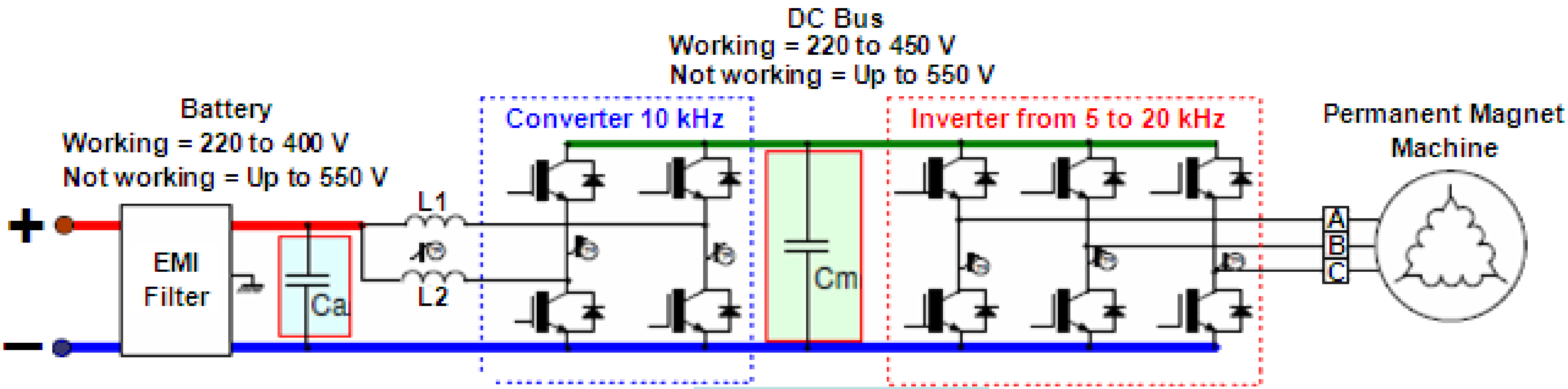
Capacitor Technology for High Density and High Temperature Power Systems Used in EV, HEV and PHEV Automotive Applications

John Prymak – KEMET Electronics
Ian Clelland – Paktron
Laird Macomber – Cornell Dubilier

DC Link & Filter Capacitors
Hybrid and Electric Vehicles

Overview on the application of the "Double Bank Capacitor"

