

Switch Block Architecture for Multi-Context FPGAs Using Hybrid Multiple-Valued/Binary Context Switching Signals

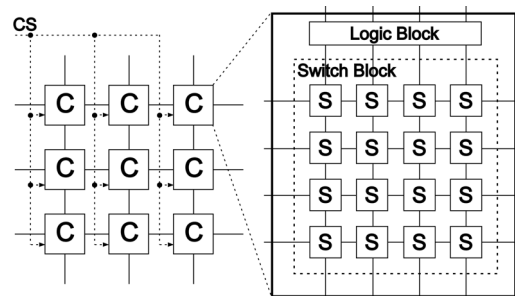
Yoshihiro NAKATANI, Masanori HARIYAMA and Michitaka KAMEYAMA
Graduate School of Information Sciences, Tohoku University
e-mail: {yoshi, hariyama, michi}@kameyama.ecei.tohoku.ac.jp

Abstract

Multi-context (MC) FPGAs have multiple memory bits per configuration bit forming configuration planes for fast switching between contexts. Large amount of memory causes significant overhead in area and power consumption. This paper presents two key technologies. The first is a floating-gate-MOS functional pass gate that merges storage and switching functions area-efficiently. The second is the use of a hybrid multiple-valued/binary context switching signal that eliminates redundancy of a conventional MC-switch with high scalability. The transistor count of the proposed MC-switch is reduced to 7% in comparison with that of a SRAM-based one.

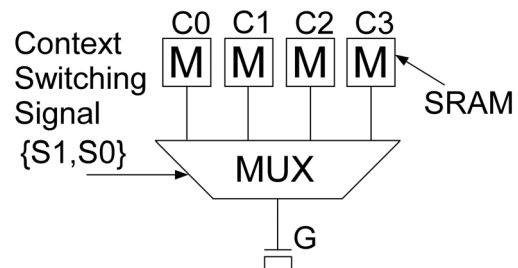
1. Introduction

Dynamically-programmable gate arrays (DPGAs) provide more cost-effective implementations than conventional FPGAs where hardware resources are dedicated to a single context [1]. A DPGA can be sequentially configured as different processors in real time, and efficiently reuse the limited hardware resources in time. One of typical DPGA architectures is a multi-context one. Multi-context (MC) FPGAs have multiple memory bits per configuration bit forming configuration planes for fast switching between contexts. However, the additional memory planes cause significant overhead in area and power consumption [2]. Figure 1 shows the overall structure of an MC-FPGA. Each cell consists of a programmable Logic Block (LB) and a programmable Switch Block (SB). An MC-SB consists of multi-context switches (MC-switches). Each context is changed by the context switching signal (CS). The CS is broadcasted all the MC-switches. Figure 2 shows the structure of a conventional SRAM (Static Random Access Memory) -based MC-switch for 4 contexts. Each MC-switch selects a configuration bit between pre-stored configuration bits according to CS. The pass transistor is ON for $G=1$, and OFF for $G=0$. A conventional SRAM-based MC-switch requires N SRAM bits for N contexts.



CS: Context Switching Signal
C: Cell
S: Multi-Context Switch

Fig. 1 Overall structure of an MC-FPGA.



M: SRAM (Static Random Access Memory) bit
G: Configuration bit

Fig. 2 Equivalent circuit of conventional MC-switch (4 contexts).

To overcome the overhead, it has proposed many ways before now. One of the ways is the way which is applied that configuration data rarely changes [3]. And another one is the way that uses floating-gate MOS functional pass-gate (FGFP) using floating-gate MOS transistor (FGMOS) with multiple-valued signal for switching between contexts [4],[5]. The work [4] proposed an MC-switch with 4 FGMOSs that use a multiple-valued signal for context switching.

