IDEC Chip Design Contest

A 92%-Efficiency Inductor-Charging Switched-Capacitor Stimulation System with Level-Adaptive Duty Modulation and Offset Charge Balancing

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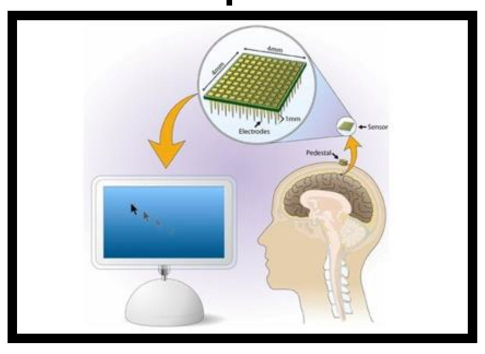
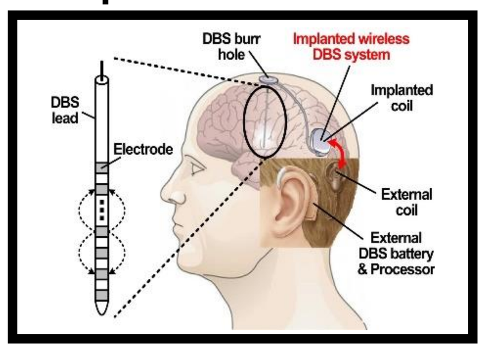
Motivation

