



# Power conditioning electronics and energy storage for MEMS/NEMS energy harvesters: Technical challenges

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Acknowledging:

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# Content

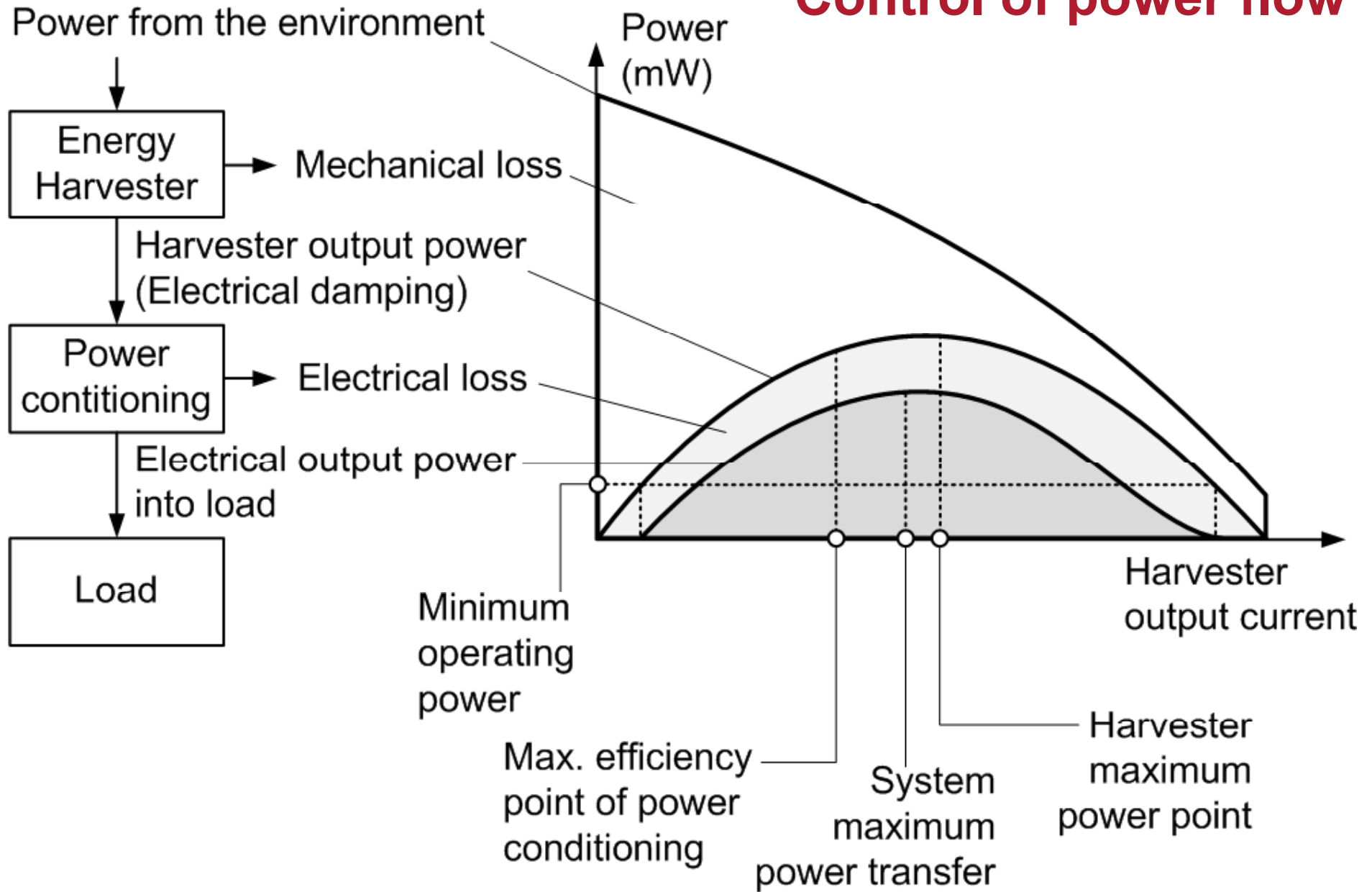
Conceptual challenges at low input power:

- Control of power flow
- Synthesis of specific input impedances
- Handling power variability
- Use of commercially available circuits

