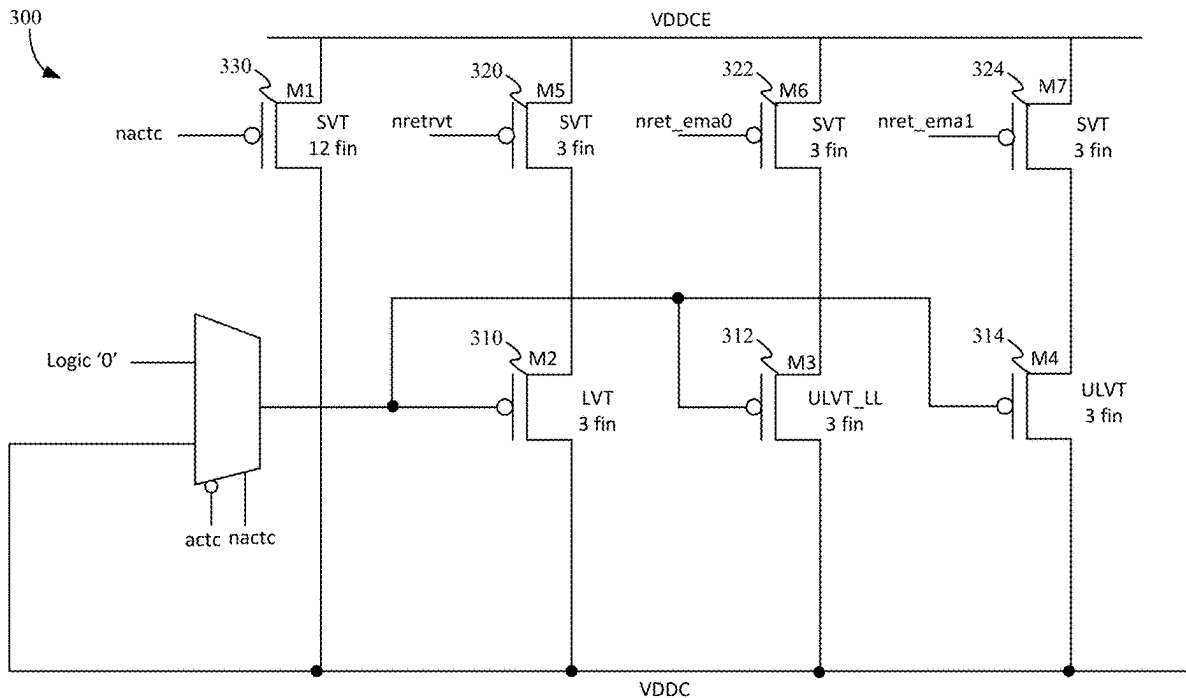




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(19) **United States**(12) **Patent Application Publication** (10) **Pub. No.: US 2025/0259659 A1**  
Kumar et al. (43) **Pub. Date: Aug. 14, 2025**(54) **POWER GATING CIRCUIT WITH MEMORY  
PRECHARGE SUPPORT**(52) **U.S. Cl.**  
CPC ..... *GI1C 5/148* (2013.01)(71) Applicant: **Arm Limited**, Cambridge (GB)(72) Inventors: **Akshay Kumar**, New Delhi (IN);  
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Austin, TX (US)(21) Appl. No.: **18/436,422**(22) Filed: **Feb. 8, 2024****Publication Classification**(51) **Int. Cl.**  
*GI1C 5/14* (2006.01)(57) **ABSTRACT**

A power gating circuit for a memory includes a plurality of header switches, the plurality of header switches comprising: a first transistor having a source tied to an external power supply line; and a second transistor coupled to a drain of the first transistor and having its own drain coupled to an internal voltage line of the memory, wherein the second transistor is structured to be used as a transistor or a diode based on control of a gate of the second transistor; and a selection device coupled to the gate of the second transistor to controllably couple the gate of the second transistor in a first state to the drain of the second transistor for diode operation and in a second state to a second voltage line for transistor operation.



