

SOFT ERROR TOLERANT HIGHLY RELIABLE MULTI PORT MEMORY CELL DESIGN

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ABSTRACT

In a Very Large Scale Integrated (VLSI) circuit, memory design and development is the predominant domain. Static Random Access Memory (SRAM) is used as a discrete component in earlier stages of the system design, and now it is used as an Embedded SRAM for System on Chip (SOC) designs. Designing and developing of memory in each manufacturing technology node is continuous challenge and it is the first priority of the evaluation of manufacturing technology. Reliability of a product describes the ability of a system or component to perform its required functions under stated conditions for a specific period of time. Quality of product is decided based on reliability of the chip. For an Integrated Circuit (IC), as a critical product specification under today's aggressive technology scaling, to achieve reliability in leading-edge technology has always been very difficult and costly to measure. In this project, highly reliable multiport SRAM memory cell for CMOS technology is designed and developed. Simulation results are reported to show that the proposed two port memory cell (14T) is highly reliable for Single Event Upset (SEU). Single soft error is modelled for evaluating the multiport memory cell which is self-tolerant with respect to SEU

Keywords: SRAM, Multi Port Memory, Single Event Upset (SEU), CMOS, Soft Error, Reliability, Read – Write Circuitry, Power Delay Product (PDP)

I INTRODUCTION

Single Event Upsets (SEUs) induced by particle radiation are becoming an increasing important threat to the reliability of memories fabricated in Nano scale CMOS technologies. SEUs are caused by particle-induced charge which is derived from direct ionization from heavy ions and indirect ionization from protons and neutrons. An energetic particle passes through the sensitive node of a semiconductor device it frees electron-hole pairs along its path as it loses energy. The electric field present in a reverse-biased junction depletion region can separate electron-hole pairs, so that the particle-induced charge is very efficiently collected through drift processes leading to an accumulation of extra charge at the sensitive node. When the amplitude of the accumulated charge is enough and the time is long enough, it can generate a large voltage transient pulse which changes temporarily the value of the sensitive node. In addition, the sensitive areas of semiconductor device are the strongly reverse biased diffusion areas where the induced transient current flows from the N-type diffusion to the P-type diffusion. As a result, when a radiation particle strikes PMOS transistor, only a positive transient pulse is generated, on the contrary, when a radiation particle strikes NMOS transistor, only a negative transient pulse is induced.

II SRAM DESIGN

The demand for static random-access memory (SRAM) is increasing with large use of SRAM in System-On-Chip and high performance VLSI circuits. Due to the need of battery operated device, the scaling in CMOS technology continues. Nanoscale CMOS SRAM memory design faces several challenges like reducing noise margins and increasing variability, due to the continuous technology scaling. In SRAM the data is lost when the memory is not electrically powered. Advances in chip design using CMOS technology have made possible the design of chips for higher integration, faster performance, and lower power consumption. To achieve these objectives, the feature size of CMOS devices has been dramatically scaled to smaller dimensions over the last few years. Power consumption of SRAMs account for a significant portion of the overall chip power consumption and due to high density, low power operation is a feature that has become a necessity in today's microprocessors. The basic architecture of a static RAM includes one or more rectangular arrays of memory cells with support circuitry to decode addresses, and implement the required read and write operations. Additional support circuitry used to implement special features, such as burst operation, may also be present on the chip