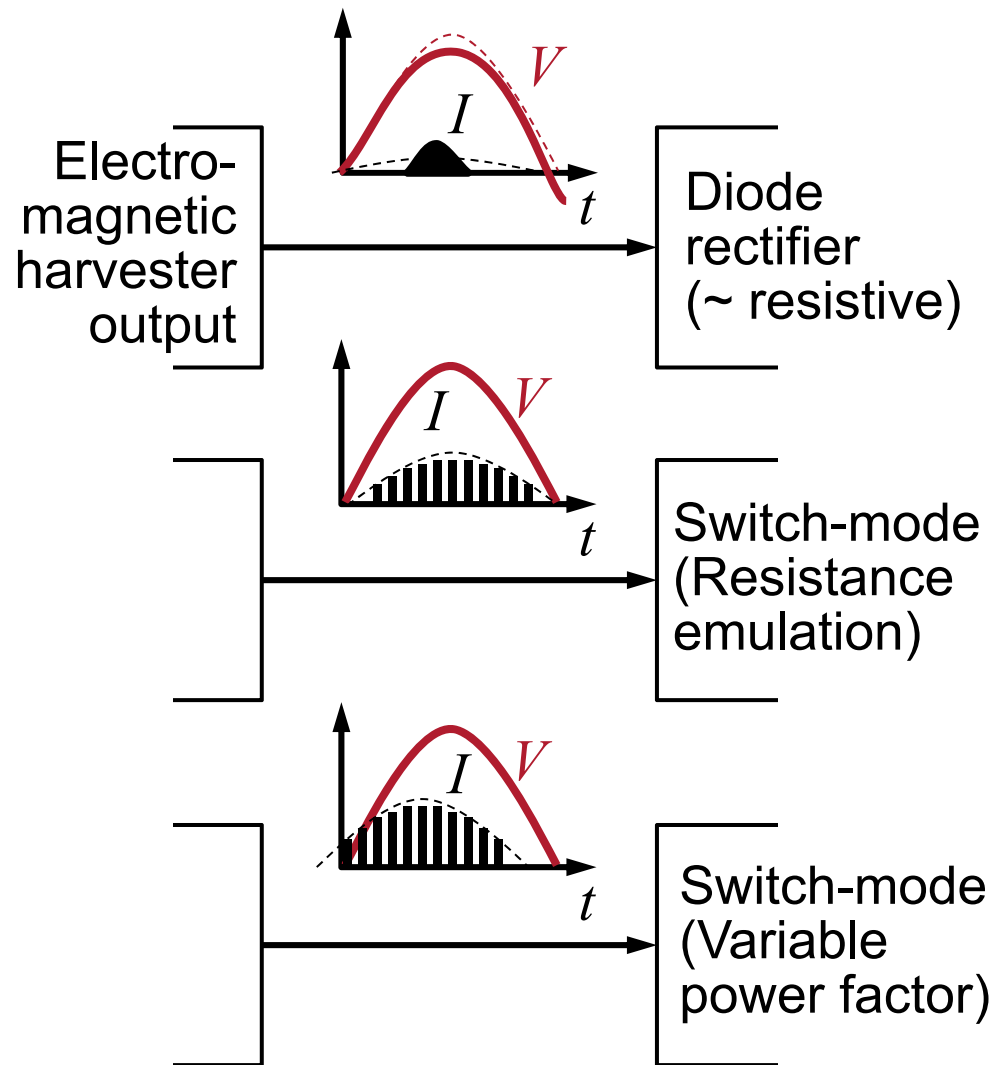
Some specifics:

- Break-even point between active and passive
- Power stage (technology and power losses)
- Gate driving, control etc (technology & power losses)
- Start-up (technology)

