UPE Inc.

Introduction To HEAVY Copper,
EXTREME Copper, And “PowerLink”
Printed Wiring Boards

Scope of Presentation

- Company Overview / Background
- Definitions
- Why UPE?
- Why use Heavy Copper?
- Production Capabilities
- Design Considerations

Company Overview

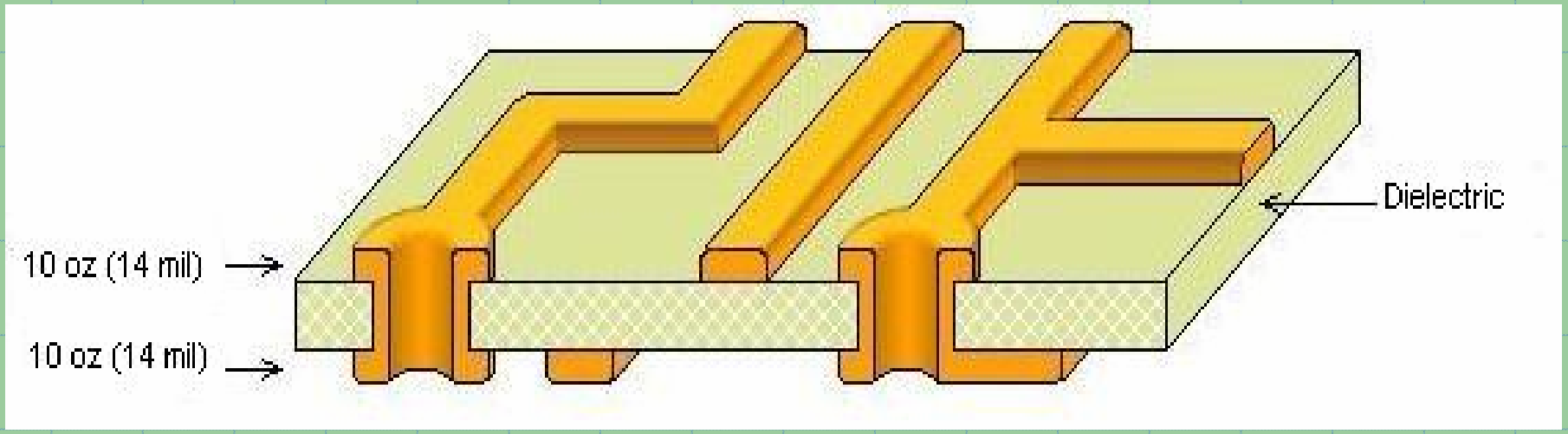
- UPE, Inc. was founded in 1990 to serve the Power Electronics Industry in North America
- Located in Richfield, Ohio
- UPE is the exclusive agent for Electronicon capacitors, ATE resistors & “PowerLink” Printed Wiring Boards

Company Overview

- UPE Canada, Inc. is the Printed Wiring Board manufacturing division of UPE, Inc.
- Founded in 1985
- Located in Carleton Place, Ontario, Canada
- Aggressive Research & Development Program in the area of heavy copper PWBs
- Developer of “PowerLink” technology
- Creator of PC~B^3 (Printed Circuit Buss Bar Boards)®
- ISO 9001:2000 certified and UL approved