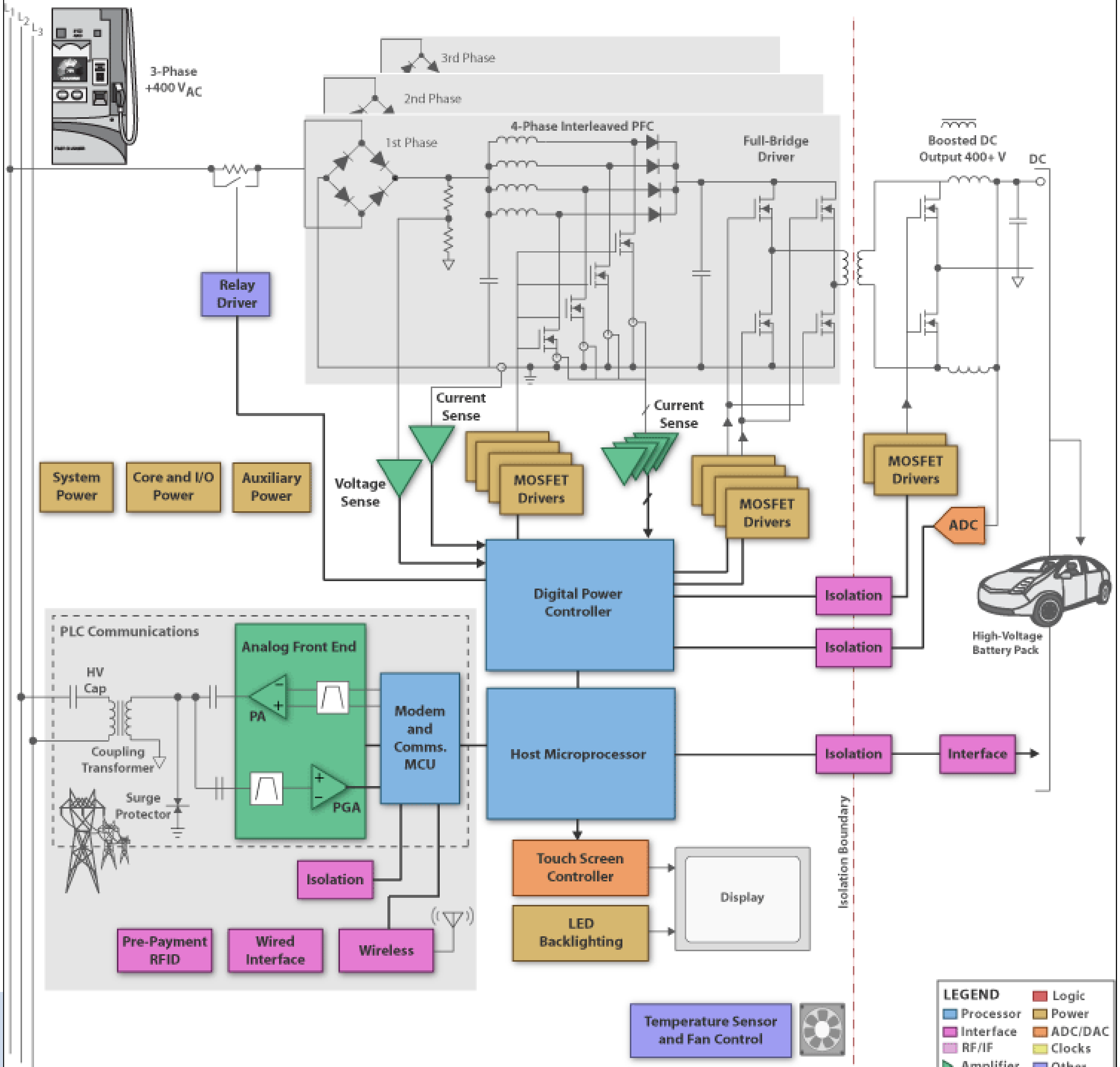


Filter Capacitor
(Auxiliary Capacitor)

DC Link Capacitor
(Main Capacitor)

EV HEV Charger Level 3

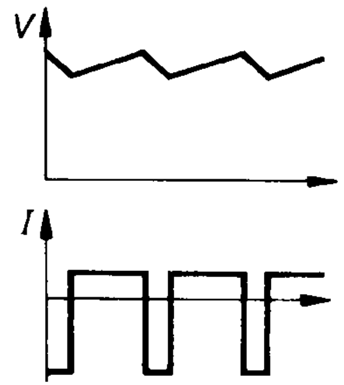
(courtesy of www.TI.com)

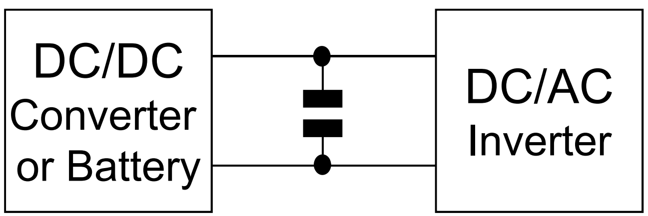


Power Converter
DC Link Capacitor

Function:

To support a DC network by supplying periodically high currents
(High Power Decoupling)





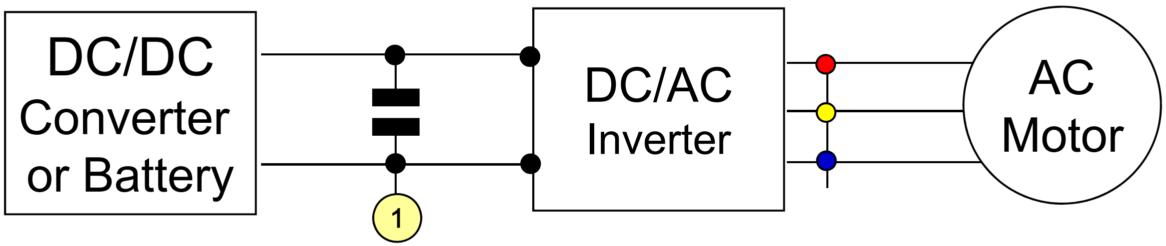
General Requirements:

Life Expectancy:	>10 years (20k hours in operation)
ESR:	low
Ripple Current:	High capability

Proposed Capacitor Technologies:

- Film
- Aluminium Electrolytic

Automotive EV, HEV Drive DC-link



Capacitor Functions:

a) enable quick energy transfer into IGBT circuit
b) smooth out DC-bus voltage variation
c) prevent ripple from interfering back to DC power source

1 DC-link (Film)

- Voltage capability requires no cascading
- Self-healing optimized with necked-down electrode patterns
- Self-healing maximized with polypropylene (PP)
- Higher cost solution

1 DC-link (Electrolytic)

- Requires cascading for high voltage (multiples of 2x to 9x for capacitance)
- Low temperature greatly reduces cap
- Dry-out over time results in lower cap, higher ESR, greater heat – eventually to short
- Lower cost solution

Comparison of Film and Electrolytic Technologies

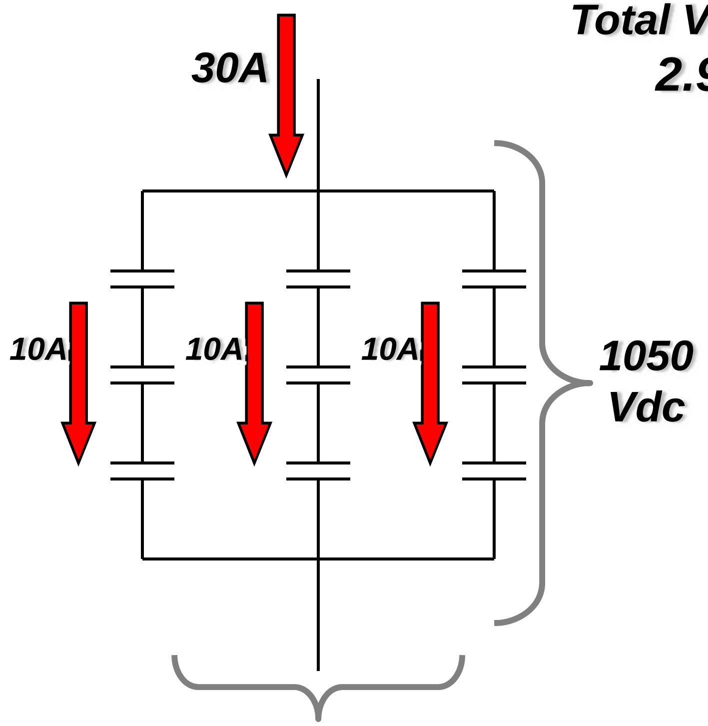
Design Conditions of DC-Link Capacitor for 3 phase AC Motor Drive

