FSAE EV ????????? 2026?

[illegible]

1. ????

1. ????

1.1 ?????????

[illegible] [illegible]

FSAE EV [illegible]

- [illegible] [illegible]
- [illegible] [illegible]

[illegible]

- [illegible] [illegible] [illegible]
- [illegible] [illegible] [illegible] Accumulator [illegible] BMS/AMS [illegible]
- [illegible] [illegible] [illegible]
- [illegible] [illegible] [illegible]

> [illegible] [illegible] [illegible] code[illegible]
> debug [illegible]

1.2 ?? / ??????

FSAE EV [illegible]

[illegible] **Tractive System, TS**[illegible]

- [illegible] 300V–600V DC[illegible] Accumulator [illegible]
- [illegible] Accumulator[illegible] Motor Controller[illegible] Inverter[illegible] HV [illegible]
- ⚠ [illegible] [illegible] TS [illegible] Grounded Low Voltage, GLV[illegible]

[illegible] **Grounded Low Voltage, GLV**[illegible]

- [illegible] 12V [illegible] 24V
- [illegible] VCU[illegible] CAN Bus[illegible] Shutdown Circuit [illegible]
- [illegible] GLV [illegible]

- TS GLV **IMD Insulation Monitoring Device**
- Contactor isolated gate driver
- **GLV** HV

1.3 ??????????

```
┌─────────────────────────────────────────────────────┐
│                    (TS)                              │
│                                                         │
│  [Accumulator] ──→ [AIR+] ──→ [Precharge] ──→          │
│                  ──→ [AIR-] ──→ [Motor Controller]      │
│                                   ↓                     │
│                              [AC Motor]                 │
│                                                         │
│  TS  AMS IMD  TS                                 │
└─────────────────────────────────────────────────────┘
        ↑ AIR               ↑ IMD
┌─────────────────────────────────────────────────────┐
│                    (GLV)                             │
│                                                         │
│  [GLV Battery] → [Shutdown Circuit] ──→ [SDC OK]       │
│       ↓                ↑                               │
│  [VCU / ECU]    [BSPD, IMD, AMS, BOTS, TSMS,          │
│       ↓           HVD, Inertia Switch, etc.]           │
│  [CAN Bus]                                              │
│   ├── Motor Controller                                  │
│   ├── AMS / BMS                                         │
│   └── Dashboard /                                     │
│                                                         │
│  [TSAL ]  [RTDS ]  [Brake Light]                  │
└─────────────────────────────────────────────────────┘
```

> **GLV** **HV** GLV Shutdown Circuit SDC HV

??

2. FSAE EV ??????????

2. FSAE EV ??????????

> □□□□ 2026 FSAE Rules□□□□□□□□ `EV X.X.X`□`TS X.X.X`
> □□□□□□□□□□□□

2.1 Shutdown Circuit?????

□□□□ □ Shutdown Circuit□ SDC□□□□□□□□□□□□□□□□□ □□
□□□□□□□□□□□□□□□□□□□□□ Accumulator Isolation Relay□ AIR
□□□□□□□□□□□□□

?? ?????SDC ???????

□□□□□□ □□ □ Shutdown Circuit □□ 2026 □□□□

□□	□□	□□
Master Switch□□□□	TSMS	Tractive System Master Switch □□□□
Master Switch□□□□	MSMS	□□□□□□□□□□□□
Brake System Plausibility Device	BSPD	□□□□ + □□□□□□□
Inertia Switch	—	□□□□□□□
High Voltage Disconnect	HVD	□□□□ HV □□□
IMD □□□□	IMD	□□□□□□□□□
AMS □□□□	AMS	□□□□□□□
□□□□□□	—	□□□□□□□□□□□

□□□□ □

```
GLV_POWER ──→ [TSMS] ──→ [MSMS] ──→ [BSPD_OK] ──→ [IMD_OK]
          ──→ [AMS_OK] ──→ [Inertia_OK] ──→ [E-Stop×N]
          ──→ SDC_CLOSED ──→ AIR □□□□
```

□□□□□□□

□□□□ **Fail-safe □□□□□** □□□□□□□□□□□□□□□□□□□□□□□□ **HV □□□** □□□□□□□□□□□□□□□□□□□□□□□

> □□ □□□□ □ SDC □□□□□□□ ——□□□□□□□□□□□□□□□□□□□ GPIO □□ High = Active□□□□□□□□□□□□□□□□□□□□

BSPD ????

⚠ □□□□ □ BSPD □□□ □□□□□ □□□□□□□□□□ EV.5.7□□

BSPD □□□□□

- □□□□ □□□□□ > □□□ AND □□□□□ □ > 5 kW equivalent□ → □□ SDC □□

□□□□□

- □□□□□ LM393 □□□□□□□□□□□□□
- □□□□□ Hall Effect Sensor□□□□□□□
- □□□□□□□□□□□□□□□□□
- □□□□□□ AND □□□□□□□□□□

```
[□□□□□□□□□] ──→ [□□□ 1] ─┐
                                     AND ──→ [□□□□□□] ──→ SDC □□
[□□□□□□]     ──→ [□□□ 2] ─┘
```

2.2 Tractive System Active Light?TSAL?

⚠ □□□□ □□□ TS □□□□ 60V□ TSAL □ □□ □□□□□□□□□□□□□□□□□□□

□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

□□□□ □

- TSAL □□□□□□□□ AIR □□□ TS □□□□□□□ □□□□□□□□
- □□□□□□ Accumulator □□□□□□□□□□□□□□□ LED □□□□
- □□□ **VCU GPIO □□□□ TSAL**□□□ VCU □□□ TSAL □□□□

```
[TS+ / TS-] ──→ [□□□□] ──→ [□□□□□ 60V] ──→ [TSAL □□] ──→ [□□]
                                          ↓□< 60V□
                                   [TSAL □□] ──→ [□□]□□□□
```

2.3 Ready-To-Drive Sound?RTDS?

⚠ □□□□ □□□□ TS □□□□□ RTD□ Ready To Drive□□□□□□□□□□□□ 1 □□□□ 80 dB □□□□

□□□ □□□□□□□□□□□□□ RTDS □□□□□□□□□□□□□

□□□□ □□□□□□□□□□□□□□□

1. TS □□□□□ AIR □□□ Precharge □□□
2. □□□□□
3. □□□□ RTD □□
4. VCU □□□□□□ → □□ RTDS □□ 1 □ → □□ RTD □□

□□□□ □

- □□□□□□□□□□□□□ VCU GPIO □□
- □□□□□□□□□ ≥ 1 □
- Scrutineering □□□□□□□□□□□□□□□□□□ buffer□□□□□ ≥ 85 dB□

2.4 Accumulator Management System?AMS?

⚠ □□□□ □ AMS □□□□□□□ Cell □□□□□□□□□□□□□□□□ SDC□

□□□□□□□□□ □

- □□ Cell □□□ Over-voltage□ / □□□ Under-voltage□
- □□□□□ Over-temperature□

□□□□ □

```
[Cell Voltage Sensors] ──→ [AMS MCU□□ LTC6811□] ──→ [□ MCU / VCU]
[Cell Temp Sensors NTC]──→                                ↓□CAN □□□□□□
                                                  [AMS_OK □□] ──→ SDC
```

□□□□□□ □ AMS_OK □□□□ □□□□□ □□□□□□□□□ GPIO□□□□ MCU □□□□□□□□□ AMS_OK □□□□□□□□

> □□ □□□□ □ AMS □□□ Scrutineer □□□□□□□□□□□□□□□□□□□□ Cell □□□□□□□□□□□□□ AMS □□□□□□ SDC□

2.5 Insulation Monitoring Device?IMD?

⚠ IMD TS GLV / SDC

500 Ω/V TS 400V → 200 kΩ

TS

- Bender ISOMETER® FSAE
- OK/Fault → SDC
- CAN RS485 VCU SDC

- IMD AIR Precharge
- IMD GLV TS
- IMD GLV

??

EV

3. ????????

3. ????????

3.1 ?????HV?

HV □□□□□□□ □□□□□□□□□□□□□□□□□□□□□

Accumulator ??

```
[Accumulator □□]
 ├── Cell Stack□□□□□□□
 ├── AMS□BMS□──→ AMS_OK → SDC
 ├── □□□□□ / □□□
 ├── HVD□High Voltage Disconnect□──→ SDC
 └── TS+ / TS-□□□□□□□

[Accumulator □□]
 AIR+□Accumulator Isolation Relay □□□
 AIR-□Accumulator Isolation Relay □□□
 Precharge Relay + Precharge Resistor
```

Contactor / AIR ??

- □ □□ **HV Contactor**□□ TE Kilovac EV200□ Tyco EV series□
- □□□□□□ 12V □ 24V□□ GLV □□□□ SDC □□
- □□□ **□□□□□ Auxiliary Contact□ **□□□ VCU□□□ AIR □□□□□□

□□□□ □ AIR+ □ AIR- □□□□ Contactor
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

3.2 ?????LV / GLV?

GLV □□□□ □

- □□□□□ GLV □□□□□□□ or □□□□□ Accumulator □□□□
- GLV □□□□□□□□□ CAN □□□□□□□□□□
- □□□ DC-DC □□□ 5V for MCU□ 12V for □□□□ 3.3V for □□□□

GLV □□□□ □

- □□□□ □ Single Point Grounding□□□□□□□ GLV □□□□□□□□□□□□□□□□□□□□□□
- □□□□□□□ Ground Loop□□□□□
- □□□□ Signal GND□□□□□□ Power GND□□□□□□□□□□□□□

> ⚠ □□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□ CAN Bus □□□□□□□□□□□ debug□□□□□□□□□□

3.3 ?????CAN Bus?

□□□□ CAN□

- □□□□□□□□□□□□□□□□□ EMI □□□
- □□□□□□□□□□□□□
- □□□□□□□□□□
- FSAE □□□□□□□□□

□□□□ □

```
[VCU] ──────────────── CAN Bus□□□□□□ 120Ω×2□
 ├── [Motor Controller / Inverter]
 ├── [AMS / BMS]
 ├── [Dashboard / □□]
 └── [Datalogger]□□□□□
```

□□□□ □ 1 Mbps□□□□□□□□□□ 1Mbps □□□□□

□□□□ □

- □□□□□□□□ Shielded Twisted Pair□
- □□□□□□□□□□□□□□□□
- □□ Bus □□□□□ 120Ω □□□□

3.4 ????VCU / MCU?

VCU□ Vehicle Control Unit□ □□□□□□□□□

- □□□□□□□□□□□□□□□□□□□□□□□□
- □□□□□□□□
- □□□□□□□□□□□□□□

- □□ RTDS□ TSAL □□□□□□□□
- □□ CAN □ Motor Controller□ AMS □□

□□□□ □

- **STM32 □□** □□ STM32F4/H7□□ FSAE □□□□□□□□□□□ CAN□□□□□□□
- **NXP S32 □□** □□□□□□□□□□□□□
- □□ **PCB vs □□□** □□□□□□□□□□□□□□□□□□□□□□□□□□ PCB

> □□ □□□□ □ VCU □□□□□□□□□□□□□□□□□□□□□□□□□□□□□
> Watchdog
> □□

??

□□□□□□□□□□ □□□□□ □ HV □□□□□ GLV
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

---

4. Shutdown Circuit ????????

4. Shutdown Circuit ????????

> □□□□□□□□□□□□□□□ Scrutineering 50% □□□□□□□□□ SDC□

4.1 ??????

