New Generation of Very Small & Precise DC/DC-Modules

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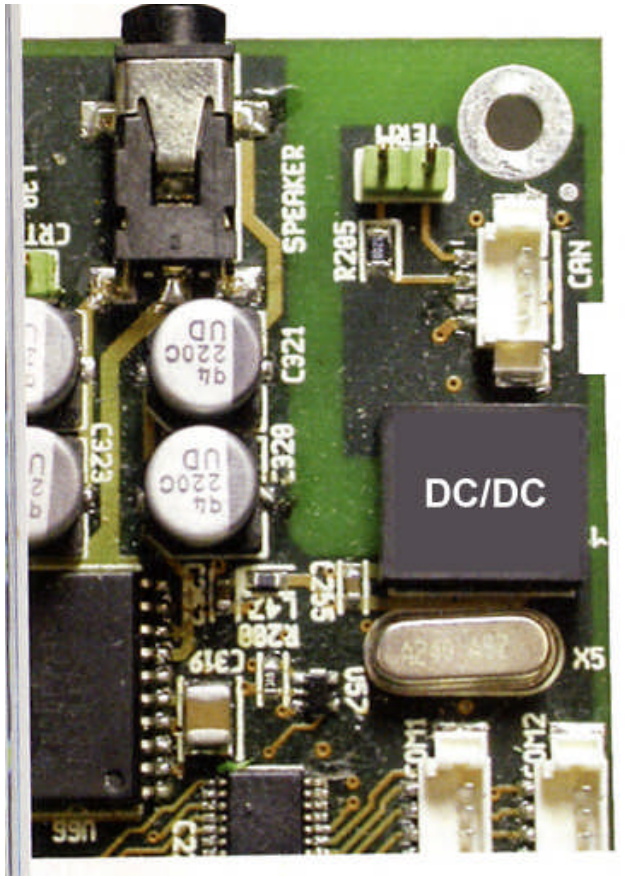
Abstract

Modular low power, un-regulated, isolated DC-DC converters are simple in principle. This talk explains some of the complexities experienced in practice in achieving a design which achieves the best combination of efficiency, load regulation and agency compliance while being cost effective and production-friendly.

Introduction

The device

- Self-oscillating push-pull DC/DC converter (saturable transformer)
- Isolated
- Un-regulated
- Ratio converter
- Low Power, less than 3W

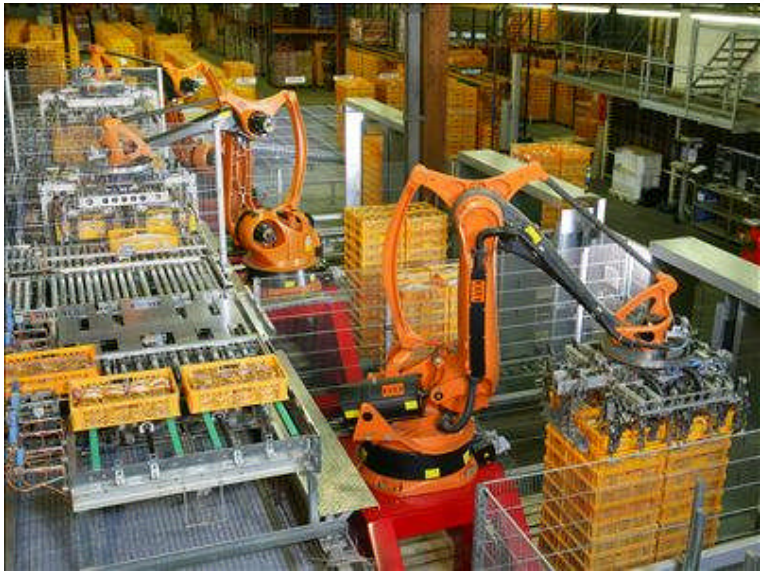


Objectives

- How can performance be maximized
- How can the device be miniaturized
- How can the device be designed for manufacture
- What can be done to reduce costs but meet the application requirements

Applications

- Safety barrier
- Break ground loops
- Creates negative rail from positive
- Voltage conversion



