dsm
Dynamic Structures & Materials, LLC

Efficient, Self-Contained, Regenerative Power Electronics for Active Materials Systems

Presented at the DARPA TIM Baltimore, 6/26/2000

OBJECTIVE:

Development, design and production of a commercially feasible,self-contained power, sensing and control electronics package that is significantly more efficient than current linear and PWM concepts.

Year 1: Basic Designs and Experimental Prototypes of Regenerative Power Supplies and Amplifiers:
Experimental prototypes for proof-of-concept testing and validation of systems. Designs focus on near-term technologies.

Year 2: Production Level Designs of Bi-Directional or Regenerative Drivers and Amplifiers

Year 3: Implementation of Optimized Designs for Testing on Multiple Test-beds.

PROGRAM SPECIFICS:

- First year funded from Virginia Tech's Efficient Hybrid Actuation using Solid-State Actuators" Program
- Dynamic Structures and Materials is a subcontractor to Virginia Tech
- Phase I effort period of performance: June, 1999 through July, 2000
- Phase I funding levels for the year were $83k from DARPA and DSM matching the funds with another 83k from a BMDO Phase II SBIR.

APPLICATIONS:

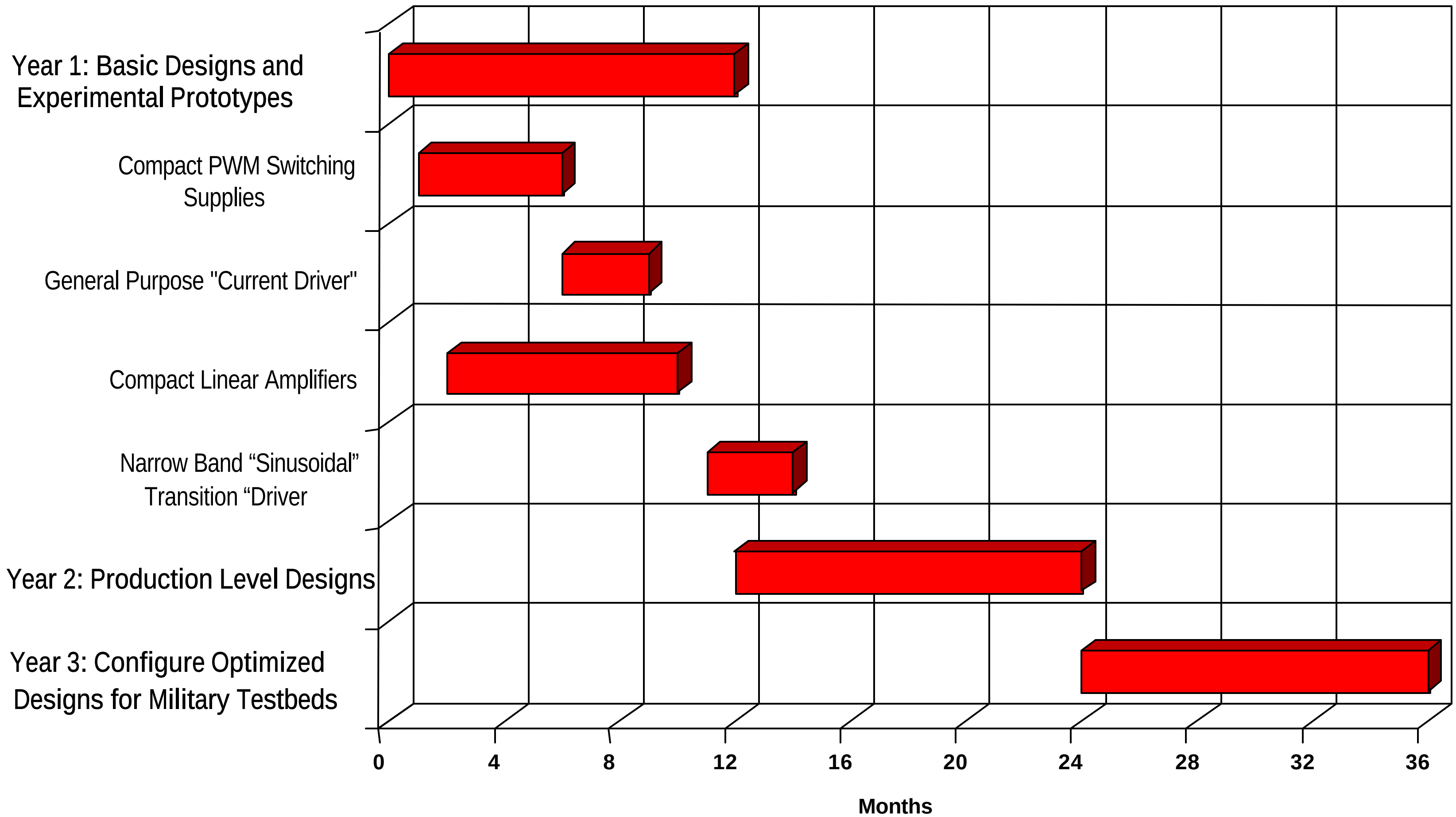
Current PZT driven active material devices require rather large, bulky and inefficient amplifiers or dedicated drivers. DSM proposed to develop some techniques for reducing the size and inefficiencies of the drivers. Virginia Tech's actuation program was the target application.