□□ SDC □□□□□□□□□□□□□□

```
GLV+ (12V)
  │
  ├── [Cockpit E-Stop□□□□]
  ├── [External E-Stop 1□□□□]
  ├── [External E-Stop 2□□□□]
  ├── [TSMS□Master Switch□□□□□□□□□□□]
  ├── [MSMS□Maintenance Switch□□□□]
  ├── [HVD Interlock□HVD □□□□□□]
  ├── [Inertia Switch□□□□□□□]
  ├── [BSPD_OK□□□□□□□]
  ├── [IMD_OK□□□□□□□]
  └── [AMS_OK□□□□□□□]
           │
           ↓ SDC_CLOSED
  [AIR+ □□] + [AIR- □□]□□□□□□
           │
          GND
```

□□□□□□□□□ □

E-Stop □□ □□□ **□□□ Normally Closed, NC□ **□□□□□□□□□□□ SDC □□□□□□ NO □□□□□□□□ ——□□□ Fail-safe □□□

TSMS / MSMS□□□□□□□□□□□□□□□□□□□□□□□□ SDC □□□□□□□□□□□□□

Inertia Switch□□□□ □□□□□□□□□□□ Ford □□□ Sensata □□
□□□□□□□□□□□□□□□

4.2 ??????

□□ 1□□ GPIO □□ SDC □□

□ □□□□ VCU □□□□□□□□□□□□□□ GPIO □□□□□□□□ SDC□

□ □□□□□□□□□□□ SDC □□□□□□□ Normally-Closed □□ VCU □□□□□ SDC □□□□□ SDC □□□□□□□

□□ □ VCU □□ bug□ MCU □□□□□□ → GPIO □□□□□□□ → □□□□□□

□□ 2□ AMS_OK / IMD_OK □□□□

□ □□□□ AMS MCU □□□□□□□□□□□□ GPIO □ Low□□□□□□□□

□ □□□□□□ □□□□□ **Watchdog**□ + □□□ AMS MCU □□□□□□□□□ toggling output□□ Watchdog □□□ → □□□□□ MCU □□ → Watchdog □□ → □□□□ → SDC □□

□□ 3□ SDC □□□□□□□□

□□□□□□□□□□□□□□□□□□□□

- SDC □□□ □□□ □□□□□□□□□□□□□□□□□□
- □□□□□□□□

□□ 4□□□ SDC □□□

SDC □□ = AIR □□□□□□ 0.5A–2A
□□□
□

4.3 ????????Scrutineering?

Scrutineer □□□□□□ □

1. **SDC** □□□□□ □□□□□□ SDC □□□□ AIR □□□□□□□□□ TS □□□□ 0 □
2. **BSPD** □□□ □□□□ + □□□□□ SDC □□
3. **AMS** □□□ □□ Cell □□□□ AMS_OK □□
4. **IMD** □□□ □□□□□□□□□□□□□□

5. **TSAL [illegible]** [illegible] TS > 60V [illegible] TSAL [illegible]

[illegible]

- [illegible] **SDC [illegible]** [illegible] Scrutineering
- [illegible] IMD_OK[illegible] AMS_OK[illegible]
- [illegible] SDC [illegible]
- [illegible]

> ⚠ [illegible] Scrutineering [illegible] BSPD [illegible] SDC [illegible] Scrutineering [illegible]

??

SDC [illegible]

---

5. Accumulator ?????

5. Accumulator ?????

5.1 AMS ?????

AMS□ Accumulator Management System□ □ FSAE □□□□□□□□□ BMS□ Battery Management System□□□ FSAE □□□□□□□□□□□

????

□□	□□	□□□□
□□□□□□	□□ Cell □□□□	□□ IC□□ LTC6811□
□□□□	□□□□□□ NTC	ADC □□□□□□□
□□□□	□□ Cell □□□□	□□□□□ + SDC □□□
□□□□	□□ Cell □□□□	□□
□□□□	□□ Cell □□□□	□□
SOC □□□□□□□□□□□	□□□□□□	□□□□ or □□□□

LTC6811 ????????

```
[Cell Stack□12S□]
      |
[LTC6811-1□□12□Cell□□□]
      |□daisy-chain SPI□
[LTC6811-2□□□□□12□□]
      |
[AMS MCU□STM32□]
      |
   ├── [AMS_OK □□□□□] → SDC
   ├── [CAN □□] → VCU
   └── [SOC □□] → Dashboard
```

□□□□ **LTC6811□**

- □□ Li-ion Stack □□□□□□□□□ < 1mV□

- Daisy-chain □□□□□□□
- □□ ADC□□□ Cell balance□ Passive Balancing□
- □□□□□□□□□□□

5.2 Precharge ??

□□□□□ Precharge□

Motor Controller □□□□□□□□□□□□□□ μF□□□□□□□□ AIR □□□□□□□□□□□□□□□□□□□□

- □□ Contactor □□□□□□□□
- □□ Motor Controller □□
- □□□□□

Precharge □□ □

```
1. AIR- □□□□□□□□□
2. Precharge Relay □□□□□□□□□□ MC □□□□□
3. □□ MC □□□□□ TS □□□ ≥ 95%□□□ 1–5 □□
4. AIR+ □□
5. Precharge Relay □□
6. □□ RTD □□□□
```

Precharge □□□□ □

□□□□ τ = R × C

- □□□□□□□ 3τ □□ 95%□□□□ 1–3 □
- MC □□□□ Motor Controller □□□
- □□ R = τ / (3 × C)
- □□□□□ $P = V^2 / R$□□□□□□□□□□□□□□□□ 3–5 □□□□

Precharge □□□□ □

- □□ Motor Controller DC Bus □□
- □□ Accumulator □□
- □□ < 5%□□□□□□□ → □□ AIR+ □□

> ⚠ □□□□ □ Precharge □□□□□□ SDC □□□ SDC □□□□ Precharge Relay □□□□□

5.3 Contactor ????

□□ Contactor □□□□□ □

```
[IDLE / □□□□]
    │ SDC_CLOSED & □□□□□□
    ↓
[AIR- □□]□□□ 50ms □□□
    │
    ↓
[Precharge □□]□□□ MC □□□□□
    │ MC_Voltage >= 0.95 × TS_Voltage
    ↓
[AIR+ □□]□□□ 50ms □□□
    │
    ↓
[Precharge □□]
    │
    ↓
[HV READY]□□□ RTDS □□□□□
    │
    ↓
[RTD□Ready To Drive□]

□□□□□□ SDC □□ → □□□□ [FAULT] → □□□□ Contactor
```

□□□□□□□□□□ □

□□ Contactor □□□□□□ Auxiliary Contact□□□□□□ VCU□□□□□□□□

- Contactor □□□□□□□□□□□□□□□□□□□□□
- Contactor □□□□□□□□□□□□□□□□□□□ welded contact□

□□□□□□□□□□□□□□□□□□□ ——□□□ HV □□□□□□□□□□□□□□□

??

Accumulator □□□□□□□□□ □□□□□□□□
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ Precharge
□□□□□□□□□□□□□□□□□□

---

6. ???????

6. ???????

6.1 CAN ???ID ???

CAN ID □□□□ □

□□□	□□	**ID □□□□□□**
□□□ ID□	□□□□□ SDC □□□ AMS Fault□	0x001–0x0FF
□	□□□□□□□□□□□□□□□	0x100–0x2FF
□	□□□□□□□□□□□□□□	0x300–0x5FF
□□	□□□□□ Log □□	0x600–0x7FF

□□□□□□□ □ CAN □□□ ID □□□□ **ID □□□□□□□□** □□□□□□□□□□ Bus □□□□□□□□□□

CAN □□□□□□□ AMS □□□ □

```
CAN ID: 0x050□□□□□
DLC: 8 bytes
Byte 0: Status□0x00=OK, 0x01=OV, 0x02=UV, 0x03=OT, 0xFF=Fault□
Byte 1: Max Cell Voltage [LSB = 1 mV]□□ 8 bits□
Byte 2: Max Cell Voltage□□ 8 bits□
Byte 3: Min Cell Voltage□□ 8 bits□
Byte 4: Min Cell Voltage□□ 8 bits□
Byte 5: Max Temperature [°C, offset -40]
Byte 6: SOC [0–100%]
Byte 7: Fault Code□□□□□□□
```

□□□□□□ □

- □□□□□□□ 10–50 ms□□□□□□
- □□□□□ 5–10 ms
- □□□□□ 50–100 ms
- □□□□□ 100–500 ms

6.2 ?????Fail-safe?

Fail-safe □□□□ ： □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

CAN □□□□ ：

```
// □□□□
void CAN_RxCallback(uint32_t id, uint8_t *data) {
    if (id == MOTOR_CONTROLLER_STATUS_ID) {
        last_mc_heartbeat = get_timestamp();
        update_mc_status(data);
    }
}

void safety_check_task(void) {  // □ 10ms □□
    if (get_timestamp() - last_mc_heartbeat > MC_TIMEOUT_MS) {
        // Motor Controller □□□□ → □□□□□□ 0
        set_torque_command(0);
        set_fault(FAULT_MC_TIMEOUT);
    }
}
```

□□□□□□□□□ ：

- AMS： 100 ms□□□□□□□□□□□□□□□□□□ HV）
- Motor Controller： 50 ms□□□□□□□ 0）
- □□□□□□□ 20 ms

□□□□ ：

□□	□□	□□□□
Warning	□□□□□□□□□	□□□□□□□□□
Soft Fault	□□□□□□□□□	□□□□□□□ 50%
Hard Fault	□□□□□□□□	□□□ 0□□□ RTD
Critical Fault	□□□□	□□ SDC □□□□□□□□□□□□□□□

6.3 State Machine????????

□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□□

[illegible]：

```
                    ┌────────────────────────────────┐
                    │                                ↓
[INIT] → [LV_READY] → [HV_PRECHARGING] → [HV_READY] → [RTD]
            ↑               │                 │          │
            │          Fault/SDC Open     Fault/SDC   Fault/SDC
            │               ↓               Open         Open
            └─────── [FAULT] ←────────────────┘←──────────┘
                        │
                    (SDC [illegible]
                   [illegible] Contactor [illegible])
```

[illegible]：

INIT[illegible] Selftest[illegible] SDC [illegible] CAN [illegible]

LV_READY[illegible] GLV [illegible] HV [illegible] TSMS [illegible] HV Precharge [illegible]

HV_PRECHARGING[illegible] AIR- → Precharge → AIR+ [illegible] 10 [illegible] MC [illegible] → [illegible] FAULT[illegible]

HV_READY[illegible] HV [illegible] RTD [illegible] + RTD [illegible]

RTD[illegible] **Ready To Drive**[illegible] RTDS [illegible]

FAULT[illegible] 0[illegible] SDC [illegible] Fault [illegible] Watchdog [illegible] TSMS [illegible]

> [illegible] FAULT [illegible] Reset[illegible]

??

[illegible] CAN [illegible] bug [illegible]

1kW ???????? (AWD EV) ????????

