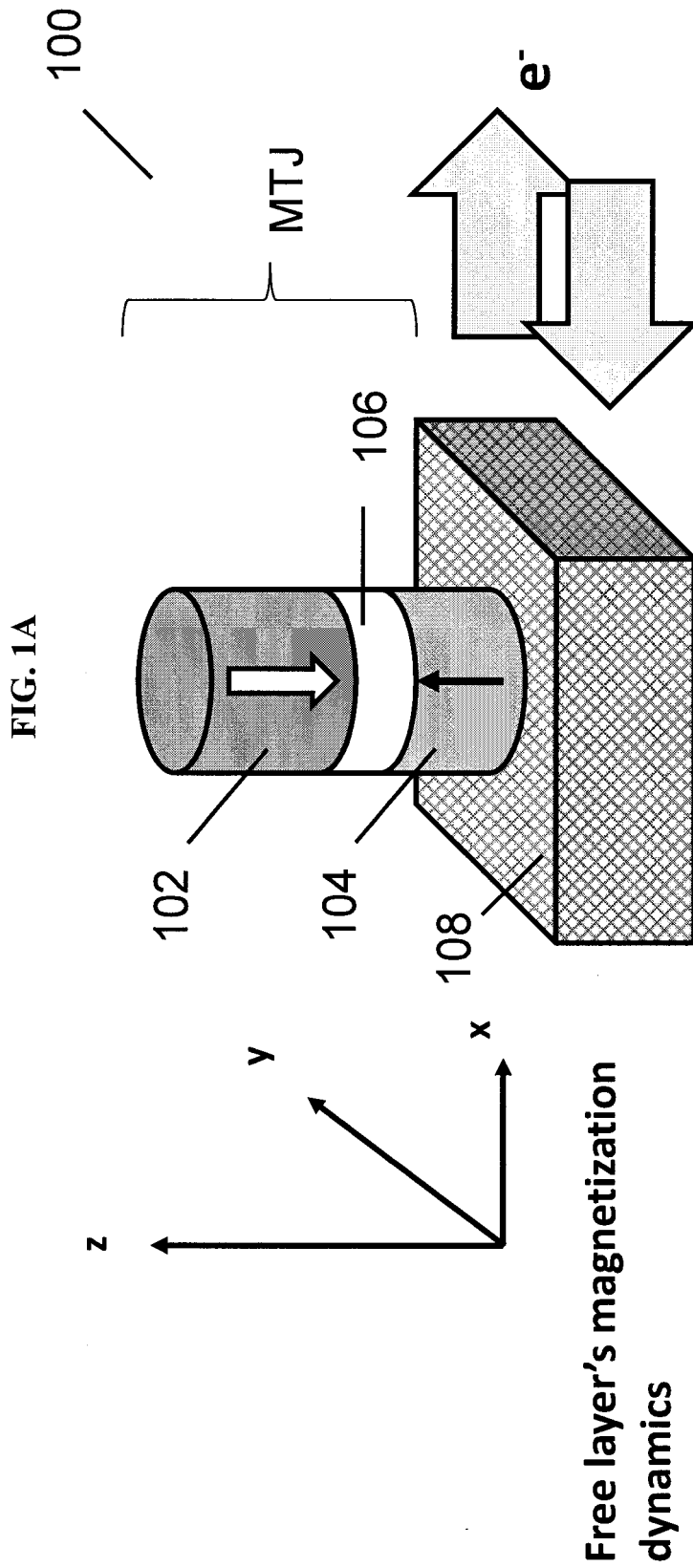


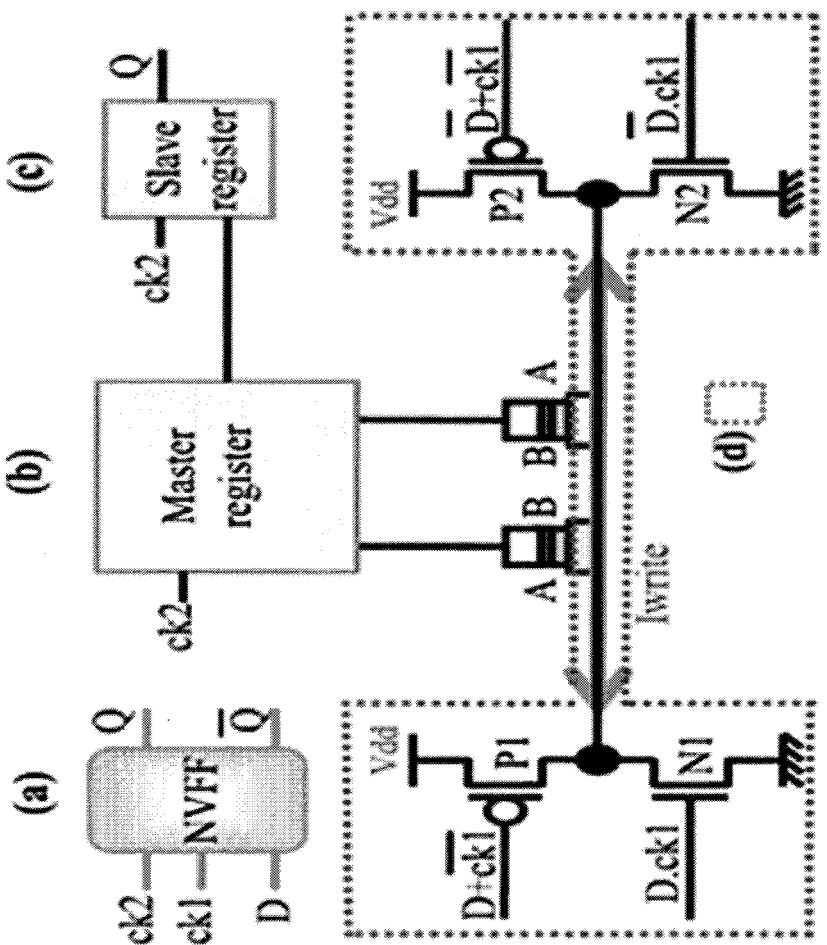
1/25



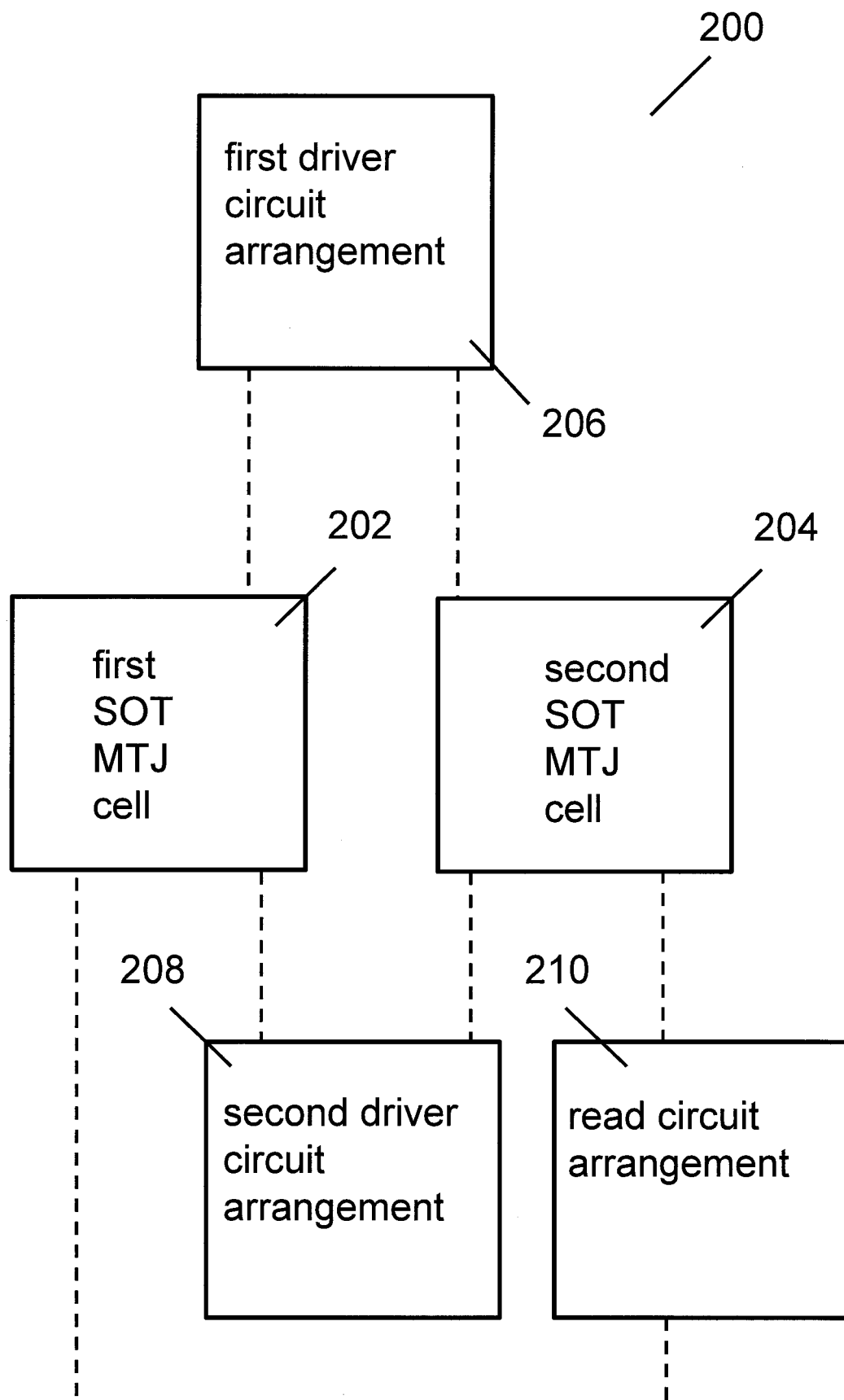
$$\frac{\partial \vec{m}}{\partial t} = -\gamma \mu_0 \vec{m} \times \vec{H}_{\text{eff}} + \alpha \vec{m} \times \frac{\partial \vec{m}}{\partial t} - \xi P J_{\text{STT}} \vec{m} \times (\vec{m} \times \vec{m}_r) - \xi \eta J_{\text{SHE}} \vec{m} \times (\vec{m} \times \vec{\sigma}_{\text{SHE}})$$

