

ESD Protection for CMOS Output Buffer by Using Modified LVTSCR Devices with High Trigger Current

Ming-Dou Ker

Abstract—Modified designs of the low-voltage triggering semiconductor-controlled rectifier (LVTSCR) devices with high trigger current are proposed to protect the CMOS output buffer against electrostatic discharge (ESD) events in submicrometer CMOS technologies. The high trigger current is achieved by inserting the bypass diodes into the structures of the modified PMOS-trigger lateral SCR (PTLSCR) and NMOS-trigger lateral SCR (NTLSCR) devices. These modified PTLSCR and NTLSCR devices have a lower trigger voltage to effectively protect the output transistors in the ESD-stress conditions, but they also have a higher trigger current to avoid the accidental triggering due to the electrical noise on the output pad in the normal operating conditions of CMOS IC's. Experimental results have verified that the trigger current of the modified PTLSCR (NTLSCR) is increased up to 225.5 mA (218.5 mA). The noise margin to the overshooting (undershooting) voltage pulse on the output pad, without accidentally triggering on the modified NTLSCR (PTLSCR), is more than $V_{DD} + 12$ V ($V_{SS} - 12$ V).

Index Terms—ESD, latchup, LVTSCR, noise margin.

I. INTRODUCTION

ELECTROSTATIC discharge (ESD) protection has become a main concern on the reliability of IC products in submicrometer CMOS technologies. Especially, the drains of NMOS and PMOS devices in the CMOS output buffer are often directly connected to the output pad to drive the external load, so the CMOS output buffer is more vulnerable to ESD stress. To improve ESD robustness of a CMOS output buffer and also to drive/sink current to/from the external heavy load, the output NMOS and PMOS devices are often designed with large device dimensions. Even with such large device dimensions, the ESD robustness of the CMOS output buffer had been reported to be seriously degraded by the advanced submicrometer CMOS technologies [1]–[4].

Recently, the lateral semiconductor-controlled rectifier (SCR) device had been used as an ESD-protection element for input protection in submicrometer CMOS IC's [5]–[8]. To effectively protect the CMOS output buffer, the low-voltage triggering SCR (LVTSCR) device has been invented with a much lower trigger voltage [9]–[12]. The trigger voltage of the LVTSCR device is equivalent to the snapback-trigger voltage of the short-channel NMOS (or PMOS) device, which is inserted into the lateral SCR structure, rather than the original switching voltage (about 30–50 V) of the lateral SCR device. To protect the output transistors in the CMOS output buffer, the inserted NMOS (or PMOS) in the LVTSCR should be designed with a shorter channel length than the output NMOS

(PMOS) in the CMOS output buffer [9]–[12]. But with such a low trigger voltage of the LVTSCR, the corresponding trigger current of the PMOS-trigger lateral SCR (PTLSCR) and NMOS-trigger lateral SCR (NTLSCR) are only about 4.7 mA and 12.3 mA in a 0.6- μ m CMOS technology, respectively [11]. The lower trigger voltage of the PTLSCR and NTLSCR can provide effective ESD protection for the CMOS output buffer, but the lower trigger current may cause the PTLSCR and NTLSCR to be accidentally triggered on by the external overshooting or undershooting noise pulses on the output pin while the CMOS IC is in its normal operating condition.

In this paper, a modified PTLSCR and a modified NTLSCR with lower trigger voltage but higher trigger current are proposed to safely protect the CMOS output buffer without being accidentally triggered on by the electrical noisy pulse when the CMOS IC's are in the normal operating conditions.

II. MODIFIED PTLSCR/NTLSCR DEVICES WITH HIGH TRIGGER CURRENT

A. Modified Device Designs

The schematic cross-sectional views of the modified PTLSCR and NTLSCR in a P-substrate N-well CMOS process are shown in Fig. 1(a) and (b), respectively. The modified PTLSCR is formed by inserting a bypass diode Dn2 into the PTLSCR structure as shown in Fig. 1(a). The modified NTLSCR is formed by inserting a bypass diode Dp2 into the NTLSCR structure as shown in Fig. 1(b). The Dn2 (Dp2) is located into the latching path of the PTLSCR (NTLSCR). This Dn2 (Dp2) has an effect of reducing the equivalent substrate resistor Rsub1 (N-well resistor Rnw2) and an effect of bypassing the latchup trigger current in the P-substrate (the N-well), so the trigger current to initiate the positive-feedback regenerative process of latchup in the PTLSCR (NTLSCR) can be significantly increased [13]–[14]. So, by adding this bypass diode Dn2 (Dp2), the trigger current of the modified PTLSCR (modified NTLSCR) can be significantly increased to avoid the accidental triggering by the external noisy pulse. The trigger voltage of this modified PTLSCR (modified NTLSCR) is still kept the same as the snapback-trigger voltage of the short-channel PMOS (NMOS) which is inserted in the PTLSCR (NTLSCR) structure [11]. This modified PTLSCR (modified NTLSCR) can be merged with the output PMOS (NMOS) in the layout to save layout area as shown in Fig. 1(a) and (b).