1. ?????? (System Architecture)

1.1 ???? (Powertrain)

- **□□□□ : 13s□□□□□** □□□□□□□□ **1000W** (□ 20.8A)□
- **□□□□ :** 4□ x 500W 20□ □□□□ (□□□□□ 2000W□□□□□□)□
  - □□ **(Front Axle):** **□□ □□□□□ (Overrunning Clutch)□**
    - □□ *:* □□□□□□□□□□□□□□□ □□□□ /□□ □
  - □□ **(Rear Axle):** **□□** (Direct Drive)□
    - □□ *:* □□□□□□□□ □□□□ **(Regen) □ □□□□ (Vectoring) □□**

Gemini_Generated_Image_y1i7ppy1i7ppy1i7

1.2 ???? (Control Unit)

- **MCU:** STM32F446 (Cortex-M4F, 180MHz)□
- **OS:** FreeRTOS (CMSIS-V2 API)□
- **□□ :** CAN Bus (500kbps) □□ 4 □ VESC □□□□
- **□□□ :**
  - □□□□ (ADC)□
  - □□□□□□□□ (ADC □ Encoder)□
  - IMU □□□□□ (I2C/SPI, MPU6050/ICM20600)□

---

2. ?????? (Control Strategy)

□□□□□□ 1kW □□□□□□□□□□ 2kW□□□□□□□ **□□□□□□□□ □ □□□□□□**□

2.1 ??????? (Drive Mode FSM)

- **□□ A: □□□□□ (4WD Mode)**
  - □□ *:* □□ < 35 km/h (□□)□
  - □□ *:* □□□□□□□□

  - [illegible] *:* [illegible] [illegible] **40% /** [illegible] **60%** ([illegible])[illegible]
- [illegible] **B:** [illegible] **(RWD Mode)**
  - [illegible] *:* [illegible] > 35 km/h[illegible]
  - [illegible] *:* [illegible] **0% /** [illegible] **100%**[illegible]
  - [illegible] *:* [illegible] 1kW [illegible] (Field Weakening) [illegible]

2.2 ?????? (Active Dynamics)

- [illegible] **(Electronic Differential):** [illegible]
- [illegible] **(Torque Vectoring):** * [illegible] IMU [illegible] (Understeer) [illegible]
  - [illegible] *:* [illegible] (Clamp to 0)[illegible]

---

3. ???????? (Detailed Logic Analysis)

[illegible] RTOS [illegible]

3.1 ????? (Observer Layer)

[illegible]

- **CalcPower (**[illegible]**):** [illegible]
  - [illegible] $Max\_Current = 1000W / V\_bat$
  - [illegible] *:* [illegible]
- **CalcSpeed (**[illegible]**):**
  - [illegible] *:* [illegible] [illegible] **(Rear Wheels)** [illegible] ERPM[illegible]
  - [illegible] *:* [illegible]

3.2 ??? (Strategy Layer) - ??

- **ModeLogic (**[illegible]**):**
  - **4WD** [illegible] **:** [illegible] Splitter [illegible] [illegible] **33% /** [illegible] **67%** ([illegible] 250W/[illegible] 500W[illegible])[illegible]
  - **RWD** [illegible] **:** [illegible] Splitter [illegible] [illegible] **0% /** [illegible] **100%**[illegible]
- **EDiff (**[illegible]**):**
  - [illegible]
  - [illegible] *:* [illegible] ΔI[illegible] ΔI[illegible]
- **TCS_ESP (**[illegible]**):**
  - [illegible] (Target Yaw)[illegible] IMU [illegible] (Actual Yaw) [illegible]
  - [illegible] ([illegible] Understeer/Oversteer)[illegible] ΔI_{ESP}[illegible]

3.3 ??????? (Mixer Layer) - ?????

□□□□□□□□□□□□□□□□□□□□□□□□□

- **□□□□ (Rear Logic - □□):** $$I_{Rear_L} = (I_{Total} \times Ratio_{Rear} \times 0.5) + \Delta I_{Diff} + \Delta I_{ESP}$$ $$I_{Rear_R} = (I_{Total} \times Ratio_{Rear} \times 0.5) - \Delta I_{Diff} - \Delta I_{ESP}$$
  - □□ *:* □□□□□□□□□□□□□□□□/□□□□□□□□□□□
- **□□□□ (Front Logic - □□□□□□□):** $$I_{Front_L} = (I_{Total} \times Ratio_{Front} \times 0.5) + \Delta I_{Diff}$$ $$I_{Front_R} = (I_{Total} \times Ratio_{Front} \times 0.5) - \Delta I_{Diff}$$
  - □□□□ **:** □□□□□□□□□□□□ Mixer □□□□□□□ □□□□ **(Clamp to 0)** □□□□□□□□□□□□□□□□□□□□□□□□□□□□□

3.4 ????? (Limiter Layer)

□□□ VESC □□□□□□□□□□

1. □□□□ **:** □□□□□□□□□□□□□□□ (□□□□ Max 10A)□
2. □□□□ **:** □□□□□□□□□□□□□□□□ $\sum I \le I_{max\_battery}$□□□□□ ESP □□□□□□□□□□□□□□□□ (Scale Down) □□□□□

---

4. ????? (Implementation)

???? (Software Architecture)

□□ **FreeRTOS** □□□□□□□□□□□□□□□□□□□□□□□ □□ **(int32)** □□□ STM32 □□□□□

□□□□	□□□	□□	□□□□
`Task_Control`	**Realtime**	**1kHz**	□□□□□ (□□□□ -> □□□□ -> CAN □□)
`Task_CanRx`	High	Event	□□ VESC □□□□ (□□□□□)□□□□□□□
`Task_Input`	Normal	100Hz	□□□□ ADC□□□□□□ IMU □□

□□□□□□□ STM32 HAL □□ CMSIS-OS V2□

4.1 ????? (main.h)

```c
/* main.h - □□□□□□□ */
#ifndef __MAIN_H
#define __MAIN_H

#include <stdint.h>

// --- □□□□ ---
#define POWER_LIMIT_W          1000     // □□□□□□
#define BATTERY_VOLTAGE_NOM    48       // □□□□
// □□□□□ (mA) = 1000W / 48V = 20833 mA
#define MAX_TOTAL_CURRENT_MA   ((POWER_LIMIT_W * 1000) / BATTERY_VOLTAGE_NOM)

// --- □□□□ ---
#define ERPM_THRESHOLD_RWD     10000    // □□□□□□□□□ (ERPM)
#define ERPM_HYSTERESIS        500      // □□□□
#define STEERING_GAIN          50       // □□□□□□□ (□□□□)
#define VECTORING_GAIN         80       // □□□□□□□□

// --- VESC CAN ID ---
#define VESC_ID_FL             1
#define VESC_ID_FR             2
#define VESC_ID_RL             3
#define VESC_ID_RR             4
#define CAN_PACKET_SET_CURRENT 1

// --- □□□□□□□□ ---
typedef struct {
    int32_t  avg_erpm;         // □□□□ (ERPM)
    int32_t  throttle_adc;     // □□ (0-4095)
    int32_t  steering_val;     // □□□ (-2048 □ ~ +2048 □)
    int32_t  yaw_rate_imu;     // IMU Z□□□□
    uint8_t  drive_mode;       // 0: 4WD, 1: RWD
} VehicleState_t;

#endif
```

4.2 RTOS ???? (freertos.c)

```
/* freertos.c - □□□□□□ */
#include "main.h"
#include "cmsis_os.h"
#include "can.h"

// □□□□□ Handles
extern VehicleState_t g_VehicleState;
extern osMutexId_t VehicleMutexHandle;
extern CAN_HandleTypeDef hcan1;

// □□□□□□□ CAN
void VESC_Send_Current(uint8_t controller_id, int32_t current_ma) {
    CAN_TxHeaderTypeDef TxHeader;
    uint32_t TxMailbox;
    uint8_t TxData[4];

    TxHeader.ExtId = (CAN_PACKET_SET_CURRENT << 8) | controller_id;
    TxHeader.IDE = CAN_ID_EXT;
    TxHeader.RTR = CAN_RTR_DATA;
    TxHeader.DLC = 4;

    // Big Endian Packing
    TxData[0] = (uint8_t)(current_ma >> 24);
    TxData[1] = (uint8_t)(current_ma >> 16);
    TxData[2] = (uint8_t)(current_ma >> 8);
    TxData[3] = (uint8_t)(current_ma);

    if (HAL_CAN_GetTxMailboxesFreeLevel(&hcan1) > 0) {
        HAL_CAN_AddTxMessage(&hcan1, &TxHeader, TxData, &TxMailbox);
    }
}

// --- Task 1: □□□□□□ (1kHz) ---
void StartControlTask(void *argument)
{
    uint32_t tick_count = osKernelGetTickCount();
    const uint32_t period = 1; // 1ms

    // □□□□ (□□ Mutex □□)
```

```
    int32_t cmd_FL=0, cmd_FR=0, cmd_RL=0, cmd_RR=0;
    int32_t loc_rpm=0, loc_thr=0, loc_steer=0;
    uint8_t loc_mode=0;

    for(;;)
    {
        // 1. □□□□□□
        if (osMutexAcquire(VehicleMutexHandle, 2) == osOK) {
            loc_rpm   = g_VehicleState.avg_erpm;
            loc_thr   = g_VehicleState.throttle_adc;
            loc_steer = g_VehicleState.steering_val;
            loc_mode  = g_VehicleState.drive_mode;
            osMutexRelease(VehicleMutexHandle);
        }

        // 2. □□□□□□□ (Base Torque)
        // □□□□□□ (>>12) □□□□ 4096□□□□□
        int32_t total_ma = (loc_thr * MAX_TOTAL_CURRENT_MA) >> 12;

        // 3. □□□□□□ (Hysteresis)
        if (loc_mode == 0) { // 4WD
            if (loc_rpm > (ERPM_THRESHOLD_RWD + ERPM_HYSTERESIS)) loc_mode = 1;
        } else { // RWD
            if (loc_rpm < (ERPM_THRESHOLD_RWD - ERPM_HYSTERESIS)) loc_mode = 0;
        }

        // 4. □□□□□□□□□
        int32_t base_front = 0;
        int32_t base_rear  = 0;

        if (loc_mode == 0) { // 4WD Mode
            // □□□□ 40%, □ 60%
            base_front = (total_ma * 40) / 100;
            base_rear  = total_ma - base_front;
        } else { // RWD Mode
            base_front = 0; // □□□□
            base_rear  = total_ma; // □□□□□
        }
```

```
// 5. □□□□□□□□□□□ (Differential & Vectoring)
// □□□□□□□□ * □□ = □□□□
int32_t diff_adj = (loc_steer * STEERING_GAIN) / 100;

// 6. □□□□□ (Mixing)
// □□ (□□□□□□□□□□□)
int32_t fl_temp = (base_front / 2) + diff_adj;
int32_t fr_temp = (base_front / 2) - diff_adj;

// Clamp logic for front clutch (No regen)
cmd_FL = (fl_temp < 0) ? 0 : fl_temp;
cmd_FR = (fr_temp < 0) ? 0 : fr_temp;

// □□ (□□□□□□□□□□□)
// □□□□□□□□□ IMU □□□□ (Yaw Control)
cmd_RL = (base_rear / 2) + diff_adj;
cmd_RR = (base_rear / 2) - diff_adj;

// 7. □□□□□□ (Total Current Limiter)
// □□□□□□□□□□□□□□□
int32_t total_req = cmd_FL + cmd_FR + cmd_RL + cmd_RR;
if (total_req > MAX_TOTAL_CURRENT_MA) {
    // □□□□□□□ (Scaling Down)
    // □□□□□□□□□□□□
    // □□□□□□□□□□□□□□□□□
}

// 8. □□□□□□
if (loc_mode != g_VehicleState.drive_mode) {
     if (osMutexAcquire(VehicleMutexHandle, 0) == osOK) {
        g_VehicleState.drive_mode = loc_mode;
        osMutexRelease(VehicleMutexHandle);
    }
}

// 9. □□ CAN □□
VESC_Send_Current(VESC_ID_FL, cmd_FL);
VESC_Send_Current(VESC_ID_FR, cmd_FR);
VESC_Send_Current(VESC_ID_RL, cmd_RL);
```

```
        VESC_Send_Current(VESC_ID_RR, cmd_RR);

        // 10. □□□□
        tick_count += period;
        osDelayUntil(tick_count);
    }
}
```

5. ????????? (Wiring Notes)

1. CAN Bus □□□□: □□ CAN H/L □□□□□□ 120Ω □□ (MCU □□□□□ VESC)□
2. □□ (Common Ground): □□□ VESC □□□ (GND) □□□ STM32 □ GND □□□
3. VESC □□ (VESC Tool):
   - App Settings: □□ `CAN Uart` □ `CAN`□
   - Controller ID: □□□□□□ 1, 2, 3, 4 □□□□□
   - Baud Rate: □□ `500K` □□□ STM32 □□□
   - Current Limits: □□□□□□ (Motor Current Max) □□□ 20A (500W□□)□□□□□□ (Battery Current Max) □□□□□ BMS □□□

6. ??????

