

Preliminary - August 24, 1999

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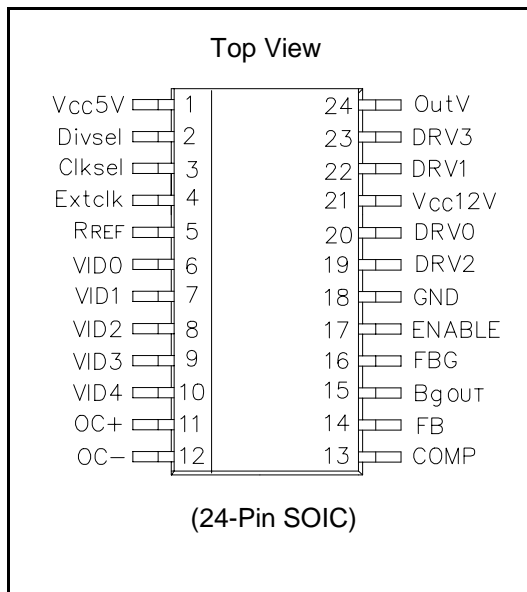
DESCRIPTION

The SC1144 is a high performance, multi-phase (PWM) controller designed for high power microprocessors requiring ultra fast transient response, such as the Pentium®II and beyond. Utilizing a novel and unique design, the controller distributes the output load across (up to) four converter channels by digitally phase shifting the PWM outputs. This approach greatly reduces the stress and heat on the output stage components while lowering input ripple current by as much as 80%. Accurate current sharing among the four phases is achieved by precision design techniques and trimming of critical elements.

The high speed transconductance error amplifier is externally initialized using a soft-start capacitor allowing the controller to "wake-up" without overshoot, thus protecting the low voltage microprocessor loads. The output drive voltage to the power MOSFETs is programmable to minimize switching losses in the drive circuitry.

The floating feedback ground allows remote sense capability. The output voltage is digitally programmable by means of a 5 bit DAC. A single resistor programs the master clock frequency (8MHz max) or the controller may be synchronized using an external oscillator. The number of operating phases is programmed independently of the external clock. The parts features under-voltage lock-out with hysteresis and over-current protection.

PIN CONFIGURATION



FEATURES

- Allows use of small surface mount components
- Ultra fast transient recovery time
- Wide, High frequency operating range
- Selectable 2, 3, 4 phase operation
- Floating feedback ground for remote sensing
- Precision load current sharing
- Selectable internal or external clock
- Soft start, Over current protection
- 5-bit DAC programmable output
- programmable clock, 200Khz-2Mhz per phase

APPLICATIONS

- High end servers and workstations
- High current/Ultra-fast transient microprocessors
- Voltage Regulator Modules

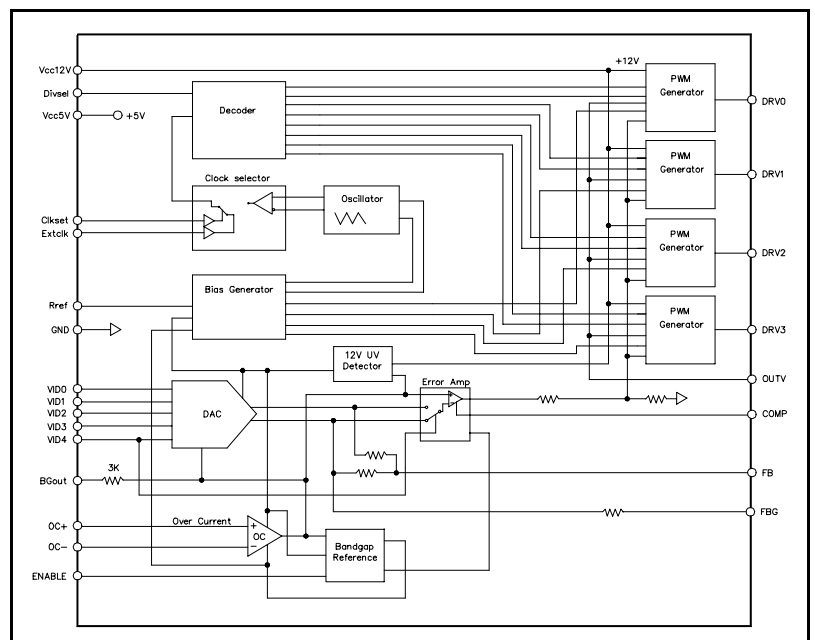
ORDERING INFORMATION

| DEVICE ⁽¹⁾ | PACKAGE | TEMP. (T _J) |
|-----------------------|---------|-------------------------|
| SC1144ABCSW | SO-24 | 0 - 85°C |

Note:

(1) Add suffix 'TR' for tape and reel.