# Control of power flow

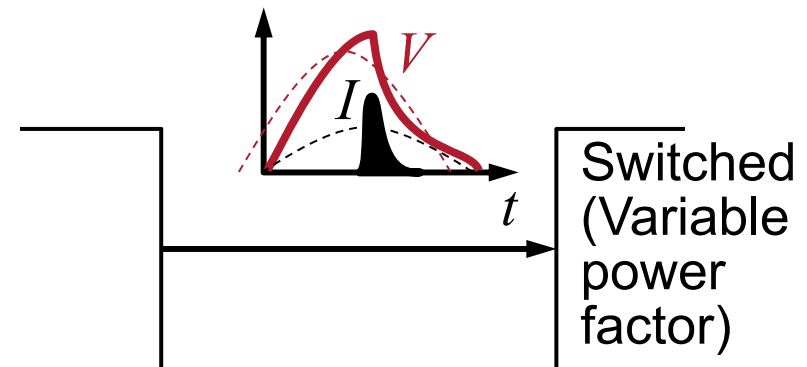


# Synthesis of input impedances

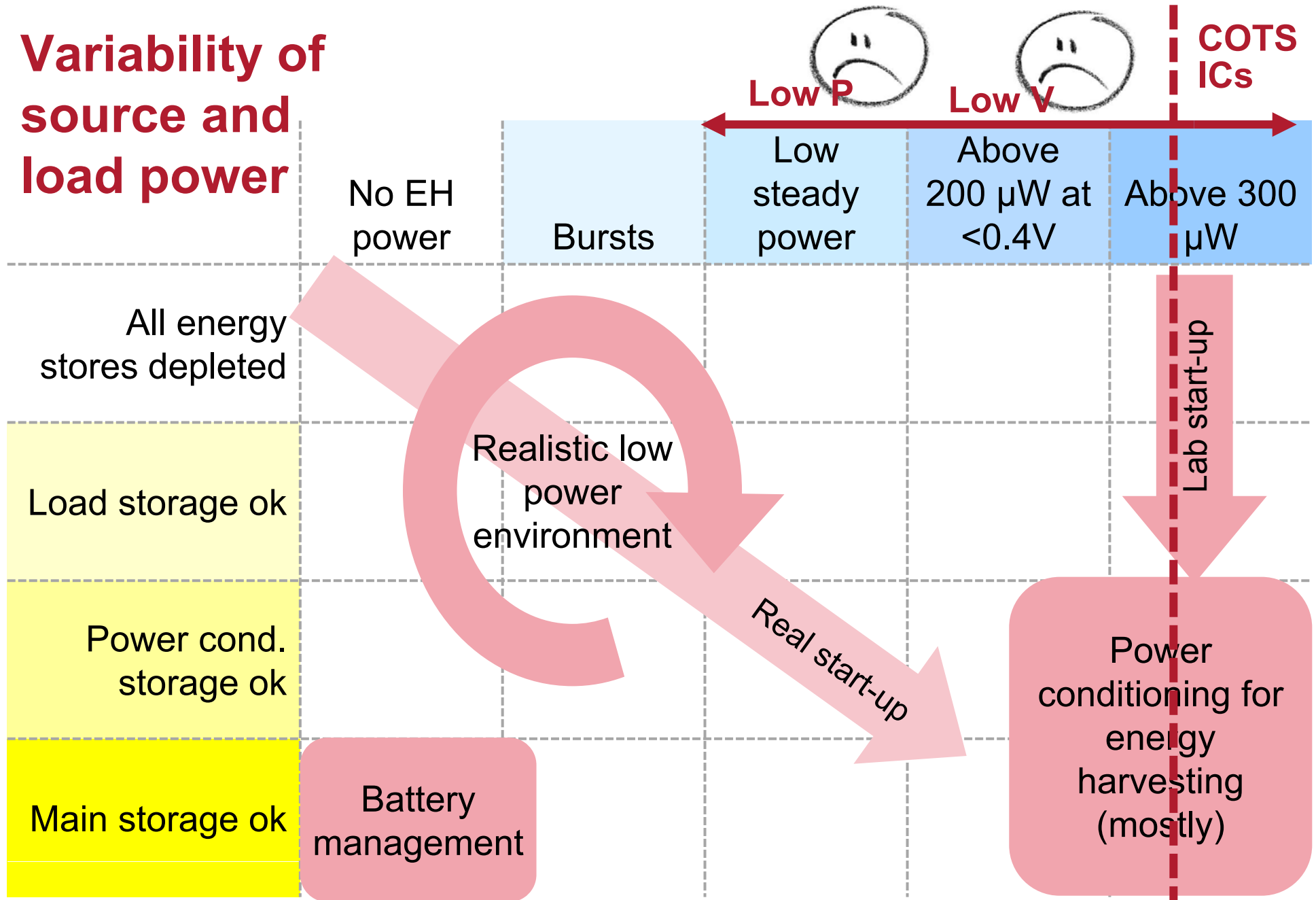


Piezo-electric is similar.

Special low-power case:



# Variability of source and load power



# Power and start-up voltage ranges

Reported in:

Degrenne et al., "Self-starting DC:DC boost converter for low-power and low-voltage microbial electric generators." *Energy Conversion Congress and Exposition (ECCE) 2011*

TESTING DC:DC CONVERTERS COMPARISON

Circuit	Description				
	Start-up voltage	Power range	Vout	MPPT	Peak efficiency
Linear technologies LTC310 (1:20) [16]	100mV	100µW to 100mW	2.35V to 5V	no	0.6
EnOcean ECT310 [18]	20mV	100µW to 100mW	3V to 5V	no	0.3
Seiko S-882Z [19]	300mV	? to 150µW	1.8V to 2.4V	no	0.2
Markus [14]	70mV	200µ to 16mW	2V to 5V	no	0.7
Qiu [20]	500mV	5µW to 10mW	0V to 5V	yes	0.7
Ramadass [11]	35mV	10µW to ?	1.8V	yes	0.58

Seiko and LT struggle at 'start-up voltage' and 100 µW

Uses a 'kinetic' switch!