SHE Only, since Rashba effect is under debate

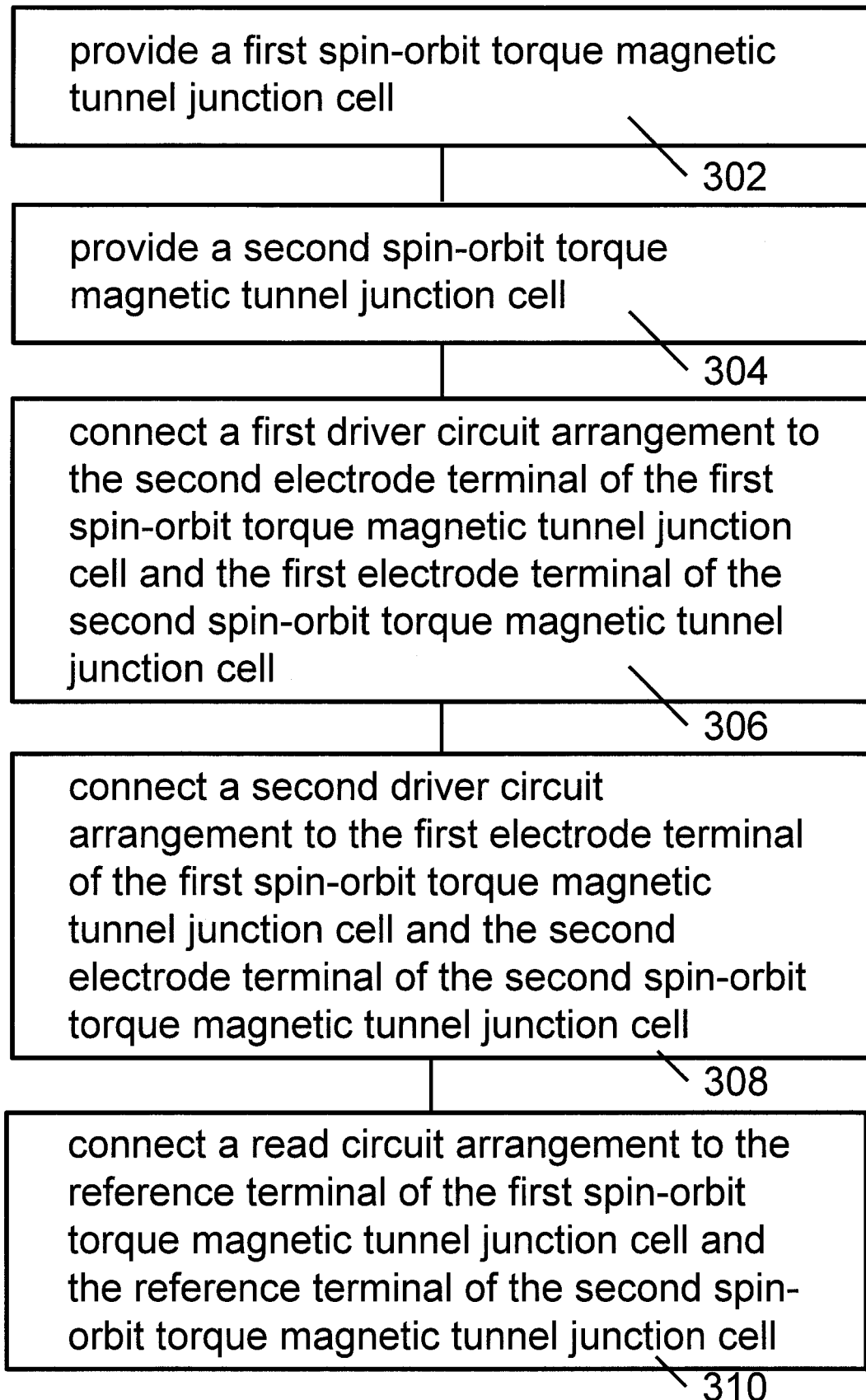
FIG. 1B



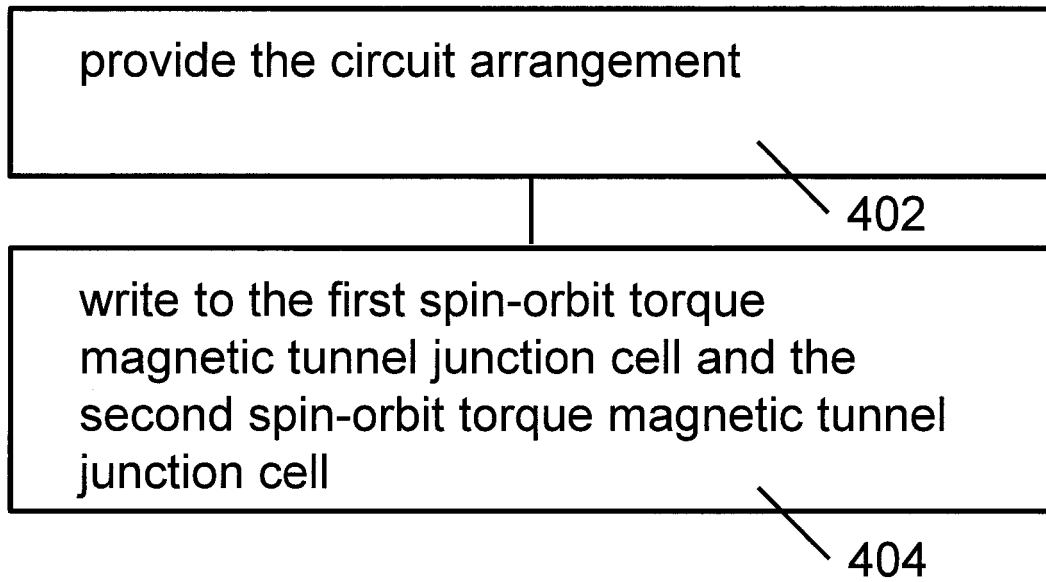
NVFF structure (a) symbol, (b) master register architecture (c) slave register, (d) writing circuit.