BLOCK DIAGRAM



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ABSOLUTE MAXIMUM RATINGS

| Parameter | Symbol | Limits | Units |
|--|--------------------|--------------|-------|
| V _{CC5V} to GND | V _{CC5V} | -0.3 to + 12 | V |
| FBG to GND | FBG | ± 1 | V |
| V _{CC12V} to GND | V _{CC12V} | -0.3 to +20 | V |
| Operating Temperature Range | T _A | 0 to +70 | °C |
| Junction Temperature Range | T _J | 0 to +125 | °C |
| Storage Temperature Range | T _{STG} | -55 to +150 | °C |
| Thermal Resistance Junction to Case | θ _{JC} | 25 | °C/W |
| Thermal Resistance Junction to Ambient | θ _{JA} | 80 | °C/W |
| Lead Temperature (Soldering) 10 sec | T _{LEAD} | 300 | °C |

ELECTRICAL CHARACTERISTICS

 Unless otherwise noted: T_A = 25°C, V_{CC5V} = 5V, V_{CC12V} = 12V, 4-Phase operation.

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|-------------------------------|--------------------|--|----------------------|------|------|-------|
| Supply Voltage Range | V _{CC12V} | | 10.0 | 12.0 | 14.0 | V |
| UVLO Range | V _{CC5V} | | | 3.9 | | V |
| UVLO Hysteresis | V _{CC5V} | | | 50 | | mV |
| UVLO Range | V _{CC12V} | | | 9.0 | | V |
| UVLO Hysteresis | V _{CC12V} | | | 100 | | mV |
| Supply Voltage Range | V _{CC5V} | | 4.5 | 5.0 | 5.5 | V |
| Supply Current | V _{CC12V} | DRV Outputs open | | 12 | 20 | mA |
| Supply Current | V _{CC5V} | V _{OUT} = 2.00V, I _O = 0 | | | 40 | mA |
| Reference Current Pin Voltage | V _{REF} | I _{ref} = 250µA | | 2.05 | | V |
| Vid0-4 Clock Select & Divide | V _{INL} | Logic Low | | | 0.8 | V |
| Select Logic Threshold | V _{INH} | Logic High | 2 | | | V |
| Vid0-4 Clock Select & Divide | I _{INL} | Vid0-4=0V | | | -20 | µA |
| Select Input Bias Current | I _{INH} | Vid0-4=4.5V | | | +50 | µA |
| Enable Pin | V _{INL} | | | | .8 | V |
| | V _{INH} | | 2 | | | V |
| DRV0-3 Output Voltage | V _{OL} | I _{sink} = 1mA | | | .3 | V |
| | V _{OH} | I _{source} =1ma, OUTV=V _{CC12} | V _{CC12} -1 | | | V |
| DRV0-3 Source Current | I _{SRC} | V _{OUT} = 2.00V | | 20 | | mA |
| DRV0-3 Sink Current | I _{SNK} | V _{OUT} = 2.00V | | 40 | | mA |

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ELECTRICAL CHARACTERISTICS (Cont.)

 Unless otherwise noted: $T_A = 25^\circ\text{C}$, $V_{CC5V} = 5\text{V}$, $V_{CC12V} = 12\text{V}$, 4-Phase operation.

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|--|--|--|-----|------|------|------------------|
| Bgout Voltage | V_{Bgout} | $V_{id} = 00000$ | | 2.05 | | V |
| Bgout Impedance | R_{O_Bg} | | | 3 | | $\text{K}\Omega$ |
| External Clock Freq. Range | F_{ext_CK} | | .80 | 8.0 | 8.5 | MHz |
| Oscillator Frequency Accuracy | F_{OSC} | $I_{ref} = 250\mu\text{A}$ | 7.2 | 8.0 | 8.8 | MHz |
| Internal Clock Freq. Range | F_{int_CK} | | .80 | 8.0 | 8.5 | MHz |
| Match DRV0-3 | Δ_D | Duty cycle deviation from Avg. | -1 | | +1 | % |
| PWM Off Time | T_{off} | | | 25 | | % |
| Drive Voltage Range | OutV | Output Freq. = 2MHz/Phase $V_O = 2.000\text{V}$ | 5 | 10 | 12 | V |
| Overcurrent Comparator, Comparator, Common Mode Range | OCC_CMR | | 3 | | 15 | V |
| OC+I/P bias Current | I_{B_OC+} | $V_{in} = 5\text{V}, R_{oc+} < 20\text{Kohm}$ | +75 | 185 | +250 | μA |
| OC-I/P bias Current | I_{B_OC-} | $V_{in} = 5\text{V}, R_{oc-} < 20\text{Kohm}$ | +75 | 125 | +250 | μA |
| Input Offset Voltage | V_{OS_OCC} | $V_{in} = 5\text{V}$ | | 10 | | mV |
| Feedback Input Impedance | R_{i_FB} | $V_O = 2.00\text{V}$ | | 12 | | $\text{K}\Omega$ |
| Maximum Duty Cycle | D_{max} | $FB=0\text{V}$ | | 75 | | % |
| Mimimum Duty Cycle | D_{min} | $FB=4.0\text{V}$ | | 0 | | % |
| CONVERTER SPECIFICATIONS, Reference Application Circuit | | | | | | |
| Output Accuracy Over Set Range | V_{OUT} | VID 0-4 = 0000-1111 $V_{CC5V} = 5.0\text{V}$ | -1 | | +1 | % |
| Load Regulation | $\frac{\Delta V_{OUT}}{\Delta I_O}$ | $V_O = 2.000\text{V}$ $I_O = 3\text{A} - 20\text{A}$ | | .025 | .05 | %/A |
| Line Regulation | $\frac{\Delta V_{OUT}}{\Delta V_{IN}}$ | $V_{CC5V} = 5\text{V}, V_O = 2.000\text{V}$ $V_{IN} = 4-6\text{V}$, (v_{in} separated from V_{CC5V}) $I_O = 5\text{A}$, Clk = external | | .15 | | %/V |