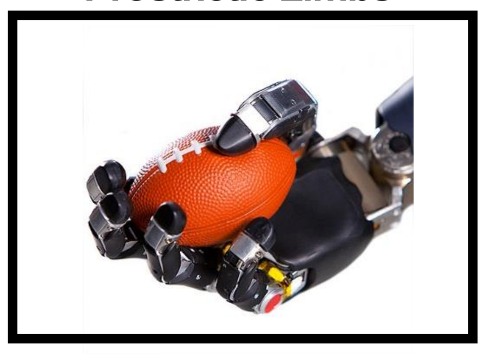
Brain & Computer Interface



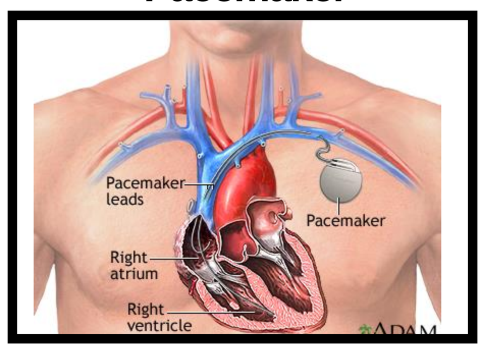
Deep Brain Stimulation



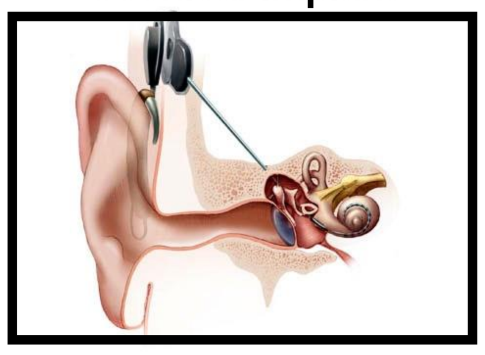
Prosthetic Limbs



Pacemaker



Cochlear Implant

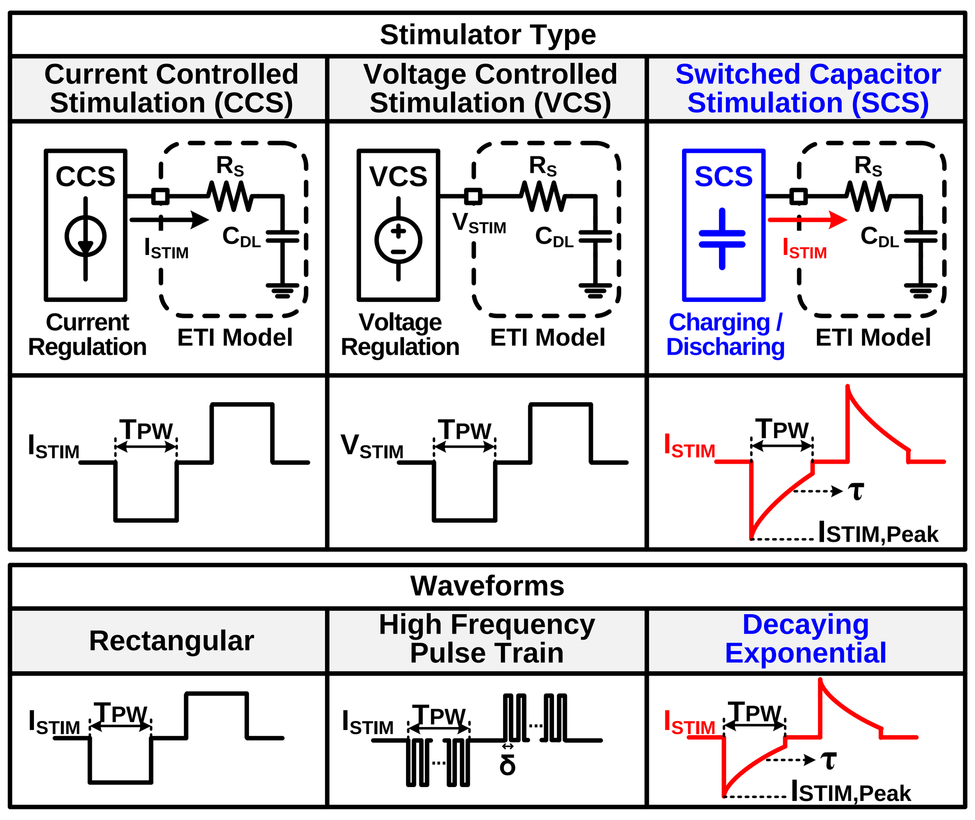


Retinal Prosthesis

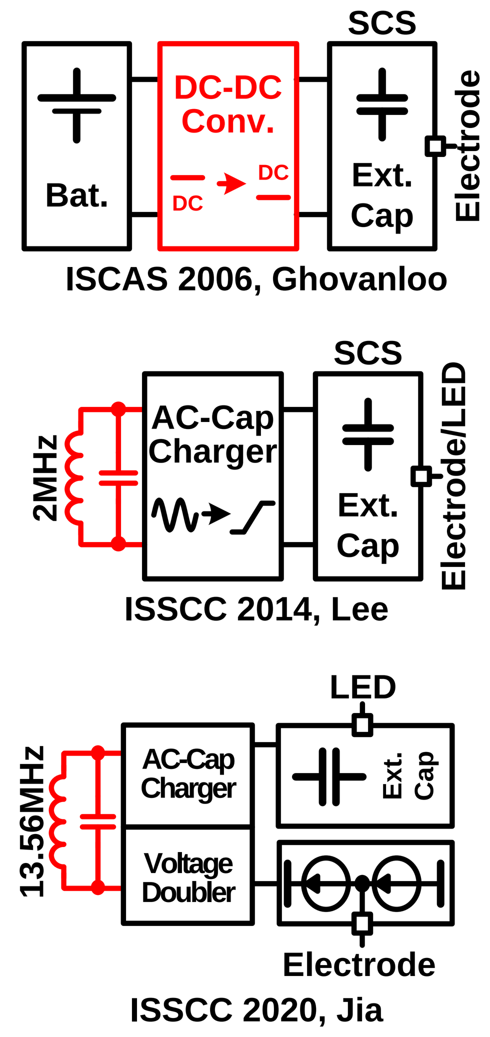
- Implantable medical devices (IMD) with ***miniaturized stimulator SoCs*** are essential technology for disease treatment and rehabilitation.
- Since the stimulator SoC ***injects a large amount of stimulus energy*** into the tissue, serious attention should be paid to safety, energy efficiency, and stimulation efficacy.

