A Power Electronic Unit to Drive Piezoelectric Actuators for Flying Microrobots

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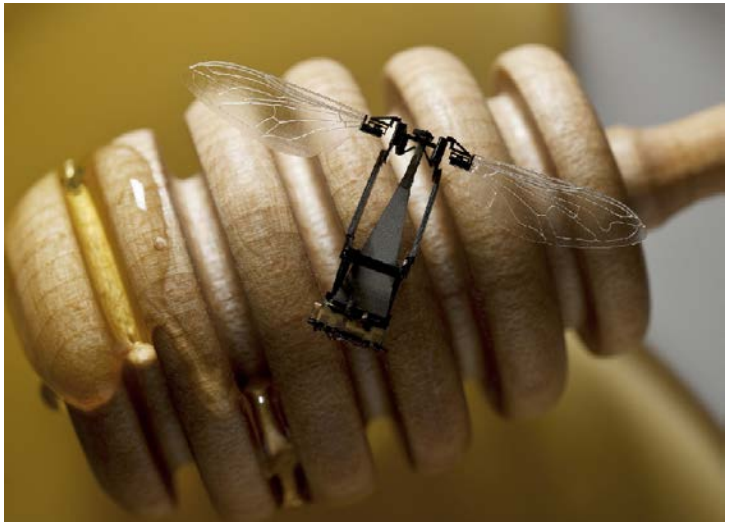
The RoboBee Vision

- **A milligram scale flapping wing robot consists of**
  - Sensor
  - Actuator
  - Power electronics
  - Computation unit
  - Battery

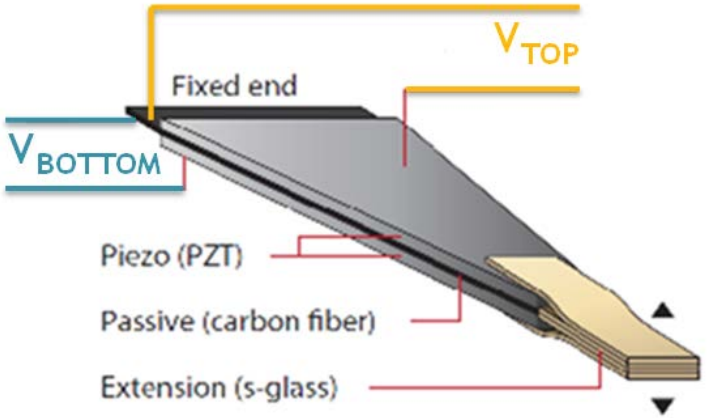


- **Potential Applications**
  - Search and rescue
  - Sensor network deployment

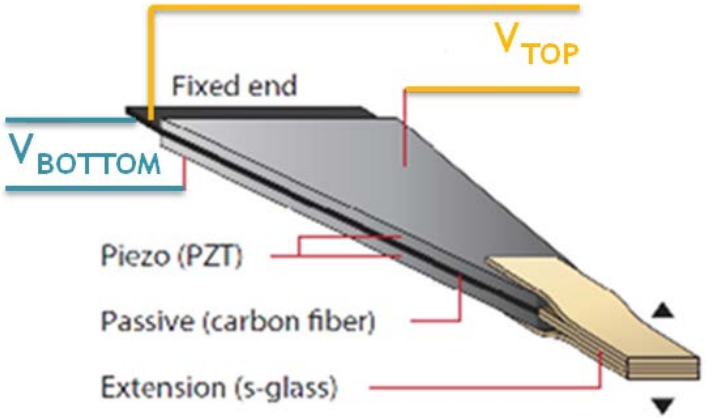
Outline of Presentation

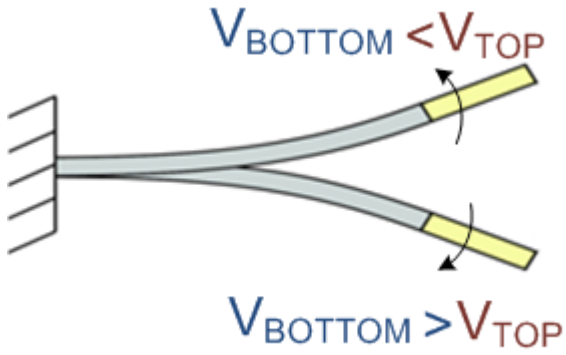
- System Overview
- Power Electronics Unit
- Power Saving Techniques
- Testing Results

Piezoelectric actuators drive requirement

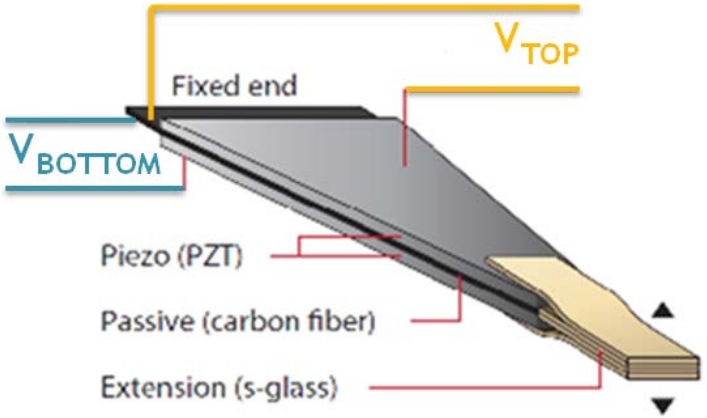


Piezoelectric actuators drive requirement





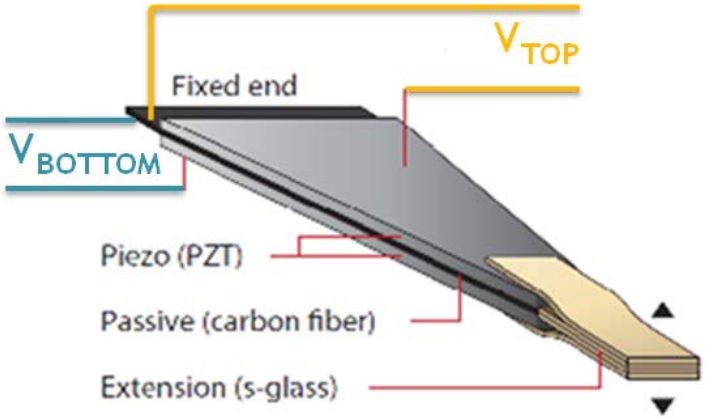
Piezoelectric actuators drive requirement



- Drive Signal (100Hz, 200-300V)
- Capacitive load

→ Low mechanical dissipation, electrical power dominates

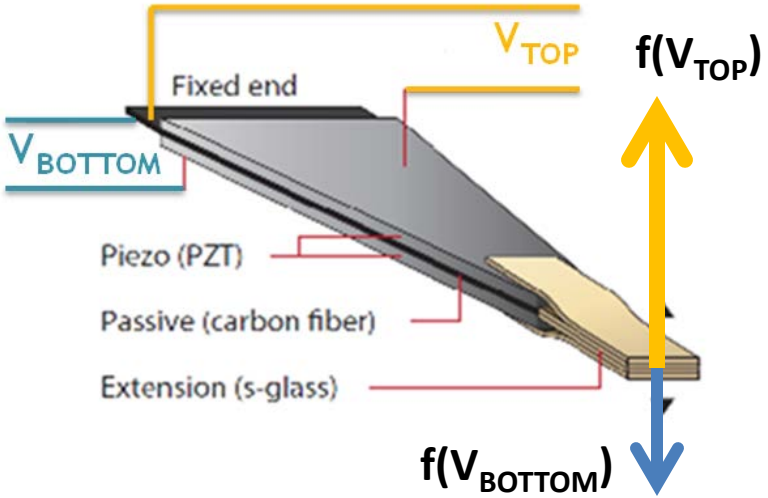
Piezoelectric actuators drive requirement



- Drive Signal (100Hz, 200-300V)
- Capacitive load
- Weight Constraint (<100mg)

Use Integrated circuits and minimum number of passives

Piezoelectric actuators drive requirement



- Drive Signal (100Hz, 200-300V)
- Capacitive load
- Weight Constraint (<100mg)
- Differential drive: V_{TOP},V_{BOTTOM} needs to be 180 degree out of phase

- Driver topology support
- Actuator motion depends on($V_{TOP} - V_{BOTTOM}$)

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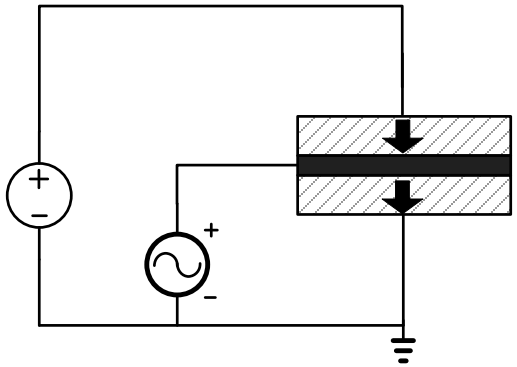
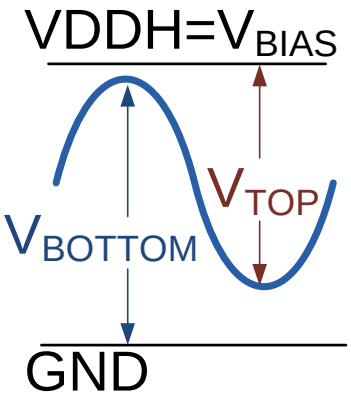
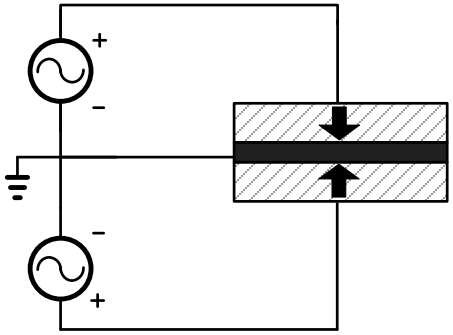
Actuator drive topology options

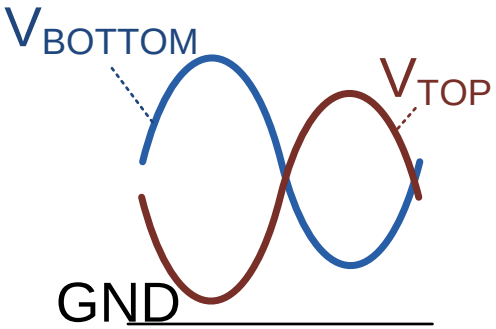
Simultaneous Drive





Alternating Drive





Actuator drive topology options

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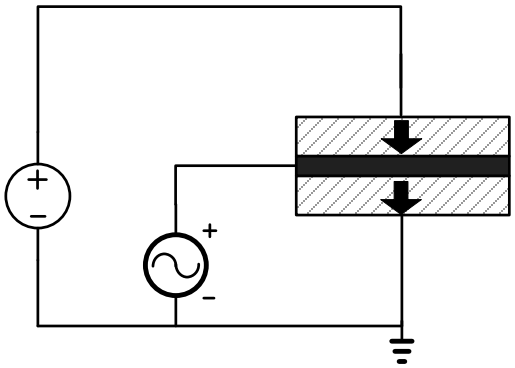
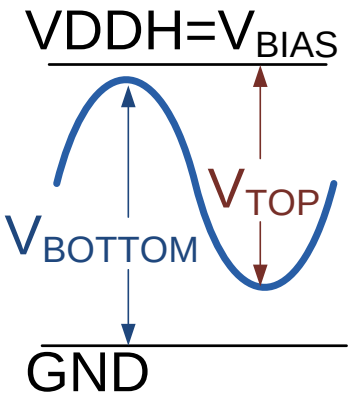
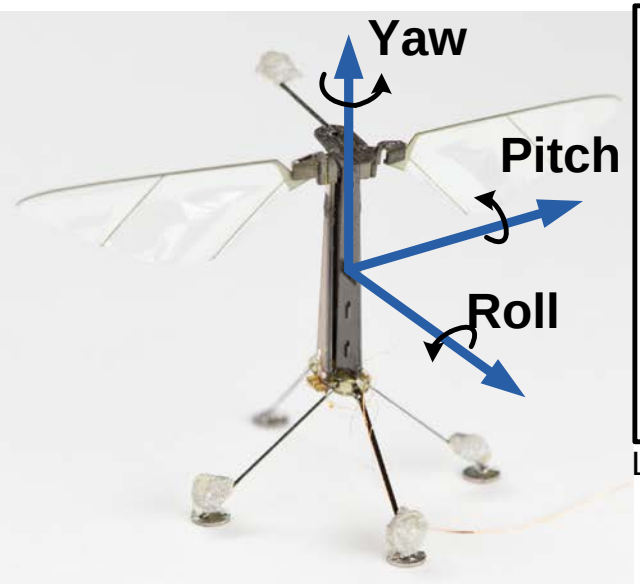
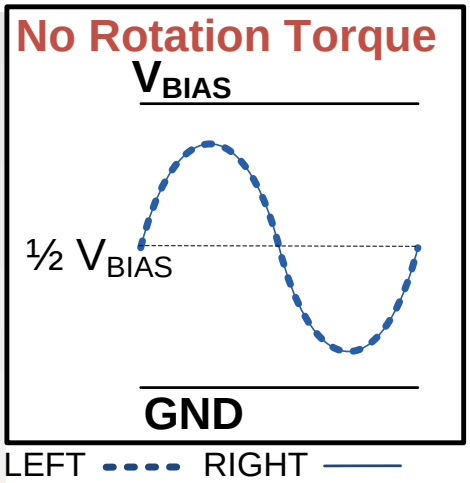


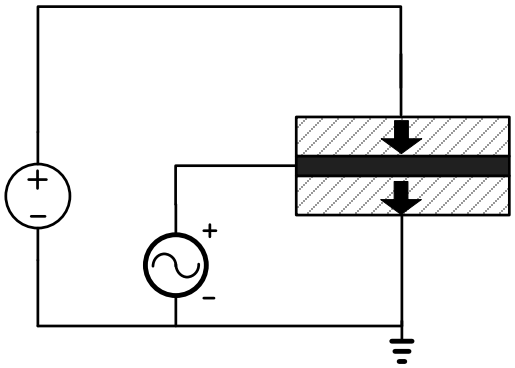


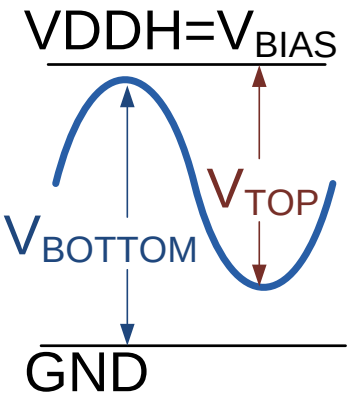


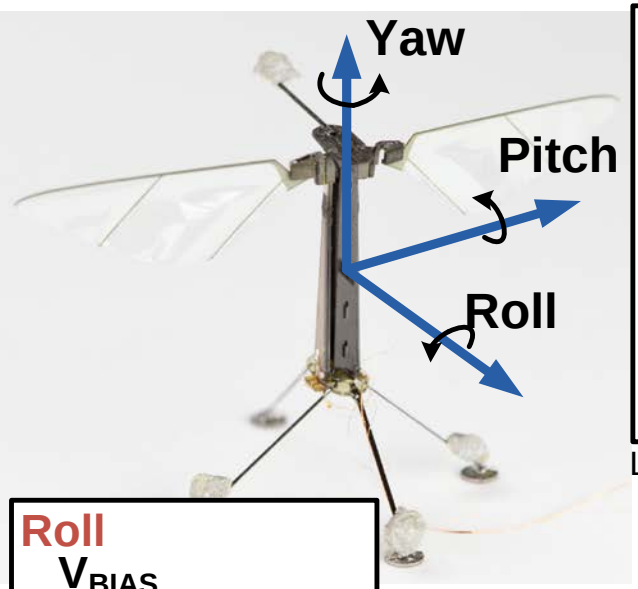


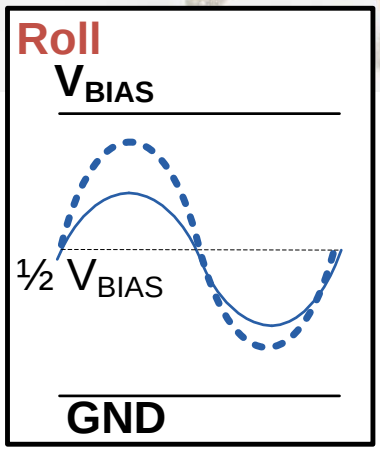
Drive Signals that Correspond to Rotation

