Current-mode Processing Possibilities in HV SoI Integrated Systems

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ABSTRACT

The paper discusses possibilities of current-mode based functional block implementation into signal path of HV SoI voltage-mode circuits. Results of research conducted by the paper authors points out that there are some application areas better suited for current-mode processing implementation rather than voltage-mode approach. Simplicity and consistence of various current-mode functional blocks is presented along with ease of implementation into HV SoI integrated circuits.

Keywords: high-voltage circuits, current-mode waveform generation, current processing, SoI technology process.

1 INTRODUCTION

The topic of the presented work arose as an effect of research on HV SoI ASICs for automotive applications. High-voltage semiconductor processes offer new design opportunities, especially in analog design. Unfortunately, there are specific problems typical to HV IC design. In many HV semiconductor processes HV MOS devices have their maximum safe gate-source voltage limited to low-voltage range. Thus, many HV MOS transistors have significantly different voltage-limits between different pairs of their terminals. This is crucial difference in comparison to LV MOS devices which have such limits very similar.

This difference decides that not all LV functional blocks may be directly turned into their HV versions. Some circuits may need modifications, some may become simply too complex and need to be replaced with different structures providing same functionality. Increased complexity of HV counterparts of LV blocks, along with poor matching of HV MOS devices may lead to increased susceptibility of HV function blocks to process variations.

2 CURRENT-MODE IN HV SYSTEMS

Current-mode signal processing generally based on precision current mirrors can be easily implemented in HV domain. MOS transistors most crucial for quality of current-mirror operation may be precisely matchable LV MOS devices, while HV MOS devices may act as e.g. cascode transistors and shields against HV swings. Thus, current-mode processing in HV ICs can in fact remain a LV operation in its core, with HV devices forming only an auxiliary circuitry ensuring safe operation of LV devices.

Moreover, utilization of SoI processes makes it possible to implement LV blocks whenever required in all voltage-range. Thus, a mirrored copy of LV circuitry originally powered by LV supply and ground nodes can be placed e.g. between a HV supply and a HV virtual ground node. Thus, in SoI processes it is possible to design precise analog circuitry placed on both low (ground-related) and high (HV supply-related) sides of accessible voltage-span.

3 SINGLE CURRENT-MODE FUNCTION BLOCKS

3.1 Logic Level Converters

The possibility of placing LV circuitry everywhere in voltage-span between HV supply and ground nodes, brings necessity of sending logic and control signals between various LV blocks that works with different virtual supply and ground voltage levels. This may be a problem to send a LV voltage-mode signal up a few tens V, unless it is done with use of currents. One type of stand-alone current-mode function blocks are logic level converters, which use currents for sending logic state information between differently polarized LV processing modules in HV SoI integrated systems.

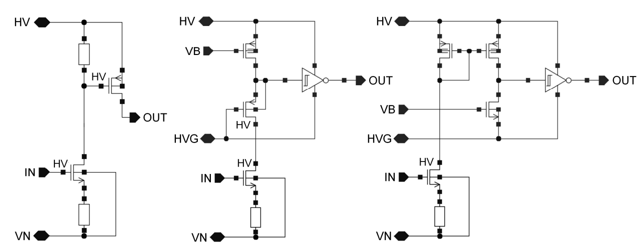

Figure 1: Current-mode control / logic signal converters [1].

Fig. 1 presents several possible structures of such converters [1]. The first to the left circuit do not use any HV virtual ground node for its operation, and in fact can be used in CMOS HV processes for providing enable/disable functionality by means of MOS transistor gate-source voltage control. All rest of these circuits uses various operation rules to produce typical CMOS voltage logic signals, ranging from HV (of virtual) supply node to virtual ground node. Though there are some CMOS technology processes, in which limited LV logic circuitry can be implemented as related to a HV supply voltage, the circuits presented in Fig. 1 are designed with SoI technology process applications in mind.

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3.2 Voltage-range Converter

Apart from digital level conversion, current-mode circuits can be used for similar tasks, but regarding analog signals. In HV systems it is advised to, if possible, convert input voltages into HV range before processing. Owing to this, signal processing by-products like noise, are not shifted up in frequency domain, as in case when elaborated and completely processed LV signal would be converted into HV range. This is important e.g. for EMC purposes.