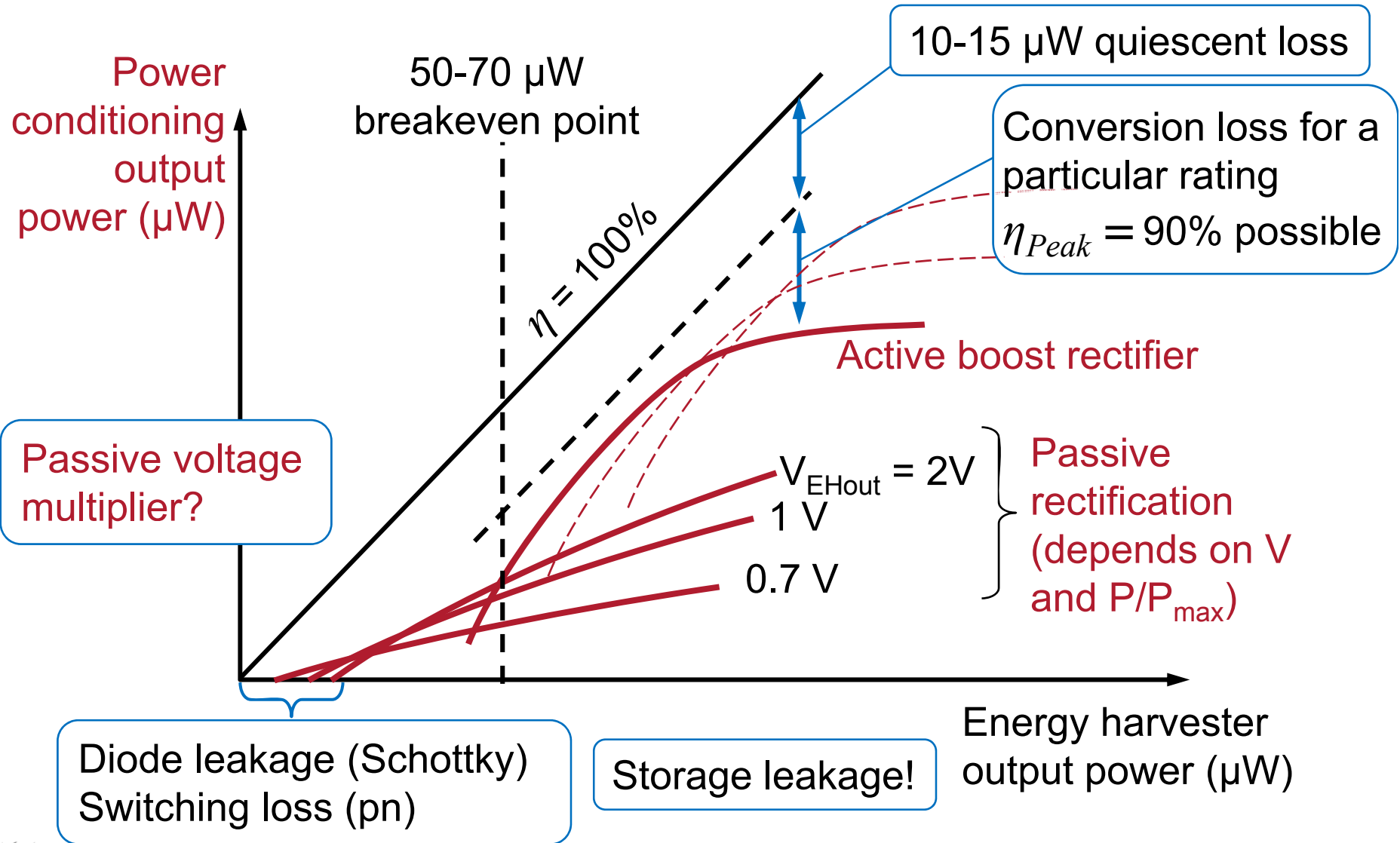
Requires many tens of mA to start up

Other good devices: LTC3588 (Piezo) & 3388 (Buck)

[11] Ramadass & Chandrakasan, "A batteryless thermoelectric energy-harvesting interface circuit with 35mV startup voltage," *IEEE Journal of Solid-State Circuits*, 2010.