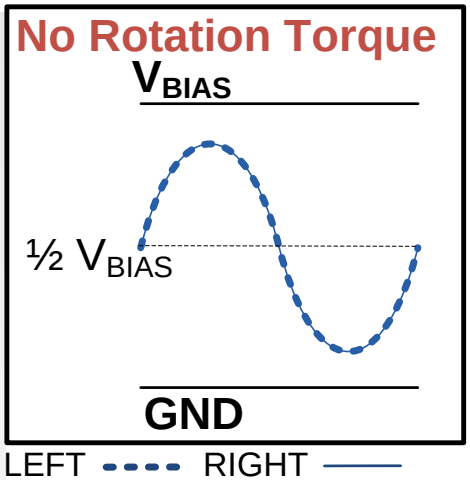
Simultaneous Drive











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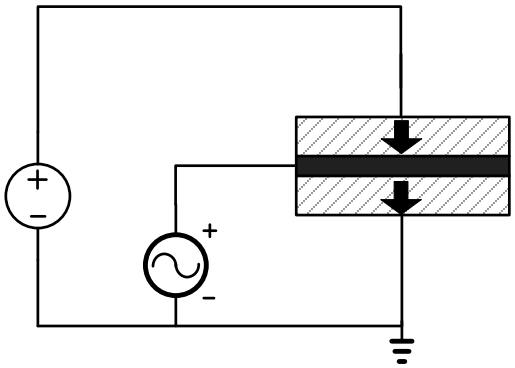
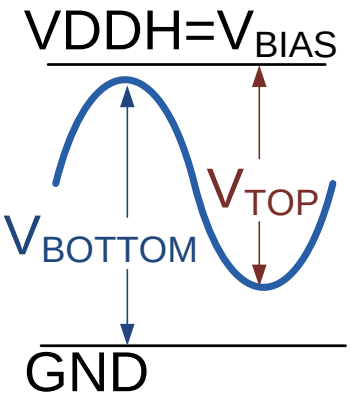
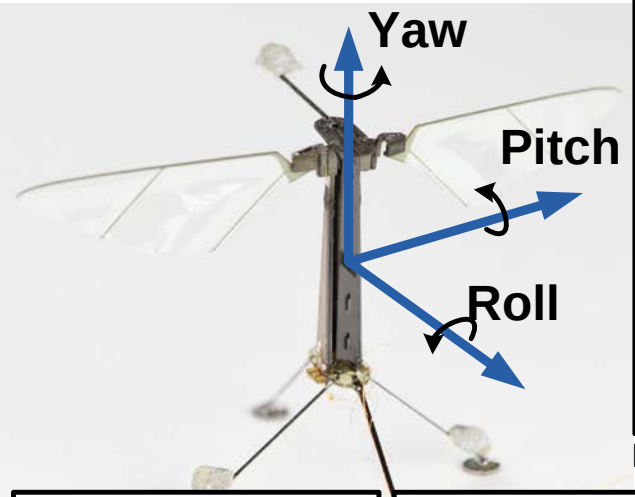
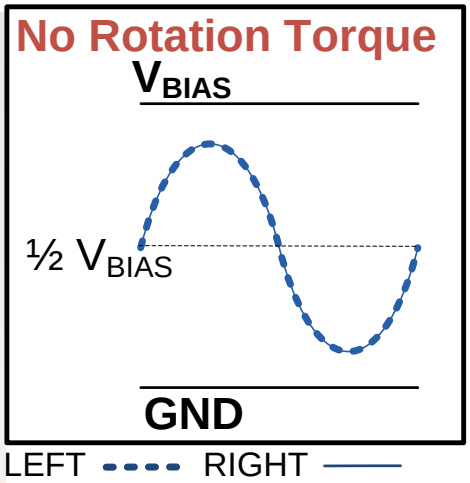
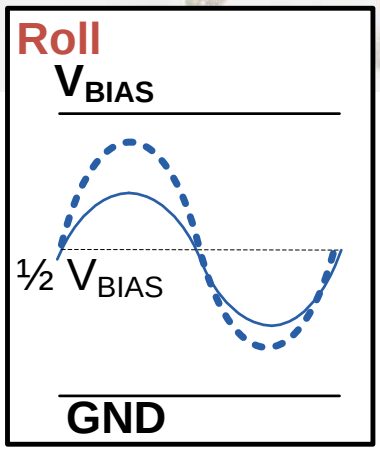
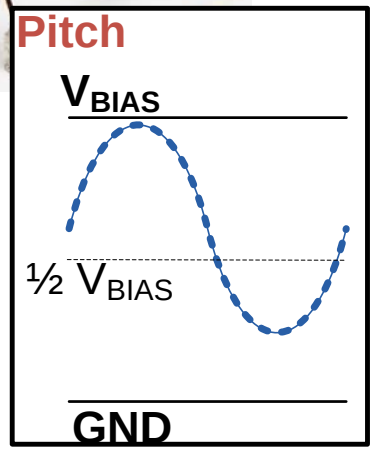






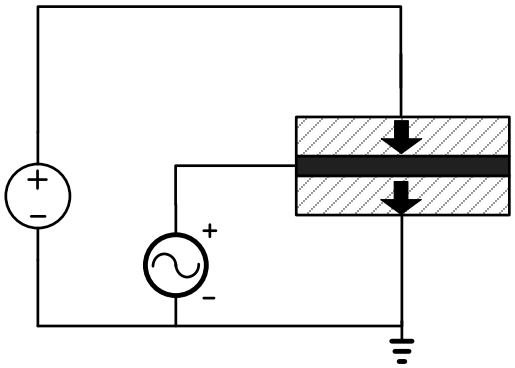


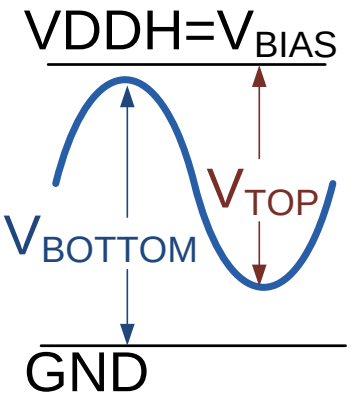


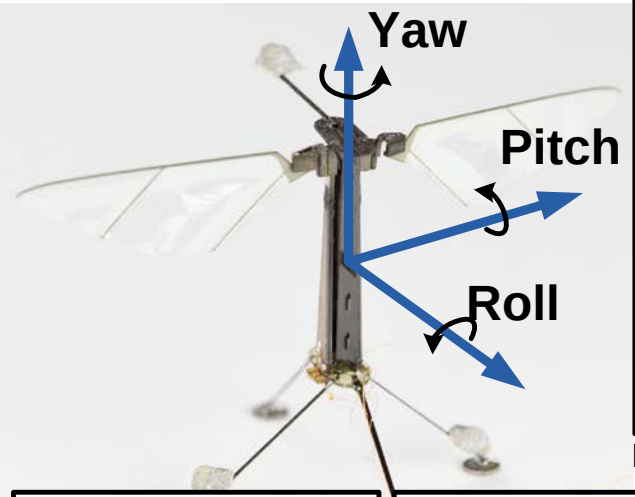


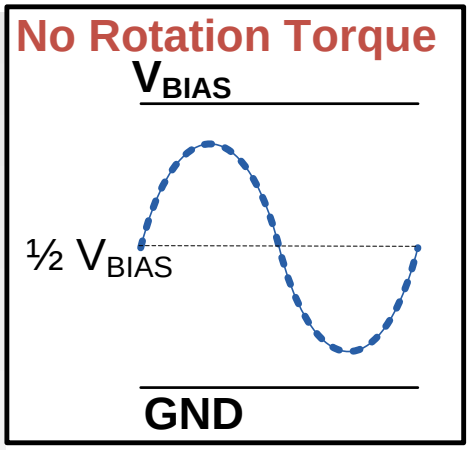
Drive Signals that Correspond to Rotation