1. □□□□ (Field Weakening): □ RWD □□□□□□ VESC Tool □□□□□□□□□□□□□□□ 1kW □□□□□□□□□
2. □□□□□ (TCS): □ Task_Control □□□□□□□□□ (Wheel_RPM - Avg_RPM) > Threshold □□□□□□□□□ cmd □□□
3. IMU □□□□: □□□□□□□□□ □□□□ □ □□□□□□□□□□ Yaw Rate □□□□□□□□□□□

7. ??????????????

7. ??????????????

7.1 ???

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- □□□□□ **Decoupling Capacitor**□ □□□ IC □□□□□ 100nF + 10μF□□□□□□□
- □□□□ □ TVS □□□□□ GPIO □□□□□□□□□□□□
- □□□□ □□□□□□□□□ LDO□□ DC-DC□□□ MCU □□□ HV □□□□□□
- **PCB Layout**□□□□□□□□□□□□□□□□□□□□□ CAN Bus □□□□□□□□□

□□□□□ □

- **Watchdog Timer**□□□ Hardware Watchdog□□□□□□□□□ → □□ Reset□□□ AMS_OK □□□□□
- **Stack Overflow** □□ □□□ Stack Canary
- **ROM/Flash** □□ □□□□□□□□□□□□ CRC □□□

7.2 ???

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- □□□□ 60V □□□□□□□□□□□□□□□□□
- HV □□□□□□□ FSAE □□ HV □□□□□□
- HV □□□□□□□□ LV □□□□□□□□□□

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- □□□□□□□ FMEA□□□□□□□□□□□□□□□□□□□□□□□ Fail-safe □□

7.3 ????

> “ □□□□□□□□□□□□□□□□□□□□□□□□□□□□

- Deutsch DT/DTM
- SDC CAN Bus Test Point

- Git
- `#define` config
- commit message

7.4 Debug ??

Debug

- **CAN Log** CAN Logger Raspberry Pi + candump CAN
- **LED** SDC AIR Fault LED
- **Serial Debug Output** UART
- **Fault Code** EEPROM Flash

> Debug
> 5 LED
> CAN

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8. ?????????

8. ?????????

8.1 ???? Fail ??

□□□□ CAN Bus □□□□□

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□□□ □□ CAN
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□□□□ Precharge □□ / □□

□□□□□ TSMS□ Precharge □□□ MC □□□□□□□□□□ Fault□

□□□□□ Precharge □□□□□□□□□□□ Precharge Relay □□□□□ MC DC Bus □□□□□□□□□

□□□ Precharge □□□□□□□□□□□□□□□□□□□□□□

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□□□□□□□□□ AMS □□□□□□□ Fault□□ CAN Bus □□□□□□□□

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□□□□ Contactor □□□□□□

□□□ SDC □□□□ AIR □□□□□□□□□□□□□□□□□

□□□□□ SDC □□□□□□□□□ Contactor □□□□□□□□□□□□□□□□□□□

SDC Contactor 12V 12V

8.2 Scrutineering ????

1 BSPD

BSPD +

BSPD Test Injection Point

---

2 AMS

Cell Cell

Cell Specification Sheet + AMS

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3 HV

Strain Relief

HV Split Loom

---

4 TSAL TS

AIR TS > 60V TSAL TSAL VCU VCU TSAL

TSAL VCU

---

5 SDC

??

Scrutineering

---

9. ?????????

9. ?????????

9.1 ????

- **FSAE EV Rules 2026**□ https://www.fsaeonline.com/
  - □□□□□ EV□ Electric Vehicle□□ TS□ Tractive System□□ IN□ Inspection□
- **Formula SAE Rules Companion**□□□□□□□□□□□□□□□□□
- **FSG**□ **Formula Student Germany**□ **Rules**□□□□□□□□□□□□□□ FSAE □□□□□□□□□□□□□□

9.2 ??????

- **AMZ Racing**□ **ETH Zürich**□ □□□□□□□□□□□□□□□□□□□
  - https://amzracing.ch/en/technical-documents
- **TUfast**□ **TU München**□ □□□□□□□□□□□□ Shutdown Circuit □□□□□
- **KA-RaceIng**□ **KIT**□ □□□□□ Accumulator □ BMS □□□□

9.3 ????

□□ **/** □□□□ □

- LTC6811 Datasheet□ Analog Devices□□ Battery Stack Monitor □□□□
- Bender ISOMETER® □□□□□ IMD □□□□□
- TE Connectivity KILOVAC Contactor □□□□□□

□□ □

- **Kvaser / PEAK CAN Interface**□ CAN Bus □□□□□□
- **CANalyzer / BUSMASTER**□□□□ □ CAN □□□□□□
- **STM32CubeIDE**□ STM32 □□□□□□□□
- **KiCad**□□□ PCB □□□□□ FSAE □□□□□

□□ **/** □□ □

- *Battery Management Systems* by Gregory Plett□□□□□□□□□□□□
- *Automotive SPICE / ISO 26262* □□□□□□□□□□□□□□□□□□
- TI □□□ CAN Bus □□□□□□□ SLLA270□

9.4 ????????

> 1. [illegible]
>   [illegible]
> 2. [illegible] **Git** [illegible]
>   [illegible]
> 3. [illegible] [illegible]
>   Scrutineering [illegible]
> 4. [illegible] **CAN Logger**[illegible] [illegible] 80% [illegible]
>   debug [illegible]
> 5. [illegible] [illegible] EV.5.7
>   [illegible]

[illegible] *2026 v1.0* | [illegible] *2026* [illegible] | [illegible] *FSAE Rules 2026*

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1.[illegible]

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[illegible]

battery mode

2.[illegible]

3.[illegible]

[illegible]

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4.[illegible]

PQ curve

[illegible]

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share topology[illegible]

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I^2R[illegible] ([illegible] 200w) [illegible] 30[illegible] ([illegible] FOS
[illegible])

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1. □□
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FSAE 6061-T6 115MPa □□□□□□ □□□□□□ SES□□

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DAY2

DAY3

DAY4

BSPD Testing Standard Procedure

Revision

- 2024/11/17, William, First version release.

Purpose

This document outlines the procedure to verify the proper functionality of the Brake System Plausibility Device (BSPD) while ensuring compliance with EV7.7 regulations. The testing ensures that the system performs accurately under any circumstance.

Related Rule

- EV7.7 Brake System Plausibility Device (BSPD)

Test Steps

:::danger Ensure the HV system remains disabled throughout the entire test. :::

1. **Driver Preparation**
   The driver gets on board and prepares for the test.
2. **Activate GLV System**
   Turn on the GLV system.
3. **Simulate Hard Braking Condition**
   a. Instruct the driver to press the brake pedal as hard as possible to simulate a hard braking scenario.
   b. Verify that **the Interlock remains closed**.
4. **Reset to Normal Condition**
   Ask the driver to release the brake pedal.
5. **Simulate Accumulator Output Exceeding 5kW**
   a. Set the laboratory power supply to 2V and 3A.
   b. Connect the positive terminal to the upper green banana jack and the negative terminal

to the lower green banana jack on the LV-BOX panel.
c. Activate the power supply's output.
d. Verify that **the Interlock remains closed**.

6. **Test Interlock with Combined Conditions**
a. Instruct the driver to press the brake pedal as hard as possible again while the simulated accumulator output exceeds 5kW.
b. Verify that **the Interlock opens**.

Core System Explanation

How to Detect Accumulator Output Power Exceeds 5kW?

To monitor whether the accumulator’s output power exceeds 5kW, we installed a Hall effect sensor “LEM DHAB/S118” on the positive HV bus inside the HV-BOX.

Given that we are using LiFePO4 batteries with a nominal cell voltage of 3.2V and a configuration of 108 cells in series, the total nominal voltage of the accumulator is:

$$ 345.6V = 108 \times 3.2V $$

At 5kW output power, the corresponding current is calculated as:

$$ I = \frac{5kW}{345.6V} \approx 14.46A $$

The current sensor, functioning as a transimpedance amplifier, converts the measured current into a voltage signal using the formula:

$$ V_{out} = 2.5V + (\text{Measured Current} \times 66.7mV/A) $$

At a current of 14.46A, the output voltage of the sensor will be:

$$ V_{out} = 2.5V + (14.46A \times 66.7mV/A) \approx 3.464V $$

To determine whether the output power exceeds 5kW, we use an operational amplifier (OPA) configured as a comparator with a precise voltage reference set at 3.464V. When the sensor’s output voltage exceeds this threshold, the comparator outputs a high signal, indicating that the power has surpassed the 5kW limit.

How to Detect Hard Braking?

To detect hard braking, we installed a pressure sensor “TE M3041” on the brake pipe.

This sensor outputs a voltage proportional to the brake pedal travel. To determine the threshold voltage for hard braking, we conducted a calibration by asking the driver to press the brake pedal as hard as possible, simulating a hard braking scenario. The corresponding sensor output voltage was recorded as the threshold.

Similar to the method used for detecting when output power exceeds 5kW, we use an operational amplifier (OPA) configured as a comparator. A precision voltage reference and a potentiometer are included in the circuit, allowing us to easily set the threshold voltage. When the sensor's output voltage exceeds this threshold, the system identifies a hard braking event.

How to Simulate Accumulator Output Exceeds 5kW Without HV Operation?

To simulate the accumulator output exceeding 5kW without operating at high voltage, we wound a wire 5 times around the current sensor. Each end of the wire is connected to separate green banana jacks located on the LV-BOX panel.

BkXcSIIMke.jpg

By applying a constant current, such as 1A, through the wire using a laboratory power supply, the sensor detects an equivalent current of 5A due to the 5 turns of the wire. Therefore, to simulate the accumulator output current for 5kW, we only need to apply:

$$ I_{simulate} = \frac{14.46A}{5} \approx 2.892A $$

This method allows for safe and accurate testing of the system under conditions equivalent to high-power operation.

Is the System Non-Programmable?

Yes, BSPD circuits only use operational amplifiers, voltage references, counter ICs, and oscillators to achieve all functionality and requirements.

Formula SAE 2026 ????????????

