"OPTIMALLY SELECTING PACKAGING TECHNOLOGIES AND CIRCUIT PARTITIONS BASED ON COST AND PERFORMANCE"

Presented as plenary paper at the IEEE Applied Power Electronics Conference, 2000, by John B. Jacobsen and Douglas C. Hopkins

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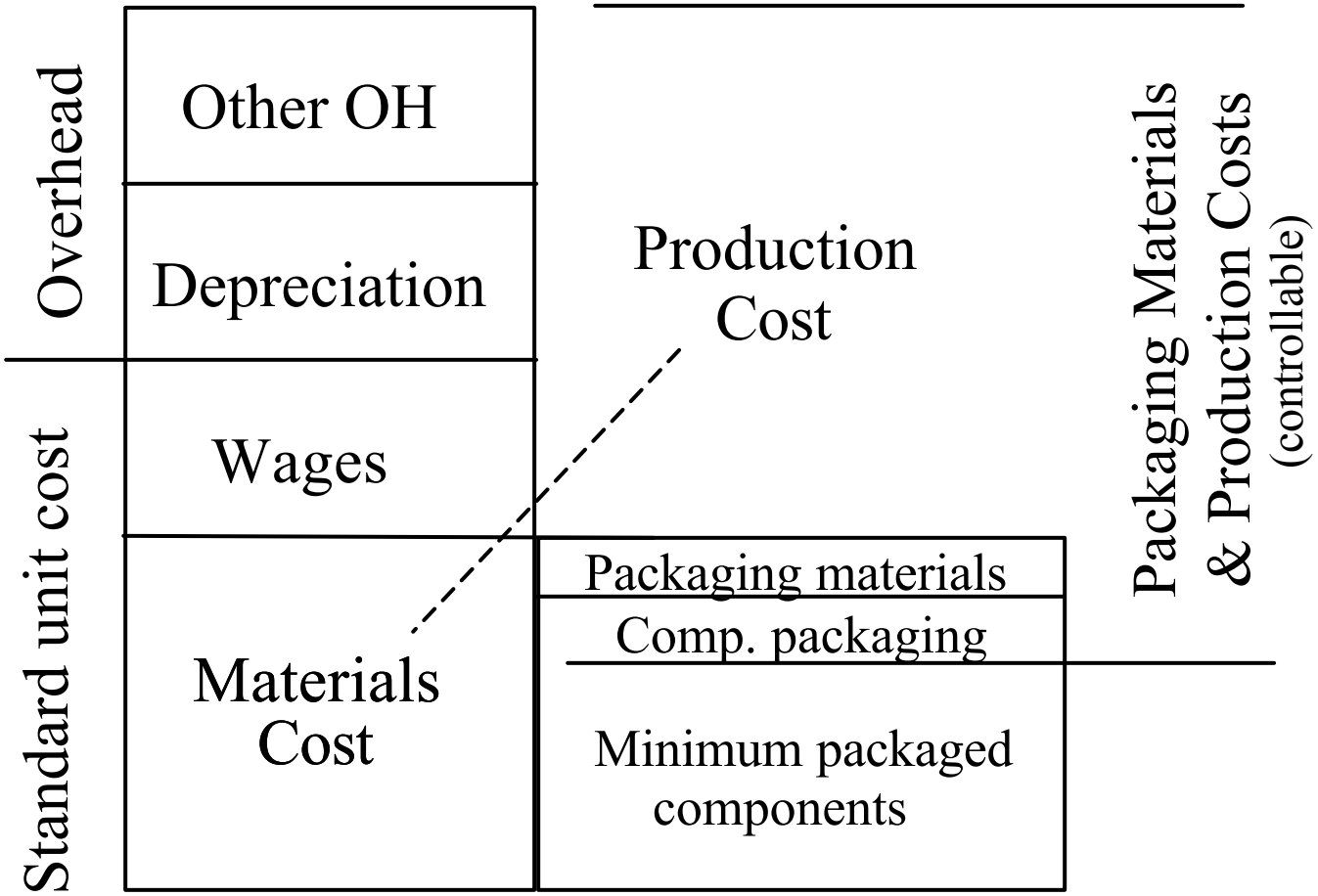
Full-Cost Model



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Centers of Cost

- *Materials cost* represent direct costs of packaging materials.
- *Production cost* includes factors for wages and product volume, but are independent of material costs.
- *Partitioning cost* is incurred for each technology used.
- *Full cost* combines material and production costs.
- *Product business cost*, i.e. return on investment for development of one product, is an investment in future payback. The total cash flow from development until end of production determines the business costs for a product.

