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ELECTRONIC SWITCH ON MOS TRANSISTORS WITH LOW VOLTAGE DROP AND LOW CURRENT LEAKAGE

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ABSTRACT

The paper considers a way to minimize the voltage drop of electronic switch on field-effect transistor (FET) in open state. It explains the advantage of using field-effect transistor for constructing electronic switch. The paper has also shown the influence of an output current of the gate of transistor on its conductivity. It compares the well-known electronic switch architectures, which are put equal to the common area. It also offers the architecture with a small magnitude of voltage drop in open state and low leakage current in closed state. The paper shows the results of open state electronic switch resistance simulation and also leakage current in closed state.

Keywords: electronic switch, analog switch, MOS field-effect transistor (MOSFET), high-speed performance, voltage drop, leakage current.

INTRODUCTION

Today the world of electronics is rich in various electronic switches which realized on MOSFET. Since the advent of their first versions, there have been made many specialized circuits, which are different in their parameters. Electronic switches find broad application in the field of modern electronics that travels the path of speed rise and, therefore, of the dimensionality reduction of integrated circuit elements. There is the need for the application of switches with the low-voltage supply and the strict requirements to current consumption. It entails some difficulties, which the developer faces [1].

In systems with a low supply voltage and current consumption the main complexity of development of a modern switch consists in two unwanted facts: leakage of the closed switch and voltage drop on open switch [2, 3]. It is easier to realize when using field-effect transistor because they have a number of advantages over the switches on bipolar transistors: low resistance in open state, higher resistance in closed state, the insignificant power consumed from the control signal source. Now there is an active replacement of bipolar transistors from area of switch devices. Field-effect transistor do not consume static power in the control circuit, there are not no main carriers in them and so there is no need for the time for their diffusion, at last, the temperature rise leads to the reduction of drain current that provides enhanced heat resistance. Among the whole variety of field-effect transistor for electronic switches MOSFET with the induced channel (of an enriched type) are the most widespread. Transistors of this type are characterized by the threshold voltage at which the channel conductance occurs. In the area of the low voltage between a drain region and a source region (open transistor) it is possible to present by equivalent resistance (unlike a saturated bipolar transistor – a voltage source) [4].

MAIN PART

The Figure-1 presents the classical and well-known architecture of analog switches on MOSFET with the induced channel. The upper voltage level on a gate U_{ctr} (above the threshold voltage – U_{thr}) is opening for such structures – the resistance is minimal; the transistors are closed when supply the lower level U_{ctr} – the resistance reaches the greatest value (R_{inp}).

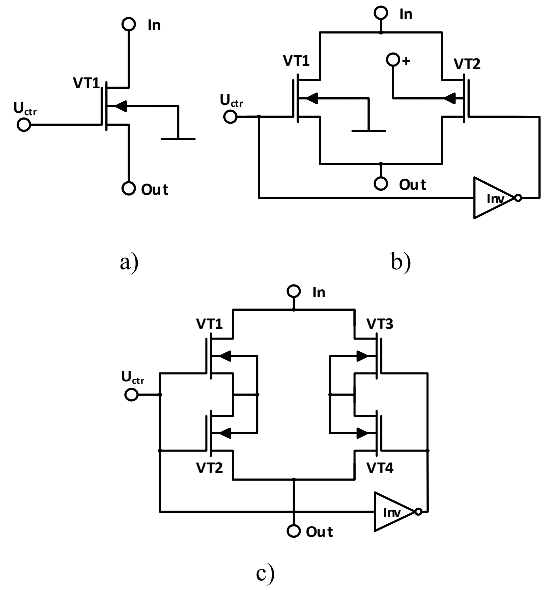

Figure-1. Classical architectures of analog MOS switches. A switch on one transistor (a), a switch with the use of a complementary pair of transistors (b), a switch with "a floating gate" (b).