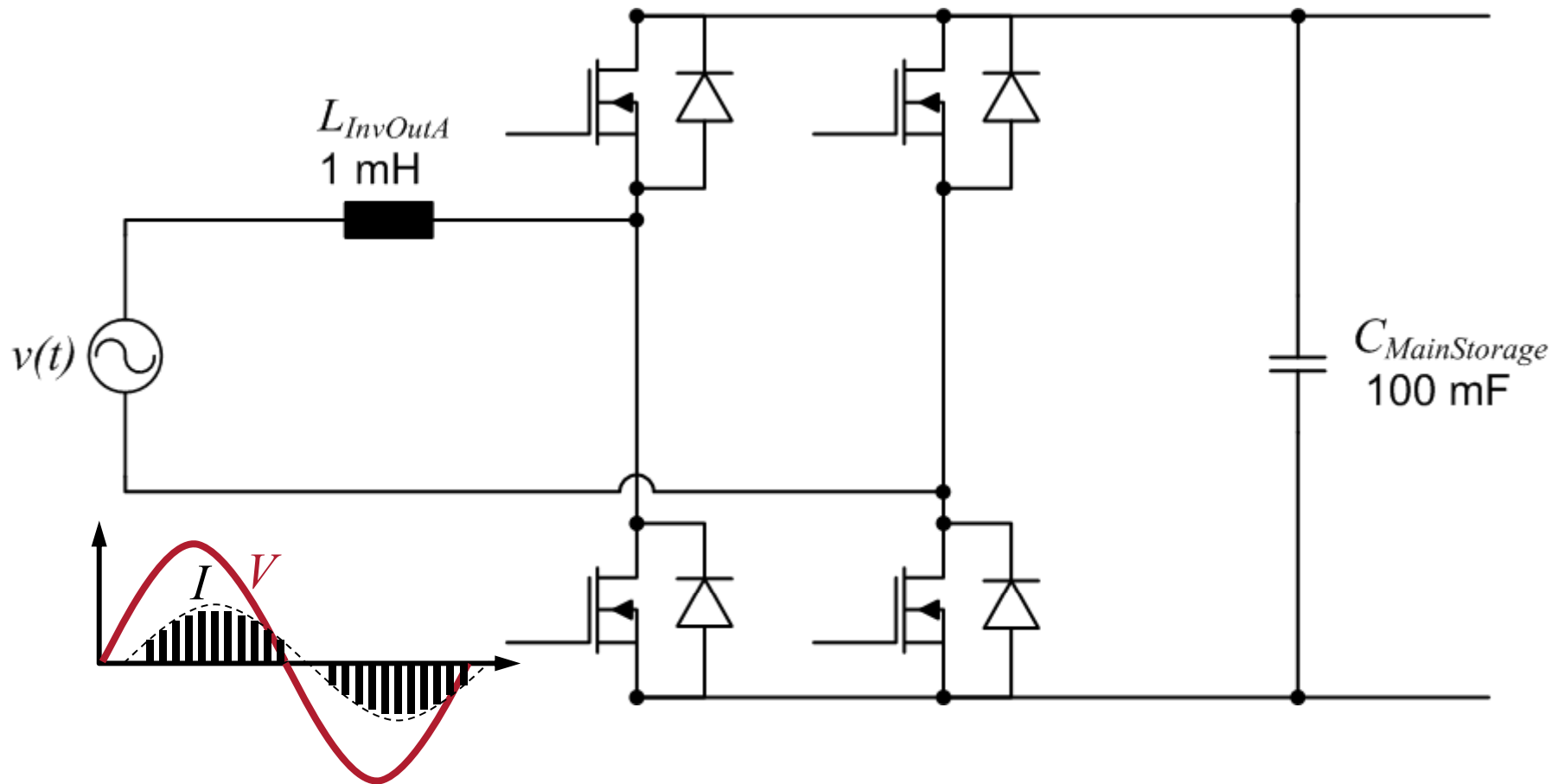
[20] Qiu et al., "5µW-to-10mW input power range inductive boost converter for indoor photovoltaic energy harvesting with integrated maximum power point tracking algorithm", *IEEE International Solid-State Circuits Conference*, 2011.