In order to reduce the overhead of configuration memory in MC-FPGAs, we employ a FGFP that merges storage and switching function on a single FGMOS. In this MC-switch, several pass transistors become ON

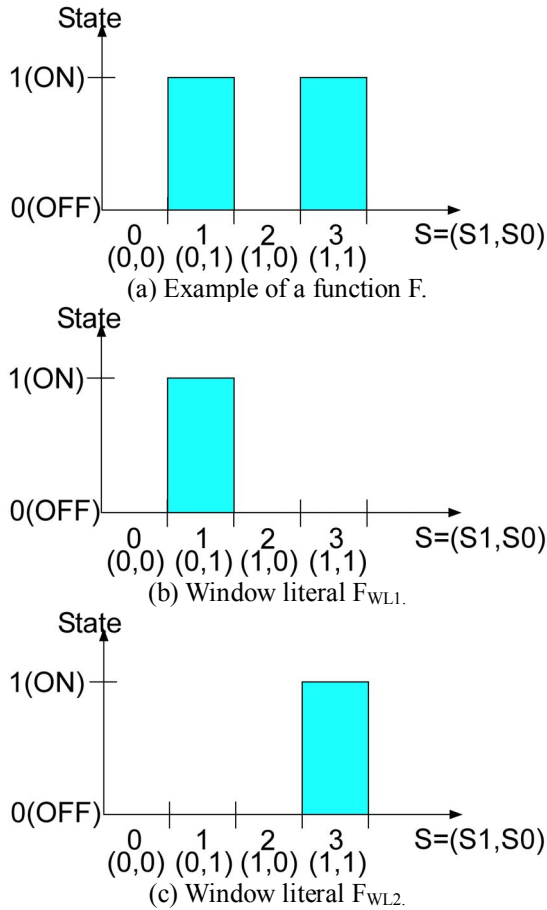


Fig. 3 Function of an MC-switch (4 contexts).

redundantly for some configuration patterns. To eliminate this redundancy, a hybrid multiple-valued/binary context switching signal is used for context switching. The proposed MC-switch has only 2 FGMOSSs, each of which is exclusively ON. Although the proposed MC-switch requires more complex circuit for generating the context switching signal, they can be shared among several MC-switches, and its overhead is negligible.

In the case of more 4 contexts, although the transistor count of an MC-switch that proposed in [5] increases nonlinearity, that of an MC-switch that proposed in this paper increase linearity. Using the proposed MC-switch, the transistor count is reduced significantly as increasing contexts.

The transistor count of MC-switch is reduced to 7% and 50% in comparison with that of the SRAM-based MC-switch and the MC-switch using only multiple-valued FGFPs, respectively. The transistor count of the proposed MC-SB is reduced to 8% and 60% in comparison with that of the SRAM-based MC-SB and the MC-SB using only multiple-valued FGFPs, respectively.

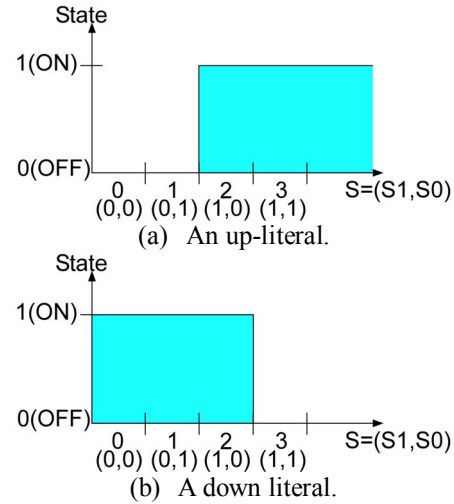


Fig. 4 An up-literal and a down-literal (4 contexts).

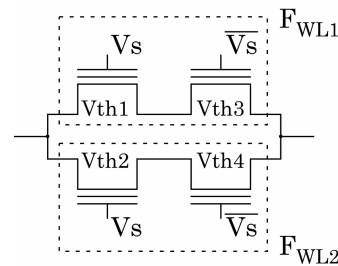


Fig. 5 MC-switch using 4 FGFPs (4 context).