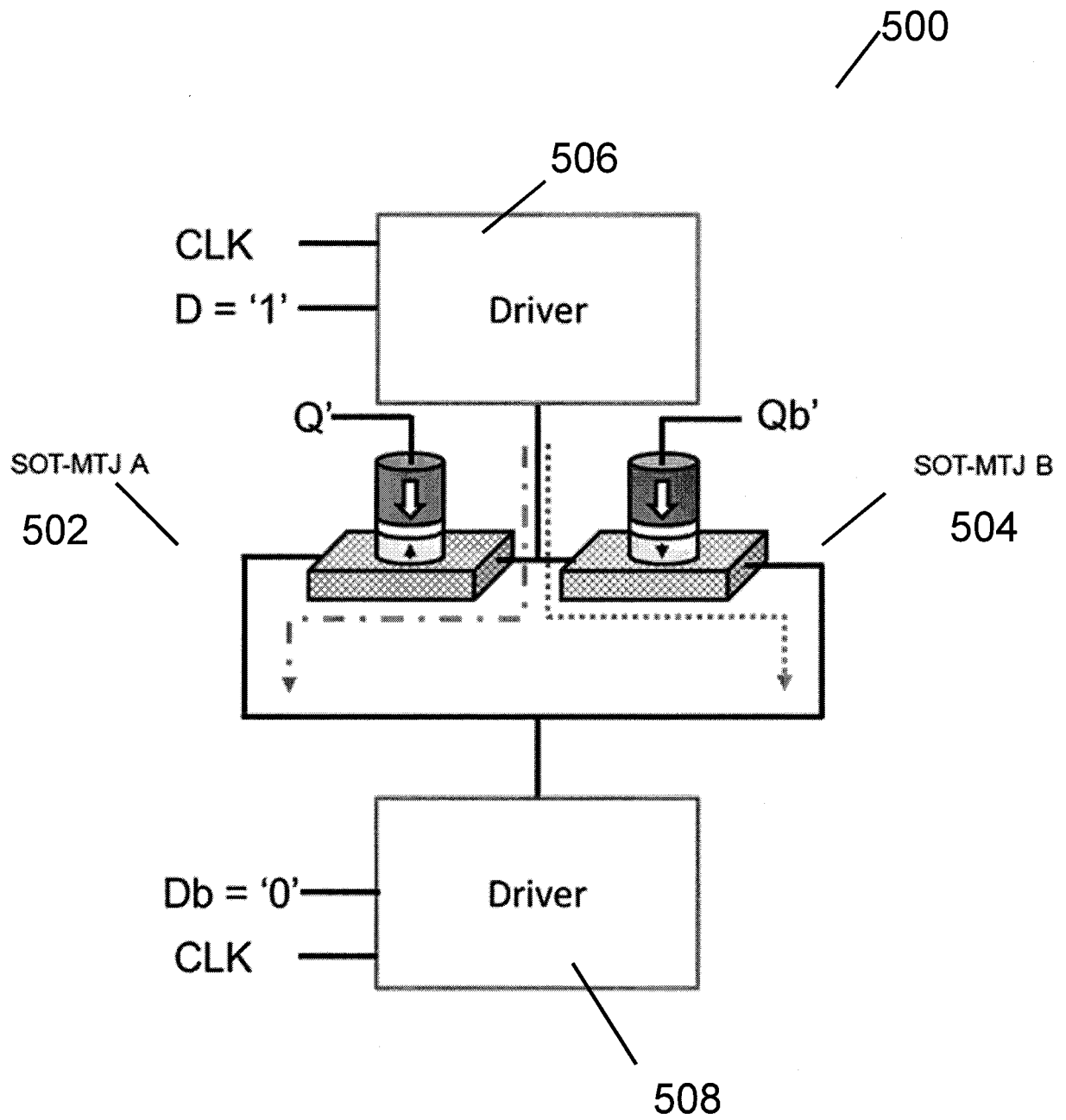
3/25
FIG. 2

4/25
FIG. 3

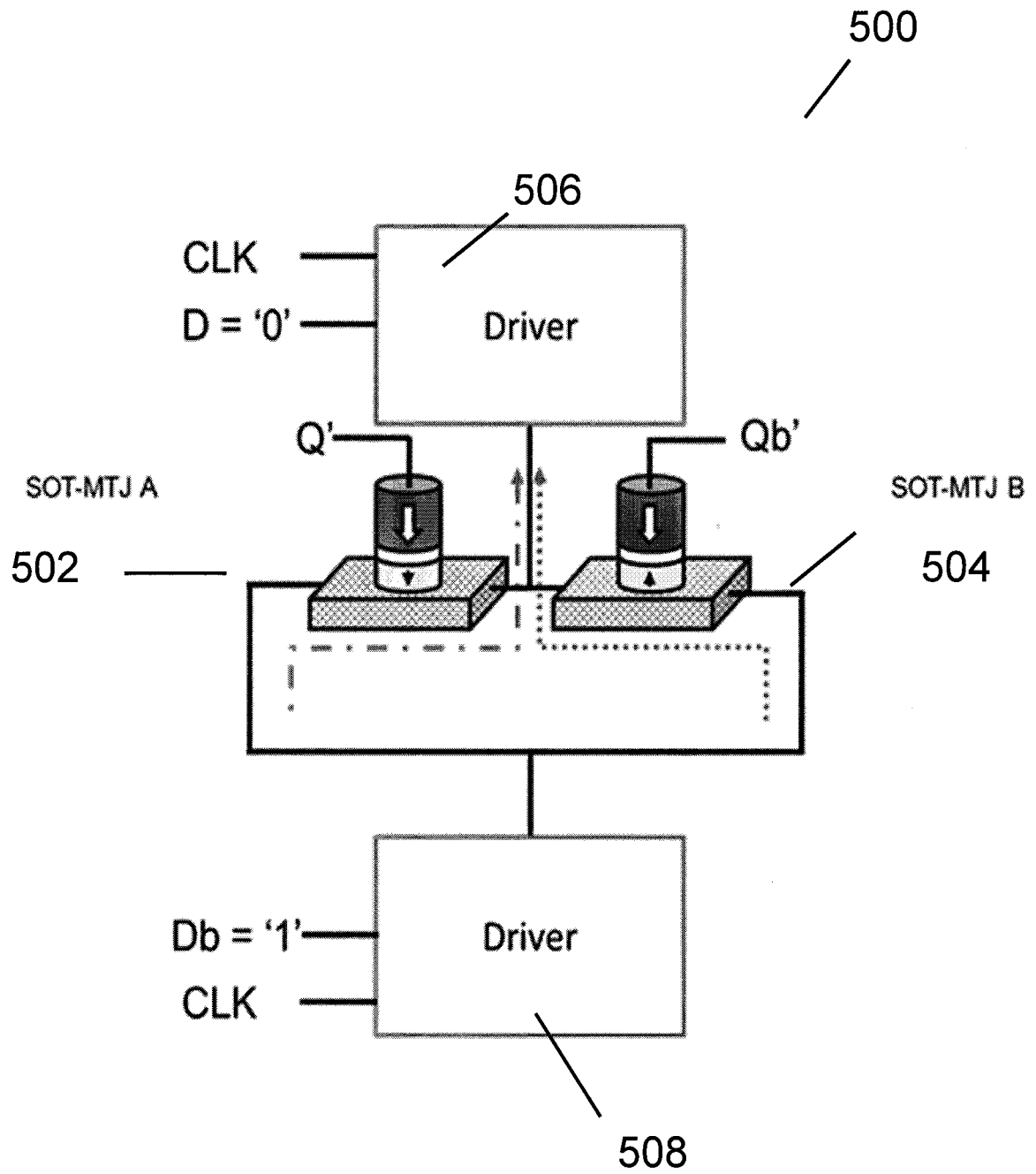


5/25
FIG. 4



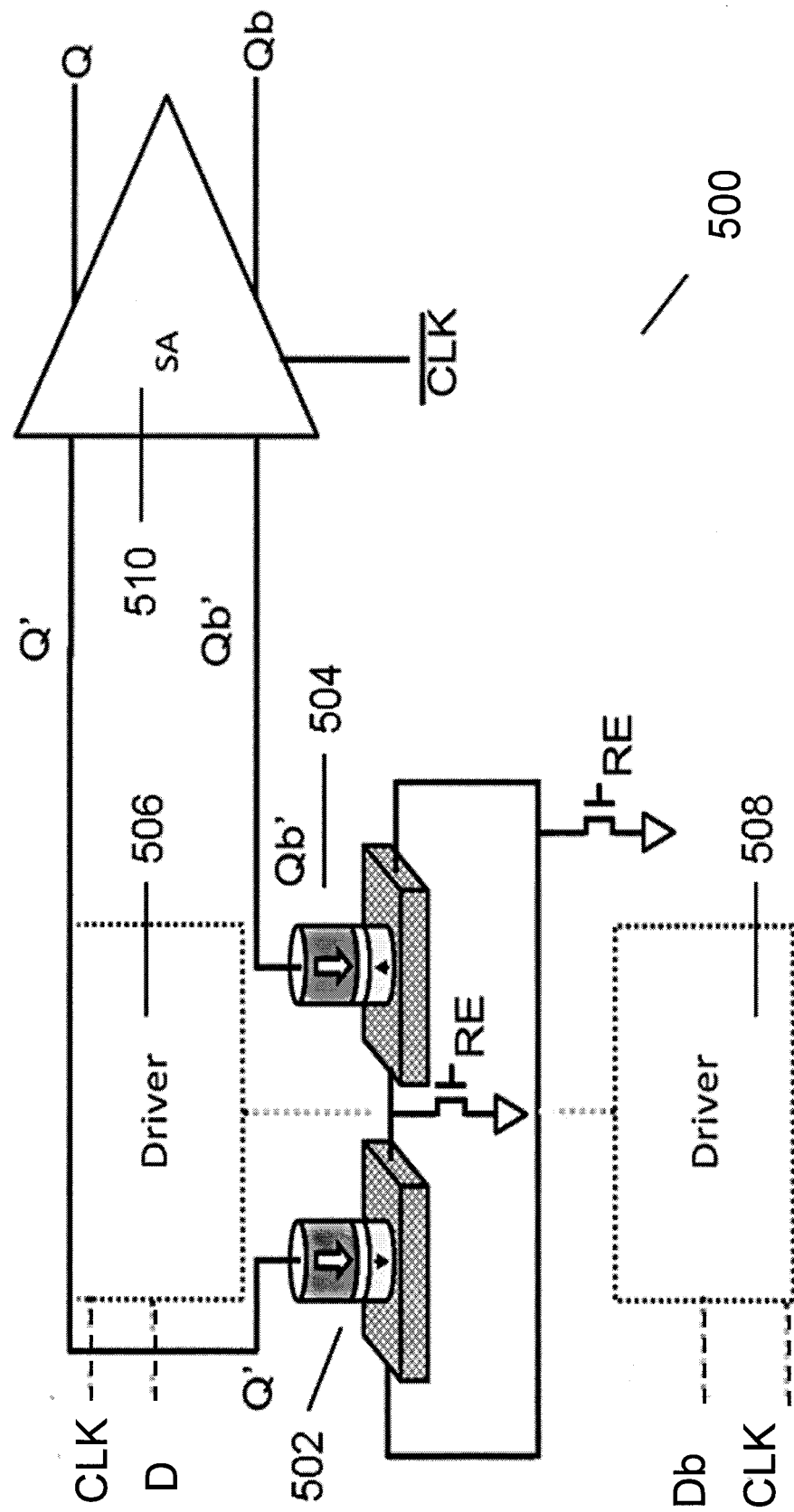
6/25
FIG. 5A

7/25
FIG. 5B



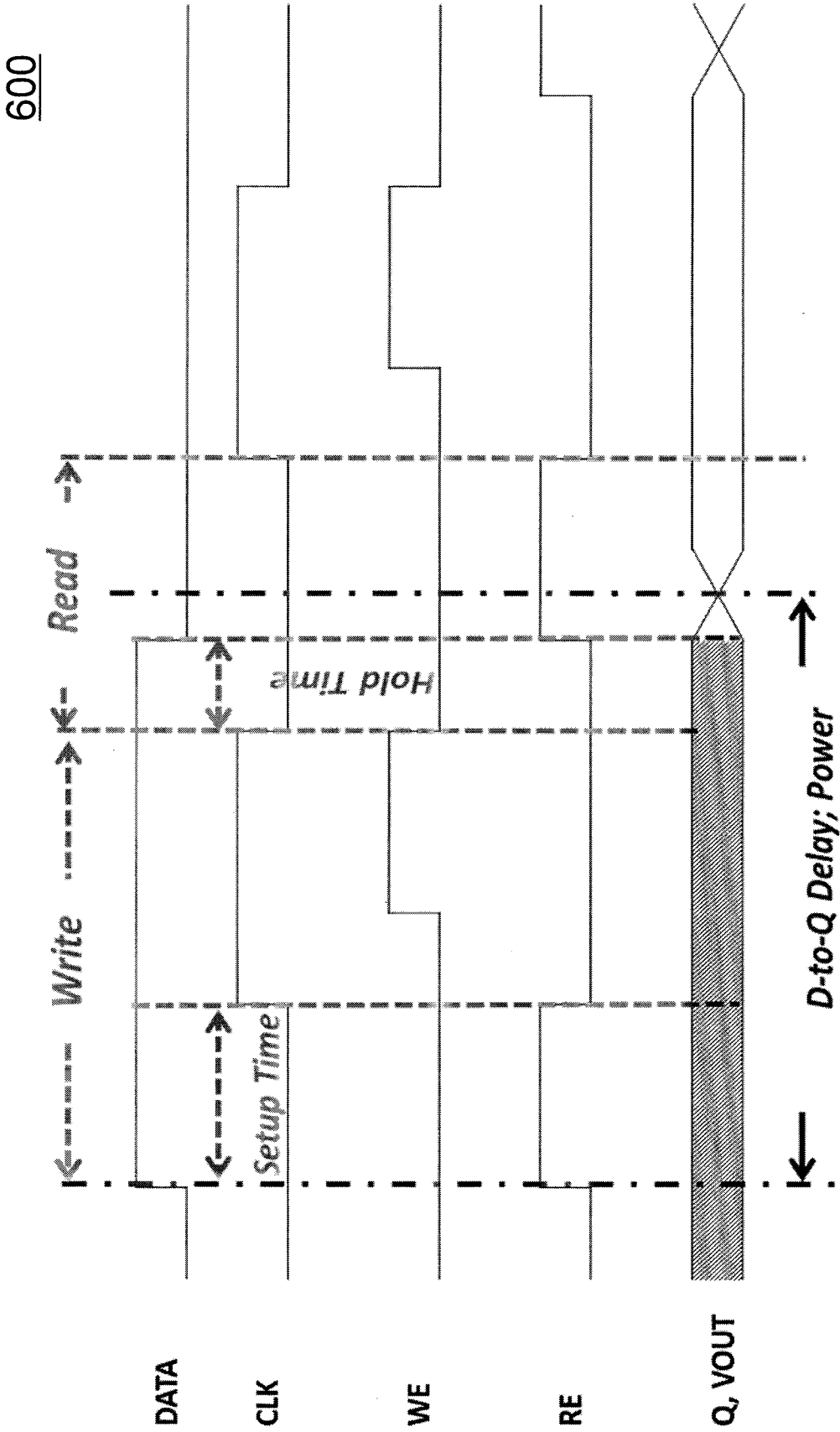
8/25

FIG. 5C



9/25

FIG. 6



11/25
FIG. 8A800a

Parameter	Value	Units
Free Layer Thickness	0.9	nm
MgO Thickness	0.85	nm
MTJ diameter	40	nm
Saturation Magnetization, M_s	0.9×10^6	A/m
Magnetic Anisotropy, H_k	8×10^4	A/m
Spin orbit efficiency, p	0.62	-
Damping constant, α	0.1	-
Spin hall angle	0.3	-
Length (SoT)	120	nm
Width (SoT)	100	nm
Thickness (SoT)	3	nm
Resistivity (SoT)	200	$\mu\Omega \cdot \text{cm}$
Gyromagnetic ratio, γ	17.6×10^{11}	$\text{rads}^{-1} \text{T}^{-1}$
R_{low}	4.5	K Ω
R_{high}	9.9	K Ω