# Break-even point between passive and active (discrete example)



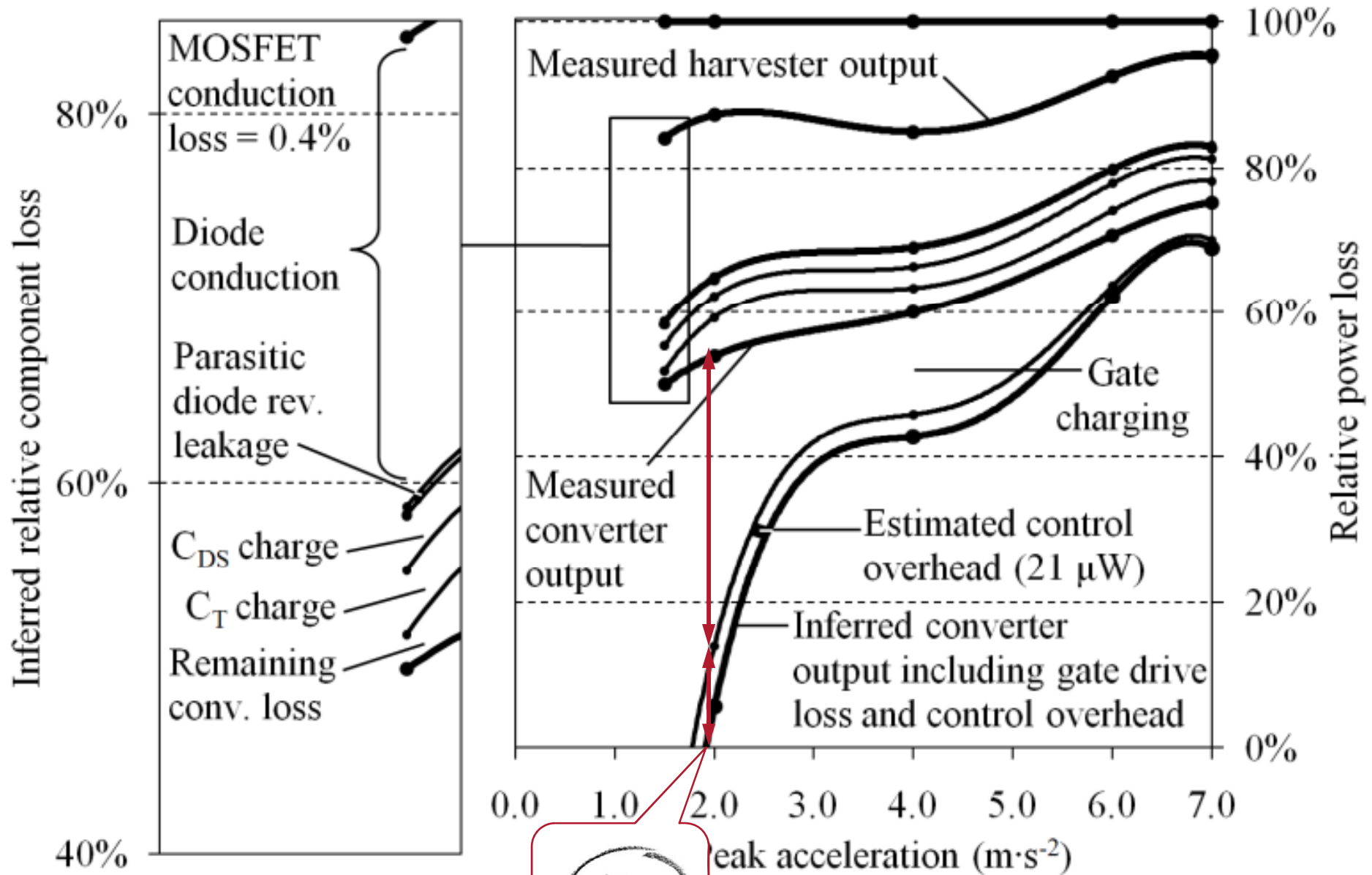
# Example topology: Synchronous boost rectifier

- Passive diodes → Schottky diodes → “Active diodes”
- Boost converter DC/DC → Synchronous → AC/DC

