EETimes Seminar- Circuit Protection for Power Management

Sept, 2017
Adam Lin
Agenda

• Circuit Protection
  – What is it?
  – Where is it used?
  – The Basic Parts

• Device Features/Options
  – Inrush, Fault, FET SOA Protection, OV, UV etc.

• Common Design Errors

• Common Test Errors
Circuit Protection – What is it?

- Many things with many names
  - Inrush Control
  - Hotswap
  - Hotplug
  - Current Limiting
  - Electronic Circuit Breaker
  - Short Circuit Protection
  - Soft Start
  - Over Voltage Protection (OVP)
  - eFuse
  - Load Power Limiting
  - FET SOA Limiting (Protecting the Protector!)
  - Reverse Current Protection (ORing)

- Often Required for Agency Rating
  - UL, CSA – North America
  - EN, IEC, (CENELEC) – Europe
  - CCC Mark (CNCA) - China
Circuit Protection – Where Is It Used?

- Telecom Equipment
- Datacenters / Servers
- Storage / HDD, SSD, Midplanes
- Industrial Control
  - 24 or 48 V typically
- Tower Mounted Antennas
- Merchant Power
Circuit Protection – What is it?

• Circuits designed specifically to….
  – Prevent Fire! --“Keep the smoke in!”
  – Keep small problems from growing big
    • Minimize damage by quickly isolating failures
  – Prevent potentially disruptive power bus disturbances
    • One small transient can take down/reset an entire system

• What Gets Protected?

SUPPLY  CONNECTORS  POWER FET  LOAD
Circuit Protection – The Basic Parts

- **Most Common Elements**
  - Element for modulating current
  - Element for sensing current
  - Element for controlling the FET

- **Location**
  - Sometimes on the Load Side of the Connector
  - Sometimes on the Supply Side of the Connector
Hot Swap Controller Circuit

- Function

Control Logic

Hot Swap Controller

Rsense Current Limit

MOSFET Power Switch

Power Supply

Load = RL + CL

Resister OVP

Resister UVLO

Resister SOA Power Limit

Resister Power Good

Timer Capacitor Setting Fault Timer

Power Switch

Texas Instruments

文騰科技
Device Features/Options
Some of the Choices

- **FET** - Internal or External
- **Inrush control** - dV/dT, or di/dT
- **Current Limit** - Always, Never, or just at startup
- **Fault response** - Latch off or Retry
- **Short Circuit Response** – Latch Off or Retry
- **Control** - I²C or Analog Control
- **Outputs** - Power Good, Fault, FET Fault
- **I\_\text{LIMIT}** Accuracy - 20% Standard, 10% Pretty Good, 5% Very Good
- **FET SOA** protection.. Or not
  - Allows use of smaller FET and provides very high survivability
- **Current Indicator Output** (IMON) – Analog or Digital Output ?
  - Digital Output requires internal ADC and typically includes PIV Monitoring
- **ORing Control** – Linear or Hysteretic
Device Features/Options

FET SOA Protection

- One of the least understood but most appreciated features
- Allows use of smaller, less expensive FETs
- Analog multiplier calculates $P_{\text{DIS_FET}}$ in real time and compares result to PROG pin
- If $P_{\text{LOAD}} > \text{PROG}$ then gate drive reduced to lower $I_{\text{LOAD}}$ and $P_{\text{FET}}$
**Device Features/Options**

**FET SOA Protection**

- Dynamically adjusts $I_{\text{LIMIT}}$ to be approximately proportional to $1/(V_{DS})^2$
- Limits $P_{\text{DIS}}$ of fet to programmed limit

---

**TPS2420 Startup into 15 Ω, 700 μF**

**TPS2420 Limits FET $P_{\text{DIS}} < 5$ Watts**
Device Features/Options
FET SOA Protection – Startup into overload

- SOA protection keeps FET safe even when starting up into a severe overload

- Fault timer limits T(ime) factor of SOA

- Some competitive devices will reduce $I_{\text{LIMIT}}$ over a limited range and with limited protection.

