EH

Switched Current Power Converter

a true breakthrough technology

Arnold Alderman
&
Edward Herbert

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Arnold Alderman

- Founder and President of Anagenesis, Inc., a technical marketing consulting firm located in Los Angeles and Phoenix
- 22 years engineering and management at Boeing, GE, and Emerson Electric and other US power conversion companies
- 16 years technical, product, and strategic marketing at Fairchild Semiconductor and International Rectifier
- Author of numerous conference papers and articles with publications in leading industry magazines, keynote speaker, plenary speaker
- Conducted marketing and technology seminars internationally.
- Board Chairperson of the Power Sources Manufacturing Association (PSMA)

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Edward Herbert

- Inventor, 37 Issued Patents, several applications pending
- Held both design and engineering management positions at Dynamic Controls Corp., South Windsor, CT; IBM., Huntsville, Alabama; Sundstrand Aviation, Rockford, Illinois; Hamilton Standard, Windsor Locks, CT; Raytheon Submarine Signal Div., Portsmouth, RI; Sikorsky Aircraft, Stratford, CT.
- Power factor correction circuits in 2001
- Founder and President of FMTT Inc.
- Invented the Matrix transformer in late 80s

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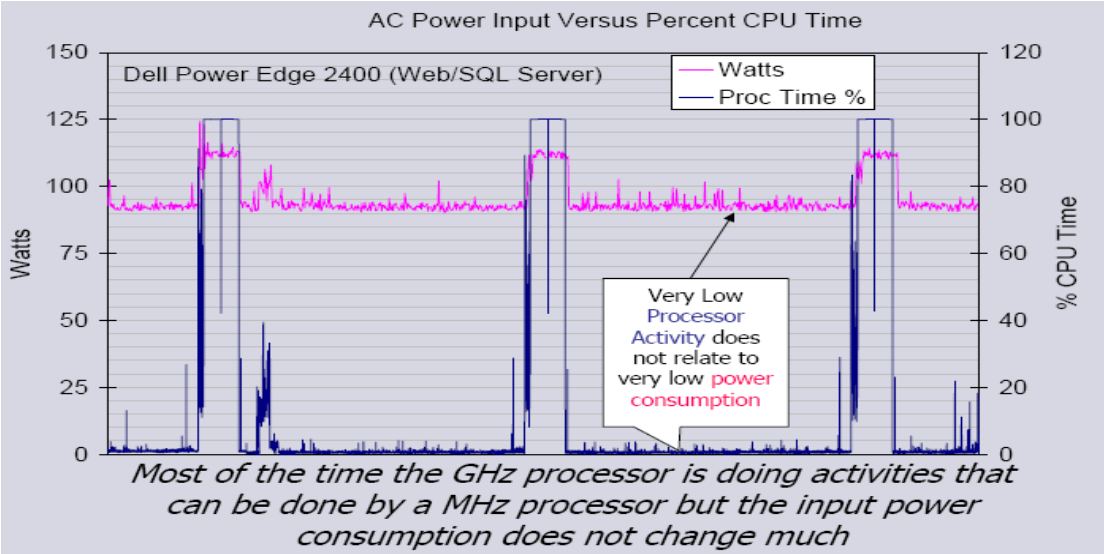
Wasted processor power



This processor is wasting power most of the time. *A power supply with very fast transition time allows the processor cores to be turned off most of the time, for very significant system power reduction.*

Reducing processor system power

The greatest dividend for reducing system power comes from enabling the processor to operate at lower power most of the time.

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Dynamic voltage

With the SCPC, the voltage can be:
ramped at up to 1500 mv/µs,
turned off in 2 µs,
and turned on to any VID voltage and
100% current capability in 2 µs.

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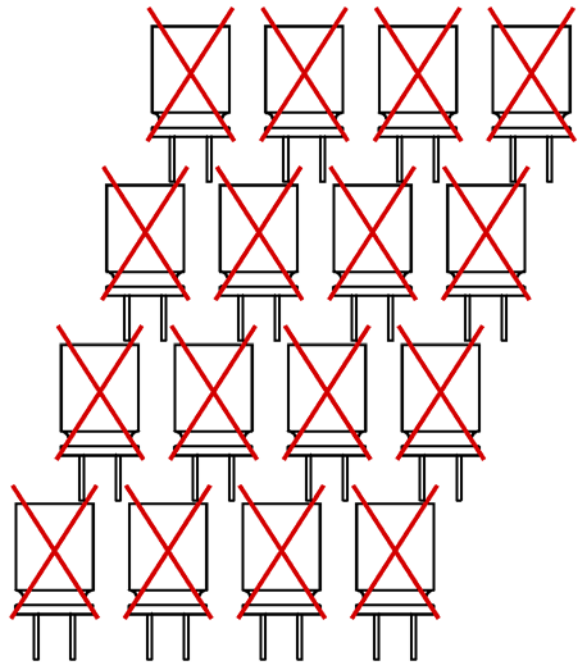
The Solution

- The Switched Current Power Converter with Switched Charge Voltage Control is a true break-through technology providing:
  - *Fastest possible di/dt*
  - *Fastest possible dv/dt*
  - *Fastest possible transition times (on, off, step voltage, or voltage ramp - up or down)*
  - *Expandable to multiple outputs*
  - *Very low standby power*

Key benefits

- Saves power:
  - *Very fast dynamic response allows the processor to remain off or in lower power states for a greater percentage of the time*
- Saves board area:
  - *The bulk capacitors can be eliminated*.
- Saves cost:
  - *Trades-off capacitors for silicon*
  - *Less heat-sinking*