POC: J. Paine, jpaine@dynamic-structures.com

dsm
Dynamic Structures & Materials, LLC

Efficient, Self-Contained Regenerative Power Electronics

Project Schedule



POC: J. Paine, jpaine@dynamic-structures.com

Dynamic Structures & Materials, LLC

Contractor and Subcontractors

Small Business Subcontractor to Virginia Tech:

- **Dynamic Structures and Materials - PI: Jeff Paine**
- **Contracted for $83k of effort with an internal matching of $83k by DSM.**

Some technical objectives include:

- **Development of charge storage strategies that recovers energy for subsequent cycles and reduces heat production and energy loss for a compact system.**
- **Design and development of switching and hybrid voltage/charge controlled amplifier strategies for efficient charge utilization. Design of low voltage designs that operate through resonant type behavior.**
- **Integration of control and sensing electronics to an effective integrated package.**
- **Demonstration on commercial and military testbeds.**

POC: J. Paine, jpaine@dynamic-structures.com

Dynamic Structures & Materials, LLC

Efficient, Self-Contained Regenerative Power Electronics

Program Accomplishments

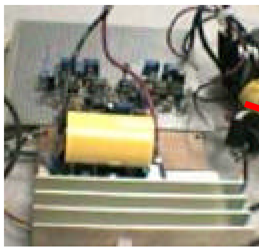
- A first and second generation laboratory prototype switching Amp was developed and tested. They operated well under lab conditions. The units were not refined enough for delivery.
- Compact linear amplifiers have also been developed. A first generation design with capabilities on the order of 1.5 Amps, 330 Vpp driving capacitance of 1.5 μF. A second generation unit is driving up to 20 μF at 180 Vpp and 1.5 Amps. The Amp is being tested for SAIC and Virginia Tech.
- DSM delivered a 2nd Generation "Current" Driver for the Virginia Tech Program. The 3 channel piezoelectric "current" driver had fair efficiency and was robust enough to drive a wide range of piezo-loads (up to 40 μF).