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Centers of Cost (con'd)

- *Company business cost*, i.e. return on investment for cross-product usage, reflects the cost of sub-optimization within one single product.
  - Reusing the same packaging technologies, designs (diagrams) and even physical circuits (building blocks) across different products should be measured at the company level. The value of building blocks becomes obvious through savings in repetitive development costs and maintenance of function

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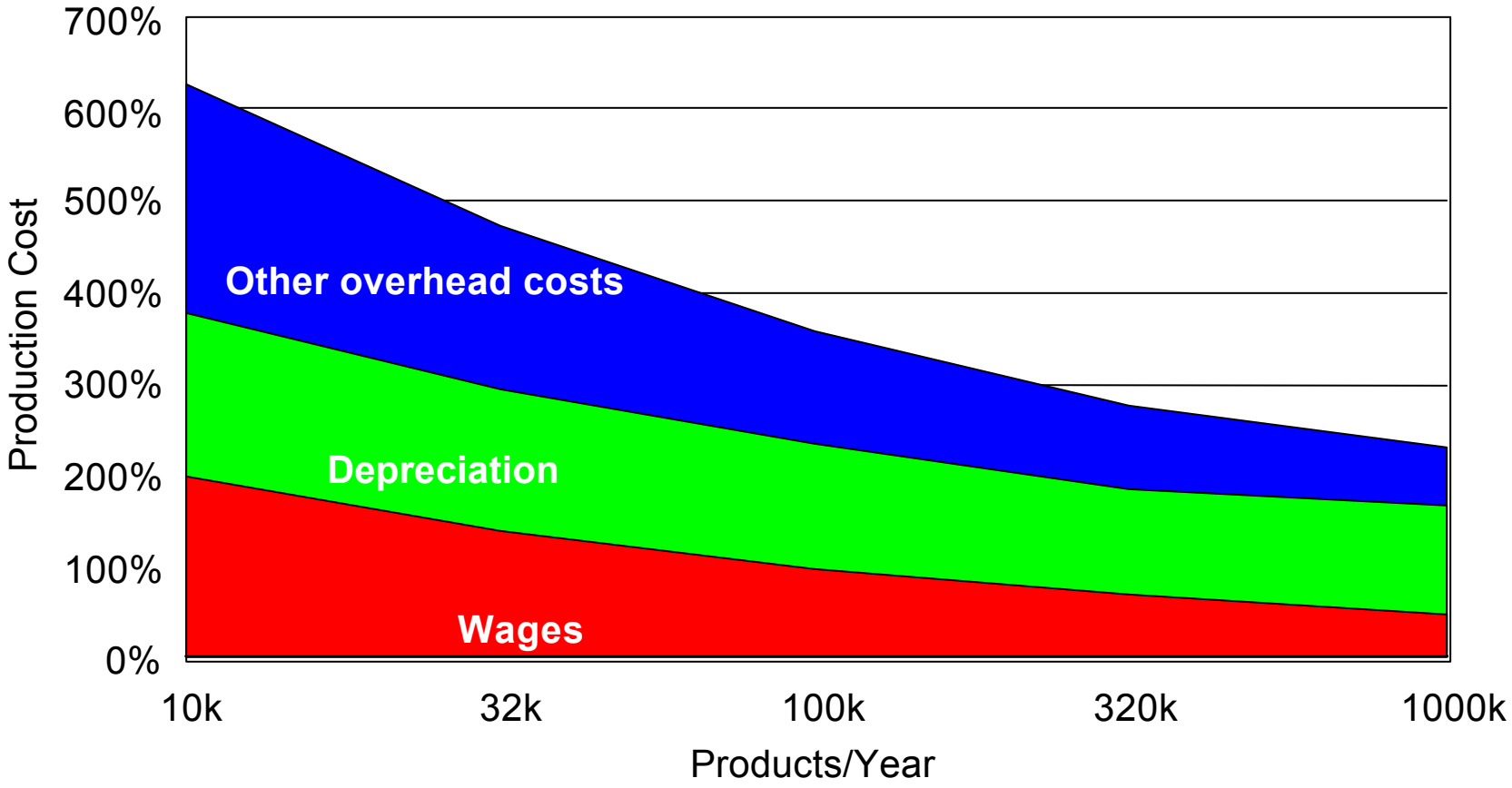
Production Cost Dependency by Volume