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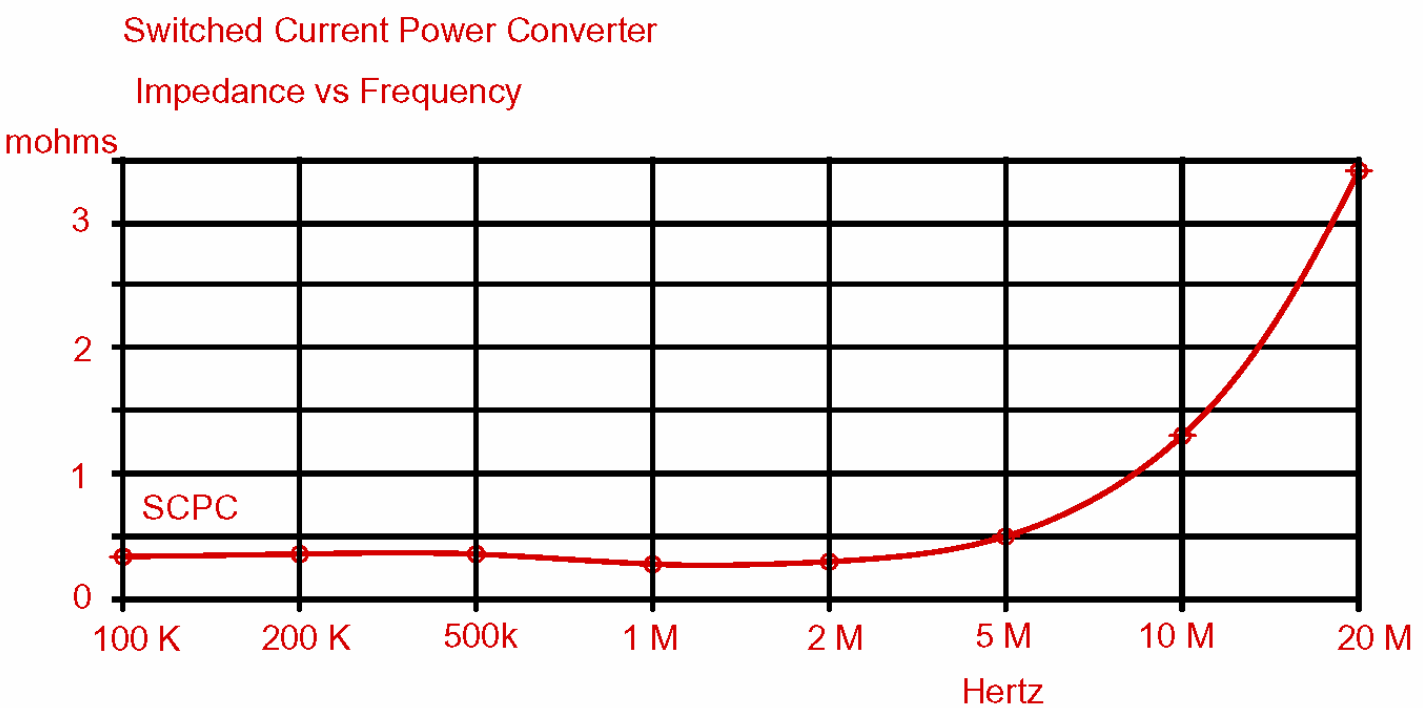
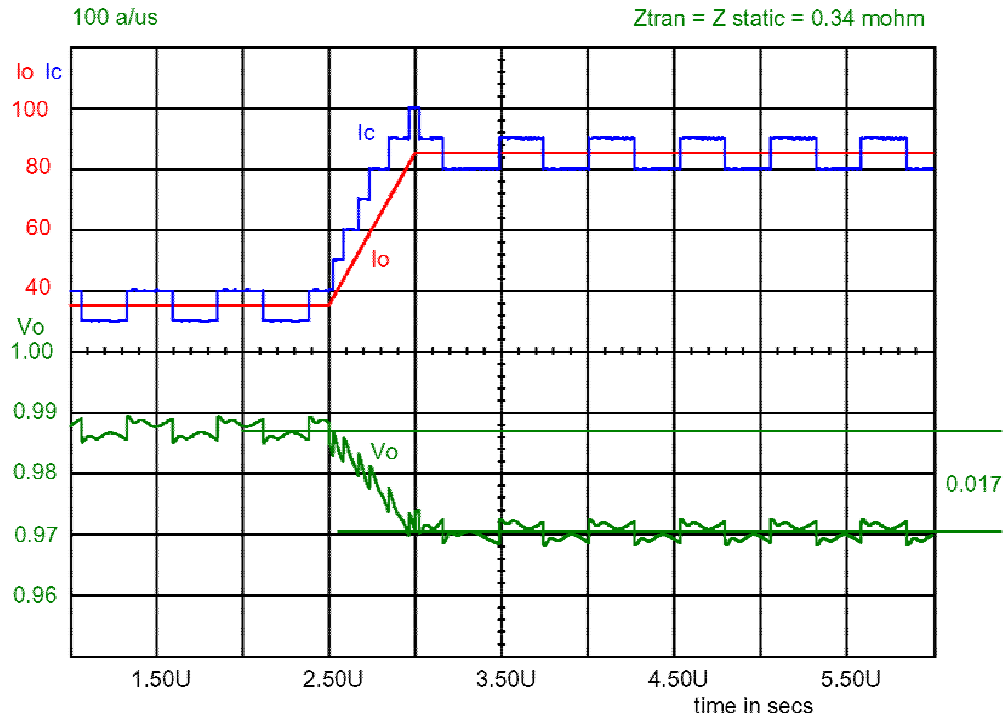
SCPC output impedance curve

- Dynamic and static impedance remains below 0.5 mΩ to 5 MHz.
- Model: 50 A_{pp} ac on 60 A dc (35 A to 85A);
- Load and parasitic impedances per VR 10.2.
- No bulk capacitors, only 500 µF MLCC.



