Sumari

Apèndix A.

Programa per al càlcul de la configuració i prestacions d'una bateria segons el model de cel·la.

Aquesta eina s'ha desenvolupat per tal de facilitar la tasca de comparar totes les opcions de models de cel·la i automatitzar la selecció de la més adient.

Es tracta d'un programa realitzat amb Microsoft Excel on fixant diversos paràmetres s'obtenen les opcions més adients. Els models que apareixen un cop s'ha realitzat una recerca compleixen amb les necessitats. Si un model no compleix alguna de les característiques fixades per l'usuari, queda descartada de les opcions i no apareix a l'apartat de Models recomanats. Pel que fa als models que compleixen amb totes les especificacions, es troben ordenats de menor a major pes, ja que és un dels factors prioritaris de la bateria en un vehicle dissenyat per a competir.

Les característiques que s'han de fixar per a realitzar una recerca dins la base de dades i extreure'n resultats són els següents:

- Tensió màxima de la bateria: Permet calcular el nombre de cel·les connectades en sèrie a la bateria.

- Energia aproximada desitjada: La selecció es fa en divisions de 0,25 kWh. S'ha dissenyat de la següent manera ja que els models recomanats no disposaran d'aquesta energia exacta, sinó una de similar (±0,24 kWh).

- Intensitat màxima de descàrrega: Aquest paràmetre procura mantenir les cel·les protegides. El que es pretén és garantir que els models recomanats puguin donar aquest corrent de descàrrega sense veure's afectada la salut de les bateries. El càlcul per a garantir aquest factor és mirar la descàrrega màxima de cada model de cel·la, i crear paral·lels fins a assegurar que la intensitat màxima que haurà de cedir cada cel·la és inferior o la mateixa que la que pot oferir.

- Potència màxima de sortida: Juntament amb la intensitat màxima de descàrrega, s'encarrega de protegir les cel·les garantint que la proposta de distribució pugui cedir aquesta potència sense malmetre les bateries.

- Factor de la intensitat de pic: A la fitxa tècnica de les bateries hi ha un factor que és la intensitat de pic. Sol ser un 125 % més elevada que la intensitat màxima de descàrrega, i només es pot donar durant un període de temps curt (generalment entre 1 i 3 segons). Sabent el temps previst de descàrrega a la màxima intensitat de pic, es pot optar per un model de cel·la que estigui limitat per aquest factor. Sempre amb el consentiment del fabricant, i sabent que la descàrrega a intensitat superior a la de pic pot malmetre o escurçar la vida útil de la bateria, es pot incrementar lleugerament aquest factor de pic.

Llistat d'equacions emprat:

$$d_{cel\cdot la} = \frac{C_{cel\cdot la}}{m_{cel\cdot la}} \qquad (Equació\ 1)$$

$$I_{max} = C_{cel\cdot la} \cdot C_{max} \cdot f_{pic} \qquad (Equació\ 2)$$

$$N_{paral\cdot lel} = \text{màxim}\left(\frac{P_{max}}{I_{max} \cdot U_{\min bateria}}, \frac{I_{imposada}}{I_{max}}\right) \qquad (Equació\ 3)$$

$$N_{serie} = \frac{U_{\max bateria}}{U_{\max cel\cdot la}} \qquad (Equació\ 4)$$

$$E_{bateria} = N_{serie} \cdot U_{nom\ cel\cdot la} \cdot N_{paral\cdot lel} \cdot C_{cel\cdot la} \qquad (Equació\ 5)$$

$$m_{bateria} = N_{paral\cdot lel} \cdot N_{serie} \cdot m_{cel\cdot la} \qquad (Equació\ 6)$$

Imatges del programa

Tensió màxima de la bateria (V)	410
Energia aproximada desitjada (kWh)	7,5
Intensitat màxima descàrrega (A):	250
Potència màxima de sortida (W)	80000
Factor de intensitat de pic	1,25

Models recomanats per max PARAL·LEL:

Model	Capacitat cel·la	pes (kg)	Energia total (kWh)	Configuració
LPB042126	7000	39,431	7,5369	97s3p
LP8859098	5300	43,456	7,60868	97s4p

Models recomanats per min PARAL·LEL:

Model	Capacitat cel·la	pes (kg)	Energia total (kWh)	Configuració	Intensitat màxima descàrrega
SLPB8498220	21000	37,83	7,5369	97s2p	131,25
SLPBA790190	21000	38,606	7,5369	97s2p	210
LPA045135	7000	39,285	7,5369	97s4p	210
LPB042126	7000	39,4305	7,5369	97s4p	210
LP9945135	7000	39,576	7,5369	97s4p	210

D'aquí es poden extreure diverses apreciacions:

- A la part esquerra, es troben les característiques que s'imposen per tal de poder realitzar la recerca de models de cel·la.

- La classificació dels models es divideix en dues taules. Començant per la classificació de l'esquerra, es troben els models que compleixen amb tots els requisits imposats. Per altra banda, hi ha la classificació de models de la dreta. Aquests models no garanteixen que la intensitat de descàrrega màxima sigui la imposada per l'usuari. Per tant, són configuracions de la bateria més arriscades, on es pot veure afectada la vida útil de les cel·les si se supera la intensitat en qüestió. En aquest cas, l'equip ha de valorar si aquest risc és assumible, o si és millor descartar aquesta opció. Quan es diu que el risc és assumible, es tracta d'explicar el cas al fabricant i rebre el seu consell. S'han de contemplar quan es poden donar aquests casos de intensitats de descàrrega superiors a la permesa, amb quina freqüència, i quina és la diferència entre totes dues.

- A la base de dades es troben els models de cel·les actuals de Melasta, Kokam i A123, que són dels fabricants amb millors prestacions. Se'n pot afegir més accedint a la pàgina de Base de dades. Per tal de poder d'entrar dins del registre, en són necessàries aquestes característiques:

  1. Marca.
  2. Model.
  3. C's de descàrrega.
  4. Capacitat.
  5. Pes.

Apèndix B.

Canvis del carregador i CAN bus del BMS

Canvi de connector de control:

Número de pin	Nom del connector	Descripció
1	Vcc 12	Alimentació de 12 V.
2	Vcc 24	Alimentació de 24 V.
3	GND	Terra comú de 12 i 24 V.
4	Air +	Senyal de 24 V per tancar el relé.
5	Air -	Senyal de 24 V per tancar el relé.
6	IMD_OK	Senyal de 24 V si el sistema està aïllat correctament.
7	GND IMD 1	Terra de mesura del IMD.
8	GND IMD 2	Terra de mesura del IMD.
9	Descàrrega	Senyal de 24 V per obrir el relé.
10	CAN H	Comunicació entre BMS i carregador.
11	CAN L	

Incorporació de l'IMD:

- Creació de l'alarma: Alarma_IMD

Incorporació del nou BMS. Canvi en la comunicació CAN:

- Configuració de la velocitat (250 kbits/s)
- Adaptació dels identificadors del BMS.