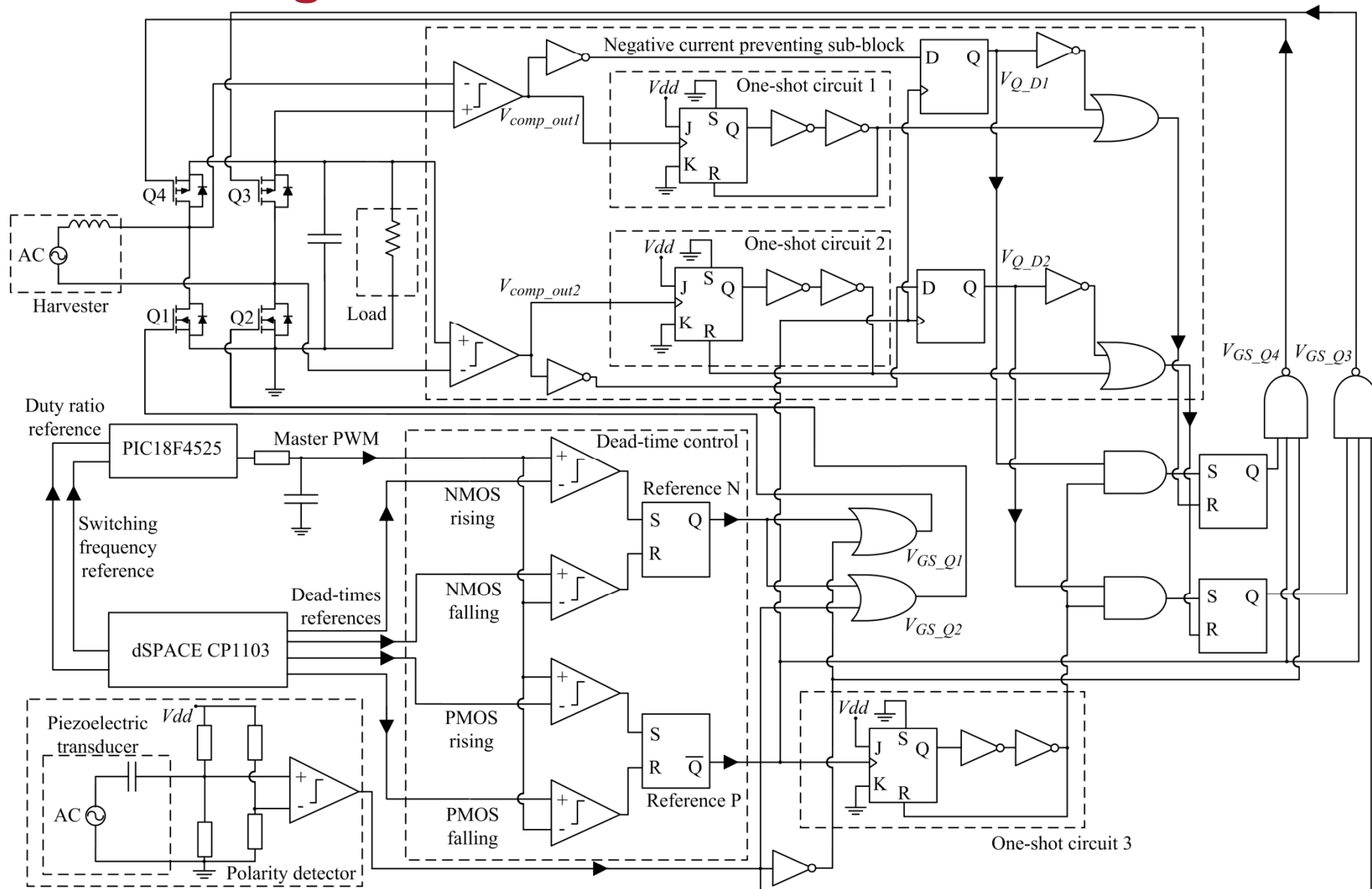




# Typical losses in power stage



# Gate driving etc.



# Gate driving etc.

## Power circuit

- 5 V blocking and fast (10ns)
- Low leakage
- Fast reverse diodes
- High- and low-side devices

## Prevent negative current

- Sensing, filtering, noise immunity
- Fast analogue circuits (<10ns delay, not currently available in low power)