Problems of Previous Stim. Systems

❖ Types of Stimulators



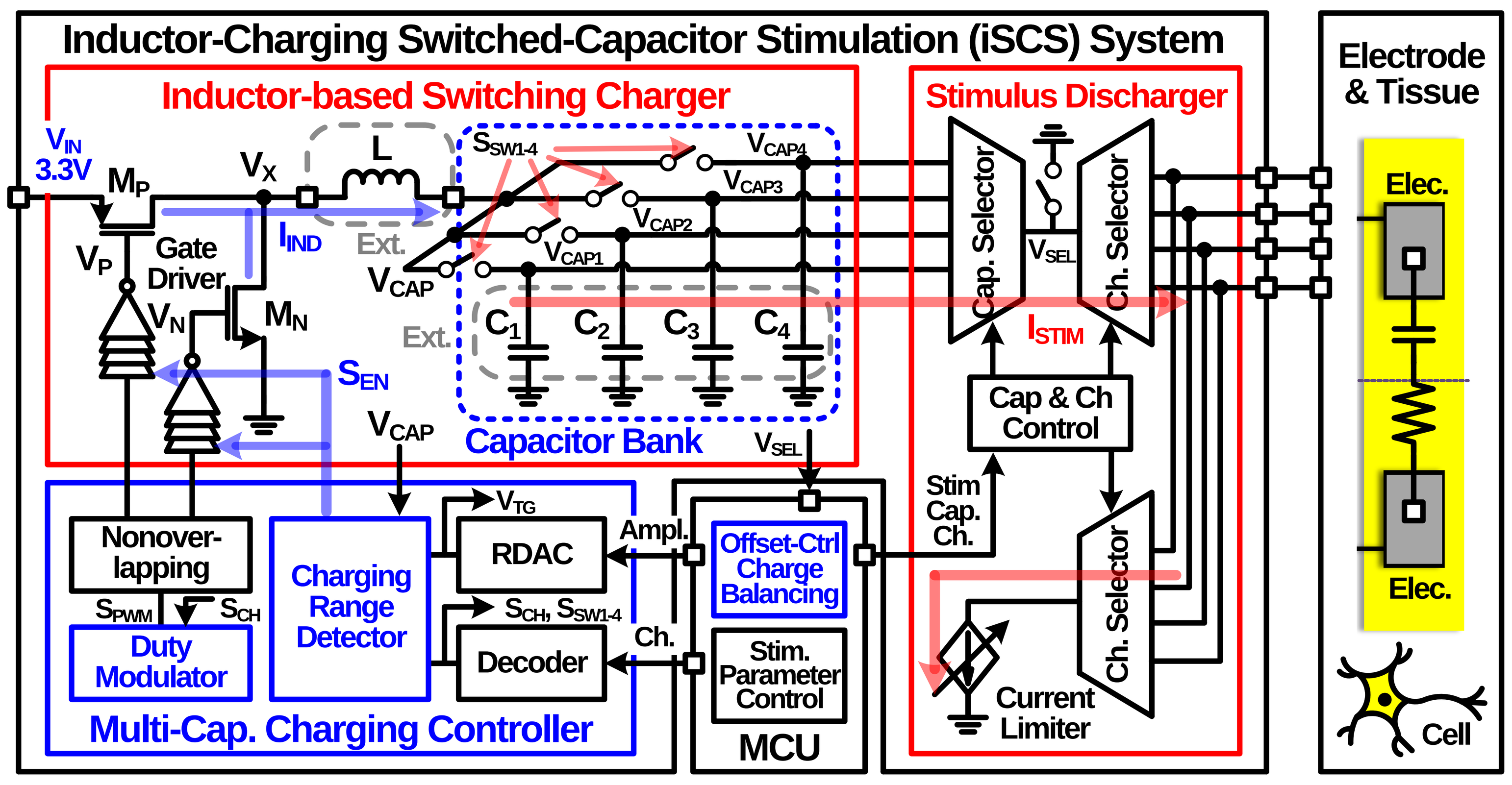
❖ Conventional SCS Systems



- Switched-capacitor stimulation (SCS) ensures ***charge-balanced*** and ***power-efficient stimulation*** ☺
- Conventional AC-input SCS systems may be disturbed by a loosely-coupled inductive links ☹

