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Design and Analysis of SRAM Cells in Ultra Deep Submicron CMOS Technology

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ABSTRACT : Since short-circuits are responsible for much of the dynamic power loss, concept of virtual source transistors is used for removing direct connection between V_{DD} and GND. Faster write time can be achieved by using transmission gates instead of simple NMOS pass transistors. By implementing these improvements seven different memory cell designs are proposed. Each of these designs has been extensively simulated in 16nm CMOS predictive technology for comparison with the standard six-transistor (6T) differential memory cell. Simulation results indicate similar type of outputs for same input while working with these designs but power dissipation and delay has significant changes with varying schemes. Secondly the technology is also scaled down to 16nm so power and speed is also optimized accordingly for future scope of designing. Besides these factors, very small device dimensions show a remarkable area reduction, which is also an added advantage. As size is a prime concern for SRAM cell as well as for all SOCs, in which memory occupies more than 50% of space.

I. INTRODUCTION

The increasing market of mobile, hand-held devices and battery powered portable electronic systems as well as the increase in data transfer rates demands that these systems use less power and reduce operational delays. These devices and systems demand high-speed, high-throughput computations, complex functionalities and often real time processing capabilities. The performance of these devices is limited by the size, weight and lifetime of batteries. Serious reliability problems, increased design costs and battery operated applications prompted the IC design community to look more aggressively for new approaches and methodologies that produce more power efficient designs, which means significant reductions in power consumption for the same level of performance. For five decades, the semiconductor industry has distinguished itself by the rapid pace of improvement in its products. The principal categories of improvement trends are shown in Table 1.1 with examples of each. Most of these trends have resulted principally from the industry's ability to exponentially decrease the minimum feature sizes used to fabricate integrated circuits. Of course, the most frequently cited trend is in integration level, which is usually expressed as Moore's Law (that is, the number of components per chip doubles roughly every 18 months). The most significant trend is the decreasing cost per function, which has led to significant improvements in economic productivity and overall quality of life through proliferation of computers, communication, and other industrial and consumer electronics.

Table 1: Improvement Trends for ICs Enabled by Feature Scaling

TREND	EXAMPLE
Integration Level	Components/chip, Moore's Law
Cost	Cost per function
Speed	Microprocessor throughput
Power	Laptop or cell phone battery life
Compactness	Small and light weight products
Functionality	Nonvolatile memory, imager

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Since memory currently makes up a large part of systems, nearly fifty percent, reducing the power and delay in memories becomes an important issue. In fact, some systems, such as the reconfigurable hardware which uses the memory latch as its most basic component, have an even larger percentage of their structure built with memory. Memories are also responsible for almost half of the total CPU dissipation.

II. BASICS OF SRAM CELLS

Static Random Access Memories (SRAMs) are used extensively in all kinds of systems and are found in almost every integrated circuit as an embedded component. They are known for their large storage density and small access latency.

Properties of SRAM

An SRAM cell offers the following basic properties:

- SRAM is a form of random access memory: A random access memory is one in which the locations in the semiconductor memory can be written to or read from in any order, regardless of the last memory location that was accessed
- Retention: An SRAM cell is able to retain the data indefinitely as long as it is powered.
- Read: An SRAM cell is able to communicate its data. This operation does not affect the data i.e., Read operation is non-destructive.
- Write: The data of an SRAM cell can be set to any binary value regardless of its original data.

- **SRAM Architecture**

Memory cells are the key components of any SRAM serving for storage of binary information. A typical SRAM cell is comprised two cross-coupled inverters forming a latch and access transistors. Different types of SRAM cells are based on the type of load used in the elementary inverter of the flip-flop cell. Access transistors enable read and write access to the cell and cell isolation for the not-accessed state. An SRAM cell has to provide non-destructive read access, write capability and infinite storage (or data retention) time provided the power is supplied to the cell. Hierarchically, memory cells are arranged in cores, which can be further divided into blocks and arrays depending on the system speed and power requirements.

We will consider three of the more recent SRAM cells: a resistive load four-transistor (4T) SRAM cell, a loadless 4T SRAM cell and a six transistor (6T) CMOS SRAM cell. We will then discuss their advantages and disadvantages. The cell design considerations represent a tradeoff between cell area, robustness, speed and power. Cell size minimization is one of the most important design objectives. A smaller cell allows the number of bits per unit area to be increased and thus, decreases cost per bit. Reduced cell size can indirectly improve the speed and power consumption due to the reduction of the associated capacitances. However, the cell area might have to be traded off for high performance or low power, radiation hardness or special functionality requirements.