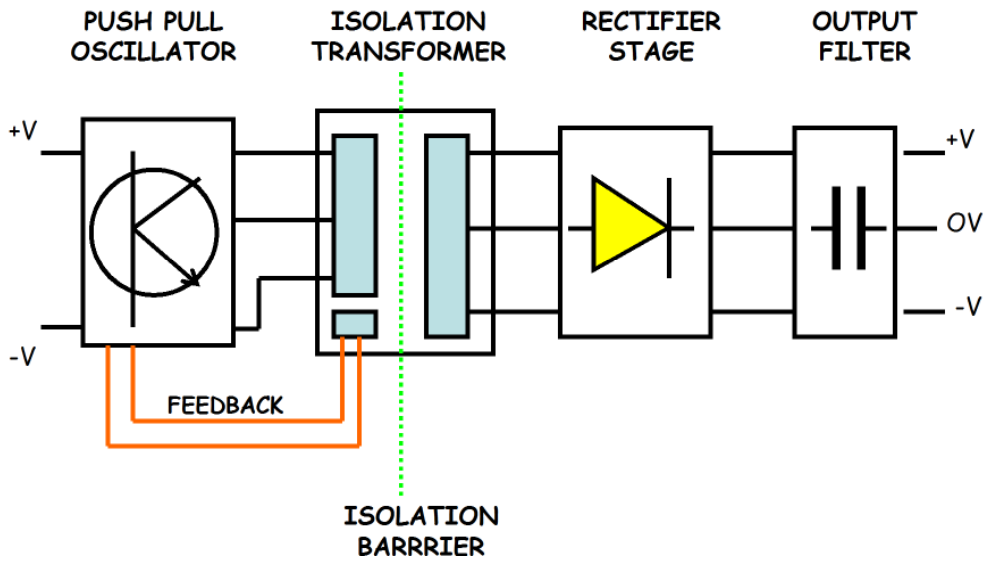
- Programmable logic control
- Motor control
- Sensors
- Instrumentation

Application Requirements

General	Cost effective
	Miniature – Small footprint/small volume
	Reliable
	RoHS compliant
	Safety approvals (UL, etc)
Electronic	Isolation
	Low noise
	Low load regulation
	High efficiency
Operating temperature	Standard industrial temperature range (-40°C to 85°C)
	Extended industrial temperature range (-40°C to 105°C)
Process environment	Reflow soldering
	Wave soldering

Topology

- Self-oscillating push-pull converter with saturable transformer (Royer oscillator)
- Square wave -oscillation
- Relies on the transformer to saturate for the device to switch



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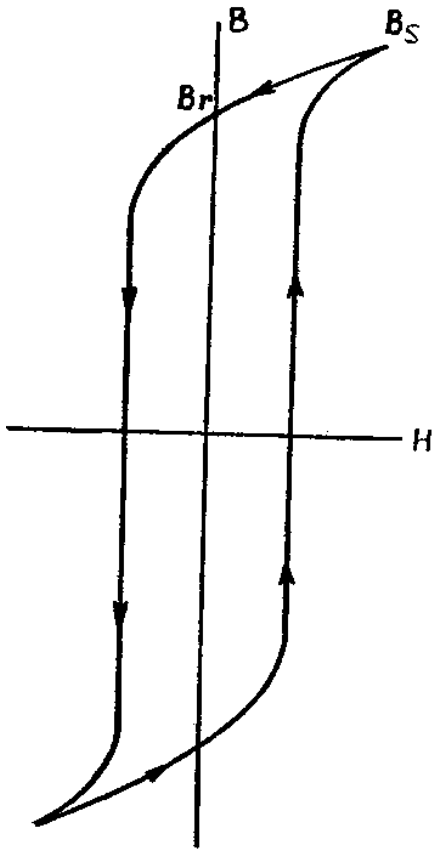
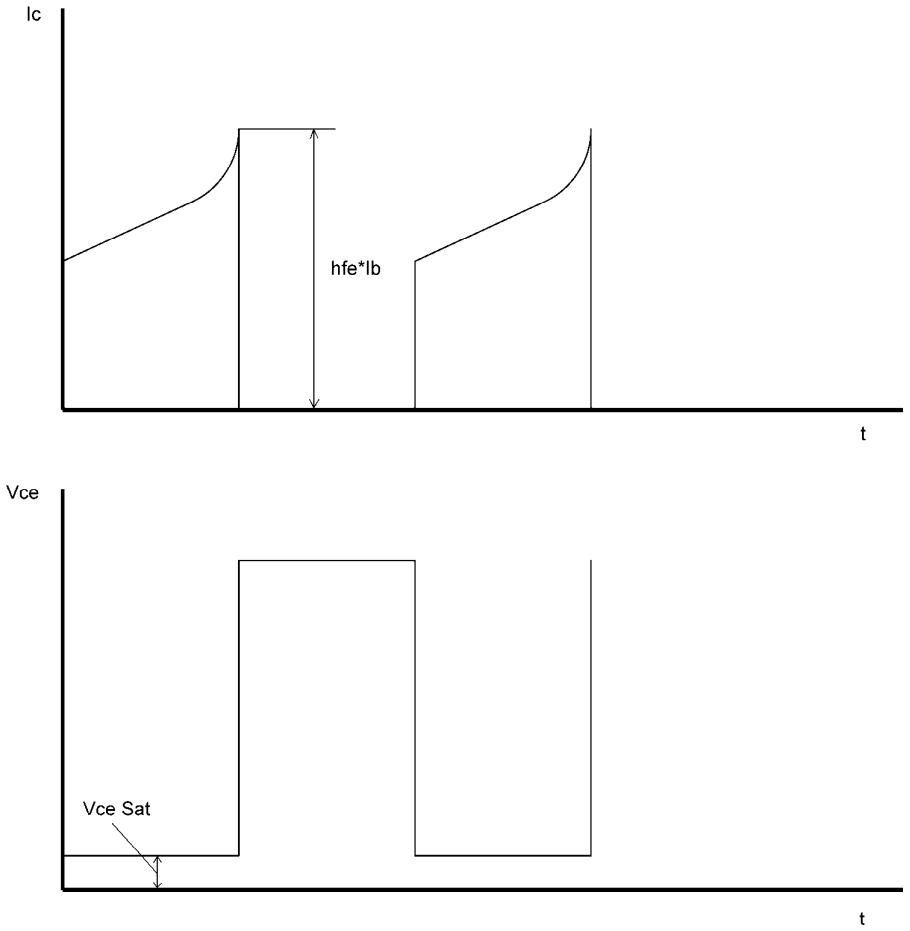
Ideal Transistor Switching Waveforms