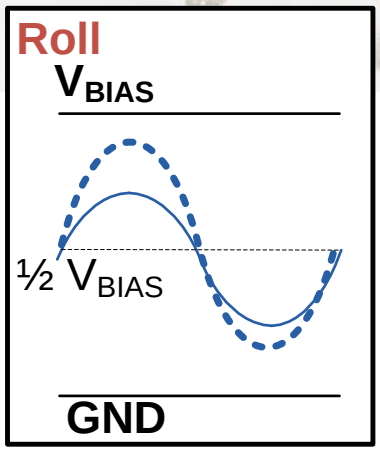
Simultaneous Drive

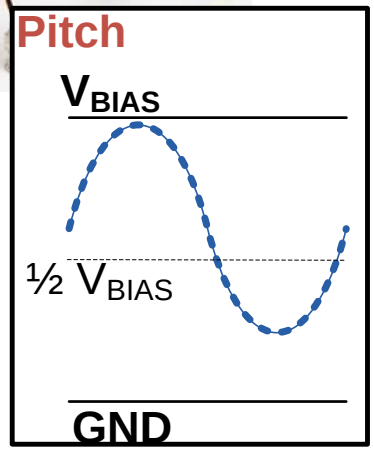


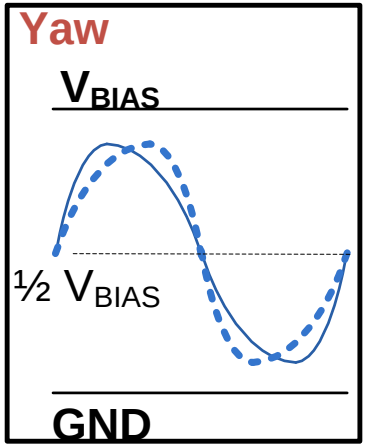






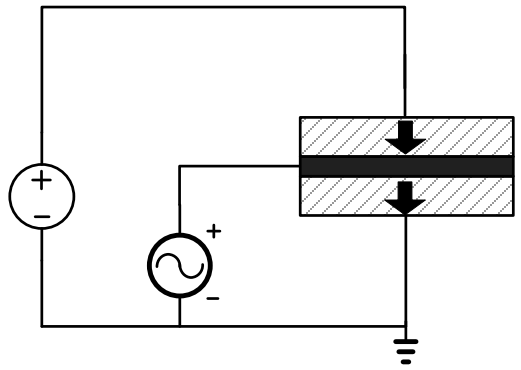


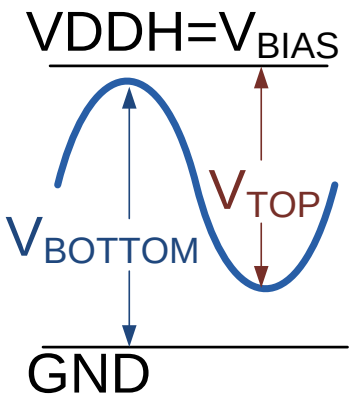


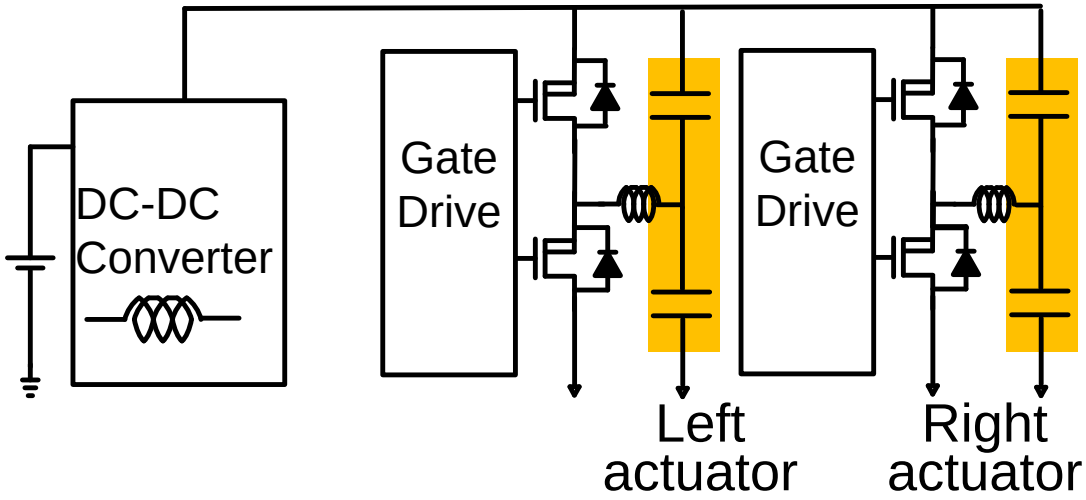


Actuator drive topology options

Simultaneous Drive



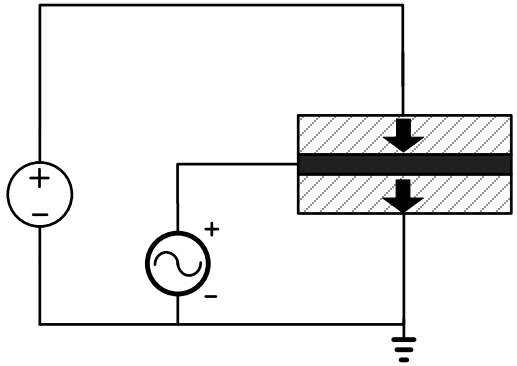


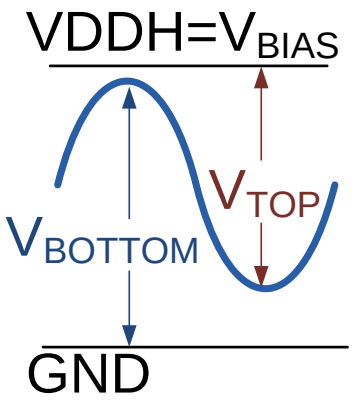


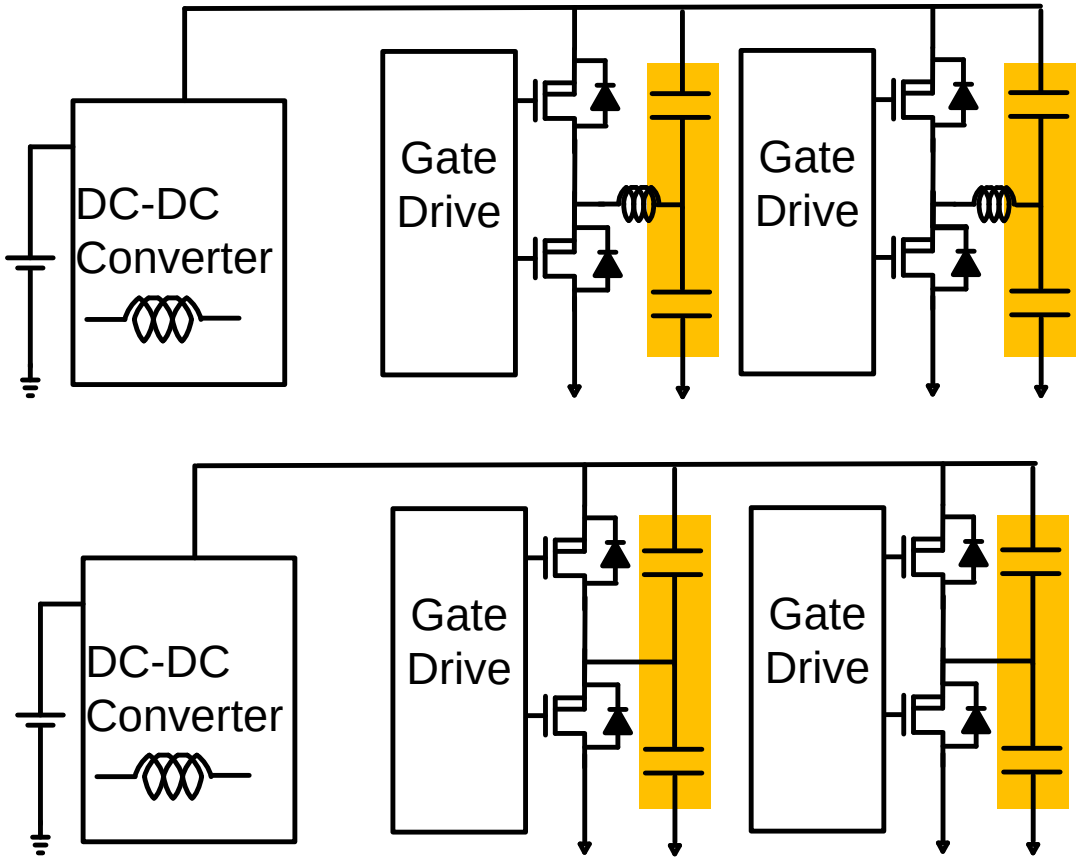
→ Too heavy (three inductors)

Actuator drive topology options

Simultaneous Drive



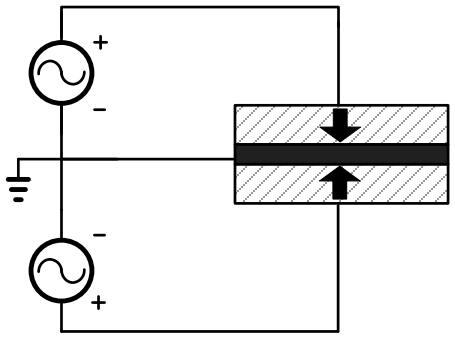


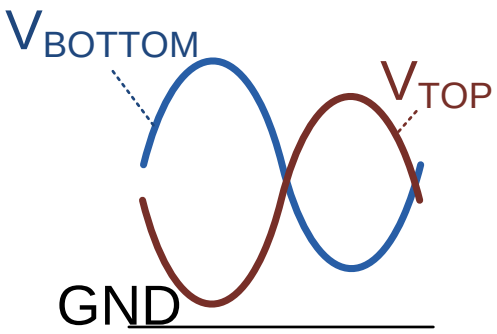


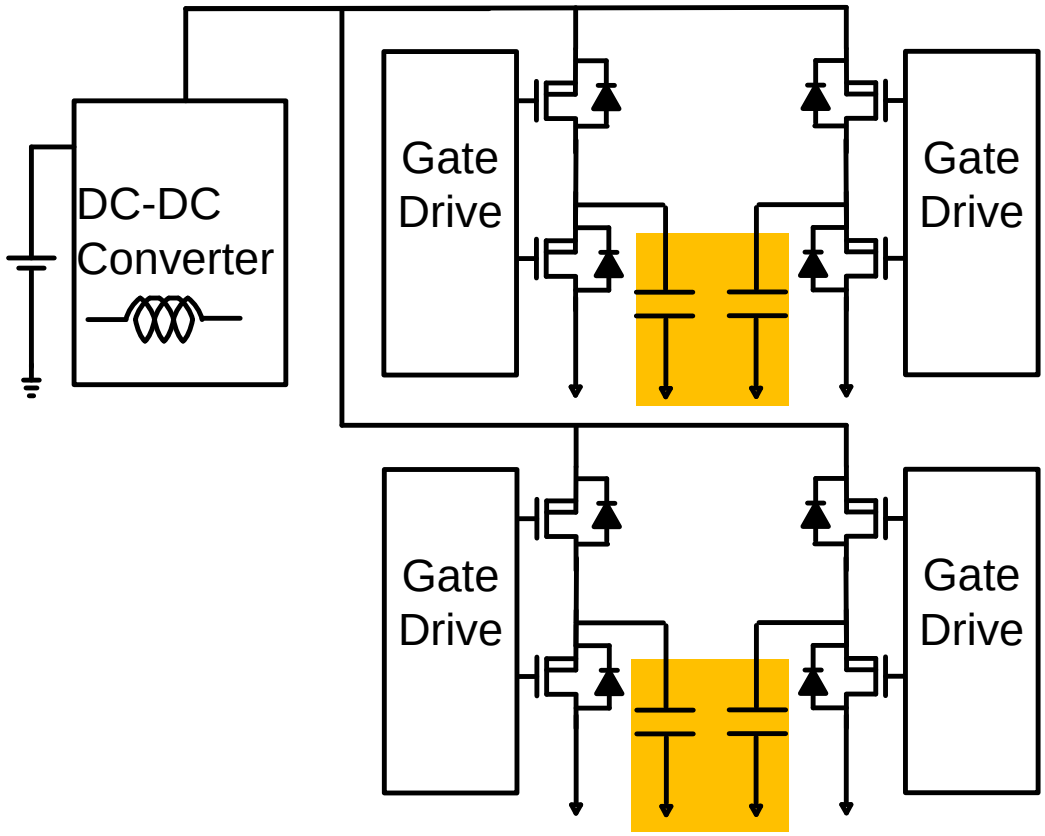
→ Power Inefficient

Using the Alternating Drive Topology

Alternating Drive

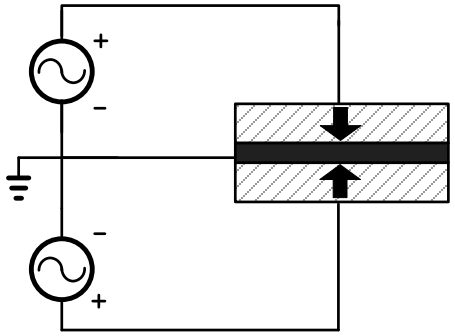


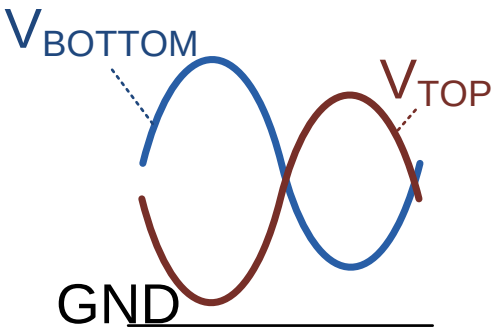


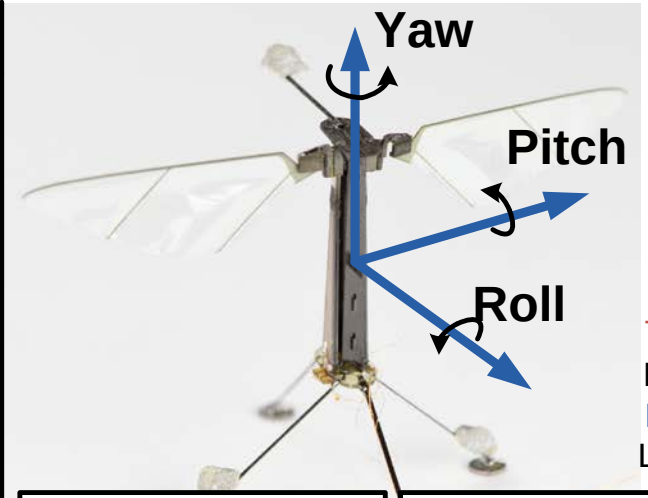


Using the Alternating Drive Topology

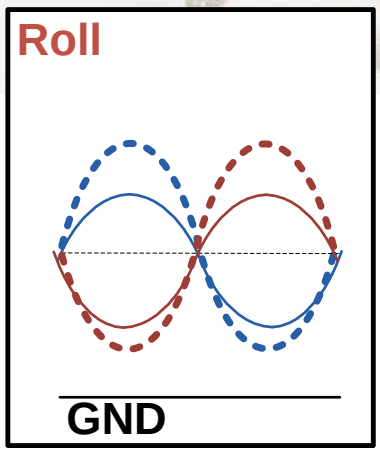
Alternating Drive

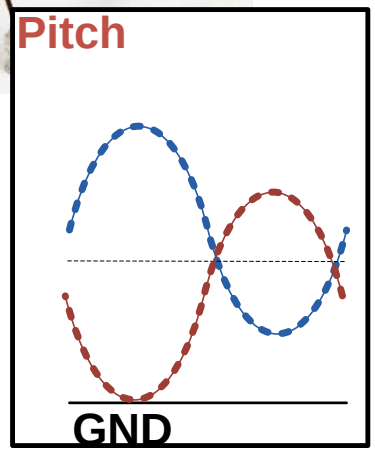


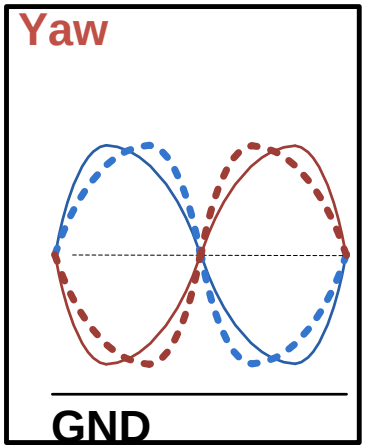




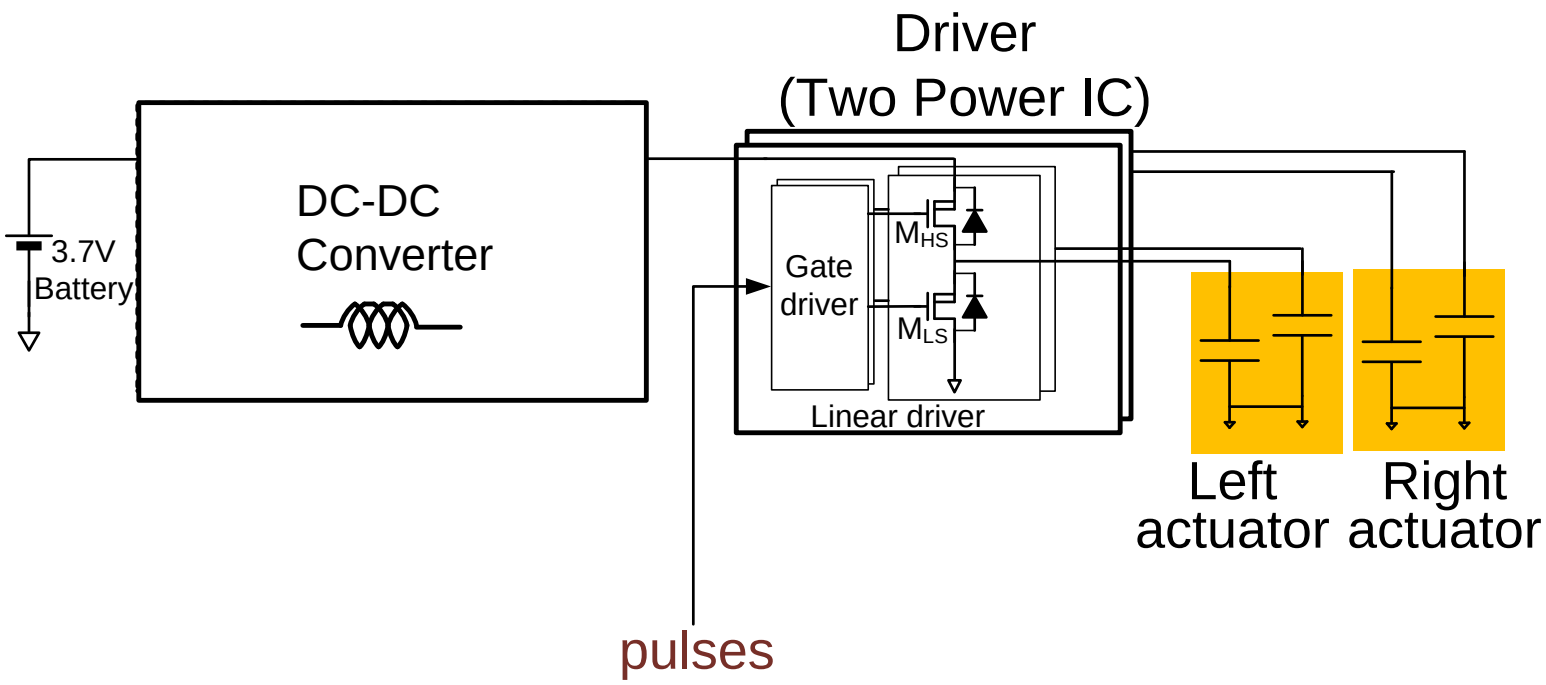
TOP
LEFT ---- RIGHT ——
BOTTOM
LEFT ---- RIGHT ——