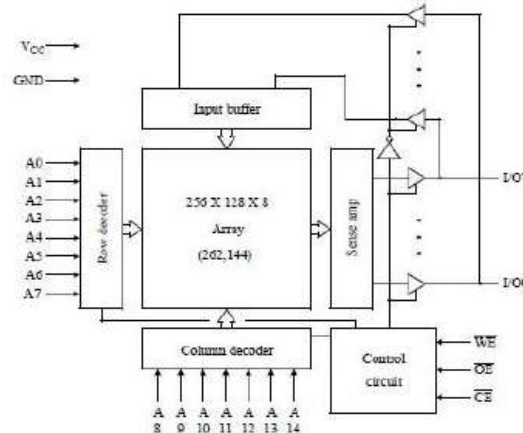


Fig 2.1 SRAM Block diagram

2.1 Conventional 6T SRAM Cell

An SRAM memory cell is a bi-stable flip-flop made up of four to six transistors. The flip-flop may be in either of two states that can be interpreted by the support circuitry to be a 1 or a 0. A typical SRAM cell is made up of six MOSFETs. Each bit in an SRAM is stored on four transistors (M1, M2, M3, M4) that form two cross-coupled inverters. This storage cell has two stable states which are used to denote 0 and 1. Two additional access transistors serve to control the access to a storage cell during read and write operations. In addition to such six-transistor (6T) SRAM, other kinds of SRAM chips use 4, 8, 10 (4T, 8T, 10T SRAM), or more transistors per bit. Four-transistor SRAM is quite common in stand-alone SRAM devices (as opposed to SRAM used for CPU caches), implemented in special processes with an extra layer of poly-silicon, allowing for very high-resistance pull-up resistors.

The principal drawback of using 4T SRAM is increased static power due to the constant current flow through one of the pull-down transistors. This is sometimes used to implement more than one (read and/or write) port, which may be useful in certain types of video memory and register files implemented with multi-ported SRAM circuitry. Generally, the fewer transistors needed per cell, the smaller each cell can be. Since the cost of processing silicon wafer is relatively fixed, using smaller cells. Access to the cell is enabled by the word line (WL in figure) which controls the two access transistors M_5 and M_6 which, in turn, control whether the cell should be connected to the bit lines: BL and BL bar. They are used to transfer data for both read and write operations. Although it is not strictly necessary to have two bit lines, both the signal and its inverse are typically provided in order to improve noise margins.

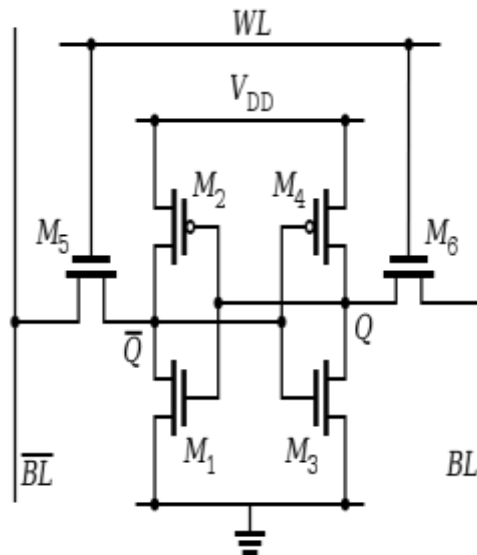


Fig.2.2 Conventional 6T SRAM cell

2.2 Read and Write Operations

To select a cell, the two access transistors must be “on” so the elementary cell (the flip-flop) can be connected to the internal SRAM circuitry. These two access transistors of a cell are connected to the word line (also called row or X address). The selected row will be set at VCC. The two flip-flop sides are thus connected to a pair of lines, B and B. The bit lines are also called columns or Y addresses. During a read operation these two bit lines are connected to the sense amplifier that recognizes if a logic data “1” or “0” is stored in the selected elementary cell. This sense amplifier then transfers the logic state to the output buffer which is connected to the output pad. There are as many sense amplifiers as there are output pads. During a write operation, data comes from the input pad. It then moves to the write circuitry. Since the write circuitry drivers are stronger than the cell flip-flop transistors, the data will be forced onto the cell. When the read/write operation is completed, the word line (row) is set to 0V, the cell (flip-flop) either keeps its original data for a read cycle or stores the new data which was loaded during the write cycle.