4T SRAM Cell with Polysilicon Resistor Load

The main advantage of static 4T cells with polysilicon resistor load (PRL) (Fig. 3.2) is the approximately 30% smaller area as compared to 6T SRAM cells. Due to the higher electron mobility ($\mu_n/\mu_p = 1.5 - 3$), all transistors in a PRL cell are normally NMOS. The load resistors serve to compensate for the off state leakage of the pull down devices. On one hand, the values of R_L must be as high as possible to retain a reasonable noise margin NM_L , i.e., to limit the "0" level rise and reduce the static power consumption. On the other hand, a high R_L severely increases the low-to-high propagation delay if $V_{DD}/2$ precharge is used and it also increases the cell size. Furthermore, precharging the bit lines to $V_{DD}/2$ can compromise the cell stability with scaling of the V_{DD}/V_{TH} ratio. Precharge of bit lines to full V_{DD} can alleviate the requirement for the low-to-high cell transition current at the cost of the additional precharge time required for a full V_{DD} precharge and the associated power consumption. The upper resistance limit on

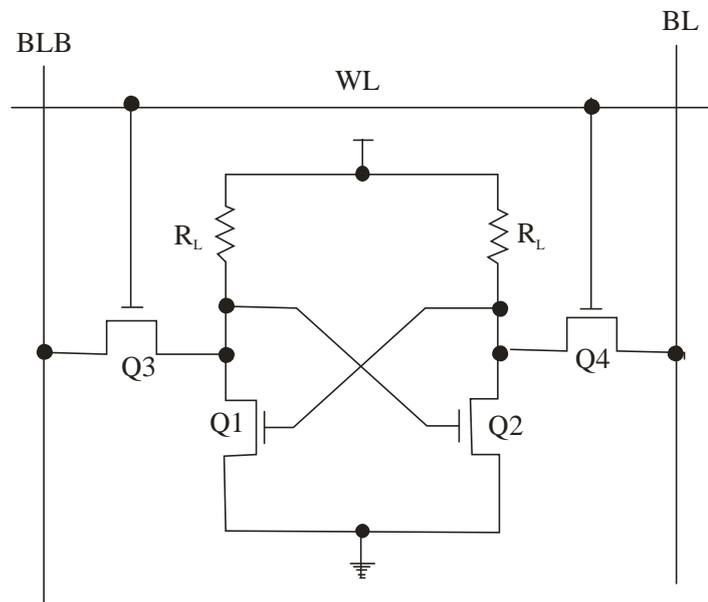
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R_L is put by the requirement to provide a pull-up current of at least two orders of magnitude larger than the leakage current [3]. The lower limit on R_L is put by the required noise immunity and power consumption requirements. The technological variations of R_L caused by the limitations of doping and annealing techniques pose another constraint on the increase of R_L .



• Fig. 1: Four Transistor (4T) SRAM Cell with Polysilicon Resistor Load

Historically, 4T polysilicon resistor load cells are the remnants of the pre-CMOS technologies. Ratioed inverters comprising the cell have lower gain in the transition region and produce inherently less steep VTCs, which reflects on the SNM values and the recovery time from a metastable state [29] of such cells. The reduction of V_{DD} from the standard 5V to 3.3V, 2.5V and so on, i.e., the switch from constant-voltage scaling to constant-field scaling to combat the short channel effects, revealed non satisfactory low-voltage stability of the PRL cells. Moreover, the extra technological steps of forming high resistivity polysilicon are not a part of the standard logic technological process. Insufficient tolerance to soft errors.

Memory Write Process

Essentially, writing to memory is a two step process. The first step involves the decoding of the memory address and conditioning the bitlines to hold the proper values to be stored into memory. The second step includes turning on the access transistors and allowing the cell to be overwritten with the new data. The speed of a write access is determined by the time it takes to decode the address plus the time to pull the word line high and pass the data from the bitlines to the cell. The write operation is similar to resetting an SR latch. One of the bit lines, e.g., BL in Fig.2, is driven from precharged value (V_{DD}) to the ground potential by a write driver through transistor Q6. If transistors Q4 and Q6 are properly sized, then the cell is flipped and its data is effectively overwritten. This is necessitated by the non-destructive read constraint that ensures that a “0” node does not exceed the switching threshold of inverter Q2 – Q4. The function of the pull-up transistors is only to maintain the high level on the “1” storage node and prevent its discharge by the off state leakage current of the driver transistor during data retention and to provide the low-to-high transition during overwriting.

