Ultra-Fast Solid State Thyatron Replacement

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Outline

• Overview of Solidtron’s Enabling Technology
  – Pulse discharge targeted designs

• Solidtron Performance
  – Ultra-fast discharge capabilities
  – High action capabilities

• Solid State Thyatron Replacements (SSTR)
  – Motivation
  – Approach
  – Performance
  – Experimental results

• Summary

• Questions
Super-GTO Vs. GTO

SGTO is an IC foundry-fabricated GTO mated with Silicon Power’s proprietary low inductance ThinPak package.

SGTO Advantages:
- Cell structure 3000 x denser
- Upper transistor >100x improved
  - Forward drop greatly reduced
  - Three times lower turn-off switching loss
  - Turn-on improved by 2 orders of magnitude

Fabricated in 3.3 cm² die in 6 inch silicon at very high yield, repeatability and uniformity!
Solidtron Vs. Super-GTO

Solidtron follows SGTO strategy, focusing on pulse discharge versus turn-off applications

Solidtron Advantages

- Emitter area maximized
- Internal metal interconnect density improved
- Upper transistor gain further improved
- Increased cathode bonding pad area

8 inch starting material and improved manufacturing process further improving yield while driving cost down
Solidtron: The Enabling Technology

GTO Versus Solidtron, Fundamental Differences

Traditional thyristor design revisited, capturing IC house capability

- Higher cell density improves current uniformity, drastically improving $\frac{di}{dt}$ capability
- Upper base doping profile improved for higher gain
- Metal interconnects improved, increased upper transistor gain and electrode bonding area

IC Foundry
Solidtron Cell

Standard GTO, ETO or IGCT Cell

K G

P-type upper base
N+ emitter
P+ emitter
Hole current
Anode

Cathode

IC Foundry
Solidtron Cell

95% unneeded:
- Large increase in resistance
- Compromised design for Vf/turn-off trade-off

Same Voltage Rating

20μm

~ 1000μm
Solidtron Performance: Ultra-Fast

1600V Solidtron Product line:
- Simple gating schemes (low power, easy isolation)
- Unmatched $\frac{di}{dt}$ capability (>200kA/μs observed)
- Easily implemented in series/parallel configurations
- Efficient bidirectional current capability

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Turn-on delay</td>
<td>&lt;90ns</td>
</tr>
<tr>
<td>Jitter</td>
<td>&lt;100ps</td>
</tr>
<tr>
<td>Fall time</td>
<td>&lt;40ns</td>
</tr>
<tr>
<td>di/dt</td>
<td>&gt;100kA/μs</td>
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170ns ½ cycle ring down – Yellow = Anode Current, Cyan = Capacitor Voltage
Solidtron Performance: Ultra-Fast

550ns ½ pulse width ring down

Solid state discharge switch offers:
- Rugged yet simple gate trigger
- Repeatable fabrication and performance
- Bidirectional current flow capability
- Very high MTBF, minimizing down time

$I_{pk} 1.8kA$

1μs ½ pulse width ring down

Ultra-Fast 1600V Solidtron Discrete products

Available in:
- TO-247
- TO-264
- Custom SMT packages
**Solidtron Performance: Ultra-Fast**

**4000V Solidtron Product line:**
- Maintains simple gating schemes
- $\frac{di}{dt}$ capability >100kA/μs
- Bidirectional current capability
- **Offers more compact HV Thyratron replacements (fewer series levels)**

**Solidtron Performance: Ultra-Fast**

- **Ultra-Fast 4.0-6.5kV Solidtron Product Family**

![Graph Image]

Single 0.9”x0.6” chip (2cm² active area), 6.5kV*

die pulse discharge test:
- 4kV
- 45kA $I_{pk}$
- Bidirectional current flow
- $\frac{di}{dt} = 105$kA/μs

*6.5kV BV, 4kV rating

**Graph Details:**
- Ch1 (black) inverted Anode current 10kA/div
- Ch2 (green) Anode Voltage

**Tek Run:** 500MS/s

**Sample**

32.4 kA

½ period 140ns

45.4 kA

**die pulse discharge test:**
- 4kV
- 45kA $I_{pk}$
- Bidirectional current flow
- $\frac{di}{dt} = 105$kA/μs

*6.5kV BV, 4kV rating
Solidtron Performance: High Action

6.5kV High Action Solidtron Performance

Single 0.9”x0.6” chip (2cm² active area), 6.5kV die pulse discharge test:
- >20kA peak capability
- 20.8V forward drop
- 1mΩ effective on-resistance
- $I^2t$ capability > 10kA²s

Measured $\frac{di}{dt}$ capability to 100kA/µs

(1) 6.5kV Solidtron Cap Discharge
20.3 kA, 20.8 Vₚ
R~1mΩ

~50µs
Solid State Thyatron Replacement

Motivation

- **Plasma Gasification**
  - waste gasification,
  - coal gasification,
  - Hydrogen production
  - Synthesized Fuel Production

- **Plasma Water/Air Purification Systems**
  - Cleaning of fracking water
  - Purifying in/out water for pharmaceutical manufacturing
  - Purifying in/out water for food processing
  - Airplane cabin conditioning
  - Industrial air pollution

- **Lasers Systems**
  - Ablation
  - Spectroscopy
  - Lithography
  - Micromachining

- **Klystron Triggers**
  - Satellite Communications
  - UHF Transmitters

- **Linear Accelerators**
  - Radiotherapy for cancer treatment
  - Radiosurgery...
  - Scientific...
  - Nuclear Fusion Reactors

- **Crowbar Circuits**
  - Protection of sensitive electronics...server farms, digital broadcast equipment, the Cloud...etc.