Codi del programa de CAN emprat:

```
#include "DSP280x_Device.h"

int Missatge_rebut_iSocket, Missatge_rebut_Convertidor, Missatge_de_configuracio;
int Enviament_solicitat_iSocket, Enviament_solicitat_configuracio,
Enviament_solicitat_convertidor;
int CAN_ready = CERT;
int CAN_ON = FALS;
int dummy=0;
int State=0;
int Warnings_BMS=0;
int Fault_Code=0;
int Alarma_Bank_Comunication=0;
int Alarma_Overcurrent=0;
int Hlim=0;
int Llim=0;
int FLT=0;
long V_1=0;
long V_2=0;
long V_3=0;
long V_4=0;
long V_5=0;
long V_6=0;
long V_7=0;
long V_8=0;
long V_9=0;
long V_10=0;
long V_11=0;
long V_12=0;
long V_13=0;
long V_14=0;
_iq Tensio_Bateries=_IQ(0.0);
int Error_Tensio_Bateries=0;
unsigned int Auxiliar_Max=0;
unsigned int Auxiliar_Min=255;
unsigned int Compt_Celes_0=1;
unsigned int Compt_Celes_1=5;
unsigned int Compt_Celes_2=9;
unsigned int Compt_Celes_4=87;
unsigned int Compt_par_impar=0;
int Cela_Minima = 0;
int Cela_Maxima = 0;
int Sensor_Temp = 0;
_iq Tensio_Minima=_IQ(0.0);
_iq Tensio_Maxima=_IQ(0.0);
long Lect_Consigna_BMS=0;
long Lect_Bateries=0;
_iq Consigna_BMS=_IQ(0.0);
int SOC=0;
int T_Max=0;
unsigned int T_1=0;
unsigned int T_2=0;
unsigned int T_aux;
int Compt_Temp=9;
unsigned int Corrent_CAN = 0;
```

```
unsigned int Comptador_Envia_CAN = 0;
unsigned int timer_envia_CAN = 0;
int Error_Envia_CAN = 0;
unsigned long Timer_CAN = 0;


/* La següent funció configura l'estructura dels mailboxes. La configuració del CAN
es pot trobar al
programa DSP280X_ECan.c*/
void ConfigMB (void)
{

		struct ECAN_REGS ECanaShadow;


	while( ECanaRegs.CANTRS.bit.TRS7 == 1)
	{
		ECanaRegs.CANTRR.bit.TRR7 = 1;
	}


	ECanaShadow.CANME.all = ECanaRegs.CANME.all;
	ECanaShadow.CANME.all = 0x0000;
	ECanaRegs.CANME.all = ECanaShadow.CANME.all;


	ECanaMboxes.MBOX0.MSGID.all = ((long)0x1801F4B0);
	ECanaMboxes.MBOX0.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX1.MSGID.all = ((long)0x1802F4B0);
	ECanaMboxes.MBOX1.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX2.MSGID.all = ((long)0x1803F4B0);
	ECanaMboxes.MBOX2.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX3.MSGID.all = ((long)0x1804F4B0);
	ECanaMboxes.MBOX3.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX4.MSGID.all = ((long)0x18FF01F4);
	ECanaMboxes.MBOX4.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX5.MSGID.all = ((long)0x1806E5F4);
	ECanaMboxes.MBOX5.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX6.MSGID.all = ((long)0x18FF05F4);
	ECanaMboxes.MBOX6.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX7.MSGID.all = ((long)0x000);
	ECanaMboxes.MBOX7.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX8.MSGID.all = ((long)0x000)<<18;
	ECanaMboxes.MBOX8.MSGID.bit.IDE = 1;
	ECanaMboxes.MBOX9.MSGID.all = ((long)0x000)<<18;
	ECanaMboxes.MBOX9.MSGID.bit.IDE = 1;



	ECanaMboxes.MBOX0.MSGCTRL.bit.DLC=8;
	ECanaMboxes.MBOX0.MSGCTRL.bit.RTR=0;
	ECanaMboxes.MBOX0.MSGCTRL.bit.TPL=0;
	ECanaMboxes.MBOX1.MSGCTRL.bit.DLC=8;