Since ESD voltages may have positive or negative polarities on a pin to either the VDD or the VSS pins, there are four different ESD-stress conditions on an output pin. The four ESD-stress conditions on a pin have been specified as PS, NS, PD, and ND modes in [12]. In the CMOS output buffers, there also exist two parasitic junction diodes, Dp1

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Index of Conference Proceedings British Library. Document Supply Centre, 1999 **The Cumulative Book Index**, 1999 Moments of Impact Jaime Schultz, 2016-01-01 In the first half of the twentieth century Jack Trice Ozzie Simmons and Johnny Bright played college football for three Iowa institutions Iowa State University the University of Iowa and Drake University respectively At a time when the overwhelming majority of their opponents and teammates were white the three men all African American sustained serious injuries on the gridiron due to foul play either because of their talents their race or most likely an ugly combination of the two Moments of Impact tells their stories and examines how the local communities of which they were once a part have forgotten and remembered those assaults over time Of particular interest are the ways those memories have been expressed in a number of commemorations including a stadium name a trophy and the dedication of a football field Jaime Schultz focuses on the historical and racial circumstances of the careers of Trice Simmons and Bright as well as the processes and politics of cultural memory Schultz develops the concept of racialized memory a communal form of remembering imbued with racial significance to suggest that the racial politics of contemporary America have generated a need to redress historical wrongs congratulate Americans on the ostensible racial progress they have made and divert attention from the unrelenting persistence of structural and ideological racism *Supporting Early Mathematical Development* Caroline McGrath, 2025-10-14 Supporting Early Mathematical Development is an essential text combining theory and practice to enable successful mathematical education for children from birth to 12 years This text considers how students academics parents and professionals can develop their mathematical thinking practice whilst acknowledging there will always be a road yet to travel we will always be practising the craft of teaching mathematics Charting the delivery of mathematical development in playgroups children s centres nurseries and primary schools the book promotes an effective pedagogy for mathematics This new edition provides a conceptualisation of mathematics and places a fresh emphasis on mathematical literacy to empower children New chapters include the following Mediators of Mathematical Thinking Understanding Pattern Pre Algebraic and Algebraic Thinking Naming Renaming and Processing Numbers Statistics Statistical Diagrams and Probability Measure Geometry Throughout the book Caroline McGrath navigates the complexity of teaching and learning mathematics through careful thought and consideration of mediators of mathematical thinking This supportive book is designed for educators who want to know how to reconstruct mathematical ideas with children and respond in the moment Returning to the root of understanding using the adaptive pedagogical style recommended in this text you can create satisfying mathematical experiences for children **Dissent in Wichita** Gretchen Cassel Eick, 2023-12-11 Winner of the Richard L Wentworth Prize in American History Byron Caldwell Smith Book Prize and the William Rockhill Nelson Award On a hot summer evening in 1958 a group of African American students in Wichita Kansas quietly entered Dockum s Drug Store and sat down at the whites only lunch counter This was the beginning of the first sustained successful

student sit in of the modern civil rights movement instigated in violation of the national NAACP s instructions Dissent in Wichita traces the contours of race relations and black activism in this unexpected locus of the civil rights movement Based on interviews with more than eighty participants in and observers of Wichita s civil rights struggles this powerful study hones in on the work of black and white local activists setting their efforts in the context of anticommunism FBI operations against black nationalists and the civil rights policies of administrations from Eisenhower through Nixon Through her close study of events in Wichita Eick reveals the civil rights movement as a national not a southern phenomenon She focuses particularly on Chester I Lewis Jr a key figure in the local as well as the national NAACP Lewis initiated one of the earliest investigations of de facto school desegregation by the Department of Health Education and Welfare and successfully challenged employment discrimination in the nation s largest aircraft industries Dissent in Wichita offers a moving account of the efforts of Lewis Vivian Parks Anna Jane Michener and other courageous individuals to fight segregation and discrimination in employment public accommodations housing and schools This volume also offers the first extended examination of the Young Turks a radical movement to democratize and broaden the agenda of the NAACP for which Lewis provided critical leadership Through a close study of personalities and local politics in Wichita over two decades Eick demonstrates how the tenor of black activism and white response changed as economic disparities increased and divisions within the black community intensified Her analysis enriched by the words and experiences of men and women who were there offers new insights into the civil rights movement as a whole and into the complex interplay between local and national events *Arts & Humanities Citation Index* ,2002

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