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□□□ Formula SAE® Rules 2026 DRAFT□□□□□□□□ 2026 □□□□□□ □□□ © 2025 SAE International □□□ Version 0.0 DRAFT□□□□□ 2025□ 8□ 11□ □□□□□□ 94-148 □□□□ 94-115 □

EV.1 ?? DEFINITIONS

EV.1.1 □□□□ Cell□ □□□□□□□□□□□□□□□□□□□□□

EV.1.2 □□□ Module□ □□□□□□□□□□□□□□□□□□□□□

EV.1.3 □□□□□ Tractive Battery□ □□□□□□□□□□□□□□□□□□□□□□□

EV.1.4 □□□□□□□ Tractive Battery Container□ □□□□□□□□□□□□□□□□□□□□□□□□□□□□

EV.1.5 □□□□□□ Tractive Battery Pack□ □□

EV.1.6 □□□□□ Tractive System - TS□ □□□□ / □□□□□□□□□□□□□□□□□□□□□□□□□

EV.1.7 □□□□□□ Grounded Low Voltage - GLV□ □□□□□□□□□□□□□□

EV.2 ???? DOCUMENTATION

EV.2.1 ???????Electrical System Form - ESF?

EV.2.1.1 □□□□□□□□□□□□□□□ ESF □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□ ESF [illegible] /[illegible]

EV.2.1.2 ESF [illegible] Formula SAE [illegible]

EV.2.1.3 [illegible] PS - [illegible] ESF

EV.2.2 ????

ESF [illegible] PS - [illegible]

EV.3 ???? ELECTRICAL LIMITATIONS

EV.3.1 ??

EV.3.1.1 [illegible] ([illegible] R[illegible])

EV.3.1.2 [illegible] drive by wire[illegible]

EV.3.1.3 [illegible] [illegible] [illegible]

EV.3.2 ????Energy Meter?

EV.3.2.1 [illegible] FSAEOnline [illegible] AD.2.2

EV.3.2.2 [illegible]

EV.3.2.3 [illegible]

EV.3.2.4 [illegible]

EV.3.2.5 [illegible]

EV.3.2.6
[illegible]

EV.3.3 ?????

EV.3.3.1 [illegible] **80 kW**

EV.3.3.2 [illegible] **600 V DC**

EV.3.3.3 [illegible] **0** [illegible] **5 km/hr** [illegible]

EV.3.4 ??

EV.3.4.1 [illegible] a. [illegible] EV.3.3.1[illegible] b. [illegible] EV.3.3.2[illegible]

[illegible]

- [illegible] 100 [illegible]
- [illegible] 500 [illegible]

EV.3.4.2 [illegible]

EV.3.4.3 [illegible] DQ[illegible]

EV.3.5 ??

EV.3.5.1 [illegible] Acceleration, Skidpad, Autocross [illegible] a. [illegible] DQ[illegible] b. [illegible]

EV.3.5.2 [illegible] Endurance[illegible]

- [illegible] 60 [illegible] D.14.2.1[illegible]

EV.3.5.3 [illegible]

EV.3.5.4 [illegible]

EV.4 ?? COMPONENTS

EV.4.1 ??

EV.4.1.1 [illegible]

EV.4.1.2 [illegible] T.5.3

EV.4.1.3 [illegible] a. [illegible] EV.7.8 [illegible] / [illegible] EV.7.2.2[illegible] b. [illegible] F.1.11[illegible] c. [illegible] F.11.1.3 [illegible]

EV.4.2 [illegible] [illegible]

EV.4.3 [illegible] EV.4.3.1 [illegible] a. [illegible] F.10 b. [illegible] c. [illegible]

EV.4.3.2 [illegible] a. [illegible] b. [illegible] F.10.4 c. [illegible] EV.6.1

EV.4.3.3 [illegible]

EV.4.3.4 [illegible]

EV.4.3.5 [illegible]

EV.4.3.6 [illegible] a. [illegible] b. ISO 7010-W012 [illegible]

- [illegible] 100 mm
- [illegible] c. [illegible] Always Energized[illegible] d. [illegible] T.9.1.1[illegible] High Voltage[illegible]

EV.4.4 [illegible] EV.4.4.1 GLV [illegible] a. [illegible] b. [illegible] Tractive Battery Pack[illegible]

EV.4.4.2 GLV [illegible] Master Switch[illegible] EV.7.9.1

EV.4.4.3 [illegible] GLV [illegible] GLVMP[illegible] a. [illegible] GLV [illegible] b. [illegible] TSMP [illegible] EV.5.8[illegible] c. 4 mm [illegible] d. [illegible] e. [illegible] GND[illegible]

EV.4.4.4 [illegible] T.9.2

EV.4.5 [illegible] APPS[illegible] APPS [illegible] T.4.2

EV.4.6 [illegible] BSE[illegible] BSE [illegible] T.4.3

EV.4.7 APPS/[illegible]

EV.4.7.1 [illegible]

- [illegible] EV.4.6, T.3.2.4[illegible]
- APPS [illegible] 25% [illegible] EV.4.5[illegible]

EV.4.7.2 [illegible] EV.4.7.1 [illegible] a. [illegible] b. [illegible] APPS [illegible] 5% [illegible]

EV.4.8 [illegible] F.11

EV.4.9 [illegible] EV.4.9.1 [illegible] a. ISO 7010-W012 [illegible] b. [illegible] T.9.1.1[illegible] High Voltage[illegible]

EV.4.9.2 [illegible] GLV [illegible] EV.6.7

EV.4.10 [illegible] Hand Cart EV.4.10.1 [illegible] Tractive Battery Pack(s)

EV.4.10.2 [illegible] Tractive Battery Pack(s)[illegible] EV.11.4.2, EV.11.5.1[illegible]

EV.4.10.3 [illegible] a. [illegible] Tractive Battery Pack(s)[illegible] b. [illegible] c. [illegible]

- [illegible] ead man type switch [illegible]
- [illegible] Tractive Battery Pack(s)[illegible]

EV.4.10.4 Tractive Battery Pack(s)[illegible]

EV.5 ????

EV.5.1 [illegible] Tractive Battery EV.5.1.1 [illegible]

- [illegible] 120 V DC
- [illegible] 6 MJ [illegible] The contained energy[illegible]
- [illegible] 12 kg

EV.5.1.2 [illegible] EV.3.1[illegible] image

EV.5.1.3 [illegible] /[illegible] ESF [illegible] SES [illegible]

EV.5.2 [illegible] EV.5.2.1 [illegible]

EV.5.2.2 [illegible] a. [illegible] / [illegible] b. [illegible] GLV [illegible] EV.6.7 c. [illegible]

EV.5.2.3 [illegible] F.1.18[illegible] a. [illegible] b. [illegible]

[illegible] /[illegible]

EV.5.2.4 [illegible] BMS [illegible]

EV.5.2.5 [illegible] GLV [illegible]

EV.5.3 [illegible] EV.5.3.1 [illegible] a. [illegible] EV.5.1.1 [illegible] b. [illegible]

EV.5.3.2 [illegible] a. [illegible] b. [illegible] c. [illegible] d. [illegible] e. [illegible] f. [illegible]

EV.5.3.3 [illegible] EV.11.4.1

EV.5.4 [illegible] IR[illegible] EV.5.4.1 [illegible] EV.6.6 [illegible] IR[illegible]

EV.5.4.2 [illegible] a. [illegible] b. [illegible]

EV.5.4.3 [illegible] T.9.1.1[illegible]

EV.5.4.4 [illegible] F.1.18[illegible]

EV.5.4.5 [illegible] 250 [illegible] EV.7.2.2[illegible]

EV.5.5 [illegible] MSD[illegible] [illegible] MSD[illegible] EV.11.3.2[illegible]

EV.5.5.1 [illegible] MSD[illegible] a. [illegible] b. [illegible] 350 mm c. [illegible] d. [illegible] 10 [illegible] e. [illegible] f. [illegible] g. [illegible] MSD[illegible]

EV.5.5.2 [illegible] MSD[illegible]

EV.5.5.3 [illegible] MSD [illegible] EV.7.8[illegible] EV.7.2.2[illegible]

EV.5.5.4 [illegible] EV.6.1.2

EV.5.6 [illegible] EV.5.6.1 [illegible] a. [illegible] IR [illegible] 90% b. [illegible] EV.7.1[illegible]

EV.5.6.2 [illegible] IR [illegible] a. [illegible]

EV.5.6.3 [illegible] a. [illegible] b. [illegible] MSD [illegible] c. [illegible] d. [illegible] 15 [illegible]

EV.5.6.4 [illegible] PTC[illegible]

EV.5.6.5 [illegible]

EV.5.7 [illegible] [illegible] IR [illegible] T.9.1.1[illegible]

EV.5.7.1 [illegible]

EV.5.7.2 [illegible]

EV.5.7.3 [illegible] IR [illegible]

EV.5.7.4 [illegible] a. [illegible] /[illegible] b. [illegible] High Voltage Present[illegible]

EV.5.8 [illegible] TSMP[illegible] EV.5.8.1 [illegible] TSMP[illegible] a. [illegible] /[illegible] b. [illegible] EV.7.9[illegible] c. [illegible] d. [illegible] /[illegible]

EV.5.8.2 [illegible] TSMP[illegible] EV.8.2[illegible] a. [illegible] b. [illegible]

EV.5.8.3 TSMP [illegible] a. [illegible] 4 mm [illegible] b. [illegible] c. [illegible] HV+[illegible] HV-[illegible]

EV.5.8.4 [illegible] TSMP [illegible] a. [illegible]

[illegible] TS [illegible] Vmax[illegible] [illegible] $V_{max} \leq 200$ V DC 5 kΩ 200 V DC < $V_{max} \leq 400$ V DC 10 kΩ 400 V DC < $V_{max} \leq 600$ V DC 15 kΩ b. [illegible] TSMP [illegible] c. [illegible]

EV.5.8.5 [illegible] TSMP [illegible]

EV.5.9 [illegible] [illegible] EV.7.8[illegible]

EV.5.10 [illegible] EV.5.10.1 [illegible] a. [illegible] b. [illegible]

EV.5.10.2 [illegible] Ready to move light(RTML)[illegible] a. [illegible] DOT FMVSS 108 [illegible] b. [illegible] c. [illegible] 1800 mm²

EV.5.10.3 [illegible] Ready to move light(RTML)[illegible] a. [illegible] b. [illegible] F.1.13[illegible] c. [illegible] 150 mm d. [illegible] e. [illegible] 1300 mm [illegible] 2000 mm [illegible]

[illegible]

EV.5.10.4 Ready to move light(RTML)[illegible] a. [illegible] GLV [illegible] b. [illegible] EV.6.5.4[illegible] c. [illegible] T.9.1.1 [illegible] 2 Hz [illegible] 5 Hz [illegible] 50% [illegible] d. [illegible]

EV.5.11 [illegible] (TSSI) EV.5.11.1 [illegible]

EV.5.11.2 [illegible] a. [illegible] b. [illegible]

EV.5.11.3 [illegible] a. [illegible] 130 mm² [illegible] b. [illegible] c. [illegible]

EV.5.11.4 [illegible] a. [illegible] b. [illegible] c. [illegible] F.1.13[illegible] d. [illegible] 150 mm e. [illegible] f. [illegible]

EV.5.11.5 [illegible] GLV [illegible]

|[illegible] | [illegible] |[illegible] | a.| [illegible] | [illegible] |[illegible] b. BMS (EV.7.3.5) [illegible] IMD (EV.7.6.5) [illegible] [illegible] [illegible] 2 Hz [illegible] 5 Hz[illegible] 50% [illegible]

EV.6 ????