Output V	690Vac
DC-Link Voltage	1,000Vdc
Max Ripple Voltage allowed	100V
Frequency	50Hz
Min Capacitance	500μF
Ripple Current	30A
DC-Link Frequency	300Hz
Ambient Temperature	75°C

Comparison of Film and Electrolytic Technologies

ELECTROLYTIC CAP

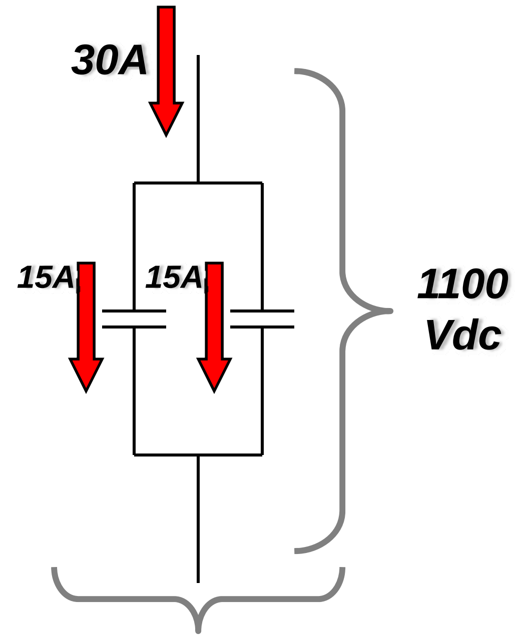
Total Volume
2.94



1500 µF
9x1500 uF @ 350 Vdc
3 times Capacitance Project

FILM CAP

Total Volume
1.59



500 µF
2x250 uF @ 1100 Vdc
(stable over years)

Dominant Film Types

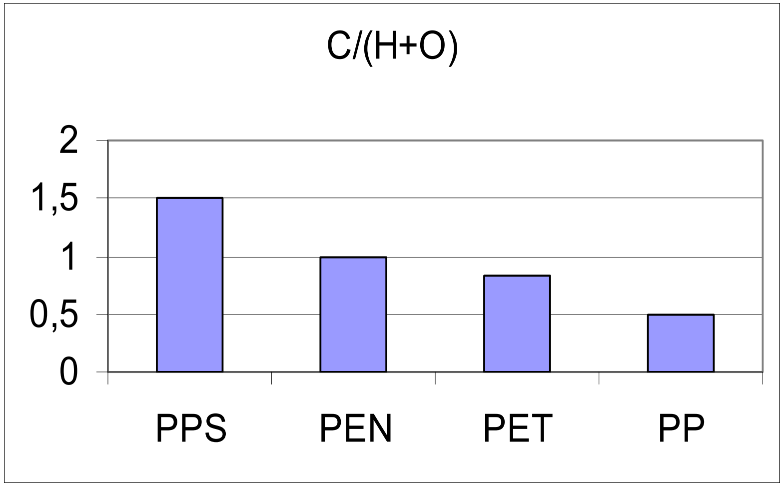
Film	Code	Best Tol. (±%)	(C/Cn-1) -25℃ to 85℃	Aging (%/yr)	DF (Typ)	Max. Temp. (℃)
polypropylene	PP	1	-3%	0.2	0.05%	120
polyethylene napthalate	PEN	5	5%	0.4	0.48%	155
polyethylene terapthalate	PET	5	5%	0.4	0.50%	140
polyethylene sulfide	PPS	2	±0.5%	0.3	0.20%	260

Clelland, I., ITW Paktron and Laird Macomber, Cornell-Dublier; iNEMI 2006 Report - Passives

Impulse Voltage Test (Capacitor Self-healing)

Comparison between different materials:

FILM	C	H	O	S	C/(H+O)
PPS	6	4	0	1	1.50
PEN	14	10	4	0	1.00
PET	10	8	4	0	0.83
PP	3	6	0	0	0.50



The graph shows what follows:

- the worst material is PPS;
- the best material is PP;
- PET is slightly better then PEN.

DC Link Capacitors
Hybrid and Electric Vehicles

- **Essential questions for a DC Link capacitor are :**
  - What is the **Capacitance** and **Voltage** profile
  - What is the **AC Spectrum Frequency** and **Ripple Current**
  - What is the **Ambient Temperature** and possible **Cooling**
  - What is the **Inductance** needed
  - What are the **Mechanical Stresses / Vibration and Shock**
  - What is the **Mechanical Shape/Dimensions/Connections**
  - **Is self-healing required? (Fail-open versus Fail-short)**

- **Hybrid Vehicles**' Internal Combustion Engine requires in general higher temperature capacitors than Full Electric vehicles