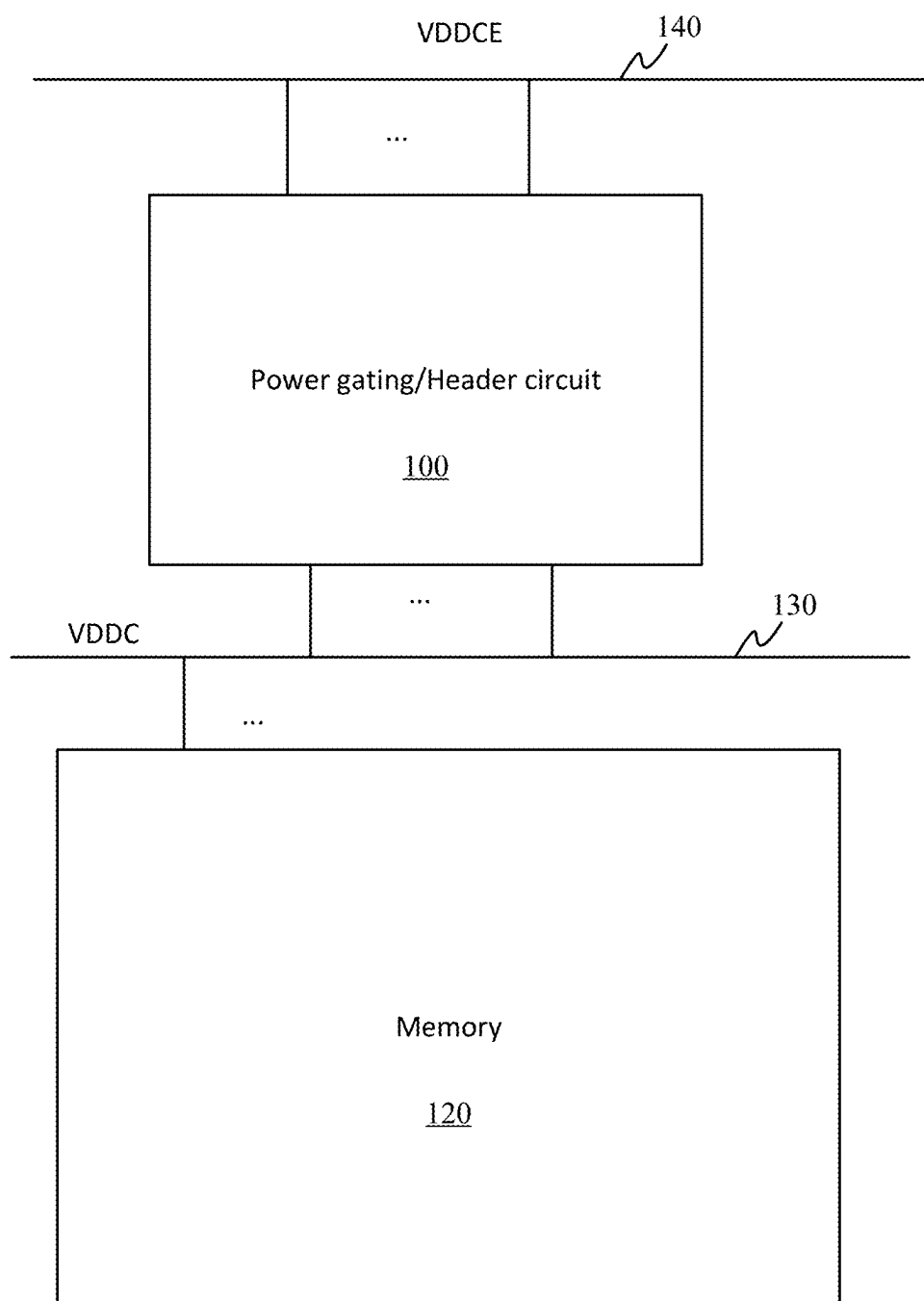


Figure 1

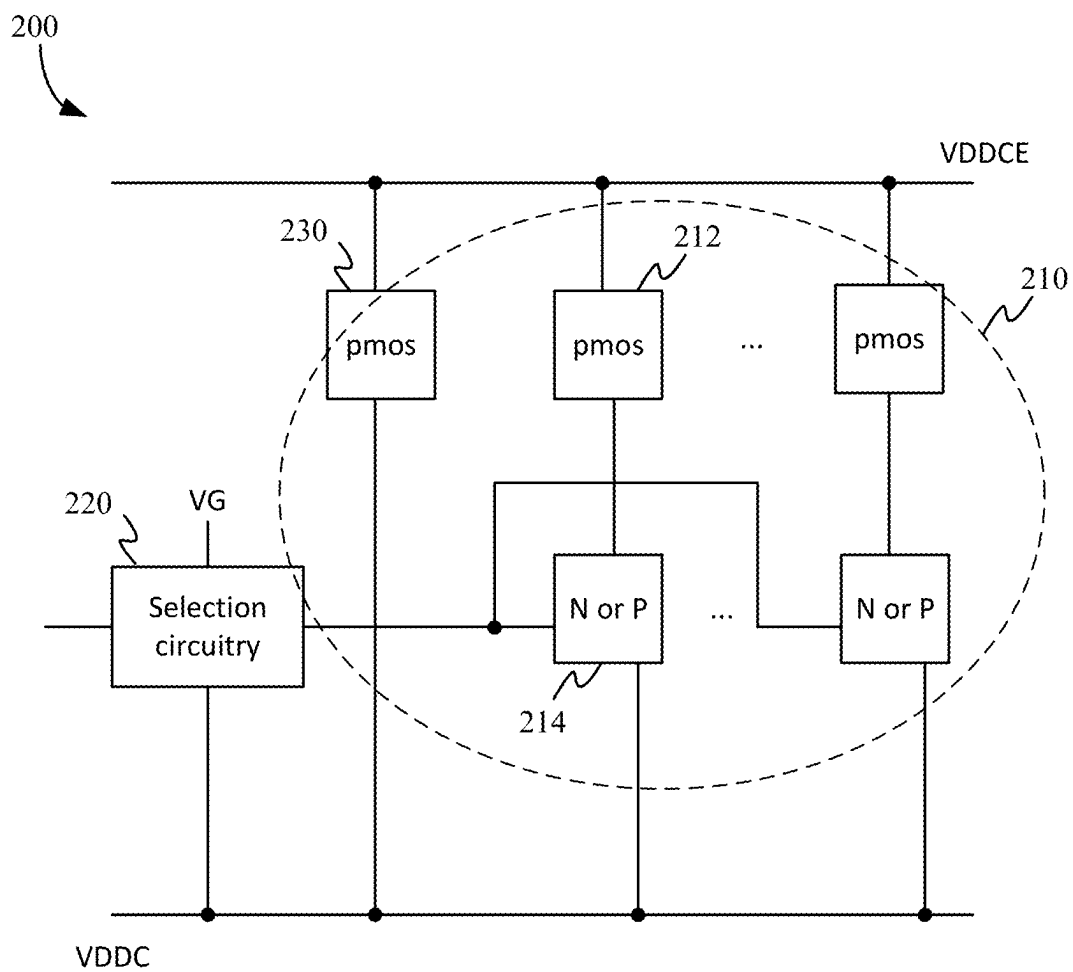


Figure 2

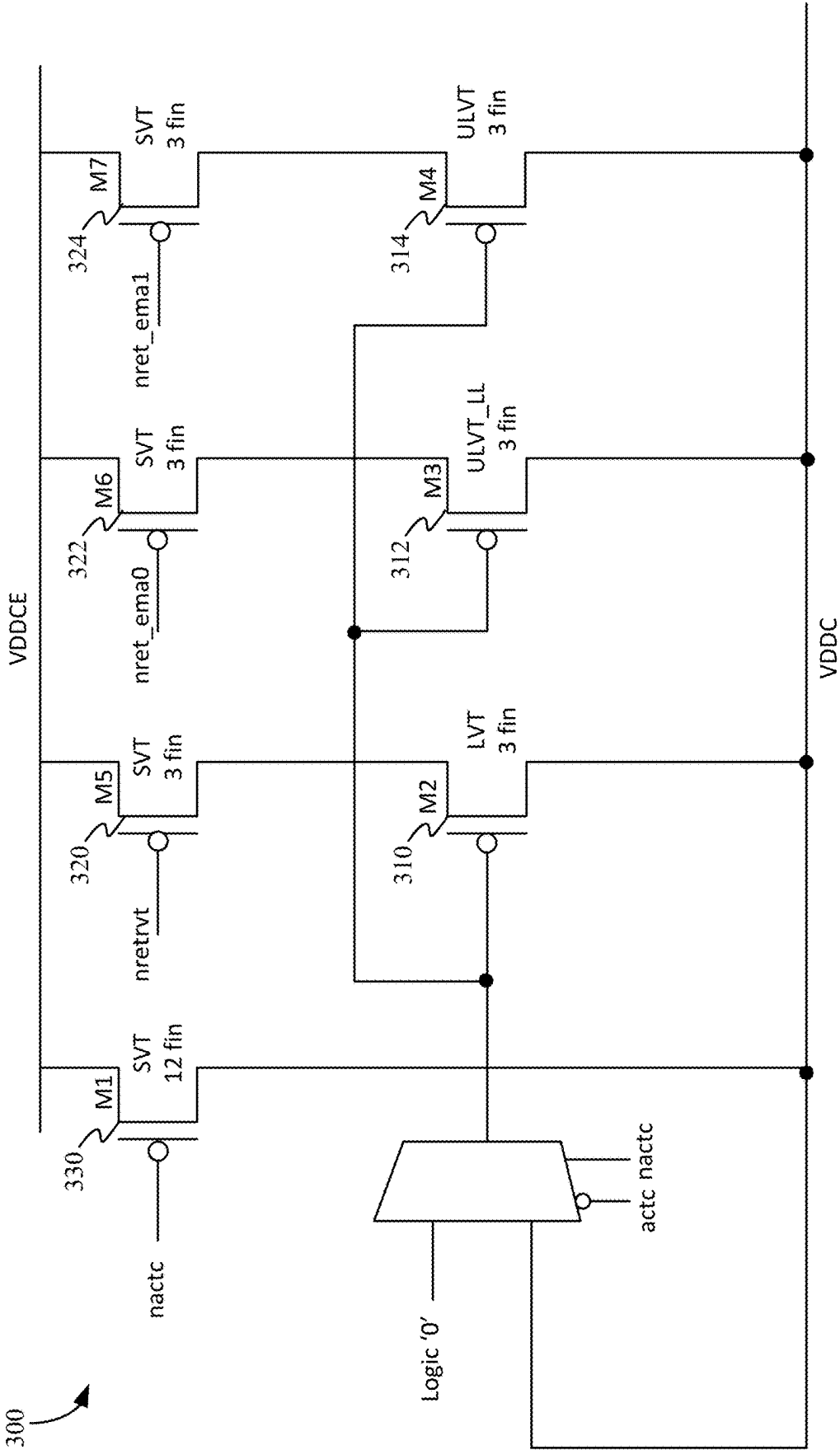


Figure 3A

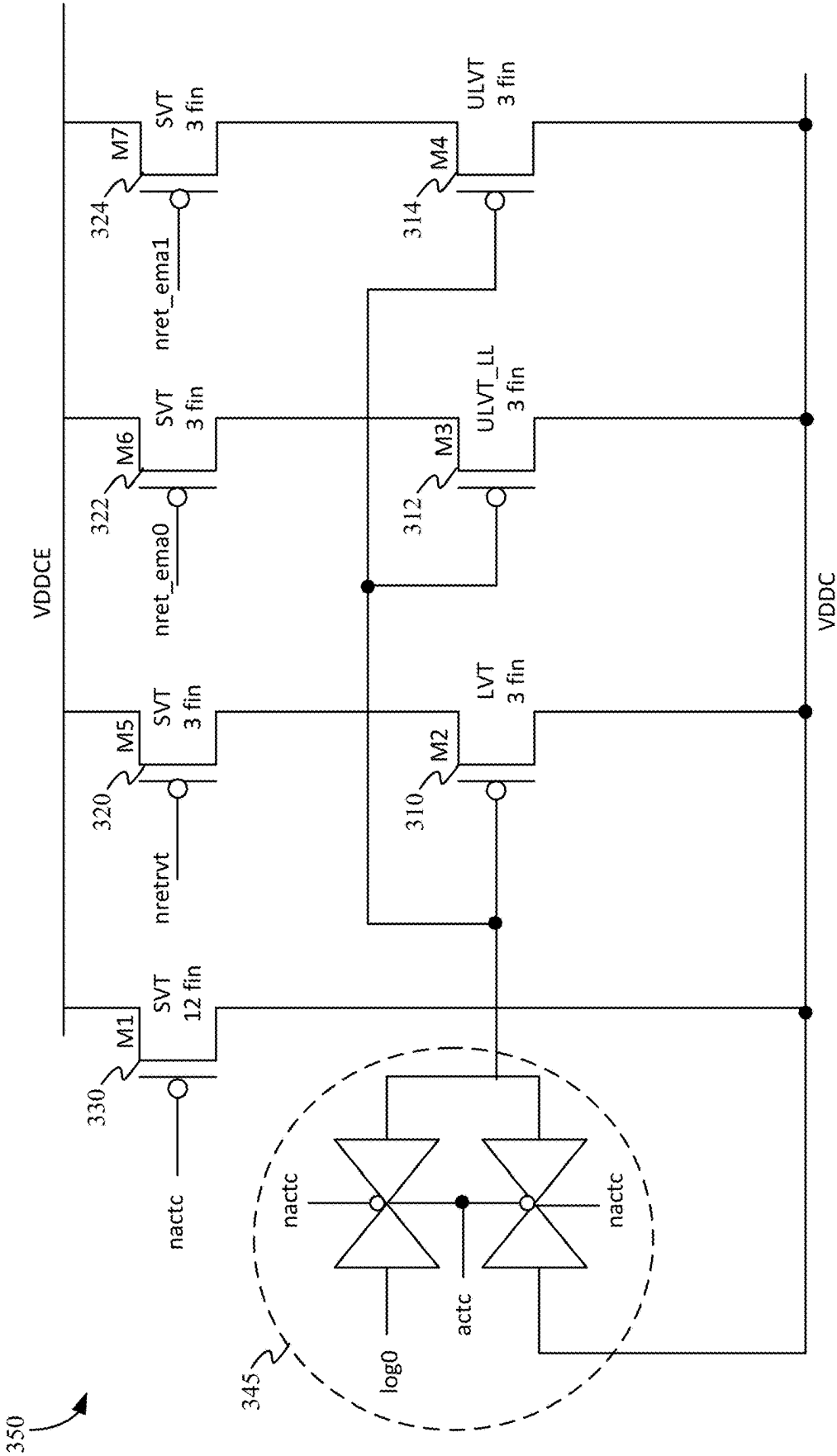


Figure 3B

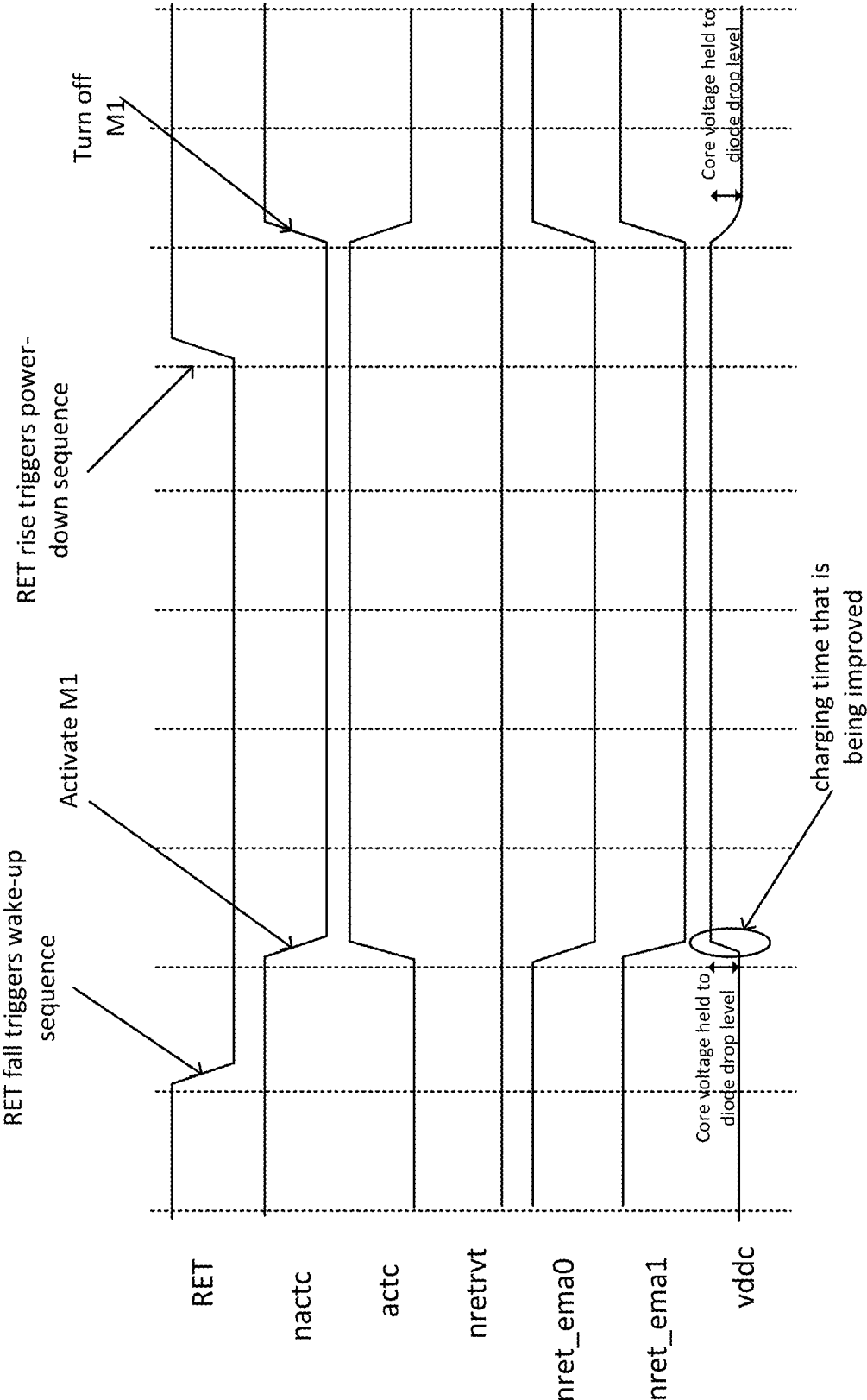


Figure 4

## POWER GATING CIRCUIT WITH MEMORY PRECHARGE SUPPORT

### BACKGROUND

**[0001]** Power gating typically uses low-leakage PMOS transistors as header switches to shut off power supplies to parts of a chip in standby or sleep mode. NMOS footer switches can also be used as sleep transistors to support sleep mode. Inserting the sleep transistors splits the chip's power network into a permanent power network connected to the power supply and a virtual power network that drives the cells and can be turned off.

**[0002]** When power gating is used, the system may include some form of state retention, such as scanning out data to a RAM, then scanning the data back in when the system is reawakened. Retention registers can be used, which are low leakage flip-flops used to hold the data of a main register of the power gated block. A power gating controller can be used to control the retention mechanism along with changing of the power gating modes.

### BRIEF SUMMARY

**[0003]** Power gating circuits with memory precharge support are described. By being able to connect diodes to provide a reduced power supply through a power gating circuit, leakage can be further reduced, which supports efficient precharge.

**[0004]** A power gating circuit for a memory includes a plurality of header switches, the plurality of header switches comprising: a first transistor having a source tied to an external power supply line; and a second transistor coupled to a drain of the first transistor and having its own drain coupled to an internal voltage line of the memory, wherein the second transistor is structured to be used as a transistor or a diode based on control of a gate of the second transistor; and a selection device coupled to the gate of the second transistor to controllably couple the gate of the second transistor in a first state to the drain of the second transistor for diode operation and in a second state to a second voltage line for transistor operation.