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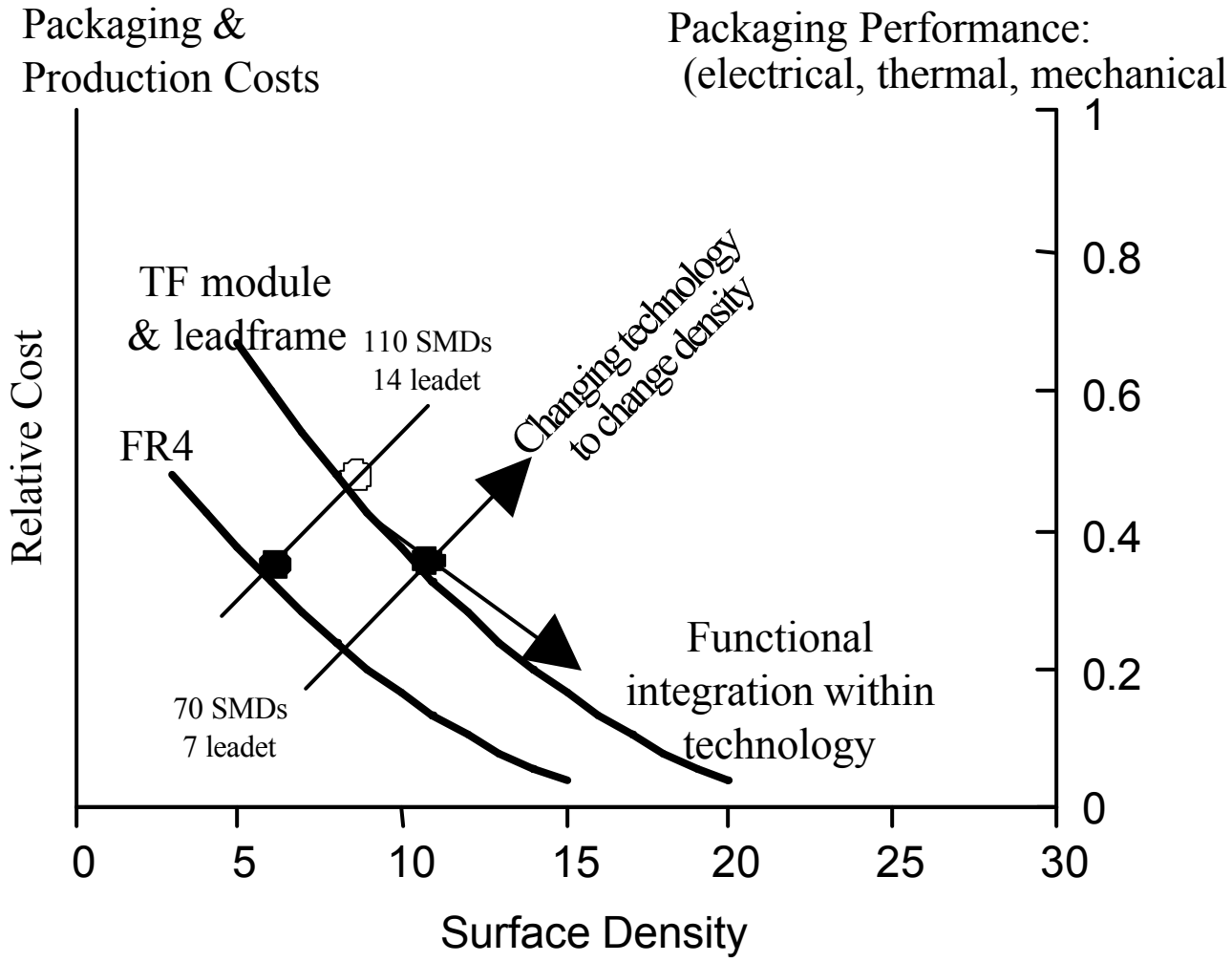
Cost Variation *Within* a Technology



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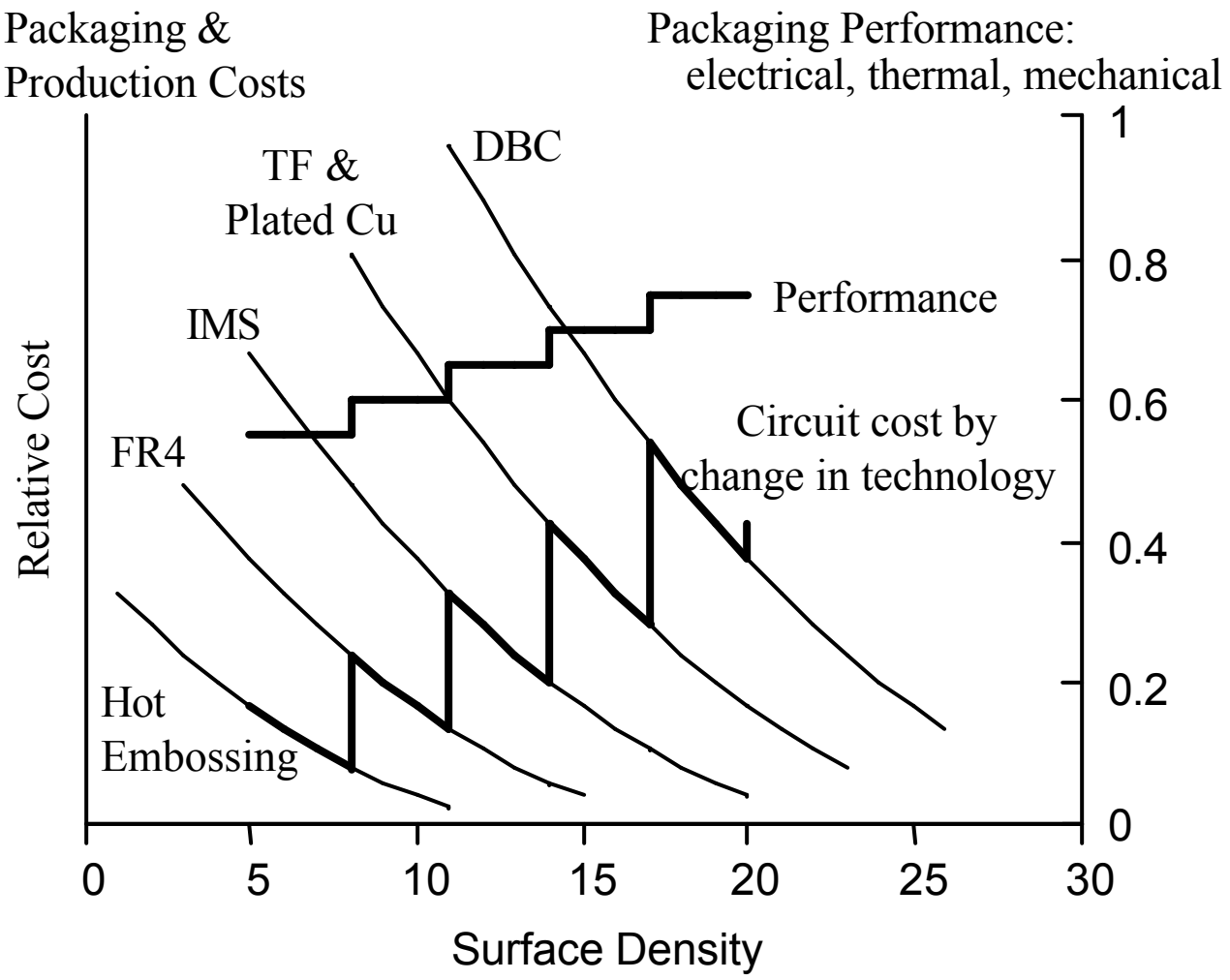
Relative Cost of Technologies



