Comparative Study in Response Time between a Current-mode and a Voltage-mode Sense Amplifier for Resistive Loads in MRAM

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Abstract--**We comparatively study the response times of a current-mode and a voltage-mode sense amplifier for the resistive loads used in MRAM. In order to limit the applied voltage below a critical value of 0.4V across the resistors, sense amplifiers with separate input/output nodes are selected. A systematic simulation study for the resistive load variations in range of 0.5 kΩ to 8.5 kΩ using a 0.35μm-CMOS technology shows that the current-mode sense amplifier shows superior response time of at least 1.3nsec over the voltage-mode sense amplifier.**

Keywords : MRAM, current mode, sense amplifier

I. INTRODUCTION

Magneto-resistive random access memories (MRAMs) possess many desirable properties for ideal memories such as fast read- and write-operations, and non-volatility. Currently, one of the critical issues for MRAM devices is to develop a stable magnetic tunnel junction (MTJ) structure with a high magneto-resistance (MR) ratio. In addition, the MR ratio needs to stay constant over a wide range of applied voltages. However, the MR ratio of the developed MTJ devices depends heavily on the voltage across the device and decreases rapidly as the applied voltage increases [1]. In order to alleviate this MR ratio degradation, various voltage clamping circuit techniques have been applied to limit the voltage across the MTJ devices [2]. The signal amplitude from the MTJ device, however, also decreases with the voltage clamping. Therefore the development of fast and highly sensitive sense amplifiers is imperative for fast access in MRAM.

In this paper, we compare the response times between a current-mode and a voltage-mode sense amplifier with separate input/output nodes to limit the voltages across MTJs below 0.1V. In section II, we elaborate the design considerations for the sense amplifiers in MRAM. We present the two sensing circuits for comparison and their simulation results in section III and analyze the respective sense amplifier response time characteristics in resistive load variations. Finally, we summarize the results in section IV.

II. DESIGN CONSIDERATION OF SENSING CIRCUIT FOR HIGH SPEED MRAM OPERATION

Of the issues related to the MRAM circuit design, the MR ratio degradation with respect to the applied voltage attracts lots of attention. The MR ratio is reduced to half when the voltage reaches the critical value (~0.4V[1]) such that it cannot function as a storage element. Therefore, it is important to maintain the voltage applied to the MTJ below the critical value. By maintaining the sense amplifier input node voltage below the critical value, the MR degradation can be overcome. However, the sense amplifier output node voltage should develop close to the supply voltage as the signal is amplified. Hence, separate input/output nodes are necessary for the sense amplifiers for this purpose.

Secondly, in order to decrease the access time associated with memory speed, fast response time of a sense amplifier needs to be considered. Two basic types of sense amplifiers are available, a voltage-mode and a current-mode amplifier. Speed comparison between these two types in MRAM application should be beneficial for the development of high speed MRAM.

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III. COMPARISON IN RESPONSE TIME BEWEEN A CURRENT-MODE AND A VOLTAGE MODE SENSE AMPLIFIER

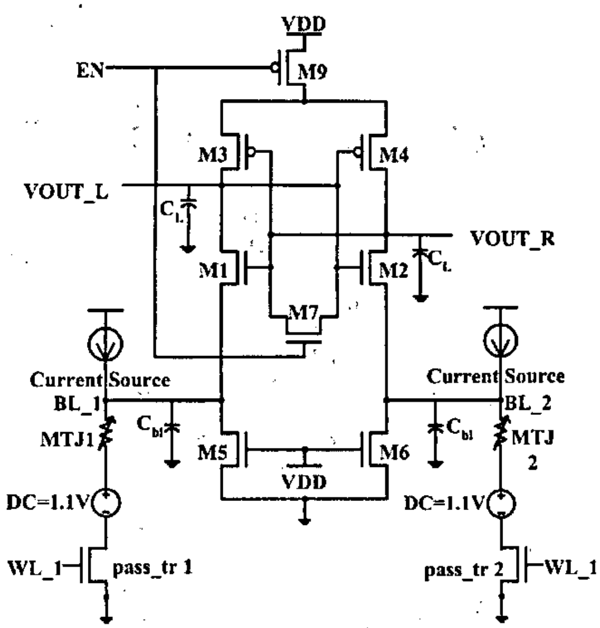

Fig. 1 A current mode sense amplifier

A current mode sense amplifier chosen for the above mentioned purpose is presented in Fig. 1 [3]. The signal sources shown in the lower left- and right- corners of Fig. 1 consist of a constant current source, an MTJ, a dc voltage source, and a pass transistor in series. Although a dc voltage source is not necessary for the current-mode sense amplifier, it is included to provide a sufficient common-mode input voltage signal level in the simulation of the voltage-mode sense amplifier shown later. In order to account for the line capacitance of the input line, a capacitance C_{bl} of 0.6pF is also included. The currents from the constant current sources supply the input currents to M5 and M6 drain-side depending on the resistance values of MTJ1 and MTJ2, respectively. This injected current signal is then amplified by the traditional CMOS cross-coupled latch amplifier formed by transistors M1-M4. The amplified voltage signal appears at the output nodes of VOUT_L and VOUT_R.