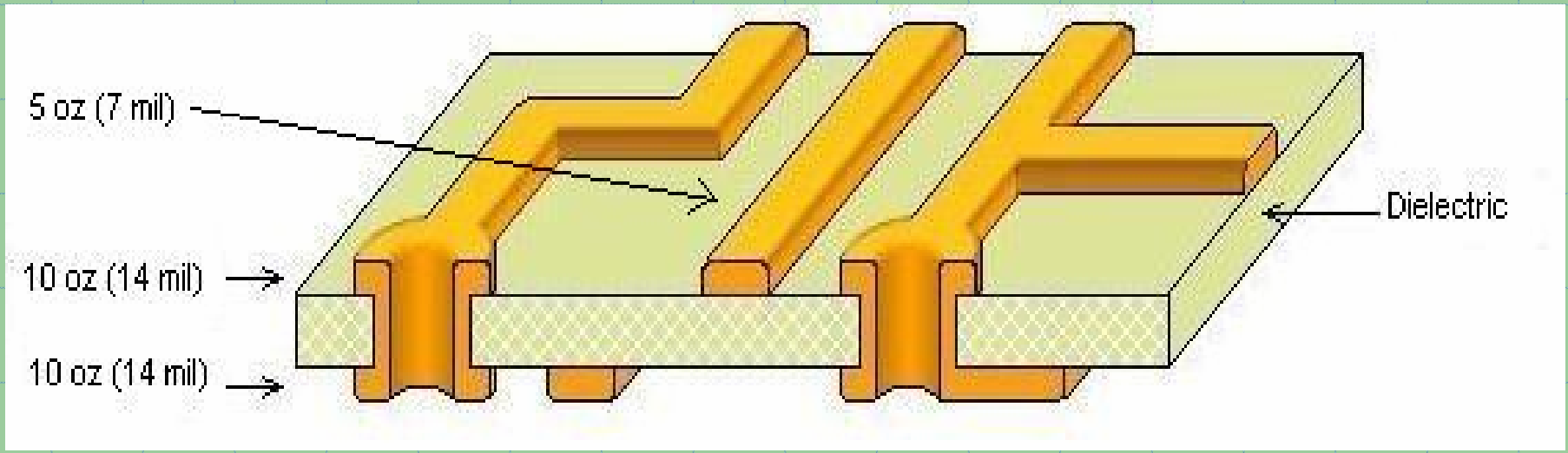
Heavy Copper / Extreme Copper

- "Heavy Copper" is defined as any circuit with a copper weight in excess of 4oz/ft^2 on a printed wiring board
- "Extreme Copper" refers to 20oz/ft^2 to 200oz/ft^2 (.028" to .280")



“PowerLink”

- “PowerLink” is defined as the use of 2 or more copper weights on the same external layer of a printed wiring board



Why UPE?

- The power electronics industry is our focus
- Years of experience developing processes and manufacturing heavy copper circuits
- Aggressive R&D program
- Unique manufacturing capabilities:
  - “PowerLink”
  - Heavy / Extreme copper tracks and vias
  - Edge Plating & Plated Castellations

Why use Heavy Copper?

- Increased mechanical strength at connector sites and plated holes
- Increase in cross-sectional area of conductors without increasing trace width or decreasing trace/trace spacing
- Higher current carrying capacity in traces AND in through holes or vias
- Use of high temperature dielectric materials to their full potential
- Reduced product size (when using “PowerLink”)
- When circuit failure is NOT an option
- Reduce number of in/out connections w/PowerLink

Production Capabilities

- Layer count: 1 - 24
- Overall board thickness: 5 - 250 mil
- Smallest drilled holes size: 6 mil
- Copper weights
  - Outer-layers: up to 200 oz/ft^2 (12.5 lbs./ft^2)
  - Inner-layers: up to 8 oz/ft^2 with standard processes & up to 90 oz w/special processing
  - In holes: only limited by drilled hole size/pad size

Production Capabilities

- Dielectric Materials: FR4, Polyimide, BT-epoxy, Cyanate Ester, High Frequency laminates – other exotics
- LPI Solder-mask (IPC-SM-840): green, red, black in semi-matte, matte or glossy
- LPI Notation Ink: available in white (5 mil or larger features)
- UV Curable Notation Ink: available in white, black or yellow (8 mil or larger features)

Production Capabilities

- Finishes: HASL PbSn Solder, Immersion Tin, Wire-bondable gold, Hard gold, OSP
- Gerber extract net-list electrical testing, flying probe
- Insulation Resistance and HI-POT testing
- Capacitance, Impedance & Resistance testing
- Production Lot traceability on all parts

Design Considerations

For Heavy Copper and “PowerLink” circuits

Board Size & Overall Layout

- Board size is limited:
  - 1-2 layers, max. board size is 16.6” x 22.6”
  - 3-24 layers, max. board size is 16.3” x 22.3”
  - Board size is limited by process equipment
- Symmetrical construction minimizes bow & twist
- Balanced circuit density minimizes uneven plating and prevents poor lamination (de-lam)

Conductor Width, Spacing and Thickness

- Conductor sizing is determined by the current carrying capacity required and the temperature rise permitted
- Minimum conductor width and spacing of heavy copper circuits is limited by the manufacturing process and/or voltage constraints
- Maximum conductor thickness is limited by the conductor width and/or spacing

Conductor Width, Spacing and Thickness

- A circuit board trace, depending on its size and manufacturing process, may not be rectangular in shape
- Additive (plating) processes are preferred to subtractive (etching) processes but are more expensive
- Typical conductor width/spacing/thickness tolerance is +/- 20%, although tighter tolerance is achievable