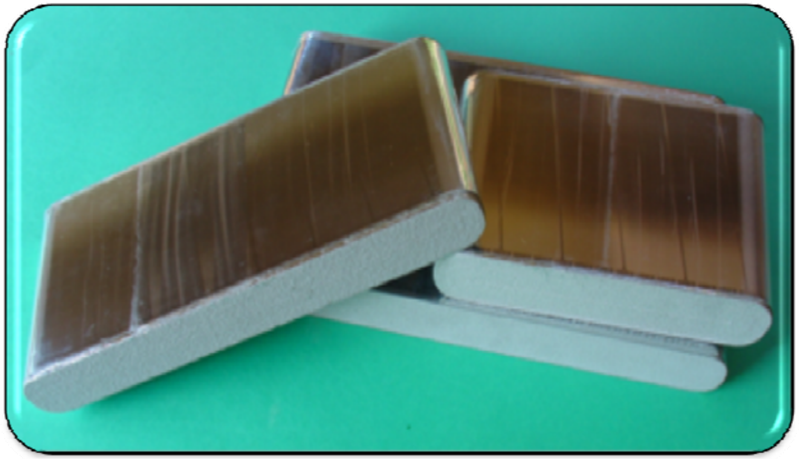
FILM Dielectric Technologies: PET, PEN, PPS, and PP

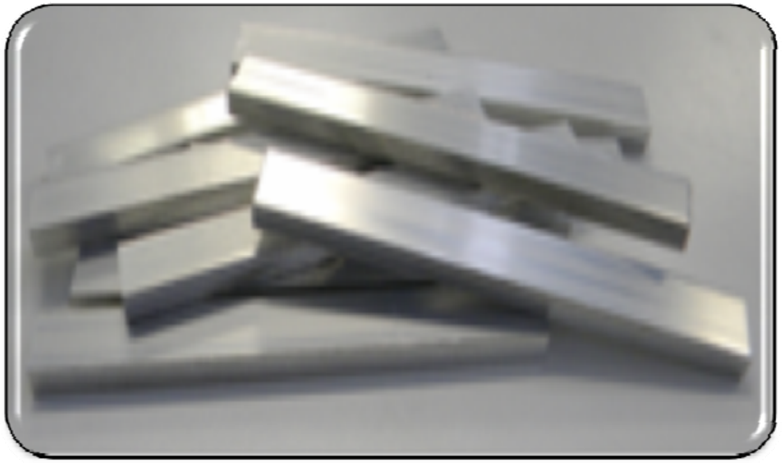
wound elements

- Film width up to 60mm
- Simple or series construction
- High Cap
- Max. voltage 2000Vdc
- DC-Link PET < 300V or PP

Stacked elements

- Film width up to 45mm
- Simple or series construction
- Typical x 100uF blocks
- Max. voltage 500Vdc
- DC-Link PET <300V or PP