Proposed iSCS System

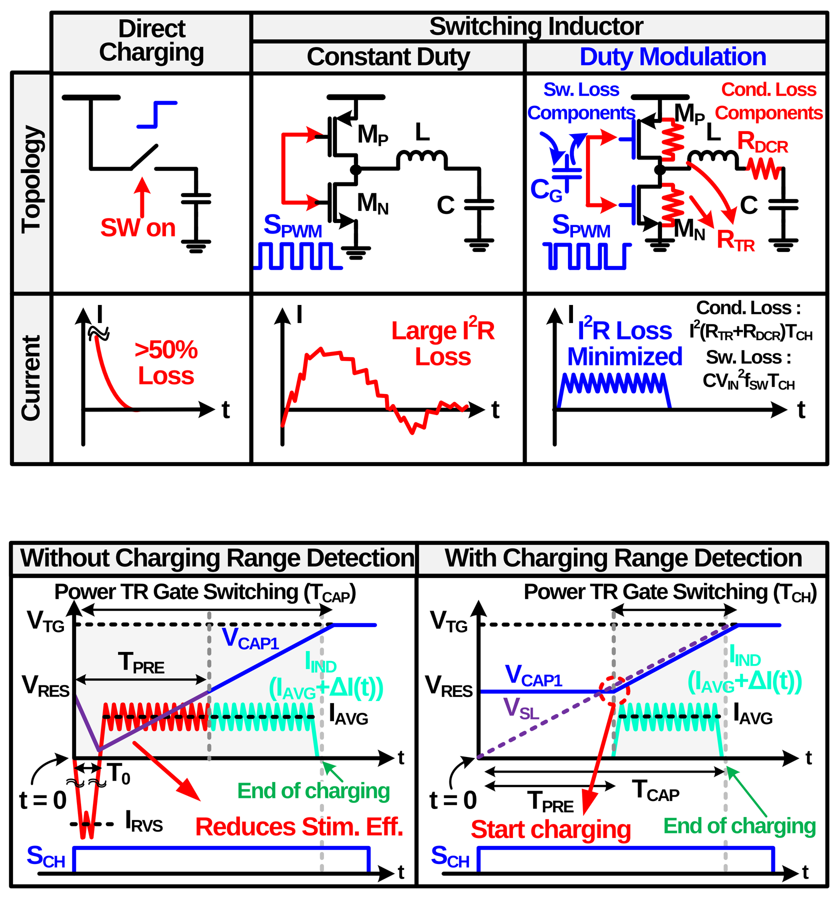
❖ Inductor-Charging Switched-Capacitor Stimulation(iSCS) System



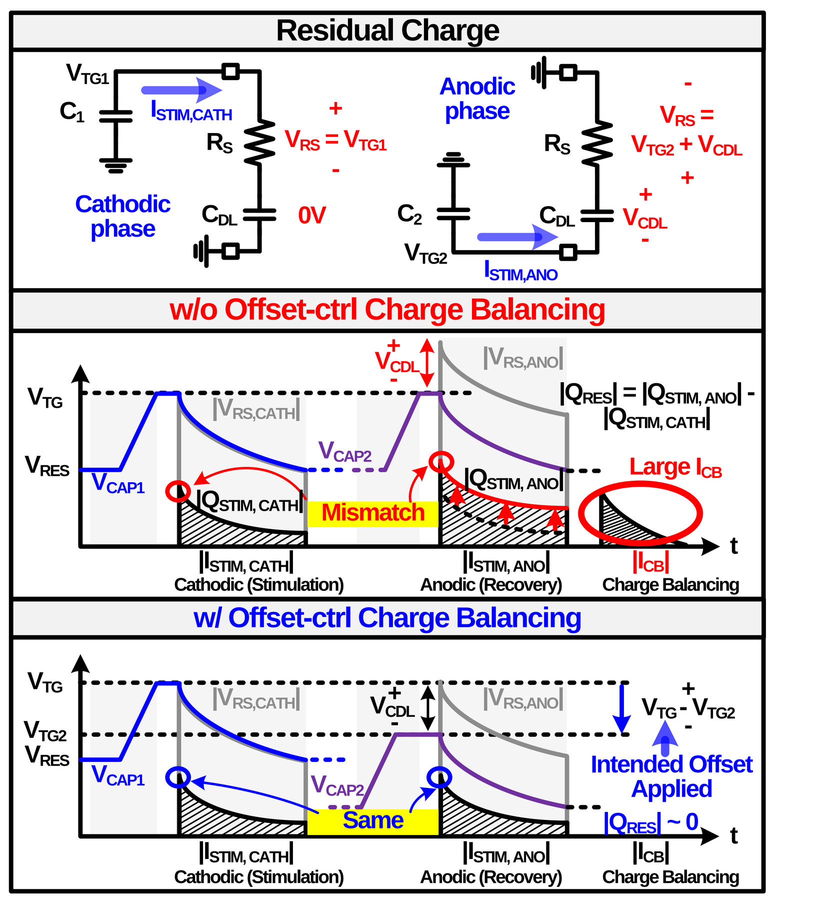
- The iSCS system ***efficiently charges the capacitor*** from DC input voltage, V_{IN}.
- Offset-control charge balancing ***minimizes the mismatch*** between cathodic and anodic charge, while the system ***provides biphasic stimulation*** by discharging charges through the electrodes to the tissue.