2. Architecture of Multi-Context Switch

This section describes the MC-switch using only a multiple-valued context switching signal.

Figure 3(a) shows an example of the function F of an MC-switch that is ON only for CS = 1 and 3. The function F can be given by “OR-ing” the function F_{WL1} (Fig.3(b)) and F_{WL2} (Fig.3(c)), each of which is called a window literal. Given $S1$ and $S2$ ($S1 \leq S2$), a window literal is defined as follows:

$$F_{WL}(S, S1, S2) = \begin{cases} 1 & S1 \leq S \leq S2 \\ 0 & \text{otherwise} \end{cases}$$

The function F is given by “OR-ing” two window literals as follows:

$$F(S) = F_{WL}(S, S0, S1) + F_{WL}(S, S2, S3)$$

The window literal can be AND-ing the functions F_{UL} and F_{DL} called “up-literal” and “down-literal”, respectively. An up-literal is a monotone increasing function as shown in Fig. 4(a). Given the threshold value T, an up-literal $F_{UL}(S, T)$ is given by

$$F_{UL}(S, T) = \begin{cases} 1 & T \leq S \\ 0 & \text{otherwise} \end{cases}$$

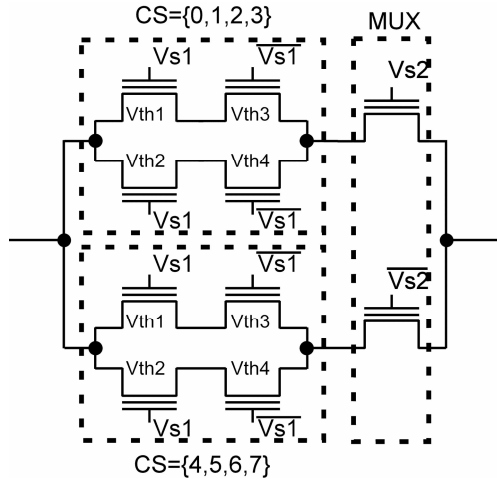


Fig. 6 The circuit of an MC-switch (8 contexts).

A down-literal is monotone decreasing function as shown in Fig. 4(b). Given the threshold value T , a down-literal $F_{DL}(S,T)$ is given by

$$F_{DL}(S,T) = \begin{cases} 1 & S \leq T \\ 0 & \text{otherwise} \end{cases}$$

A window literal F_{WL} is given by “AND-ing” the function F_{UL} and F_{DL} as follows:

$$F_{WL}(S, S1, S2) = F_{UL}(S, S1) \cdot F_{DL}(S, S2)$$

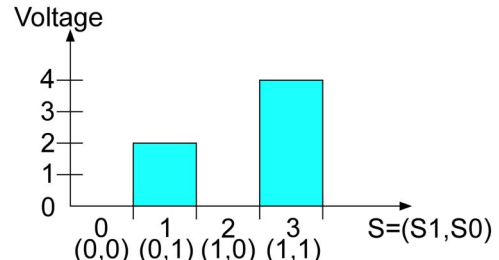
Each of an up-literal and a down-literal can be implemented only a single FGFP [3]. Therefore a window literal is implemented by series-connected FGMOSSs for wired-AND. An MC-switch is implemented by connecting the circuit for window literal parallel for wired-OR as shown in Fig.5. Four FGMOSSs are sufficient for 4 contexts since the function of an MC-switch includes 2 window literals at most.

Let us consider implementing more than 4 contexts. Figure 6 shows the MC-switch for 8 contexts. It consists of 2 MC-switches for 4 contexts and an additional multiplexer (MUX).