12/25
FIG. 8B

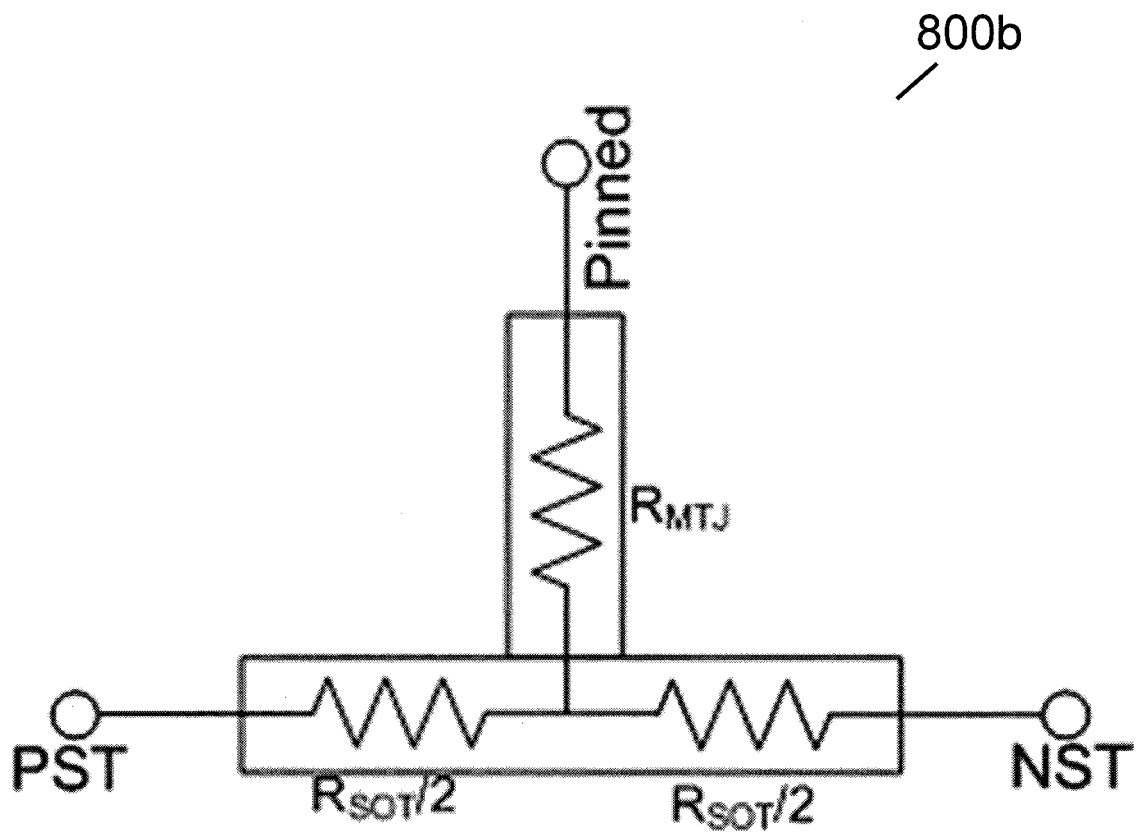


FIG. 9A
Waveform for SOT based Non-volatile Flip-Flop
900a

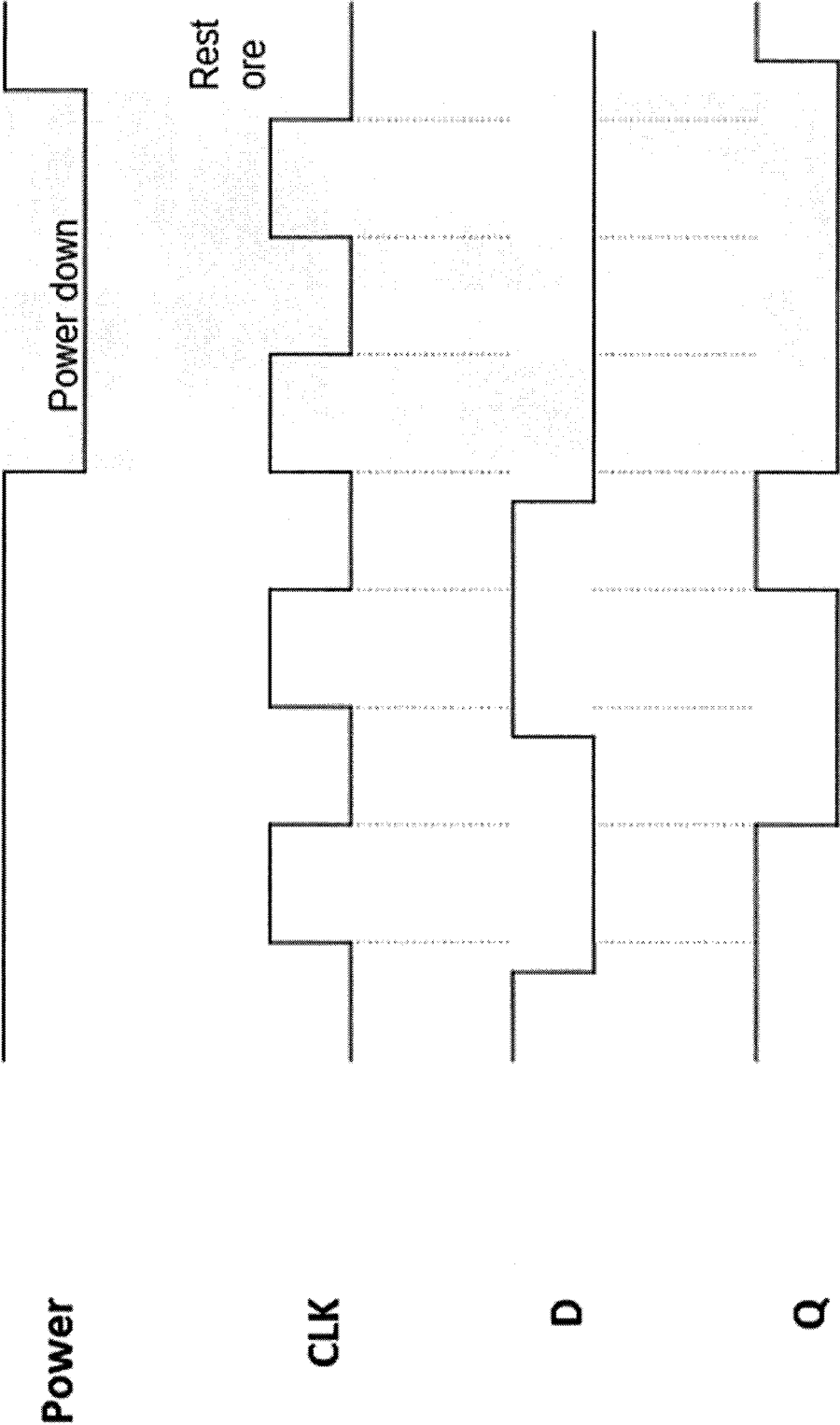