TPS2420 Startup into overload
Typical Inrush/OCP Design Steps

1. Select $R_{\text{SENSE}}$ to set $I_{\text{LIMIT}}$ and $I_{\text{FASTTRIP}}$
   - $I_{\text{LIMIT}} = V_{\text{TH}}/R_{\text{SENSE}}$ - $V_{\text{TH}}$ typically 25 – 50 mV
     • Simplest controllers have fixed $V_{\text{TH}}$
     • High $V_{\text{TH}} \rightarrow$ Better Accuracy but Higher $I^2R$ Losses
   - Fast trip – (Short Circuit) threshold usually 1.5x -3x $I_{\text{LIMIT}}$ Level

2. Select $C_{\text{FAULT}}$ to get desired $T_{\text{FAULT}}$
   - Set $T_{\text{FAULT}}$ long enough to allow all caps to charge ($T_{\text{CHARGE}}$) before time out
     • $T_{\text{CHARGE}} \sim CV/I$ ($C =$ Bulk Cap, $V = V_{\text{OUT}}$, $I = I_{\text{LIMIT}}$)
   - Set $T_{\text{FAULT}}$ as short as possible to limit FET stress during overcurrent events
   - Ensure that $T_{\text{FAULT}} \times V_{\text{IN}} \times I_{\text{LIMIT}}$ is within SOA curve

3. Select FET that can withstand $T_{\text{FAULT}} \times V_{\text{IN}} \times I_{\text{LIMIT}} \times ~1.5$ ..... SOA !!

4. Set FET SOA Power Limit on devices so equipped
   - Design tools available for some devices - check webpage
   - $TPS24700/10/20$, $TPS2490/1/2/3$, $TPS2480/1$, $LM5064/6/7/9$, $LM25061/6/9$
Common Design Errors

1. **SOA of FET too Small**

2. **Layout Issues**

3. **Inadequate Transient Protection**
Common Design Errors
SOA of FET Too Small

- **SOA = Safe Operating Area**
  - SOA Chart – Every FET has one
  - Defines Bounds of FET Operation
  - $V_{DS\_MAX} = \text{Vertical Limit}$
  - $I_{D\_MAX} = \text{Horizontal Limit}$
  - $R_{DSON}$ limits $I_D$ at lower voltages
  - *Theoretical* $P_{MAX} = 3000 \text{ W}$

- **Fault Time Is Critical**
  - Longer Fault time means bigger FET
  - Shorter Fault Time allows higher peak power

- **Most Stressful FET Events**
  - Startup into short
  - Shorted load while under full load
Common Design Errors
SOA of FET Too Small - Example - 12 V, 50 A Server

- **Without Power Limiting** (current limit)
  - \( P_{\text{MAX}} = I_{\text{LIMIT}} \times V_{\text{SUPPLY}} = 600 \text{ W} \)
  - \( T_{\text{SOA_MAX}} = \sim 800 \text{ us} \)

- **With Power Limiting**
  - \( P_{\text{MAX_LIMITED}} = 50 \text{ W} \)
  - As \( V_{DS} \) increases \( I_{\text{LIMIT}} \) is reduced
  - \( T_{\text{SOA_MAX}} = 10 \text{ ms} \)
  - Smaller FET can be used
  - @ 50 A will start limiting when \( V_{DS} > 1 \text{ V} \)

- **Common Error to Pick FET Too Small**
Common Design Errors
Layout Issues - A Little Stray R Can Make a Big Error

- **Critical Kelvin Connections**
  - Sense Runs
- **Critical Short Run**
  - Ground
  - Gate
- **High Current Runs**
- **Poor Kelvin Runs...**
  - Inaccurate/variable $I_{LIMIT}$
- **Poor High Current Runs**
  - Voltage droop
  - Power loss
  - Overheating
Common Design Errors
Inadequate Transient Protection

• All wires are inductive
• Inductance stores energy \[ E = \frac{L I^2}{2} \]
• When the FET turns off, voltage spikes occur
  \[ V = L \frac{di}{dt} \quad \frac{di}{dt} \Rightarrow \infty \]

Positive Spikes at Input to Switch/FET
Negative Spikes at Output of Switch/FET
Common Design Errors
Inadequate Transient Protection