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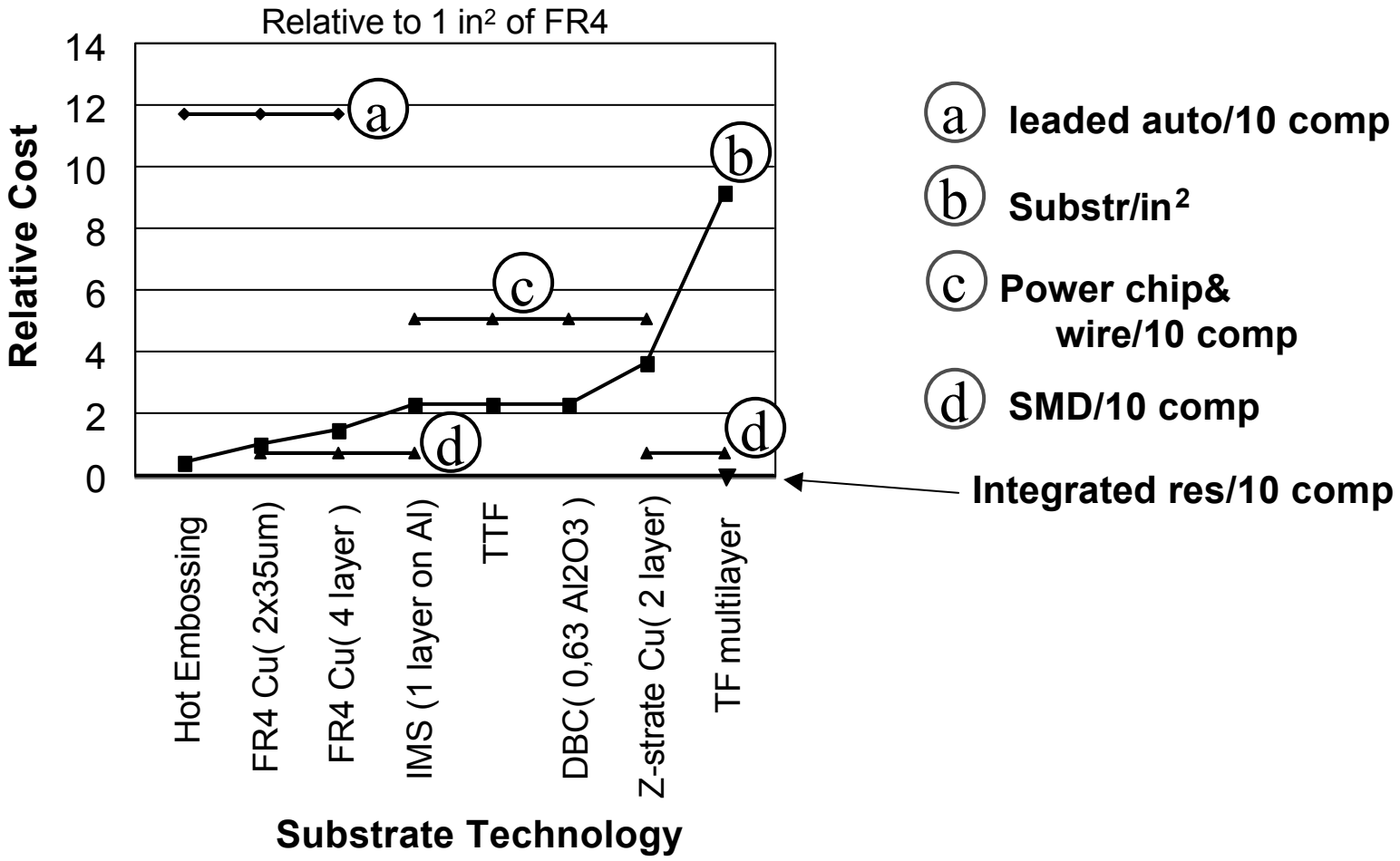
Relative Packaging & Production Cost