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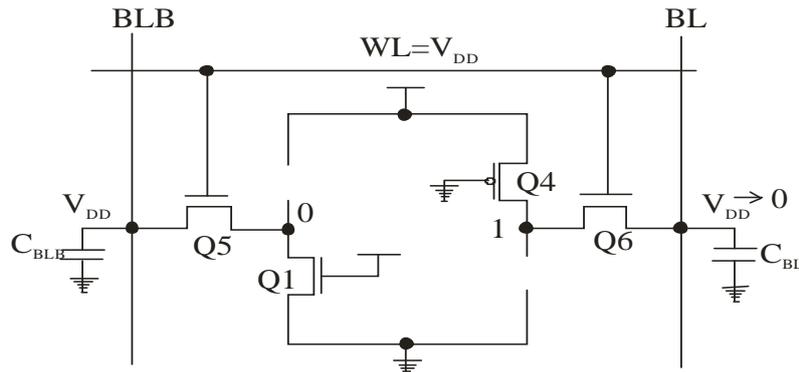


Fig. 2: Simplified Model of a 6T CMOS SRAM Cell During a Write Operation

Lower case letters written in these names designates which type of pass transistors the memory latch uses to access the bitlines. Following the previous example, the name that is used from now on for the CMOS Virtual GND/ V_{DD} memory is VGVC. In the last column additional transistors used with the standard 6T SRAM cell are shown.

Table 2: The 6T memory cell and its seven novel variations

Fig.3	Cell Description	Abbreviated Name	Additional Transistor
a.	Standard SRAM with nMOS access Transistor	6T	
b.	6T with nMOS access and Virtual GND Transistor	VGn	TVG
c.	6T with nMOS access and Virtual V_{DD} Transistor	VVn	TVV
d.	6T with nMOS access and Virtual GND/ V_{DD} Transistor	VGVn	TVG and TVV
e.	SRAM with CMOS TG access Transistor	8T	TG
f.	8T with TG access and Virtual GND Transistor	VGc	TVG and TG
g.	8T with TG access and Virtual V_{DD} Transistor	VVc	TVV and TG
h.	8T with TG access and Virtual GND/ V_{DD} Transistor	VGVc	TVG, TVV and TG

6T with Gated GND/ V_{DD} (VGVn) Structure

Schematic of VGVn structure shown in Fig 3 has one extra pMOS and one nMOS transistor insertion. Control signals are VSp and VSn respectively.

Here both VSp and VSn signal by controlling pMOS and nMOS provides the gated supply for V_{DD} and GND respectively. Thus these transistors become virtual supply transistors. As this structure eliminates all the three types of short circuits i.e. One-to-GND, V_{DD} -to-Zero and Short- V_{DD} -GND can be expected most power efficient structure discussed till now.

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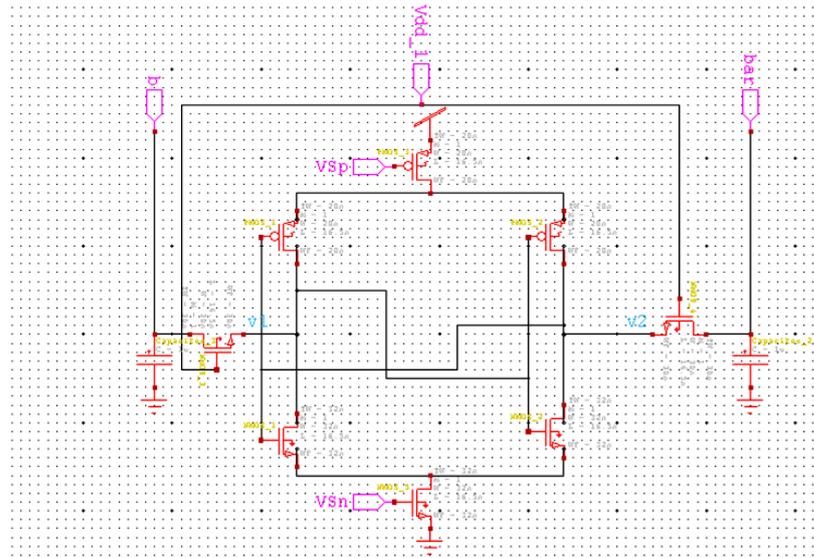


Fig. 3: Schematic Designing of VGVn

Fig. 4 depicts simulated waveforms for both VSp and VSn control signals with other signals. Power may be optimized by this structure but situation is different in case of delay. VSp and VSn both providing complimentary pulses at the switching of write enabling signal for duration sufficient to provide cut off from supplies at that time. This will effectively reduce short circuit power losses. That will be apparent from power result obtained after simulation.