**[0005]** A method of operating such a power gating circuit can include maintaining an internal voltage line of the memory at a first voltage based on a diode drop level by operating the selection device to couple the gate of the second transistor in the first state to the drain of the second transistor, wherein the first transistor is ON; receiving a signal triggering a wake-up sequence; and in response to receiving the signal triggering the wake-up sequence, operating the selection device to couple the gate of the second transistor in the second state to the second voltage line.

**[0006]** This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0007]** FIG. 1 shows a representative diagram of a power gating circuit for memory.

**[0008]** FIG. 2 shows a block diagram example power gating circuit.

**[0009]** FIGS. 3A and 3B show example implementations of a power gating circuit.

**[0010]** FIG. 4 shows timing diagrams for operation of an example power gating circuit with memory precharge support.

### DETAILED DESCRIPTION

**[0011]** Power gating circuits with memory precharge support are described. By being able to connect diodes to provide a reduced power supply through a power gating circuit, leakage can be further reduced, which supports efficient precharge.

**[0012]** Memory circuitry, such as for caches, may be designed to have the best leakage (i.e., optimized for minimal leakage) in retention mode, where the memory is intended to stay most of the time. The usage model of certain memory, including system level caches, involves waking up out of retention mode inside one CLK cycle, and then doing an operation in 1-5 cycles, and then going back into retention mode. Consequently, it can be seen that a wake-up from retention mode must happen within one clock cycle. In some cases, the size of the memory is so large that precharging the core array power supply from a diode drop voltage (to optimize leakage) to the full rail is the dominating component of this wake-up time.

**[0013]** Advantageously, a power gating circuit is provided that enables fast wake-up from retention mode.

**[0014]** FIG. 1 shows a representative diagram of a power gating circuit for memory. Referring to FIG. 1, a power gating circuit 100 can be used to control how memory 120 is connected to an external power supply. That is, the value of voltage VDDC 130 supplied to the memory 120 can be controlled, in part, by the power gating of the voltage VDDCE 140 of the external power supply by the power gating circuit 100. The circuitry and operation of power gating circuit 100 can be designed for reducing leakage and providing different modes of operation. The memory 120 can be a cache memory.

**[0015]** FIG. 2 shows a block diagram example power gating circuit. Referring to FIG. 2, a power gating circuit 200 for a memory (e.g., memory 120 of FIG. 1) includes a plurality of header switches 210. The plurality of header switches include a first transistor 212 having a source tied to an external power supply (VDDCE) line; and a second transistor 214 coupled to a drain of the first transistor 212 and having its own drain coupled to an internal voltage line (VDDC) of the memory. The second transistor is structured to be used as a transistor or a diode based on control of a gate of the second transistor 214. The power gating circuit 200 further includes a selection device 220 coupled to the gate of the second transistor 214 to controllably couple the gate of the second transistor 214 in a first state to the drain of the second transistor 214 for diode operation and in a second state to a second voltage line (VG) for transistor operation. The selection device 220 is operated to cause the second state in a precharge mode for the memory. Advantageously, the reconfigurability of the second transistor(s) between being in a diode configuration and being turned off by connection of the gates to a full-rail voltage (e.g., VDD for PMOS and VSS for NMOS) allows for further reduction in leakage when not in the diode configuration. Additionally, when the second transistor(s) is turned on by connection of the gates to a full-rail voltage (e.g., VSS for PMOS and VDD for NMOS), this can assist with the precharging

operations of the memory (e.g., for precharging bitlines and precharging sense amplifiers).

**[0016]** As also shown in FIG. 2, the plurality of header switches **210** can further include a header transistor **230** having a source coupled to the external power supply line (VDDCE) and a drain coupled to the internal voltage line (VDDC) of the memory. The header transistor **230** can be a larger size (e.g., width of channel) than the first transistor **212**.

**[0017]** The selection device **220** can be a multiplexer (MUX) receiving signals from a controller (see e.g., FIG. 3A). In some cases, pass gates can be used as the MUX (see e.g., FIG. 3B). The selection device **220** can be a controller. In some cases, each second transistor (when provided in plurality) has a separate control. In such cases, it can be possible to only turn on one diode instead of all.

**[0018]** The plurality of header switches **210** can all be PMOS transistors. Alternatively, the first transistor **212** can be a PMOS transistor and the second transistor **214** can be a NMOS transistor.

**[0019]** In addition, more than one first and second transistor can be provided. These additional first and second transistors may be independently controllable. For example, the first transistor **212** can be provided in plurality with a corresponding second transistor **214**, wherein each of the header switches are of different sizes, the first transistor being a largest of the header switches. Indeed, as illustrated in FIGS. 3A and 3B, different  $V_t$  types are demonstrated to allow for different precharge times and/or different retention voltages through different diode types.