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PIN DESCRIPTION

| Pin # | Pin Name | Pin Function |
|-------|---------------------|--|
| 1 | V _{CC5V} | Supply voltage input (5V nominal) |
| 2 | Divsel | Connect to Gnd for four phase operation and to logic High for three Phase operation. |
| 3 | Clkssel | Clock Select: Logic high selects internal clock. Logic low selects external clock. |
| 4 | Extclk | External Clock Input. The output frequency is determined by (Clock Input Freq.)/4. Output freq.= (Clock Input)/4. Pull up to Vcc5v to select internal clock. |
| 5 | R _{REF} | Connects to external reference resistor. Sets the operating frequency of the internal clock and the ramp time for the PWM. Reference voltage at this pin is 2.05V. Trimmed to set 250µA at 8MHz. |
| 6 | VID0 ⁽¹⁾ | Programming Input (LSB) |
| 7 | VID1 ⁽¹⁾ | Programming Input |
| 8 | VID2 ⁽¹⁾ | Programming Input |
| 9 | VID3 ⁽¹⁾ | Programming Input |
| 10 | VID4 ⁽¹⁾ | Programming Input (MSB) |
| 11 | OC+ | Over current comparator. Non-Inverting input. |
| 12 | OC- | Over current comparator. Inverting input. |
| 13 | COMP | Compensation Pin. Compensation is achieved by connecting a capacitor in series with a resistor between this pin and FBG. A 300k ohm resistor must also be directly connected between this pin and FBG. |
| 14 | FB | Feedback input connected to supply output. |
| 15 | B _{GOUT} | Bandgap Reference Output. Output resistance=3kohm. Must be bypassed with 4.7nf -100nf capacitor to FBG. This capacitor programs the soft start time. |
| 16 | FBG | Feedback Ground. This pin must be connected to return side of output caps. This pin is floating, (within one diode drop of GND pin). |
| 17 | ENABLE | Connects to 5V to enable. Connect to GND to disable entire device. |
| 18 | GND | Ground Pin |
| 19 | DRV2 | Phase 2 output |
| 20 | DRV0 | Phase 0 output |
| 21 | V _{CC12V} | Supply voltage for the FET Drivers/DRV0-3 |
| 22 | DRV1 | Phase 1 output |
| 23 | DRV3 | Phase 3 output |
| 24 | OutV | Sets the maximum DRV0-3 drive voltage in order to reduce switching losses in the external MOSFETs. |

NOTE: (1) All logic inputs and outputs are open collector TTL compatible.