Thus the sense amplifier can respond to current signals rather than voltage signals. Transistors M5 and M6 operating in the linear region serve in two purposes. They provide low impedance paths to ground to effectively sink current signals and thus clamp the input voltages below the critical value. Furthermore the charging and the discharging of the line capacitor are minimized due to this low impedance path to ground.

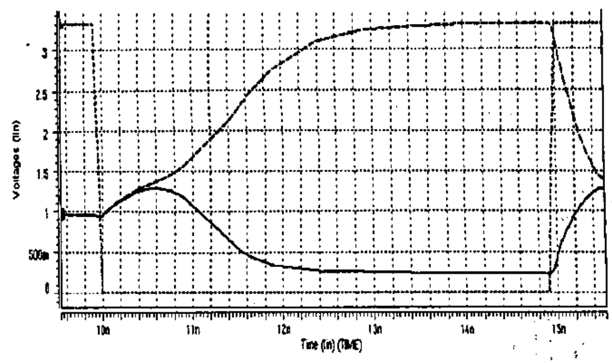

Fig. 2 Current mode sense amplifier simulation result

The simulation result from this current-mode sense amplifier with a current source of 20μA, C_L=0.1pF, R(MTJ1)=2.95 kΩ and R(MTJ2)=2.50 kΩ[5] is shown in Fig. 2. We assume a two phase operations: a precharge phase and an amplification phase. In precharge phase, the enable signal is high, that is, M9 is in the cutoff region to disconnect the supply voltage from the circuit and M7 is in the linear region to equalize the voltages of the output nodes. In order to begin amplification, the enable signal switches to low, turning on M9 and turning off M7. The cross-coupled latch, M1-M4, then acts as a positive feedback amplifier that amplifies the voltage difference between the input nodes resulting from the current difference as shown in Fig. 2. If we define the response time as the time taken from the activation of the enable signal to the development of the output voltage becoming 1V, we obtain the value of 1.10nsec.

In Fig. 3, we show a voltage-mode sense amplifier [4]. We apply the same signal sources as the ones used in the current-mode sense amplifier circuit for comparison. In this circuit, however, unlike current mode sense amplifier, the input nodes are connected to the gates of transistors M5 and M6.

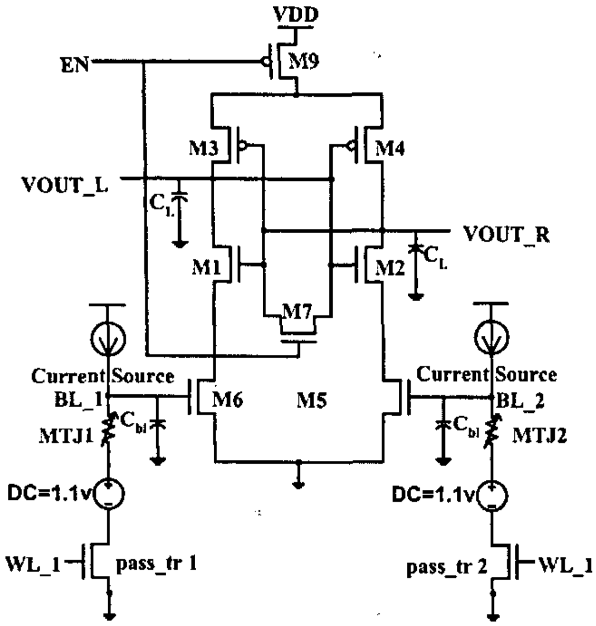

Fig. 3 Voltage mode Sense Amplifier

Therefore this sense amplifier detects a voltage signal from the inputs. Once the voltage difference is detected at the input nodes, it is amplified by the cross-coupled latch formed by M1- M4. The voltage clamping for this amplifier is achieved by carefully selecting the values of the current source and the MTJ resistance.

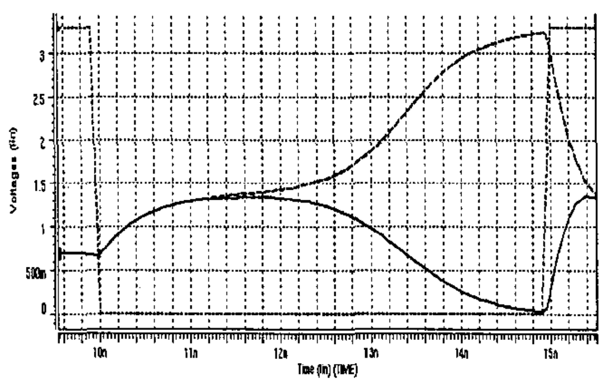

Fig. 4 Voltage mode sense amplifier simulation result

Fig. 4 shows the simulation result of the voltage-mode sense amplifier with the same load conditions as the ones in the current-mode sense amplifier. The response time is obtained to be 3.11nsec if the same definition is applied.