**[0020]** FIGS. 3A and 3B show example implementations of a power gating circuit; and FIG. 4 shows timing diagrams for operation of an example power gating circuit with memory precharge support.

**[0021]** Referring to FIGS. 3A and 3B, in the header circuit **300**, **350**, there are three diodes (formed by second transistors **310**, **312**, **314**) that offer different diode drop voltages (selected by first transistors **320**, **322**, **324** using corresponding signals `nretrvt`, `nret_ema0`, and `nret_ema1`), and a header transistor **330** that is responsible for pre-charging the internal power supply (`vddc`) to a core memory array. For example, as shown in a first time period in FIG. 4, `nretrvt` is low (to turn ON first transistor **320**) and `nret_ema0` and `nret_ema1` are high (such that transistors **322**, **324** are OFF) to hold the core voltage (VDDC) to a diode drop level of the first diode provided by second transistor **310**. In this configuration, the second transistors **310**, **312**, **314** are each connected as diodes, with drain-gate shorted by selection of MUX **340** of FIG. 3A or, in a specific implementation, pass gates **345** of FIG. 3B, for example, using the control signal to the header transistor **330** of `nactc`, which is asserted high and provided along with a low `actc` as selection device control signals.

**[0022]** When the RET signal is asserted low (signal not shown in FIGS. 3A and 3B), the wake-up sequence is triggered. Typically, for a wake-up sequence, the diodes turn off and it is the job of the core header (e.g., header transistor **330**) to precharge the core array power supply. However, by using a circuit such as shown in FIGS. 2, 3A, and 3B, it is possible to speed up the process of precharging the core array power supply by using the second transistors **310**, **312**, **314** not as diodes but as additional headers to provide additional support to the header transistor **330** and help make the precharging time faster.

**[0023]** In particular, the `nactc` can be asserted signal low, which disconnects the passgate/MUX that provides the diode-like configuration to the gates of the second transistors **310**, **312**, **314**, and instead provides a logic 0 to the gates, allowing the diodes to act as header transistors and help precharge the circuit with a higher drive strength (and improving charging time to bring VDDC from the lower diode drop level to the higher voltage level). Indeed, as can be seen, instead of disconnecting diodes, after RET triggers the wake-up sequence, the second transistors **310**, **312**, **314** are all turned on (with `nretrvt`, `nret_ema0`, and `nret_ema1` all low to turn ON first transistors **320**, **322**, **324**) with gates connected to logic 0 with the selection device input signal of `nactc` being low and `actc` being high. Accordingly, in response to receiving the RET signal triggering the wake-up sequence, the header transistor can be activated and the same control signal activating the header transistor also operates the selection device to couple the gate of the second transistor to the logic 0 (e.g., by a second voltage line).

**[0024]** When RET is asserted high to trigger a power-down sequence, the `nactc` signal is asserted high, which re-enables the diode configuration, and allows the core voltage to drop to the diode level instead, for example, as shown in the final cycles shown in FIG. 4.

**[0025]** Accordingly, a method of operating a power gating circuit such as described herein can include maintaining an internal voltage line of the memory at a first voltage based on a diode drop level by operating the selection device to couple the gate of the second transistor in the first state to the drain of the second transistor, wherein the first transistor is ON; receiving a signal triggering a wake-up sequence; and in response to receiving the signal triggering the wake-up sequence, operating the selection device to couple the gate of the second transistor in the second state to the second voltage line. In this manner, the “diodes” can be converted to transistors and used to improve charging time during wake-up.

**[0026]** Certain embodiments of the illustrated methods and circuitry include the following.

**[0027]** Clause 1. A power gating circuit for a memory, comprising: a plurality of header switches, the plurality of header switches comprising: a first transistor having a source tied to an external power supply line; and a second transistor coupled to a drain of the first transistor and having its own drain coupled to an internal voltage line of the memory, wherein the second transistor is structured to be used as a transistor or a diode based on control of a gate of the second transistor; and a selection device coupled to the gate of the second transistor to controllably couple the gate of the second transistor in a first state to the drain of the second transistor for diode operation and in a second state to a second voltage line for transistor operation.

**[0028]** Clause 2. The power gating circuit of clause 1, wherein the selection device is operated to cause the second state in a precharge mode for the memory.

**[0029]** Clause 3. The power gating circuit of clause 1 or 2, wherein the plurality of header switches further comprises: a header transistor having a source coupled to the external power supply line and a drain coupled to the internal voltage line of the memory, the header transistor being a larger size than the first transistor.



[0030] Clause 4. The power gating circuit of any preceding clause, wherein the selection device comprises a multiplexer receiving signals from a controller.

[0031] Clause 5. The power gating circuit of any of clauses 1-3, wherein the selection device comprises a controller.

[0032] Clause 6. The power gating circuit of any preceding clause, wherein the plurality of header switches are PMOS transistors.

[0033] Clause 7. The power gating circuit of any preceding clause, wherein the first transistor is a PMOS transistor.

