Front-End Triboelectric Nanogenerator & Back-End Power Management IC Design

EnerHarv 2024
PSMA International Workshop | 26-28 June, 2024 | Perugia, Italy

Presenter: Ir. Wenyu Peng;
Supervisor: Prof. Sijun Du
Department of Microelectronics, TU Delft, Netherlands

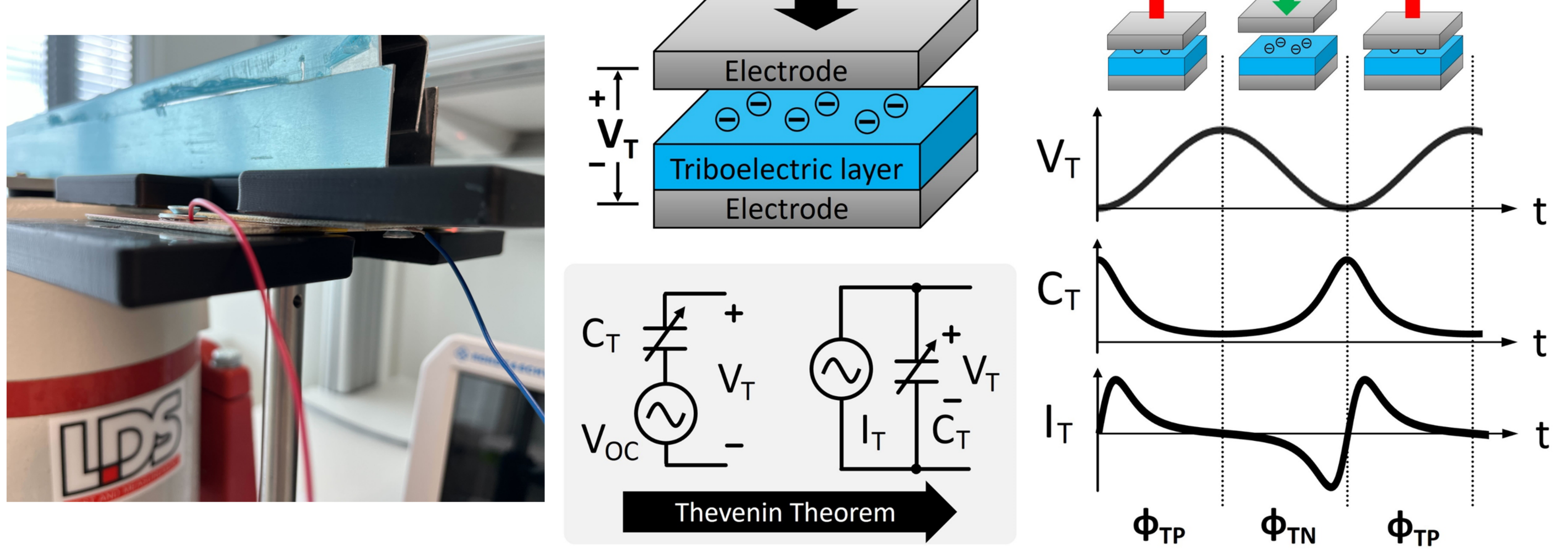
TU Delft

Section 1: TENG mechanism and design

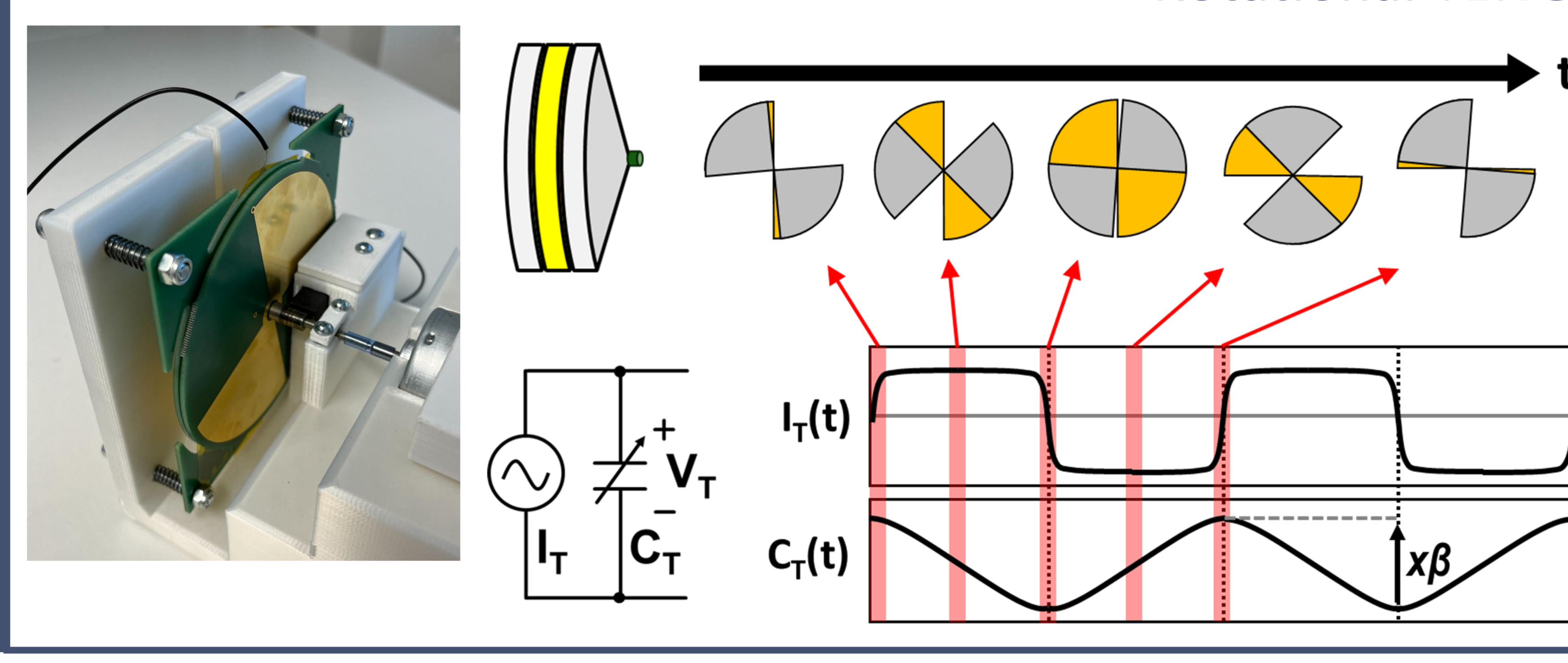
Energy harvesting (EH), which harvests ambient sustainable energy and converts it into usable electrical form, provides a good solution to the power supply of IoT devices and, thus, has drawn much research interest in the past decade. A triboelectric nanogenerator (TENG) is a new mechanoelectrical transducer, advantageous in harvesting mechanical energy from irregular movement, e.g., human motions and tides. Thanks to its flexibility and high energy density, it is promising in supplying power for wearable devices and environment sensors with sustainability.

