefore received by sensing connections 180 and 178 of sensing amplifier 100.

Timing diagram 508 shows the bias voltages at gut-nodes 300 and 302. As illustrated, prior to time t_0 , both gut-nodes 300, 302 are biased at $V_{cc}/2$. At t_0 , once memory cell 116 (i.e., stored logic "1") and isolation transistor 108 are accessed, electrical-charge sharing occurs between "active" digit line 104 and memory cell 116. This causes a voltage increase (V_2) in the "active" digit line bias voltage. As the "active" digit line 104 and gut-node 300 are connected via the turned ON isolation transistor, the first "gut-node" bias voltage 510 is charged to the increased "active" digit line bias voltage (V_2 increase). Also following time t_0 , the second "gut-node" bias voltage 512 is the same as the "reference" digit line bias voltage.

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Referring to timing diagram 504, at time t_1 , the gate signal 506 applied to isolation transistors 106 and 108 returns to $V_{CC}/2$ (or lower). This causes transistors 106, 108 to partially or completely turn OFF (depending on device threshold). In either case, digit lines 102 and 104 are isolated from respective gut-nodes 302 and 300. However, both the increased "active" digit line bias voltage and the "reference" digit line bias voltage are present (stored) on both "gut-node" 300 and "gut-node" 302 respectively. Therefore, these bias voltages are also received at sensing connections 178 and 180 of sensing amplifier 100.

Now that sufficient isolation exists between gut-nodes 302 and 300, and digit lines 102 and 104, at time t_1 , voltage is decoupled from "reference" digit line 102 by means of coupling/decoupling device 140. Timing diagram 514 shows the coupling/decoupling drive voltage signal (V_{CSL2}) 516 generated by signal driver device 142. At time t_1 , the coupling/decoupling drive voltage signal 516 makes a high-to-low voltage transition from V_{CC} to ground (ΔV_{CSL}). This voltage switching magnitude (ΔV_{CSL}) applied by signal driver device 142 to the capacitor network (C_c and $C_{\text{gut-node}}$) decouples a desired percentage or fraction of the "reference" digit line bias voltage that is now stored on "gut-node" 302. This is illustrated in timing diagram 508, wherein the second "gut-node" bias voltage 512 decreases (by V_1) at time t_2 . Thus, the bias voltage on "gut-node" 302 is reduced in favor of increasing the refresh performance.

The coupling/decoupling drive voltage signal (V_{CSL1}) 518 is generated by signal driver device 132. As illustrated in the timing diagram, at time t_1 , drive voltage signal 518 makes no voltage transition ($\Delta V_{CSL}=0$). Referring to equation (2), no voltage

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coupling or decoupling (i.e., $\Delta V_{\text{NODE}}=0$) occurs unless a voltage transition occurs in the coupling/decoupling drive voltage signal (V_{SCL}). Thus, the bias voltage on "gut-node" 300 is unchanged.

5 As illustrated in timing diagram 520, at time t_1 , the N-sense amplifier is "fired," wherein the common node bias voltage 522 on common node connection 166 is dropped from $V_{\text{CC}}/2$ (half the supply voltage) to near ground. This connects gut-node 302 to
10 ground, as illustrated in timing diagram 508 at time t_1 . At time t_2 of timing diagram 520, the P-sense amplifier is "fired," wherein the common node bias voltage 524 on common node connection 170 is raised from ground (0V) to V_{CC} (supply voltage). This connects gut-node 300 to
15 the supply voltage, as illustrated in timing diagram 508 at time instant t_2 .

As illustrated in timing diagram 504, at time instant t_1 , the isolation transistors are turned ON by increasing the voltage of the ISO gate signal 506 from
20 $V_{\text{CC}}/2$ to V_{CCP} . Consequently, an electrical path between "gut-node" 300 and "active" digit line 104 is established. Therefore, the applied supply voltage on "gut-node" 300 is also received by "active" digit line 104. Because memory cell transistor 118 is still
25 fully ON, memory cell capacitor 120 is fully charged by the supply voltage. Thus, the electrical charge within memory cell 116 is fully restored by the application of a charge voltage (e.g., supply voltage) to "active" digit line 104.

30 FIG. 6 illustrates different signaling schemes for coupling and decoupling voltage onto or off of digit lines and their respective "gut-nodes" during the sensing operation of the sense amplifiers.