SCPC step response

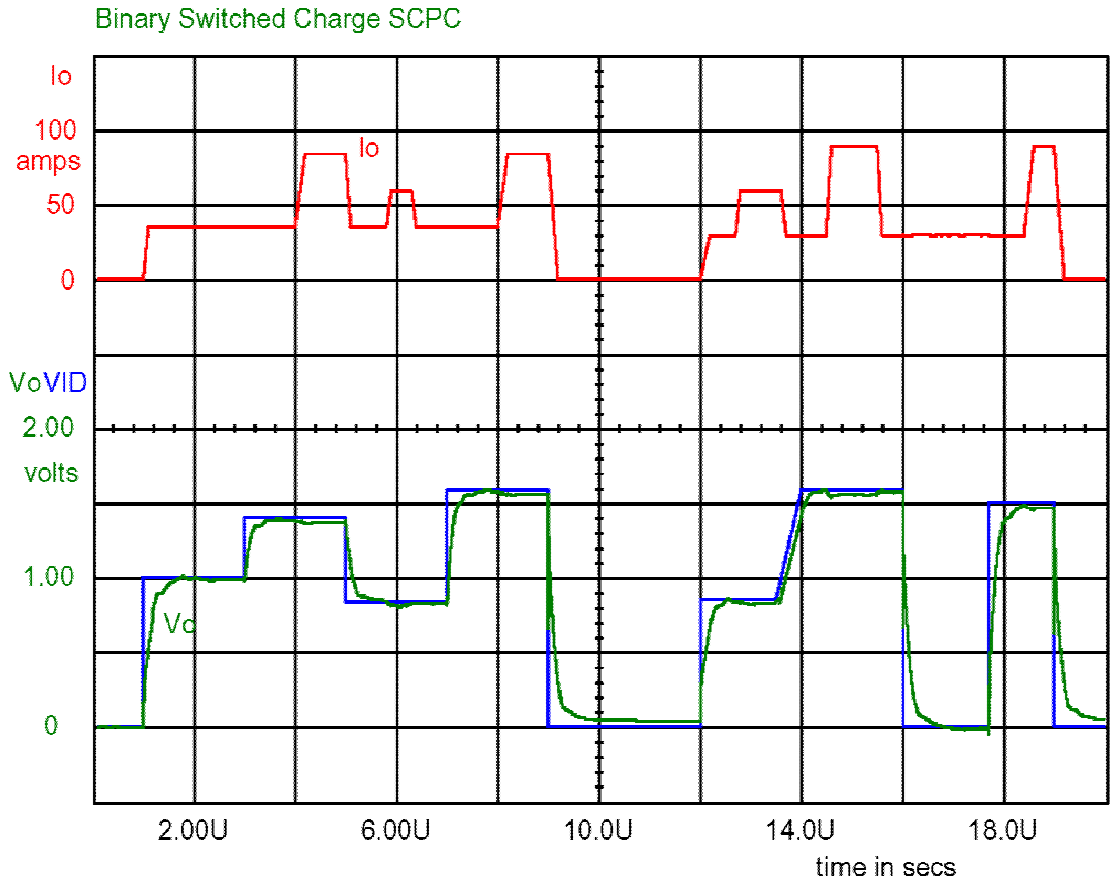
- Current step is 35 A to 85 A, 100 A/µs
  (Spice model load and parasitic impedances per VR 10.2.)
- *At 100 A/µs, the voltage Vo is regulated through the transient.*



SCPC voltage step response with SCC

Switched current power converter with binary switched charge.
(Spice model load and parasitic impedances per VR 10.2.)

- Step, 0 to VID, < 1 µs;
  Step, VID to 0, < 2 µs;
  Step, VID to VID', < 0.5 µs
- VID slew: 1,500 mV/µs
- No overshoot or undershoot
- Full rated current is immediately available
- Blue curve is digital VID input command.
- Green curve is Vo.
- Red curve is load, Io.



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Switching frequency

As compared to a multiphase buck converter, the SCPC has a much lower switching frequency at steady state conditions, or for slow transients (<100 A/us; <20 mV/us).

$$Fs \approx 100\ kHz$$

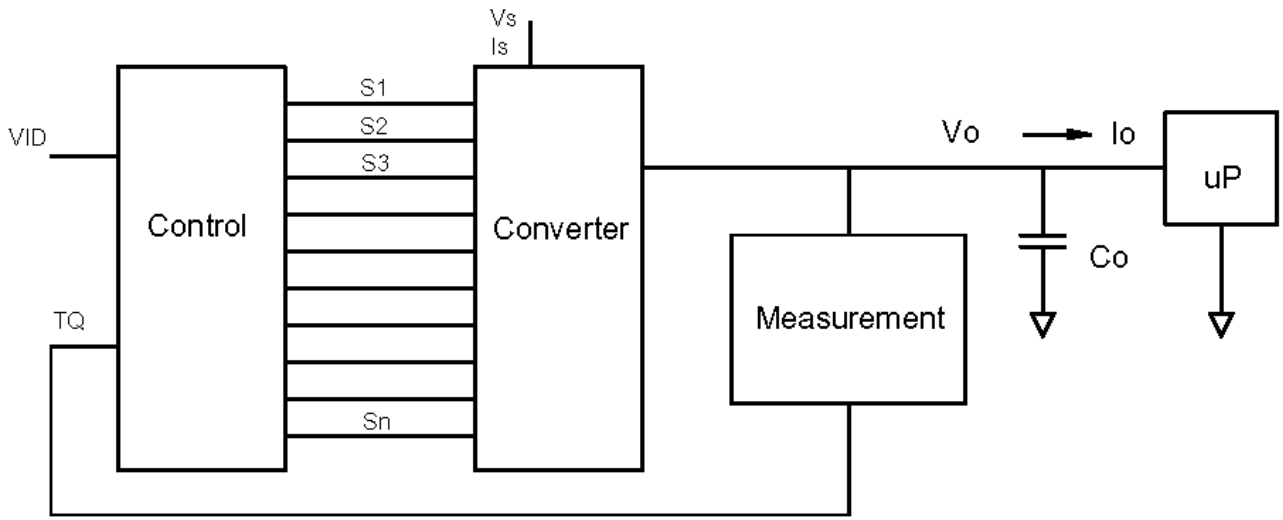
The switching is hysteretic, so the switching frequency varies somewhat.

Frequency is for distributed switching. For details, see "Switched Current Power Converters", Revised 3/13/2006. Chapter 5.0; at http://eherbert.com.