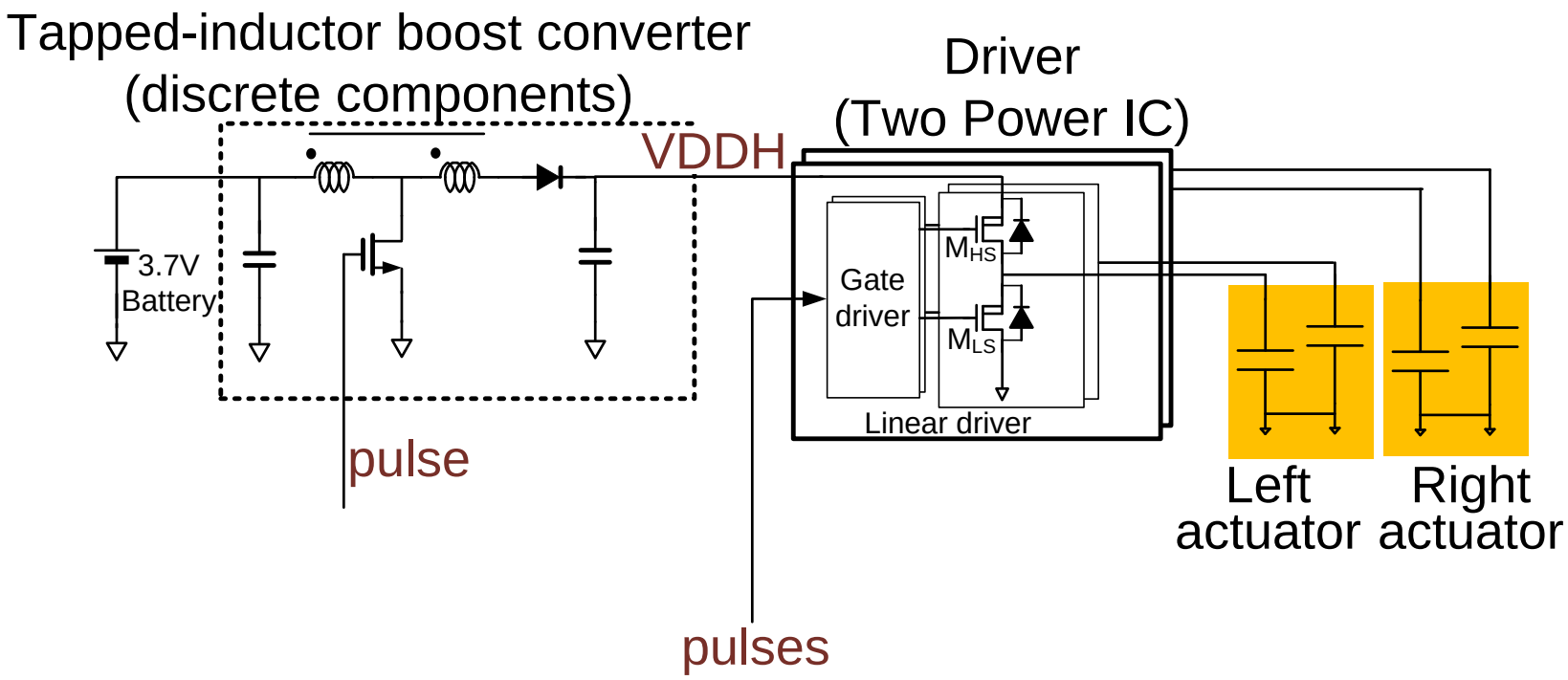




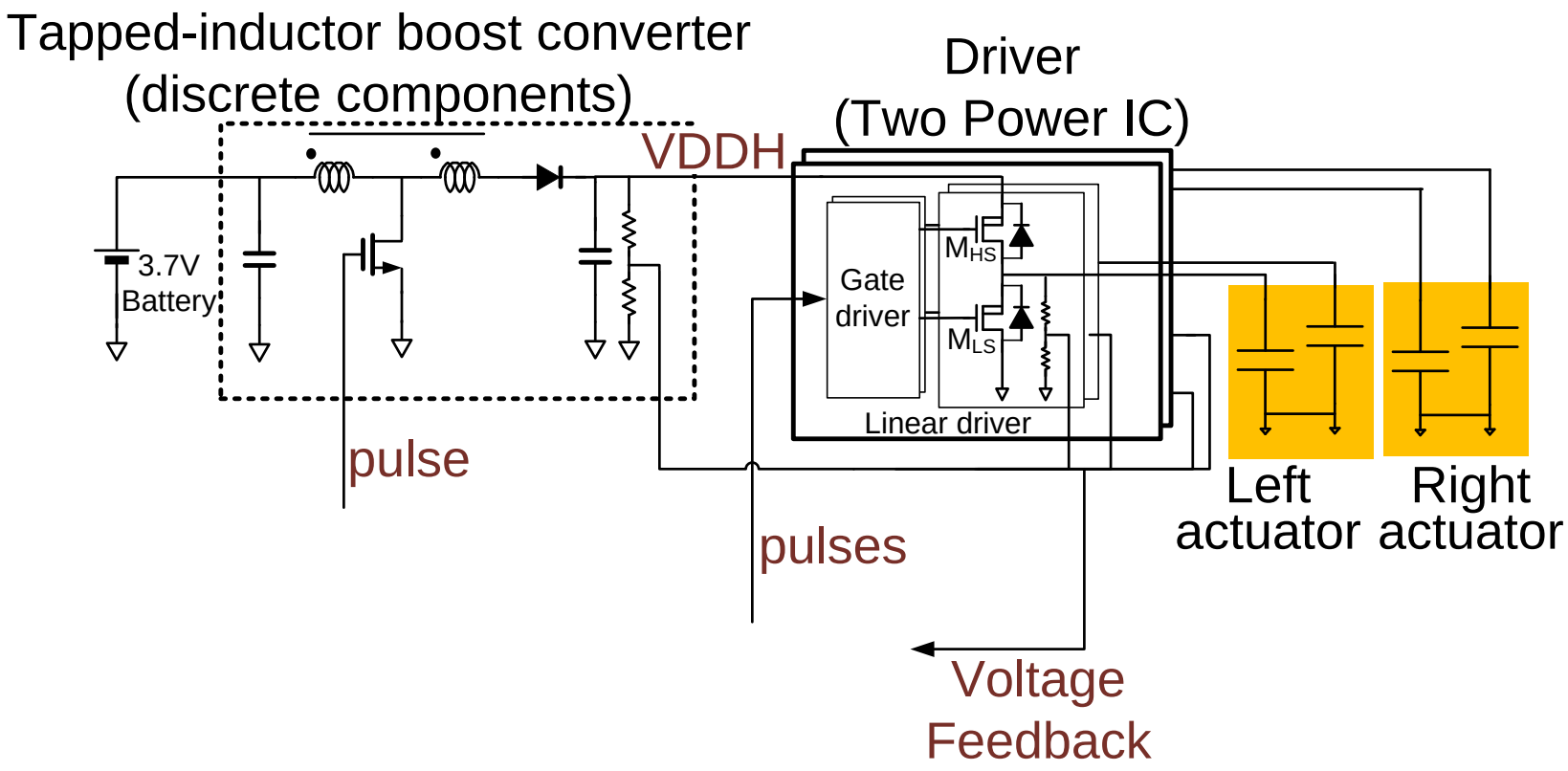
Power Electronics Unit Architecture



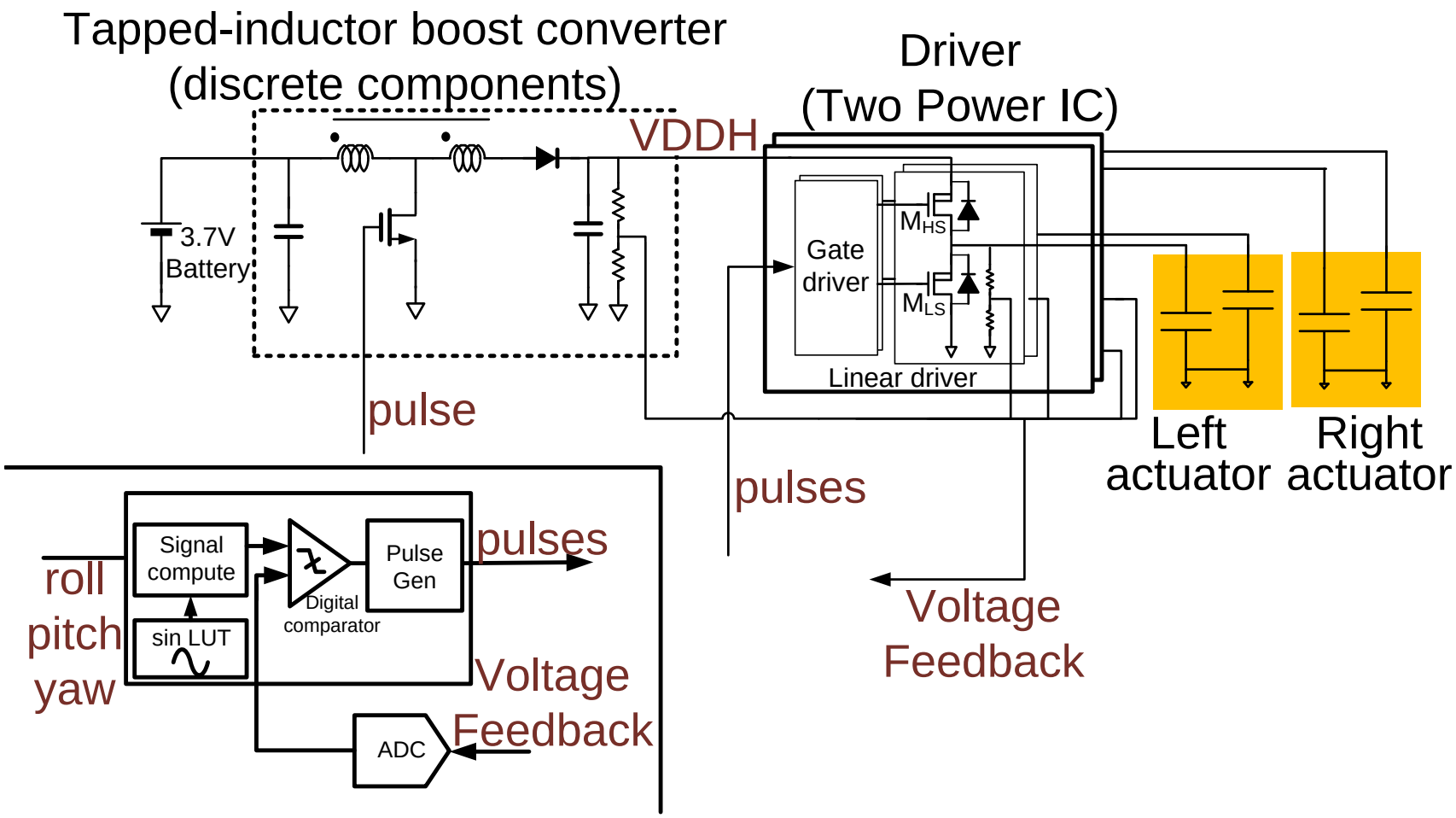
Power Electronics Unit Architecture



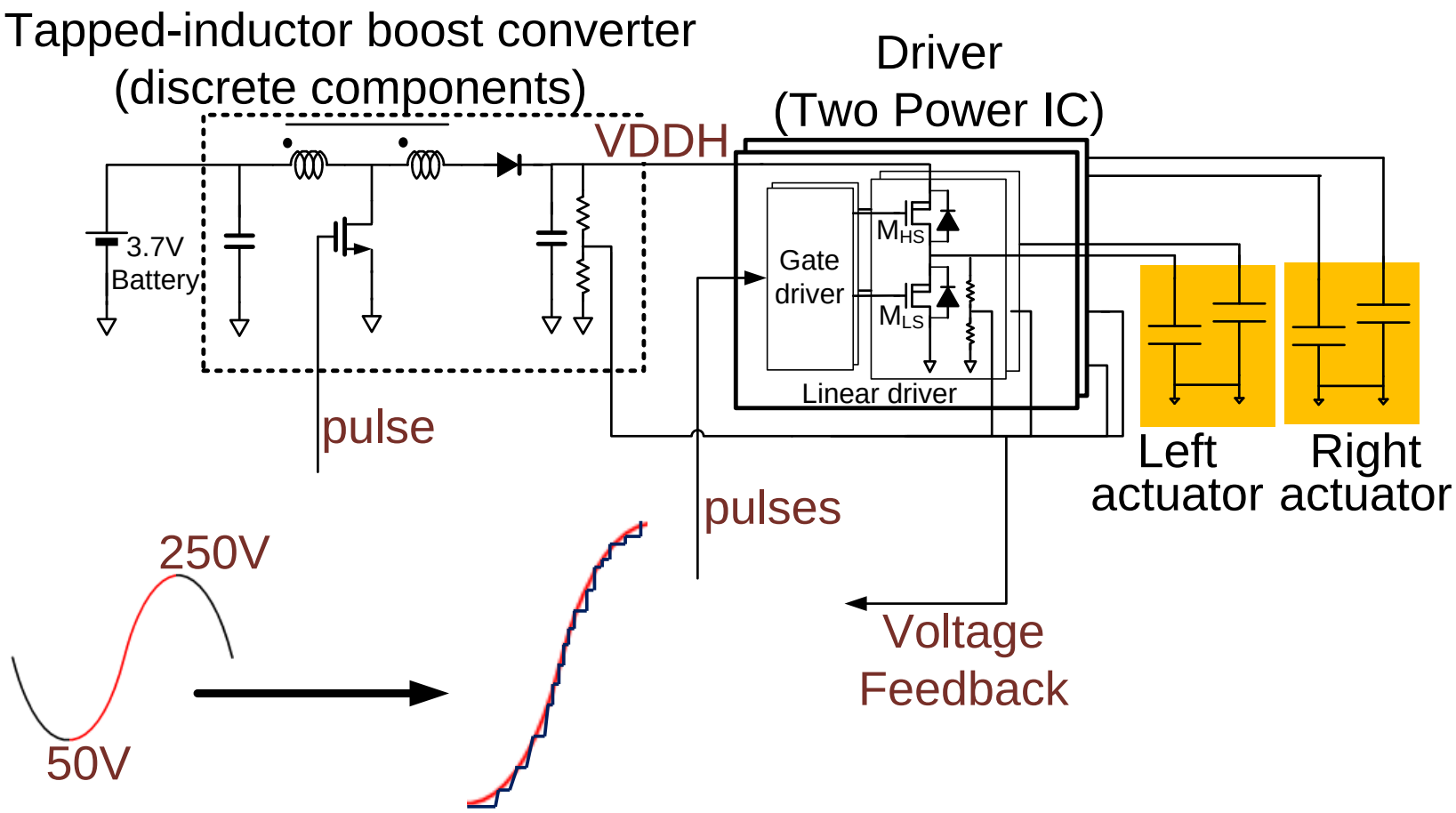
Power Electronics Unit Architecture



Power Electronics Unit Architecture



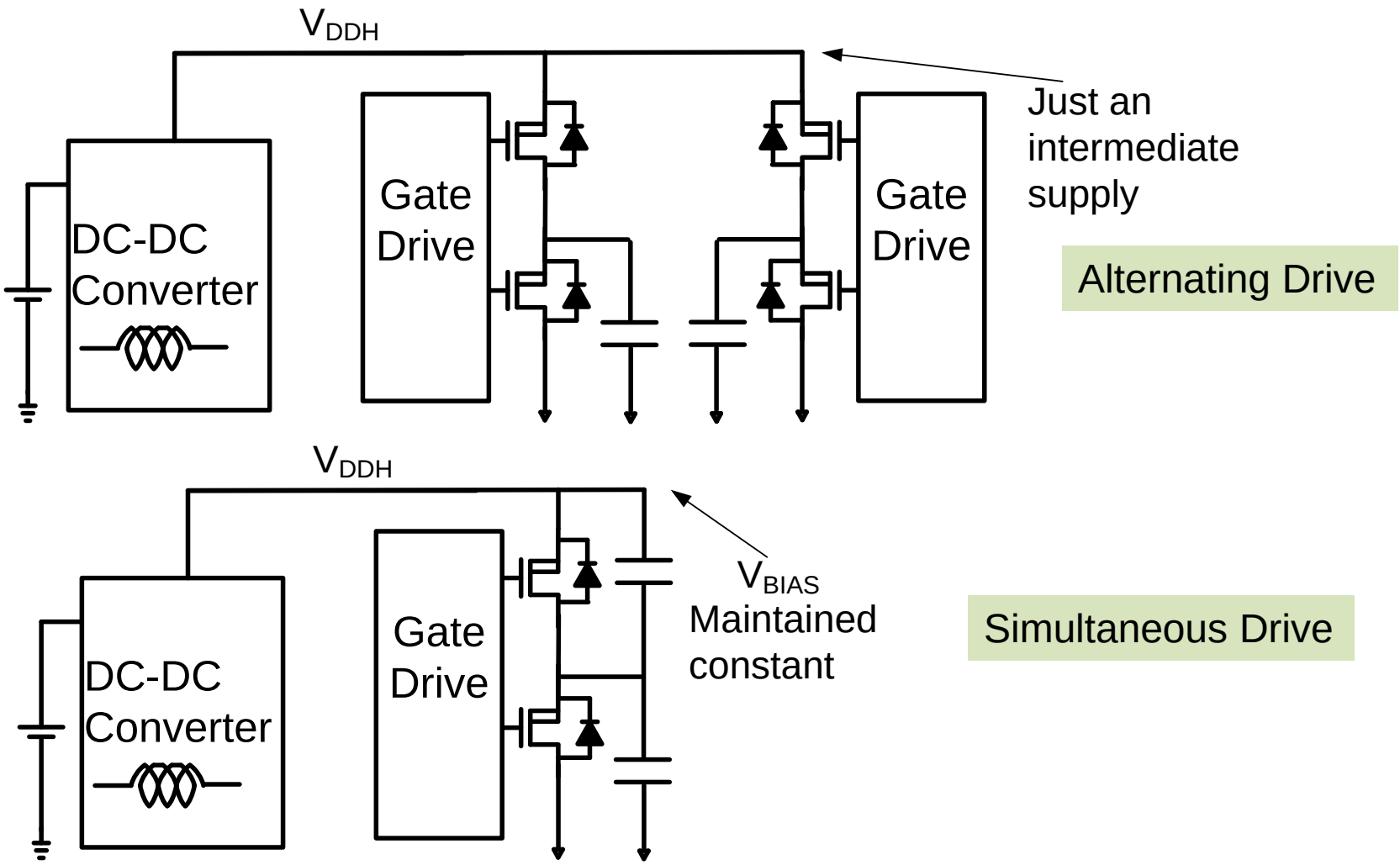
Power Electronics Unit Architecture



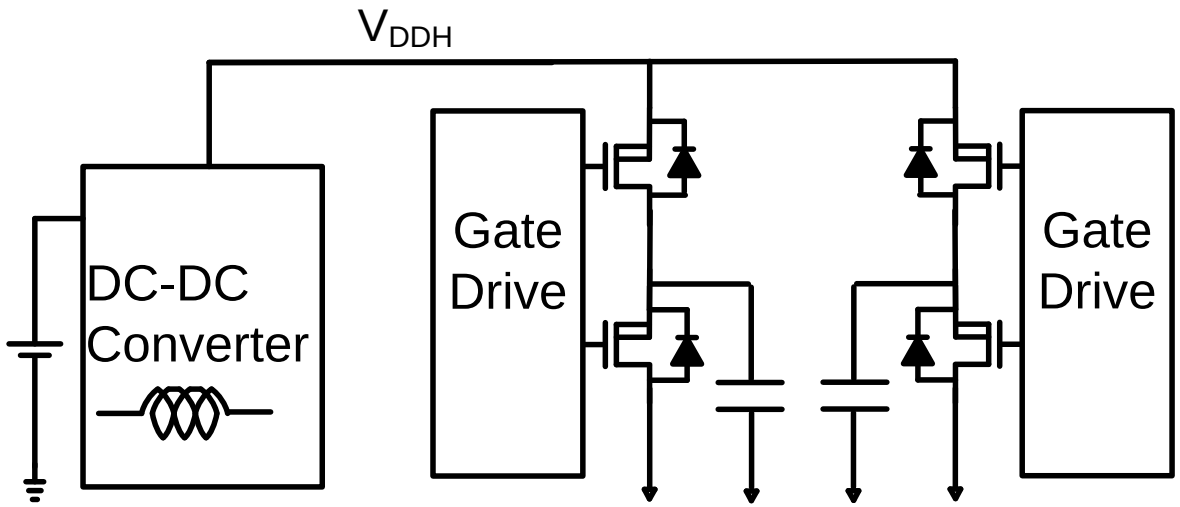
Outline of Presentation

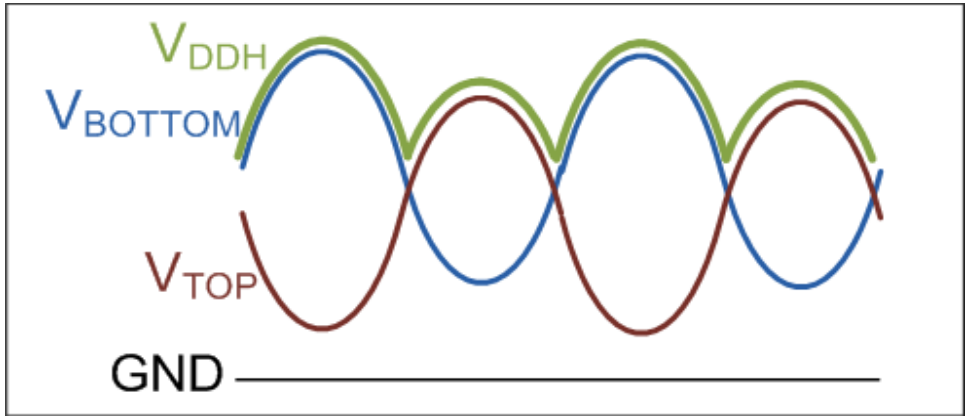
- System Overview
- Power Electronics Unit