Timing diagram 602 is identical to timing
35 diagram 514 shown in FIG. 5. Timing diagram 602 shows that at time t_2 , the second coupling/decoupling drive

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voltage signal 604 (V_{CSL2}) makes a high-to-low voltage transition (ΔV_{CSL}) from V_{CC} to ground. This provides voltage decoupling from the "reference" digit line bias voltage stored on "gut-node" 302. The first

5 coupling/decoupling drive voltage signal 606 (V_{CSL1}) is in the "logic high" state and makes no voltage transition at time t_2 . Therefore, no voltage change is applied to the "active" digit line bias voltage stored on "gut-node" 300. Timing diagram 608 shows the first

10 coupling/decoupling drive voltage signal 610 (V_{CSL1}) in the "logic low" state. Once again, no voltage change is applied to the "active" digit line bias voltage stored on "gut-node" 300. Thus, the "gut-node" bias voltage remains unchanged (i.e., no coupling or

15 decoupling). If the voltage is kept constant, no voltage coupling or decoupling will occur.

As previously described, the refresh performance of a DRAM device can also be improved by both coupling bias voltage onto an active digit line or

20 "gut-node," and decoupling bias voltage from a "reference" digit line or "gut-node." The coupling/decoupling drive signals for achieving this are shown in timing diagram 612. Timing diagram 612 shows that at time t_2 , second coupling/decoupling drive

25 voltage signal 614 (V_{CSL2}) makes a high-to-low voltage transition (ΔV_{CSL}) from V_{CC} to ground. This provides voltage decoupling from the "reference" digit line bias voltage stored on "gut-node" 302. Also, at time t_2 , first coupling/decoupling drive voltage signal 616

30 (V_{CSL1}) makes a low-to-high voltage transition (ΔV_{CSL}) from ground to V_{CC} . This provides voltage coupling onto the "active" digit line bias voltage stored on "gut-node" 300. This couples a percentage or fraction of the low-to-high voltage transition (ΔV_{CSL}) onto the

35 "active" digit line or "gut-node," wherein the fraction

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or percentage of coupling is determined by the capacitor values in the formed capacitor network.

As determined at time t_2 , the first coupling/decoupling drive voltage signal 616 (V_{CSL1}) makes a low-to-high voltage transition (ΔV_{CSL}) and couples a percentage or fraction of the low-to-high voltage transition (ΔV_{CSL}) onto the "active" digit line or "gut-node." In accordance with the invention, the second coupling/decoupling drive voltage signal 614 (V_{SCL2}) may be kept at a constant voltage (i.e., no voltage transition) such that voltage is not decoupled from the "reference" digit line. By increasing the bias voltage on the "active" digit line alone, the refresh performance is also improved.

Note that in the embodiment of FIG. 1, the coupling/decoupling fraction or coupling/decoupling percentage is determined by the capacitance of the coupling/decoupling capacitor (e.g., capacitor 134) and the digit line capacitance (e.g., $C_{digitline}$ of "active" digit line 104). Alternatively, in the embodiment of FIG. 3, the coupling fraction or coupling percentage is determined by the capacitance of the coupling/decoupling capacitor (e.g., capacitor 134) and the corresponding "gut-node" capacitance (e.g., $C_{gut-node}$ located at 300).

Note again that references made to particular "active" or "reference" digit lines were made for illustrative purposes. In accordance with the invention, coupling/decoupling devices are connected to any pair of digit lines that correspond to a particular sense amplifier.

FIG. 7 shows a system that incorporates the invention. System 700 includes a plurality of DRAM chips 775, a processor 770, a memory controller 772, input devices 774, output devices 776, and optional storage devices 778. DRAM chips 775 include one of the

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embodiments illustrated respectively in FIGS. 1 and 3. Data and control signals are transferred between processor 770 and memory controller 772 via bus 771. Similarly, data and control signals are transferred
5 between memory controller 772 and DRAM chips 775 via bus 773. Input devices 774 can include, for example, a keyboard, a mouse, a touch-pad display screen, or any other appropriate device that allows a user to enter information into system 700. Output devices 776 can
10 include, for example, a video display unit, a printer, or any other appropriate device capable of providing output data to a user. Note that input devices 774 and output devices 776 can alternatively be a single input/output device. Storage devices 778 can include,
15 for example, one or more disk or tape drives.

Thus it is seen that DRAM sense amplifiers are provided that have improved refresh performances. One skilled in the art will appreciate that the invention can be practiced by other than the described
20 embodiments, which are presented for purposes of illustration and not of limitation, and the invention is limited only by the claims which follow.

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WE CLAIM:

1. A memory device comprising:
 - a plurality of memory cells;
 - a plurality of digit lines wherein each digit line is coupled to at least one of said memory cells;
 - a plurality of sense amplifiers wherein each sense amplifier is coupled to at least one of said memory cells; and
 - a voltage coupling/decoupling device having an output coupled to a first of said digit lines, wherein said voltage device couples voltage onto or decouples voltage from said first digit line after one of said memory cells is accessed and before one of said sense amplifiers is fired, said one sense amplifier coupled to said one memory cell.
2. The memory device of claim 1 wherein said voltage coupling/decoupling device comprises:
 - a voltage driver having an output, said voltage driver operative to generate a first or a second voltage signal; and
 - a capacitor having a first terminal and a second terminal, said first terminal coupled to said driver output and said second terminal coupled to said first digit line.
3. The memory device of claim 2 wherein said first and second voltage signals are of different voltage switching magnitudes, opposite switching transitions, or both.
4. The memory device of claim 1 wherein:

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said first digit line is coupled to said one memory cell and to said one sense amplifier; and

said voltage coupling/decoupling device couples voltage onto said first digit line.