- To resolve inductive spikes from supply / load leads
  - Caps and/or TVS at Input to clamp positive spike during hot plug
  - Schottky Clamp output negative spike during output short circuit
  - Short, Wide Leads and Runs
Common Test Error Sources

1. **Electronic Loads**

2. **Transients From Long Supply Leads**

3. **Supply $I_{\text{LIMIT}}$ Too Low**
Common Test Error Source 1

Electronic Loads

• Electronic Loads
  – Good for DC Loading and Automated Tests
  – Proper Setup Very Important
    • Ex. - Constant Current, Constant Power, Constant Resistance
  – but….
  – Often Have Switch Transients When Stepping Load
    • Transients Can Cause Premature Trip When Measuring $I_{\text{LIMIT}}$
Common Test Error Source 1

Electronic Loads

- For Minimal Transients While Adjusting Load
  - **Method One** - Use Power Resistors as Loads
    - A bit tedious and Old School… but accurate
    - A collection of fixed and variable resistors is best
    - Apply “Last Half Amp” With Small Wire Rheostat
      - Can be effective with eLoads also

- **Method Two** - Use Power FET as Load
  - Connect FET and Series Resistor as Load
  - Adjust Potentiometer to vary Current
  - *Make Sure the FET can Handle the power!!!!*
Common Test Error Source 2
Long Supply Leads

- All wires are inductive
- Long Supply Leads can have significant L
- Lab Test Environment Usually Worse Than Final Application!
  - Reason for TVS and diodes on most TI EVMs
- When the FET turns off, voltage spikes occur
- To counter inductive spikes from supply / load leads
  - Caps and/or TVS at UUT Input to clamp positive spike
  - Schottky Clamp across output to clamp negative spike
  - Twisted Supply leads

\[
\text{Power Supply} \quad \Rightarrow \quad \text{Load} = R_L + C_L
\]

Control IC
## Positive Low Voltage Protection
### TI Device Portfolio

<table>
<thead>
<tr>
<th>PART</th>
<th>Input Range</th>
<th>Package</th>
<th>$V_{THRESH}$ (mV)</th>
<th>SOA Prot.</th>
<th>OV</th>
<th>I2C</th>
<th>PG</th>
<th>Imon Acc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS2420</td>
<td>3 to 20</td>
<td>QFN16 (4x4mm)</td>
<td>Internal FET $R_{DSON}$ typ. = 30 mΩ $I_{LIMIT} = \pm 10%$ @ 2 A</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Lo</td>
<td>17%@2A</td>
</tr>
<tr>
<td>TPS2590/910</td>
<td>QFN16 (4x4mm)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>-</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>TPS2421-1/2</td>
<td>SOIC8</td>
<td>na</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Lo</td>
<td>na</td>
</tr>
<tr>
<td>TPS2592A/B</td>
<td>QFN10 (3x3 mm)</td>
<td>Fixed $I_{LIMIT}$</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>TPS2593A/B</td>
<td>QFN10 (3x3 mm)</td>
<td>na</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>TPS24720</td>
<td>QFN16 (3x3)</td>
<td>Prog</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Lo</td>
<td>Prog</td>
</tr>
<tr>
<td>TPS24710/1/2/3</td>
<td>MSOP10</td>
<td>25 ± 10%</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>l/l/h/h</td>
<td>na</td>
</tr>
<tr>
<td>TPS24700/1</td>
<td>MSOP8</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Lo</td>
<td>na</td>
</tr>
<tr>
<td>LM25066</td>
<td>LLP24 (4x5mm)</td>
<td>25 ± 10%</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Hi</td>
<td>2.40%</td>
<td></td>
</tr>
<tr>
<td>LM25066A/i</td>
<td>LLP24 (4x5mm)</td>
<td>46.5 ± 11.8%</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Hi</td>
<td>1.00%</td>
<td></td>
</tr>
<tr>
<td>LM25069-1/2</td>
<td>MSOP10</td>
<td>50 ± 10%</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Hi</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>LM25061-1/2</td>
<td>MSOP10</td>
<td>50 ± 10%</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Hi</td>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>TPS2480/1</td>
<td>PW20</td>
<td>25</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Hi</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>TPS2482/3</td>
<td>PW20</td>
<td>25</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Hi</td>
<td>0.5%</td>
<td></td>
</tr>
</tbody>
</table>
# Device Features/Options