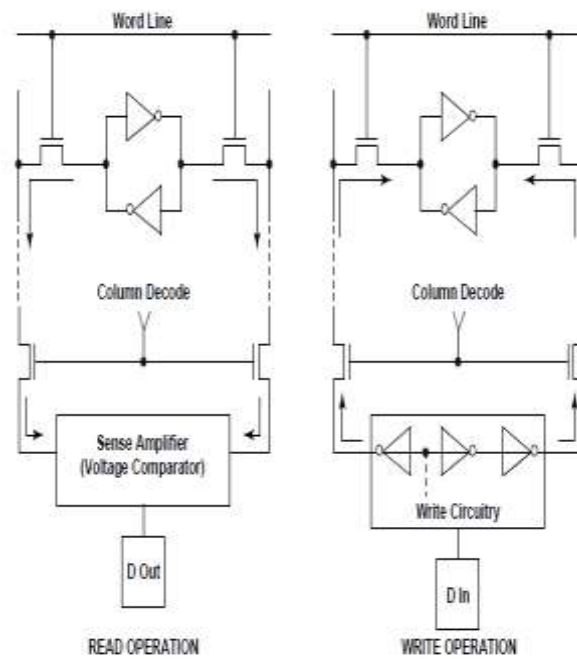


Fig2.3 Read Write Operation of SRAM

2.3 Problems in 6T SRAM Cell

The potential stability problem of this design arises during read and writes operation, where the cell is most vulnerable towards noise and thus the stability of the cell is affected. If the cell structure is not designed properly, it may change its state during read and write operation. There are two types of noise margin which affects the Cell stability that are discussed shortly.

During the read operation, a stored “0” can be overwritten by a “1” when the voltage at node V1 reaches the V_{th} of nMOS N1 to pull node V2 down to “0” and in turn pull node V1 up even further to “1” due to the mechanism of positive feedback. This results in wrong data being read or a destructive read when the cell changes state. Conventional 6T SRAM suffers severe stability degradation due to access disturbance at low-power mode.

2.4 8T SRAM Cell

With the aggressive scaling in technology, substantial problems have been encountered when the conventional 6T (six transistors) SRAM cell configuration is utilized. This cell shows poor stability at very small feature sizes, the hold and read static noise margins are small for robust operation. Therefore, an extensive literature can be found on designing SRAM cells for low power operation in the deep sub-micron/nano ranges. The common approach to meet the objective of low power design is to add more transistors to the original 6T cell. An 8T cell can be found to solve the problem. This cell employs two more transistors to access the read bitline. The transistor configuration (i.e. M1

through M6) is identical to a conventional 6T SRAM cell. Two additional transistors M7 and M8 (thus yielding an 8T cell design) are employed in to reduce the leakage current.

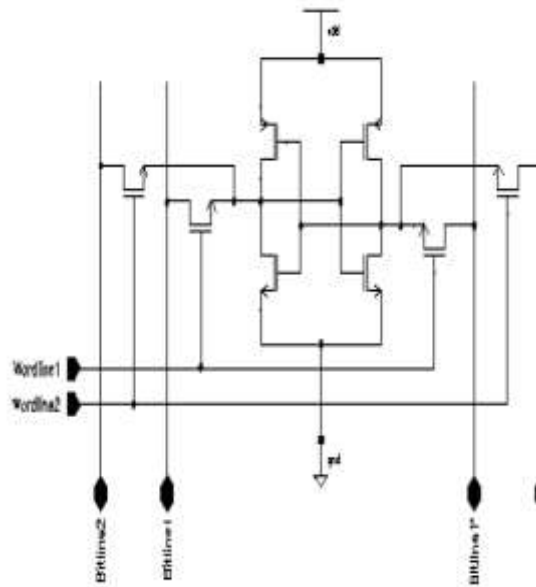


Fig 2.3 8T SRAM Circuit

2.5 Read and Write Operations

This Circuit is two write-read(2WR) type of 8T-SRAM memory cell which has similar structure with the standard single-port SRAM. But it has two sets of data and address paths. So this is a dual-port memory cell. Each address and data path can complete the write and read operation independently. This SRAM cell is the component to store binary information. It has both read and write capabilities. The word line defines operational modes.

- When both Wordline1=Wordline2=0, both access transistors are off and cell is isolated. To perform read operation.
- When Wordline1=1 and Wordline2=0, the Bitline1 is selected and perform the write operation.
- When Wordline1=0 and Wordline2=1, the Bitline2 is selected and perform the write operation.
- When Wordline1=1 and Wordline2=1, the output is “AND” operation of Bitline1 and Bitline2.