EV.6.1 [illegible] EV.6.1.1 [illegible]

EV.6.1.2 [illegible] 100 mm [illegible] 6 mm [illegible]

EV.6.1.3 [illegible] IP65 [illegible]

EV.6.2 [illegible] EV.6.2.1 [illegible] a. [illegible] b. [illegible] 90°C

EV.6.2.2 [illegible]

EV.6.3 [illegible] EV.6.3.1 [illegible]

EV.6.3.2 [illegible] a. [illegible] b. [illegible] 90°C

EV.6.3.3 [illegible] a. [illegible] b. [illegible] c. [illegible] / [illegible] d. [illegible]

EV.6.3.4 [illegible] a. [illegible]

[illegible]

[illegible] b. [illegible] 200 N [illegible] c. [illegible]

EV.6.3.5 [illegible]

EV.6.4 [illegible] EV.6.4.1 [illegible] a. [illegible] b. [illegible] c. [illegible]

EV.6.4.2 [illegible] GLV [illegible] EV.6.7

EV.6.4.3
[illegible]
[illegible] Loctite® [illegible] OEM [illegible]

EV.6.4.4 [illegible]

EV.6.5 [illegible] EV.6.5.1 [illegible] GLV [illegible] a. [illegible] GLV [illegible]
IN.10.2.2[illegible] b. [illegible] GLV [illegible]

[illegible]

EV.6.5.2
[illegible]

EV.6.5.3 [illegible] GLV [illegible] EV.7.8.4 [illegible]

EV.6.5.4 [illegible] IR[illegible] EV.5.4[illegible] EV.5.6[illegible] HV DC/DC [illegible] BMS[illegible] EV.7.3[illegible]
IMD[illegible] EV.7.6[illegible] EV.5.10[illegible] EV.3.1[illegible] GLV
[illegible]

EV.6.5.5 [illegible] GLV [illegible] a. [illegible] 90°C [illegible]
UL [illegible] Nomex [illegible] b.
[illegible] UL1741 [illegible]

[illegible] [illegible] U < 100 V DC 10 mm 100 V DC < U < 200 V DC 20 mm U > 200 V DC 30 mm EV.6.5.6
[illegible]

EV.6.5.7 [illegible] GLV [illegible] a. [illegible] b.
[illegible] /[illegible]

[illegible] [illegible] [illegible] [illegible] 0-50 V DC 1.6 mm 1.6 mm 1 mm 50-150 V DC 6.4
mm 3.2 mm 2 mm 150-300 V DC 9.5 mm 6.4 mm 3 mm 300-600 V DC 12.7 mm 9.5 mm 4 mm
EV.6.5.8
[illegible]

EV.6.5.9 [illegible]

EV.6.6 [illegible] EV.6.6.1 [illegible] /[illegible]

EV.6.6.2 [illegible] a. [illegible] DC
[illegible] DC [illegible] DC [illegible] b.
[illegible] c.
[illegible]

EV.6.6.3 [illegible]

EV.6.6.4 [illegible] a. [illegible] b. [illegible]

EV.6.6.5 [illegible]

[illegible] EV.6.6.2.b [illegible]

BMS [illegible] EV.7.2.2

[illegible]

EV.6.6.6 [illegible] 150 mm [illegible] a. [illegible] 150 mm [illegible] b. [illegible] c. [illegible]

EV.6.6.7 [illegible] EV.6.6.5 [illegible]

EV.6.7 [illegible] EV.6.7.1 [illegible] a. [illegible] 100 mm [illegible] T.1.8.4 [illegible] b. [illegible] T.1.8.4[illegible]

[illegible]

EV.6.7.2 [illegible] GLV [illegible] a. [illegible] 300 mΩ[illegible] 1 A [illegible] b. [illegible] 5 Ω [illegible]

[illegible] 5 Ω

EV.6.7.3 [illegible]

EV.7 ????

EV.7.1 [illegible] EV.7.1.1 [illegible] a. [illegible] BMS[illegible] EV.7.3[illegible] b. [illegible] IMD[illegible] EV.7.6[illegible] c. [illegible] BSPD[illegible] EV.7.7[illegible] d. [illegible] EV.7.8 [illegible] e. [illegible] GLVMS, TSMS[illegible] EV.7.9[illegible] f. [illegible] EV.7.10[illegible] g. [illegible] BOTS[illegible] T.3.3[illegible] h. [illegible] T.9.4[illegible]

EV.7.1.2 [illegible] IR[illegible]

EV.7.1.3 [illegible] BMS[illegible] IMD [illegible] BSPD [illegible]

EV.7.1.4 BMS[illegible] IMD [illegible] BSPD [illegible]

EV.7.1.5 [illegible] BOTS[illegible] TSMS[illegible] GLVMS [illegible]

EV.7.1.6 [illegible]

EV.7.2 [illegible] EV.7.2.1 [illegible] a. EV.7.1.1 [illegible] b. GLV [illegible]

EV.7.2.2 [illegible] a. [illegible] b. [illegible] EV.5.4.3[illegible] c. [illegible] T.9.1.2[illegible] d. [illegible]

EV.7.2.3 [illegible] BMS[illegible] IMD [illegible] BSPD [illegible] a. [illegible] b. [illegible] c. [illegible] d. [illegible] TSMS [illegible]

[[illegible]]

EV.7.3 [illegible] BMS[illegible] EV.7.3.1 [illegible] EV.7.4 [illegible] EV.7.5[illegible] a. [illegible] EV.11.5[illegible] b. [illegible] EV.8.3[illegible]

EV.7.3.2 BMS [illegible] ESF [illegible]

EV.7.3.3 [illegible] EV.7.2, EV.8.4[illegible]

EV.7.3.4 BMS [illegible] a. [illegible] EV.7.4.2[illegible] b. [illegible] c. [illegible] EV.7.5.2[illegible] d. [illegible] e. BMS [illegible]

EV.7.3.5 [illegible] BMS [illegible] EV.7.3.4 [illegible] BMS [illegible] a. [illegible] EV.7.2.2[illegible] b. [illegible] BMS [illegible] EV.5.11.5[illegible]

[illegible] BMS [illegible] EV.7.2.3[illegible]

EV.7.3.6 BMS [illegible] a. [illegible] b. [illegible] c. [illegible] BMS [illegible]

EV.7.4 [illegible] EV.7.4.1 BMS [illegible]

EV.7.4.2 [illegible]

EV.7.4.3 [illegible] BMS [illegible] a. [illegible] EV.7.4.4 [illegible] b. [illegible] Error! Reference source not found [illegible]

EV.7.4.4 [illegible] BMS [illegible] a. [illegible] PCB [illegible] b. [illegible]

EV.7.5 [illegible] EV.7.5.1 BMS [illegible]

EV.7.5.2 [illegible]

[illegible]

60°C

EV.7.5.3 [illegible]

EV.7.5.4 [illegible]

[illegible]

[illegible] 10 mm [illegible]

EV.7.5.5 [illegible] a. BMS [illegible] 20% [illegible] b.
[illegible]

[illegible]

EV.7.5.6 [illegible] EV.7.5[illegible]

EV.7.5.7 [illegible]

[illegible]

[illegible]

[illegible] GLV/TS [illegible]

EV.7.6 [illegible] IMD[illegible] EV.7.6.1 [illegible] IMD[illegible]

EV.7.6.2 IMD [illegible] Bender ISOMETER® IR155-3203 [illegible] IR155-3204[illegible] IMD
[illegible] FSAE Online [illegible] IMD

EV.7.6.3 IMD [illegible] 500 Ω/V [illegible]

EV.7.6.4 IMD [illegible] a. [illegible] b. IMD [illegible]

[illegible]

EV.7.6.5 [illegible] IMD [illegible] EV.7.6.4 [illegible] IMD [illegible] a. [illegible] EV.7.2.2[illegible] b.
[illegible] IMD [illegible] EV.5.11.5[illegible]

[illegible] IMD [illegible] EV.7.2.3[illegible]

EV.7.6.6 IMD [illegible] a. [illegible] b. [illegible] c. [illegible] IMD [illegible]

EV.7.7 [illegible] BSPD[illegible] EV.7.7.1 [illegible] BSPD [illegible] APPS/[illegible] EV.4.7[illegible]

EV.7.7.2 [illegible] BSPD [illegible] EV.7.2.2[illegible]

[illegible] EV.4.6[illegible]

[illegible] 5 kW [illegible] DC [illegible]

BSPD [illegible] 0.5 [illegible]

EV.7.7.3 [illegible] BSPD [illegible] EV.7.2.2[illegible]

EV.7.7.4 [illegible] BSPD [illegible] a. [illegible] b. [illegible] BSPD [illegible]

[illegible]

EV.7.8 [illegible] EV.7.8.1 [illegible] EV.4.1.3, EV.5.5.2, EV.5.9[illegible]

EV.7.8.2 [illegible]

EV.7.8.3 [illegible] a. [illegible] EV.7.2.2[illegible] b. [illegible] IR [illegible]

EV.7.8.4 [illegible] EV.6.5 [illegible] a. [illegible] b. [illegible] EV.5.9[illegible] c. [illegible] 75 mm

EV.7.9 [illegible] EV.7.9.1 [illegible] a. [illegible] T.9.3 b. [illegible]

EV.7.9.2 [illegible] GLVMS[illegible] a. [illegible] GLV [illegible] EV.4.4[illegible] b. [illegible] > 50 mm [illegible] c. [illegible] LV[illegible]

EV.7.9.3 [illegible] TSMS[illegible] a. [illegible] OFF [illegible] EV.7.2.2[illegible] b. [illegible] IR [illegible] c. [illegible] > 50 mm [illegible] d. [illegible] TS[illegible] ISO 7010-W012 [illegible] e. [illegible] OFF [illegible] / [illegible] EV.11.3.1[illegible]

EV.7.10 [illegible] EV.7.10.1 [illegible]

EV.7.10.2 [illegible] a. [illegible] b. [illegible] OFF [illegible] EV.7.2.2 [illegible] c. [illegible] OFF [illegible] d. [illegible] ON [illegible]

EV.7.10.3 [illegible] a. [illegible] F.5.9[illegible] b. [illegible] 40 mm c. [illegible]

EV.7.10.4 [illegible] a. [illegible] b. [illegible] 24 mm

EV.7.10.5 [illegible]

EV.8 ?????

EV.8.1 [illegible] EV.8.1.1 [illegible] IN.5.1[illegible]

EV.8.1.2 [illegible] IN.5.2.2[illegible]

EV.8.2 [illegible] EV.8.2.1 [illegible] AC[illegible] DC[illegible]

EV.8.2.2 [illegible] AC [illegible]

EV.8.2.3 [illegible]

EV.8.2.4 [illegible]

EV.8.2.5 [illegible]

EV.8.2.6 [illegible] TSMP[illegible] EV.5.8.2

EV.8.2.7 [illegible] a. [illegible] b. [illegible] 25 mm c. [illegible] OFF [illegible] EV.8.4.2[illegible] d. [illegible] OFF [illegible] e. [illegible]

EV.8.3 [illegible] EV.8.3.1 [illegible] a. [illegible] EV.8.2.7[illegible] b. [illegible] BMS [illegible] EV.7.3[illegible] c. [illegible] IMD[illegible] EV.7.6[illegible]

EV.8.3.2 [illegible] BMS [illegible] IMD [illegible] a. [illegible] b. [illegible]

[illegible]

EV.8.4 [illegible] EV.8.4.1 [illegible] BMS [illegible] IMD [illegible] a. [illegible] b. [illegible]

EV.8.4.2 [illegible] a. [illegible] b. [illegible] T.9.1.2[illegible] c. [illegible] d. [illegible]

EV.9 ????