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Switching Frequency

$d\phi = 2\phi_s$ (Changes from ϕ_s to $-\phi_s$)

$dt = 1/2f$ (For each half cycle)

$d\phi / dt = 2\phi_s / (1/2f) = 4f\phi_s$

$V = N_{pri} d\phi / dt$

$\therefore V = N_{pri} 4f\phi_s$

$$f = \frac{V}{4N_{pri}\phi_s}$$

ϕ = flux

ϕ_s = Saturation Flux

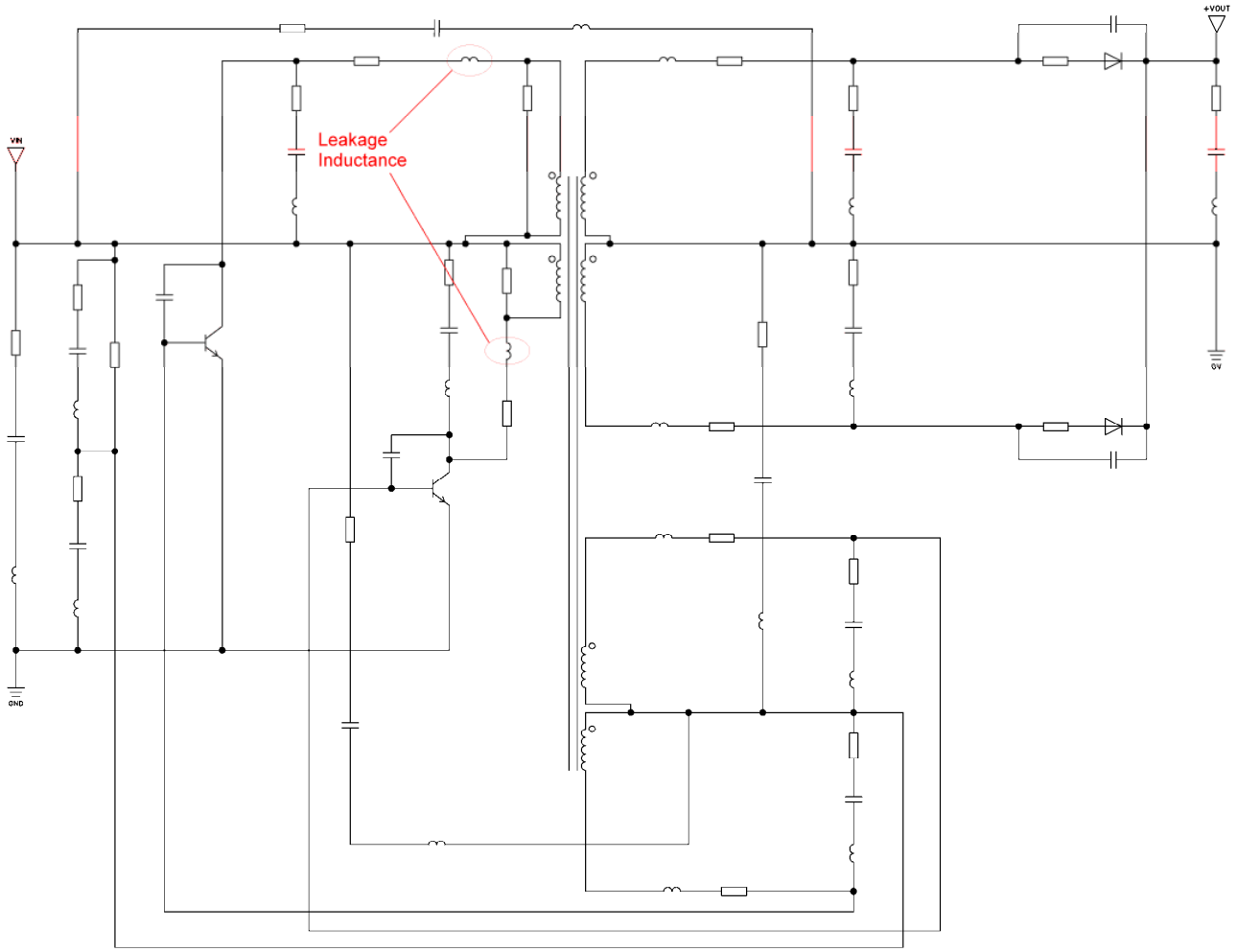
V = Voltage

f = Switching frequency

N_{pri} = Primary turns

A_e = Effective cross-sectional area

Parasitic and Real Components

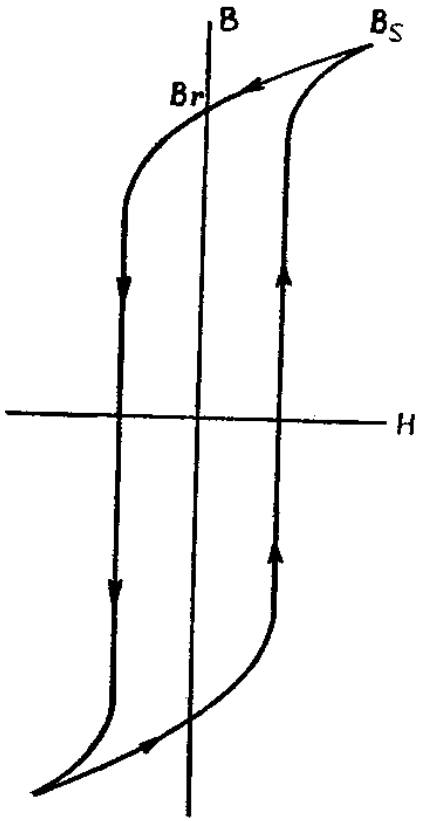


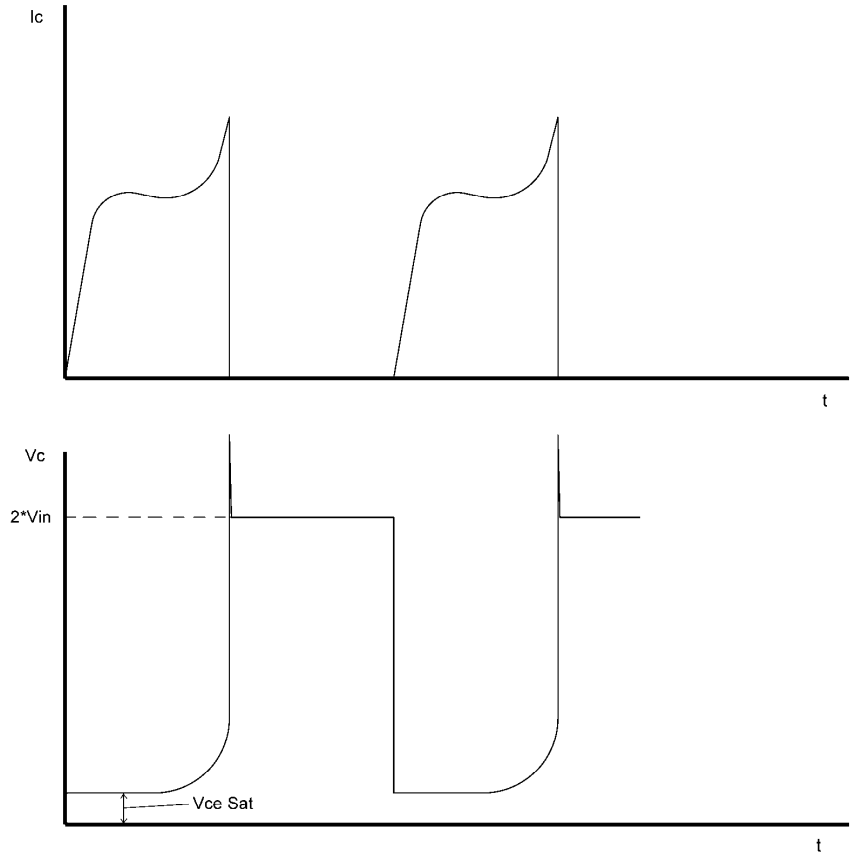
Switching in the Real World

$$E = L_{Leakage} dI / dt$$

- Poor coupling of the primary winding causes high leakage inductance
- This cause high switching spikes when the transistor switches off
- Could cause reliability issues
- High leakage inductance can also cause issues when the converter starts

Transistor Switching Waveforms in the Real World





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Performance Improvements

How can performance be improved

Improve semiconductors

- Reduce Vce saturation of the transistor
  - Reduce Vce saturation
  - Reduce Base drive
- Schottky vs. standard diodes
  - Reduce forward drop of diode
  - Reduce Ir of diodes
- Higher performance components
  - Increase internal placement area

Improve transformer design

- Reduce resistance of winding
  - Increases winding window
- Improve materials, change shape of B-H loop
  - Improve materials
  - Increase the size of core