2.6 12T SRAM Cell

The proposed SRAM cell is demonstrated in figure 2.4. This structure consists of 12 transistors which six main transistors are same as conventional 6T. The four additional transistors respect with 6T are used to separating the read and write path of cell. The cell is single ended structure which does the read operation from one side of cell. Using separated path for read and write operation increases the control over the array of the cell in the catch design by simultaneous read and write operations which is in contrast with shared access path as conventional 6T cell. Circuit functionality modes are; Write, read and hold mode. The WWL and RWL are independent signals and Hold

Signal (HS) is produced by them. Both write and read modes are called active mode. For choosing between active and idle (hold) mode, M12 transistor is used on the top place which separates virtual supply voltage from supply voltage rail. This transistor acts as a power gating transistor. In active mode the M12 transistor should be in ON mode by producing zero in HS signal ($HS=0$). After that the write and read operation can be done.

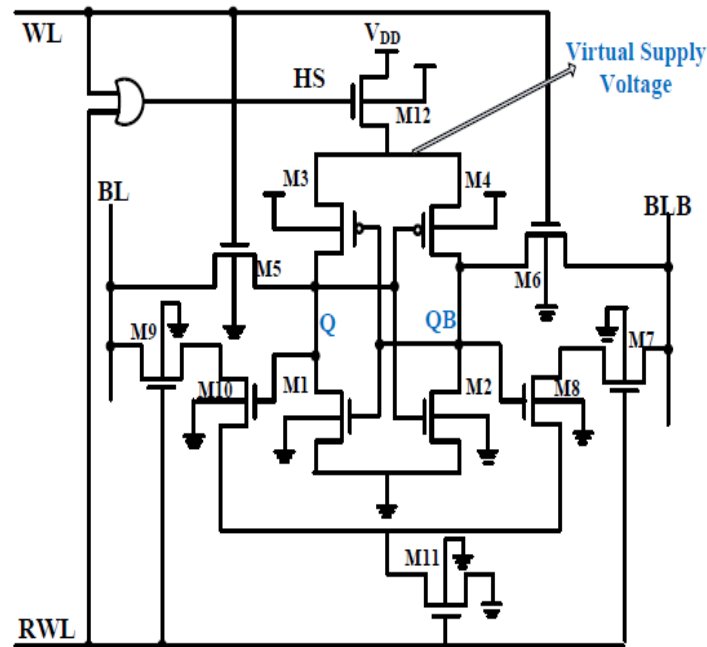


Fig 2.412T SRAM Circuit

2.6 Read and Write Operations

The write paths proposed architecture consist of two transistors (M5 and M6). In write mode, these transistors activate with WWL signal and write the value of BL and BLB on the storage nodes. The write operation can be performed at supply voltages as lower voltage. Inability of access transistors to change the cell's value in write operation is called write failure. The read operation is done only from QB storage node. In this mode RWL signal becomes one and BL and BBL pre-charge to one. When cell saves the one, ($Q=1$ and $QB=0$) the M10 becomes ON and reads the Q node by passing the current through M8 and M9. On the other case, when zero is saved in cell ($Q=0$ and $QB=1$) the M8 becomes ON and BLB line discharges through M7 and M11.

2.7 Single Event Upset

Single Event Upsets (SEU) occurs when the SEE leads to a logic gate switch, voltage transients, or alteration of stored information. Single Event Effects (SEE) are caused by the interaction of ionizing particles with

semiconductor devices. The passing of an ionizing particle through a semiconductor device generates electron-hole pairs (EHPs) along the track path and may be collected at the terminals of a device. Linear Energy Transfer (LET) is defined as the energy loss per unit path length, normalized by the density of the material. LET has units of MeV/mg/cm². A calculation of the charge deposited per unit length can be determined if the LET of the ion, average energy needed to create an EHP for a material, and density of the material are known. For silicon, an ion with a LET of 97 MeV/mg/cm² will deposit 1pC of charge per micron length of the ion track. SEUs don't just happen in deep space or when high levels of radiation are present. The same cosmic rays that warm the earth's atmosphere carry energetic particles that cause upsets in earth-based equipment.

III SENSITIVE NODES

In CMOS circuits, the “off” transistors struck by a heavy ion in the junction area are most sensitive to single event upset (SEU) by particles with high enough LET (linear energy transfer) of around 20 MeV-cm²/mg. When these particles hit the silicon bulk, the minority carriers are created and if collected by the source drain diffusion regions, the change of the voltage value of those nodes occurs. The induced transient voltage pulse may propagate through several of logic gates. Because a particle can induce an SEU when it strikes either the channel region of an off NMOS transistor or the drain region of an off PMOS transistor, it is considered that the strike at an off PMOS drain area. Particles can induce SEU when it strikes at the channel region of an off NMOS transistor or the drain region of an off PMOS transistor. The ionization can induce a current pulse in a p-n junction. A schematic view of how the SEE induced current pulse translates into an SEE induced voltage pulse is shown in figure 3.1. Single event upsets are events in which an incident particle can strike key node within a device resulting in a local ionization that can cause a state change in a bit with sufficient voltage.

