Study of VTCMOS characteristics and its optimum conditions with a compact analytical model
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Variable Threshold Voltage MOSFET (VTCMOS) has promised to be amongst the next generation of ultra-low power devices operating at low supply voltage [i]. The performance of a VTCMOS is mainly determined by the body effect factor ($\gamma$) and $S$-factor at a given $|V_{bs}|$. In this study, a very compact analytical model of VTCMOS is proposed to study the active on-current ($I_{on}(a)$), linking it with the stand-by off-current ($I_{off}(s)$) characteristics.

Fig 1 shows the modeled $I_{on}(a)$ and its contour map projected onto the $\gamma - V_{bs}$ plane, at a fixed $I_{off}(s)$ of $10^{-13}$ A/\u. When $|V_{bs}| = 0$ (a normal MOSFET), as $\gamma$ increases $V_{th}$ increases due to increased $S$ and thus $I_{on}(a)$ decreases. However, when $V_{bs}$ is sufficiently large (for example, $|V_{bs}| = 1.2$V), as $\gamma$ increases $V_{th}$ decreases and $I_{on}(a)$ increases. Therefore, there are two completing factors that degrade and enhance $I_{on}(a)$. When the two factors are balanced at a certain $|V_{bs}|$, $I_{on}(a)$ does not depend on $\gamma$, as shown in Fig 1. We denote the characteristic value of $|V_{bs}|$ as $|V_0|$. $V_0$ is very important because its value would give a rough idea for the optimum conditions of a VTCMOS performance. Importantly, when $|V_{bs}| > |V_0|$, as $\gamma$ increases $I_{on}(a)$ increases, whilst when $|V_{bs}| < |V_0|$ as $\gamma$ increases $I_{on}(a)$ decreases. Recent numerical simulations are consistent with these modeling results [ii]. The physical origin of $|V_0|$ can be understood by differentiating $I_{on}(a)$ with respect to $\gamma$ and given by: $|V_{bs}| = |V_0| = \left\{ \log_{10}(I_{off}(s))^{-\gamma} \right\} dS/d\gamma$. We found that the value of $dS/d\gamma$ is closely related to the SCE. When the SCE appears, $dS/d\gamma$ tends to decreases and $|V_0|$ decreases. This is because when the SCE appears S-factor is degraded at a smaller $\gamma$ and the $S$-dependence of $I_{on}(a)$ is weakened even when $|V_{bs}| = 0$V. However, it is found that worse SCE causing $S$ and $\gamma$ to degrade quickly makes $I_{on}(a)$ smaller at a given $|V_{bs}|$. Thus, in order to enhance $I_{on}(a)$ it is essential to reduce the SCE.