FIG. 9B

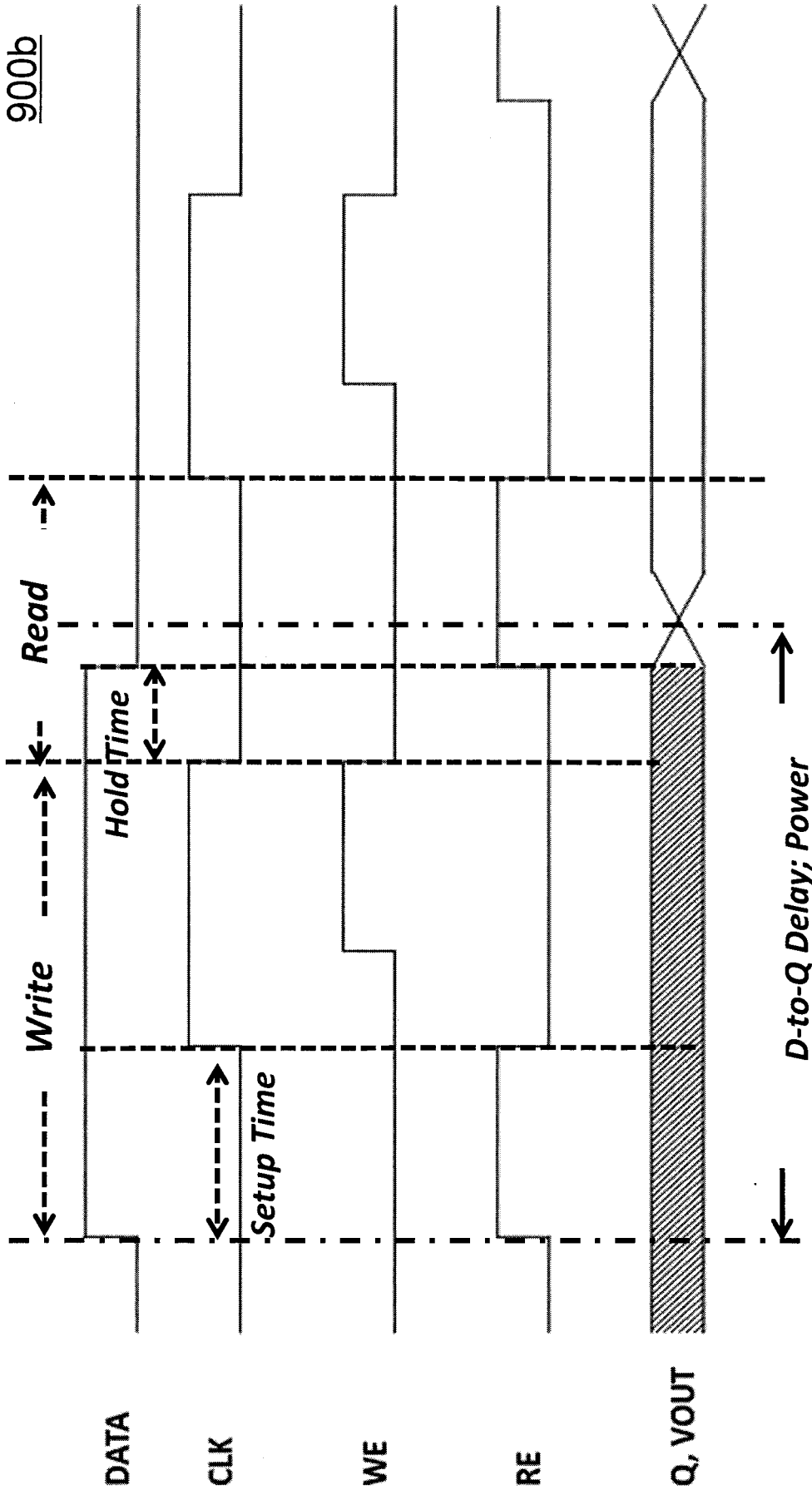
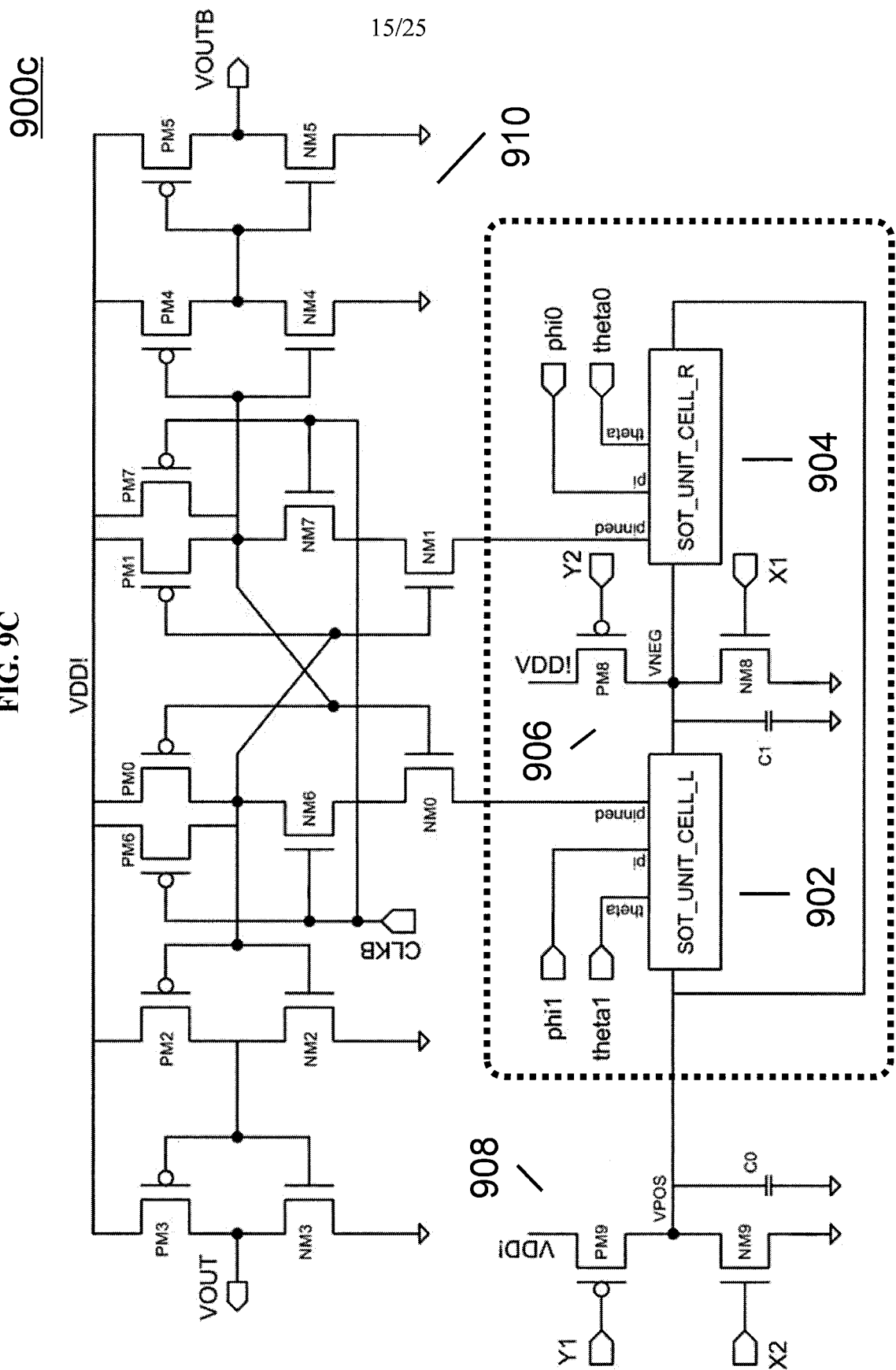
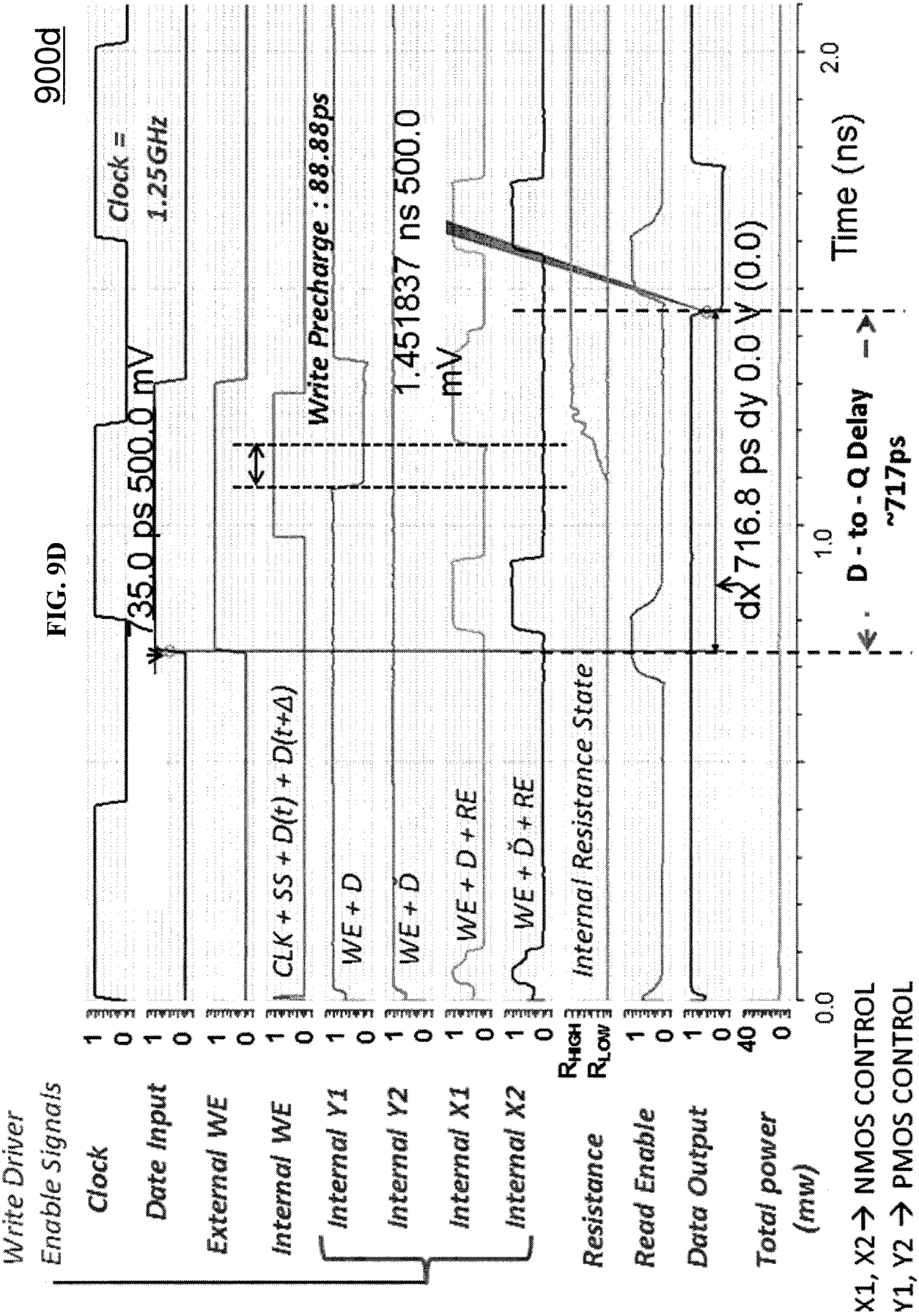