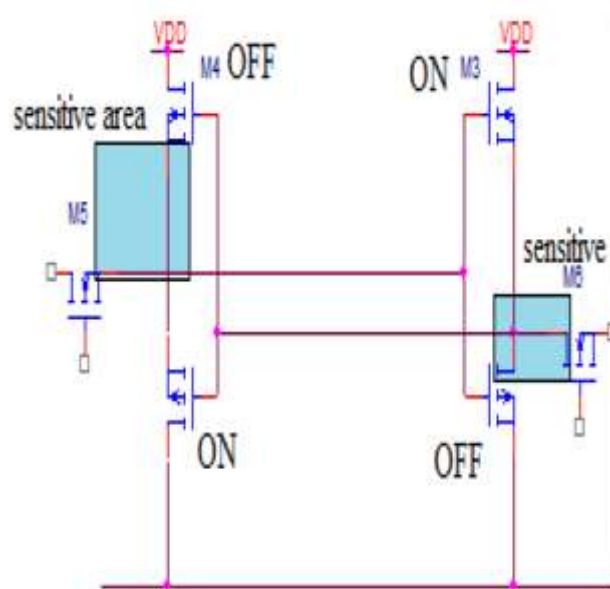


Fig 3.1 Critical Nodes within Circuit

When a PMOS is struck, a positive transient pulse is induced which is 0 to 1 SEU and when NMOS is struck a negative transient pulse is generated which is 1 to 0 SEU.

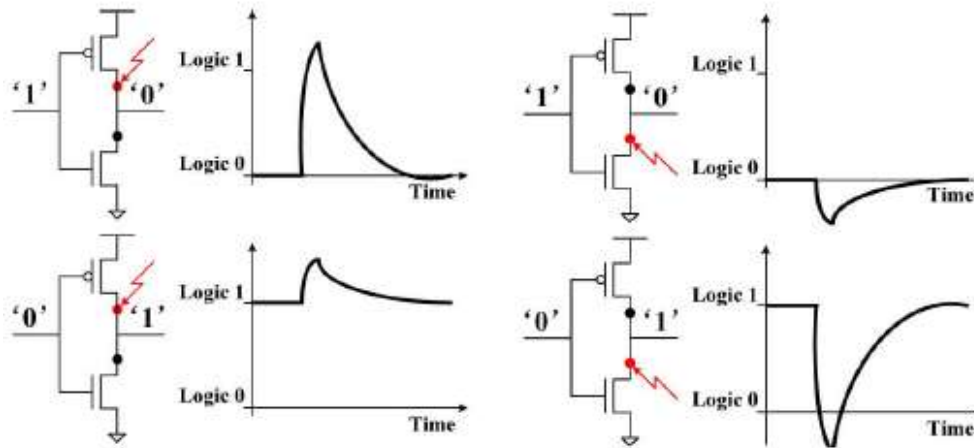


Fig 3.2 0 to 1 SEU and 1 to 0 SEU

A particle can induce SEU when it strikes at the channel region of an off NMOS transistor or the drain region of an off PMOS transistor. The ionization can induce a current pulse in a p-n junction.

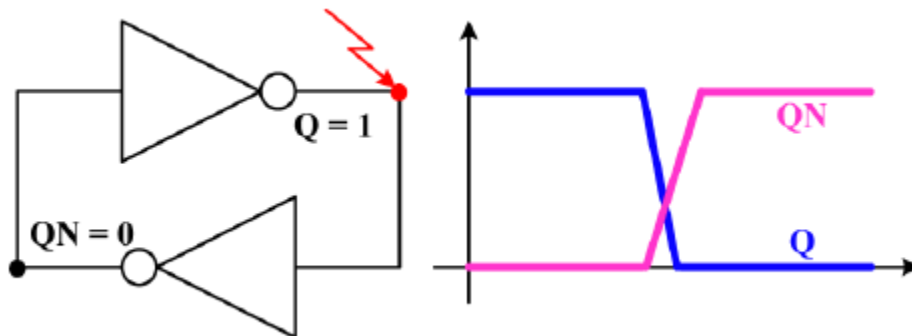


Fig 3.3 1 to 0 SEU occurrence in SRAM 6T cell

Using radiation hardened memory cells to increase the SEU immunity is a less area, power and delay consuming solution.