Minimum Conductor Width/Spacing Charts

For heavy copper and “PowerLink” circuits

Figure 1A: Minimum Conductor Width/Spacing for Copper Weights up to 5oz/ft^2

Cu (oz/ft^2)	Cu (oz/ft^2)	0.25			0.5			1			2			3			4			5		
		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
0.25		5	5	0.4	5	5	0.7	5	5	1.4	5	5	2.8	6	5	4.2	8	6	5.6	10	8	7.0
0.5		X	X	X	5	5	0.7	5	5	1.4	5	5	2.8	6	5	4.2	8	7	5.6	10	8	7.0
1		X	X	X	X	X	X	5	6	1.4	5	6	2.8	6	6	4.2	8	7	5.6	10	9	7.0
2		X	X	X	X	X	X	X	X	X	5	8	2.8	6	8	4.2	8	7	5.6	10	10	7.0
3		X	X	X	X	X	X	X	X	X	X	X	X	6	10	4.2	8	9	5.6	10	10	7.0
4		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	8	10	5.6	10	11	7.0
5		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	10	12	7.0

Starting Copper (Foil) Weight in Blue Text

Required Copper (Foil + Plating) Weight in Red Text

A Minimum Conductor Width (mils)

B Minimum Conductor Spacing (mils)

C Finished Conductor Thickness (mils)

Figure 1B: Minimum Conductor Width/Spacing for Copper Weights 6oz/ft^2 - 12oz/ft^2

Cu (oz/ft^2)		6			7			8			9			10			11			12		
Cu (oz/ft^2)		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
0.25		12	9	8.4	14	10	9.8	16	12	11.2	18	13	12.6	20	14	14.0	22	16	15.4	24	17	16.8
0.5		12	9	8.4	14	11	9.8	16	12	11.2	18	13	12.6	20	15	14.0	22	16	15.4	24	18	16.8
1		12	10	8.4	14	11	9.8	16	13	11.2	18	14	12.6	20	15	14.0	22	17	15.4	24	18	16.8
2		12	11	8.4	14	13	9.8	16	14	11.2	18	15	12.6	20	17	14.0	22	18	15.4	24	20	16.8
3		12	13	8.4	14	14	9.8	16	15	11.2	18	17	12.6	20	18	14.0	22	20	15.4	24	21	16.8
4		12	12	8.4	14	15	9.8	16	17	11.2	18	18	12.6	20	20	14.0	22	21	15.4	24	22	16.8
5		12	13	8.4	14	14	9.8	16	18	11.2	18	20	12.6	20	21	14.0	22	22	15.4	24	24	16.8
6		12	14	8.4	14	15	9.8	16	16	11.2	18	21	12.6	20	22	14.0	22	24	15.4	24	25	16.8
7		X	X	X	14	17	9.8	16	18	11.2	18	19	12.6	20	24	14.0	22	25	15.4	24	27	16.8
8		X	X	X	X	X	X	16	19	11.2	18	20	12.6	20	21	14.0	22	27	15.4	24	28	16.8
9		X	X	X	X	X	X	X	X	X	18	22	12.6	20	23	14.0	22	24	15.4	24	29	16.8
10		X	X	X	X	X	X	X	X	X	X	X	X	20	24	14.0	22	25	15.4	24	26	16.8
11		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	22	26	15.4	24	27	16.8
12		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	24	29	16.8

Figure 1C: Minimum Conductor Width/Spacing for Copper Weights 13oz/ft^2 - 19oz/ft^2