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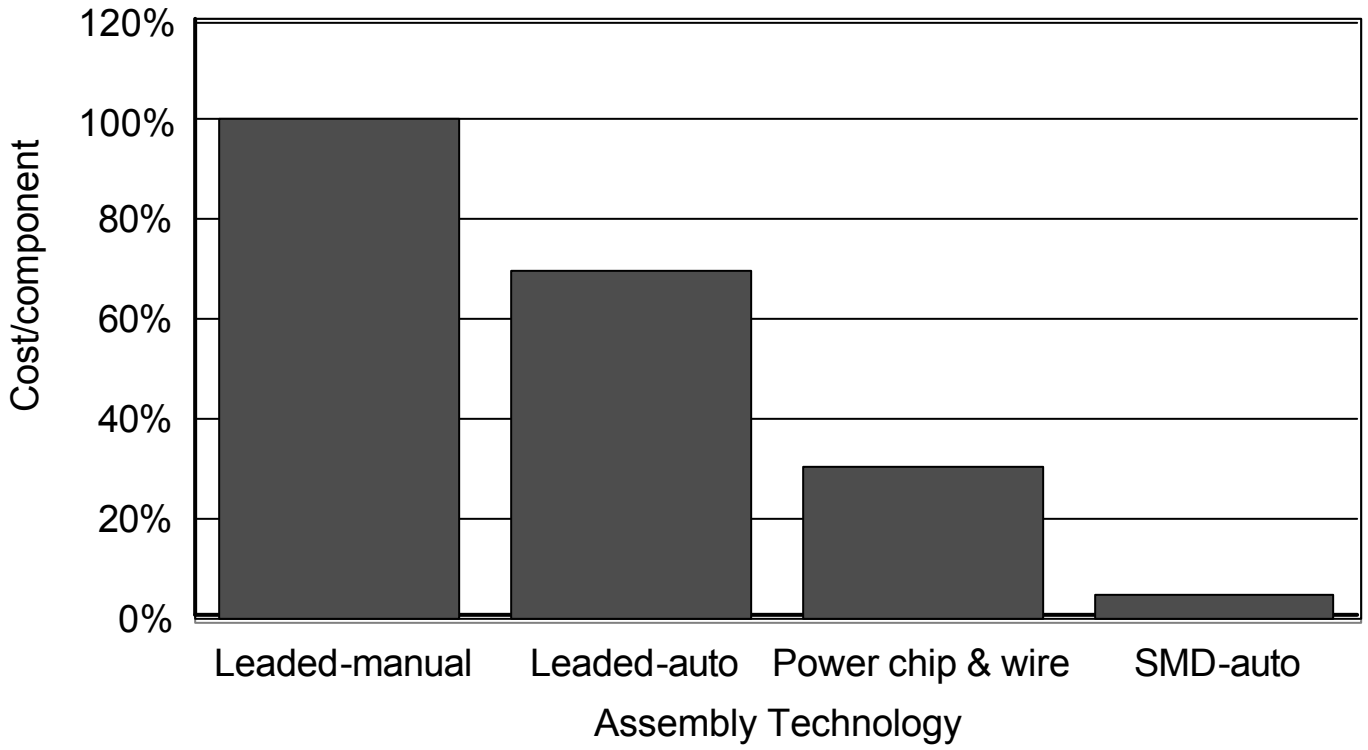
Relative Production Cost per Technology



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Circuit Partitioning

Optimally Selecting Packaging Technologies
and Circuit Partitions Based on Cost and Performance

APEC' 2000 Conference

John B. Jacobsen and Douglas C. Hopkins

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Partitioning Approach

…to meet performance requirements and provide maximum business profit

Steps to Partitioning:

- User Requirements
- Component Characterization
- Component Grouping
- Strategic Partitioning with constraints
- Optimizing within partitions

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X2100S-*User Requirements (constraints)*

- Several requirements place specific constraints on packaging the 2.2 kW drive:
  - Mechanical: Built into stainless steel tube with a diameter of 65mm and as short as possible.
  - Thermal: Cooling through tube with non-flow of water at 30°C.
  - Environment: Potting complete electronics inside tube not allowed.
  - Regulatory: UL, CE
  - Reliability: 1.000.000 quick start/stop
    30.000 max gradient start/stop
    40.000 h lifetime @ 10°C water