## TI IMON Devices vs. Output Type

<table>
<thead>
<tr>
<th>Part</th>
<th>$V_{IN}$</th>
<th>Current Monitor Output</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS2358/9</td>
<td>8.5 – 17 V</td>
<td>$I_{LOAD} = \frac{V_{MON}I_{LIMIT}}{675\text{mV}}$</td>
<td>$\pm 4%_{FS}$</td>
</tr>
<tr>
<td>TPS2458/9</td>
<td>8.5 – 17 V</td>
<td>$I_{LOAD} = I_{MON} \times 61000$</td>
<td>$\pm 8.2%$</td>
</tr>
<tr>
<td>TPS2456</td>
<td>8.5 – 17 V</td>
<td>$I_{LOAD} = \frac{V_{MON}}{48 \times R_{SENSE}}$</td>
<td>$\pm 6%$</td>
</tr>
<tr>
<td>TPS2420</td>
<td>2.8 – 20 V</td>
<td>PMBus Output</td>
<td>$\pm 2.4%<em>{FS} / \pm 1%</em>{FS}$</td>
</tr>
<tr>
<td>TPS2492/3</td>
<td>9 – 80 V</td>
<td>PMBus Output</td>
<td>$\pm 3%_{FS}$</td>
</tr>
<tr>
<td>LM25066/A</td>
<td>2.9 – 17 V</td>
<td>PMBus Output</td>
<td>$\pm 3%_{FS}$</td>
</tr>
<tr>
<td>LM5064</td>
<td>-80 to -18</td>
<td>PMBus Output</td>
<td>$\pm 3%_{FS}$</td>
</tr>
<tr>
<td>LM5066</td>
<td>10 to 80</td>
<td>PMBus Output</td>
<td>$\pm 3%_{FS}$</td>
</tr>
<tr>
<td>TPS2480/1</td>
<td>9 – 26 V</td>
<td>Digital $I^2C$ Output</td>
<td>$\pm 1%$</td>
</tr>
</tbody>
</table>
LM5069EVM-627
Reverse Current Blocking, Surge Clamping, Reverse Connection Protection

Take me to SNVA683!

These circuits will also work with TPS248x/9x parts

Reverse Connection Gate Drain

Reverse Current Blocking

Surge Clamp

Reverse Connection Protection

Red indicates modifications from the existing EVM
What is an eFuse: Integrated Hotswap IC

• Most Common Elements:
  – Element for modulating current
  – Element for sensing current
    • \( R_{\text{SENSE}} \) shown, usually senseFET
  – Element to control the FET

\[
\text{Power Supply} \rightarrow \text{eFuse} \rightarrow \text{Control Logic} \rightarrow \text{Load} = R_L + C_L \rightarrow \text{Load Board} \rightarrow \text{Backplane}
\]
## Hot Swap VS eFuse

### Hot Swap (Desecrated MOSFET)

- **Power Supply**
- **Load** $= R_L + C_L$
- **Control Logic**
- **Hot Swap Controller**

- **Features**
  - Flexible $R_{DSON}$ (Designers Choice)
  - More feature options
    - No limit on upper current limit
    - Generally more accurate
  - More external parts
    - $R_{SENSE}$, FET
    - Rs, Cs for configuration

### eFuse (Integrated MOSFET)

- **Power Supply**
- **Load** $= R_L + C_L$
- **Control Logic**
- **eFuse**

- **Features**
  - Highly integrated
    - Few external parts
    - Internal FET, Current Sense
    - Thermal protection
    - Matched FET & protection
  - Today, support $< 10$ A (18V)
  - support $< 55$ V (2A)
Discrete Fuse Protection Circuit

Replace all these components…

- Overload protection
- Reverse current blocking
- Load switch with soft start

…with 1 eFuse.
Typical Applications for eFuse

- Enterprise Class SSD
- m-SATA SSD
- SAS HDD
- Storage Server Chassis
- Set-Top Box
- DVD Player
- Internet TV
- Appliances
Why not use a fuse?