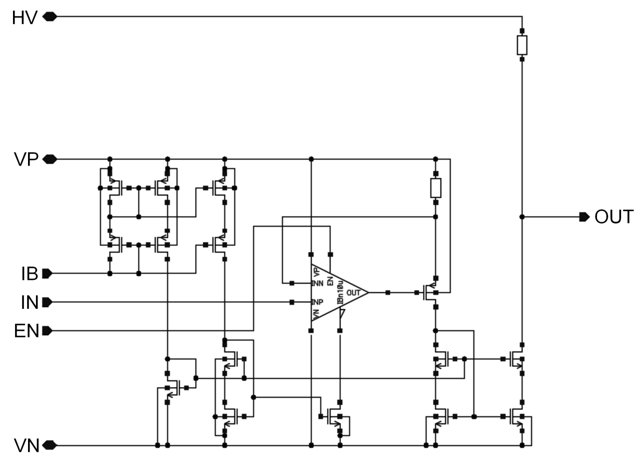

Figure 2: LV to HV current-mode signal conversion circuit.

Fig. 2 presents a LV to HV range signal conversion circuit based on voltage-current and current-voltage conversions. It can be seen that the circuitry do not require any HV active devices for proper operation. The only HV device is a resistor. Still, if there are no fitting HV resistors present in a utilized process, series-connected LV resistors might be used for the current-voltage conversion task.

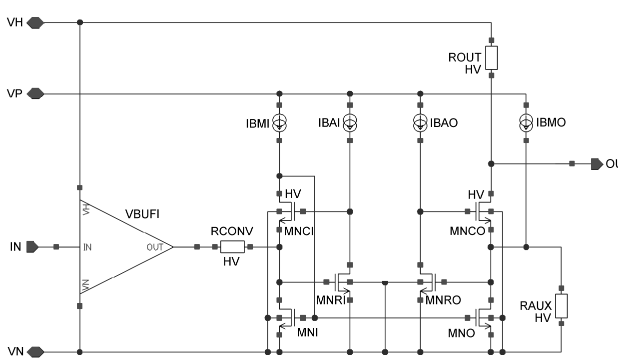

Figure 3: Alternative topology of LV to HV current-mode signal conversion circuit without an OPAMP inside [2].

The V/I and I/V conversion process by means of a single resistor use (or a composite device working as a single resistor) is not a precise way to perform these tasks. Though, in the presented circuit, V/I and I/V conversions are performed consecutively on the same signals. If resistors of same type are used for both these conversions, the final V/I/V conversion ratio is well defined and precise.

One could argue that a circuit that contains an OPAMP inside may be considered as a quite complex. Fig. 3 presents an alternative approach to voltage-range conversion process [2]. This circuit does not require an OPAMP inside for proper operation. Instead, the circuit requires an input signal source able to be feed the input V/I resistor. As the input conversion resistor is connected between input and the current-mirror point of non-ground potential, the resulting conversion current is not proportional to the input-node – ground-node voltage.

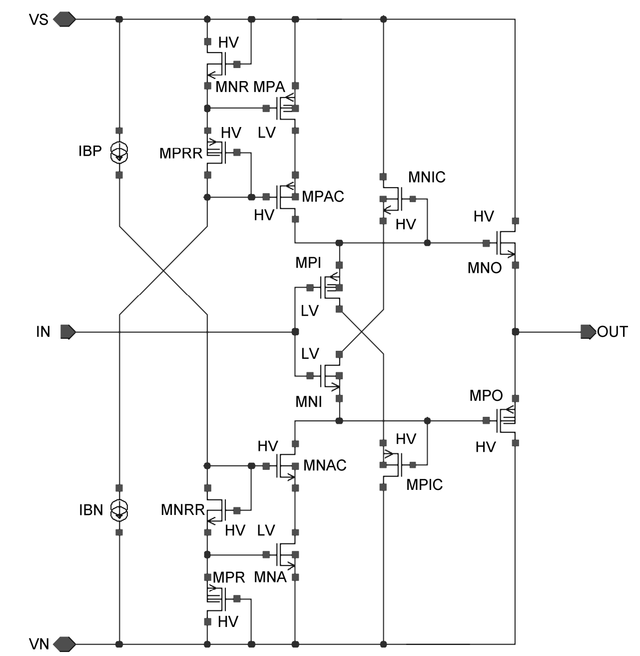

Figure 4: Improved high input-impedance buffer [3].

To amend this issue, another resistor is added at the output side of the current-mirror. This modification works, because both input- and output-side points of resistor-mirror connections have same and nearly-constant voltage.

The input circuit of the Fig. 3 circuit needs to be a highly-loadable unity-gain buffer. The unity-gain buffer, as usually opposed to an OPAMP, can be easily implemented as a fully HV function block. The Fig. 3 V/I conversion subcircuit may also be used for HV to LV range conversion purposes. In fact, both Fig. 2 and Fig. 3 circuits have current-mode outputs. Thus, both these circuits require specific output buffers with no DC current-path, as current flows to and from the I/V conversion circuit output would falsify result of such a conversion process.