POC: J. Paine, jpaine@dynamic-structures.com

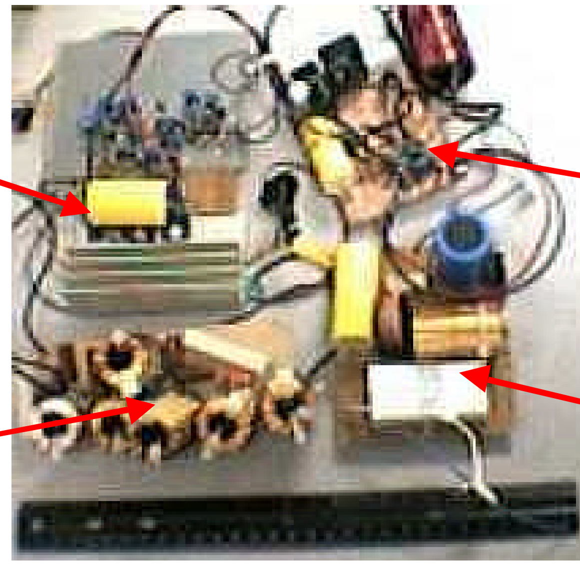
Dynamic Structures & Materials, LLC

Efficient, Self-Contained Regenerative Power Electronics

Accomplishments: 2nd Gen. Switching Amp

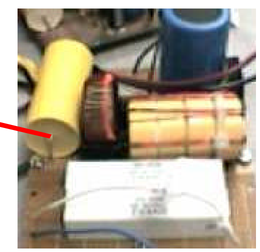


Amp Stage



Boost Stage

Filter Stage



Rectifier Stage

Targeted for 400 Volts, 5 amps. Prototype components are 10 by 10 by 2 inches

Performed successfully in Laboratory conditions at 2 Amps, 150 Vpp driving a 26 µF load

Produced very low switching ripple (less than 0.5%)

Bandwidth: DC to 500 Hz

POC: J. Paine, jpaine@dynamic-structures.com

dsm

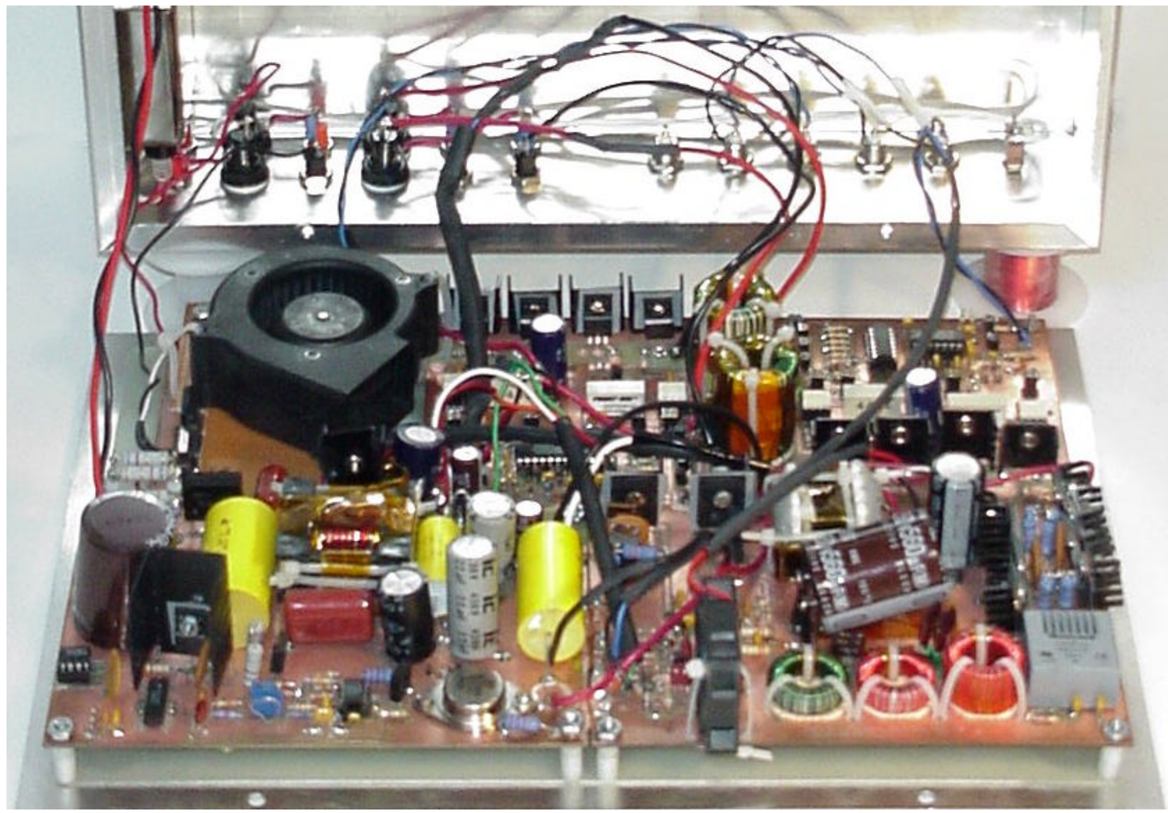
Dynamic Structures & Materials, LLC

Efficient, Self-Contained Regenerative Power Electronics

Accomplishments: 2nd Gen. “Current Source” Driver

Specifications

- Targeted for 3-Channels:
  1x150 Volts,
  2x400 Volts.
- Max Current of 1.8 amps.
- Prototype is 13 x 9 inch
- Produces 270 Watts
- Bandwidth: DC to 600 Hz
- Current Ripple less than 20 mApp