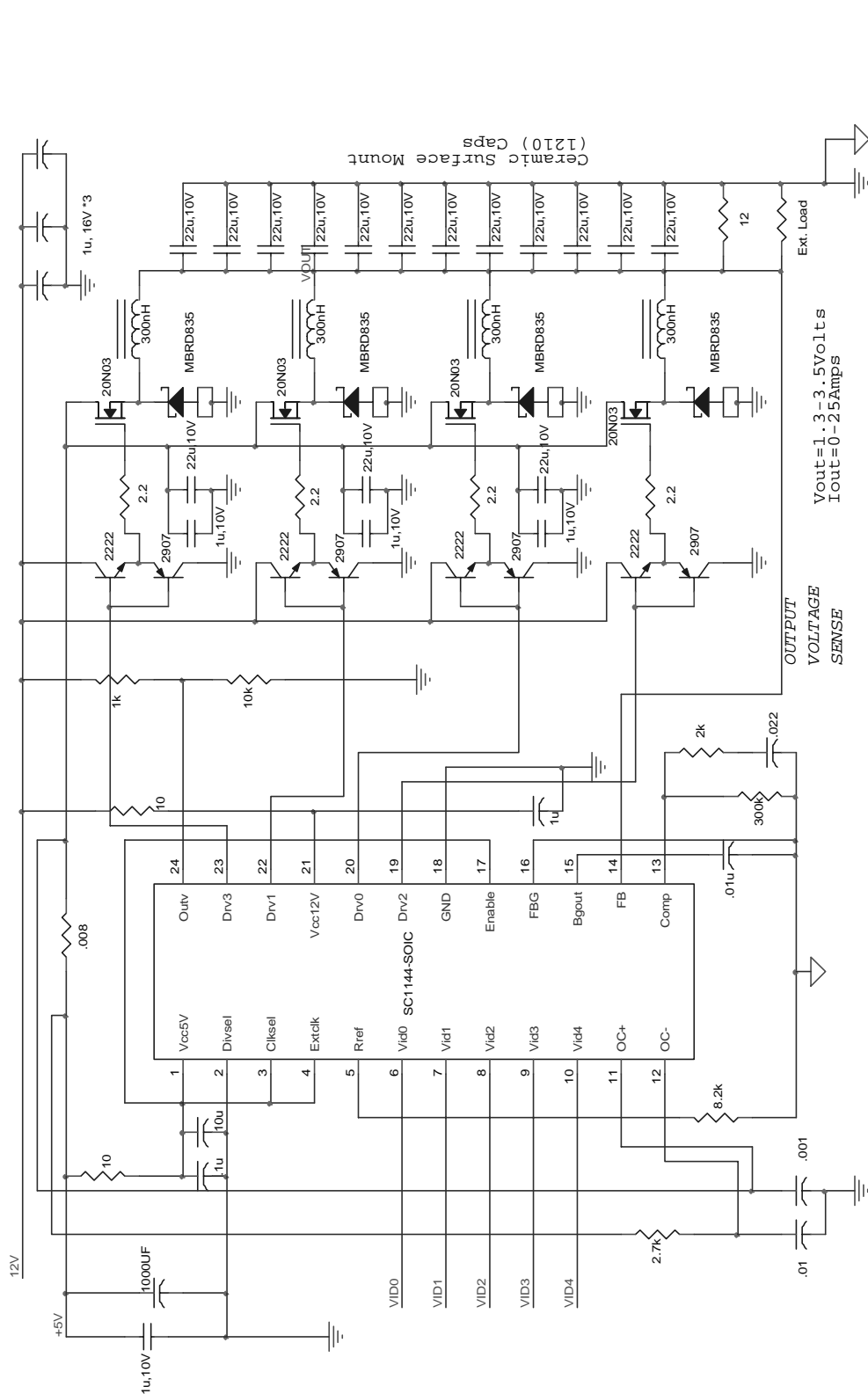
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OUTPUT VOLTAGE

 Unless specified: 0 = GND; 1 = High (or Floating).
 $T_A = 25^\circ\text{C}$, $V_{CC5V} = 5\text{V}$, $V_{CC12V} = 12\text{V}$, 4-Phase operation.

| PARAMETER | VID 43210 | MIN | TYP | MAX |
|----------------|--------------|-------|-------|-------|
| Output Voltage | 01111 | 1.287 | 1.300 | 1.313 |
| | 01110 | 1.336 | 1.350 | 1.364 |
| | 01101 | 1.386 | 1.400 | 1.414 |
| | 01100 | 1.435 | 1.450 | 1.465 |
| | 01011 | 1.485 | 1.500 | 1.515 |
| | 01010 | 1.534 | 1.550 | 1.566 |
| | 01001 | 1.584 | 1.600 | 1.616 |
| | 01000 | 1.633 | 1.650 | 1.667 |
| | 00111 | 1.683 | 1.700 | 1.717 |
| | 00110 | 1.732 | 1.750 | 1.768 |
| | 00101 | 1.782 | 1.800 | 1.818 |
| | 00100 | 1.831 | 1.850 | 1.869 |
| | 00011 | 1.881 | 1.900 | 1.919 |
| | 00010 | 1.930 | 1.950 | 1.970 |
| | 00001 | 1.980 | 2.000 | 2.020 |
| | 00000 | 2.029 | 2.050 | 2.071 |
| | 11111 | 1.980 | 2.000 | 2.020 |
| | 11110 | 2.079 | 2.100 | 2.121 |
| | 11101 | 2.178 | 2.200 | 2.222 |
| | 11100 | 2.277 | 2.300 | 2.323 |
| | 11011 | 2.376 | 2.400 | 2.424 |
| | 11010 | 2.475 | 2.500 | 2.525 |
| | 11001 | 2.574 | 2.600 | 2.626 |
| | 11000 | 2.673 | 2.700 | 2.727 |
| | 10111 | 2.772 | 2.800 | 2.828 |
| | 10110 | 2.871 | 2.900 | 2.929 |
| | 10101 | 2.970 | 3.000 | 3.030 |
| | 10100 | 3.069 | 3.100 | 3.131 |
| | 10011 | 3.168 | 3.200 | 3.232 |
| | 10010 | 3.267 | 3.300 | 3.333 |
| | 10001 | 3.366 | 3.400 | 3.434 |
| | 10000 | 3.465 | 3.500 | 3.535 |

