Micro-MMC

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**Motivation and objectives:** Support research and teaching by delivering a compact MMC, suitable for low-voltage test equipment, typically less than 30 V and 3 A.

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# Changelog:

2019-07-03: document created

# Architecture

Stacked PCBs, each containing a stack, possibly a phase leg. A stack consists of 4 SMs, each rated at 10V and of half-bridge type.

An additional PCB will carry the arm and phase inductors, as well as AC and DC measurement.

The microcontroller will be a separate card which slots in a master PCB.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Vdc** | **Vphase (peak)** | **Zbase** | **Nsm** | **Etot (H = 5 ms)** |
| 30 V | 15 V | 3.75 Ω | 4 | 4.5 J |
| **Idc** | **Vphase (rms)** | **F** | **Vsm** | **Csm** |
| 3A | 10.6 V | 50 Hz | 7.5 V | 5 mF |
| **P** | **Vline (rms)** | **Fpwm** | **DS (optional)** | **L (0.2 pu)** |
| 90 W | 18.4 V | 5 kHz | 30 V | 2.4 mH |

# Components

## SM PCB

### MOSFET

Focus on TO220 as medium-low switching frequency and easy replacement/cooling

MOSFET, IRLB8748PBF, 30V 78A 15nC TO-220, 4.8mOhm through hole, £0.69

### Gate Driver

Isolated gate driver to avoid additional bulky isolation layer.

* **[CHOICE]** UCC20225-Q1, 6 A, 2.5 kVrms dual-channel gate driver EN/PWM, LGA, £3.52
* (Si8234AB-D-IM, **DIS**/PWM4.0 A 8 V 2.5 kVrms LGA-14 5x5 mm, £2.25)

If full-bridge is considered, then use logic gate to have one DIRECTION bit, one PWM bit, and one ENABLE bit. Use demultiplexer <https://www.ti.com/product/SN74LVC1G18> with pull-down resistor. Prefer tiny DCK package DRY and DSF packages are too small.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **EN** | **DIR** | **PWM** | **Out A** | **Out B** |
| 0 | X | X | OFF | OFF |
| 1 | 0 | D | 0 | D |
| 1 | 1 | D | D | 0 |

### Isolated Power Supply

5 V power is provided to the stack PCB. One isolated power supply will ensure proper 12 V supply to the bottom driver and bootstrap ensures power is provided to the top gate driver (thanks to regular PWM switching). The isolated gate driver has a UVLO of 8 V for cut-off in case of low power.

* Traco Power, TBA 1-0512, Isolated DC/DC Converters Encapsulated SIP-4; 1W, 1.5 kV isolation, 5 Vin – 12 Vout, £2.47

### Capacitors

**Ideal characteristics:**

* <10 mOhm\*1mF (Eff = (RxI^2)/(VxI) = RxI/V @<)
* >1000 mA/mF ()
* >1 kJ/L (20 kW/L x 50 J/kW)

Shortlisted candidates:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Manufacturer Part Number** | **Manufacturer** | **Unit Price (GBP)** | **C (µF)** | **V** | **R (mΩ \*mF)** | **Ir (mA /mF)** | **Energy Density (mJ/cm3)** |
| EGPD250ELL472MK35H | United Chemi-Con | £2.040 | 4700 | 25V | 117.5 | 930 | 833 |
| EGPD250ELL512MK40H | United Chemi-Con | £1.166 | 5100 | 25V | 122.4 | 968 | 795 |
| EGPD250ELL512MU30H | United Chemi-Con | £1.149 | 5100 | 25V | 127.5 | 813 | 778 |
| EGPD250ELL362MK30H | United Chemi-Con | £1.680 | 3600 | 25V | 100.8 | 935 | 740 |
| EGPD250ELL562MU35H | United Chemi-Con | £1.257 | 5600 | 25V | 128.8 | 823 | 737 |
| UBY1E302MHL1TO | Nichicon | £1.540 | 3000 | 25V | 99 | 870 | 733 |
| EGPD250ELL302MK25H | United Chemi-Con | £1.510 | 3000 | 25V | 99 | 870 | 728 |
| AXLH332P025EH | CDE | £2.730 | 3300 | 25V | 112.2 | 944 | 239 |
| PEG226HJ4330QE1 | KEMET | £6.250 | 3300 | 25V | 112.2 | 944 | 226 |

Retained candidates:

* EGPD250ELL472MK35H
* EGPD250ELL512MK40H
* **ELBK350ELL842AM40S, Aluminium Electrolytic Capacitors - Radial Leaded 35V 8400uF +30% Tol. AEC-Q200, 4 A ripple, 18 mm diameter 40 mm length, 15 mΩ**
* CAP ALUM, B41505A7338M000, 3300UF 20% 35V SNAP 56mOhm, 3.8A Iripple

Bend the capacitor over the electronic circuitry of the SM to save vertical space.