The architecture of the Figure-1(a) is the simplest method for the switch construction, but signal switching in the full range of supply voltages demands the additional circuit that creates the overvoltage on the gate in the open state. This is connected to the fact that the above circuit will operate at the commutation voltage when it is less than U_{ctr} – U_{thr} at the higher level the voltage on a lock will be insufficient to hold a transistor in conduction state

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(R_{inp} starts to increase). There are the tasks at which the commutation voltage is comparable in magnitude with the control voltage. In this case the simple circuit will not operate at one transistor as the high control voltage level will not have sufficient offset. The task of such signals commutation is solved by the use of switches in a complementary pair of the Figure-1b. At the high level of the control signal VT1 commutes the signals with the levels from the grounding to U_{ctr} without several volts. VT2 commutes a signal with the levels from U_{ctr} to a magnitude higher than the level of the grounding by several volts. The control signal switching to the grounding level closes both transistors disconnecting thus a circuit. As a result this circuit has some advantages in comparison with the first architecture. At parallel connection of p- and n-channel transistors the open state resistance (R_{inp}) has less dependence on the input voltage. Both transistors are connected and disconnected at the same time when the high signal injection at the expense of an inverter. The third architecture of the Figure 1c has the voltage on the gate output which depends on commutation state that allows to lower leakage current, but to increase the input open state resistance and, therefore, the voltage drop on a switch [5, 6]. Theoretically, it is necessary to go for resistance minimization (R_{inp}) and leakage current (I_{leak}) that will allow reducing the losses in a switch and signal propagation delay. The simple R_{inp} reduction is realized by change of ratio of the channel width (W) to length (L) of a MOSFET that, in turn, will lead the increased leakage current of closed state and parasitic capacitance which constricting a switch bandwidth [7, 8].

The Figure-2 presents the architecture of an offered switch. A switch is constructed on the basis of the circuit of connected in parallel p- and n- channel MOSFET with the operated gates by means of the inverters (VT3-VT4, VT5-VT6) with the use of current sources (I1, I2).

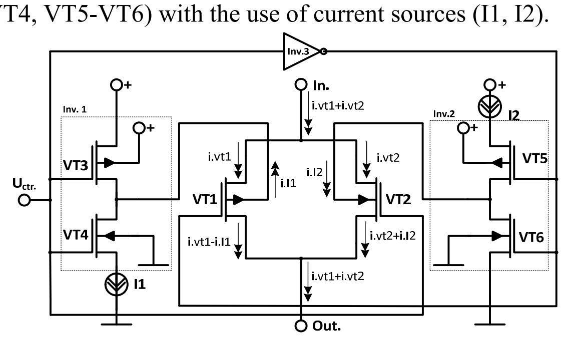
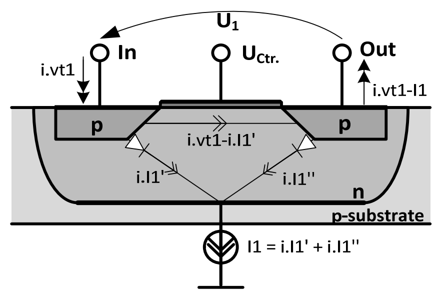


Figure-2. An analog switch with an operated gate.

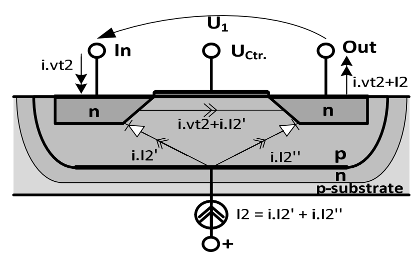
The Figure-3 shows the structure of p- and n-channel field-effect transistor with currents explaining the principle of the circuit operation (Figure-2). The main task of the circuit will provide high transistor conductivity in open state and low one in closed state. It is provided by the inverter Inv.1 on VT3 and VT4 transistors with the current source I1 for the transistor VT1 and the inverter the Inv.2 on VT5 and VT6 transistors with the current source I2 for the transistor VT2. The principle of operation of a left part of the circuit is diametrically-opposite to a right one except for commutation current and looks is the following. The lower voltage is open state formed on a p-channel transistor gate VT1 (Figure-3a). At the same time, the voltage on the Inv.1 input (Figure-2) has high level. A transistor VT4 passes into open state, thereby there is the current source I1 attached to a gate of transistor (Figure-3) additionally increasing conduction. The high conduction is provided by gate voltage bias (U_{gate}) relative to a voltage drain region (U_d), source region (U_s). Thus, there are the following conditions satisfied:

$$U_{gate} < (U_d, U_s),\ U_{inp} > U_{out},\ i.I1' >> i.I1'',\ i.I1' \approx I1$$