Optimise parasitic effects

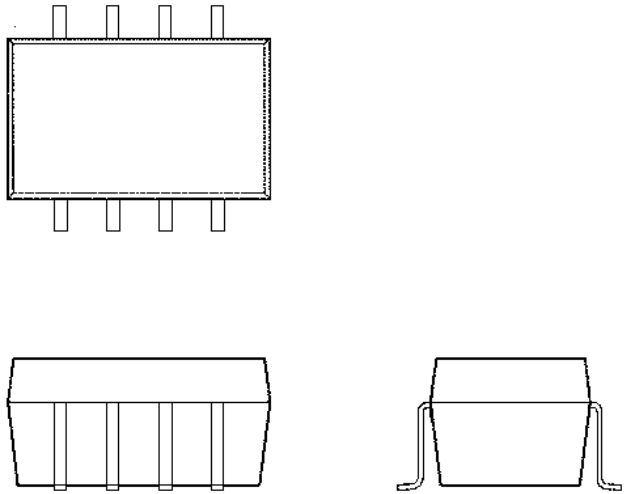
- Improve switching
- Improve efficiency
- Reduce I/O coupling capacitance

Optimise passive components

- Increase internal placement area

Mechanical Design – Current Industry Standard Package

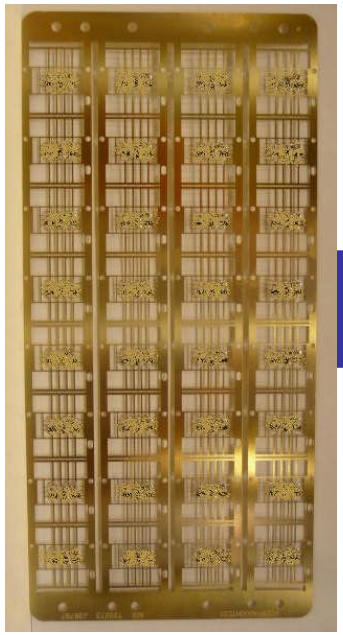
- Surface-mount
- Resin Transfer molded
- Lead-frame design (no PCB)
- Toroidal transformer
- RoHS complaint
- Peak reflow temperature 245°C
- Time above liquidus (217°C) - 60s
- Internal-placement area ~ 45mm^2
- Area available for transformer ~75mm^3

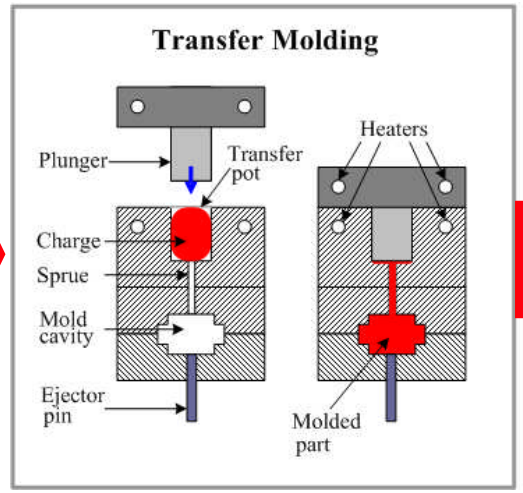


$\text{Footprint} = 1.37 cm^2$

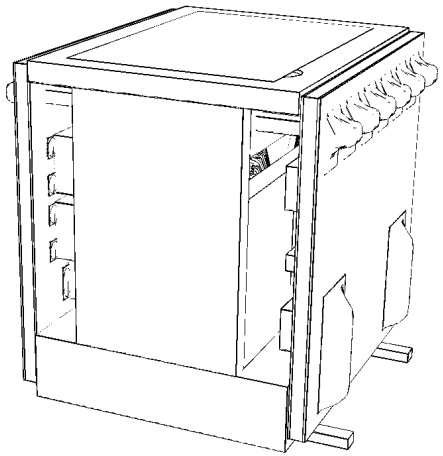
$\text{Power density} = 1.8 \text{Wcm}^{-3}$

