USB Type C & Power Delivery

All in one: Type C connector

One for all: PD adapter/charger
Mu One 45W PD: World Thinnest Adapter

- 5V/3A, 9V/3A, 12V/3A, 15V/3A, 20V/2.25A
- 14 mm profile
- CE, UL, etc.
- Available now on www.amazon.com

Images courtesy Made-in-Mind
RAVPower 45W: Same Platform

45W Power Delivery
2.5X Faster

Macbook 12”
2.0 hrs

iPhone XS Max
1.8 hrs

Available now on www.amazon.com

Images courtesy RAVPower
AUKEY 24W, 27W, 30W

Up to 3x faster charging with half the size and weight for unparalleled mobility.

- 27W USB-C PD
- 30W USB-C PD
- 2 x 12W USB-A

Available now on www.amazon.com

Images courtesy AUKEY
How Can We Make It?

A. Select the right semiconductor devices
B. Select the right topology, frequency and control
C. Select the right magnetics and design properly
World First GaN Power IC

Single GaN IC

- Monolithic integration, 650V
- GaN FET + GaN Driver + GaN Logic

Half-bridge GaN IC

- Monolithic integration, 650V
- 2x GaN FETs
- 2x GaN drivers
- GaN Logic (level-shift, bootstrap, shoot-through)
Active Clamp Flyback with Soft-Switching

\[ i_{Lm} \]
\[ V_{SW} \]
\[ S1 \]
\[ V_{IN} \]
\[ V_{SW} \]
\[ n:1 \]
\[ S1 \]

Commercial IC Available !!
GaN vs. Si in ACF
2%-3% Higher Efficiency with Low \( C_{OSS}, Q_G, Q_{rr}, E_{off} \)

**GaN: NV6260**
- \( i_{Lr} \text{ (RMS)} = 0.9A \)
- \( i_{Lr} \text{ (1 A/div)} \)
- \( V_{SR} \text{ (20 V/div)} \)
- \( V_{SW} \text{ (100 V/div)} \)

**Si: IPA60R299CP**
- \( i_{Lr} \text{ (RMS)} = 1.1A \)
- \( i_{Lr} \text{ (1 A/div)} \)
- \( V_{SR} \text{ (20 V/div)} \)
- \( V_{SW} \text{ (100 V/div)} \)

### Table: IPA60R299CP vs. NV6260 (per FET)

<table>
<thead>
<tr>
<th></th>
<th>IPA60R299CP</th>
<th>NV6260 (per FET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Rating (V)</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>( R_{DS(ON)} )</td>
<td>270</td>
<td>160, 40% ↓</td>
</tr>
<tr>
<td>( C_o(\text{tr}) ) (pF)</td>
<td>120</td>
<td>50, 60% ↓</td>
</tr>
<tr>
<td>( Q_g ) (nC)</td>
<td>22</td>
<td>2.5, 90% ↓</td>
</tr>
<tr>
<td>( Q_{rr} ) (nC)</td>
<td>3900</td>
<td>0</td>
</tr>
</tbody>
</table>

- 40% ↓, 60% ↓, 90% ↓

**Efficiency Diagram: DC/DC Efficiency (%)**
- 650V GaN+ Full ZVS tuning: 3%
- 600V Si + Partial ZVS tuning: 2%

**Courtesy of Texas Instruments (ACF w/ pri resonance)**
Modified Performance factor $F_{3/4} = Bf_{3/4} (T \cdot Hz^{3/4})$

- **ML91S** (Hitachi Metal) ~2010s
- **67** (Fair-Rite) ~2015s
- **3C90** (Ferroxcube) ~1990s
- **3F35** (Ferroxcube) ~2000s

$F_{3/4}$ vs $F_s$ (MHz) for various magnetic materials.

- **3.0 $x 10^3$$\times$\(\frac{P_v}{500mW/cm^3}\)


Magnetic: Bulky / Expensive $\Rightarrow$ Small / Cheap

<table>
<thead>
<tr>
<th>Vol ($\text{mm}^3$)</th>
<th>Freq (kHz)</th>
<th>Size Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>12000</td>
<td>65kHz → 200kHz</td>
<td>2.5x size reduction</td>
</tr>
<tr>
<td>10000</td>
<td>200kHz → 400kHz</td>
<td>1.5x size reduction</td>
</tr>
<tr>
<td>8000</td>
<td>400kHz → 1MHz</td>
<td>1.5x size reduction</td>
</tr>
</tbody>
</table>

RM10

Chrome book (65kHz)

Innergie (200kHz)

~ EQ25

Navitas (400kHz)

ER25

CPES (1MHz)

Navitas (400kHz)
Planar Magnetics → Manufacturability

- SR on sec winding, minimized $L_k$ & $R_{ac}$
- Shielding integrated as pri winding
- Safety rule compliance

Pri as shielding
45 W in 11 mm = HF Planar ACF

- Size: 29 cc (41 cc with case)
- Density: 1.7 W/cc (27 W/in³), 1.1 W/cc (18 W/in³) cased
Cool Operation

GaNFast Power IC 75°C, 80°C
AC Bridge 80°C
SR IC 85°C
SR FET 85°C
Transformer 80°C

90 V_{AC}, 45 W, 25 °C, uncased, no airflow, no thermal compound / heatsinking
High Efficiency

Full Load Efficiency

4-Point Average Efficiency

Vo=5V  Vo=9V  Vo=15V  Vo=20V

115Vac  90Vac  230Vac

115V_{AC}  230V_{AC}  CoC Tier 2
Quiet EMI (Conducted, Radiated)

CE: 115Vac 20V/2.25A
CE: 230Vac 20V/2.25A

RE: 230Vac 20V/2.25A
Horizontal

RE: 230Vac 20V/2.25A
Vertical
Thanks to Matt Judkins, CEO of Made-in-Mind (Mu)
Available via www.amazon.com and airport stores in NOW!

Images courtesy Made-in-Mind
The New World of Fast Charging

600kHz ACF low profile planar xfrmr

500kHz ACF low profile planar xfrmr USB-PD

300kHz ACF Wound xfrmr USB-PD

300kHz ACF wound xfrmr USB-PD Convention

2-stage 200/300kHz CrCM PFC/ACF wound xfrmr USB-PD

2-stage 200/500kHz CrCM PFC, plus LLC wound xfrmr

Conventional Silicon-based Designs

Power Density (uncased, W/m²)

27W 45W 65W 100W 150W

Information available on www.navitassemi.com