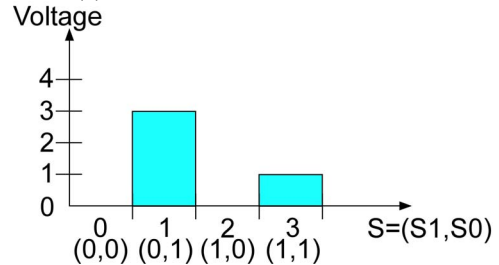
In the case of 4 contexts, the window-literal based implementation of the MC-switch has redundancy. For example, it requires 4 FGMOSSs even when the function of the MC-switch is a single window literal.

3. Architecture of an MC-Switch Using Hybrid Multiple-Valued/Binary Context Switching Signals

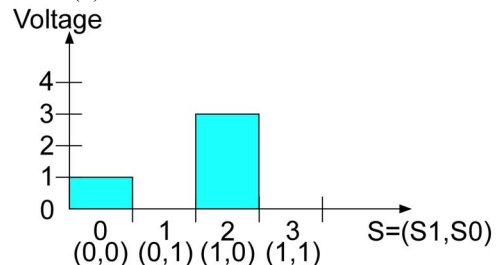
Figure 7 shows an example of a hybrid multiple-valued/binary context switching signal. Figure 8 shows the circuit to generate the hybrid multiple-valued/binary context switching signal. The circuit of generating the hybrid multiple-valued/binary context switching signal is small and that is broadcasted all MC-



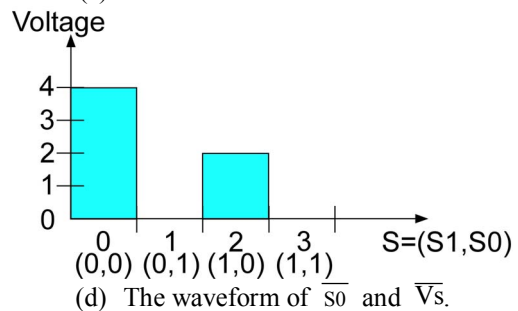
(a) The waveform of S_0 and V_s .



(b) The waveform of S_0 and $\overline{V_s}$.



(c) The waveform of $\overline{S_0}$ and V_s .



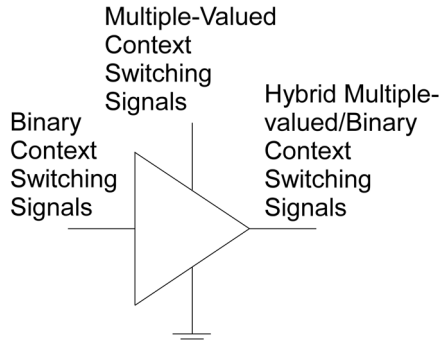
(d) The waveform of $\overline{S_0}$ and $\overline{V_s}$.

Fig. 7 Waveforms of hybrid multiple-valued/binary context switching signals.

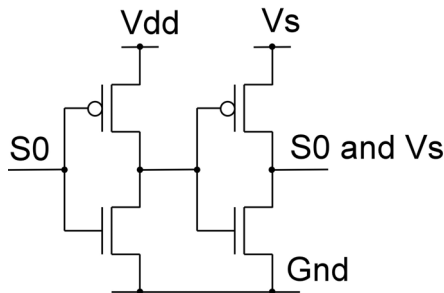
switches. The overhead of using the hybrid multiple-valued/binary context switching signal is small. The output is same as the multiple-valued CS signal when the binary CS signal is 1. Otherwise, the output is 0. Hybrid multiple-valued/binary signals are defined as follows:

$$S_0 \quad \text{and} \quad V_s = \begin{cases} V_s (S_0 = 1) \\ 0 (S_0 = 0) \end{cases}$$

$$S_0 \quad \text{and} \quad \overline{V_s} = \begin{cases} \overline{V_s} (S_0 = 1) \\ 0 (S_0 = 0) \end{cases}$$



(a) The symbol of the circuit performs the hybrid multiple-valued/binary context switching signal.



(b) The circuit performs the hybrid multiple-valued/binary context switching signal.