Resin Transfer Molded Process





Mechanical Design – New Open-Framed Package

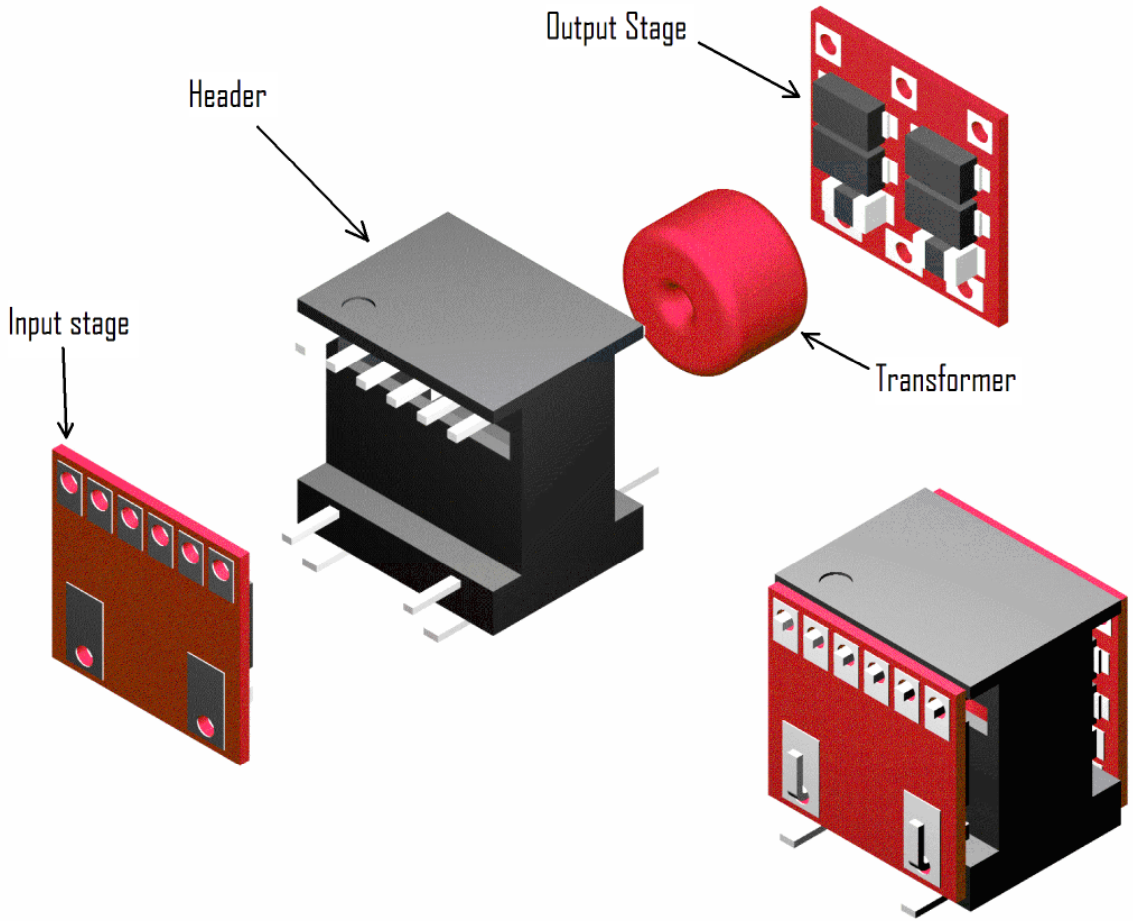


Footprint = $0.69 cm^2$

Power density = $1.71 Wcm^{-3}$

- Surface-mount
- Open-frame design
- Separate PCB for input and output stages
- Toroidal transformer
- Semi-automated assembly
- RoHS complaint
- Peak reflow temperature 245°C
- Time above liquidus (217°C) - 150s
- Internal-placement area ~ 90mm^2
- Area available for transformer ~ 100mm^3

New Open-Framed Package



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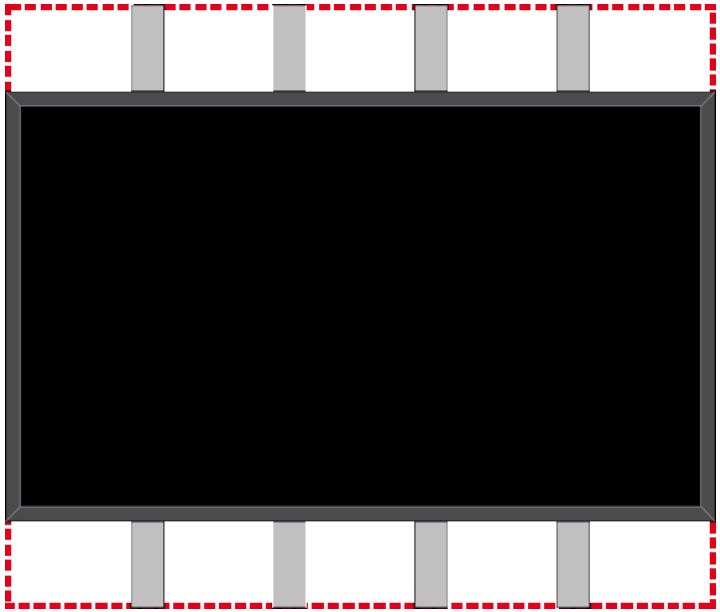
Characteristics – Transfer molded vs. Open Frame DC/DC