- Power Saving Techniques
  - Envelope Tracking
  - Charge Sharing
  - Dynamic Common Mode
- Testing Results

Envelope Tracking



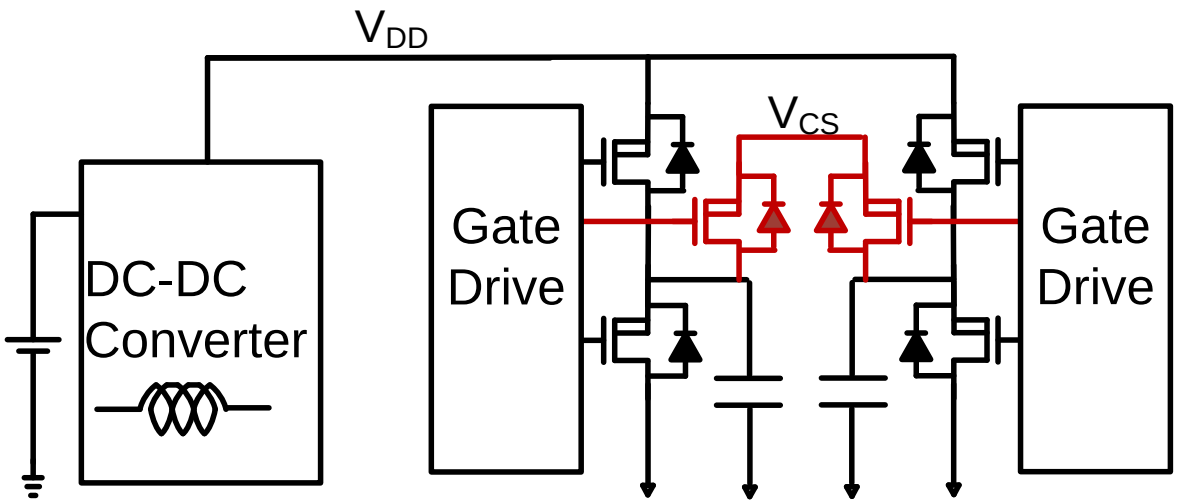
Envelope Tracking





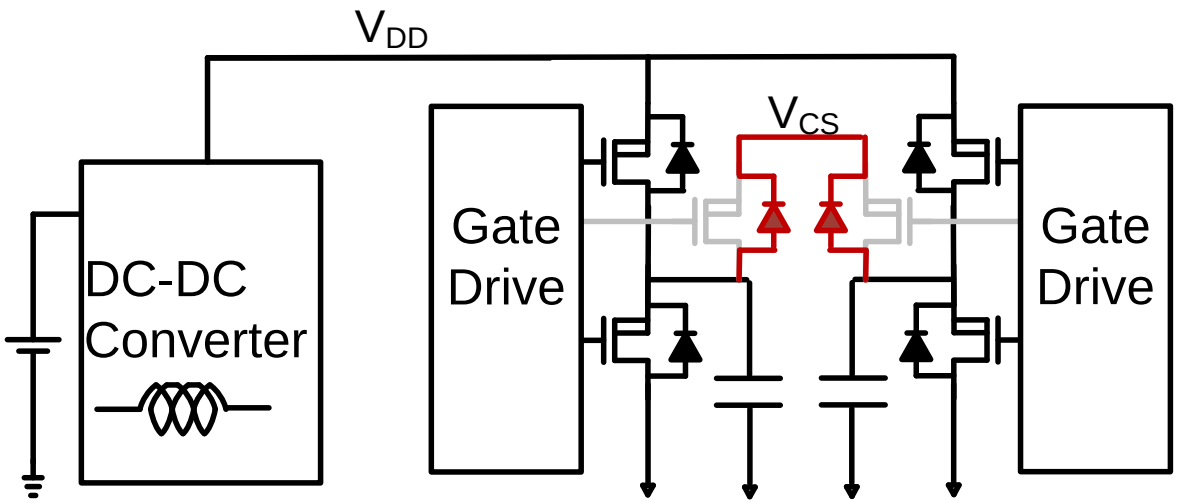
Improve efficiency by having Vddh track max(Vtop, Vbottom)

Charge Sharing



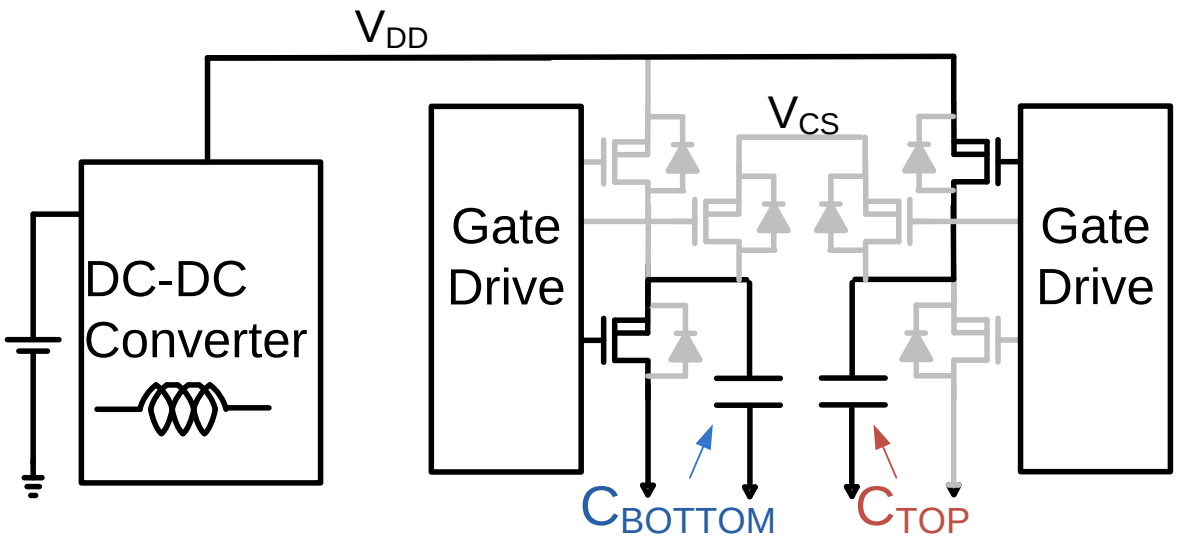
Require addition of two high-side switches

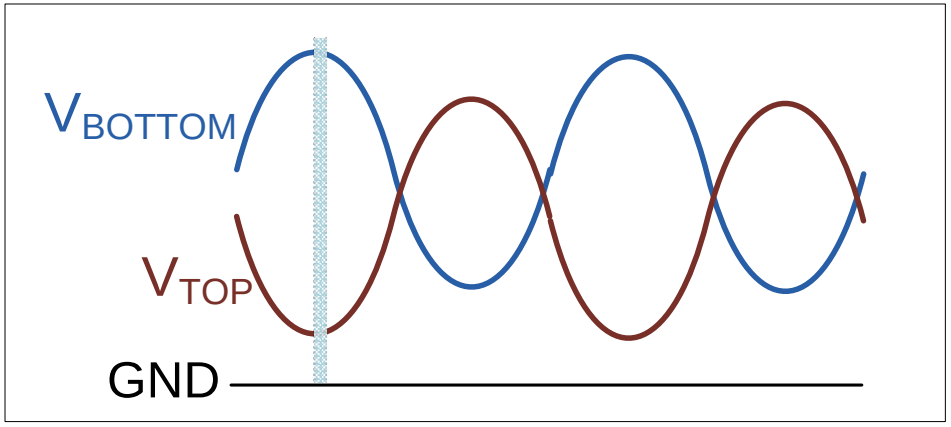
Charge Sharing



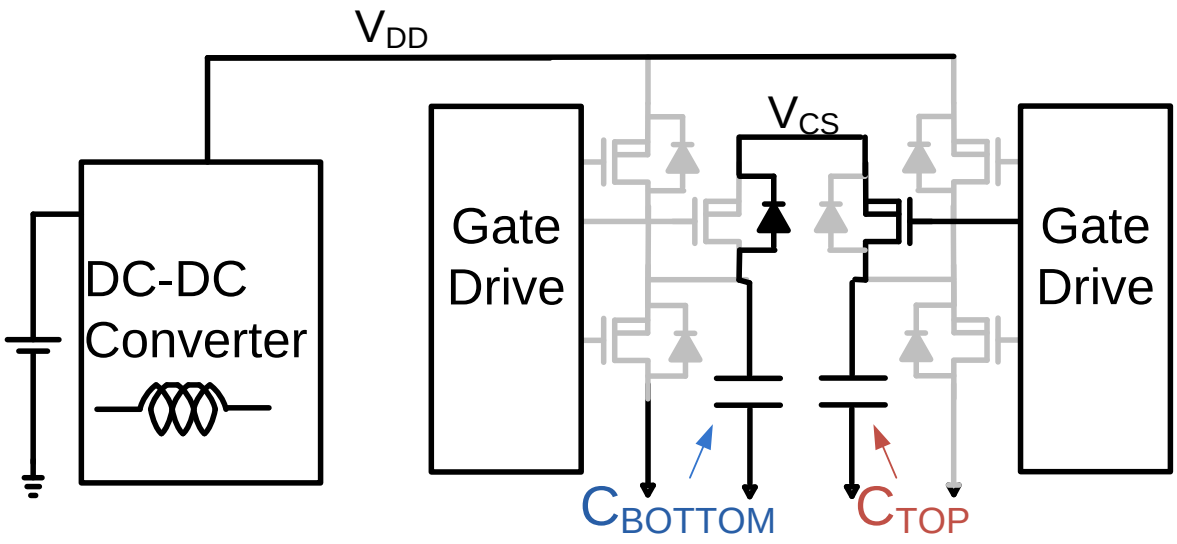
When both switches are off, they act as back-to-back diodes.