- Slow
- Inaccurate
- Lossy
- Leave a load unpowered after event
“Fast Blo Fuse ” Trip time vs Current
eFuse vs fuse

Time and trip limit inaccuracies mean bigger power supplies
Fuses are slow ....even the fast ones

<table>
<thead>
<tr>
<th>Rated Current</th>
<th>1.0 x I&lt;sub&gt;N&lt;/sub&gt;</th>
<th>1.5 x I&lt;sub&gt;N&lt;/sub&gt;</th>
<th>2.75 x I&lt;sub&gt;N&lt;/sub&gt;</th>
<th>4 x I&lt;sub&gt;N&lt;/sub&gt;</th>
<th>10 x I&lt;sub&gt;N&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00 A ... 16.00 A</td>
<td>&gt; 1 h</td>
<td>&lt;30 min</td>
<td>2 ms ... 100 ms</td>
<td>1 ms ... 25 ms</td>
<td>&lt;3 ms</td>
</tr>
</tbody>
</table>

**eFuse Performance**
- \( I_{\text{LIMIT}} \) is programmable, predictable, and stable over temp
- Bus droop and supply stress reduced by tight over current tolerance
Fuses are Lossy

- Higher resistance -> more energy -> more heat -> **higher OPEX**
- **13x more power lost with fuse!**
  - 800 mV/2A = 400 mΩ vs. eFuse @ 30 mΩ
- Lifetime cost of 1 Watt = $2 to $18 (customer supplied numbers)
  - Includes energy cost, distribution infrastructure, HVAC, product life

### Little Fuse 231Series

<table>
<thead>
<tr>
<th>Rated Current</th>
<th>Amp Code</th>
<th>Voltage Rating</th>
<th>Voltage Drop 1.0 x Iₙ max. (mV)</th>
<th>Power Dissipation 1.0 x Iₙ max. (W)</th>
<th>Melting Integral 10 x Iₙ max. (A²s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00 A</td>
<td>1200</td>
<td>500 V</td>
<td>800</td>
<td>3.0</td>
<td>0.12</td>
</tr>
<tr>
<td>2.50 A</td>
<td>1250</td>
<td>500 V</td>
<td>800</td>
<td>3.0</td>
<td>0.19</td>
</tr>
<tr>
<td>3.15 A</td>
<td>1315</td>
<td>500 V</td>
<td>800</td>
<td>3.0</td>
<td>0.30</td>
</tr>
<tr>
<td>4.00 A²</td>
<td>1400</td>
<td>500 V</td>
<td>700</td>
<td>3.6</td>
<td>0.48</td>
</tr>
<tr>
<td>5.00 A²</td>
<td>1500</td>
<td>500 V</td>
<td>600</td>
<td>3.6</td>
<td>0.75</td>
</tr>
<tr>
<td>6.30 A²</td>
<td>1630</td>
<td>500 V</td>
<td>600</td>
<td>3.6</td>
<td>1.19</td>
</tr>
<tr>
<td>8.00 A²</td>
<td>1800</td>
<td>500 V</td>
<td>600</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>10.00 A²</td>
<td>2100</td>
<td>500 V</td>
<td>500</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>12.50 A²</td>
<td>2125</td>
<td>500 V</td>
<td>500</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>16.00 A¹²</td>
<td>2160</td>
<td>500 V</td>
<td>480</td>
<td>6.3</td>
<td></td>
</tr>
</tbody>
</table>

**Lower Losses using TPS2590 (30 mΩ)**
eFuse vs. Polyfuse

- **eFuse (USB power switch)**
  - Current based $I_{\text{LIMIT}}$
  - Stable, accurate (20% - 30%) $I_{\text{LIMIT}}$
  - Fixed or Programmable $I_{\text{LIMIT}}$
  - Repeatable $I_{\text{LIMIT}}$
  - Fast (< 1.5 us typ)
  - Wide temp range
    - -40 °C to +125 °C