Typical simple unity-gain complementary followers, used in HV systems, have limited input impedance – there is a DC current-path in the input of this buffer. For such and similar purposes a special modified HV buffer has been devised. It is a concatenation of gate-follower and source-follower topologies. Fig. 4 presents the new buffer that offers no DC current-path and very high input impedance of the gate-follower and appropriate gain and low level-shift of the source-follower [3].

3.3 Analog Switches

LV switches and transmission gates are widely used both in analog and digital circuits. They usually are fairly simple but effective structures. HV switches design is a different case. Many HV MOS devices have limited their maximum gate-source voltage to LV range, which is different from HV range maximum gate-drain voltage limits of such devices. This is a significantly different situation than in case of LV MOS devices which have their inter-terminal voltage limits very similar one to another, usually. Thus, HV switch problem is a voltage mode of operation control. Input voltage swing in HV systems may by far exceed safe levels of gate-source voltages of MOS devices available for use in HV switches.

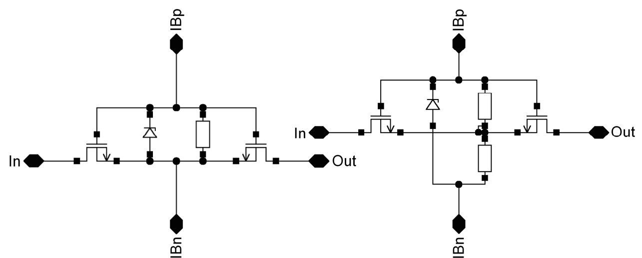

Figure 5: Current-controlled HV switches.

The answer to this problem is current-mode of switch operation. The switch-core devices (transistors that pass the signal from switch input to output) are voltage-controlled. But it is possible to install a very simple current-voltage converter at the switch-core and provide current or currents to such a device, in order to control the switch operation. Examples of current-controlled analog switches are presented in Fig. 5. As the switches are controlled with current mirrors, wide input voltage swings can be passed through the switches. Presence of control currents means that the switches conduct, absence of control currents means the switch MOS devices, and thus the whole switches, turn off. Fig. 6 presents exemplary control-current module for Fig. 5 switches. Similar two-transistor switch-core structures are known and used in HV applications [4]. Though, they are most often voltage-controlled devices.

3.4 Waveform Generators

Waveform generators are use both in LV and HV integrated systems. One way of providing a HV waveform is generation of a LV waveform and its proper amplification into HV range. As mentioned before, such an approach may cause some signal and system operation quality issues, like EMC problems. Sometimes it is preferred to generate a HV full-range waveform. Some function blocks referred to as generators generate their output signal due to presence of internal feedback. Other circuits rather put their input signals into a new form, e.g. digital input signals are turned into HV trapezoidal waveforms.

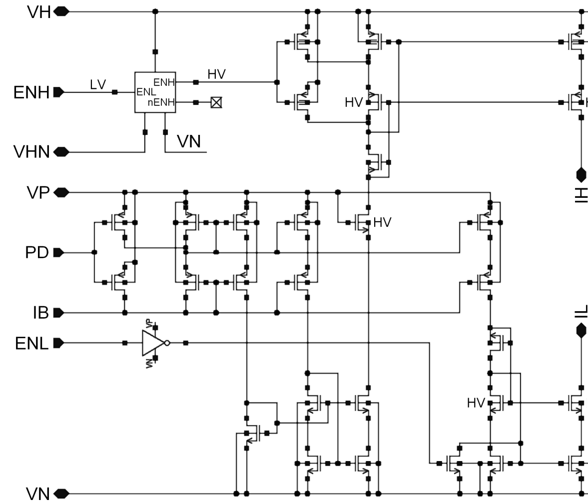

Figure 6: Control circuit of current-mode HV switches.

Trapezoidal waveforms may seem untypical signals, but precisely such waveforms are often used for coil driving purposes in automotive Passive-Entry – PE and Remote-Keyless-Entry – RKE systems. Voltage-mode generation of such HV waveforms is, of course, possible.