FIG. 9C





900e

FIG. 9E

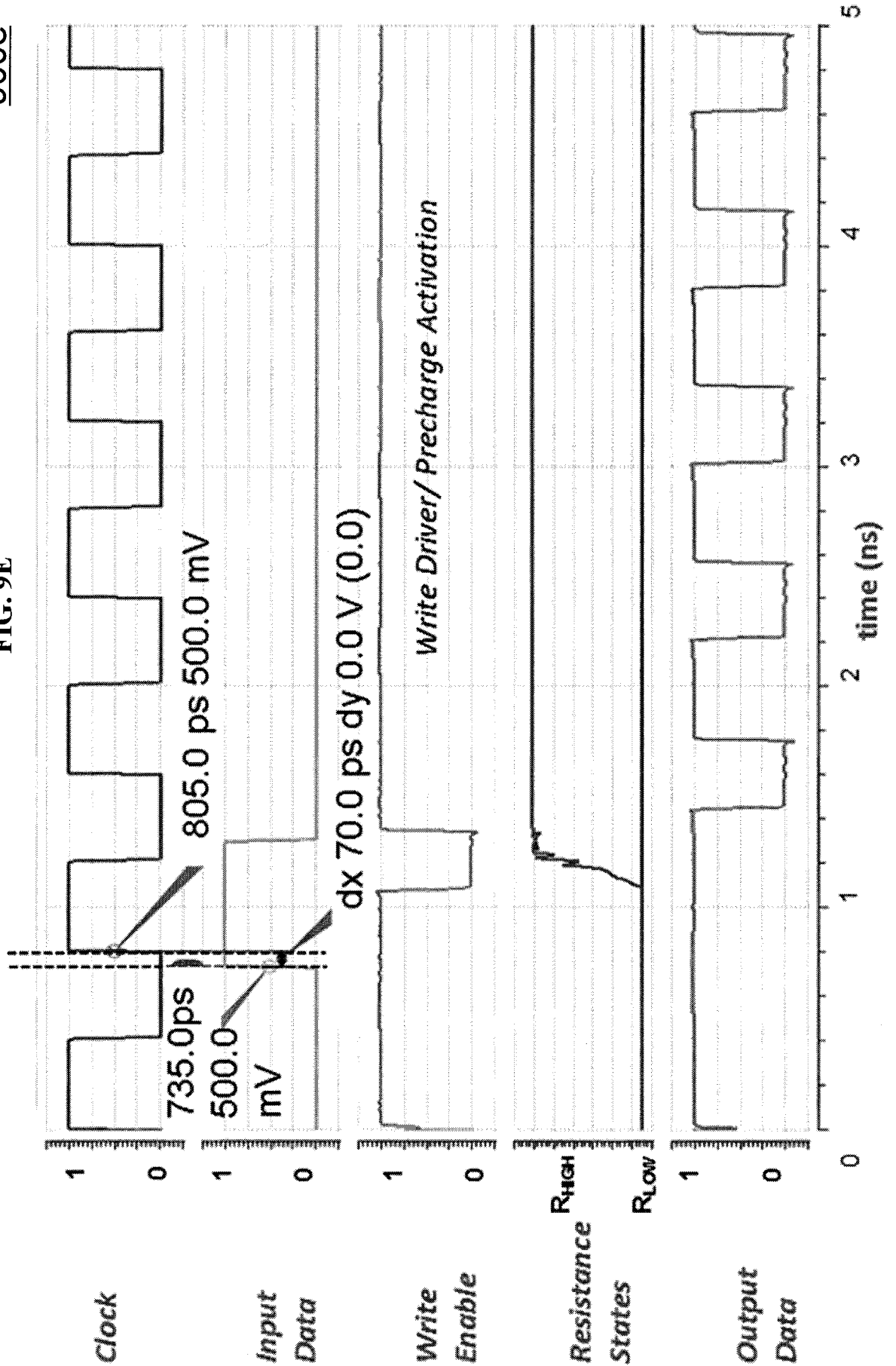
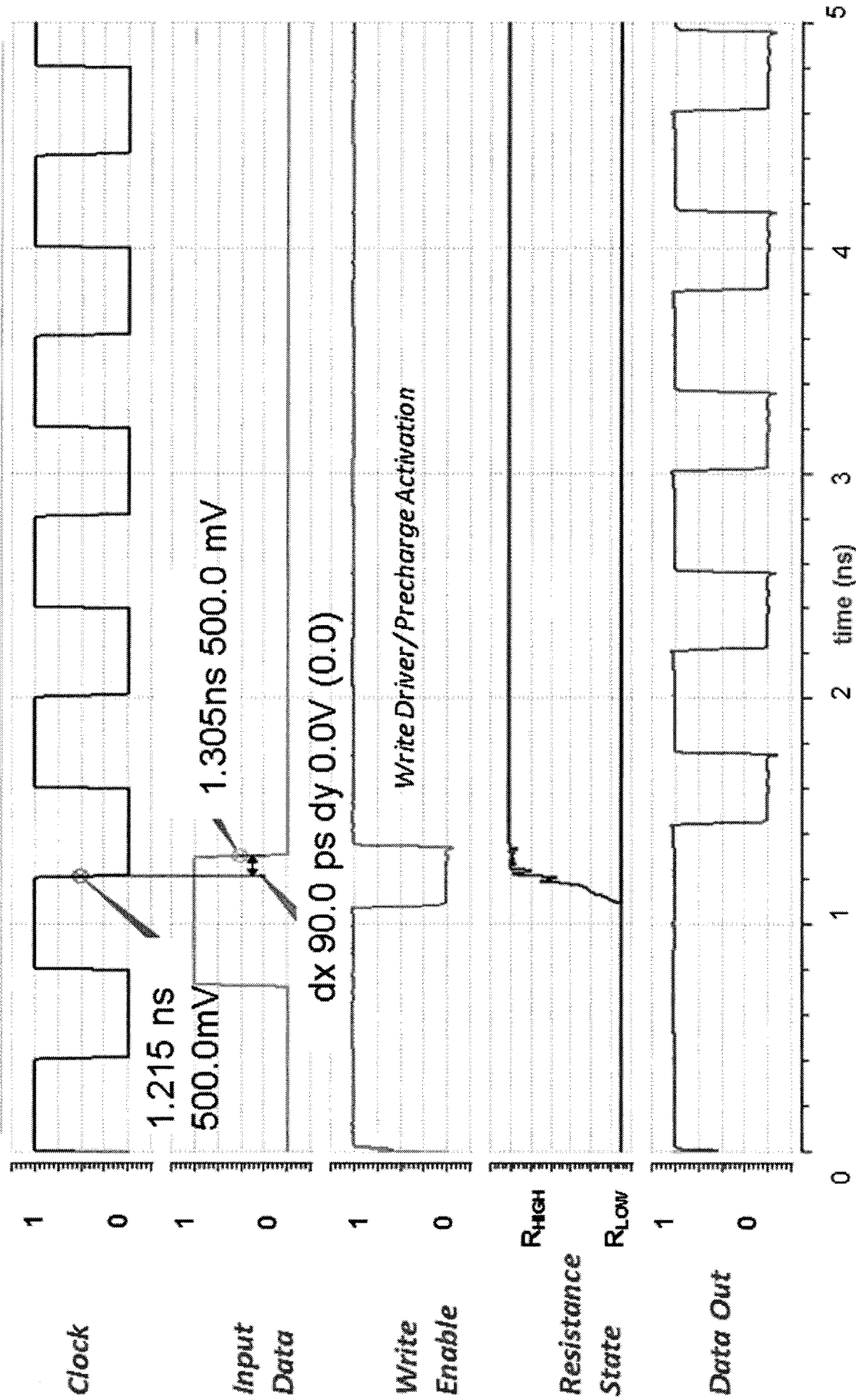
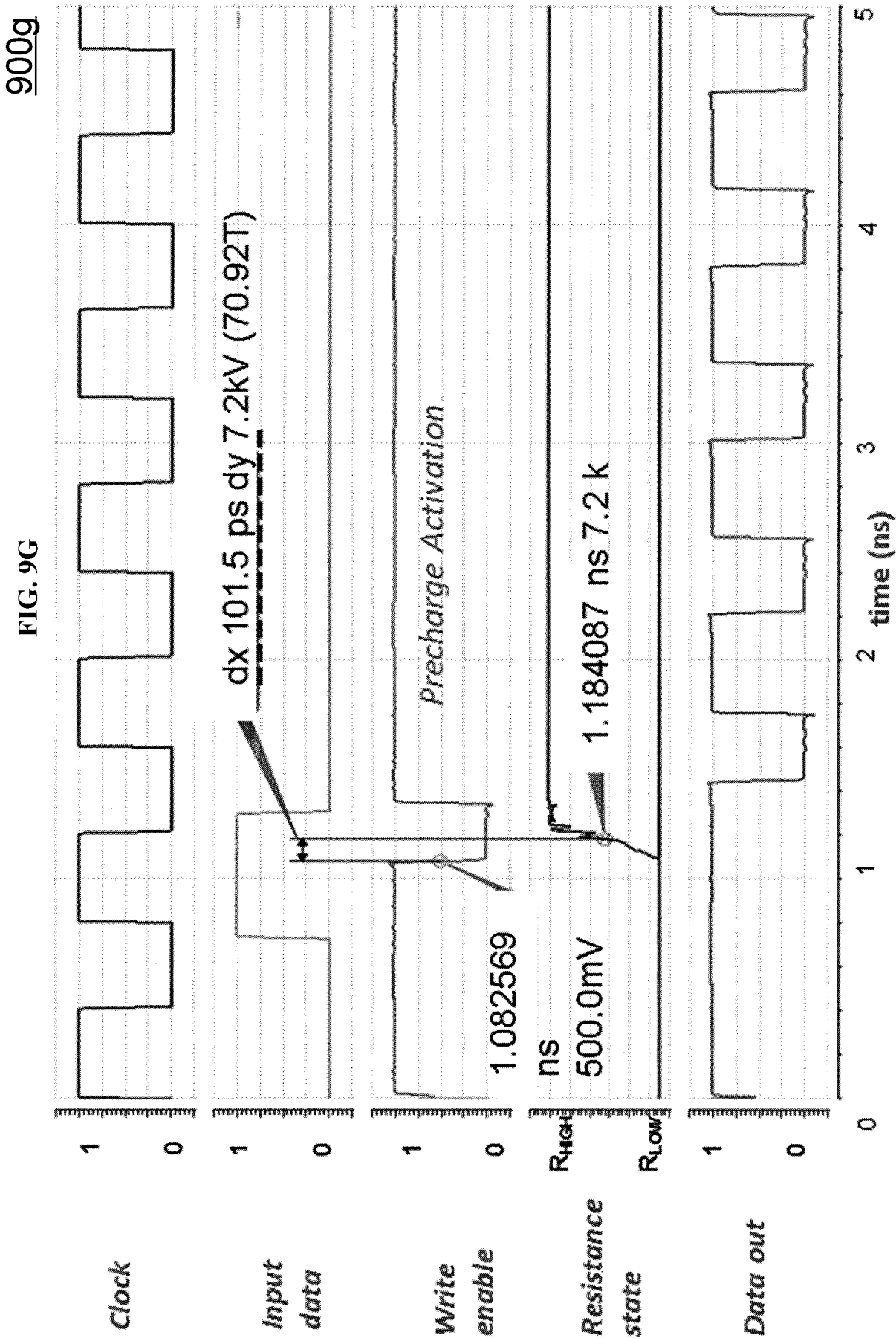
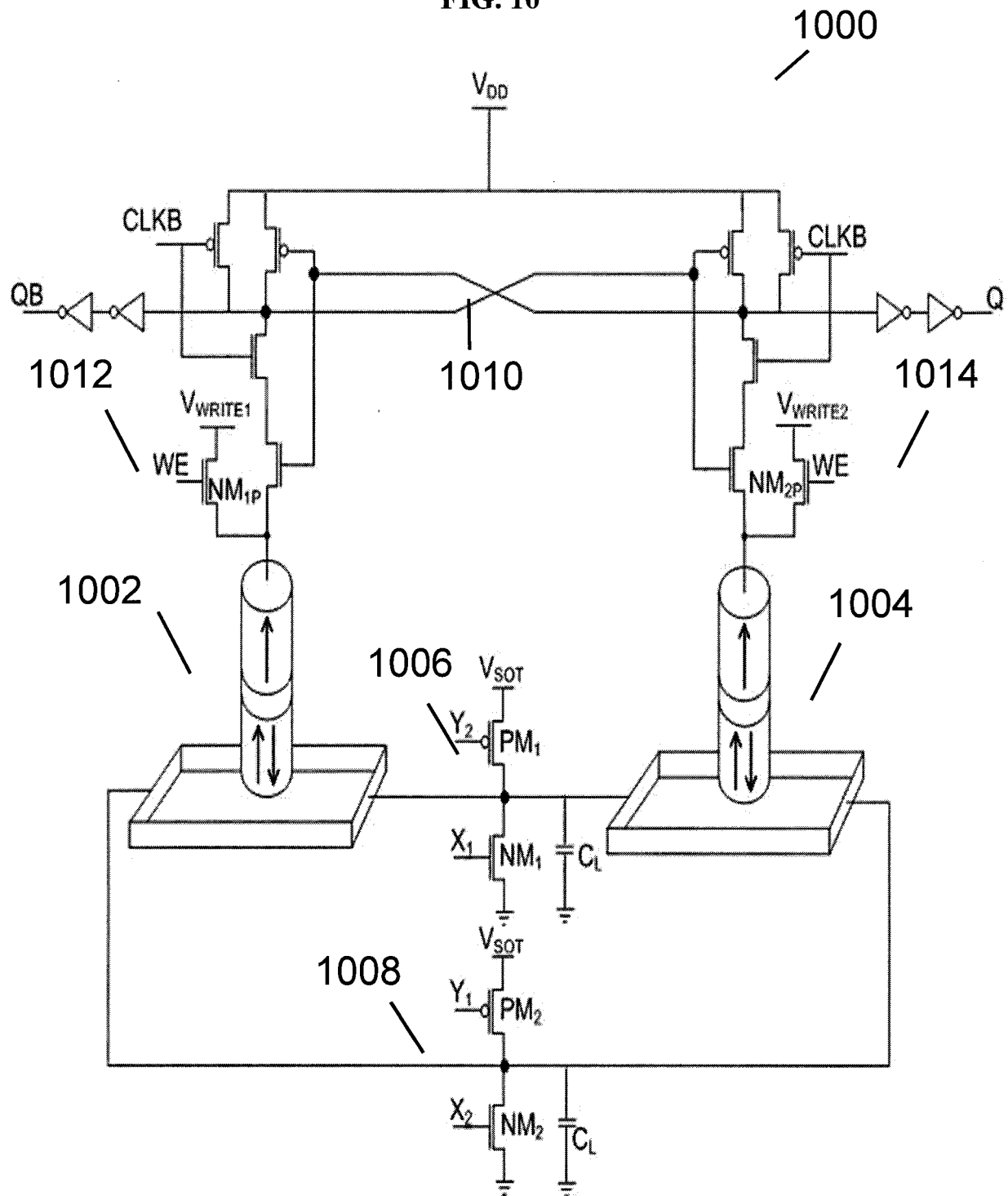