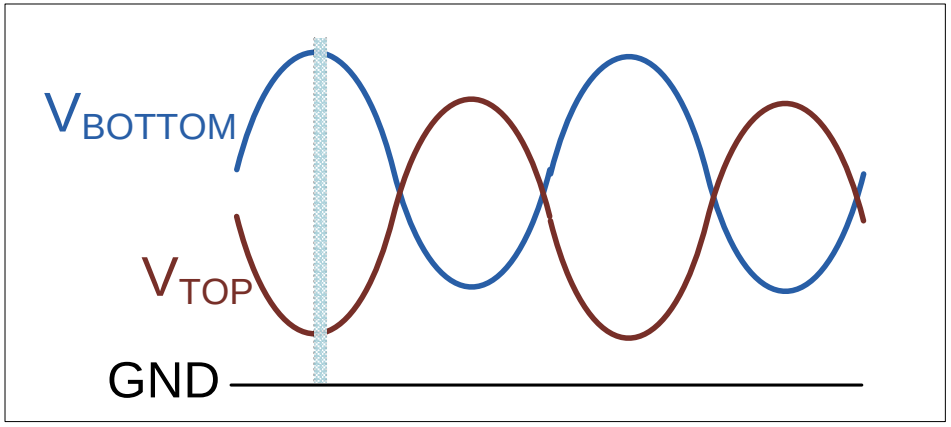
Charge Sharing



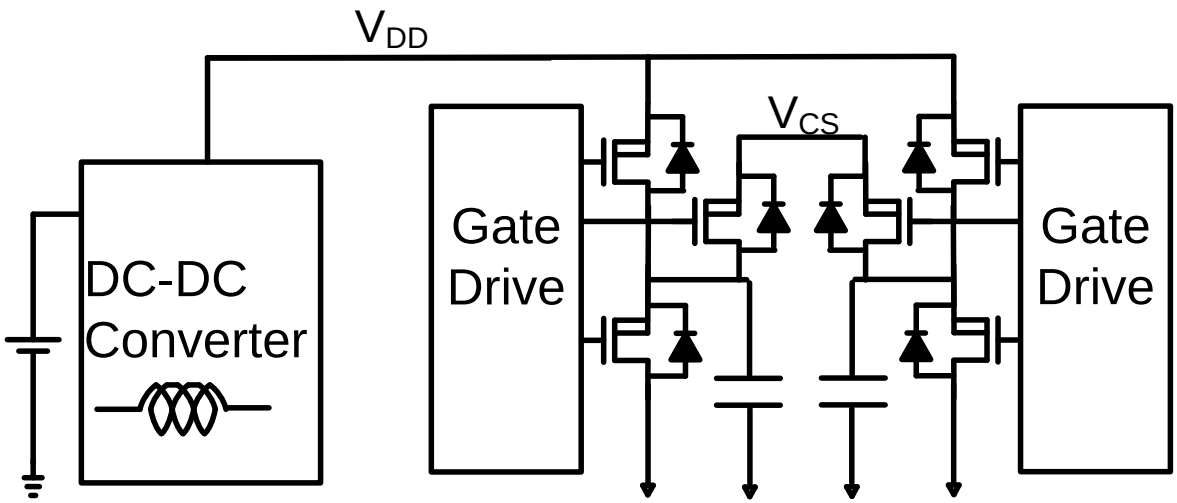


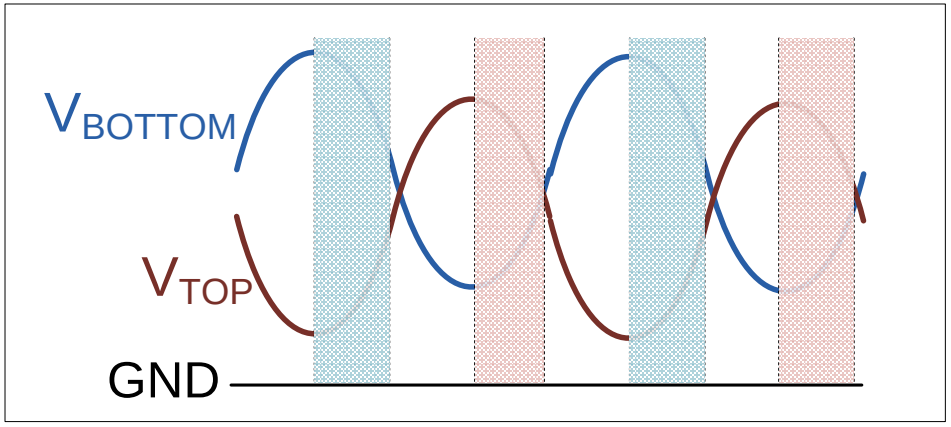
Charge Sharing



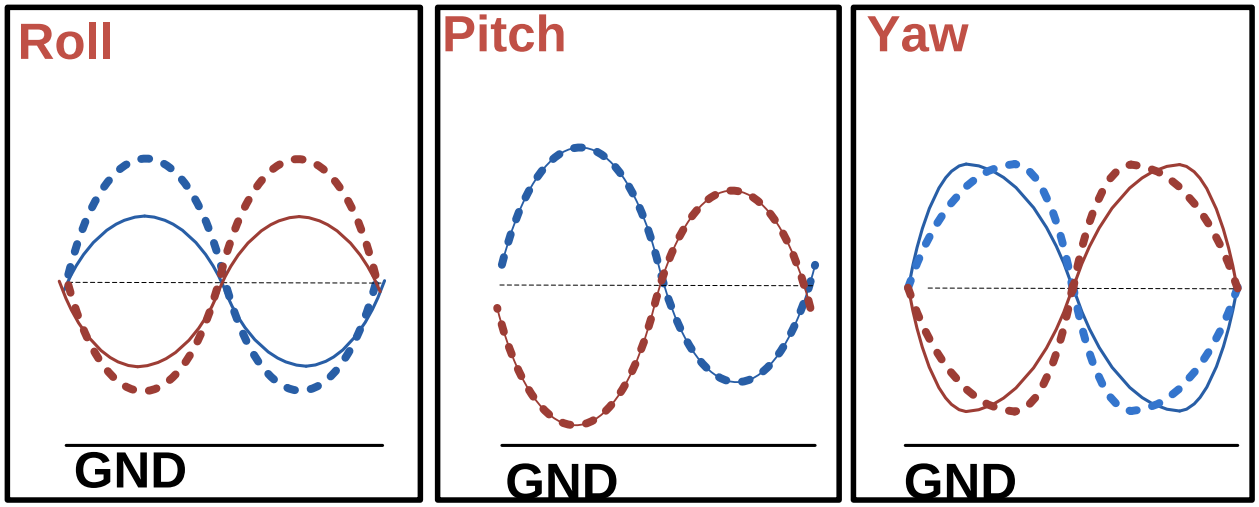


Charge Sharing





Dynamic Common Mode



Constant

$V_{TOP} + V_{BOTTOM}$

$V_{CM} = (V_{TOP} + V_{BOTTOM})/2$

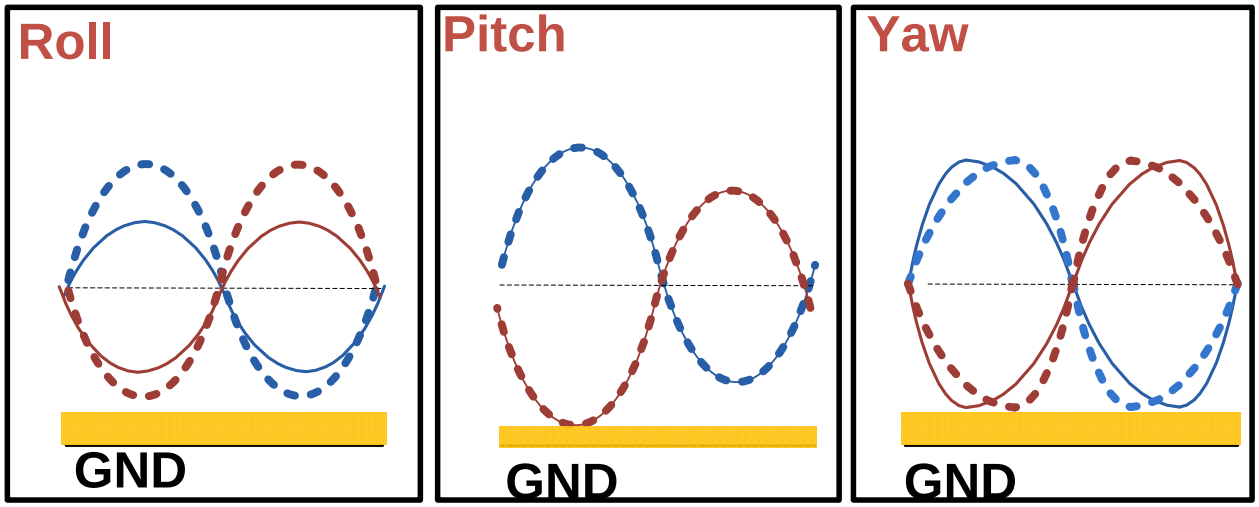
TOP

LEFT ---- RIGHT ——

BOTTOM

LEFT ---- RIGHT ——

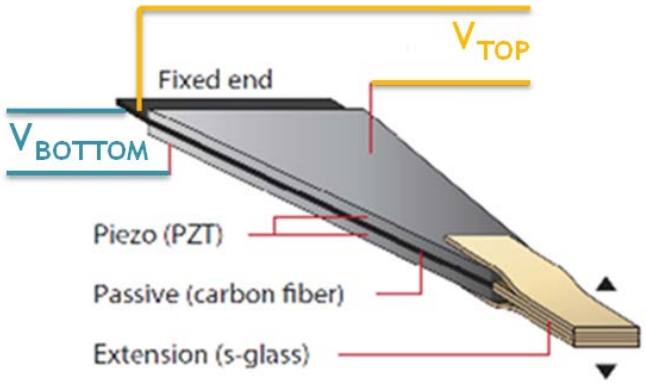
Dynamic Common Mode



Constant

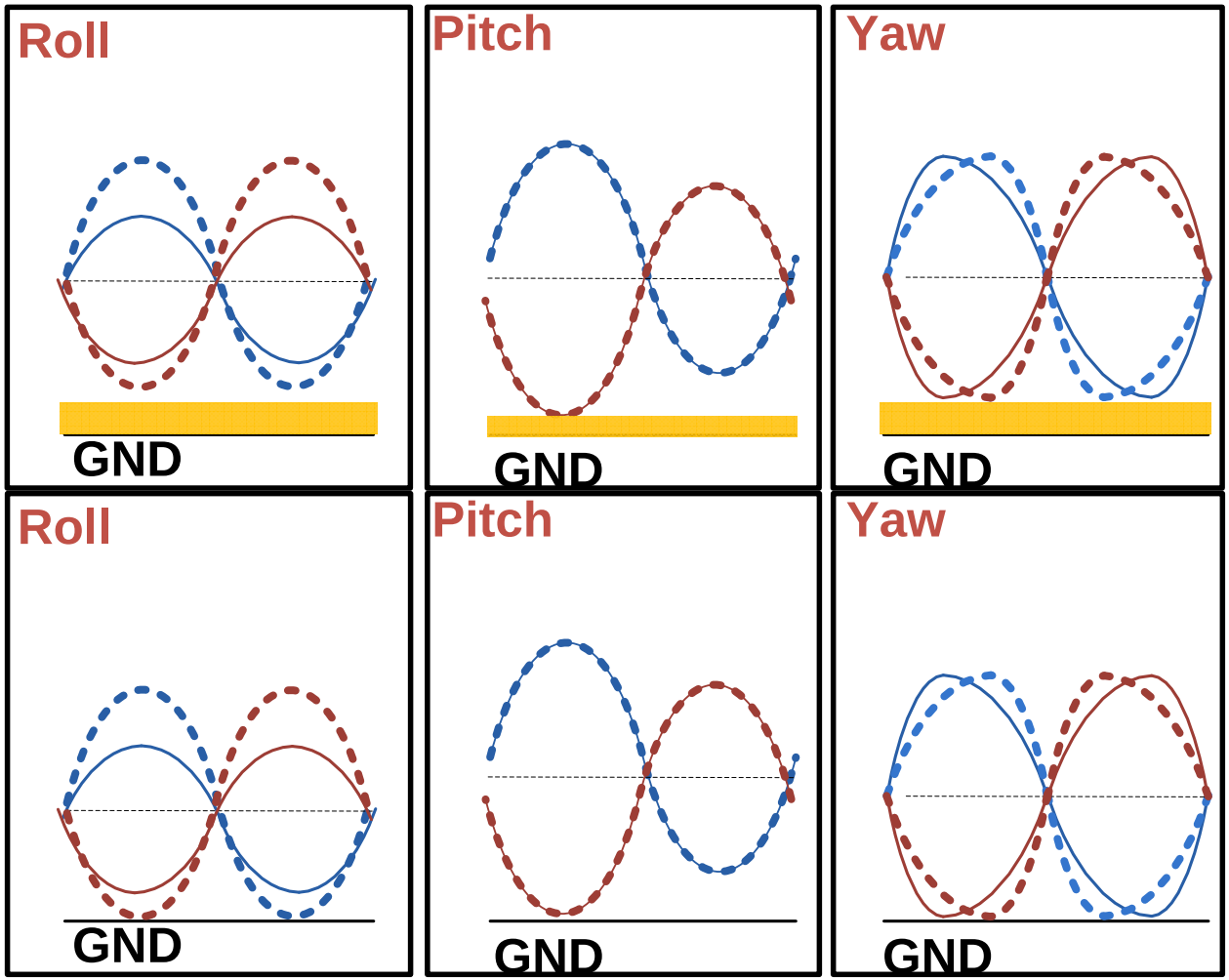
$V_{TOP} + V_{BOTTOM}$

$V_{CM} = (V_{TOP} + V_{BOTTOM})/2$



TOP
LEFT ---- RIGHT ——
BOTTOM
LEFT ---- RIGHT ——

Dynamic Common Mode



Constant

$V_{TOP} + V_{BOTTOM}$

$V_{CM} = (V_{TOP} + V_{BOTTOM})/2$

Adapt V_{CM} based on roll, pitch and yaw

TOP

LEFT ---- RIGHT ——

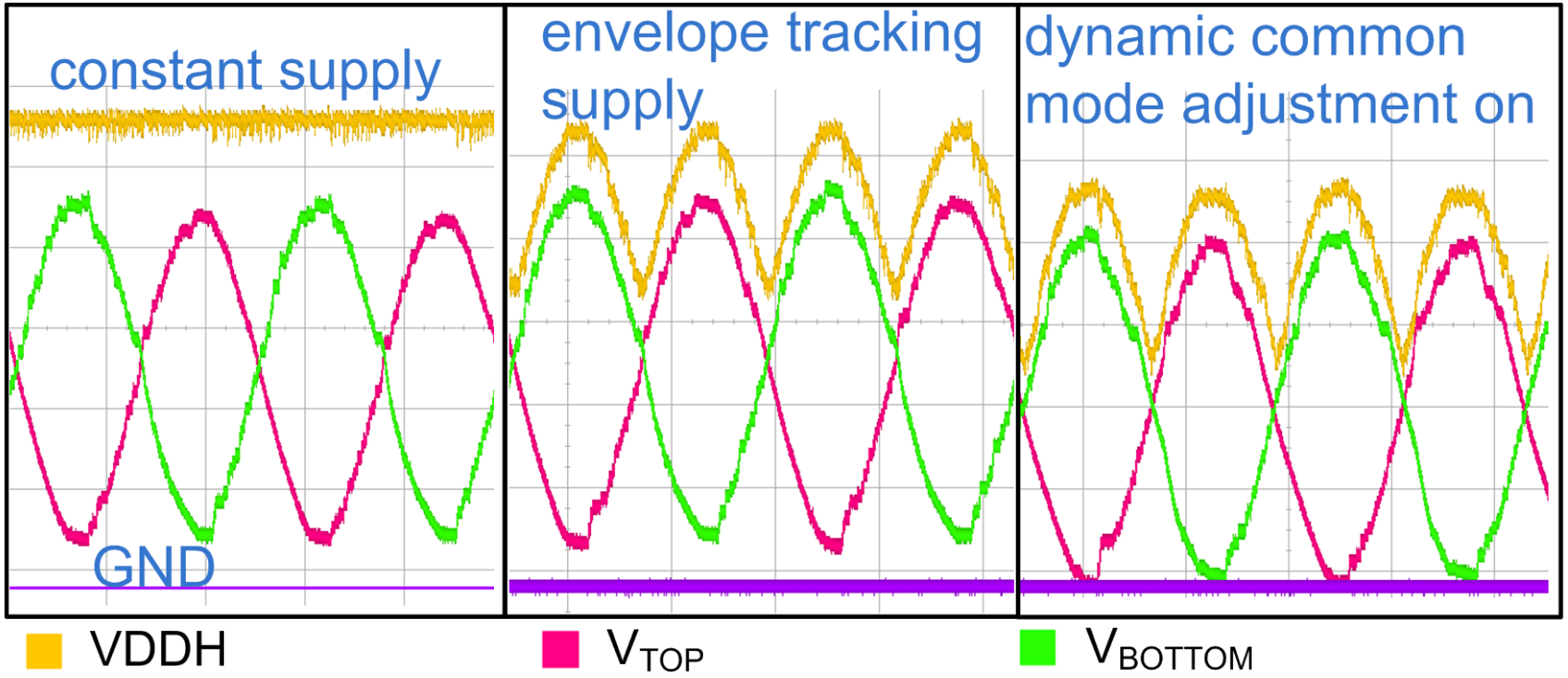
BOTTOM

LEFT ---- RIGHT ——

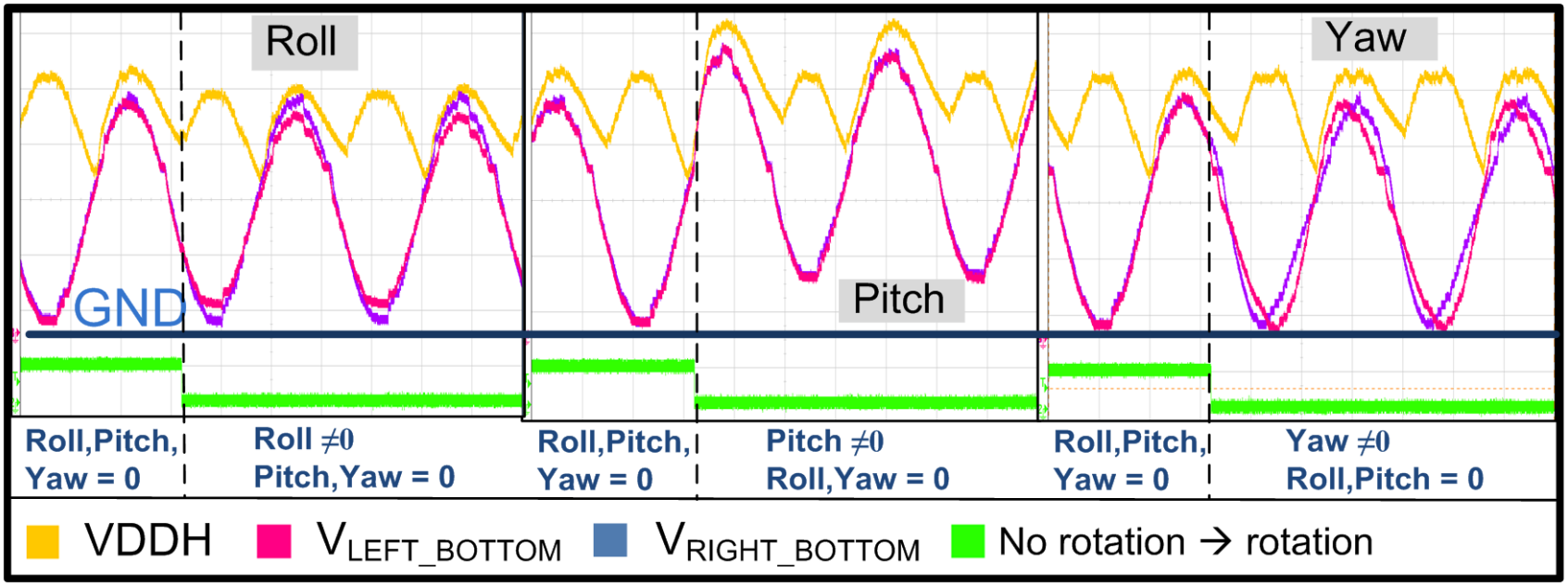
Outline of Presentation

- System Overview
- Power Electronics Unit
- Power Saving Techniques
- Testing Results