	ECanaMboxes.MBOX1.MSGCTRL.bit.RTR=0;
	ECanaMboxes.MBOX1.MSGCTRL.bit.TPL=0;
	ECanaMboxes.MBOX2.MSGCTRL.bit.DLC=8;
	ECanaMboxes.MBOX2.MSGCTRL.bit.RTR=0;
	ECanaMboxes.MBOX2.MSGCTRL.bit.TPL=0;
```

```
EcanaMboxes.MBOX3.MSGCTRL.bit.DLC=6;
ECanaMboxes.MBOX3.MSGCTRL.bit.RTR=0;
ECanaMboxes.MBOX3.MSGCTRL.bit.TPL=0;
ECanaMboxes.MBOX4.MSGCTRL.bit.DLC=8;
ECanaMboxes.MBOX4.MSGCTRL.bit.RTR=0;
ECanaMboxes.MBOX4.MSGCTRL.bit.TPL=0;
ECanaMboxes.MBOX5.MSGCTRL.bit.DLC=8;
ECanaMboxes.MBOX5.MSGCTRL.bit.RTR=0;
ECanaMboxes.MBOX5.MSGCTRL.bit.TPL=0;
ECanaMboxes.MBOX6.MSGCTRL.bit.DLC=7;
ECanaMboxes.MBOX6.MSGCTRL.bit.RTR=0;
ECanaMboxes.MBOX6.MSGCTRL.bit.TPL=0;
ECanaMboxes.MBOX7.MSGCTRL.bit.DLC=8;
ECanaMboxes.MBOX7.MSGCTRL.bit.RTR=0;
ECanaMboxes.MBOX7.MSGCTRL.bit.TPL=0;
ECanaMboxes.MBOX8.MSGCTRL.bit.DLC=8;
ECanaMboxes.MBOX8.MSGCTRL.bit.RTR=0;
ECanaMboxes.MBOX8.MSGCTRL.bit.TPL=0;
ECanaMboxes.MBOX9.MSGCTRL.bit.DLC=5;
ECanaMboxes.MBOX9.MSGCTRL.bit.RTR=0;
ECanaMboxes.MBOX9.MSGCTRL.bit.TPL=0;

//Configura la direcció de la comunicació
ECanaShadow.CANMD.all = ECanaRegs.CANMD.all;
ECanaShadow.CANMD.bit.MD0=1; //MBOX0=recepció
ECanaShadow.CANMD.bit.MD1=1; //MBOX1=recepció
ECanaShadow.CANMD.bit.MD2=1; //MBOX2=recepció
ECanaShadow.CANMD.bit.MD3=1; //MBOX3=recepció
ECanaShadow.CANMD.bit.MD4=1; //MBOX4=recepció
ECanaShadow.CANMD.bit.MD5=1; //MBOX5=recepció
ECanaShadow.CANMD.bit.MD6=1; //MBOX6=recepció
ECanaShadow.CANMD.bit.MD7=0; //MBOX7=transmissió
ECanaShadow.CANMD.bit.MD8=0; //MBOX8=transmissió
ECanaShadow.CANMD.bit.MD9=0; //MBOX9=transmissió
ECanaRegs.CANMD.all = ECanaShadow.CANMD.all;


ECanaMboxes.MBOX0.MSGID.bit.AME = 1;
ECanaMboxes.MBOX0.MSGID.bit.IDE = 1;
ECanaLAMRegs.LAM0.bit.LAM_H = 0x01FFF;
ECanaLAMRegs.LAM0.bit.LAM_L = 0xFFFF;
ECanaLAMRegs.LAM0.bit.LAMI = 1;

ECanaMboxes.MBOX1.MSGID.bit.AME = 1;
ECanaMboxes.MBOX1.MSGID.bit.IDE = 1;
ECanaLAMRegs.LAM1.bit.LAM_H = 0x1FFF;
ECanaLAMRegs.LAM1.bit.LAM_L = 0xFFFF;
ECanaLAMRegs.LAM1.bit.LAMI = 1;

ECanaMboxes.MBOX2.MSGID.bit.AME = 1;
ECanaMboxes.MBOX2.MSGID.bit.IDE = 1;
ECanaLAMRegs.LAM2.bit.LAM_H = 0x1FFF;
ECanaLAMRegs.LAM2.bit.LAM_L = 0xFFFF;
ECanaLAMRegs.LAM2.bit.LAMI = 1;

ECanaMboxes.MBOX3.MSGID.bit.AME = 1;
ECanaMboxes.MBOX3.MSGID.bit.IDE = 1;
ECanaLAMRegs.LAM3.bit.LAM_H = 0x1FFF;
```

```
        ECanaLAMRegs.LAM3.bit.LAM_L = 0xFFFF;
        ECanaLAMRegs.LAM3.bit.LAMI = 1;

        ECanaMboxes.MBOX4.MSGID.bit.AME = 1;
        ECanaMboxes.MBOX4.MSGID.bit.IDE = 1;
        ECanaLAMRegs.LAM4.bit.LAM_H = 0x1FFF;
        ECanaLAMRegs.LAM4.bit.LAM_L = 0xFFFF;
        ECanaLAMRegs.LAM4.bit.LAMI = 1;

        ECanaShadow.CANME.all = ECanaRegs.CANME.all;
        ECanaShadow.CANME.all = 0x03FF;
        ECanaRegs.CANME.all = ECanaShadow.CANME.all;

}

interrupt void ECAN0INTA_ISR(void)  // eCAN-A
{

        Timer_CAN = 0;

        if (ECanaRegs.CANRMP.bit.RMP3==1)
        {
                if (ECanaMboxes.MBOX3.MSGID.bit.STDMSGID >= 0x1804F4B0 &&