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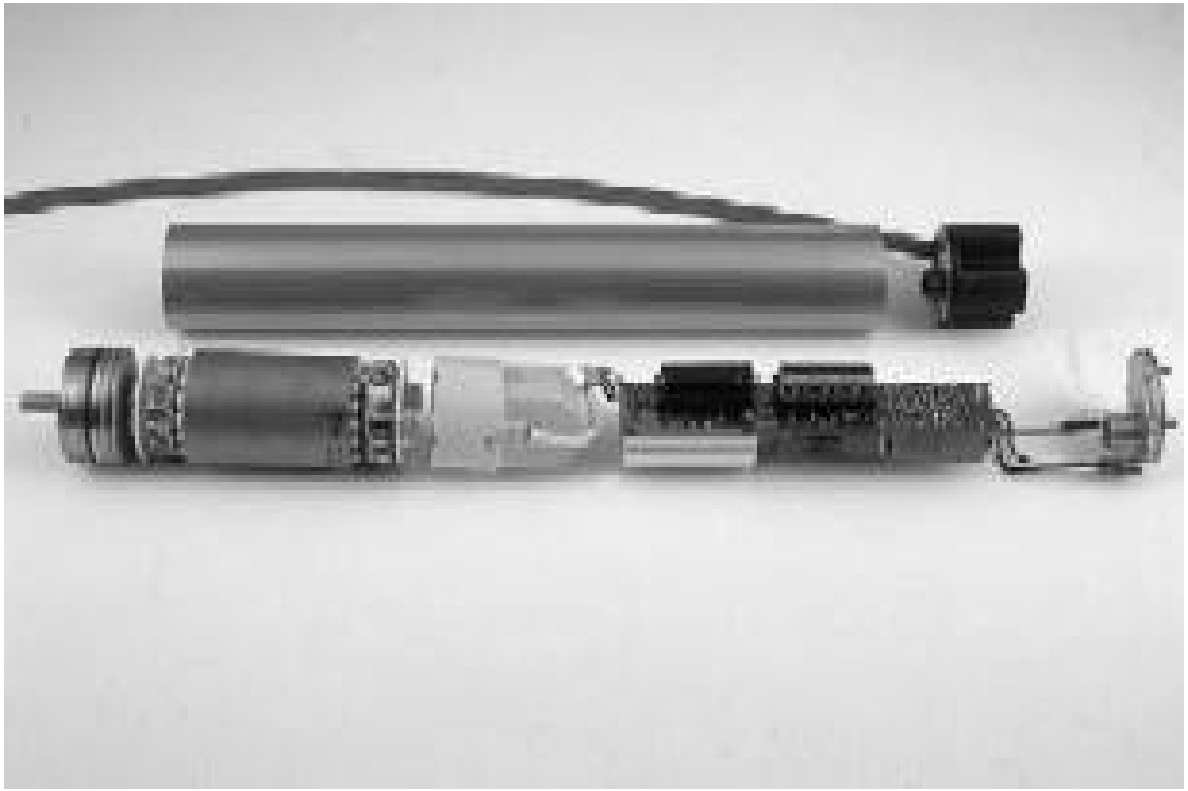
Motor and Integrated Converter



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Electronics Block Characterization-MtrDr

EMC
- 1 coil 10W
- 10 X,Y,pulse-caps
- 3 VDR
- 1 Resistor

Rectifier
- 5 dies 20W

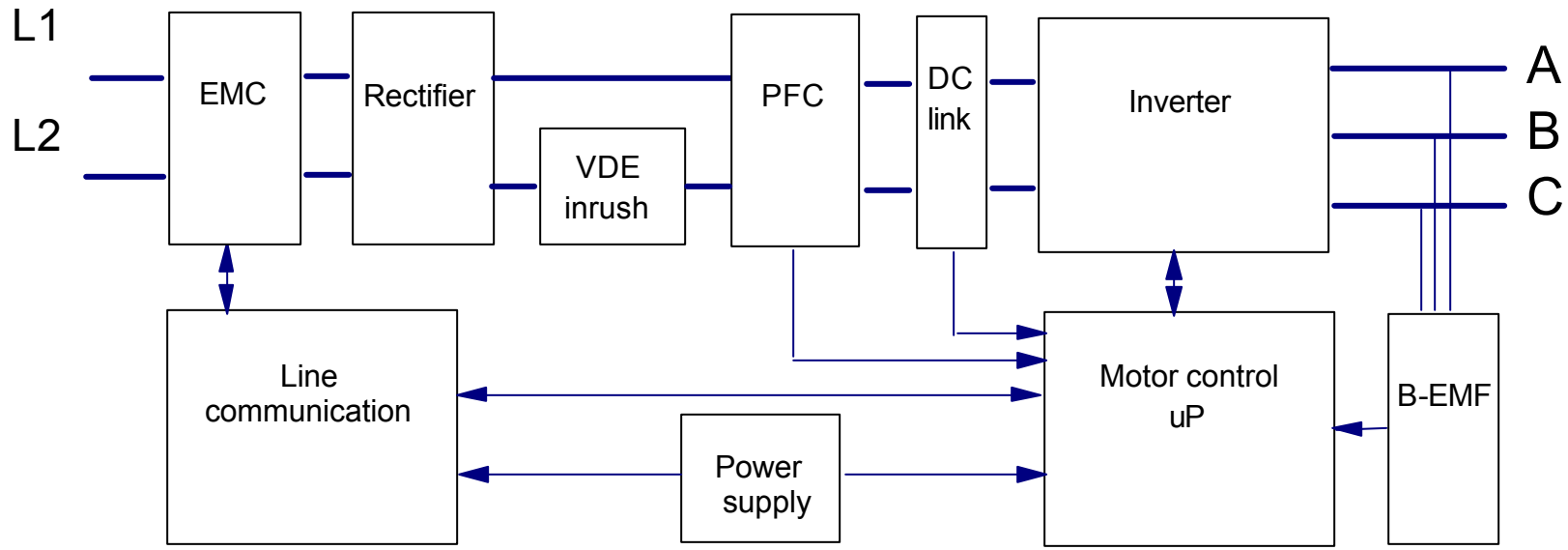
VDE/inrush
- 1 dies 15W
- 1 shunt 2W
- 1 IC
- 4 SMD
- 8 Resistors
- 1 VDR