In comparison, for this specific case of load conditions, the response time for the current-mode is 1.10nsec much shorter than 3.11nsec for the voltage-mode sense amplifier.

IV. Response Time Analysis with Respect to Resistive Load Variations

Thus far, we have concentrated on the specific load conditions of R(MTJ1)=2.50 kΩ and R(MTJ2)=2.95 kΩ. However, the MTJ resistance values are highly process dependent [1]. Therefore we have performed an analysis on the resistive load variations to verify the effect of MTJ resistance values on the MRAM sense amplifiers for a constant MR ratio. The MR ratio of our MRAM cell is assumed to be 18% in accordance with the reference [5], we have first simulated with the current-mode sense amplifier with various resistance values for R(MTJ1) ranging from 0.5 kΩ to 8.5 kΩ in increment of 1 kΩ [5].

Fig. 5 shows the simulation waveforms of various resistive load values. The waveform at the top corresponds to the resistance value of 0.5 kΩ and the waveforms subsequently below correspond to the incrementing resistance values down to the one at the bottom to 8.5 kΩ. Although the respective waveform moves down as the resistance value goes up, the response time stays relatively constant.

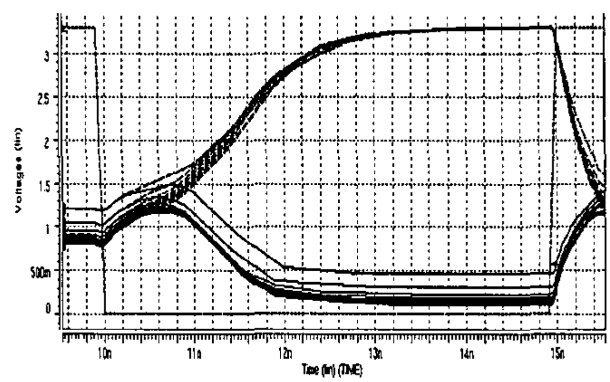

Fig. 5 Simulation result of Current mode sense amplifier

We have performed the same analysis for the case of the voltage-mode sense amplifier. The simulation results are shown in Fig. 6. As the resistance value goes up, the corresponding waveform moves to the left side resulting in faster response time.

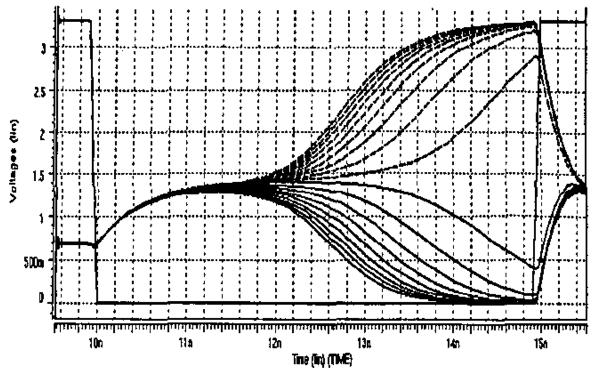

Fig. 6 Simulation result of voltage mode sense amplifier

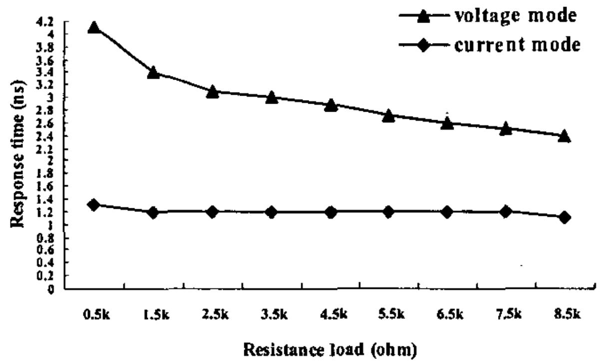

Fig. 7 Response time of various resistive loads

These results are clearly shown in Fig. 7. This result is mainly due to the fact that as the resistance goes up, the gate-to-source voltages of the input transistors M5 and M6 increase resulting in higher signal level. However, this will cause an undesirable effect of increasing the voltage across the MTJ resistor. Therefore this reduction of the response time cannot continue in reality. Throughout the range of the resistance values we investigated, the current-mode sense amplifier shows at least 1.3nsec faster response time than the voltage-mode sense amplifier.

V. CONCLUSION

In this paper, we present a comparative study in response time for the sense amplifiers that might be used in MRAM. We carefully select a current-mode and a voltage-mode sense amplifier with separate input/output nodes according to the limitations imposed by the properties of the MTJ storage element. For the two types of sense amplifiers compared for the resistive load conditions ranging from 0.5 kΩ to 8.5 kΩ, the current-mode sense amplifier consistently shows better response time characteristics at least by 1.3nsec over the voltage-mode sense amplifier.

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