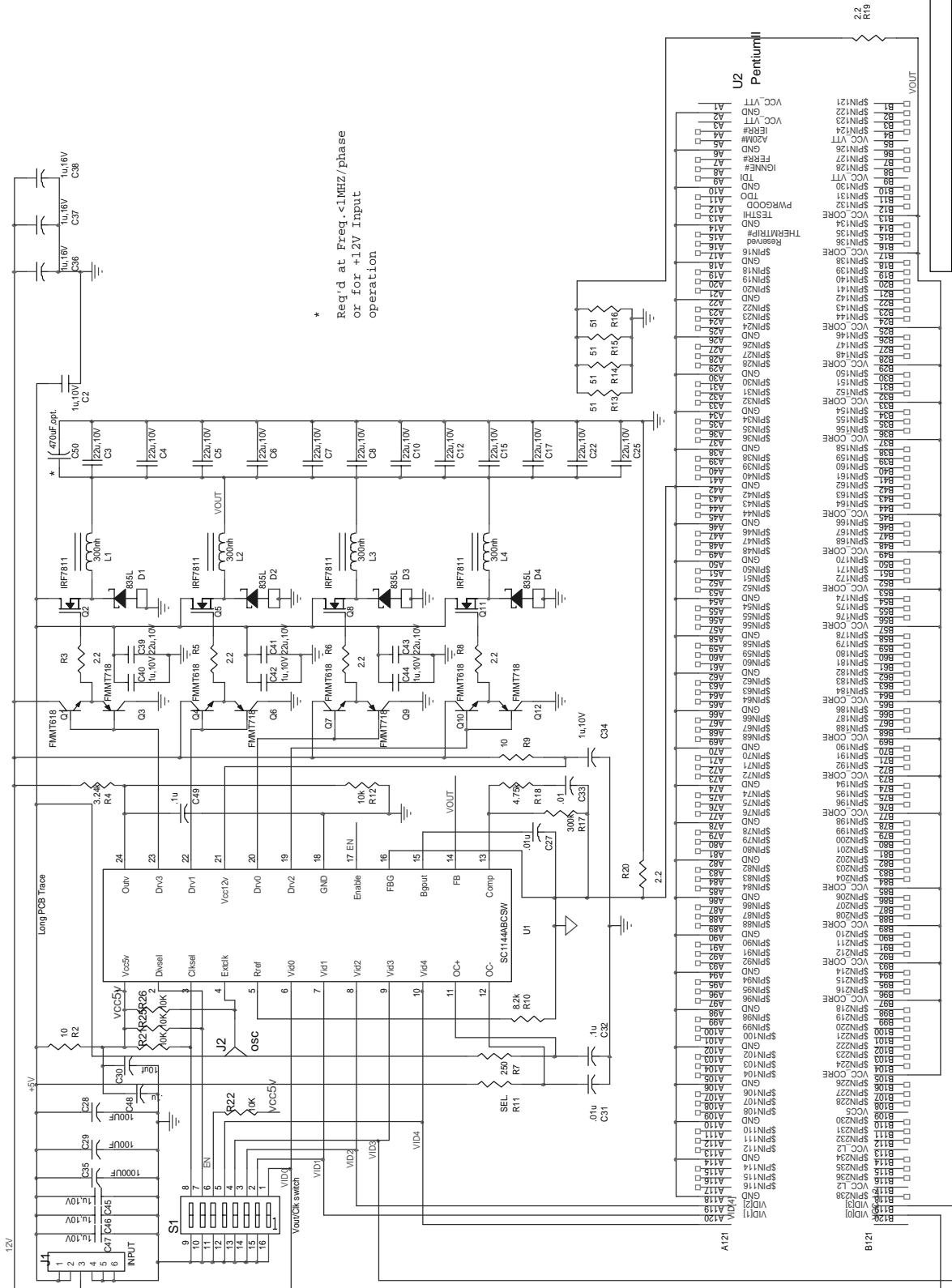
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TYPICAL APPLICATION CIRCUIT


| | | | |
|-------|-----------------------------|----------------------------|-----------|
| Title | | SC1144 Application Circuit | |
| Size | Document Number | Rev | (RevCode) |
| A | | | |
| Date: | Wednesday, January 06, 1999 | Sheet | 1 of 1 |