POC: J. Paine, jpaine@dynamic-structures.com

Gained by/ Learned

Things DSM Learned and Gained:

1. Strong dependence exists between optimized piezo-drivers (efficiency,volume) & specific application (capacitance, voltage waveform and frequency)

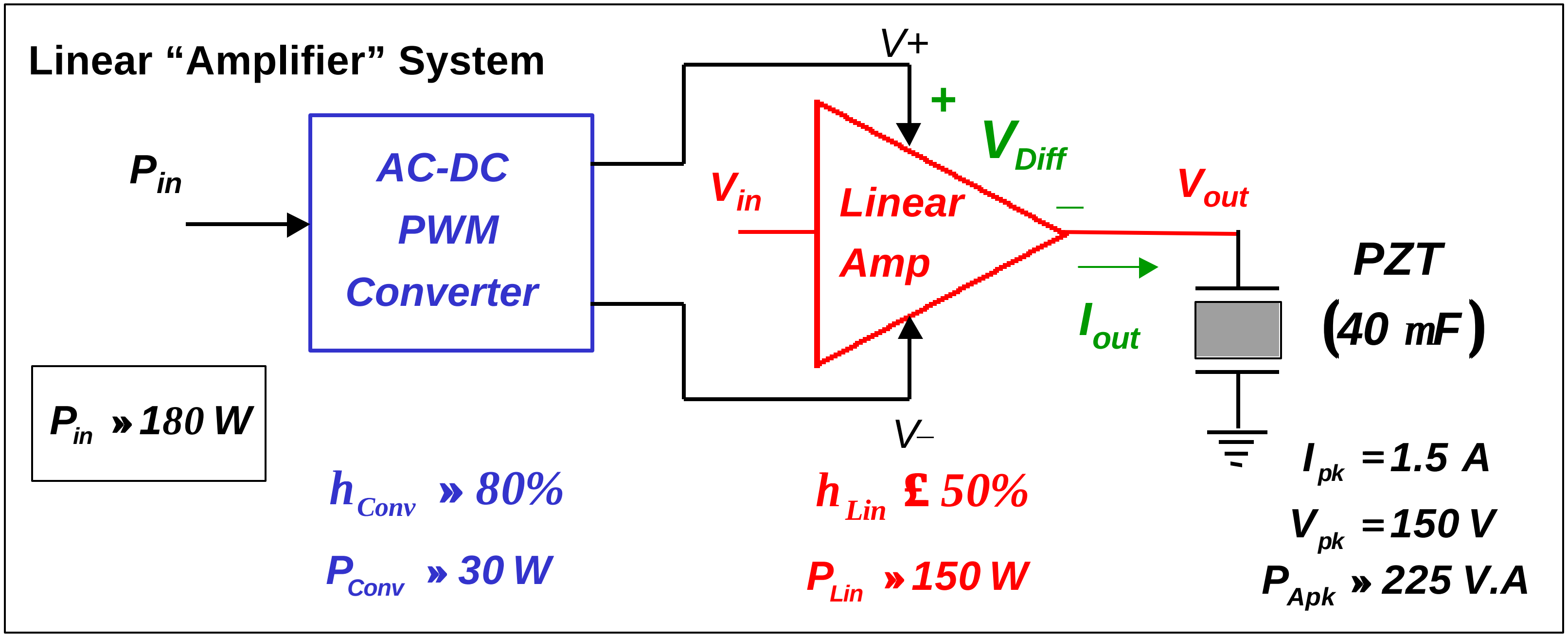
2. High frequency voltage ripple from switching amplifiers is harmless to PZTs and irrelevant to mechanical output

3. Need for a versatile “hybrid “ driver: Large bandwidth, wide load and voltage range, good efficiency (current source and proposed work variable power supply linear amplifier)

POC: J. Paine, jpaine@dynamic-structures.com

Efficient, Self-Contained Regenerative Power Electronics

Efficiencies of Various Drivers



Pros & Cons:

↑ Large Bandwidth (Low THD)