### SM Measurement

Analog Devices, AD8203 High Common-Mode Voltage, Single-Supply (5V) Difference Amplifier, £2.73

Ti, INA146 High-Voltage, Programmable Gain (0.1 - 100) Difference Amplifier, dual or single supply, £3.45, <http://www.ti.com/product/INA146>

## Director Switch PCB

### MOSFET

MOSFET, STP55NF06, N-CH 60V 50A 45nC TO-220, 18mOhm, £0.85

### Gate Driver

Simple high-side driver:

* (Silicon Labs, Si8271AB-IS, single isolated gate driver, 5V UVLO SOIC-8, £1.35)
* Infineon, IRS25752LTRPBF, High-Side Gate Driver IC Non-Inverting SOT-23-6, £0.77

### Isolated Power Supply

* Traco Power, TBA 1-0512, Isolated DC/DC Converters Encapsulated SIP-4; 1W, 1.5 kV isolation, 5 Vin – 12 Vout, £2.47

## Phase PCB

### Measurements

Phase PCB board measurement will be done by dedicated multi-channel ADCs, one channel per SM:

* MAX11136ATI+ 12-bit 8-channel 500 ksps, 28 TQFN package
* Communicate with microcontroller through SPI
* Anti-aliasing filters:
  + 6us sampling time\*8 => 20 kHz,
  + AA filter: 10 kHz
  + RC filter: R (1Ω) x C (1uF+[15uF, IC input]) = 16us
* SM Voltage Measurements [x2 x4]
* One SM can be replaced by a Director Switch with a different voltage divider.

### Signal Connector

Signal requirement:

* SM [NSM x 2 x 2 = 16]
  + 1 PWM (P1\_1 … P4\_2)
  + 1 EN (E1\_1 … E4\_2)
* ADC channel [x4]
  + SCLK
  + SDI
  + SDO
  + SCS
* Power [x10]
  + VCC 5 V [x2]
  + GND [x6]

For 4 SMs per stack, this makes a total of 28 pins. Arranged in this manner:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| GND | SCLK | SCS | GND | P1\_1 | P2\_1 | P3\_1 | P4\_1 | P4\_2 | P3\_2 | P2\_2 | P1\_2 | GND | VCC | GND |
| GND | SDI | SDO | GND | E1\_1 | E2\_1 | E3\_1 | E4\_1 | E4\_2 | E3\_2 | E2\_2 | E1\_2 | GND | VCC | GND |

* (Header) Molex 5015713007, 1.00mm Pitch Pico-Clasp Wire-to-Board Header, Surface Mount, Dual Row, Right-Angle, 0.10µm Gold Plated, with Inner Positive Lock, 30 Circuits (£1.51)
* (Mate) Molex 5011893010, 1.00mm Pitch Pico-Clasp Wire-to-Board Receptacle Housing, Dual Row, 30 Circuits (£0.405)
* (Cable claw) 501334-0100 - Contact, Pico-Clasp™, Pico-Clasp 501334 Series, Socket, Crimp, 28 AWG, Tin Plated Contacts (£0.047)

### Power Connector

Use classic 4-terminal block with 0.1 in pitch.

* TE Connectivity 1546215-4, Fixed Terminal Blocks PCB mount, 90 4P, £1.83

### LDO Voltage regulator

Stack PCB provided with 5 V power so need to get down to 3.3 V for ADC.

* Microchip MIC5365-3.3YC5-TR, LDO Voltage Regulators Ultra Small Single 150mA 5 V-3.3 V LDO, SC-70-5 package, £0.092

## Master PCB

### Microcontroller

TMDSCNCD28388D F28388D controlCARD evaluation module

Function requirement:

* SM (x NSM): (1 ADC +) 3 Inputs
  + 1 ADC per capacitor voltage: 1 <= Done by dedicated ADC through SPI
  + 1 PWM per half-bridge: 1
  + 1 Enable per SM: 1
* Main – current: 11 ADC
  + 1 ADC per arm current: 6
  + 1 ADC per phase current: 3
  + 1 ADC per DC current terminal: 2
* Main - voltage: 11 ADC
  + 1 ADC per stack voltage: 6
  + 1 ADC per phase voltage: 3
  + 1 ADC per DC voltage terminal: 2

Ti Delfino F28388D limited to 24 ADCs and 32 PWMs.