Fig. 8 The circuit which makes a hybrid multiple-valued/binary context switching signal.

$$\overline{S0} \text{ and } Vs = \begin{cases} Vs (\overline{S0} = 1) \\ 0 (\overline{S0} = 0) \end{cases},$$

$$\overline{S0} \text{ and } \overline{Vs} = \begin{cases} \overline{Vs} (\overline{S0} = 1) \\ 0 (\overline{S0} = 0) \end{cases}.$$

The context ID $CS = \{0,1,2,3\}$ is represented by a voltage $Vs = \{1,2,3,4\}$. The reason why $CS = 0$ corresponds to $Vs = 1$ is that $(S0 \text{ and } Vs)$ and $(\overline{S0} \text{ and } Vs)$ make difference when $CS = 0$. The multiple-valued signals, Vs and \overline{Vs} are defined as follows:

$$Vs = 2 * S1 + S0 + 1,$$

$$\overline{Vs} = 5 - Vs.$$

It is necessary to make a clear distinction between the 0-level of binary and that of multiple-valued. It is necessary that multiple-valued signal has 5-level.

Figure 9 shows the circuit of an MC-switch using a hybrid multiple-valued/binary context switching signal. The FGMOS Tr1 works when $S0 = 1$ ($Vs = 2, 4$), and the gate input of Tr1 is selected from two signals: “ $S0 \text{ and } Vs$ ” and “ $S0 \text{ and } \overline{Vs}$ ”. Similarly, the FGMOS Tr2 works when $S0 = 0$ ($Vs = 1, 3$), and the gate input of Tr2 is selected from two signals: “ $\overline{S0} \text{ and } Vs$ ” and “ $\overline{S0} \text{ and } \overline{Vs}$ ”.

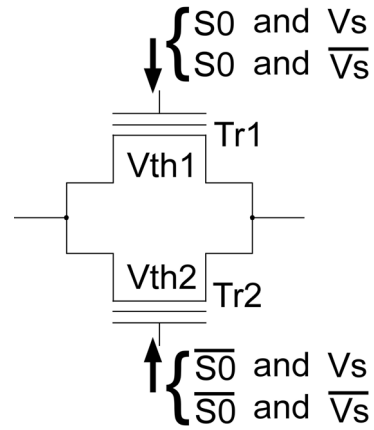


Fig. 9 A circuit of an MC-switch using hybrid multiple-valued/binary context switching signals.

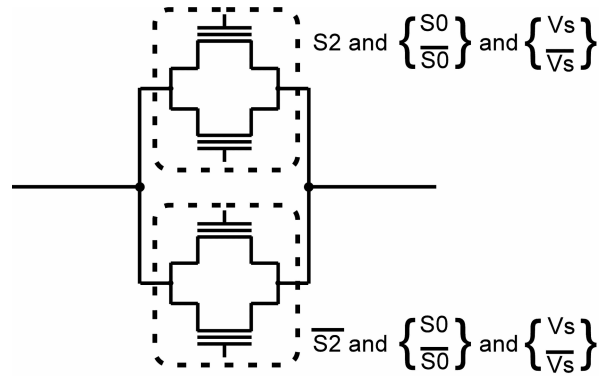


Fig. 10 The circuit of an MC-switch using hybrid multiple-valued/binary context switching signals (8 contexts).

Threshold operation for “AND-ing” the multiple-valued context switching signal and the binary one implements the same function as “AND-ing” two window literals. If we do not consider transistors to select the control signals, only 2 FGMOSs are sufficient for an MC-switch for 4 contexts. Table 1 shows the relations between configuration data, the context switching signals, and threshold voltages of Tr1 and Tr2. From Table 1, all of context patterns for 4 contexts can be generated only by 2 FGMOSs.