[0034] Clause 8. The power gating circuit of any preceding clause, wherein the second transistor is a NMOS transistor.

[0035] Clause 9. The power gating circuit of any preceding clause, wherein the first transistor is provided in plurality with a corresponding second transistor, wherein each of the header switches are of different sizes, the first transistor being a largest of the header switches.

[0036] Clause 10. A method of operating a power gating circuit for memory, the power gating circuit being according to any preceding clause, the method comprising: maintaining an internal voltage line of the memory at a first voltage based on a diode drop level by operating the selection device to couple the gate of the second transistor in the first state to the drain of the second transistor, wherein the first transistor is ON; receiving a signal triggering a wake-up sequence; and in response to receiving the signal triggering the wake-up sequence, operating the selection device to couple the gate of the second transistor in the second state to the second voltage line.

[0037] Clause 11. The method of clause 10, further comprising: receiving a signal triggering a power-down sequence; and in response to receiving the signal triggering the power-down sequence, operating the selection device to couple the gate of the second transistor in the first state to the drain of the second transistor.

[0038] Clause 12. The method of clause 10 or 11, wherein the power gating circuit further comprises a header transistor having a source coupled to the external power supply line and a drain coupled to the internal voltage line of the memory, the header transistor being a larger size than the first transistor, wherein the method further comprises: in response to receiving the signal triggering the wake-up sequence, activating the header transistor, wherein a control signal activating the header transistor also operates the selection device to couple the gate of the second transistor in the second state to the second voltage line, wherein both the header transistor and the first transistor are ON.

[0039] Although the subject matter has been described in language specific to structural features and/or acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as examples of implementing the claims and other equivalent features and acts that would be recognized by one skilled in the art are intended to be within the scope of the claims.

What is claimed is:

1. A power gating circuit for a memory, comprising:
  - a plurality of header switches, the plurality of header switches comprising:
    - a first transistor having a source tied to an external power supply line; and
    - a second transistor coupled to a drain of the first transistor and having its own drain coupled to an internal voltage line of the memory, wherein the second transistor is structured to be used as a transistor or a diode based on control of a gate of the second transistor; and
  - a selection device coupled to the gate of the second transistor to controllably couple the gate of the second transistor in a first state to the drain of the second transistor for diode operation and in a second state to a second voltage line for transistor operation.
2. The power gating circuit of claim 1, wherein the selection device is operated to cause the second state in a precharge mode for the memory.
3. The power gating circuit of claim 1, wherein the plurality of header switches further comprises:
  - a header transistor having a source coupled to the external power supply line and a drain coupled to the internal voltage line of the memory, the header transistor being a larger size than the first transistor.
4. The power gating circuit of claim 1, wherein the selection device comprises a multiplexer receiving signals from a controller.
5. The power gating circuit of claim 1, wherein the selection device comprises a controller.
6. The power gating circuit of claim 1, wherein the plurality of header switches are PMOS transistors.
7. The power gating circuit of claim 1, wherein the first transistor is a PMOS transistor.
8. The power gating circuit of claim 1, wherein the second transistor is a NMOS transistor.
9. The power gating circuit of claim 1, wherein the first transistor is provided in plurality with a corresponding second transistor, wherein each of the header switches are of different sizes, the first transistor being a largest of the header switches.
10. A method of operating a power gating circuit for memory comprising a plurality of header switches, the plurality of header switches comprising: a first transistor having a source tied to an external power supply line; and a second transistor coupled to a drain of the first transistor and having its own drain coupled to an internal voltage line of the memory, wherein the second transistor is structured to be used as a transistor or a diode based on control of a gate of the second transistor; and a selection device coupled to the gate of the second transistor to controllably couple the gate of the second transistor in a first state to the drain of the second transistor for diode operation and in a second state to a second voltage line for transistor operation, the method comprising:
  - maintaining an internal voltage line of the memory at a first voltage based on a diode drop level by operating the selection device to couple the gate of the second transistor in the first state to the drain of the second transistor, wherein the first transistor is ON;
  - receiving a signal triggering a wake-up sequence; and

in response to receiving the signal triggering the wake-up sequence, operating the selection device to couple the gate of the second transistor in the second state to the second voltage line.

**11.** The method of claim **10**, further comprising: receiving a signal triggering a power-down sequence; and in response to receiving the signal triggering the power-down sequence, operating the selection device to couple the gate of the second transistor in the first state to the drain of the second transistor.

**12.** The method of claim **10**, wherein the power gating circuit further comprises a header transistor having a source coupled to the external power supply line and a drain coupled to the internal voltage line of the memory, the header transistor being a larger size than the first transistor, wherein the method further comprises:

in response to receiving the signal triggering the wake-up sequence, activating the header transistor, wherein a control signal activating the header transistor also operates the selection device to couple the gate of the second transistor in the second state to the second voltage line, wherein both the header transistor and the first transistor are ON.

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