

# 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- $\mu$ 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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# Kssats Papers 1997

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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     Advertising & Selling ,1910     *Forthcoming Books* Rose Arny,1998-04     **Economics of College Sports** John L. FizeL,2004-03-30 Operating behind a veil of amateurism the NCAA and collegiate athletic departments oversee big business sports programs These entities generate revenues comparable to professional sports practice and play in facilities that rival those found in professional sports and pay their top coaches salaries comparable to the salaries paid to coaches of professional sports teams Athletes are courted with lavish stadiums training facilities and locker rooms Customers are wooed with branded apparel videos logos and advertisements Business interests are captured with stadium billboards electronic ads on scoreboards sponsorship of bowl games logos on uniforms and exclusive apparel and equipment contracts Where do or should these lucrative athletic ventures fit in the mission of higher education To what extent is the central mission of creating an environment for learning and extending the frontiers of knowledge enhanced or limited by college sports Are declarations by the NCAA to promote amateurism and competitive balance supportive of the university mission Does the NCAA even follow its purported objectives The Economics of College Sports contains both empirical and theoretical research to address these and related issues Perhaps the most unique contributions focus on the interactions between legal and institutional aspects of the NCAA and their impact on the objectives and goals of university education all of the contributions provide insights that will generate significant discussion about the policies necessary to sustain the vitality and integrity of the university education sports coalition     *A Prescription for Dignity* Michael L. Perlin,2016-03-16 Examining the treatment of persons with mental disabilities in the criminal justice system this book offers new perspectives that are crucial to an understanding of the ways in which society projects onto criminal defendants prejudices and attitudes about responsibility free will autonomy choice public safety and the meaning and purpose of punishment all with a focus on ways to enhance dignity in the criminal trial process It is a detailed exploration of issues of adequacy of counsel the impact of international human rights law following the ratification of the United Nations Convention on the Rights of Persons with Disabilities CRPD the role of mental health courts and the influence of therapeutic jurisprudence procedural justice and restorative justice on the legal process It considers all of these perspectives in the context of criminal justice system issues such as competency findings the insanity defense and sentencing Demonstrating how the question of treatment of persons with mental disabilities in the criminal justice system is not only a vital one for both scholars and practitioners but also a central facet of international human rights law this book suggests policy development further scholarly inquiries and newly invigorated thinking and action to place dignity at the core of the criminal justice system     **Indo-European Origins** John V. Day,2001 A comprehensive survey of the evidence from biological anthropology for Indo European origins based on the

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