IV PROPOSED METHOD

In order to cope with the different drawbacks a new low-power and highly reliable radiation hardened memory cell is proposed using 12 transistors, which is capable of fully tolerating SEU at its any sensitive node, but also can tolerate multiple-node upset on two fixed nodes independent of the stored value. Here, access transistors are NMOS transistors N1 and N8 which are controlled by a word line WL. In the proposed cell, the output nodes are Q and QN

which are connected to bit lines BL and BLN through access transistors N8 and N1 respectively. First, Hold operation is considered. Word line WL is '0', transistors P3, P4, N5, N6 and N4 are turned ON and the other transistors are turned OFF. It is shown that the state of the memory cell is maintained. Second, Read operation is introduced. Bit lines BL and BLN are pre-charged to VDD. When word line WL is '1', node Q keeps its initial state '1', because transistors P3, P4 and N5 are still ON. However, bit line BLN is discharged through transistors N1 and N4. Then according to the voltage difference between bit lines BL and BLN, the state of the memory cell is output by a differential sense amplifier.

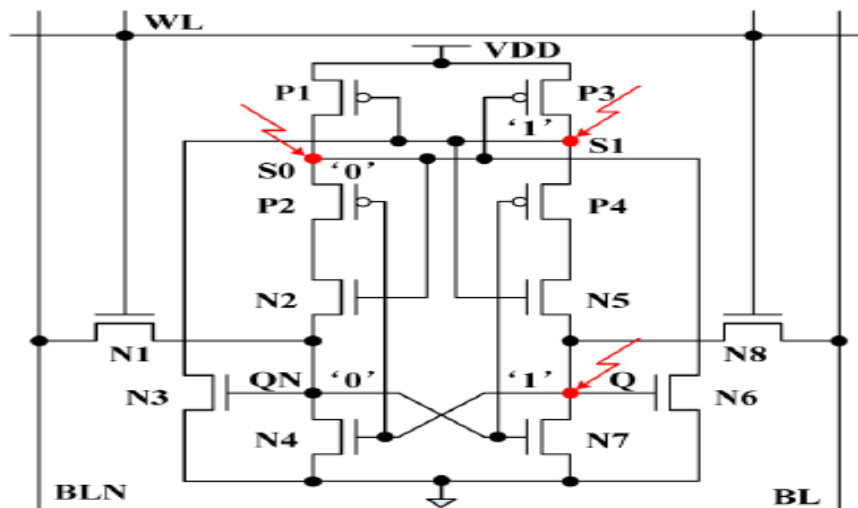


Fig 4.1 Radiation Hardened Memory Cell – 12T

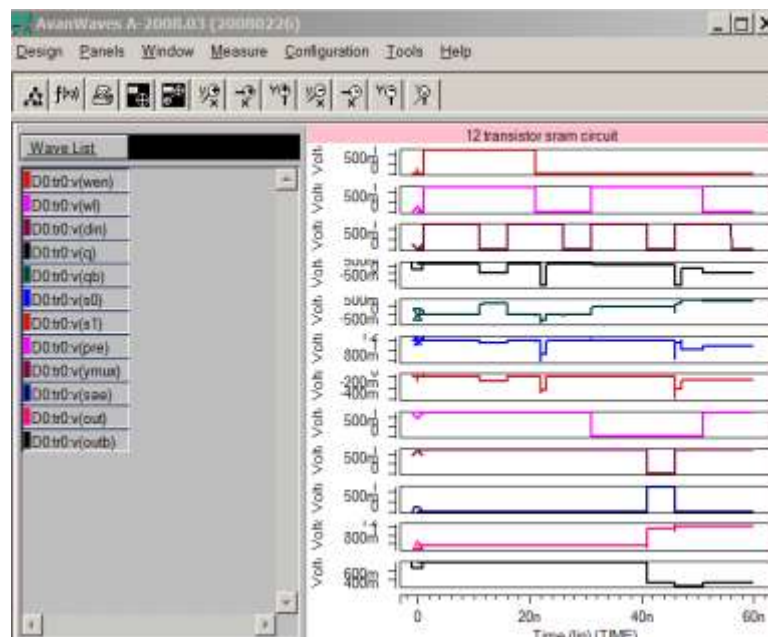


Fig 4.2 12T SRAM with SEU @ Q with Read Protected

Finally, in order to modify the state of this cell, word line WL is '1', and bit lines BL and BLN are set to '0' and '1' respectively. Node QN is forced to '1', thus transistors N7, N3, P1 and N2 are turned ON, transistors P3, P4 and N5 are turned OFF. Simultaneously node Q is pulled down to '0' so that transistors N4 and N6 are both OFF and transistor P2 is ON. Then word line WL is changed to '0', the new state of the memory cell is stored.