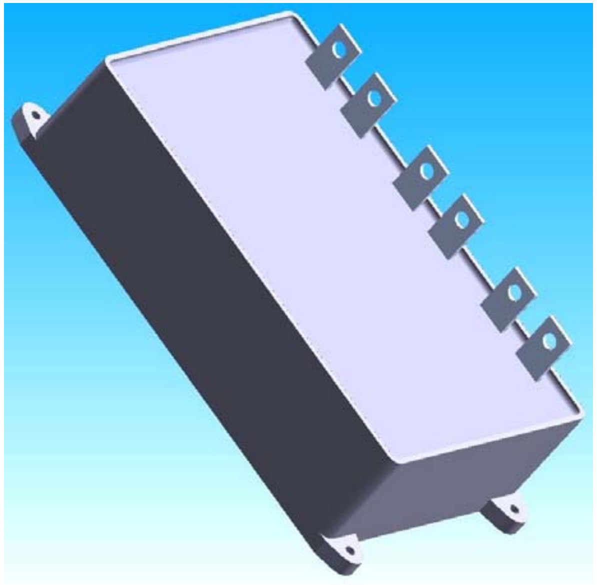


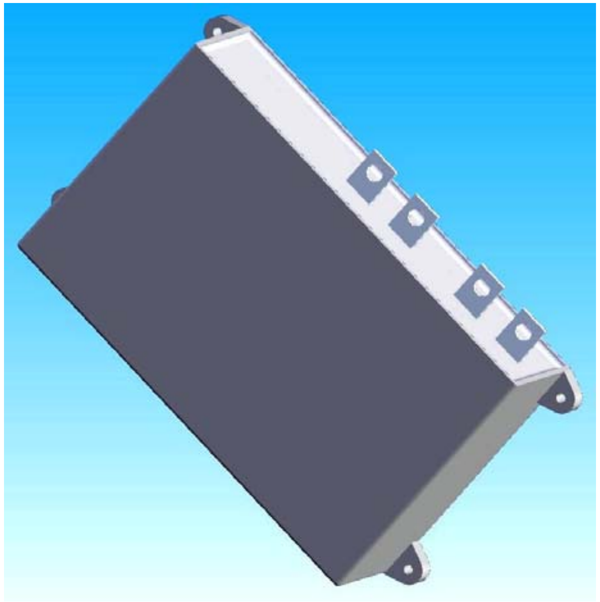


DC-Link Film Capacitors: Automotive
High ripple & Cap & Temp Modules

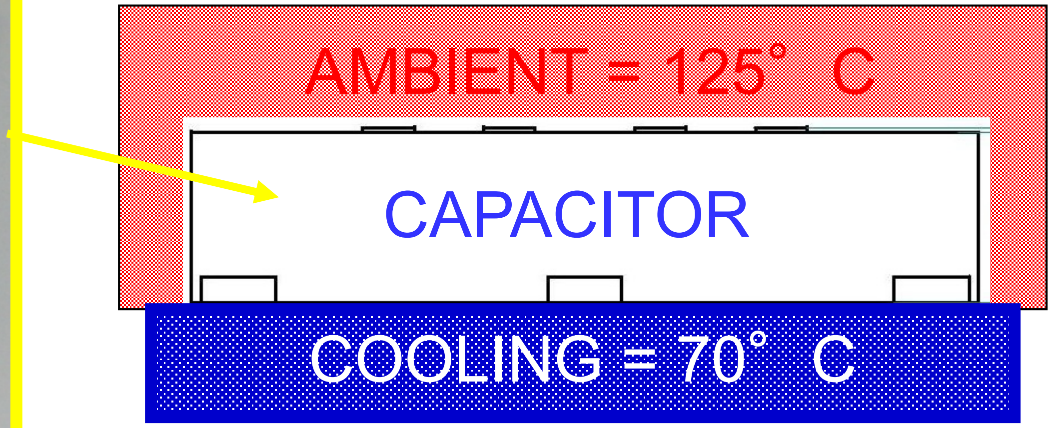
- **"Soft-winding Brick Thin Film**
  - Dielectric : metalized polypropylene (PP) film, thickness<3.5µm
  - Winding : non-inductive type with flattened oval shape
  - Case : plastic or metal material
  - Terminals : high current screw or tinned copper bus-bar

- **"Stacked" – Brick**
  - Dielectric : metalized polypropylene PP and polyethylene teraphthalate PET
  - Winding : non-inductive type with several stacked cut elements
  - Case : plastic or metal material
  - Terminals : high current screw or tinned copper bus-bar





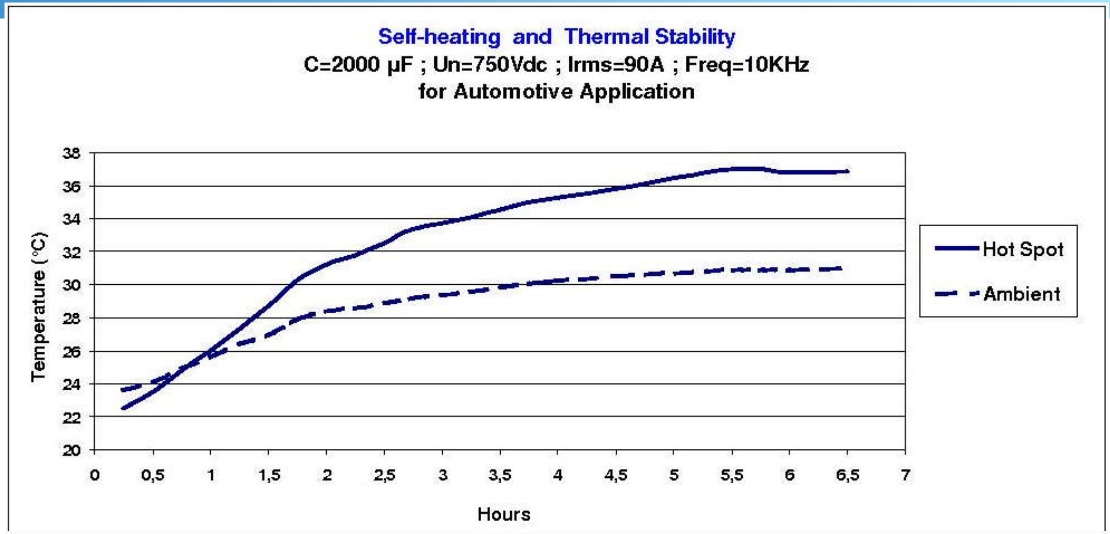
Automotive DC-Link Capacitors
Heat Dissipators, Soft Winding

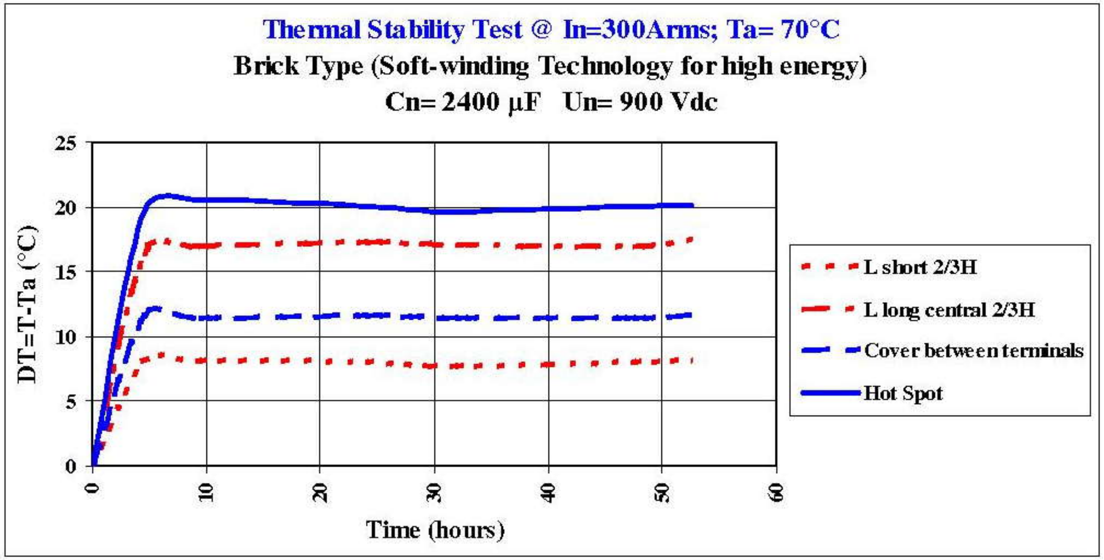


DC-Link Capacitor for Hybrid Vehicle

Advances in Film Capacitors

- Ripple Current and Thermal Stability





Film Capacitors: Working Life Time

- Film Advantages:

  - High rated voltages (no need of series connections and balancing resistors

  - Stability vs. time of Capacitance and ESR

  - Long life

  - Low dissipation / high ripple current

  - Low losses and high efficiency

- Long life contributing factors:
  - new metallization configuration of the film,
  - plastic or metallic housing, sealed by epoxy or polyurethane resins,
  - new production process for the thermal treatment.

- Working life time at rated voltage using these technologies :
  - "Soft-winding for thin film in Brick" for Automotive applications : 20,000hours at 90°C ambient temperature.

DC Link Capacitor
KEMET Commercial Solutions - Film

General Construction

Typical rated voltages:	600-700 Vdc	automotive,(welders)
	(900 Vdc	solar converters
	1100 Vdc	wind converters
	1300 Vdc	wind converters)

Typologies: Mainly dictated by the layout and the mechanical needs:

Individual or Box types for PCB mounting

- Most adaptable, least expensive

Aluminum Can types for modular configurations (cable and bus bar)

- Cheaper than brick if less than 2000 µF required
- Less efficient in terms of dimensional occupation / flexibility of form factor

Custom Brick for the best dimensional efficiency (cap density/volume)

- Can work at higher power / temperatures due to the special soft winding capacitive elements used that optimize the thermal dissipation

DC Link Capacitor
Commercial Solutions – KEMET Electrolytic

General Construction

Typologies:

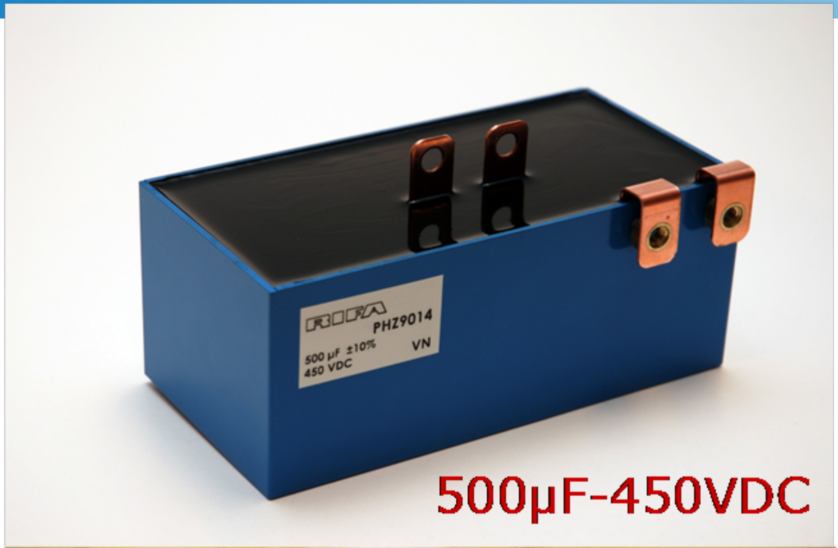
Snap-In types for low power drives/inverters/(UPS,)

PCB mounting
- ALC10, ALC40 (European manufacture)
- PEH506, PEH536 (Chinese manufacture)

Screw Terminal for medium to high power drives/inverters/(UPS)
- ALS30/31, ALS40/41, PEH200, PEH169 (European manufacture)
- ALS32/33, ALS42/43 (Chinese manufacture)

All electrolytic capacitors manufactured using extended cathode construction for enhanced thermal dissipation.

KEMET DC Link Capacitors
Custom Brick Design Examples



500µF-450VDC


850µF-450VDC

1000µF-600VDC


1000µF-450VDC

DC Link Capacitor
Commercial Solutions – CD Electrolytic

<u>General Construction</u>

Typologies: Snap-In types for low power drives/inverters/(UPS,)

PCB mounting

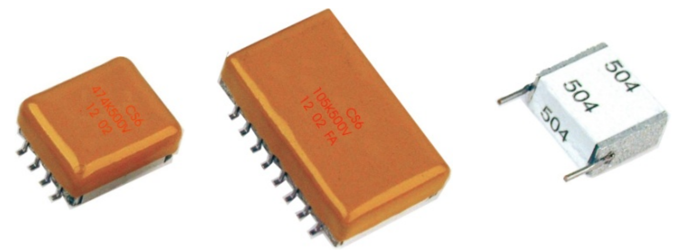
Screw Terminal for medium to high power drives/inverters/(UPS)

All electrolytic capacitors manufactured using extended cathode construction for enhanced thermal dissipation.