$V_{out} = K * V_{in}$

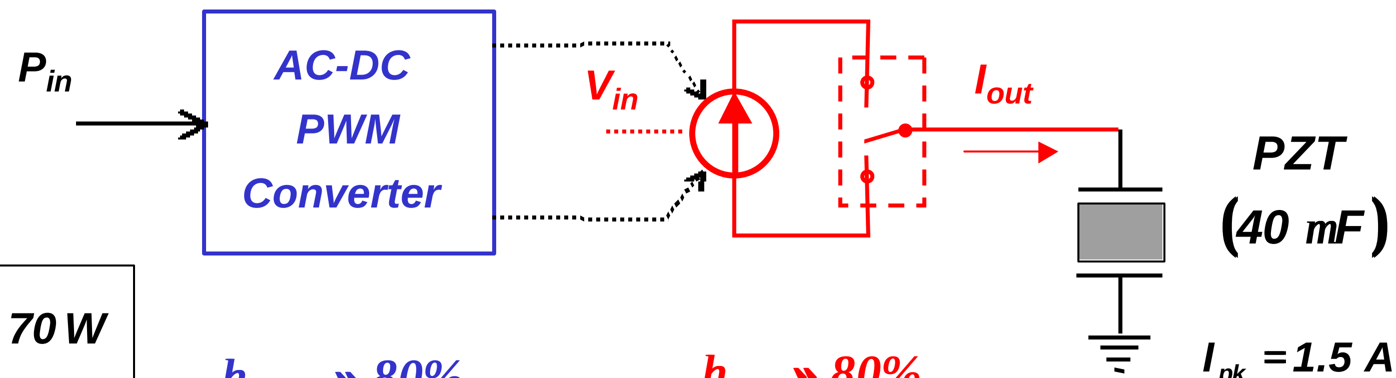
↓ Very Poor Efficiency $(V_{Diff} \cdot I_{Out})$

Bulky and Heavy

POC: J. Paine, jpaine@dynamic-structures.com

Efficiencies of Various Drivers

"Current Source" Driver



$P_{in} \approx 70\ W$

$\eta_{Conv} \approx 80\%$

$P_{Conv} \approx 25\ W$

$\eta_{Lin} \approx 80\%$

$P_{Lin} \approx 45\ W$

$I_{pk} = 1.5\ A$

$V_{pk} = 150\ V$

$P_{Apk} \approx 225\ V.A$

Pros & Cons:

↑ Low Complexity

Robust Under Wide load Range

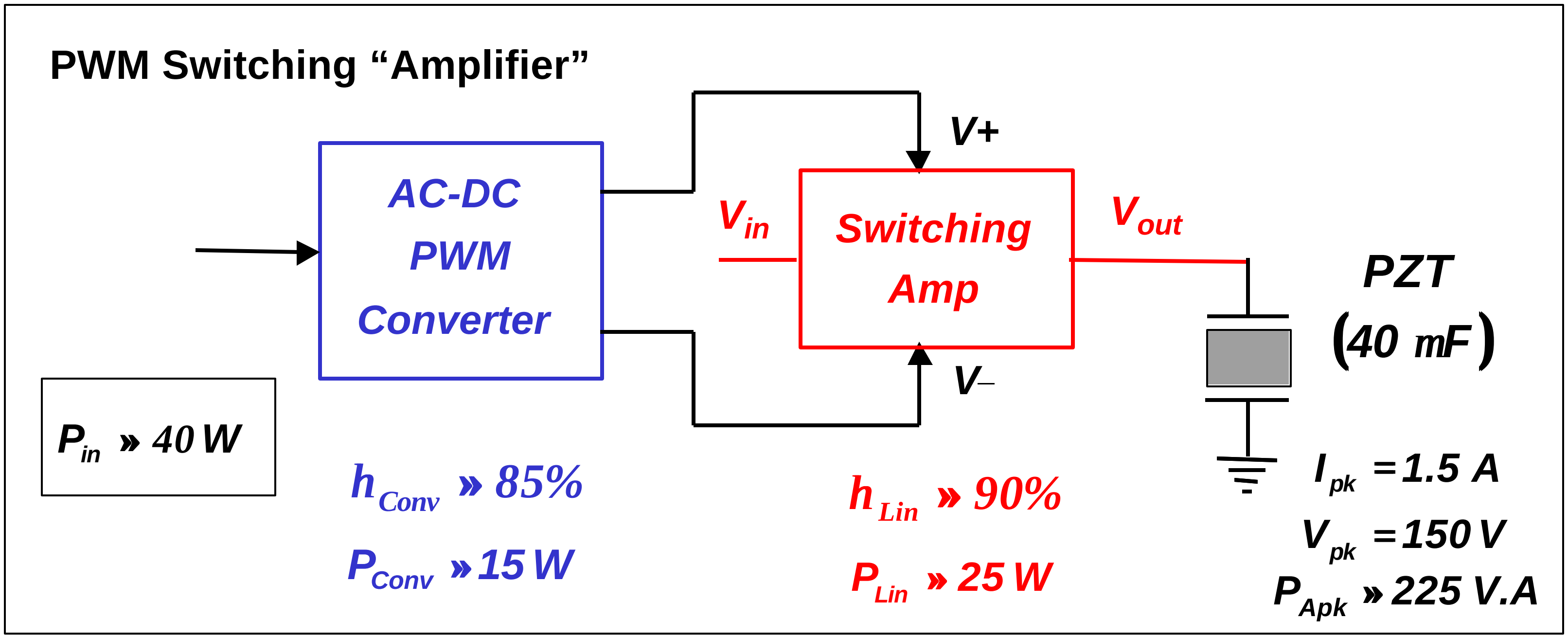
↓ Fair Efficiency

$I_{out} = K * V_{in}$

POC: J. Paine, jpaine@dynamic-structures.com

Efficient, Self-Contained Regenerative Power Electronics

Efficiencies of Various Drivers



Pros & Cons:

↑ Very Good Efficiency

Vout = K * Vin

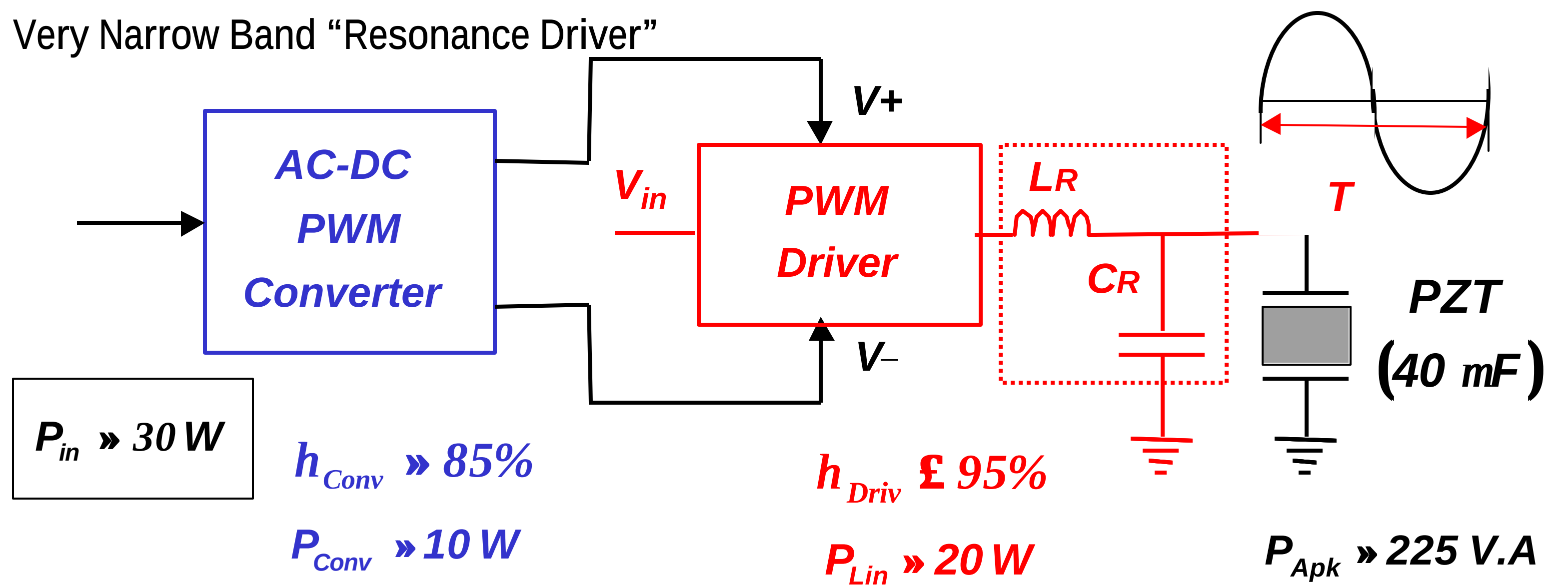
↓ Reduced Bandwidth/Load Range

High Complexity

POC: J. Paine, jpaine@dynamic-structures.com

Efficiencies of Various Drivers

Very Narrow Band “Resonance Driver”