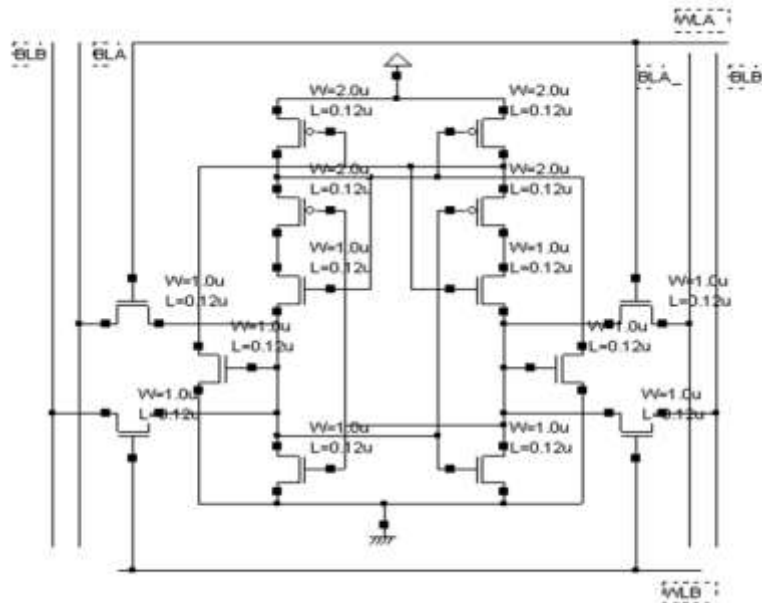


Fig 4.3 14T Radiation Hardened Memory Cell

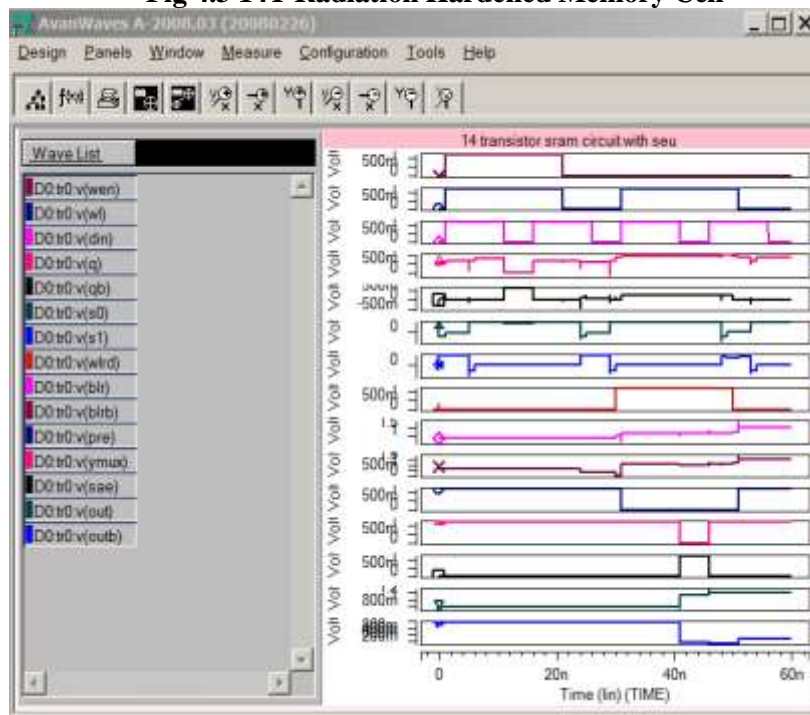


Fig 4.4 14T SRAM Write with SEU @ S0, S1

SRAM circuits are designed for both read and write operation also with and without SEU for 6T, 8T, 12T and 14T techniques. From Results we analyzed that 12T and 14T SRAM circuits are not affected even if the SEU are injected and retain the data and are proved reliable circuits. Also analysis have shown that 14T SRAM transistor consume very less power when compared to other circuits. But when there is a SEU and when the data reliability is maintained 14T SRAM consumes more power and very less delay.

Table: 4.1 Comparison of Power, Delay and PDP for SRAM circuits.

Circuit Model	RESULTS		
	DELAY	POWER	PDP
6T SRAM_WR	39ns	251uw	10pJ
6T SRAM_SEU	9.9ns	2.71Mw	2.71mJ
8T SRAM_WR	29ns	241uw	7.2pJ
8T SRAM_SEU_RD	29ns	1.68Pw	50.6MJ
12T SRAM_WR	40ns	232uw	9.3pJ
12TSRAM_SEU_RD	39ps	6.6Gw	26.7MJ
14T SRAM_WR	29ns	124uw	3.73pJ
14T SRAM_SEU	41ps	48.7Gw	19J

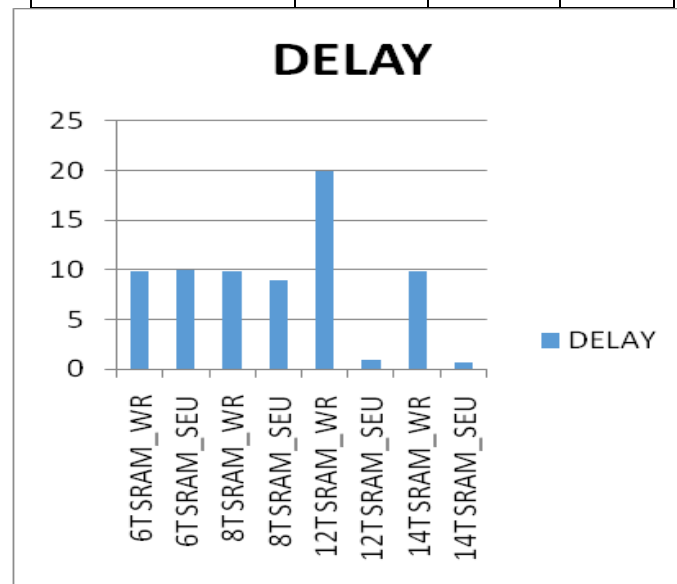


Fig 4.5 Comparison chart for delay (ns) in various SRAM logic

Table 4.1 shows that when there is a SEU, the proposed 12T and 14T hardened memory cells consume higher power with reduced delay which is shown in the comparison chart.

V CONCLUSION

In this paper, a novel low-power and highly reliable radiation hardened memory cell RHM-12T and RHM 14-T structures are proposed to provide perfect protection against SEU in memory. Reliability of a product describes the ability of a system or component to perform its required functions under stated conditions for a specified period of time. Quality of product is decided based on reliability of the chip. For an Integrated Circuit (IC), as a critical product specification under today's aggressive technology scaling, reliability has always been very difficult and costly to measure, and to achieve in leading-edge technology. In this project design and development of SRAM circuits with various methods of implementation carried out with different transistor count with 6T, 8T, 12T and 14T logics with and without Single Event Upset. From the results, it is proved that 12T and 14T transistors are reliable and retain the data even at presence of SEU whereas other two logic undergoes SEU error. Therefore, designers should choose the optimal sizes of transistors to provide a good tradeoff in terms of static noise margin and other performances. Also power consumption is very less for 14T structure when compared to other logics. The future enhancement can be extended to work on the power consumed by this 14T structure during the SEU event occurrence which consumes higher power but with promising decrease in delay parameter. The future work can be done with the SRAM logic implementation on Multi Port Memories.

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