- **Polyfuse**
  - Temp based $I_{\text{LIMIT}}$
  - Sloppy, variable $I_{\text{LIMIT}}$
  - No Programmable $I_{\text{LIMIT}}$
  - $R_{\text{ON}}$ Increases with each event
  - Slow to trip (several ms)
  - Not usable above 85 °C
  - Auto−resets after trip event
Polyfuses (PTC Devices) Require derating

Temperature Derating Curves Comparing PTCs to Fuses

Chart Key

- **Curve A**: Thin-Film Fuses and 313 Series (.010 to .150A)
- **Curve B**: FLAT-PAK®, Telelink®, Nano®, PICO®, Blade Terminal, Special Purpose and other leaded and cartridge fuses (except 313.010 – .150A)
- **Curve C**: Resettable PTCs
- **Curve D**: TPS2420/21, TPS2590/910

AMBIENT TEMPERATURE

PERCENT OF RATING

-60°C - 25°C - 104°F
-76°F - 40°F - 4°F
-60°F - 32°F - 0°C
40°F - 68°F - 20°C
80°F - 104°F - 40°C
120°F - 248°F - 120°C
Polyfuse Summary

- Slow
- Lossy – 2x regular fuse
- Inaccurate
- Each OC event increases resistance
- Not suitable for high temp.
  - R increases with Temp.
- Resets after OC event
- Low Cost
- Can provide Safety Agency compliance
  - UL, IEC, CSA
## Common Circuit Protection

<table>
<thead>
<tr>
<th>Fuses</th>
<th>Polyfuse (PTC)</th>
<th>Texas Instruments eFuses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physically breaks once tripped, only one time use (Not resettable)</td>
<td>Temp-based current limit</td>
<td>High accuracy adjustable current limit (up to ±2%)</td>
</tr>
<tr>
<td>Fast acting / time delay trip</td>
<td>Auto-resets after fault</td>
<td>Fast trip (&lt;1.5 us typ)</td>
</tr>
<tr>
<td>System is offline until fuse is physically replaced</td>
<td>Resistance increases with temp and after each fault</td>
<td>UL recognized devices</td>
</tr>
<tr>
<td></td>
<td>Slow response/trip after fault (Several ms)</td>
<td>Able to auto retry (PTC) or latch off (fuse) after fault</td>
</tr>
<tr>
<td></td>
<td>Time-delay trip only</td>
<td>Fault reporting, PG, IMON</td>
</tr>
</tbody>
</table>

- ![Image of fuses](image1.png)
- ![Image of polyfuses](image2.png)
- ![Image of Texas Instruments eFuses](image3.png)
**eFuses (Integrated FET)**

- **TPS25921A/L**
  - 4.5 – 18V, 0.4 – 1.6A, 90mΩ, with +/- 2% Current Limit Accuracy

- **TPS25926**
  - 13.8V, 5A, 30mΩ, 15V V_OUT Clamp with Adjustable Current Limit

- **TPS25925**
  - 5.5V, 5A, 30mΩ, 6V V_OUT Clamp with Adjustable Current Limit

- **TPS24750/51**
  - 2.5 – 18V, 12A, 3mΩ eFuse with PG, I_MON, Adj. Current Limit

- **TPS25924**
  - 4.5 – 13.8V, 5A, 28mΩ, 15V V_OUT Clamp with Adjustable Current Limit

- **TPS25923**
  - 5.5V, 5A, 28mΩ, 6V V_OUT Clamp with Adjustable Current Limit

- **TPS25944A/L**
  - 2.7 – 18V, 5A, 42mΩ, Circuit Breaker for Power MUX with PG, I_MON, Adj. CL

- **TPS25942A/L**
  - 2.7 – 18V, 5A, 42mΩ, Current Limiter for Power MUX with PG, I_MON, Adj. CL

- **TPS25940A/L**
  - 18V, 5A, 42mΩ, SSD Power Manager with PG, I_MON, Adj. Current Limit

- **TPS2660**
  - 55V, 2A, 150mΩ, Industrial eFuse with I_MON, Adjustable Current Limit