- **Radar Modulators**
  - Military...Army, USN, USCG, USMC, USAF
  - Commercial...Airports, Weather, Maritime

- **Marx Generators**
  - Lightning simulation
  - Utilities HV insulation testing

  *The List goes on*...
ABB Solid State Thyatron Replacements:

<table>
<thead>
<tr>
<th>Part Number</th>
<th>VDRM V</th>
<th>VRRM V</th>
<th>I-Pulse kA</th>
<th>Device</th>
<th>Type</th>
<th>Gate Driver</th>
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<td>60</td>
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<td>Crowbar Diode</td>
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ABB: “Due to having higher reliability and lower maintenance costs, ABB’s optimized semiconductor components, mostly as complete assemblies, are increasingly being used to replace thyatrons and ignitrons.”

**However, due to having relatively low di/dt capability, ≤ 20kA/μs, they can be used in only a few thyatron applications.**

*Remember (1) 2cm² Solidtron demonstrates 100kA/μs!!!
Disruptive Design

Solidtron designed specifically for Thyratron replacement
- low cost discrete package
- Easily Paralleled or connected/gated in series
- Easily cooled with Off-The-Shelf Heatsink (Max dissipation only 29W/level)
- No more large presspack clamps and heatsinks !!!

**Predicted Performance**
1µs ½ Pulse Width (500ns rise)

- f ambient
- f fan cooled

- E2v & equivalent L3 models
- Excelitas models

**Solidtron TO-264 Lead Frame**
Ultra-Fast Solid State Thyratron Replacement

40kV SSTR-1 (Twin Stack) Vs. e2v CX2282

- Initial TO-247 version demonstrated 365k pulses
  - 3kA, 300ns square wave
- Similar 20kV and 60kV derivatives planned to complete the product offering
- TO-264 version offers $36 \times$ increase in action
Prototype Thyratron Replacement Switch using
*Ultra-Fast 1600V Solidtron*

- $\frac{di}{dt}$ capability is >100kA/μSec
- Fiber Optically Triggered
- Small size - 9” Tall, 3.75” Base diameter
- Voltage capability of 40kV

- Yellow - 4.3kA Peak Current w/average $\frac{di}{dt}$ of ~60kA/μSec (Circuit Limited)
- Run at 100 Pulses Per Second without cooling
Solid State Thyatron Replacement

6.5kV High Action Solidtron

Gen1 20kV Bi-directional Switch Assembly Pulsing 200kA
Replaced NL-8900 Ignitrons in Magnetic Pulse Welding System

- Yellow - Demonstrates 200kA Ringing Waveform (169kA Peak reverse)
- Magenta – Voltage across a single level – ~2500V to Vf
- Cyan – 1 of 12 legs – worse case current imbalance (perfect 16.6kA)

10kV (4 level) model shown (13.25” x 10.5” x 4”)

- 8 levels of 6 parallel modules (192 chips operating in concert, 96 high action Solidtron and 96 S-diodes)
- 4 of these units were paralleled for 800kA
- More than 10,000 operational events recorded

NL-8900 Ignitrons failed after only 200 such events – customer’s original motivation to change switching technology
Solid State Thyatron Replacement

6.5kV High Action Solidtron Pulse Switch Assembly

Testing of Gen1 80kA unit at ARL

- Superior Current Sharing (Cathode 1-Cathode 2)
- Excellent Voltage Balance (Across 4 levels)
- Synchronized and repeatable 32 Chip turn-on
Solid State Thyatron Replacement

1x3 PSA with gate drive and grading
R built into the low footprint cover (<100in³!)

Pulse Switch Assembly (PSA):
- Simple isolated current transformer gating
- Coaxial current delivery for very low inductance
- 10kV DC continuous operation
- Only 375μΩ resistance with a diode knee of 3.63V!

PSA Current vs. Forward Drop

| PSA: | R = 375μΩ | V_D = 3.63V |
| Modules: | R = 125μΩ [1] | V_D = 1.21V |

[1] includes ~ 26 μΩ parasitics

58kA, V_F 25.35V
I²t = 217 kA²s
E_{switch} = 131 J

dT ~ 24°C
Summary

• Solidtron offers unparalleled $\frac{di}{dt}$ capabilities
  – Ultra fast capable of 200kA/μs
  – High action capable of 100kA/μs
• $f(i(t))$ capability, determined by experimental and/or sim data exceeds most if not all commercially available gas or solid state thyristors available
• Designed with modular, scalable sub-assemblies
  – Enables fitment for most thyatron or ignitron applications