### Measurements

Measurement done by microcontroller’s own ADCs:

* Anti-aliasing filters:
  + 6us sampling time\*8 => 20 kHz,
  + AA filter: 10 kHz
  + RC filter: R (1Ω) x C (16uF) = 16us
* Measurements [x7]:
  + 3 phase voltages (AC phase to negative DC terminal)
  + 2x3 arm voltages (bottom positive stack / top negative stack to negative DC terminal)
  + 1 DC bus voltage (positive DC terminal to negative DC terminal)
  + 3 phase current (see below)
  + 2x3 arm currents (see below)
  + 2 DC currents (see below)
* Current sense amplifier [x3]:
  + Ti INA303A3, 100 V/V with Dual Integrated Comparators, TSSOP package
  + Phase current peak magnitude: 30 W / (0.8 x 15 V / 2) = 5 A
  + Use 2 mΩ precision resistor as trade-off between losses and resolution
  + Set under- and over-current detection to ±6A.

CPU allocation:

* C28x\_A: Measurement
* C28x\_B: Switching
* CLA\_A: Network control
* CLA\_B: Current control
* Connectivity Manager (Arm Cortex M4): interconnectivity through CAN or EtherCAT

### Inductors

Inductor, 4A 1.8mH 42mOhm: <https://www.mouser.fr/ProductDetail/Schaffner/RN122-4-02-1M8?qs=sGAEpiMZZMv126LJFLh8y4nIgXZRDtpGDFQZpbMrw%252BU%3D>

### Power Supply

Take power at 5 V from DC bus, with possibility to switch to AC bus with protection diodes.

* Traco Power TSR 2-2433, Non-Isolated DC/DC Converters 6.5-36Vin 5V 2A SIP, £9.54

## List of Components

|  |  |  |
| --- | --- | --- |
| Manufacturer Reference | Description | Indicative Unit Price |
| TSR 2-2450 | Non-Isolated DC/DC Converters 6.5-36Vin 5V 2A SIP switching regulator | £9.54 |
| RN122-4-02-1M8 | Inductor 4A 1.8mH 42mOhm | £1.50 |
| TMDSCNCD28388D | Ti Delfino F28388D Control Card | £190 |
| MAX11136ATI+ | Analog to Digital Converters 12-bit 16-channel 500 ksps | £2.42 |
| Ti INA303A3 | Current Sense Amplifiers, 100 V/V with Dual Integrated Comparators | £2.56 |
| ULR15S-R002FT2 | SMD Current Sense Resistor, 0.002 ohm, ULR Series, 2010 [5025 Metric], 1.5 W, ± 1%, Metal Strip | £0.37 |
| IRS25752LTRPBF | High-Side Gate Driver IC Non-Inverting SOT-23-6 | £0.70 |
| STP55NF06 | MOSFET N-CH 60V 50A 45nC TO-220, 18mOhm | £0.88 |
| Ti INA146 | High-Voltage, Programmable Gain (0.1 - 100) Difference Amplifier, dual or single supply | £3.50 |
| ELBK350ELL842AM40S | Aluminium Electrolytic Capacitors - Radial Leaded 35V 8400uF +30% Tol. AEC-Q200, 4 A ripple, 18 mm diameter 40 mm length, 15 mΩ | £3.19 |
| IRLB8748PBF | MOSFET 30V 78A 15nC TO-220, 4.8mOhm | £0.69 |
| Si8234AB-D-IM | Isolated Gate Driver, DIS/PWM, 4.0 A, 8 V, 2.5 kVrms | £2.25 |
| SN74LVC1G18DCKR | Encoders, Decoders, Multiplexers & Demultiplexers Noninverting Demultiplexer | £0.28 |
| TBA 1-0512, | Isolated DC/DC Converters Encapsulated SIP-4; 1W, 1.5 kV isolation, 5 Vin – 12 Vout | £2.47 |
| 1546215-4 | Fixed Terminal Blocks PCB mount, 90 4P | £1.83 |
| 5015713007 | 1.00mm Pitch Pico-Clasp Wire-to-Board Header, Surface Mount, Dual Row, Right-Angle, 0.10µm Gold Plated, with Inner Positive Lock, 30 Circuits | £1.51 |
| MIC5365-3.3YC5-TR | LDO Voltage Regulators Ultra Small Single 150mA 5 V-3.3 V LDO, SC-70-5 package | £0.092 |
|  |  |  |