Pros & Cons:

↑ Very Good Efficiency
Low Complexity

↓ Fixed Output Frequency
Volume: Application Dependent

POC: J. Paine, jpaine@dynamic-structures.com

dsm
Dynamic Structures & Materials, LLC

Efficient, Self-Contained Regenerative Power Electronics

Issues on Driver's Size

Large Bandwidth and High Output Voltage & Current Driver

1. Linear Amp:

   High voltage, high current transistor's sluggishness and safe operating area (stress) lead to device paralleling. Inefficiency forces large heat sinks.

2. Switching Amp & Current Driver:

   High switching-frequency and high voltage and current induce large transistor and diode losses and force module paralleling. High voltage, high current filter capacitors exhibit large volume

3. Very Narrow Band Resonance Driver:

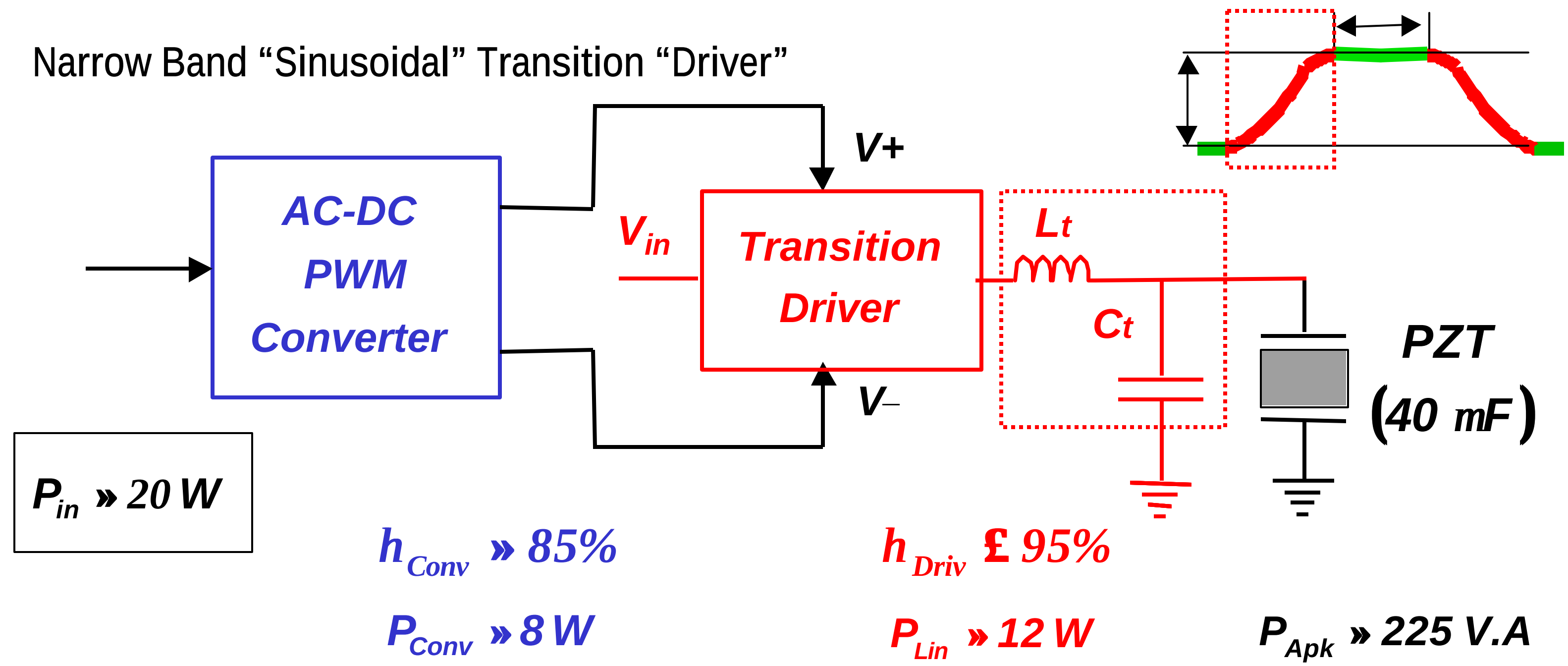
   High voltage, high current, low frequency signals lead to large resonant components.