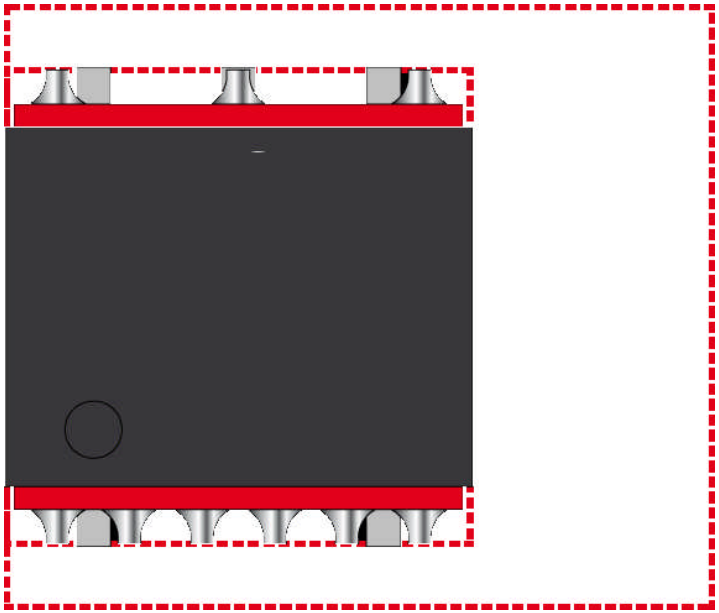
Characteristics	Industry standard Transfer molded DC/DC	New Open-framed DC/DC
Footprint (cm^2)	1.37	0.69
Power density (Wcm^{-3})	1.8	1.71
Internal placement area (mm^2)	45	90
Volume available for transformer (mm^3)	75	100
Efficiency (%)	77	83
Load regulation (%)	10	7