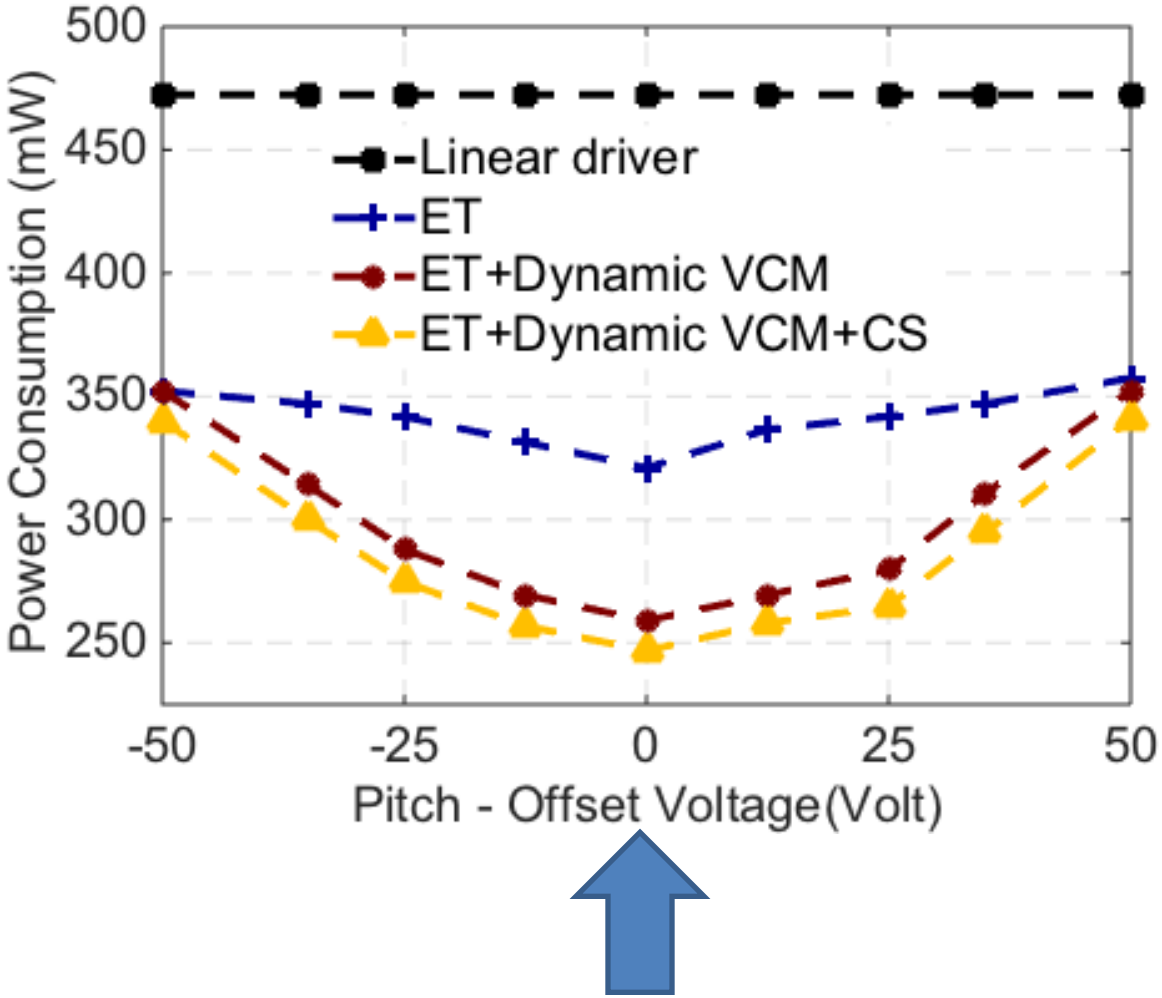
Functional Verification #1



Functional Verification #2



Power Reduction



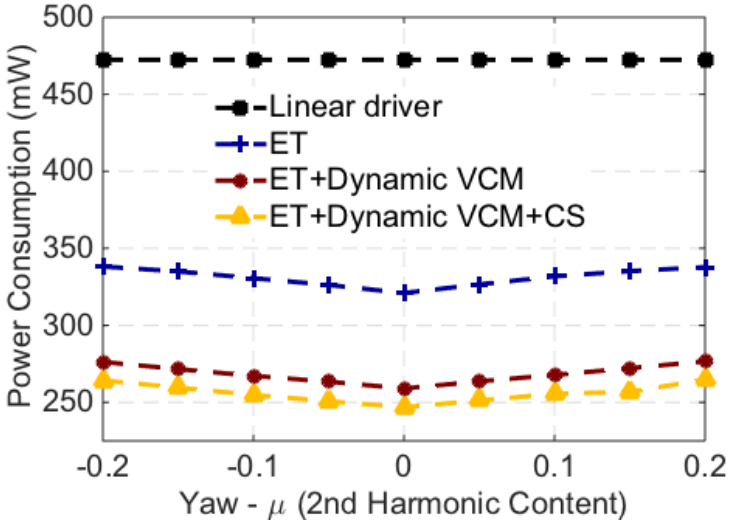
Power Reduction 26% - 48%

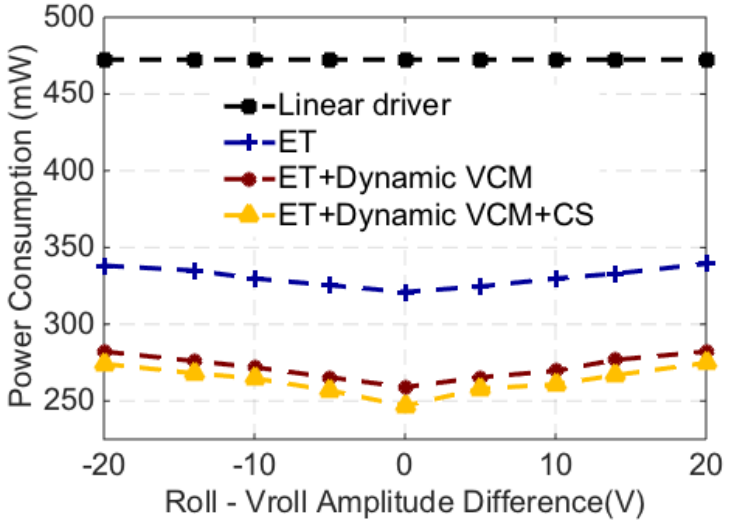
37% reduction for the common case

15nF per piezo layer cap load

80Hz

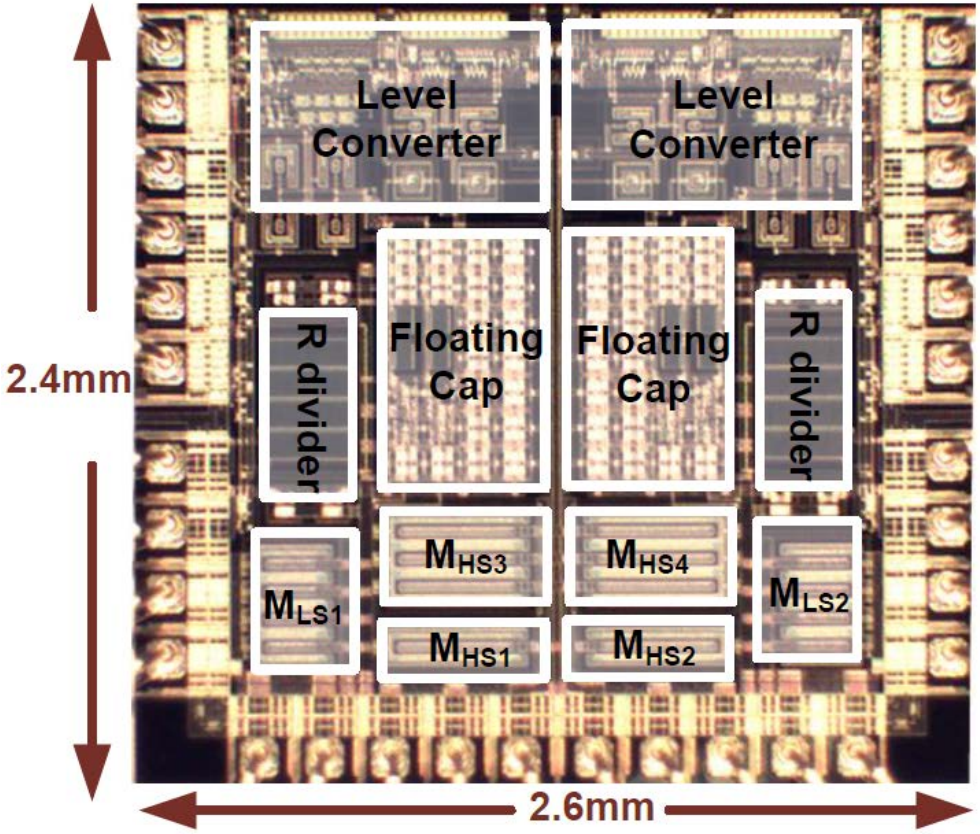
Power Reduction

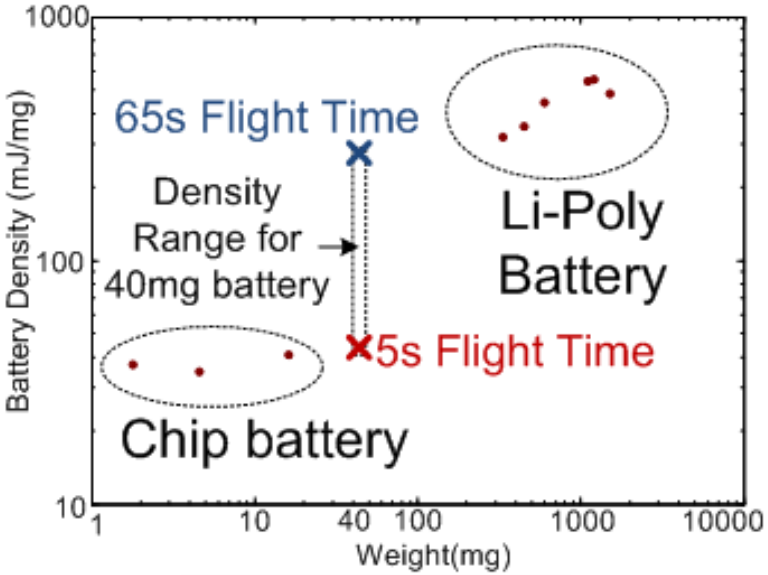


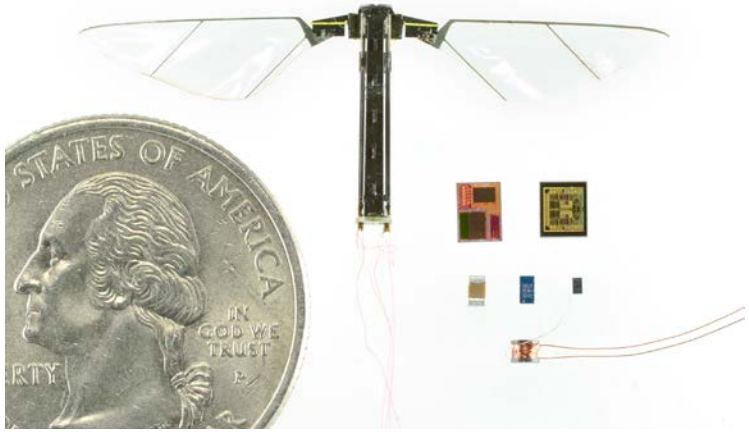


Yaw and Roll rotation affects the envelope

Conclusion



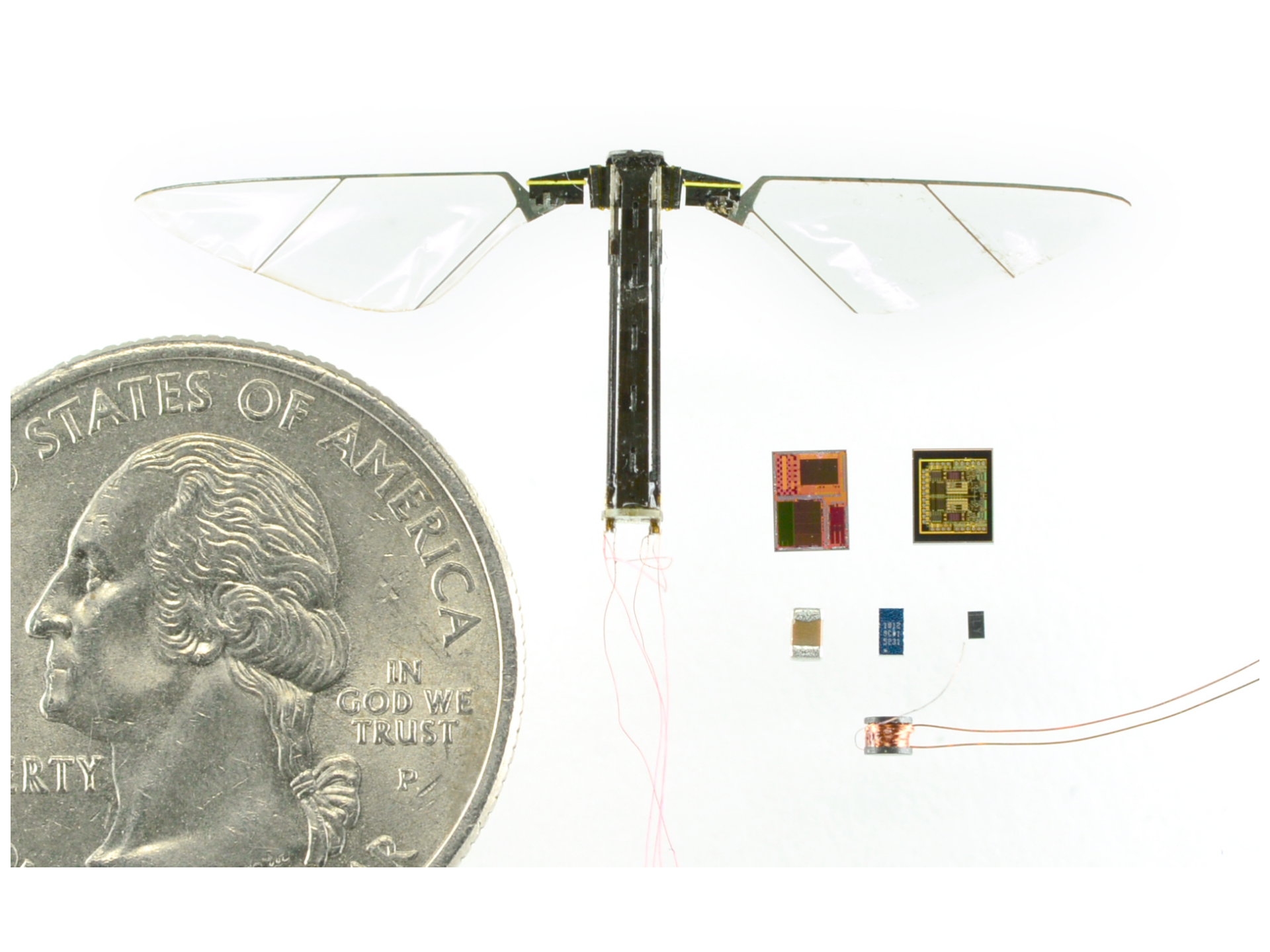




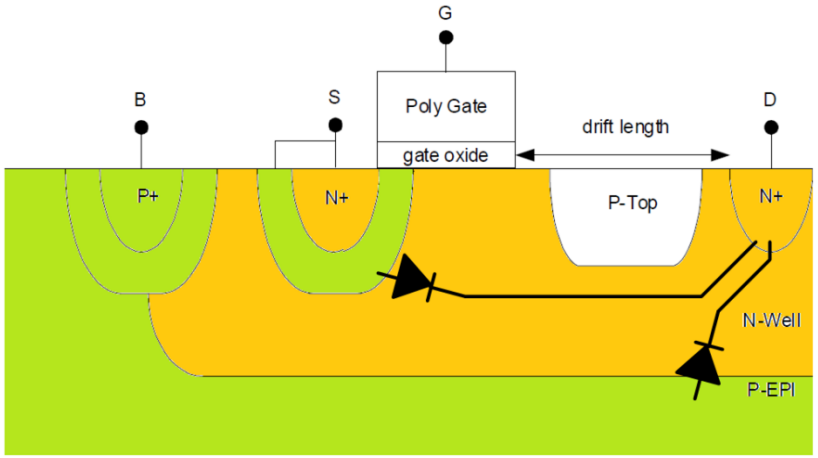
290mW average power

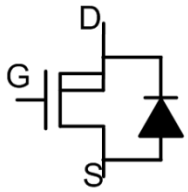