PFC
- 2 dies 23W
- 1 shunt 2W
- 1 IC
- 1 diodes
- 8 SMD
- 12 Resistors
- 1 coil 15W

X2100S module

DC link
- 1 Voltagedevider
- 2 Capacitors 7W

INVERTER
- 12 dies 102W
- 1 shunt 2,5W
- 1 HVIC
- 13 diodes
- 13 SMD
- 23 Resistors



Colur code
- Blue = leadet
- Green = SMD/die/TF
- Red = powerloss >1W

Line communication
- 1 coil 5W
- 1 IC ½W
- 27 SMD

Power suply
- 1 Transformer ½W
- 4 Capacitors
- 1 IC 1W
- 9 SMD

Motor control-uP
- 3 IC
- 12 SMD

BEMF
- 2 IC
- 3 SMD
- 36 Resistors

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Motor Drive Packaging Technology

Technology characteristics @ typical strongest version for motor drive

Characteristics and cost for chosen version of technology (most competitive in motor drives)		MID	Hot Emb	FR4	FR4	IMS-P M	IMS-PS	TF		Z-str	DBC
								TTF	Multi-layer		
For component delivery/carrier forms		Leaded	Leaded (SM)	Leaded SM (dies)	Leaded SM (dies)	SM, dies	SM,dies	SM,dies	SM,dies TF 1)	SM,dies	SM,dies
Power interconnection		X	X	(X)	X	X	X	X		X	X
Fine line interconnection				X	X				X	X	
Condutor layers		1(3D)	1(2½D)	2	4	1	2	1	2	2	1
Rear side cooling						X	X	X	X	X	X
Integrated resistors									X		
Dielectric For 2.5kV	type			Glass epoxy	Glass epoxy	Polymer	Cement	Al2O3	Al2O3	Al2O3	Al2O3
	W/mK			0,3?	0,3?	3?	?	25	25	25	25
	kV/mm										
	Thickness										
	K/Wcm2										
Power conductor	Material	Cu	Cu	Cu	Cu	Cu		Ag			
	Thickness	0,5mm	0,2mm	0.04	0.07	0.07	?	0,08?		0.07	0,2-0,3
	J/Kcm2										
Relative cost	$/area	*)	0.4	1	1.5	2	?	2	9	4	2

1) resistors integrated in substrate

*) strongly dependent of quantity because of inexpensive tooling

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Component Characterization Map

Functional block	Function	Comp	Qty	Mechanical		Electrical			Thermal		
				Delivery form/ carrier	Size	Voltage	Current	Constraint/remarks	Power loss	Max temp	Rth
						V	A/ comp		W/comp	degC	K/W
EMC	Filter	Y-cap	2	leaded	13x5x10	300 ac		low L to earth			
	Filter	X-cap	2	leaded	26x10x18	300 ac		low L to L1-L2			
	Choke	inductor	1	leaded	ø37x20	300 ac	11 rms		10	105	
	Filter	X-cap	1	leaded	17x6x12	300 ac		low L to earth			
	Transient clamp	VDR	3	leaded	ø21x5	300 ac		1 low L to L1-L2 2 low L to L-Earth			
	Filter	Y-cap	2	leaded	18x9x15	300 ac		low L to earth			
	Filter	Y-cap Resistor	2 1	leaded leaded	12x8x10 ø4x10	300 ac		low L to earth			
	Pulse	MKT	1	leaded	31x18x28	300 ac		Close to DCP-DCN			
Rectifier	Bridge	Diode	4	die	3,5x2,5	600	11 rms		5	125	
	Clamp	Diode	4	die	3,5x2,5	600			<1	125	
Inrush/ VDE	Switch	IGBT	1	die	6x4,3	1,200	11 rms		15	125	
	Cur. sense	Shunt	1	TF			11 rms		2	note1	
	Controller	IC	1	die		<18			<1	125	
	Support	C R	4 8	SMD TF	0603->B						
	Transient clamp	VDR	3	leaded	ø21x5	300 ac		Low L DCN-PGND			
PFC	Switch	MOS	1	die	7,5x7,5	500	26 peak		16	125	
	Freewheel	Diode	1	die	3x4	500			7	125	
	Cur. sense	Shunt	1	TF			11 rms		2	note1	
	Controller	IC	1	die			10 m		<1	125	
	Suport	C R	8 12	SMD TF	0603->B	< 70V					
	Choke	L	1	leaded		500	11 rms		15	130	

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Component Characterization Map (con'd)