Footprint – Transfer Molded vs. Open Frame DC/DC

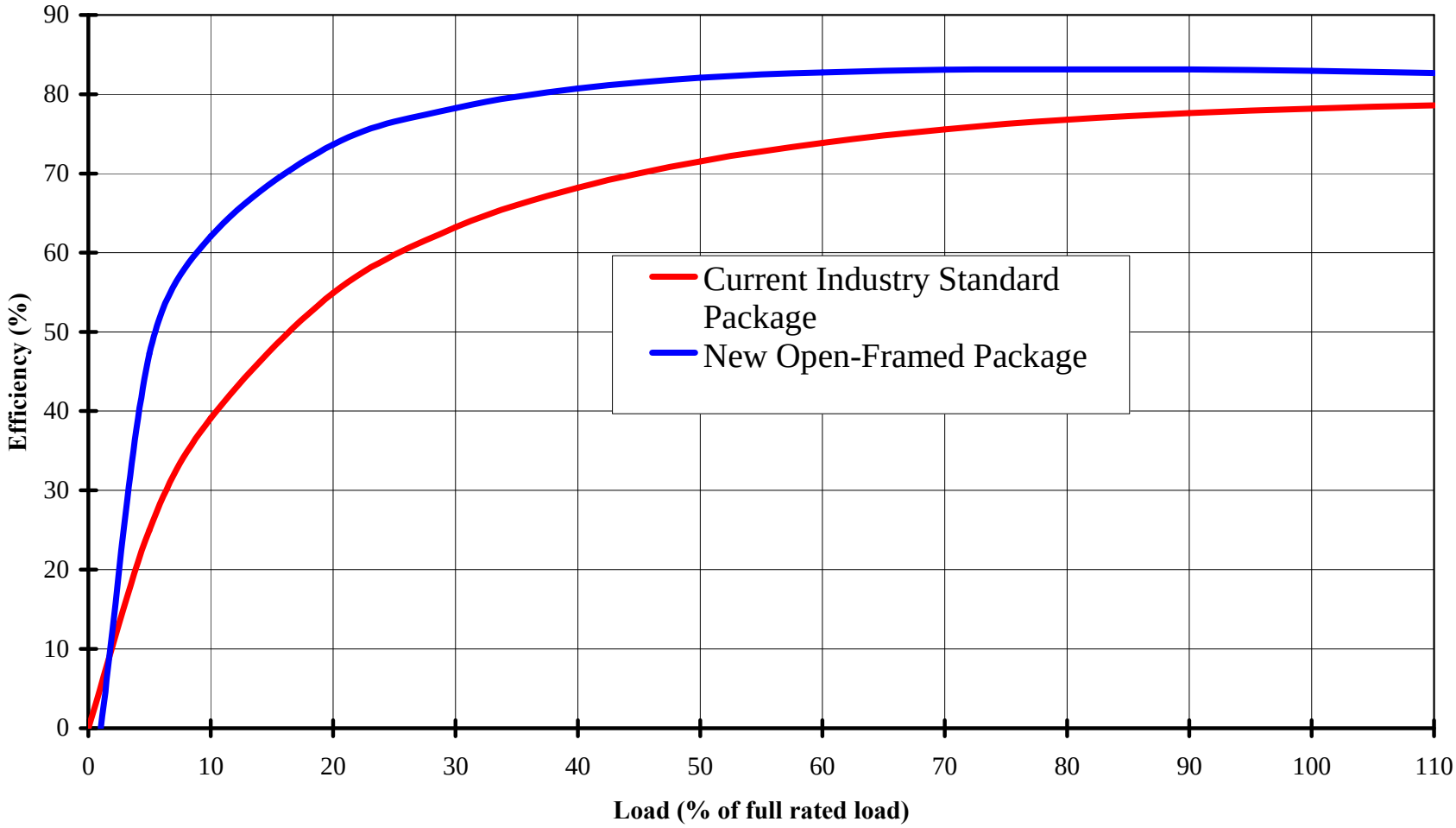
Transfer molded part



Open Frame part



Efficiency Vs. Load



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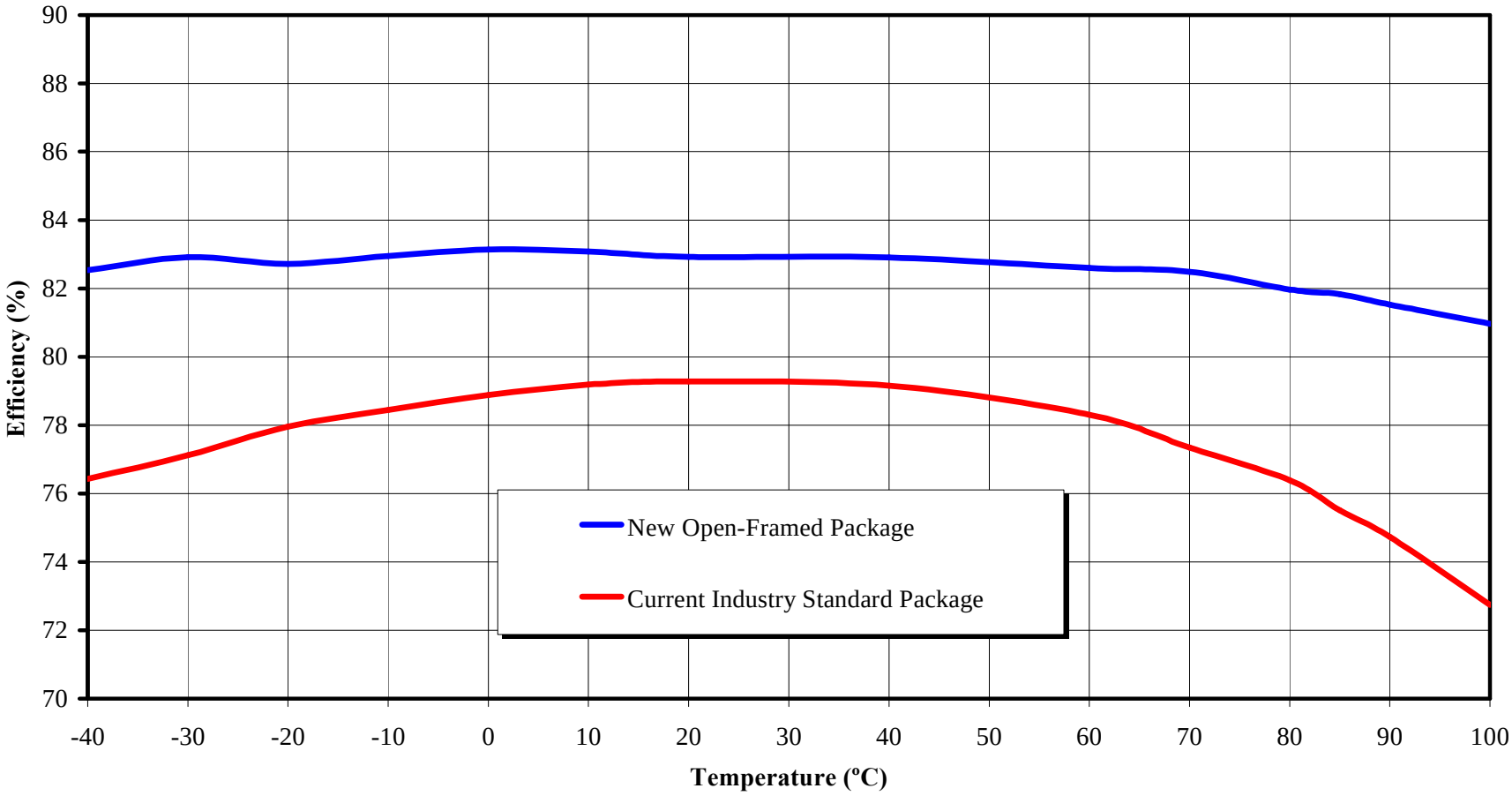
Efficiency Vs. Temperature at 100% Load



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Safety approvals

Industry
- General electronics approvals
- Medical approvals
- Transport approvals
- Etc

Isolation Level
- Functional
- Basic
- Reinforced

Requirements
- Creepage and clearance distances
- Material approvals
- Isolation system approvals
- Time
- Training
- Financial input

Costs

How can cost be balanced with the requirements of the application?

- Pick the correct components for the application
  - Balance parameter - Forward drop of diode vs. Ir, etc
  - Do not compromise on reliability
- Lower the component count
  - Optimise parasitic components
- Design for manufacture
  - Reduce processes
  - Design for assembly
  - Design for automation

Summary

- Design of a low power DC/DC converter is not simple
- Optimisation of Parasitic components can improve performance
- Costs implications should always be taken into account
- Mechanical design is key to achieve the applications requirements
- Questions?