HEV Inverter Power Film Capacitor
Cornell Dubilier

Paktron 500-volt Technology For On-Board Converters

0.47μF   1.00μF   0.50μF



Parameter	0.47μF	1.00μF	0.50μF
Capacitance Tolerance	±10%	±10%	±10%
Dissipation Factor	≤1.0%	≤1.0%	≤1.0%
Insulation Resistance (MΩ)	>1000	>1000	>1000
Temperature Range (°C)	–55 to 125	–55 to 125	–55 to 125
ESR @ 500 kHz (Ω)	0.011	0.008	0.100
Irms @ 500 kHz (A)	6.2	9.5	5.8
Max dV/dt (V/μs)	120	120	120

Multilayer Polymer Film (MLP)
Stable under DC voltage
Stable under AC voltage
Chip is plastic with good TCE
Stable over temperature
No aging mechanism
Resilient under thermal shock
Self-clearing thin electrodes
Stable under mechanical stress
Low Cost
Ultra Low ESR
Dissipation Factor ≤ 1%
High dV/dt
SMD and Thru-hole Mounting
Flame Retardant Enclosures

Detailed

LIGHTING/AUTOMOTIVE

HID – Xenon Technology

Lighting Automotive
HID – Xenon vs. Halogen

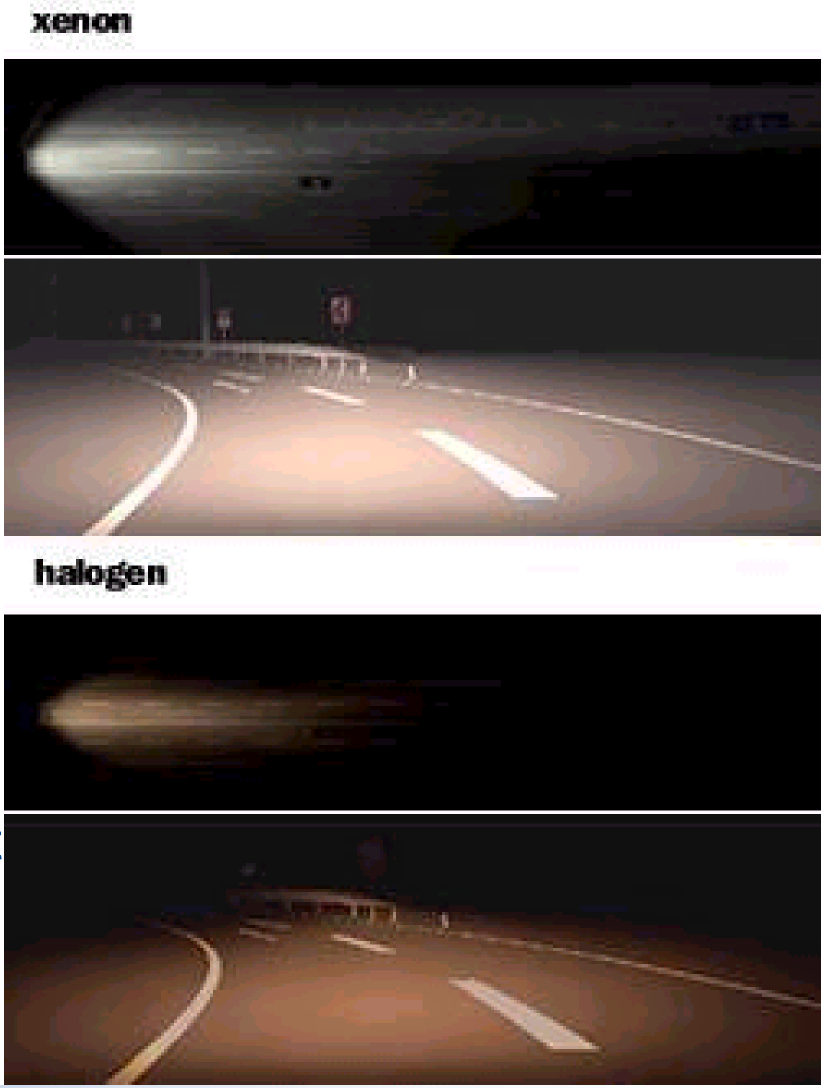
H I D = High Intensity Discharge Lamps

Benefits:

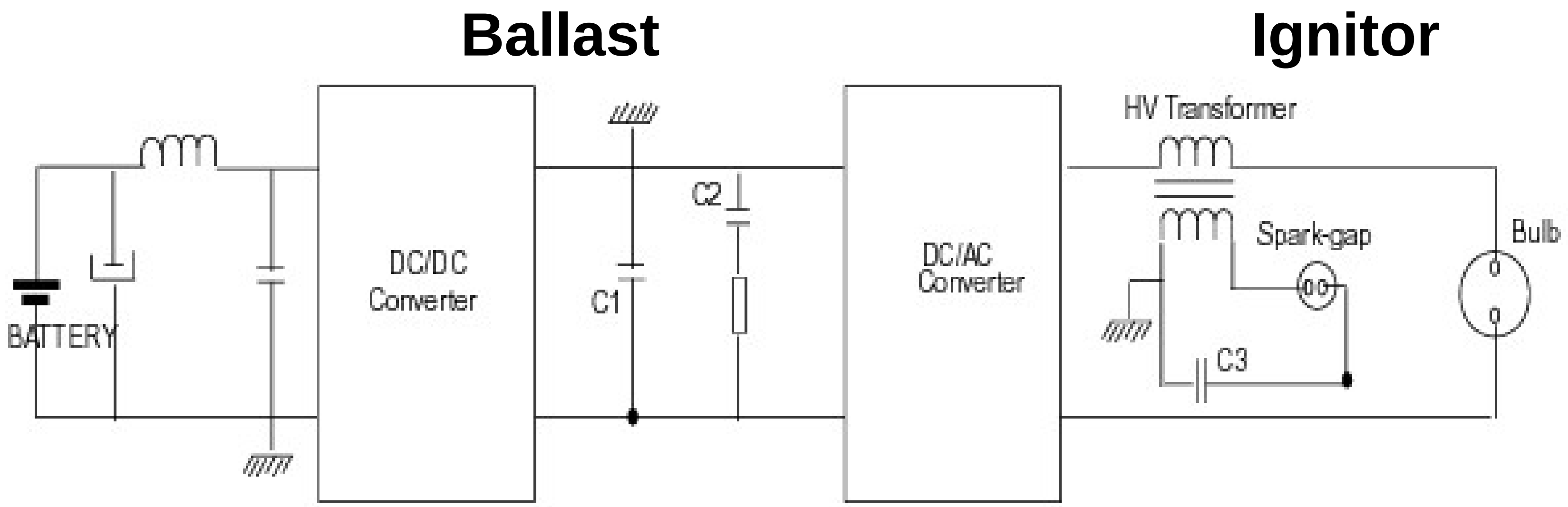
- 3 x brighter
- 3 x longer life ~ 6000 hours
- 2 x as efficient ~ 35W