Proposed Ideas & Circuit Details

❖ Level-Adaptive Capacitor Charging



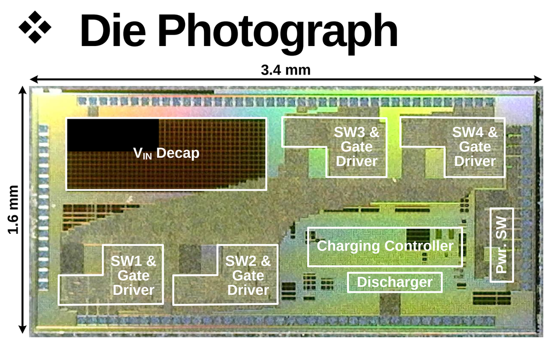
❖ Offset-Control Charge Balancing



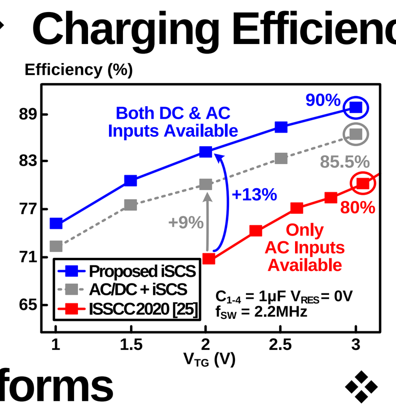
- High-efficiency capacitor charging ***regardless of charging start voltage.***
- Minimizes charge mismatch by ***applying offsets to the anodic stimulation voltage.***