Cu (oz/ft^2)	Cu (oz/ft^2)	13			14			15			16			17			18			19		
		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
0.25		26	19	18.2	28	20	19.6	30	21	21.0	32	23	22.4	34	24	23.8	36	26	25.2	38	27	26.6
0.5		26	19	18.2	28	20	19.6	30	22	21.0	32	23	22.4	34	25	23.8	36	26	25.2	38	27	26.6
1		26	20	18.2	28	21	19.6	30	22	21.0	32	24	22.4	34	25	23.8	36	27	25.2	38	28	26.6
2		26	21	18.2	28	22	19.6	30	24	21.0	32	25	22.4	34	27	23.8	36	28	25.2	38	29	26.6
3		26	22	18.2	28	24	19.6	30	25	21.0	32	27	22.4	34	28	23.8	36	29	25.2	38	31	26.6
4		26	24	18.2	28	25	19.6	30	27	21.0	32	28	22.4	34	29	23.8	36	31	25.2	38	32	26.6
5		26	25	18.2	28	27	19.6	30	28	21.0	32	29	22.4	34	31	23.8	36	32	25.2	38	34	26.6
6		26	27	18.2	28	28	19.6	30	29	21.0	32	31	22.4	34	32	23.8	36	34	25.2	38	35	26.6
7		26	28	18.2	28	29	19.6	30	31	21.0	32	32	22.4	34	34	23.8	36	35	25.2	38	36	26.6
8		26	29	18.2	28	31	19.6	30	32	21.0	32	34	22.4	34	35	23.8	36	36	25.2	38	38	26.6
9		26	31	18.2	28	32	19.6	30	34	21.0	32	35	22.4	34	36	23.8	36	38	25.2	38	39	26.6
10		26	32	18.2	28	34	19.6	30	35	21.0	32	36	22.4	34	38	23.8	36	39	25.2	38	41	26.6
11		26	28	18.2	28	35	19.6	30	36	21.0	32	38	22.4	34	39	23.8	36	41	25.2	38	42	26.6
12		26	30	18.2	28	31	19.6	30	38	21.0	32	39	22.4	34	41	23.8	36	42	25.2	38	43	26.6
13		26	31	18.2	28	32	19.6	30	33	21.0	32	41	22.4	34	42	23.8	36	43	25.2	38	45	26.6
14		X	X	X	28	34	19.6	30	35	21.0	32	36	22.4	34	43	23.8	36	45	25.2	38	46	26.6
15		X	X	X	X	X	X	30	36	21.0	32	37	22.4	34	38	23.8	36	46	25.2	38	48	26.6
16		X	X	X	X	X	X	X	X	X	32	38	22.4	34	39	23.8	36	40	25.2	38	49	26.6
17		X	X	X	X	X	X	X	X	X	X	X	X	34	41	23.8	36	42	25.2	38	43	26.6
18		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	36	43	25.2	38	44	26.6
19		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	38	46	26.6

Figure 1D: Minimum Conductor Width/Spacing for Copper Weights 20oz/ft^2 - 26oz/ft^2

Cu (oz/ft^2)	Cu (oz/ft^2)	20			21			22			23			24			25			26		
		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
0.25		40	28	28.0	42	30	29.4	44	31	30.8	46	33	32.2	48	34	33.6	50	35	35.0	52	37	36.4
0.5		40	29	28.0	42	30	29.4	44	32	30.8	46	33	32.2	48	34	33.6	50	36	35.0	52	37	36.4
1		40	29	28.0	42	31	29.4	44	32	30.8	46	34	32.2	48	35	33.6	50	36	35.0	52	38	36.4
2		40	31	28.0	42	32	29.4	44	34	30.8	46	35	32.2	48	36	33.6	50	38	35.0	52	39	36.4
3		40	32	28.0	42	34	29.4	44	35	30.8	46	36	32.2	48	38	33.6	50	39	35.0	52	41	36.4
4		40	34	28.0	42	35	29.4	44	36	30.8	46	38	32.2	48	39	33.6	50	41	35.0	52	42	36.4
5		40	35	28.0	42	36	29.4	44	38	30.8	46	39	32.2	48	41	33.6	50	42	35.0	52	43	36.4
6		40	36	28.0	42	38	29.4	44	39	30.8	46	41	32.2	48	42	33.6	50	43	35.0	52	45	36.4
7		40	38	28.0	42	39	29.4	44	41	30.8	46	42	32.2	48	43	33.6	50	45	35.0	52	46	36.4
8		40	39	28.0	42	41	29.4	44	42	30.8	46	43	32.2	48	45	33.6	50	46	35.0	52	48	36.4
9		40	41	28.0	42	42	29.4	44	43	30.8	46	45	32.2	48	46	33.6	50	48	35.0	52	49	36.4
10		40	42	28.0	42	43	29.4	44	45	30.8	46	46	32.2	48	48	33.6	50	49	35.0	52	50	36.4
11		40	43	28.0	42	45	29.4	44	46	30.8	46	48	32.2	48	49	33.6	50	50	35.0	52	52	36.4
12		40	45	28.0	42	46	29.4	44	48	30.8	46	49	32.2	48	50	33.6	50	52	35.0	52	53	36.4
13		40	46	28.0	42	48	29.4	44	49	30.8	46	50	32.2	48	52	33.6	50	53	35.0	52	55	36.4
14		40	48	28.0	42	49	29.4	44	50	30.8	46	52	32.2	48	53	33.6	50	55	35.0	52	56	36.4
15		40	49	28.0	42	50	29.4	44	52	30.8	46	53	32.2	48	55	33.6	50	56	35.0	52	57	36.4
16		40	50	28.0	42	52	29.4	44	53	30.8	46	55	32.2	48	56	33.6	50	57	35.0	52	59	36.4
17		40	52	28.0	42	53	29.4	44	55	30.8	46	56	32.2	48	57	33.6	50	59	35.0	52	60	36.4
18		40	45	28.0	42	55	29.4	44	56	30.8	46	57	32.2	48	59	33.6	50	60	35.0	52	62	36.4
19		40	47	28.0	42	48	29.4	44	57	30.8	46	59	32.2	48	60	33.6	50	62	35.0	52	63	36.4
20		40	48	28.0	42	49	29.4	44	50	30.8	46	60	32.2	48	62	33.6	50	63	35.0	52	64	36.4
21		X	X	X	42	50	29.4	44	51	30.8	46	52	32.2	48	63	33.6	50	64	35.0	52	66	36.4
22		X	X	X	X	X	X	44	53	30.8	46	54	32.2	48	55	33.6	50	66	35.0	52	67	36.4
23		X	X	X	X	X	X	X	X	X	46	55	32.2	48	56	33.6	50	57	35.0	52	69	36.4
24		X	X	X	X	X	X	X	X	X	X	X	X	48	58	33.6	50	59	35.0	52	60	36.4
25		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	50	60	35.0	52	61	36.4
26		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	52	62	36.4