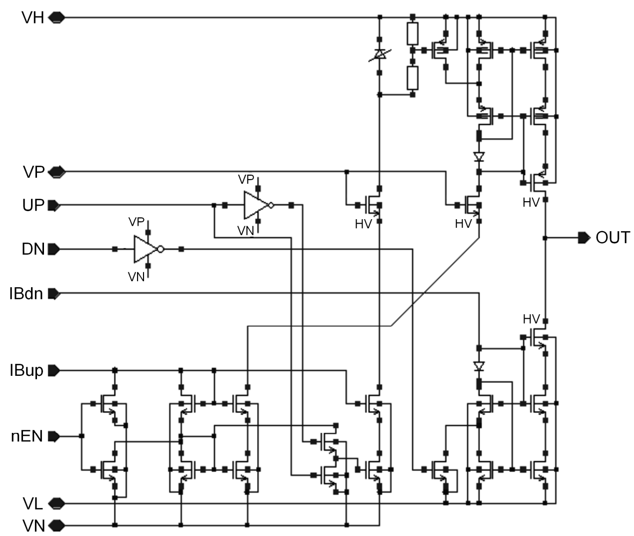

Figure 7: Current-mode trapezoidal waveform generator.

Though, application of current-mode of operation enables very simple and consistent structures of trapezoidal waveform generation. General idea of such current-mode generators is based on consecutive charging and discharging of an output capacitor. Solutions based on that principle were even patented [5]. Fig. 7 presents example of a HV current-controlled trapezoidal waveform generator.

Structure of this waveform generator enables simple and linear control over slew-rates of the output waveform. The generator is driven with two bias currents. They, along with the output capacitor, independently define both slew-rate values of the rising and falling edge of the waveform. Application of virtual supply and ground voltage levels enables control over voltage-range of the waveform.

4 CURRENT-MODE CIRCUIT CHAINS IN VOLTAGE-MODE SIGNAL-PATHS

4.1 V/I and I/V Conversion Blocks

Single current-mode function blocks with voltage-mode inputs and outputs can be useful circuits. Though, sometimes more complex multistage current-mode signal processing modules would be beneficial inside HV voltage-mode signal paths.

Current-mode signal-processing sub-paths need to be somehow placed in HV signal-paths. A special set of HV/I and I/HV converters is required for this task. Fortunately, previously presented topology of a LV to HV voltage range converter, shown in Fig. 3, can be adapted to fulfill this task. This circuit can be used in full HV configuration, which requires application of a proper HV buffer. The buffer presented in Fig. 4 can be used as both input and output buffer in the discussed HV signal conversion circuitry. The modified set of HV/I and I/HV converters can work as a kind of interface for current-mode functionality inside HV voltage-mode signal paths [2].

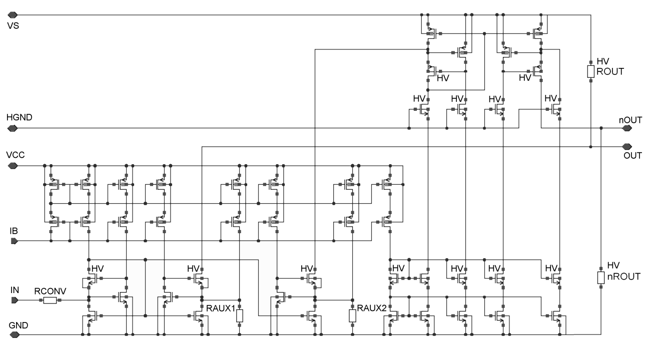

Figure 8: Current-mode amplifier with differential outputs.

4.2 Current-mode Signal Processing Blocks

Current mode circuits are very handy as tools for performing numerous mathematical functions, both linear [6] and non-linear ones [7]. These functions include summation, subtraction, multiplication, inversion, division, squaring, etc. Various kinds of amplifiers can be implemented as current-mode circuits [7]. Important fact is that most of all this extensive functionality can be implemented with use of only current-mirrors and switches. Consistent structure of current-mode analog circuits also enables design of universal modules with programmable functionality [6].

An example of consistent current-mirror dominated structure of current-mode function block is presented in Fig. 8. This circuitry amplifies its input signal and provides both simple and inverted output signal at the output. Both output signals are processed in similar manner, so as to delay both output signals and keep their total value nearly constant. The circuit is presented in version with input- and output-stage resistors, so that it can cooperate with HV mode circuits both at its input and output nodes. It is enough to only remove all resistors, to get circuitry that works with current input signals and produces current-mode output signals. This simple change turns the whole function block from HV/I/HV conversion system into a purely current-mode circuitry. This clearly shows application ease.

5 CONCLUSIONS

Numerous application possibilities of current-mode circuitry in HV SoI ICs are presented and discussed in the paper. Results of conducted research show that current-based signal processing can be implemented both in form of stand-alone separate voltage-mode interfaced function blocks and as complete current-mode complex signal-processing modules placed inside voltage-mode HV range signal processing paths.

Topology consistence of current-mode circuitry along with ease of implementation into HV systems turns this class of circuits into an alternative design approach worth considering especially when voltage-mode designs go into dire straits in HV systems.

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