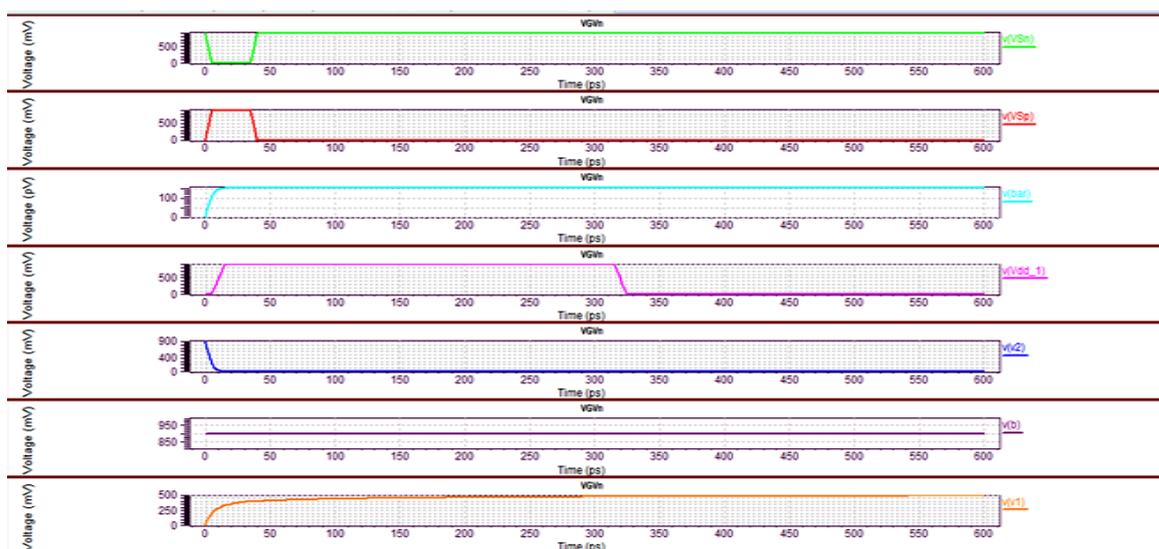


Fig. 3: Waveforms of VGVn

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The details of timing signals in waveforms simulation are as follows:

Vdd_1- Write Enable Signal

b- Bit Line Signal

bar- Inverted Bit Line Signal

v1- Internal Node corresponding to Bit Line

v2- Internal Node corresponding to Inverted Bit Line

VSp- Control Signal for Virtual V_{DD} Transistor

VSn- Control Signal for Virtual GND Transistor

Timing of nodes for pulling up and down is changed as it happens with every changed design.

III. RESULTS AND PERFORMANCE ANALYSIS

Here we will show the results obtained after simulation and then analyze the performance on the basis of these results first for power and delay then for area.

Power and Delay

Simulations of the 6T SRAM and its seven variations were run using the Tanner Tool simulator. This section reports the measured power and delay values gathered from those simulations. The power-delay product is also reported with the results since typically it is a more effective method of comparing data and not as easily manipulated by changing voltage levels or simulation times.

On the basis of this table we can represent best performance results in tabular form as shown below in Table 2:

Table 2: Best Performance Results

Performance Metrics	Configuration	% Saving (Compared to 6T)
Power	VGv _n	25.85
Delay	VGc	11.1
Power-Delay	VGn	23.8

Using the 6T SRAM as a standard for comparison, the VGv_n latch demonstrates a 25.85% decrease in power dissipation. Delay is reduced by 11.1% when the VGc cell is used in memory write operations. In terms of the power-delay product, the VGn SRAM exhibited 23.8% savings over the 6T cell. Based on the discussion given in 4, the memory cells performed as would be expected: the virtual source transistors helped to reduce power and including TG in the memory cells decreased the speed to overwrite the stored value. An exception to this is the 8T memory.

IV. CONCLUSION

The most successful designs in terms of power consumption, delay, power-delay product and size are reviewed below.

- **Lowest Power Consumption:** In comparison with the 6T memory cell, VGv_n reduces the overall power used during a write cycle by 25.85%. This confirms that virtual source transistors are effective in eliminating short circuits that exist while switching the data stored in memory cells.
- **Shortest Delay:** Through the combined efforts of the virtual ground transistor and the CMOS transmission gates, VGc is able to reduce the delay to store data by 11.1%.
- **Smallest Power-Delay Product:** For the best combination of power and delay savings, VGn should be used since it has the smallest power-delay product, which is 23.8% lower than the standard 6T cell.

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- Smallest Size: Although VVn has smallest size after 6T latch but VGn latch is a good option for memory use since only one extra nMOS transistor and with 18.5% more area is needed and it uses less power than the standard 6T memory.

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