Board Stack-Up

- Heavy copper conductors can significantly add to the overall board thickness
- Copper thickness (1.4mil / oz) must be taken into account during circuit design
- Standard overall thickness tolerance is +/- 10%, although tighter tolerance is possible
- Designs using “PowerLink” will have an overall thickness defined by the heaviest copper used

Holes & Interconnections

- Plated holes/vias are drilled larger then the specified finished size to allow for plating thickness
- There is no limit to the copper plating thickness in holes other then the hole size itself
- Conductor lands and pads must be sized to accommodate the heavy copper plating (+3 mil of diameter for every oz plated)
- Minimum pad diameter = (oz Cu plated X 3) + required drill size + 10 mil (internal or external layers)
- Minimum clearance diameter = (oz Cu plated X 3) + required drill size + 20 mil (internal layers)

Holes & Interconnections

- Vias can be plated shut as necessary
- Designs using “PowerLink” require 1 drill file per copper weight
- Non supported holes (NPT with copper pad) are not affected by heavy copper or “PowerLink”
- Edge plating
- Plated castellations

Current Carrying Capacity

- A baseline method of sizing conductors is based on current, temperature rise and cross-sectional area
- Optimizing the size of any conductor requires an understanding of the energy generated by the flow of electrical current and the resulting power dissipation
- Optimization also requires the use of computer aided thermal analysis; this is due to the multitude of factors affecting power dissipation

Current Carrying Capacity

Baseline Calculation

- External traces:
  - $I = 0.025 \times \Delta T^{0.45} \times W^{0.79} \times Th^{0.53}$
  - I=current in Amps, ΔT =temp. rise due to power loss,
  - W=trace width, Th=trace thickness
- Internal traces should be derated by 50%

Thermal Management

- Components, their peak temperature and their performance are of primary concern
- Design decisions should be based on electrical design, mechanical design, manufacturing, and assembly
- Power dissipation should be considered from all sources; planes, traces & components
- It may be beneficial to size conductors in such a way as to minimize local temperature rise in areas of high power dissipating components

Thermal Management

- Some variables to consider:
  - Environment (exposed to air, space, another gas)
  - Board material properties such as:
    - Thermal conductivity
    - Material density
    - Fluid velocities and viscosities
    - Thickness between layers/planes
  - Number of copper planes and their thickness
  - Number of plated vias, their diameter and Cu weight
  - Heat sources other then trace power loss

Methods of Heat Transfer

- Conduction
  - Copper planes and their thickness play a key role
- Convection
  - Dependant on the environment, fluid temperature & velocity, forced or natural
- Radiation
  - Dependant on nearby heat sources or sinks
- Consider all three when optimizing a design

“Built-In” Copper Heat-sinks

- Their purpose is to dissipate heat away from the source by conduction and emit this heat to the environment by convection
- Built-in heat-sinks are possible with the use of thermally conductive dielectrics such as “Thermal Clad” or ‘T-preg”
- Heavy copper “thermal” vias can be incorporated into the board design to facilitate the heat transfer
- The same procedures used to create heavy copper circuits are used to create “built-in” copper heat-sinks

Planar Transformers

- Windings are created using heavy copper manufacturing techniques
- Excellent dielectric isolation compared to standard transformer manufacturing
- Expect the same degree of accuracy and repeatability inherent in PWB manufacturing
- Heavy copper vias allow for primary windings to be split so that the secondary windings are sandwiched between the primaries, achieving low leakage inductance