POC: J. Paine, jpaine@dynamic-structures.com

Efficient, Self-Contained Regenerative Power Electronics

Future Work

Narrow Band "Sinusoidal" Transition "Driver"



Pros & Cons:

↑ Very Good Efficiency

Low Complexity & Volume

↓ Fixed Output Voltage Shape

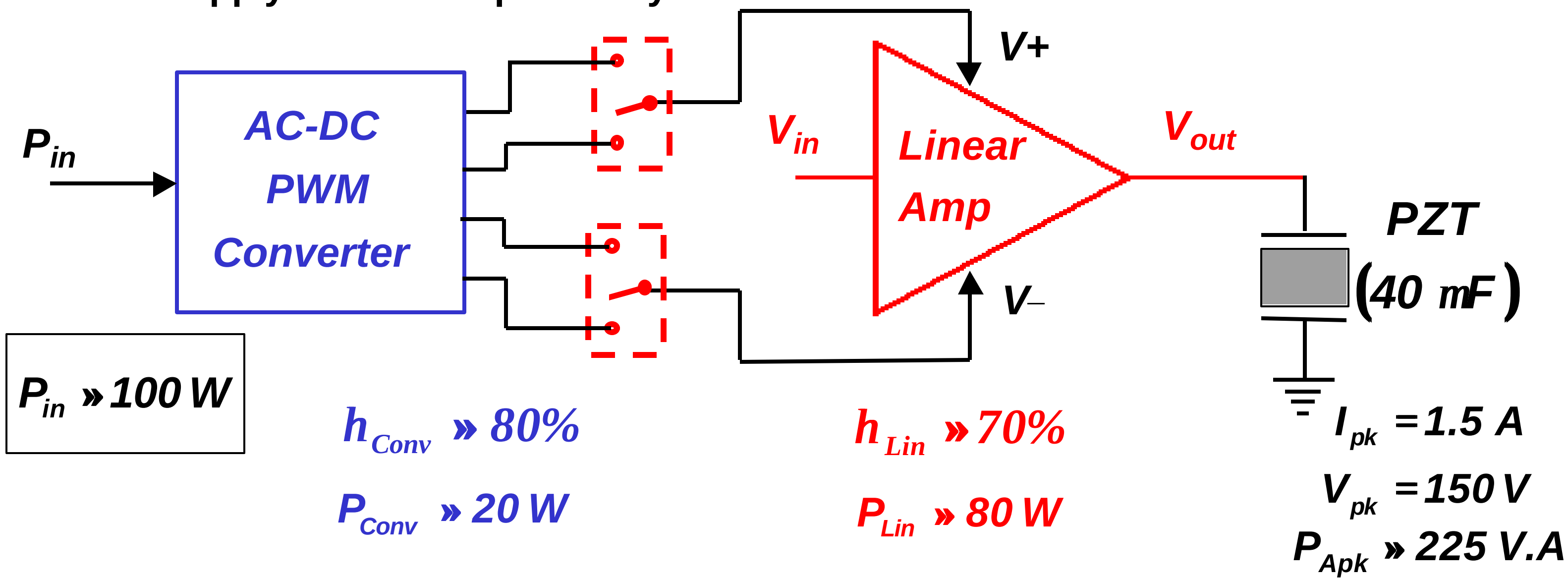
Transition Duration: L/C Dependent

dsm
Dynamic Structures & Materials, LLC

Efficient, Self-Contained Regenerative Power Electronics

Future Work

Variable Supply Linear "Amplifier" System



Pros & Cons:

↑ Large Bandwidth & Output Current

$V_{out} = K * V_{in}$

↓ Good Efficiency

High Complexity

POC: J. Paine, jpaine@dynamic-structures.com