Estimated 60mg total weight (13mg per IC)

Back Up

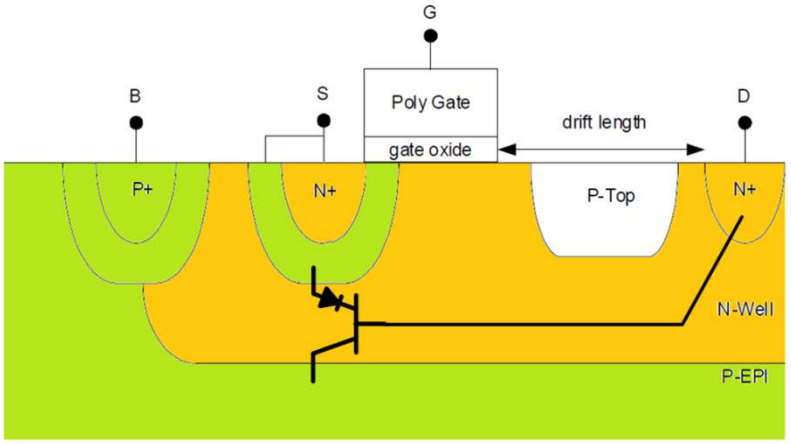

STATES OF AMERICA
IN
GOD WE
TRUST

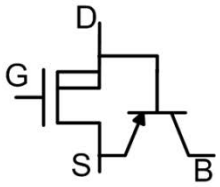
Leaky Diode





A simulation model for the integrated LDMOS



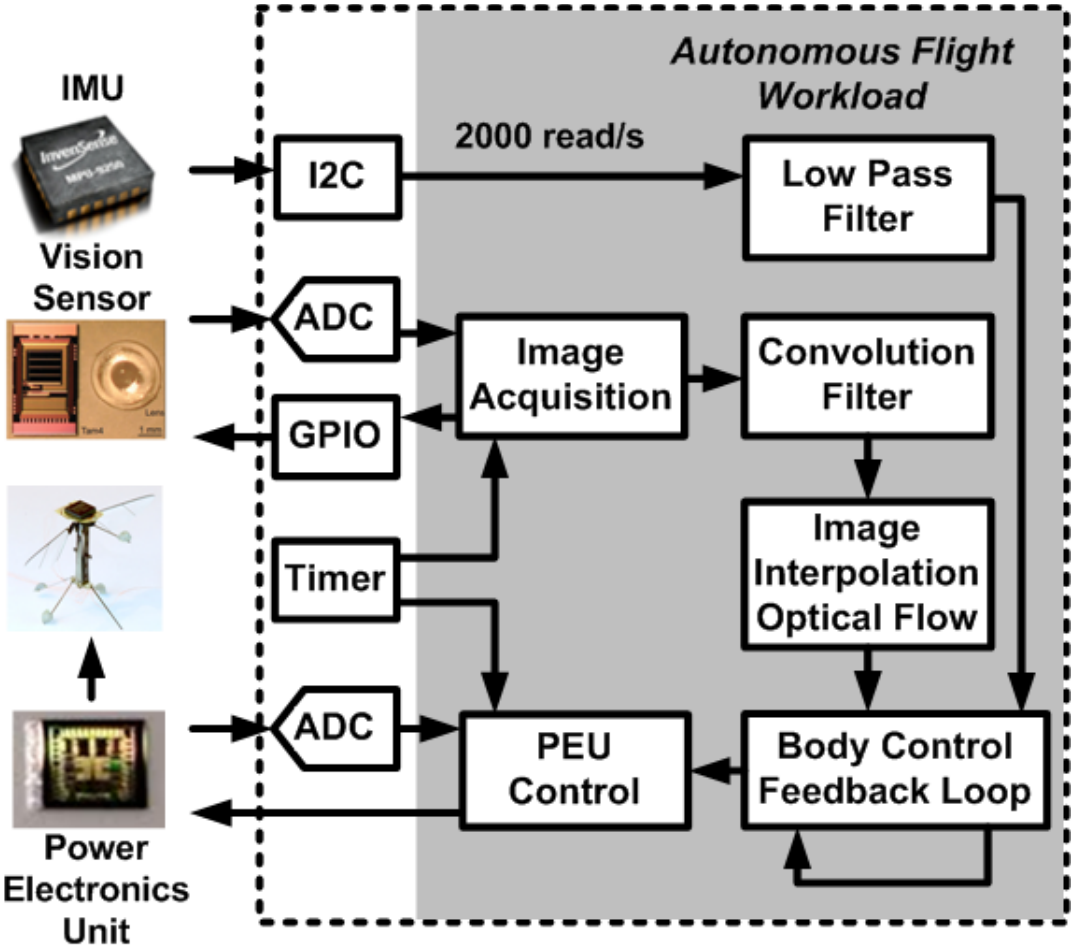


Actual equivalent circuit for the integrated LDMOS

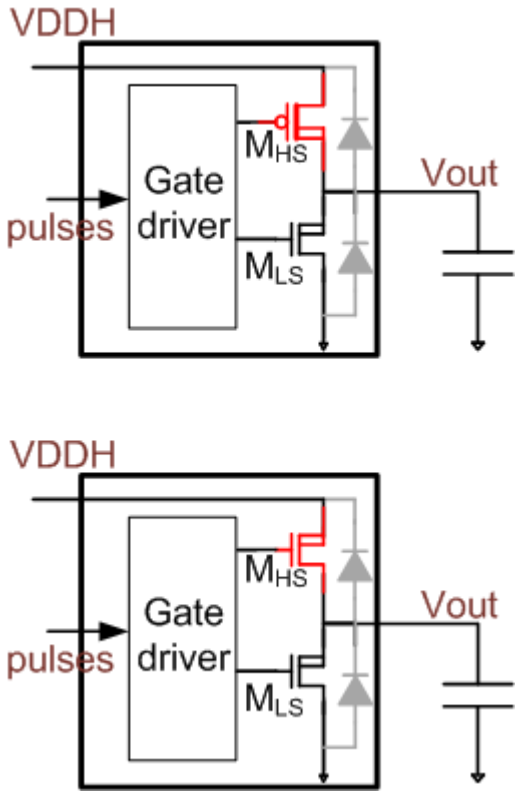
Experimentally the β of this BJT is measured to be about 4-6.

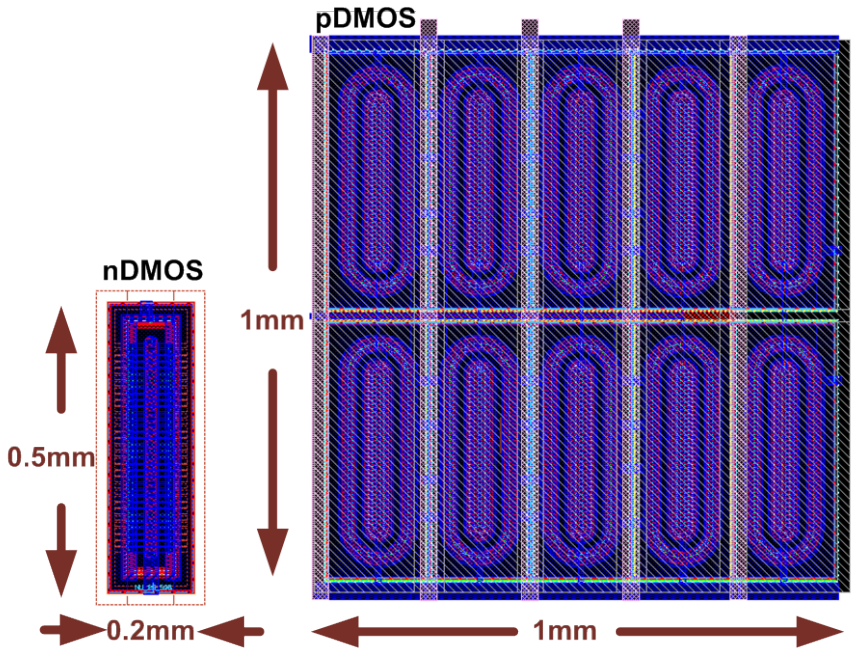
In other words, 4-6 units of current will leak to substrate for one unit of current conducting through the diode

Computation Need by Brain SoC



Can we use a N-type highside device





Floating Supply