## PWM and control

- I/V measurement
- Precision resistors
- Low voltage
- Use COTS

## Dead times

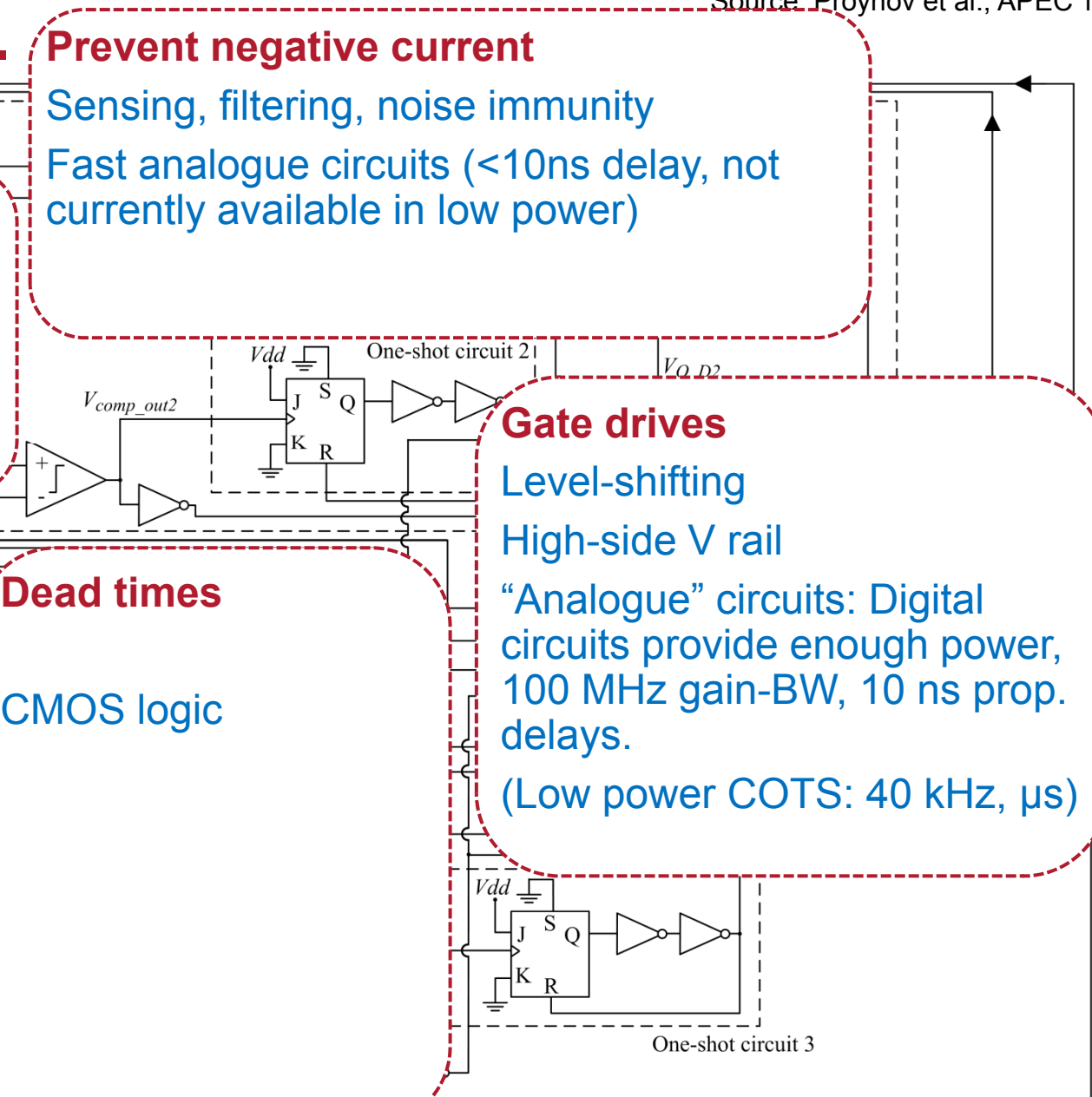
CMOS logic

## Gate drives

- Level-shifting
- High-side V rail
- “Analogue” circuits: Digital circuits provide enough power, 100 MHz gain-BW, 10 ns prop. delays.
- (Low power COTS: 40 kHz,  $\mu$ s)

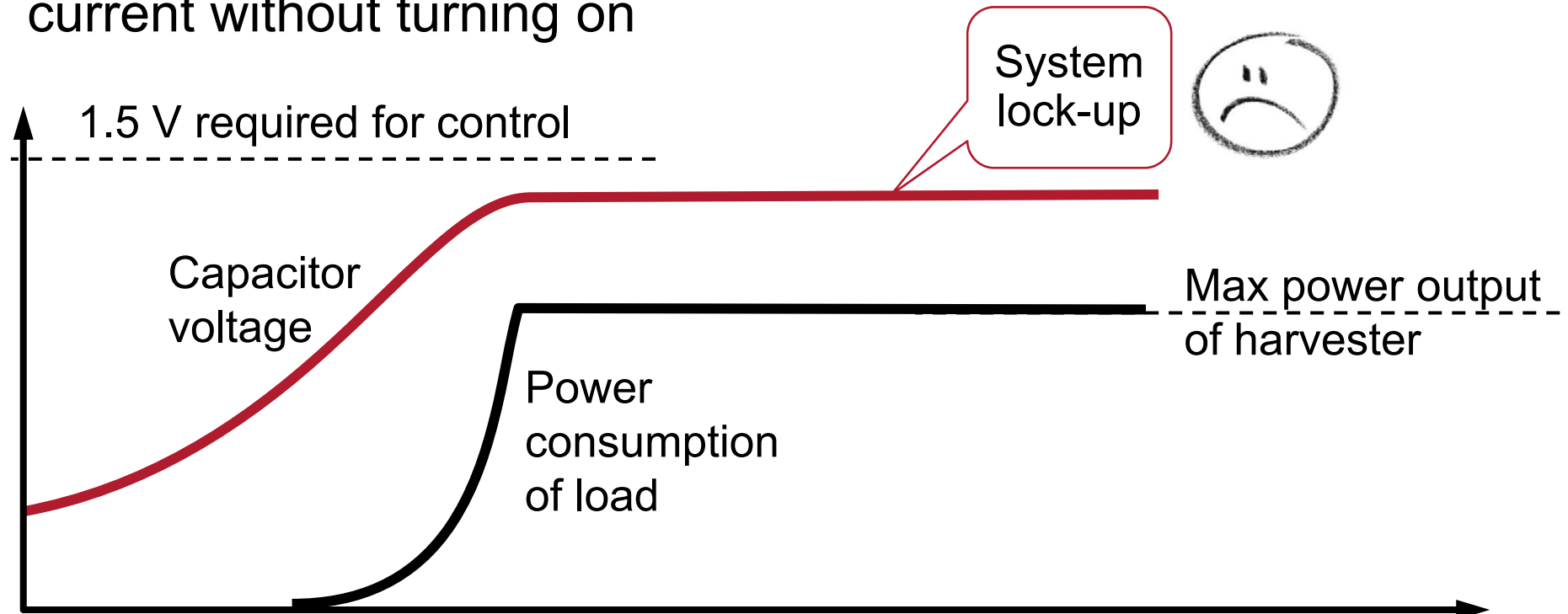
## Input polarity detection

- Low noise
- Low input V (or high)
- Dual polarity



# New circuits required with minimal start-up leakage

- Supply capacitor voltage rises gradually
- Control circuits enter faulty states where they draw a lot of current without turning on



- Power-on-reset circuits work for power rail slew-rates of  $V/ms$  but not for  $V/s$  or slower.
- Use 'isolator' circuits, e.g. Torex voltage detectors ( $>1 \mu A$ )