EV.9.1 [illegible] [illegible] EV.7.9[illegible]

EV.9.2 [illegible] [illegible] a. [illegible] GLV[illegible] EV.9.3[illegible] b. [illegible] EV.9.4 [illegible] c. [illegible] EV.9.5[illegible]

EV.9.3 [illegible] GLV[illegible] [illegible] GLV [illegible]

EV.9.4 [illegible] EV.9.4.1 [illegible] - [illegible]

EV.9.4.2 [illegible]

GLV [illegible]

[illegible]

EV.9.5 [illegible] EV.9.5.1 [illegible] - [illegible] D.2.3[illegible] D.1.2.1[illegible]

EV.9.6 [illegible] EV.9.6.1 [illegible] - [illegible] APPS [illegible]

EV.9.6.2 [illegible]

[illegible] EV.9.4[illegible]

[illegible] T.3.2[illegible]

[illegible]

[illegible]

EV.9.7 [illegible] EV.9.7.1 [illegible]

EV.9.7.2 [illegible] a. [illegible] 1 [illegible] 3 [illegible] b. [illegible] 80 dBA[illegible] IN.10.3[illegible] c. [illegible]

EV.9.7.3 [illegible]

EV.10 ??????

EV.10.1 [illegible] EV.10.1.1 [illegible]

EV.10.1.2 [illegible] a. [illegible] b. [illegible]

EV.10.2 [illegible] EV.10.2.1 [illegible]

EV.10.2.2 [illegible]

EV.11 ????

EV.11.1 [illegible] EV.11.1.1 [illegible] ESO[illegible] AD.5.2[illegible] a. [illegible] b. [illegible] c. [illegible]

EV.11.2 [illegible] EV.11.2.1 [illegible] a. [illegible] b. [illegible]

EV.11.2.2 [illegible]

EV.11.3 [illegible] EV.11.3.1 [illegible] TSMS[illegible] EV.7.9.3[illegible] OFF [illegible]

EV.11.3.2 [illegible] MSD[illegible] EV.5.5[illegible] a. [illegible] b. [illegible]

EV.11.4 [illegible] EV.11.4.1 [illegible] IN.5[illegible] EV.5.3.3 a. [illegible] b. [illegible] c. [illegible]

EV.11.4.2 [illegible] /[illegible] a. [illegible] EV.4.3 [illegible] EV.4.10.2 b. [illegible] /[illegible] EV.11.4.3[illegible]

EV.11.4.3 [illegible] /[illegible] a. [illegible] b. [illegible]

EV.11.4.4 [illegible] /[illegible] EV.5.1.1 [illegible]

EV.11.5 [illegible] EV.11.5.1 [illegible] EV.4.10[illegible]

EV.11.5.2 [illegible]

EV.11.5.3 [illegible]

EV.11.5.4 [illegible]

[illegible]

[illegible]

EV.11.5.5 [illegible]

EV.12 ????

EV.12.1 [illegible] [illegible] a. [illegible] b. [illegible] EV.5.11 [illegible] c. [illegible]

EV.12.2 [illegible] a. [illegible] b. [illegible]

[illegible]

c. [illegible]

FSAE EV ????????

????????

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□□□□□□□□□	EV.4.3.6 a	□□□□□□□□□□□□□ Tractive Battery Container□□
ISO 7010-W012 □□□□□□□□□□□□□□□	EV.4.3.6 b	□□□□□□□□□□□□□□□□ 100 mm□□□□□□□□□□□□□□□□
“Always Energized” □□	EV.4.3.6 c	□□□□□□□□□
“High Voltage” □□	EV.4.3.6 d	□□□□□□ T.9.1.1 □□□□□□□□□□□□□□□ “High Voltage”
GLV □□□□□□□ “LV”	EV.7.9.2 c	□□□□□□ “LV” □□□□□ >50mm □□□□□□□□□□□
TS□□□□□□□□□□□ “TS” + ISO 7010-W012 □□	EV.7.9.3 d	□□□□□□ “TS” □□□□□□□□□ ISO 7010-W012□
□□□□□□□□□□□□□□□□□□ □□□□□□□□□	EV.7.10.5	□□□□□□□□□□□□□
□□□□□□□ “High Voltage Present”	EV.5.7.4 b	□□□□□□□□□□□□□□□□□□ □□□□ “High Voltage Present”
TSMP□□□□□□□□□□□ “HV+” □ “HV-”	EV.5.8.3 c	□□□□□□□□□□□□□□□
GLV □□□□□ “GND”	EV.4.4.3 e	□□□□□□□□□□□ GND

FSAE-E ???? (TC) ??? Simulink_Simscape ????????

[illegible] MathWorks [illegible] (Simulink, Simscape) [illegible] FSAE [illegible] (TC) [illegible]

[illegible]

1. **UTAS [illegible] (Pengcheng Ji, 2020):** [illegible] DTC ([illegible]) [illegible]
2. [illegible] **(Tiago Marques, 2023):** [illegible] FOC ([illegible]) [illegible] PSO ([illegible]) [illegible] PID[illegible]

[illegible]

- **Simulink®:** [illegible]
- **Simscape™:** [illegible] (Plant)[illegible]

????????????

[illegible]

1.1 ??? MathWorks ??? (Toolboxes)

[illegible]

- `Simulink` ([illegible])
- `Simscape` ([illegible])
- `Simscape Multibody` ([illegible] 3D [illegible])
- `Simscape Electrical` ([illegible])
- `Motor Control Blockset` ([illegible] [illegible] FOC/DTC [illegible])
- `Vehicle Dynamics Blockset` ([illegible] /[illegible])
- `Optimization Toolbox` ([illegible] PSO [illegible])

1.2 ???????? (????)

[illegible] 0 [illegible] **MATLAB Central File Exchange**[illegible]

1. **(Plant)**
   - `Formula Student Vehicle with Simscape` `Racing Lounge: Vehicle Modeling with Simscape Multibody`
   -
2.
   - `Motor Control Blockset` `Field-Oriented Control (FOC) of PMSM` `Direct Torque Control (DTC) of PMSM`
   -

1.3 ????????????

(Parameterization)

- **[ ] (Chassis):** (Mass), (CG) , (Inertia)
- **[ ] (Suspension):** (Hard points), K , C
- **[ ] (Motor):** ( ) L_d, L_q, R_s, (Flux Linkage)
- **[ ] (Tire):** ( ) **Magic Formula (Pacejka)** `Tire (Simple)` block

?????????? (Plant)?- ?????? (Simscape)

1. `1.2` `Formula Student Vehicle with Simscape`
2. Simscape block (`Rigid Body`, `Spring-Damper`, `PMSM`) `1.3`
3. TC
   - Simscape `Tire (Magic Formula)` block
   -
   - block (Normal Force) (Slip) (Longitudinal Force)
4.
   - `Simscape Electrical` `PMSM` block
   -
5.
   - TC
   -
   - `Simscape Multibody Explorer` (3D)
   - TC

?????????? (Controller)?- TC ??? (Simulink)

□□□□□□□□□□ Simulink□□□□□□□□□□□□ TC □□□□

[□□] □□ TC □□□□□□ Subsystem□□□□□

3.1 Step 1: ??????? (FOC / DTC)

1. □□ `Motor Control Blockset` □□ FOC (□ DTC) □□□
2. □□□□ /□□□□□□□□□□□□□ Subsystem□□□□ `Motor_Controller_L` (□ `_R`)□
3. □□□ □□ Subsystem □□□□ `Target_Torque` (□□□□)□
4. □□□ □□□ `PWM Signals` (□□□□) □ `Actual_Torque` (□ Simscape □□)□

3.2 Step 2: ?? TC ?? (Slip Ratio Control)

□□□□□□□□□

1. **□□□□ (Slip Ratio Calculator):**
   - □□□ 4 □□□□ (Wheel Speeds)□□□ Simscape Plant□
   - □□□
     - $V_{vehicle} \approx \text{avg}(\text{WheelSpeed_FL}, \text{WheelSpeed_FR}) \times R_{wheel}$ (□□□□□□□□□□□)
     - $Slip_{RL} = (\text{WheelSpeed_RL} \times R_{wheel} - V_{vehicle}) / V_{vehicle}$
   - □□□ `Actual_Slip_RL`, `Actual_Slip_RR`
2. **□□□□ (Target Slip Generator):**
   - □□□□□□□□ `Constant` block□□□ `0.15` (□□ 15% □□□□□)□
   - □□□□□□ `1-D Lookup Table` □□□□□□ $V_{vehicle}$ □□□□□□□
3. **PID □□□ (The Core)□**
   - □□□□□□□□□ `PID Controller` block□
   - □□□ `Error = Target_Slip - Actual_Slip_RL`
   - □□□ □□□□□□□ (□□ 0~1 □□□□□□□□□□)□
4. **□□□□ (Torque Limiter)□**
   - □□ **1□** `Driver_Requested_Torque` (□□□□□)□
   - □□ **2□** `TC_Limited_Torque` (□□ PID □□□)□
   - □□□ □□ `Min` block□ `Final_Commanded_Torque = min(Driver_Requested_Torque, TC_Limited_Torque)`
   - □□□ `Final_Commanded_Torque`□

???????? (Controller + Plant)

1. **[Plant -> Controller]**
   - Simscape 4 (`Wheel_Speeds`) Simulink `Slip_Ratio_Calculator`
2. **[Driver -> Controller]**
   - (`Step` block 0 -> 100%) `Torque_Limiter`
3. **[Controller -> Plant]**
   - `Torque_Limiter` `Final_Commanded_Torque` `Motor_Controller_L/R` (FOC/DTC)
   - `Motor_Controller_L/R` (`Phase_Voltages`) Simscape (`Inverter`) Gating ports

> **Pro-Tip ( )** FOC/DTC TC (3.2) `Final_Commanded_Torque` Simscape `PMSM` block (T) **TC**

????????????

5.1 ?? (Tuning)

PID (Kp, Ki, Kd)

- **1 ( )** PID `Scope` `Target_Slip`
- **2 ( )** Simulink **`PID Tuner` App**
- **3 (-)** MATLAB `Optimization Toolbox` `pso()` ( ) Kp, Ki, Kd

5.2 ?? (Validation) - A/B Test

TC (ON) > TC (OFF)

1. **TC :**
   - `Torque_Limiter` `Manual Switch` block
   - **ON (A)** TC (`Final_Commanded_Torque`)
   - **OFF (B)** TC `Driver_Requested_Torque`
2. **A (TC ON)**
   - **(Scope)** `Actual_Slip` `Target_Slip` `Commanded_Torque` `Requested_Torque`
   - **(Simscape Explorer)** 3D
3. **B (TC OFF)**
   - **(Scope)** `Actual_Slip` 100% `Commanded_Torque` = `Requested_Torque`
   - **(Simscape Explorer)** 3D (Fishtail)

TC

??????

(SIL - Software-in-the-Loop) VCU

- TC (Simulink) **`Simulink Coder`** **`Embedded Coder`** C/C++
- **(HIL)** C (dSPACE Speedgoat) Simscape (Real-Time)
- VCU

FSAE-E ???? (TC) ?????????

(Traction Control System, TC)
Pengcheng Ji UTAS, 2020

https://repositorio-aberto.up.pt/bitstream/10216/152698/2/640636.pdf

---

1. ?? (Methodology) - ??????