- **TPS25926**
  - 13.8V, 5A, 30mΩ, 15V V_OUT Clamp with Adjustable Current Limit

- **TPS2420**
  - 3 – 20V, 5A, 33mΩ Load Switch with PG, I_MON, Adj. Current Limit

- **TPS2421-1/-2**
  - 3 – 20V, 6A, 33mΩ Load Switch with PG, Adjustable Current Limit

- **TPS25927**
  - 18V, 5A, 28mΩ Load Switch with Adjustable Current Limit

- **TPS25922A/L**
  - 4.5 – 18V, 1.7A, 28mΩ Load Switch with Adjustable Current Limit

**Integrated Blocking FET**

- **TPS25926**
  - 13.8V, 5A, 30mΩ, 15V V_OUT Clamp with Adjustable Current Limit

- **TPS2420**
  - 3 – 20V, 5A, 33mΩ Load Switch with PG, I_MON, Adj. Current Limit

- **TPS2421-1/-2**
  - 3 – 20V, 6A, 33mΩ Load Switch with PG, Adjustable Current Limit

- **TPS25927**
  - 18V, 5A, 28mΩ Load Switch with Adjustable Current Limit

- **TPS25922A/L**
  - 4.5 – 18V, 1.7A, 28mΩ Load Switch with Adjustable Current Limit

**New** - **Existing** - **ROADMAP**
Device Features/Options
ORing Control - What is it and why do it?

• What is it?
  – *Make a FET act like a diode*
    • No more, no less
    • A simple concept
    • A challenge to implement

• Why do it?
  – Save Energy, $$$
  – Improve PS margin
Device Features/Options
ORing Control –Linear vs. Hysteretic

**Linear Control**
- Regulates $V_{AC}$ ($V_{SD}$) to 10 mV
- Reverse current less likely
- May not like reactive loads

**Hysteretic Control**
- FET on if $V_{AC} > 10$ mV
- FET off if $V_{AC} < 3$ mV
- Fast off if $V_{AC}$ goes negative
- Less sensitive to reactive loads
- More prone to light load oscillation
# Oring Control Selection guide

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Channels</th>
<th>$V_{IN}$ Range (V)</th>
<th>Enable/Shutdown</th>
<th>UV</th>
<th>OV</th>
<th>Fault</th>
<th>PG</th>
<th>ORing Linear Gate Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS2410</td>
<td>ORing FET controller/MUX controller</td>
<td>1</td>
<td>0.8 to 16.5</td>
<td>1H</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TPS2411</td>
<td>ORing FET controller/MUX controller</td>
<td>1</td>
<td>0.8 to 16.5</td>
<td>1H</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TPS2412</td>
<td>ORing FET controller</td>
<td>1</td>
<td>0.8 to 16.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TPS2413</td>
<td>ORing FET controller</td>
<td>1</td>
<td>0.8 to 16.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TPS2419</td>
<td>ORing FET controller with OV/enable</td>
<td>1</td>
<td>3 to 16.5</td>
<td>1H</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>LM5050-1</td>
<td>Positive HV ORing controller with AUX input</td>
<td>1</td>
<td>5 to 80</td>
<td>L</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>LM5050-2</td>
<td>Positive HV ORing controller with FET test</td>
<td>1</td>
<td>6 to 80</td>
<td>L</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>LM5051</td>
<td>Negative HV ORing controller with FET test</td>
<td>1</td>
<td>−6 to −100</td>
<td>L</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TPS24740/1/2</td>
<td>High performance hotswap/ORing controller</td>
<td>1</td>
<td>2.5 to 18</td>
<td>1H</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TPS2456/A</td>
<td>Inrush/reverse current controller for dual sources</td>
<td>2</td>
<td>8.5 to 15</td>
<td>2H</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TPS2358</td>
<td>Dual 12-V/3.3-V hotswap/ORing controller</td>
<td>2</td>
<td>8.5 to 15</td>
<td>2L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TPS2359</td>
<td>Dual 12-V/3.3-V hotswap/ORing controller</td>
<td>2</td>
<td>8.5 to 15</td>
<td>Via I²C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
Thanks You!