SCPC block diagram

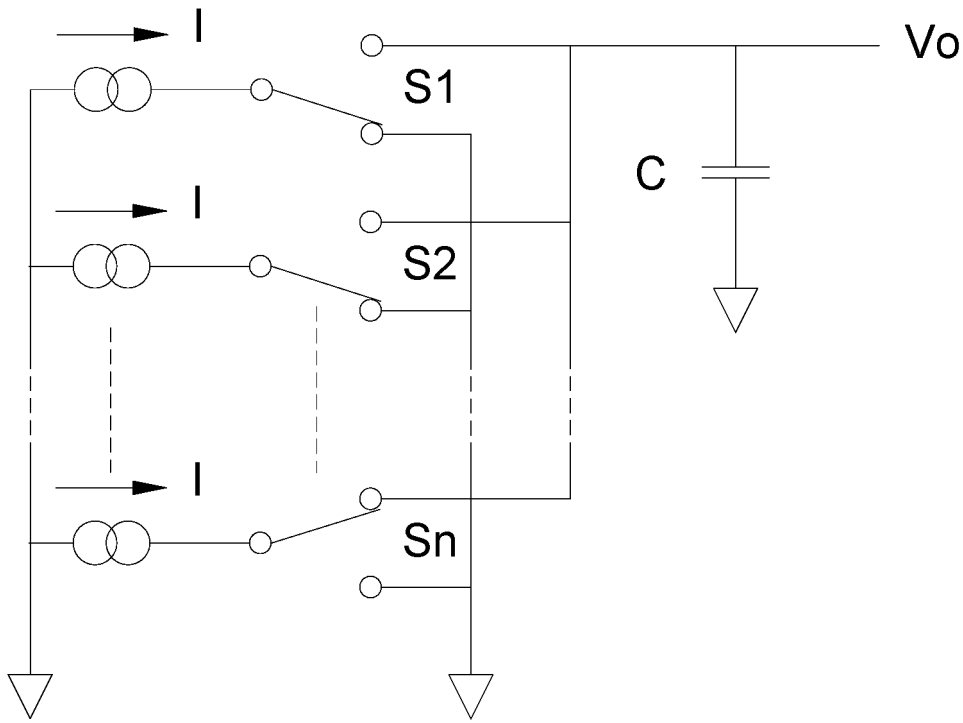
- Current sources
- Current switches
- Measurement and control

Switched Current Power Converter
Block Diagram



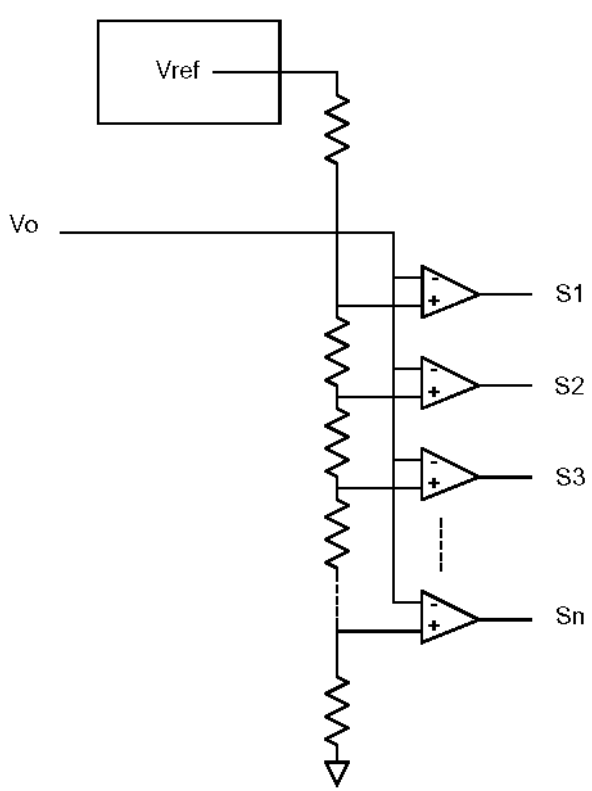
Theory: Switched current power converter

- The SCPC controls the output current and steady state voltage by switching currents with solid-state switches.
- ***There is no faster converter!***



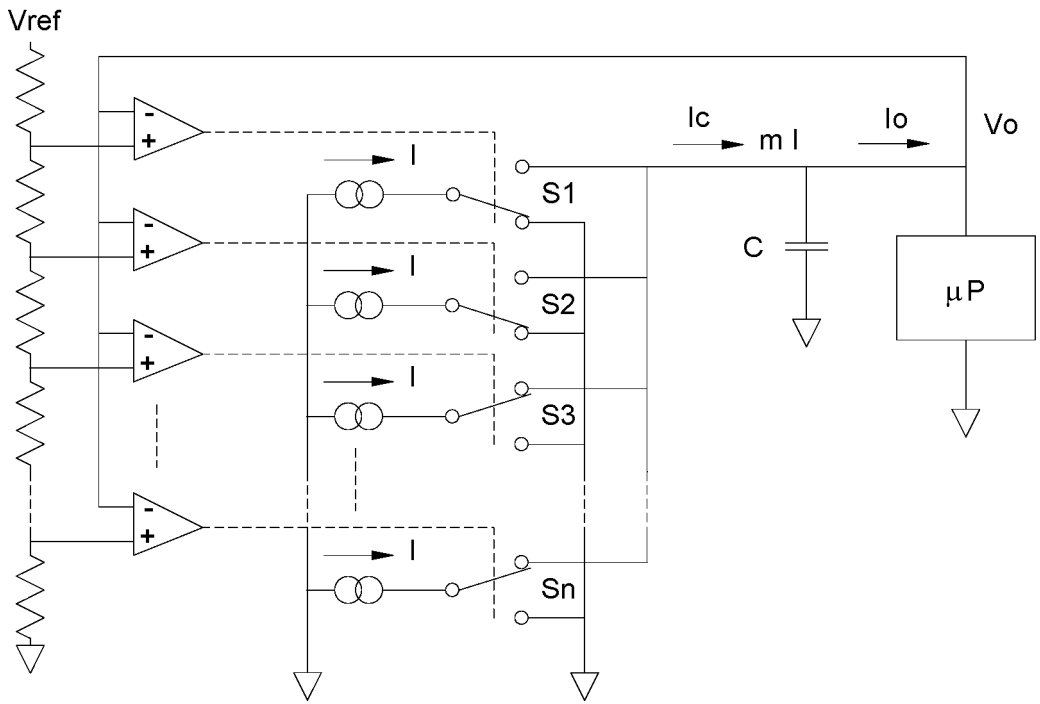
Voltage measurement

- The output voltage is measured using a flash a-d converter.
- ***There is no faster voltage measurement!***