In-house fabricated TENG prototype

Contact-separation TENG



Rotational TENG

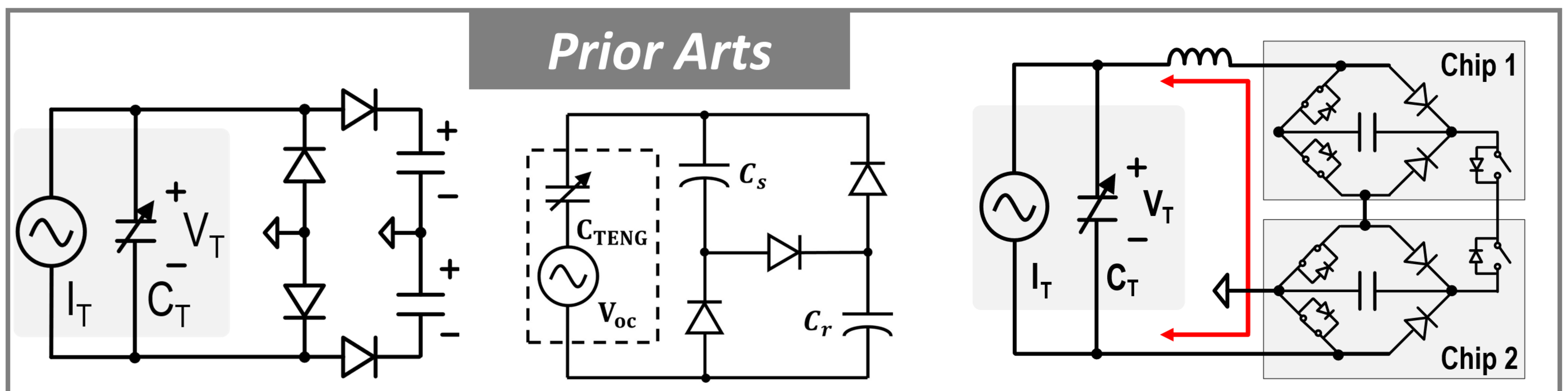


✓ Flexible ✓ 2D transducer ✓ High energy density ✓ Wide application scenarios

○ High internal impedance – hard to extract electric energy from TENG

Section 2: Triboelectric energy harvesting circuits

Prior Arts



- **Dual-output FBR [1]**
- Easy to implement
- Low efficiency

- **Bennet's doubler [2]**
- Extra energy extracted @ HV
- Low efficiency @ LV

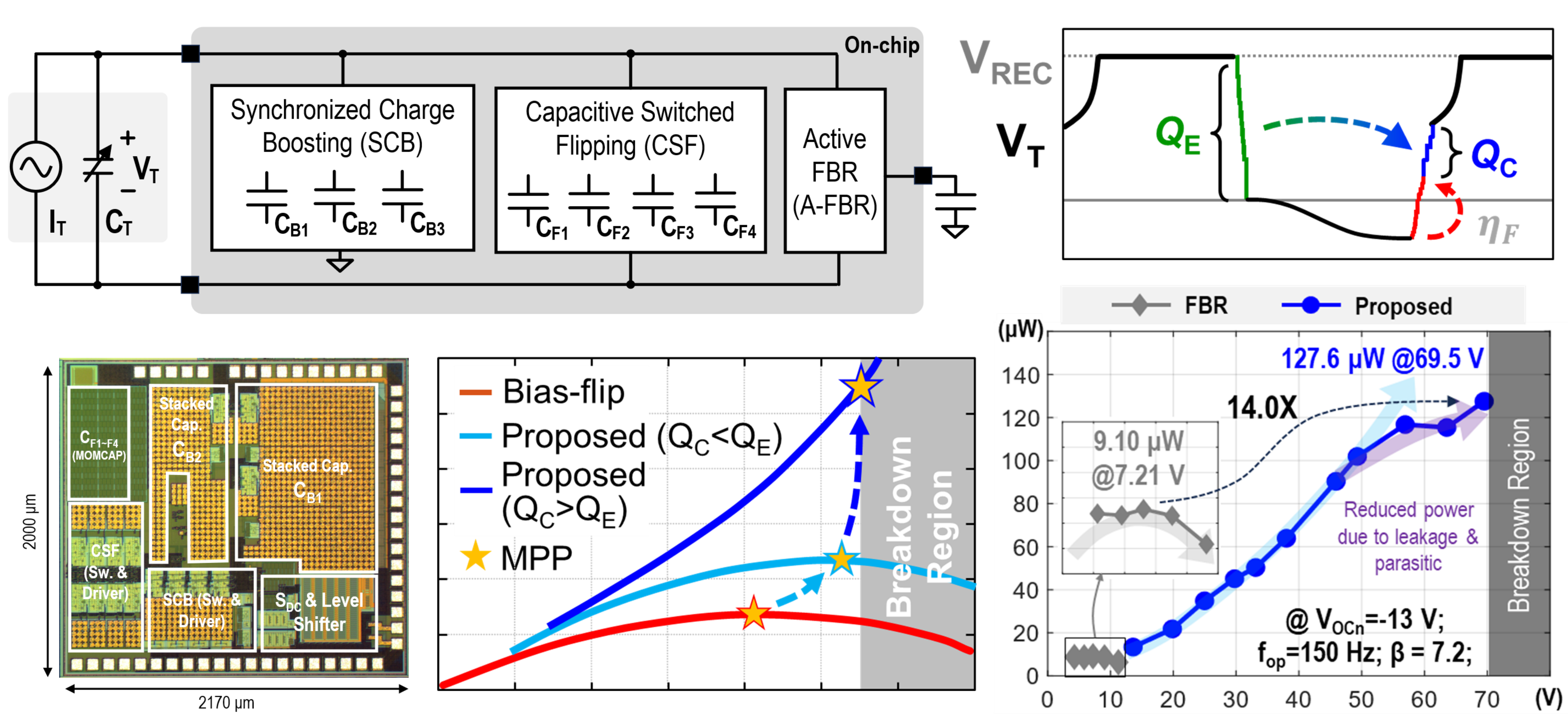
- **Multi-chip-stacked bias-flip [3]**
- High efficiency
- Bulky inductor needed
- Electrostatic energy degradation

Comparison of the state-of-the-arts

	[1]	[2]	[6]	[3]	[4]	[5]
Year	2021	2020	2021	2022	**2024**	**2024**
Publication	JSSC	MEMS	TCAS-I	ISSCC	**ISSCC**	**CICC**
Process	180-nm BCD	Discrete	180-nm BCD	180-nm BCD	**180-nm BCD**	**180-nm BCD**
Rectifier size	Small	Large	Medium	Medium	**Small**	**Small**
MPPT	FOCV	N/A	N/A	N/A	**Auto-MPPT**	**DCB-MPPT**
P_{OUT} (μW)	3.9~10.5	15	722	1200	**127.6**	**85.4**
V_{REC} (V)	0~70 (MPP)	300/425	70	65*N	**70**	**0~70 (MPP)**
FoM*	N/A	145	1.62	3.14	**14.0**	**5.98**

*Figure of merit (FoM) is equal to the power output enhancement of this work compared to the full-bridge rectifier.