Process:

- Initial ionized Xenon gas in the bulb changes energy states.
- After initial ionization, the light-emitting arc is sustained by 90VAC
- The resulting arc emits high intensity light



HID – Xenon
Two-Stage Electrical System



DC-DC Step-up converter: boosts the battery voltage to the ignition voltage.

DC-AC full bridge inverter:

converts DC to a low frequency square wave.

Two Inverter operating modes:

i) voltage-source mode prior to ignition

ii) current-source mode after ignition during steady state operation.

FILM – HID, Xenon
Capacitor Functions & Requirements

C1: Ballast filter capacitor Function

filters the 100kHz current pulses from the flyback inverter

C2: Ballast boost capacitor energy preheats the lamp electrodes and enables the glow to arc transition of the HID lamp.

- Max working temperature: 135˚C → high temperature rating
- High switching frequency 100 kHz → low DF
- Severe vibration characteristics → robust design

C3 Ignitor Capacitor Function:

The ignition transformer, the ignitor capacitor and spark gap generate a high voltage pulse to ignite the lamp .

- Max working temperature: 150˚C → 170˚C hotspot temperature
- Max dv/dt :6000 V/µs → 300 to 600A peak currents
- Severe vibration characteristics → robust design
- fit in the integrated ignitor assembly → small dimensions

FILM – HID, Xenon Technology
KEMET Solutions

C1 Ballast Filter Capacitor PEN: SWN / GMW

Capacitance range: 0.33µF to 0.56µF

Rated voltage: 400 Vdc

C2 Ballast Boost Capacitor:

Capacitance range: 1µF to 1.5µF

Rated voltage: 250 Vdc

C3 Ignitor Capacitor PEN: HNS Series

Capacitance range: 70nF to 120nF

Rated voltage: 1000 Vdc

Paktron Technology For Lighting

100Vdc		250vdc	500Vdc		
4.00 µF	10.0 µF	1.00 µF	0.47 µF	1.00 µF	0.50 µF

Part	Lead Spacing (in.)	Dimensions (TxHxW) (in.)	Temperature Range (°C)
4.00 µF @ 100 Vdc	0.400	0.200x0.380x0.394	–55 to 85
10.00 µF @ 100 Vdc	0.400	0.250x0.995x0.500	–55 to 85
1.00 µF @ 250 Vdc	0.600	0.300x0.440x0.700	–55 to 85
0.47 µF @ 500 Vdc	0.600	0.320x0.625x0.700	–55 to 125
1.00 µF @ 500 Vdc	0.600	0.320x1.135x0.700	–55 to 125
0.50 µF @ 500vdc	0.600	0.280x0.540x0.650	–55 to 125

MLCC Lighting Application: Customer Requirement Example

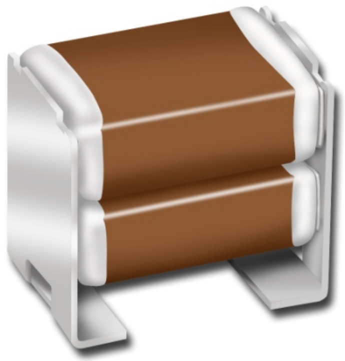
- 500nF @ 430v and 150°C
- 3 positions currently available with 1812 pad sizes
- 4000 hour life time required at these conditions
- Customer considering Aluminum substrate

- Current Status:
  - Supplied 1812 330nF 500V rated prototypes
  - TCVC @ 330nF 430V and 150°C loses 80% of cap = 66nF X 3 positions = 198nF

- Based on these design constraints we recommend (see next slide)…

MLCC Lighting Application: KEMET Solution Alternatives

- Option 1
  - Use 3 KEMET KPS 2x1812 330nF J lead stacks with current pad layout
  - Total cap 396nF at required conditions lower than 500nF but may be enough
- Option 2
  - Use 3 KEMET KPS 2x2220 470nF J lead stacks but with larger pad layout for 2220
  - Total cap 564nF at required conditions meeting the 500nF requirement



Thank You