5. The memory device of claim 1 wherein:

said first digit line is coupled to said one sense amplifier and serves as a reference digit line; and

said voltage coupling/decoupling device decouples voltage from said first digit line.

6. The memory device of claim 1 wherein said

memory device is a dynamic random access memory.

7. A memory device comprising:

a memory cell; a digit line coupled to said memory cell;

a sense amplifier coupled to said memory cell via said digit line; and

a voltage coupling/decoupling device having an output coupled to said digit line wherein said voltage device couples voltage onto said digit line after said memory cell is accessed and before said sense amplifier is fired.

8. The memory device of claim 7 wherein said

voltage coupling/decoupling device comprises:

a voltage driver having an output, said voltage driver operative to generate a first or a second voltage signal; and

a capacitor having a first terminal and a second terminal, said first terminal coupled to said driver output and said second terminal coupled to said digit line.

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9. The memory device of claim 8 wherein said first and second voltage signals are of different voltage switching magnitudes, opposite switching transitions, or both.

10. The memory device of claim 8 wherein said memory device is a dynamic random access memory.

11. A memory device comprising:
a memory cell; a sense amplifier coupled to said memory cell;
a digit line coupled to said sense amplifier;
and
a voltage coupling/decoupling device having an output coupled to said digit line wherein said voltage device decouples voltage from said digit line after said memory cell is accessed and before said sense amplifier is fired.

12. The memory device of claim 11 wherein said voltage coupling/decoupling device comprises:
a voltage driver having an output, said voltage driver operative to generate a first or a second voltage signal; and
a capacitor having a first terminal and a second terminal, said first terminal coupled to said driver output and said second terminal coupled to said digit line.

13. The memory device of claim 12 wherein said first and second voltage signals are of different voltage switching magnitudes, opposite switching transitions, or both.

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14. The memory device of claim 11 wherein said memory device is a dynamic random access memory.

15. A method of operating a memory device, said method comprising:

applying a same voltage to first and second digit lines;

accessing an electrical charge stored within a memory cell via said first digit line, said accessing resulting in said first digit line having a first digit line bias voltage;

capacitively decoupling a voltage from said second digit line to generate a second digit line bias voltage; and

restoring electrical charge in said memory cell to a predetermined level.

16. The method of claim 15 wherein said restoring comprises:

comparing the voltage difference between said first digit line bias voltage and said second digit line bias voltage; and

restoring electrical charge in said memory cell to a predetermined level when said voltage difference equals a threshold.

17. The method of claim 15 wherein said capacitively decoupling a voltage from said second digit line reduces said voltage applied to said second digit line.

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18. A method of operating a memory device, said method comprising:

applying a same voltage to first and second digit lines;

accessing an electrical charge stored within a memory cell via said first digit line, said accessing resulting in said first digit line having a first digit line bias voltage;

capacitively coupling a voltage onto said first digit line to generate an increased first digit line bias voltage; and

restoring electrical charge in said memory cell to a predetermined level.

19. The method of claim 18 wherein said restoring comprises:

comparing the voltage difference between said first digit line bias voltage and the voltage of said second digit line; and

restoring electrical charge in said memory cell to a predetermined level when said voltage difference equals a threshold.

20. The method of claim 18 further comprising capacitively decoupling a voltage from said second digit line to generate a second digit line bias voltage, said second digit line bias voltage less than said first digit line bias voltage.

21. Memory apparatus comprising:

means for applying a same voltage to first and second digit lines;

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means for accessing an electrical charge stored in a memory cell coupled to said first digit line; means for creating or increasing a voltage difference between said first and second digit lines wherein said second digit line voltage is lower than said first digit line voltage; and means for restoring said electrical charge in said memory cell to a predetermined level in response to said voltage difference reaching a threshold.

22. An electronic system comprising:
a processor;
a memory controller;
a memory circuit comprising:
at least one memory cell,
a sense amplifier coupled to said one memory cell,
at least two digit lines, one of said two digit lines coupled to said memory cell and both of said two digit lines coupled to said sense amplifier, and
a voltage coupling/decoupling device having an output coupled to one of said two digit lines, said voltage device capacitively coupling voltage onto or decoupling voltage from said one of said two digit lines after said memory cell is accessed and before said sense amplifier is fired; and
a plurality of signal buses coupling said processor to said memory controller and said memory controller to said memory circuit.

23. The system of claim 22 wherein said memory circuit is a dynamic random access memory.