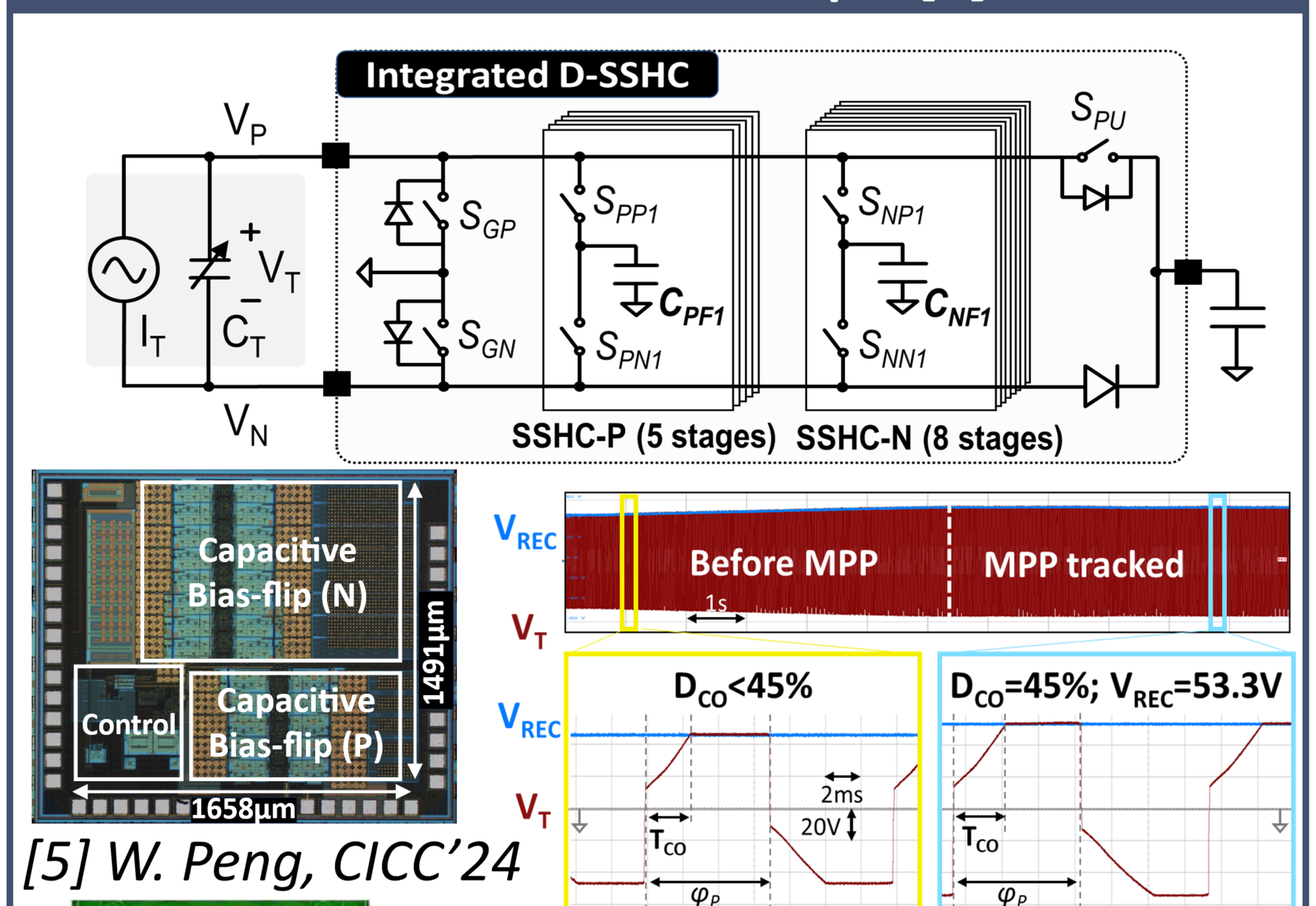
Electrostatic charge boosting (ECB) [4]: an active technique implemented with capacitors to extract extra electrostatic energy



[4] W. Peng, ISSCC'24 P_{EXT} vs. V_{REC} (theoretical) P_{EXT} vs. V_{REC} (measured)

✓ Small form factor
✓ 14X enhancement in extraction performance;
✓ Automatic MPPT @ breakdown voltage.

Dual-SSHC rectifier with full-digital duty-cycle-based MPPT technique [5]



[5] W. Peng, CICC'24

✓ Robust and precise MPPT
✓ Generalizable for different types of TENG
✓ 5.98X enhancement in extraction performance

[1] J. Maeng, JSSC, 2021;
[2] H. Zhang, MEMS, 2020;
[3] J. Lee, ISSCC, 2022;
[6] I. Kara, TCAS-I, 2021.