DClink.	DC-cap	Elektrolyt	2	leadet	ø26x50	500	1,25 rms		3.5	75 internal	
	Voltage sense	R	2	TF							
Inverter	Fullbridge	Igbt	6	Die	6x4,3	600	17peak		12	125	
		Diode	6	Die	3x4	600	17peak		5	125	
	Cur. sense	Shunt	1	TF			6 average		2.5	note1	
	Driver	IC	1	die		600	30 mA		<1	125	
	Boot,clamp	Diodes	6	die		600	<1		1/2	125	
	Suport	C&L R D	12 23 7	SMD TF die	0603->B	< 15V					
	Tempsense	PTC	1	MELF							
BEMF	Filtering	R C	36 6	SMD	0805-1206						
	Conditioning	IC	2								
Motor control	uP	IC	1	SMD							
	Reset	IC	1	SMD							
	eeprom	IC	1	SMD							
	Suport	C,R,crystal	12	SMD	0805->?						
Power Suply SMPS	Transformer		1	leaded	22x20x15	500			0.5	85	
	Capacitors	Electrolyts	4	leaded	Ø5x12 -> ø10x16						
	Switch	IC	1	SMD8				100KHz	1	127	
	Suport	D R	7 2	SMD TF	MELF->? 0805	< 15V					
Line communication	Powerline coil	1	1	leaded	21x20x24		11 rms	133KHz	5	105	
	Control	IC	1	SMD			50 m	133KHz	0.5	95	
	Suport	C,R,crystal	27	SMD	0805->?						

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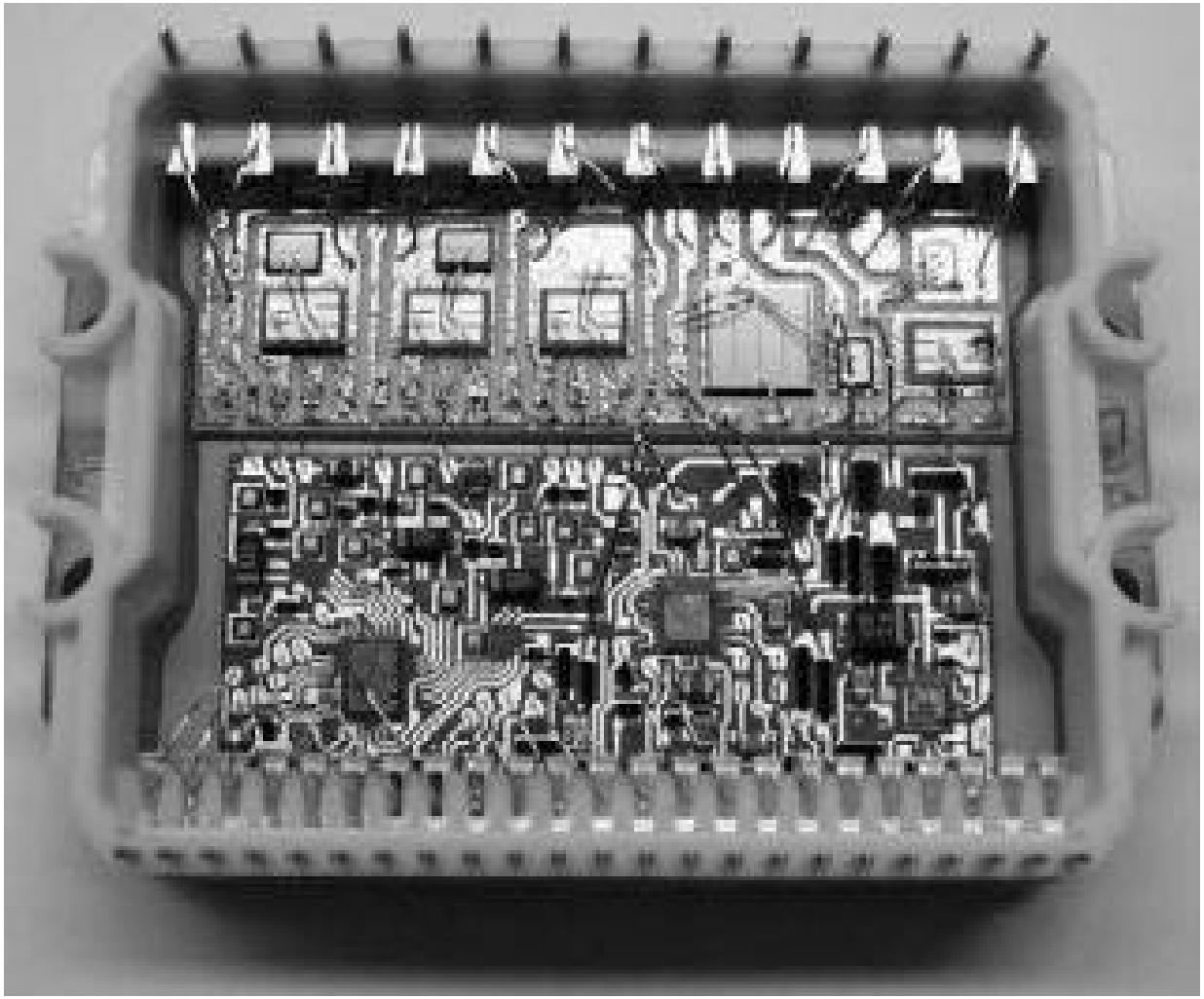
X2100S Module with MID Housing



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