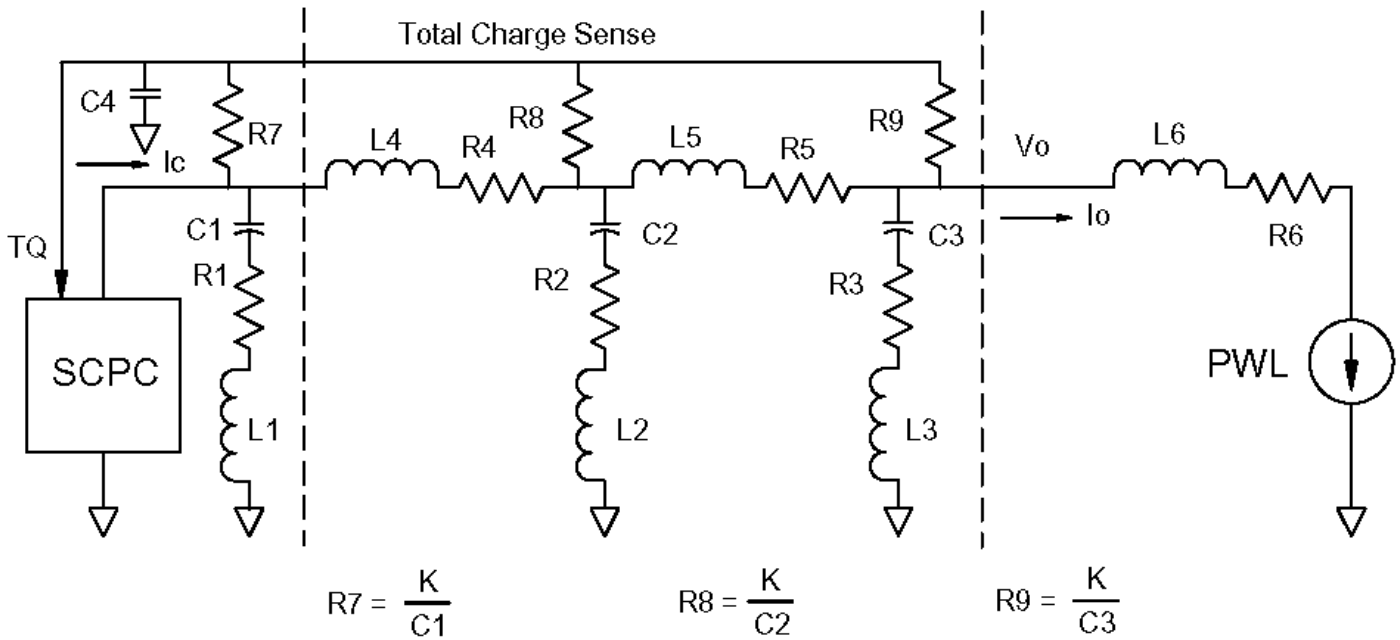
SCPC digital control

- The outputs of the flash a-d directly control the current switches – a true digital control
- ***There is no faster control!***



Total charge measurement

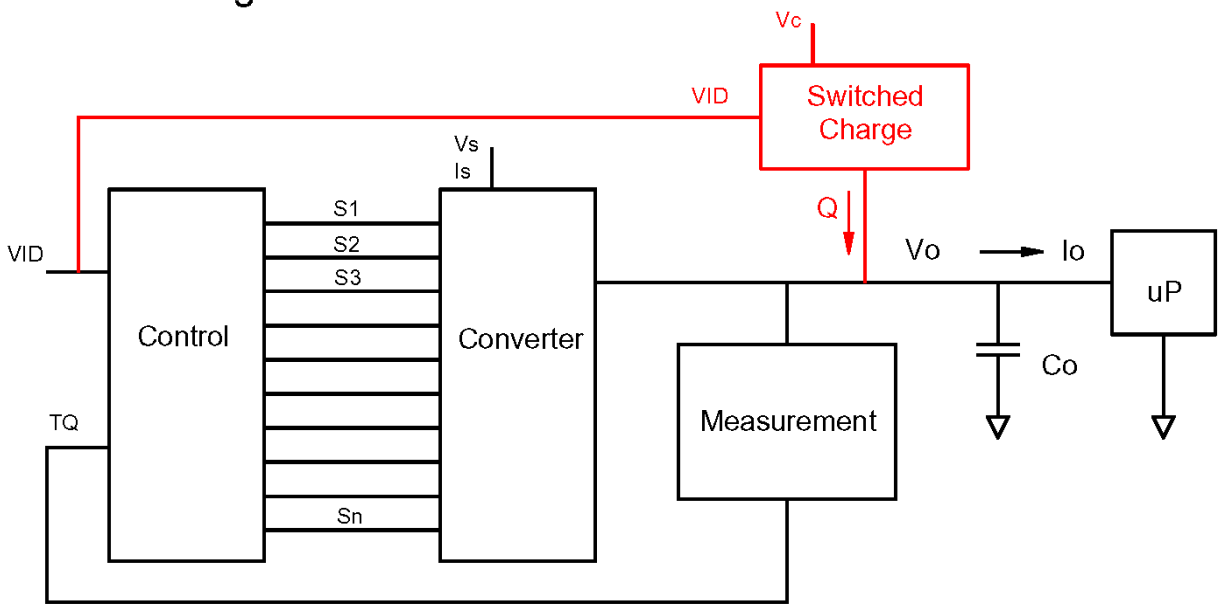
- With distributed capacitors and parasitic inductance, the output voltage is not stable enough to use as control input.
- The answer: measure total charge as the control input.
- ***There is no faster measurement for control!***



Switched charge circuits

- Switched Charge circuits are added to the SCPC for very fast dv/dt, with no changes to the other circuits
- ***There is no faster upgrade!***

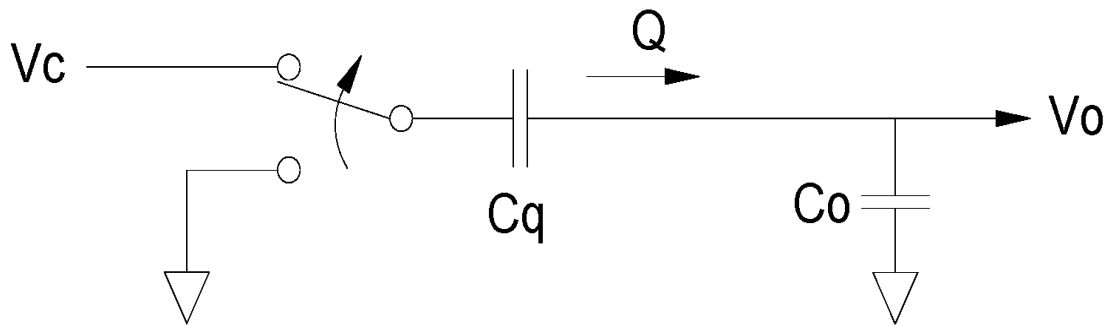
Switched Current Power Converter
with Switched Charge Circuits
Block Diagram



Theory: switched charge circuit

- The output voltage can be stepped very quickly and accurately, up or down, using the Switched Charge Circuit. A precise charge Q is added to the output capacitor Co.