Let us consider implementing more than 4 contexts. Figure 10 shows the MC-switch for 8 contexts using hybrid multiple-valued/binary context switching signals. It consists of 2 MC-switches for 4 contexts. Note that it does not require any additional MUX unlike the MC-switch using only the multiple-valued context switching signal. That is because more context selection bits such as S2 are merged into the hybrid multiple-valued/binary context switching signal without any overhead.

Table 1 The selection of V_{th} and control lines in MC-switches.

configuration data				Tr1		Tr2	
context0	context1	context2	context3	V_{th}	Control line	V_{th}	Control line
0	0	0	0	5	S_0 and V_s	5	$\overline{S_0}$ and V_s
0	0	0	1	1.5	S_0 and V_s	5	$\overline{S_0}$ and V_s
0	0	1	0	5	S_0 and V_s	1.5	$\overline{S_0}$ and V_s
0	0	1	1	1.5	S_0 and V_s	1.5	$\overline{S_0}$ and V_s
0	1	0	0	1.5	S_0 and $\overline{V_s}$	5	$\overline{S_0}$ and V_s
0	1	0	1	0.5	S_0 and V_s	5	$\overline{S_0}$ and V_s
0	1	1	0	1.5	S_0 and $\overline{V_s}$	1.5	$\overline{S_0}$ and V_s
0	1	1	1	0.5	S_0 and V_s	1.5	$\overline{S_0}$ and V_s
1	0	0	0	5	S_0 and V_s	1.5	$\overline{S_0}$ and $\overline{V_s}$
1	0	0	1	1.5	S_0 and V_s	1.5	$\overline{S_0}$ and $\overline{V_s}$
1	0	1	0	5	S_0 and V_s	0.5	$\overline{S_0}$ and V_s
1	0	1	1	1.5	S_0 and V_s	0.5	$\overline{S_0}$ and V_s
1	1	0	0	1.5	S_0 and $\overline{V_s}$	1.5	$\overline{S_0}$ and $\overline{V_s}$
1	1	0	1	0.5	S_0 and V_s	1.5	$\overline{S_0}$ and $\overline{V_s}$
1	1	1	0	1.5	S_0 and $\overline{V_s}$	0.5	$\overline{S_0}$ and V_s
1	1	1	1	0.5	S_0 and V_s	0.5	$\overline{S_0}$ and V_s

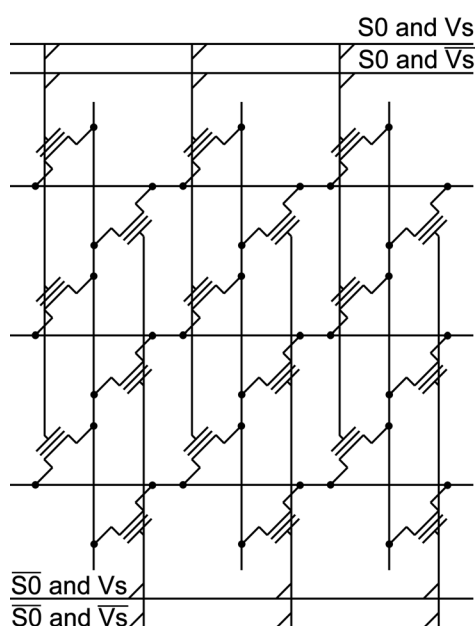


Fig. 11 The circuit of an MC-SB (4 contexts).

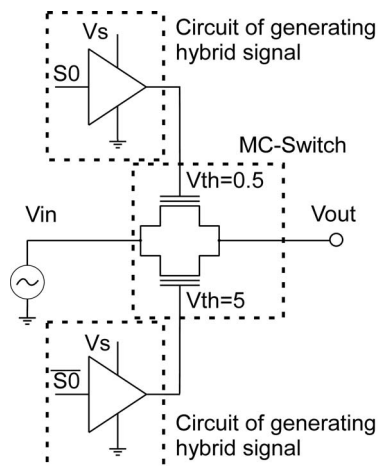
Let us consider a Multi-context Switch Block (MC-SB). Figure 11 shows the circuit of an MC-SB. The MC-SB has the structure of cross bar network. The MC-switches is used as a cross-point switch. For simplicity, three the MC-SB has 3 columns and 3 rows. For a certain context, a single cross point switch on each column and row is ON at most. We can map the possibly-ON cross-point

switch on a column to the same MC-switch on the column for any context. As a result, N independent control signals are sufficient for an $N \cdot N$ MC-SB. In other words, a context switching signal is shared with MC-switches on the same column.