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EVALUATION BOARD SCHEMATIC



| | | | |
|-----------------|-----------------------------|----------|--------|
| File | SC1144evb1 Evaluation Board | | |
| Document Number | SC1144_EVB | | |
| Size | B | Revision | A |
| Date: | Wednesday, July 07, 1999 | Sheet | 1 of 1 |

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BILL OF MATERIAL

| Item | Qty | Reference | Value | Manufacturer |
|------|-----|---|-------------------------------|--|
| 1 | 11 | C2,C34,C36,C37,C38,C40,C42,C44,C45,C46,C47 | 1u,10V | AVX (818)883-7606 X7R |
| 2 | 15 | C3,C4,C5,C6,C7,C8,C10,C12,C15,C17,C22,C25,C39,C41,C43 | 22u,10V | Murata (512)250-5082 PN #GRM235Y5V226Z010 |
| 3 | 2 | C27,C31 | .01u | AVX,Murata,Nichicon |
| 4 | 2 | C29,C28 | 100UF, 6.3v | Murata,Al. Elec. |
| 5 | 1 | C30 | 10uf, 6.3v | Murata,Al. Elec. |
| 6 | 1 | C32 | .001 | Murata |
| 7 | 1 | C33 | .01u | Murata |
| 8 | 1 | C35 | 1000UF, 6.3v | Murata,Al. Elec. |
| 9 | 1 | C48 | .1u | Murata,X7R |
| 10 | 4 | D1,D2,D3,D4 | 835L | Motorola |
| 11 | 1 | J1 | INPUT | |
| 12 | 1 | J2 | osc | |
| 13 | 4 | L1,L2,L3,L4 | 300nH, 8Amp or 450nH, 8Amp | Falco (305)662-7276 PN #T025A2 or T025O2 |
| 13A | 4 | L1,L2,L3,L4 | 300nH, 6Amp | Steward PN# DI2220V301R-00 |
| 14 | 4 | Q1,Q4,Q7,Q10 | FMMT618 | Zetex |
| 15 | 4 | Q2,Q5,Q8,Q11 | 20N03HL | Motorola |
| 16 | 4 | Q3,Q6,Q9,Q12 | FMMT718 | Zetex |
| 19 | 2 | R2,R9 | 10 | Dale,any |
| 20 | 6 | R3,R5,R6,R8,R19,R20 | 2.2 | Dale |
| 21 | 1 | R4 | 680 | any |
| 22 | 1 | R7 | 250 | any |
| 23 | 1 | R10 | 8.2k | any |
| 24 | 1 | R11 | 2.32k | any |
| 25 | 1 | R12 | 3k | any |
| 26 | 4 | R13,R14,R15,R16 | 51, 1/4W, 1206 | Dale |
| 27 | 1 | R17 | 300k | any |
| 28 | 1 | R18 | 4.75k | any |
| 29 | 4 | R21,R22,R25,R26 | 10K | any |
| 30 | 1 | S1 | Vout/Clk switch C&K | (800)cal-swch |
| 31 | 1 | U1 | SC1144ABCSW | Semtech (805)498-2111 |
| 32 | 1 | U2 | PentiumII conn. | Foxconn (714)256-1880 |

Unless otherwise noted, all resistors are 1/10W, 5%, 0805 and all capacitors are 20%, 50v, 0805.

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THEORY OF OPERATION

FUNCTIONAL DESCRIPTION

The SC1144 is a programmable, high performance, multi-phase controller designed for the most demanding DC/DC converter applications in which transient response, space, input ripple current and component form factor and cost are paramount. The SC1144 based dc/dc converter consists of four asynchronous converters. The gate drives to the converters are alternated sequentially by the SC1144 allowing equal sharing of the load current among the stages. The high clock frequency allows for smaller inductor value and miniature surface mount, low inductance output capacitors. Since each stage has $\frac{1}{4}$ the output current, the conduction losses in each stage is reduced by a factor of 1/16. Precision active trimming ensures 1% matching of duty cycles among phases, thus ensuring the heat and component stress is shared equally. This allows use of lower cost components in each phase and virtual elimination of heat sinks.