- ***There is no faster way to step the output voltage!***

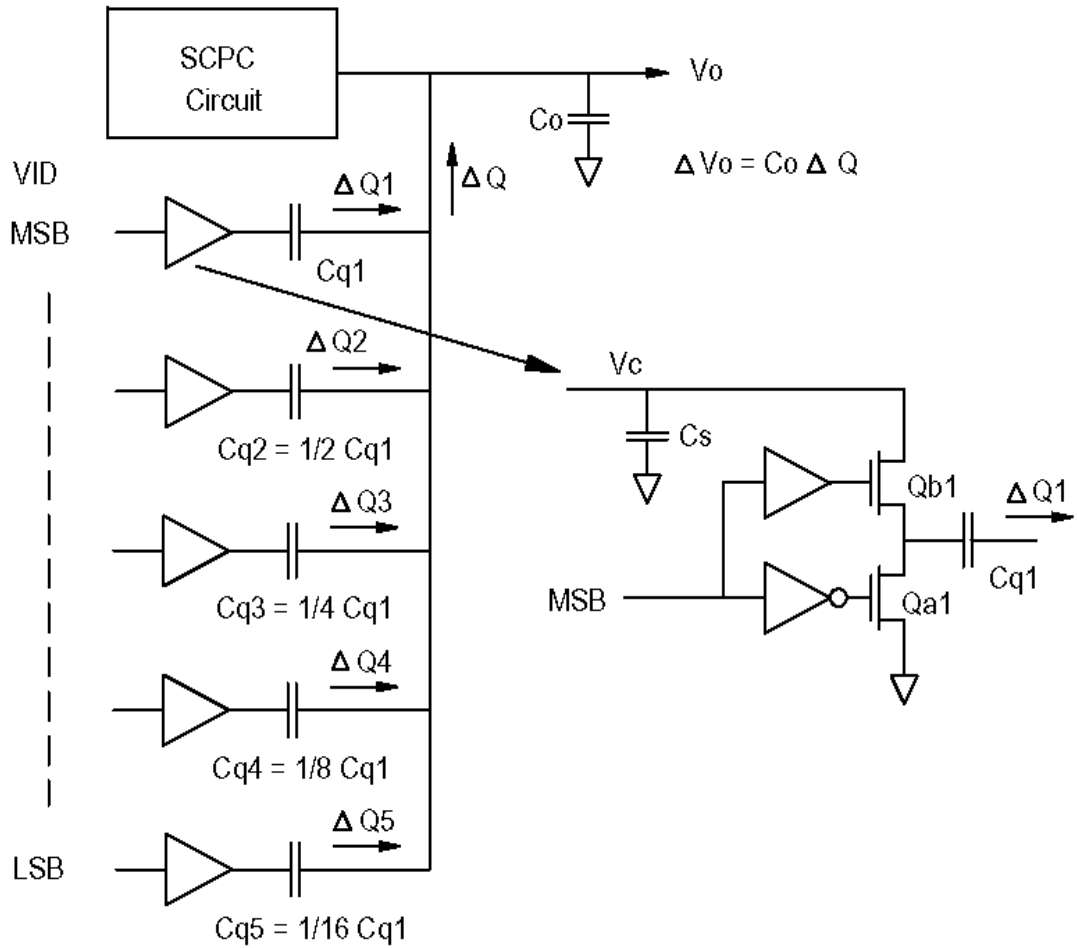


(*Note:* The switched charge circuit does not regulate voltage, it only steps the voltage – very rapidly and accurately – with no overshoot. The SCPC current control maintains regulation after the step.)

Binary switched-charge

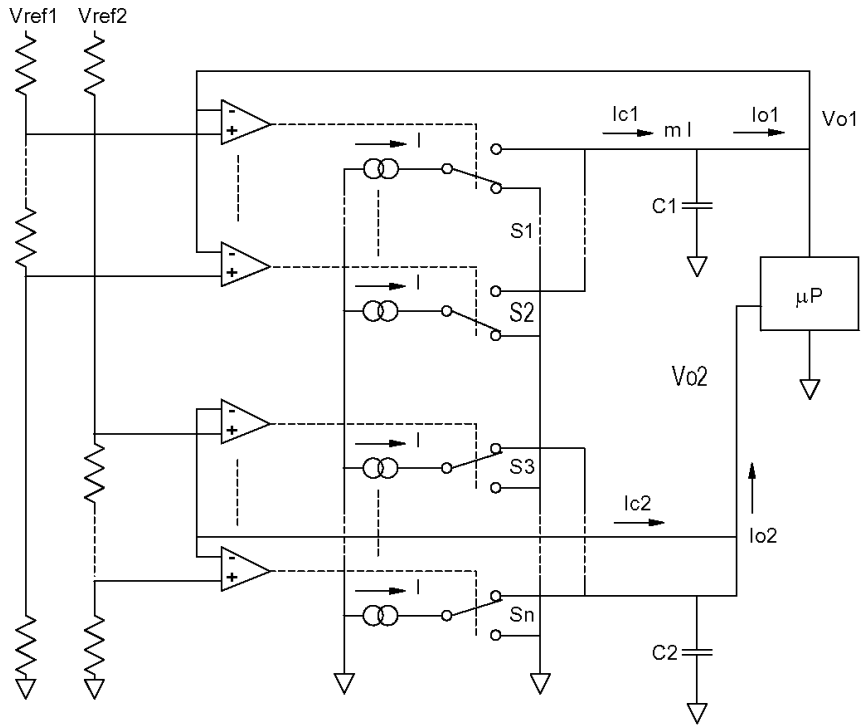
True digital control!