FIG. 9F

900f





20/25
FIG. 10

* V_{WRITE1} & V_{WRITE2} can be equal or different

21/25

FIG. 11A 1100a

Parameter	Serial Write	Parallel Write	Change
Clock Frequency	1GHz	1.25GHz	0.25GHz (1.25X)
Driver Size	750nm	1.6μm	850nm (2.14X)
Write Current	110μA	110μA	0
Setup time	110ps	70ps	40ps
Hold Time	-	90ps	90ps
Precharge Time (Write)	-	~90ps	-
Cell Write Time	207ps	104ps	103ps (~50%)
Delay (D → Q)	845ps	717ps	128ps (~15%)
Memory Core Power	66μW	149μW	83μW** (~2.25X)
Power (D → Q)	124μW	466μW @ 1.25GHz 395μW @ 1GHz	342μW*** (~3.75X) 271μW (~3.18X)
Power Delay Product	104fJ	334fJ	230fJ (~3.2X)
Energy Delay Product	8.788e-23	2.294e-22	1.415e-22 (2.4X)

22/25

FIG. 11B 1100b

Parameter	Serial Write	Parallel Write (1)	Parallel Write (2)	Change (Parallel Write (1))	Change (Parallel Write (2))
Clock Frequency	1GHz	1.25GHz	1GHz	0.25GHz (1.25X)	Nil
Driver Size	750nm	1.6μm	1.6μm	850nm (2.14X)	850nm (2.14X)
Write Current	80μA	80μA	80μA	Nil	nil
Setup time	110ps	70ps	70ps	40ps	40ps
Hold Time	-	90ps	80ps	90ps	80ps
Precharge Time (Write)	-	~90ps	~90ps	-	-
Cell Write Time	207ps	104ps	121ps	103ps (~50%)	86ps (~41%)
Delay (D → Q)	845ps	717ps	825.7ps	128ps (~15%)	20ps(2%)
Memory Core Power	66μW	149μW	140μW	83μW (~2.25X)	74μW (2.12X)
Power (D → Q)	124μW	466μW	419μW	342μW (~3.75X)	295μW (3.38X)
Power Delay Product	104fJ	334fJ	345.9fJ	230fJ (~3.2X)	241fJ (3.32X)
Energy Delay Product	8.788e-23	2.294e-22	2.85e-22	1.415e-22 (2.6X)	1.975e-22 (3.2X)

FIG. 12A

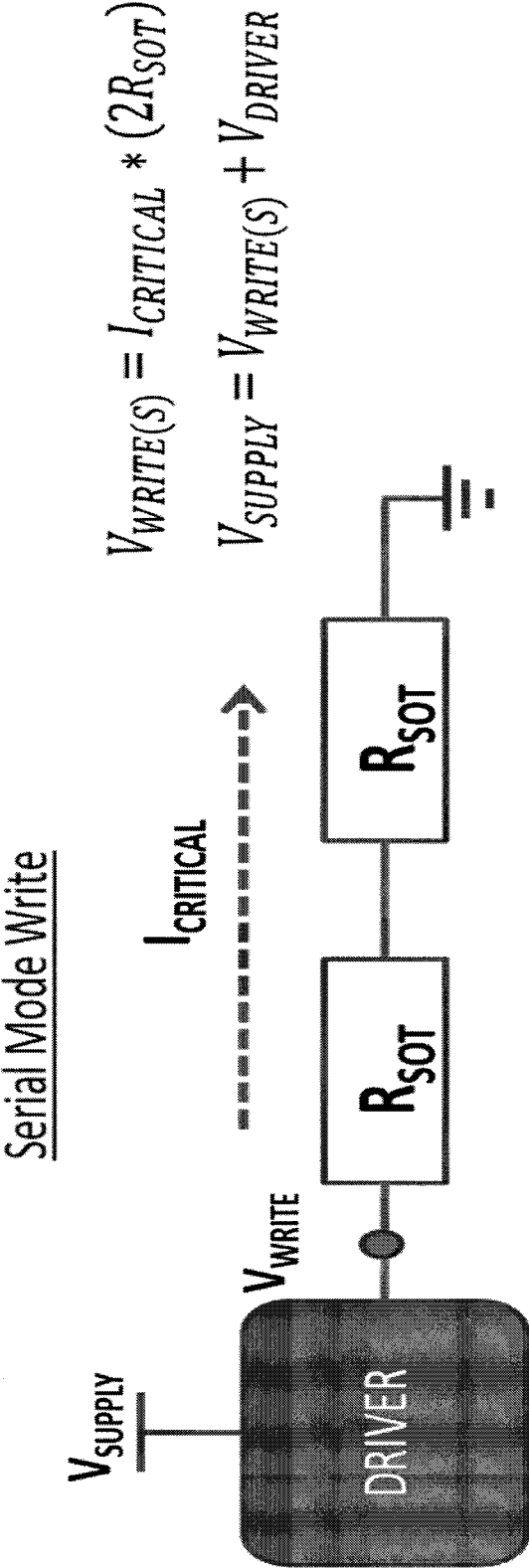


FIG. 12B

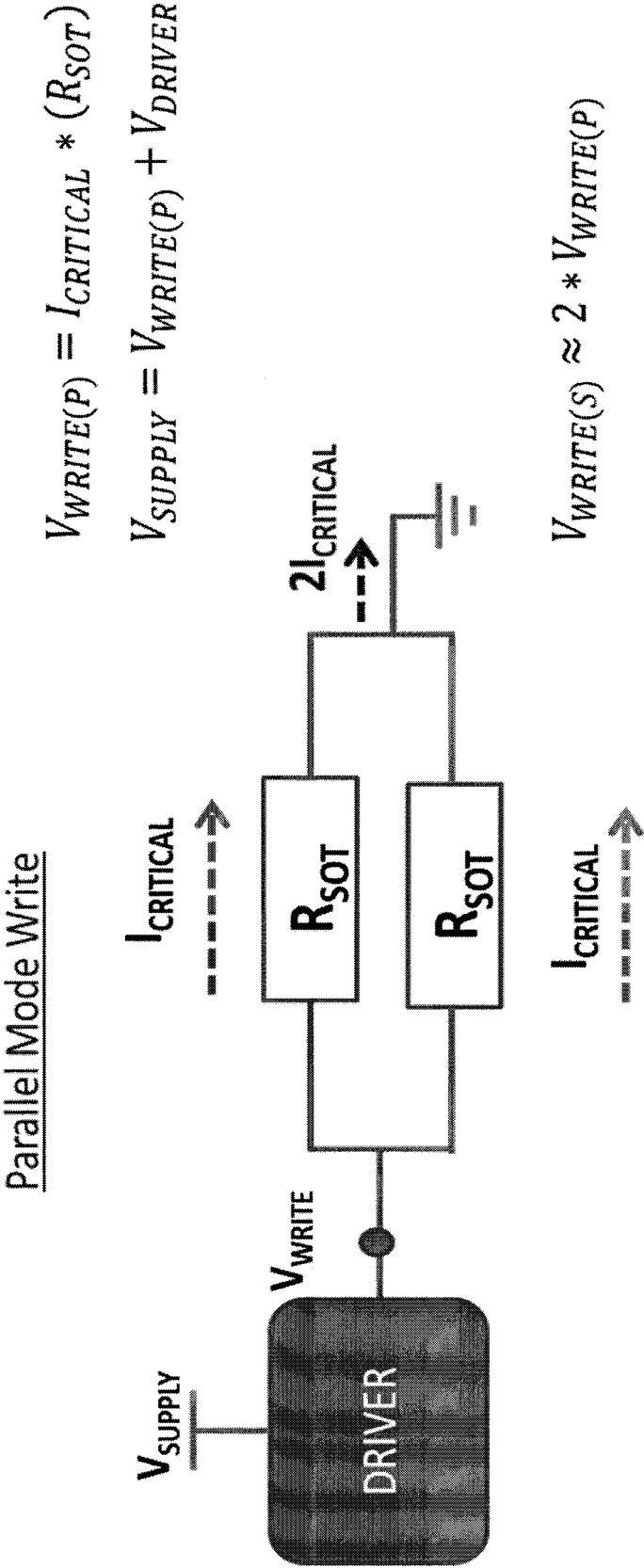


FIG. 13