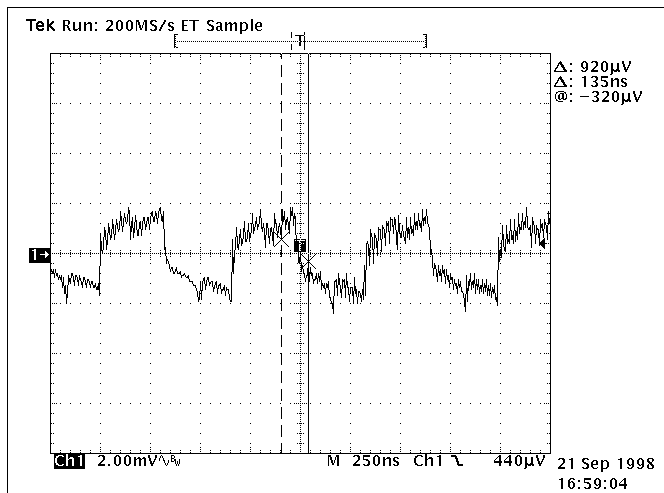


Fig. 4: V_{OUT} Ripple, $V_{OUT} = 2.0V$, $I_{OUT} = 30A$

DECODER/BIAS GENERATOR/PWM CONTROLLER

The 8 MHz clock is divided down to 2 MHz for four phase operation by the clock decoder. The start of the output pulses are time shifted 90 degrees by the decoder with respect to each other. The Bias Generator generates the ramps to each phase by a precision trimmed current source and on-chip capacitors. The decoder, which is synchronized to the bias generator via the master clock, phase shifts the ramps and enables the PWM controller sequentially. A resistor from R_{REF} pin to FBG programs the frequency and ramp

time. The ramps are then compared to the error amplifier output at the high speed PWM comparator inputs. The oscillator master clock frequency is programmed as follows:

$$\text{Clock Freq} = (8.2K/R_{ref}) * 8Mhz$$

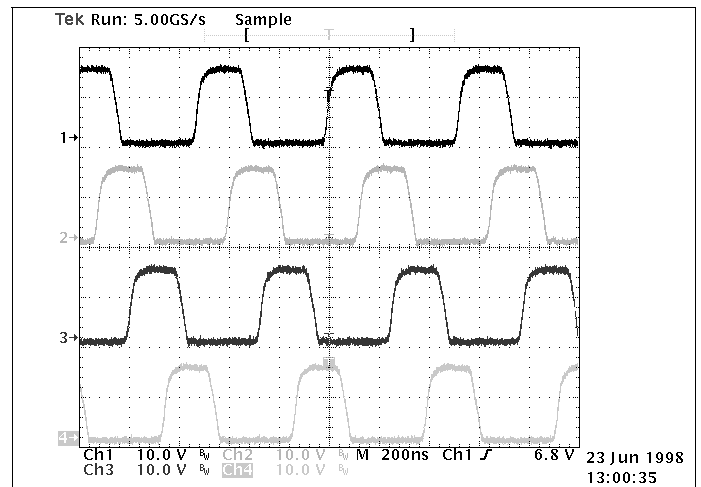


Fig. 1: The four Gate Drives firing 90° out of phase.
 $V_{OUT} = 2.0V$, $I_{OUT} = 10A$

ERROR AMPLIFIER

At the heart of the controller is an ultra-fast, transconductance error amplifier. Since the output inductor values can be selected to be a minimum, usually less than a micro-Henry, the delays due to inductor ramp time are minimized during transient load recovery. The higher frequency of operation also allows use of much smaller capacitance on the output. This means that the dc/dc converter output capacitors "hold Time" is less. The error amplifier must therefore respond extremely fast "Recover the Fort" after a transient. The SC1144 error amplifier recovers to its normal duty cycle after application of a full load transient within 2 usec maximum, (largely dependant on input and output capacitance) and usually within 1usec. This minimizes undershoot and overshoot during application of a transient. Operation at high frequency minimizes the output inductor thus allowing faster current ramp to the output capacitors.

The effective gain of the error amplifier stays constant in both VID ranges, keeping the loop gain constant regardless of output voltage range.

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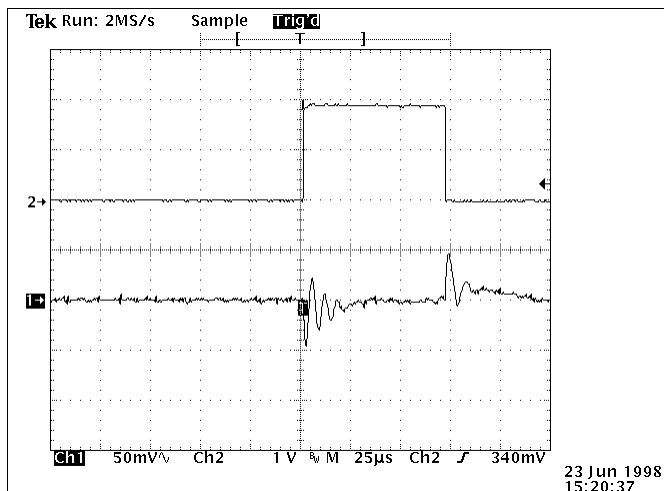
ERROR AMPLIFIER CONT.