- Digital VID controls the binary switched charge circuits
- Digital VID change causes a rapid voltage step (< 0.5 µs)
- Output voltage can slew very rapidly (up to 1500 mV/µs) when the digital VID is sequenced



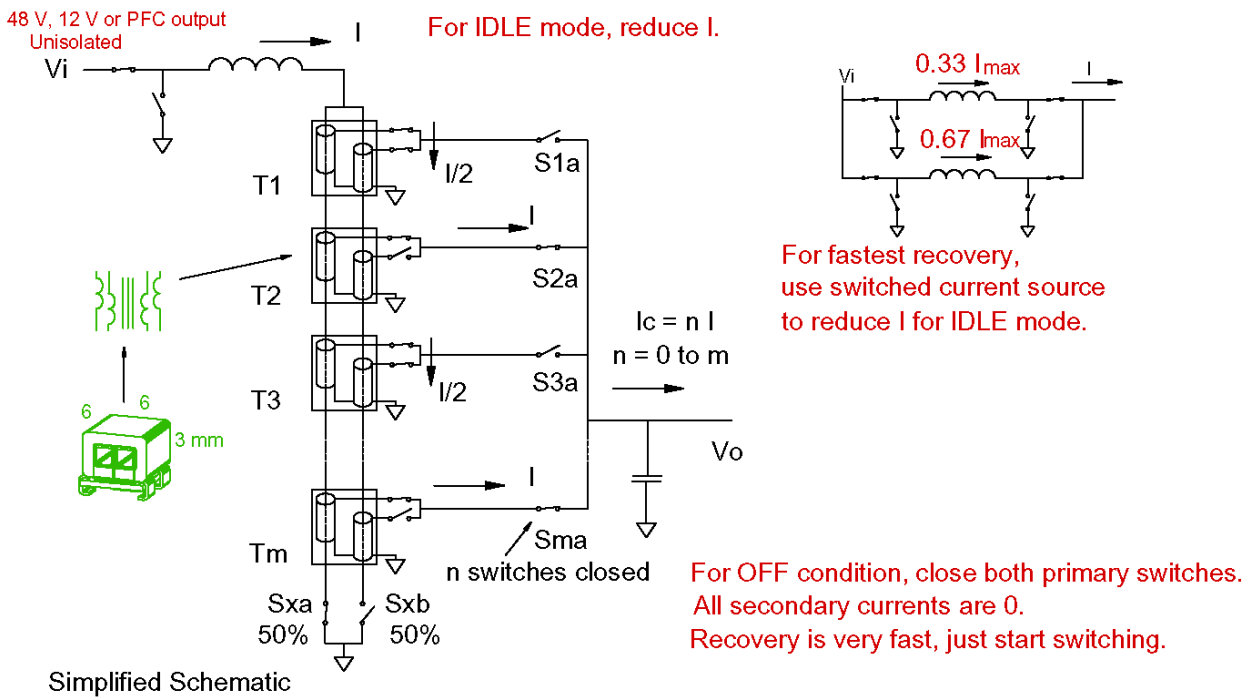
Dual outputs are easy!

- For two voltage outputs for dual core processors, *just divide the SCPC into two halves.*
- Each has its own voltage reference (VID) and flash a-d converter



Idle current

- For higher efficiency in low power modes, the current in the current sources can be reduced:

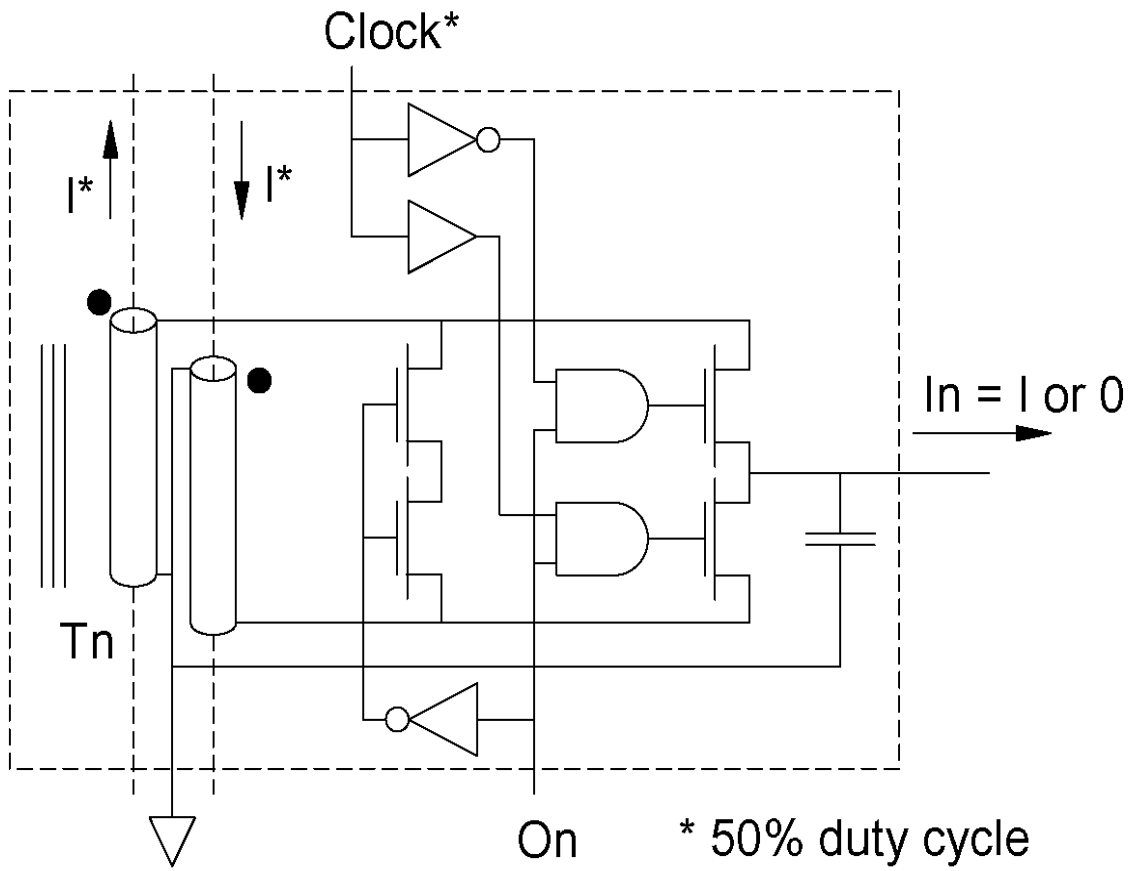


If the primary current is reduced, fewer switches carry circulating current, and the circulating current is lower.