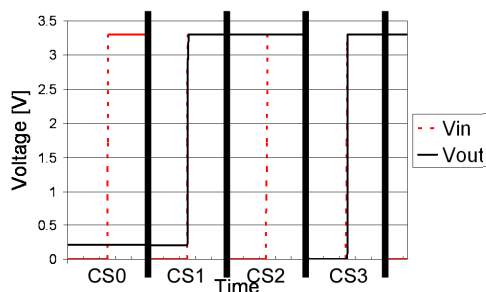
4. Evaluation

We simulated the function of an MC-switch using the hybrid multiple-valued/binary context switching signal. Figure 12(a) shows the simulated circuit. We used the simulator "HSPICE" for simulation. In the simulation, we replace FGMOSS with MOS transistors. Programming the threshold voltage of an FGMOSS is implemented by changing HSPICE parameter. Set the configuration data $CS\{0,1,2,3\} = \{0,1,0,1\}$. The result is shown in Fig. 12(b). Only when CS is 1 or 3, the input is transferred to the output.

We compare the transistor count of the proposed MC-switch and the proposed MC-SB with the SRAM-based MC-switch and MC-SB respectively for 4 contexts. The transistor count of the proposed MC-switch is reduced to 7% of SRAM-based one (Table 2). Table 3 show the comparison result when assuming that the switch block consists of 10×10 cross-point switches. The transistor count of the proposed MC-SB is reduced to 8% of that of the SRAM-based one. Figure 13 shows the proposed MC-switch has more advantage than SRAM-based one as the size of MC-SB increases.



(a) The circuit of simulation about an MC-switch using hybrid multiple-valued/binary context switching signals.



(b) The result of simulation about an MC-switch using multiple-valued/binary context switching signals.

Fig. 12 The simulated circuit and the result.

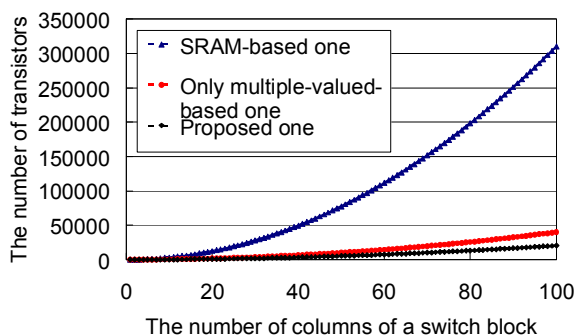


Fig. 13 The relationship between the number of columns of an MC-SB and the number of transistors.

5. Conclusion

This paper presents MC-switch architecture. The key technologies are a FGFP and the use of a hybrid multiple-valued/binary context switching signal. Using FGFPs for MC-switch, the area of an MC-switch is less

Table 2 The transistor count of an MC-switch.

	Transistor count
SRAM-based one	31
Only multiple-valued-FGFP-based one [4]	4
Proposed one	2

Table 3 The transistor count of an MC-SB (10×10).

	Transistor count
SRAM-based	3100
Only multiple-valued-FGFP-based one [4]	400
Proposed one	240

than that of the SRAM-based one. Using the hybrid multiple-valued/binary context switching signal, the area of an MC-switch becomes small further. The use of FGFPs will be efficient in static power consumption in comparison with the SRAM-based one because no supply voltage is required to keep the storage.

Acknowledgment

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