Chip Test & *In Vivo* Animal Experiment

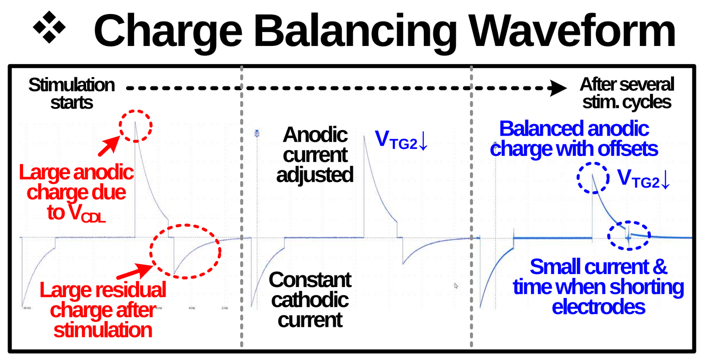
❖ Die Photograph



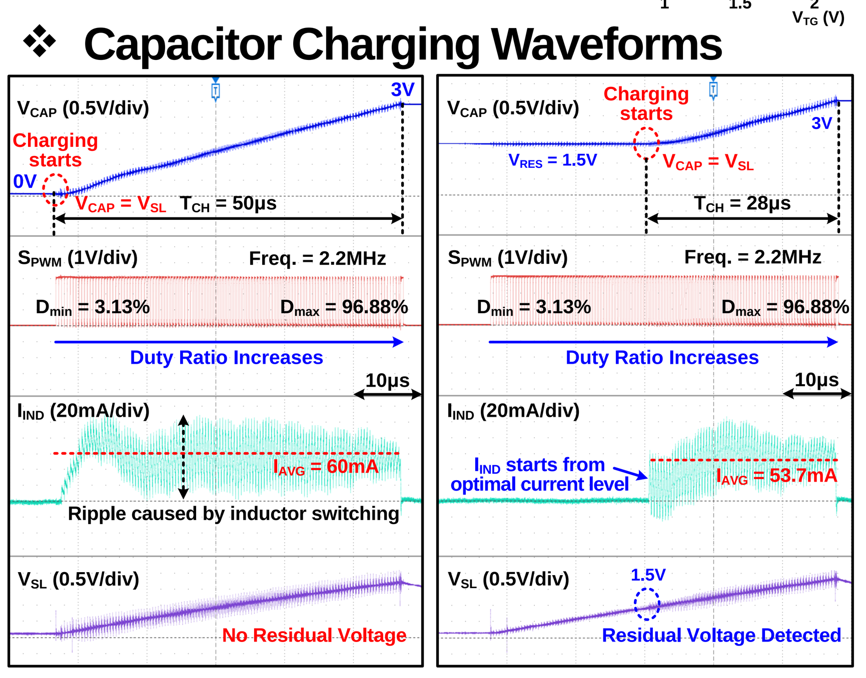
❖ Charging Efficiency



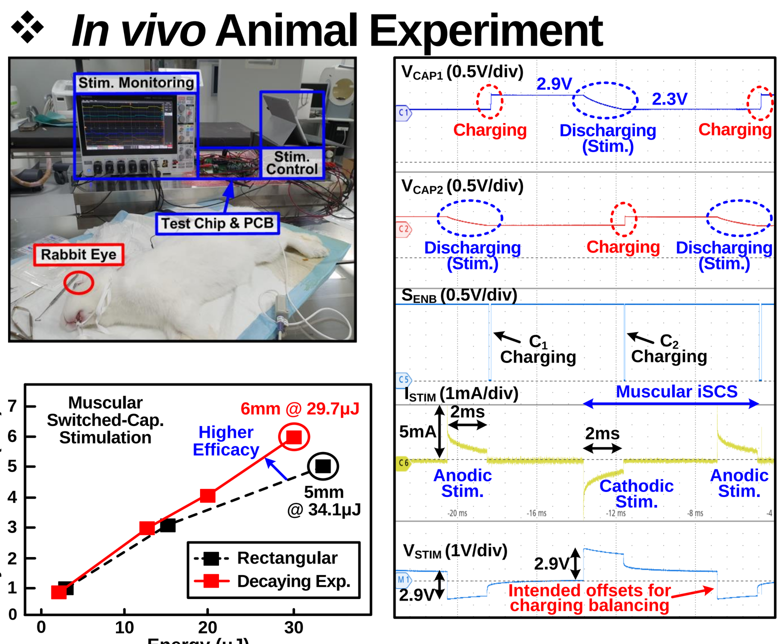
❖ Charge Balancing Waveform



❖ Capacitor Charging Waveforms



❖ *In vivo* Animal Experiment



- High stimulus efficacy of iSCS was ***verified through in vivo animal experiments.***

Performance Comparison

❖ Comparison Table with State-of-the-art Stimulation Systems & Conclusion

Publication	JSSC 2015 [15]	TBioCAS 2017 [17]	TBioCAS 2017 [13]	TBioCAS 2019 [19]	TBioCAS 2019 [23]	TBioCAS 2020 [25]	This Work	
Technology	0.35-μm	0.18-μm	0.18-μm	0.18-μm HV	0.18-μm	0.35-μm	0.18-μm	
Stimulator Type	SCS	SCS (High Freq.)	Current Stim.	Current Stim. (High Freq.)	CCS	SCS	Inductor-based SCS (iSCS)	
# Channels	4	1	4	8	16	4	4	
Supply Voltage (V)	± 2.1	5	12 ($4V_{DD}$)	3.5	-3.3 to +3.9 ($9V_{DD}$)	4	3.3	
Cap. Charging Efficiency (%)	82[A]	50	-	- 2	-	84.8[A]	90 (0→3V)	92.7 (1.5→3V)
Charge Transfer Efficiency (%)	98	98	-	-	-	99	99.2	
Stimulator Peak Efficiency (%)	80.4	49	54	68	-	83.9	89.3	92
Stimulus Shape	Decaying Exponential	Pulse Train	Rectangular	Pulse Train	Rectangular	Decaying Exponential	Decaying Exponential	
Series RC Model	0.5kΩ + 1μF	-	1kΩ + 100nF	0.2kΩ + 200nF	1.1kΩ + 33nF//36kΩ	-	1kΩ + 1μF	
Cap. Charging Time (μs)	40 - 420 (1μF)	-	-	-	-	-	15.9 - 50 (1μF)	
Cap. Charging Freq. (MHz)	2	-	-	-	-	13.56	2.2	
Stim. Amplitude	0.45 - 2V (5 bit)	5 V	0 - 3mA	< 10mA (6 bit)	-	2 - 4V (3 bit)	0 - 3V (6 bit)	
Stim. Freq. (Hz)	7.6 - 244Hz[B]	-	-	-	-	2 - 50Hz	75 - 250Hz[B]	
Stim. Pulse Width (μs)	16 - 512μs[B]	-	-	-	-	1.25 - 20ms (4 bit)	250 - 2000μs[B]	
Chip Area (mm^2)	12	0.035 (1 ch)	3.5	3.65	0.22	9.6	1.28	
In Vivo Verification	Yes	No	Yes	No	No	Yes	Yes	

[A] Charging with AC input voltages [B] Adjustable

- The proposed iSCS system achieves the highest stimulation efficiency of ***up to 92%.***
- Offset-control charge balancing minimizes residue charge after stimulation.
- The *in vivo* experiments verified ***that decaying exponential waveform enables longer eye movement*** than conventional rectangular waveform.

Acknowledgement

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