Coaxial transformer module

The logic is simple:

- The “Clock” is synchronized to the primary switching.
- The “On” is the flash a-d comparator output.



Simple power IC

The simple power IC is based on the premise that if all of the MOSFETs in a power IC are the same type, differing only in their active area, then they can all be made at once using nearly the same processing as for an ordinary discrete power MOSFET.

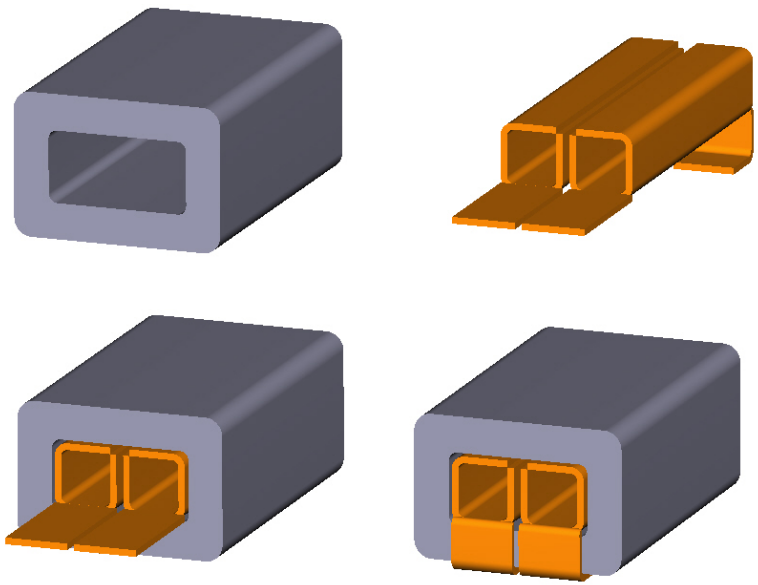
Using this concept, all of the power components of the SCPC secondary circuits can be on one IC, if the current is low.

For a VRD (100 A or so), five identical Ics are optimum (20 A each).

One additional logic and control IC completes the secondary circuits.

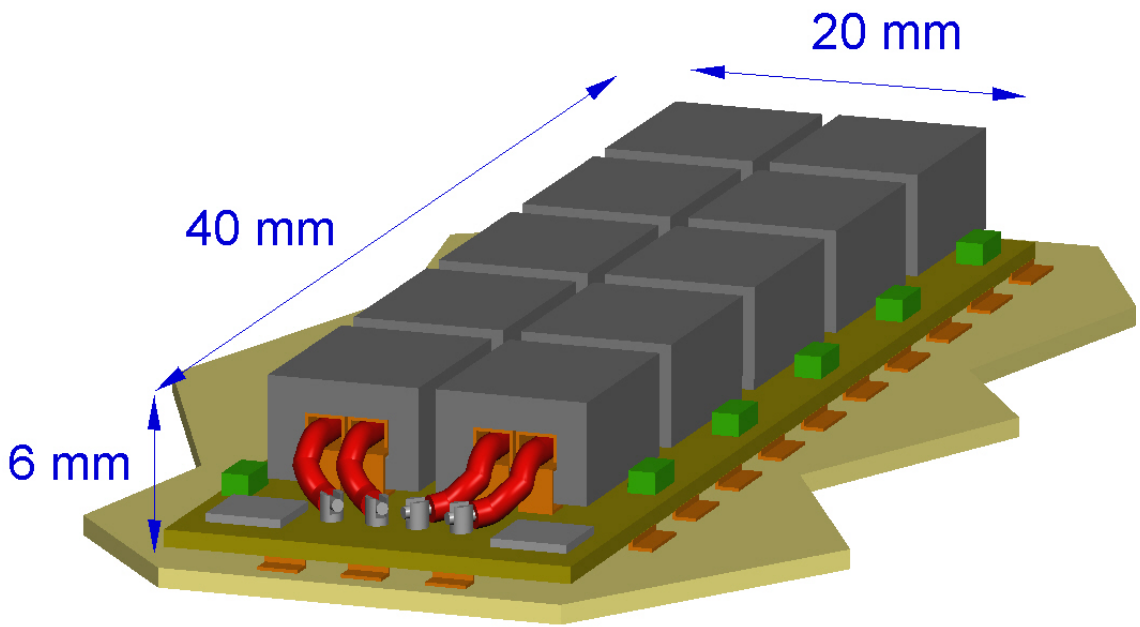
Coaxial transformer

- The coaxial transformer has two formed metal secondary windings that are inserted into a simple, gap-less pressed 3 x 6 x 6 mm core. The ends are folded back as self-leads.



SCPC module

The SCPC is assembled on a small daughter board, 6 x 20 x 40 mm. The master control logic and power ICs mount under the transformers or on the under side. Decoupling capacitors are on the edge.



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Multiple outputs

- The SCPC may be modified to provide multiple outputs, for example, a nine-core processor may have ten separately controlled voltages, one for overhead, timing and the cache, and one for each of the nine cores.
- Each output has a separate VID which may be varied dynamically at up to 1,500 V/us, or it may be turned off (VID, 100% current to 0 V, 0 A) in 1 us, and it may be turned back on (0 V, 0 A to any VID and any current up to 100%) in 1 us.

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Summary

- ***Market trends: Faster di/dt; Faster dv/dt; More multiple outputs***
- ***The SCPC: There is no faster converter***
- ***Flash A/D connected directly to current switches: There is no faster control***
- ***Total Charge Measurement: There is no faster measurement for control***
- ***Adding the Switched Charge Circuit: There is no faster upgrade!***

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Patent status and link

- This technology is covered in part by U. S. Patent No. 6,121,761, "Fast Transition Power Supply", issued September 19, 2000. Other patents have been allowed are more are pending.
- For more information, see http:eherbert.com/

Thank You – Any Questions?