Fig. 2: Transient response, Top trace, Current sense 8A/div @ 30A/usec. Bottom trace, V_{OUT} .

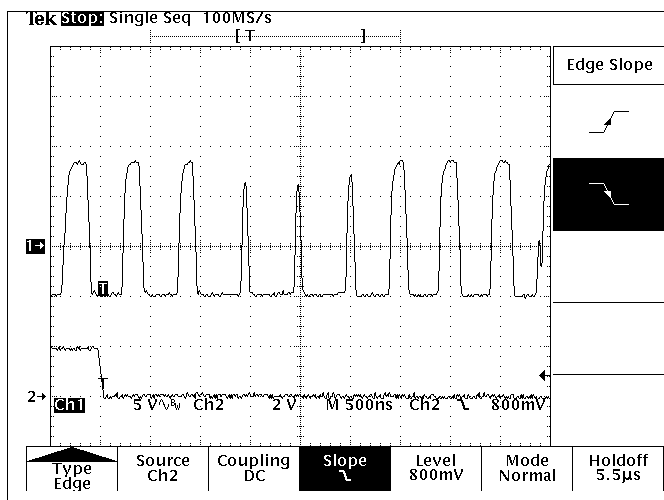


Fig. 3: Top Trace, Gate drive responding to removal of transient load. Bottom trace, Load current transient 16A/div.

BANDGAP REFERENCE/SOFT START

The precision internal bandgap reference provides a stable, temperature compensated 2.05 V reference for the error amplifier's non-inverting input, the D_{ACREF} for the VID digital to analog converter, the under-voltage lock-out circuitry as well as the reference for the Bias generator current sources. The error amplifiers non-inverting input is connected to the bandgap reference through a 3 kohm resistor, which is also externally connected to a soft-start capacitor via the B_{GOUT} pin. Upon

application of power, the non-inverting input of the error amplifier is held low for a short time allowing for the decoder and PWM controller to settle. This prevents any harmful output voltage overshoots upon start up or after a converter shut-down (as a result of over-current or the enable pin pulled low). The non-inverting input then ramps up according to the RC time constant allowing gradual rise of output voltage.

ISOLATED FEEDBACK GROUND

The feedback ground pin on the SC1144, FBG, is isolated from the GND. The maximum voltage between the two pins is set by the ESD diode forward voltage drop. This allows the SC1144 to be configured for remote sensing thus compensating for wiring and connector voltage drops at high currents or during transients. Remote sensing is typically implemented by using differential amplifiers. The use of this feature on the SC1144 eliminates the need for additional components.

OVER-CURRENT COMPARATOR

The SC1144 has an internal over-current comparator designed to sense current in the input supply path. The comparator inputs have a high common voltage range thus allowing operation under all possible voltage/current combinations. The output of the comparator pulls the B_{GOUT} (soft start) pin low thus disabling the error amplifier and causing the PWM outputs to enter minimum duty cycle mode.

SYNCHRONOUS VS. ASYNCHRONOUS MODE

The SC1144 can be configured to drive Synchronous MOSFET drivers, such as the SC1405 for higher efficiency. Refer to SC1405 datasheet for example designs.

COMPONENT SELECTION AND LAYOUT CONSIDERATIONS

Care must be taken in component selection and PCB layout in high frequency power applications. Refer to SC1144EVB user manual for more application information on component selection and layout guidelines as well as example Artwork and Bill of materials.

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An evaluation board is available which may be ordered directly from the factory. SC1144EVB is a DC/DC converter utilizing the SC1144 four-phase controller in an asynchronous application. The SC1144-SYNCH-EVB utilizes SC1405 high speed MOSFET drivers to drive the TOP and Synchronous MOSFETs with enhanced features. The evaluation boards are intended as guidelines for board design, layout and to assess key performance parameters, such as transient response, thermal stress management and input and output ripple considerations. The SC1144EVB includes a SLOT1 connector for Pentium II, a DIP switch for mode/voltage selection as well as qualified selection of components for the SC1144 operation. The SC1144EVB user manual contains useful applications information. Both Evaluation boards may be ordered from our website at www.semtech.com.

OUTLINE DRAWING - SO-24