In a closed switch when forming the high voltage on a transistor gate VT1 the Inv.1 forms the high voltage, thereby transferring a transistor VT4 to closed state limiting current I1, and a transistor VT3 to open state that reduces conduction VT1 and reduces leakage current in closed state. The offered architecture cannot be used in technologies with a non-insulated n-channel transistor.



a)



b)

Figure-3. The field-effect transistor structure showing currents of the circuit (Figure-2) for n-channel (a) and p-channel (b) conduction type.

RESULTS

The Table-1 presents the switches parameters' comparison (Figures 1, 2) subject to the results of simulation in Cadence on the models of TSMC-40nm transistors. The compared switches were simulated under the same conditions. The area was a general sign of comparison. General size of each switch is 2000mkm widthwise to 600nm lengthwise at equal transistor sizes of p- and n- conduction types. The supply voltage is 3.3V, open state current capacity is set by a magnitude of 10mA. Currents I1=I2, the effect of the decreasing conduction is at currents more than 10nA.

Table-1. The comparisons of switch parameters of presented analog switches

Parameter	U_{inp}, V	The simplest switch on one transistor (Figure 1a)	Complementary pair (Figure 1b)	Complementary switch with «a floating gate» (Figure 1c)	Offered architecture of a switch with a directed gate (Figure-2)
Open state resistance R_{inp}, Ohm	3.3	116.4	6.3	25.7	5.7
	2	4.6	5.3	11.2	2.3
	1.5	1.2	2.4	8	1.7
Leakage current in closed state I_{leak}, nA	3.3	1.3	0.69	1.1	0.69
	2	0.34	0.17	0.21	0.17
	1.5	0.29	0.12	0.06	0.12

The Table-1 shows that the simplest switch (Figure-1a) when using the whole available area has the smallest input resistance at low U_{inp}, but thus the greatest leakage current in closed state. In case if the input commutation voltage is equal to the control one, the resistance of a switch reaches 116Ohm, subject to U_{inp}. = $U_{inp.}$ An application of this switch is inexpedient. A complementary pair (Figure-1b) solves the problem of a switch on one n-channel transistor. It is also possible to reduce leakage current. A complementary switch with "a floating gate" (Figure-1c) has low leakage current of closed state. Input resistance in such switching will considerably increase in comparison with a complementary pair. The offered architecture of a switch with a directed gate (Figure-2) constructed on the basis of a complementary pair is based on its properties (Figure-1b) but has lower resistance and leakage current in closed state. Thus, it is possible to make a conclusion that the offered architecture of an electronic switch possesses a number of the advantages at the same area with compared analogs; the area minimization reduces the price of chip production, reduces the risk of technological defect, and increases the high-speed performance.

CONCLUSIONS

The paper has considered a way of electronic switch voltage drop minimization on an electronic open state switch constructed on MOSFET. It has explained the advantages of the field-effect transistor usage. It has defined that the complexity of a modern switch development in the systems with the low voltage supply and the consumption current consists in two undesirable phenomena: closed switch leakage and the voltage drop on an open state one. The paper has presented the comparison of well-known classical architecture of electronic switches and the offered architecture also. The paper shows the conclusion concerning the transistor's gate output current influence on its conduction. It has also received the results of simulation. The simulation results show that the offered architecture at the equal area has the advantages over classical switches and possesses the low open state resistance and low leakage current in closed state. All these facts allow using an offered electronic switch in the high-speed systems with the low supply voltage and the strict requirements to the consumption current.

ACKNOWLEDGEMENT

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