TC **(Slip Ratio Control)**

-
  - **(High-Level)** (PID)
  - **(Low-Level)**
- **(Motor Control)**
  - **(PMSM)**
  - **(DTC)**
  - **MTPA (** **)**
- **(Modelling)**
  - **Magic Formula (MF)** TC
  -

[!] TC /

---

2. ?? (Phases) - ????

?????????????

- ☐ **(** **)**

- [illegible]
- [illegible] ([illegible]) [illegible] Magic Formula [illegible]

☐ [illegible] 4 [illegible] (Wheel Speed Sensors)[illegible] IMU (G[illegible] /[illegible])[illegible]

?????? (Simulation)

☐ [illegible] MATLAB/SIMULINK [illegible]

☐ [illegible]

☐ [illegible]

☐ [illegible] SIMULINK [illegible] TC [illegible]

☐ [illegible] TC [illegible]

?????? (Implementation)

☐ [illegible] SIMULINK [illegible] C/C++ [illegible] ([illegible] Embedded Coder) [illegible]

☐ [illegible] TC [illegible] VCU ([illegible])[illegible]

☐ **CAN Bus** [illegible] VCU [illegible] ([illegible] 100Hz+) [illegible] 4 [illegible] (Inverter) [illegible]

☐ [illegible] **(Logging)** [illegible]

????????? (Validation & Tuning)

☐ [illegible] A/B Test[illegible]

☐ [illegible] **(Tuning)**[illegible] * [illegible] `Target_Slip_Ratio` ([illegible] 10%? 15%?) [illegible]

- **PID** [illegible] TC [illegible] Kp, Ki, Kd [illegible] TC [illegible]
  - [illegible] (Harsh)[illegible]
  - [illegible] (Soft)[illegible] TC [illegible]

---

3. ???? (Validation Process)

[illegible] **A/B Test**[illegible] **TC** [illegible] **(ON)** vs **TC** [illegible] **(OFF)**[illegible]

3.1 ????? (Data Logging)

[□□] □□ TC □□□□□□□□□□□□□□□□

[□□□□ (100Hz+)]

- `TCS_Active` (□□□): TC □□□□□□ (1=□□, 0=□□)
- `Slip_Ratio_RL`, `Slip_Ratio_RR`: (□□□) □ /□□□□□□
- `Target_Slip_Ratio`: (□□□□□□)
- `Requested_Torque`: (□□□□) □□□□□□□
- `Commanded_Torque`: (TC □□) □□□□□□□□□□□□□□
- `Wheel_Speed_FL`, `FR`, `RL`, `RR`: □□□□
- `Longitudinal_G`: (□□ IMU) □□ G □ (□□□)
- `Yaw_Rate`: (□□ IMU) □□□□ (□□□□)

[□□□□]

1. **□□□□ (0-60kph □□□□)**
   - **TC OFF (□□□)□**
     - □□□□ `Slip_Ratio` □□□□□ `Wheel_Speed_RR` □□□ `Wheel_Speed_FR`□ `Commanded_Torque` = `Requested_Torque`□
   - **TC ON (□□□)□**
     - □□□□□ `TCS_Active` □□ 1 -> `Commanded_Torque` < `Requested_Torque` -> `Slip_Ratio` □□□□ `Target_Slip_Ratio` □□□
     - □□□□□ 0-60kph □□□□ □□ □ `Longitudinal_G` □□□□□□
2. **□□ (Corner Exit) □□**
   - **TC OFF (□□□)□**
     - □□□□□□□□ -> □□□□□□□□□□ -> `Yaw_Rate` □□□□ -> □□□□ (Spin)□
   - **TC ON (□□□)□**
     - □□□□□ `TCS_Active` □□ -> □□□□□□□ -> `Yaw_Rate` □□□□ -> □□□□□□□

3.2 ???? (Video Recording)

[□□] □□□□ TC □□□□□□□□□□□

- **[□□□□ 1] GoPro □□□□□□□□□□□□□**
  - **TC OFF□** □□□□□□□
  - **TC ON□** □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
- **[□□□□ 2] GoPro □□□□□□□□□□□**
  - □□□□□□□□□
  - □□□□□□□□ TC □□□□□□□□□□□□
- **[□□□□ 3] □□□□□**
  - **TC OFF□** □□□□□□ (Fishtail)□
  - **TC ON□** □□□□□□□

3.3 [??] ????? (Drone View)

[□□] □□ TC □□□□□□ (Sideslip)□□ □□ □□□□

- **TC OFF□**
  □□□
  □□□
- **TC ON□** □□□□□□ TC □□□□□□□□□□□□□ □□□□
  □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

IEM????????

https://forum.gamer.com.tw/C.php?bsn=60535&snA=21826

image

PDOC Test Report

Test Date

- 2024/11/25, William

Purpose

This document outlines the test methods and results to verify the effectiveness of our PDOC system. The system is designed to open the shutdown loop when over-temperature conditions occur on the precharge or discharge resistor. Additionally, the report includes explanations of several circuit operations.

Related Rule

- EV5.6.6 Add Clause defining the PDOC (Local Addendum)

PDOC Test Method

In order to **simulate the worst-case scenario** for the system, we directly connect a 400V DC voltage source (approximately the maximum voltage of the accumulator) to each terminal of our discharge and precharge resistors. **Using a thermal camera, we can verify whether the system successfully triggers the shutdown loop to open at the designed temperature.** Additionally, it allows us to assess the thermal conductivity of the resistors, heat sink, and thermal paste to ensure effective heat dissipation.

H1uAbvQXJg.jpg

PDOC Test Result

The temperature for triggering the shutdown loop is designed to be 80°C. However, due to the thermal conductivity limitations of the heatsink and thermal paste, it takes some time for the NTC thermistor to respond. **In the worst-case scenario, the system may only trip when the resistor's surface temperature reaches 90°C. This is still within safe limits,** as the resistor's operating temperature range, according to the datasheet, is -65°C to +175°C.

r1tB5PXXJx.png SkOFuwX71l.png

Core System Explanation

How to Detect The Temperature

In our system, we use an NTC thermistor (Littelfuse KX103J2) with a Beta value of 3892. The Beta value is a critical characteristic that determines the thermistor's resistance at specific temperatures. When paired with a resistor, it forms a voltage divider, which outputs varying voltages corresponding to different temperatures. The following graph illustrates the relationship between temperature and resistance.

rJcpTvXXJg.png

To monitor the temperature, a hysteresis OPA comparator is used to determine whether the temperature exceeds 80°C based on the voltage. Additionally, the hysteresis OPA comparator ensures system stability by introducing a hysteresis effect. Once the over-temperature protection is triggered, it will only disengage when the temperature drops back to 70°C, preventing rapid on/off switching and ensuring reliable operation.

S1WLpvmXJx.png

TTR8 ???????

- □□□ Amphenol Sine Systems
- □□□□□ 250V
- □□□□□ 13A(Normal Connector), 25A(Mixed Connector)
- □□□□□ IP68, IP69K(□□□□□□□)

??

?????????

AT11-310-1605 (□□□□□□) AT62-16-0844 (Size-16 2022AWG □□ □□ □□□□) AT62-16-0644 (Size-16 1820AWG □□ □□ □□□□) AT60-16-0844 (Size-16 2022AWG □□ □□ □□□□) AT60-16-0644 (Size-16 1820AWG □□ □□ □□□□) A114017 (□□□)

2P???

??

AT04-2P-PM11 (□□□□□)

????

AW2P (Green) AW2P-A (Keyed-A Grey) AW2P-B (Keyed-B Black) AW2P-C (Keyed-C Green) AW2P-D (Keyed-D Brown)

??

AT06-2S (Grey)

????

AW2S (Green) AW2S-A (Keyed-A Grey) AW2S-B (Keyed-B Black) AW2S-C (Keyed-C Green) AW2S-D (Keyed-D Brown)

?????

AT2S-BT (Grey) AT2S-BT-BK (Black) AT2S-BT-YW (Yellow)

??

AT04-XP-PM1X-G7 (□□□□□□□□□□□ □□□)

3P???

??

AT04-3P-PM05 (□□□□□ □□□) AT04-3P-PM11 (□□□□□)

????

AW3P (Green) AW3P-J1939 (Keyed-J1939 Blue)

??

AT06-3S (Grey)

????

AW3S (Green) AW3S-J1939 (Keyed-J1939 Blue)

?????

AT3S-BT (Grey) AT3S-BT-BK (Black) AT3S-BT-YW (Yellow)

??

AT04-XP-PM1X-G7 (□□□□□□□□□□□□ □□□)

4P???

??

AT04-4P-PM11 (□□□□□)

????

AW4P (Green) AW4P-A (Keyed-A Grey) AW4P-B (Keyed-B Black) AW4P-C (Keyed-C Green) AW4P-D (Keyed-D Brown)

??

AT06-4S (Grey)

????

AW4S (Green) AW4S-A (Keyed-A Grey) AW4S-B (Keyed-B Black) AW4S-C (Keyed-C Green) AW4S-D (Keyed-D Brown)

?????

AT4S-BT (Grey) AT4S-BT-BK (Black) AT4S-BT-YW (Yellow)

??

AT04-XP-PM1X-G7 (□□□□□□□□□□□□ □□□)

6P???

??

AT04-6P-PM05 (□□□□□ □□□) AT04-6P-PM11 (□□□□□)

????

AW6P (Green)

??

AT06-6S (Grey)

????

AW6S (Green)

?????

AT6S-BT (Grey) AT6S-BT-BK (Black) AT6S-BT-YW (Yellow)

??

AT04-XP-PM1X-G7 (□□□□□□□□□□□□ □□□)

8P???

??

AT04-08PA-PM05 (□□□□□ □□□ Keyed-A Grey) AT04-08PA-PM11 (□□□□□ Keyed-A Grey) AT04-08PB-PM11 (□□□□□ Keyed-B Black) AT04-08PC-PM11 (□□□□□ Keyed-C Green) AT04-08PD-PM11 (□□□□□ Keyed-D Brown)

????

AW8P (Green)

??

AT06-08SA (Keyed-A Grey) AT06-08SB (Keyed-B Black) AT06-08SC (Keyed-C Green) AT06-08SD (Keyed-D Brown)

????

AW8S (Green)

?????

AT8S-BT (Grey) AT8S-BT-BK (Black) AT8S-BT-YW (Yellow)

??

AT04-08PB-G7 (□□□□□□□□□□□□ □□□)

12P???

??

AT04-12PA-PM05 (□□□□□ □□□ Keyed-A Grey) AT04-12PA-PM11 (□□□□□ Keyed-A Grey) AT04-12PB-PM11 (□□□□□ Keyed-B Black) AT04-12PC-PM11 (□□□□□ Keyed-C Green) AT04-12PD-PM11 (□□□□□ Keyed-D Brown)

????

AW12P (Green)

??

AT06-12SA (Keyed-A Grey) AT06-12SB (Keyed-B Black) AT06-12SC (Keyed-C Green) AT06-12SD (Keyed-D Brown)

????

AW12S (Green)

?????

AT12S-BT (Grey) AT12S-BT-BK (Black) AT12S-BT-YW (Yellow)

13P???

AT1612-13PB-G (□□□□□□□ Keyed-B Black □□□□□□) AT1612-PB-G7 (□□□□□□□□□□□□ □□□)

18P???

AT16-18PA-PM11 (□□□□□□□ □□□ Keyed-A Grey □□□□□□) AT16-18SA (□□ Keyed-A Grey)

Column 1	Column 2	Column 3
Text	Text	Text

ATHP062S25EL-S2 ATHP062S25ELB-S2

ATHP042P25EL ATHP042P25ELB

1-2103124 4-2103177