ECanaMboxes.MBOX3.MSGID.bit.STDMSGID <= 0x1804F4B8)
                {
                        T_1 = (((long)ECanaMboxes.MBOX3.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX3.MDL.byte.BYTE1;
                        T_2 = (((long)ECanaMboxes.MBOX3.MDL.byte.BYTE2)<<8) +
(long)ECanaMboxes.MBOX3.MDL.byte.BYTE3;
                        T_1 = (int)(T_1-128);
                        T_2 = (int)(T_2-128);
                        if(Compt_Temp>= 1 || Compt_Temp <= 9)
                        {
                                if (T_1 > T_2) T_aux = T_1;
                                if (T_2 > T_1) T_aux = T_2;
                                if (T_aux > T_Max)
                                {
                                        T_Max = T_aux;
                                        Sensor_Temp = Compt_Temp;
                                }
                        }
                        if (Compt_Temp == 0)
                        {
                                        Compt_Temp=10;
                                        T_aux=0;
                        }
                        Compt_Temp -=1;
                }
                else
                {
                }
        }

        if (ECanaRegs.CANRMP.bit.RMP4==1)
        {
                if (ECanaMboxes.MBOX4.MSGID.bit.STDMSGID == 0x18FF04F4)
                {
```

```
                    T_1 = (((long)ECanaMboxes.MBOX4.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX4.MDL.byte.BYTE1;
                    T_2 = (((long)ECanaMboxes.MBOX4.MDL.byte.BYTE2)<<8) +
(long)ECanaMboxes.MBOX4.MDL.byte.BYTE3;
                    if (T_1 > T_2) T_aux = T_1;
                    if (T_2 > T_1) T_aux = T_2;
                    if (T_aux > T_Max)
                    {
                           T_Max = T_aux;
                           Sensor_Temp = 0;
                    }
                    T_aux=0;
             }
      }

      if (ECanaRegs.CANRMP.bit.RMP0==1)
      {
             if (ECanaMboxes.MBOX0.MSGID.bit.STDMSGID >= 0x1801F4B0 &&
ECanaMboxes.MBOX0.MSGID.bit.STDMSGID <= 0x1801F4B8) //
             {
                    V_1 = (((long)ECanaMboxes.MBOX0.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX0.MDL.byte.BYTE1;
                    V_2 = (((long)ECanaMboxes.MBOX0.MDL.byte.BYTE2)<<8) +
(long)ECanaMboxes.MBOX0.MDL.byte.BYTE3;
                    V_3 = (((long)ECanaMboxes.MBOX0.MDH.byte.BYTE4)<<8) +
(long)ECanaMboxes.MBOX0.MDH.byte.BYTE5;
                    V_4 = (((long)ECanaMboxes.MBOX0.MDH.byte.BYTE6)<<8) +
(long)ECanaMboxes.MBOX0.MDH.byte.BYTE7;
                    if (V_1 > Auxiliar_Max)
                    {
                           Auxiliar_Max = V_1;
                           Cela_Maxima = Compt_Celes_0 + 1;
                    }
                    if (V_2 > Auxiliar_Max)
                    {
                           Auxiliar_Max = V_2;
                           Cela_Maxima = Compt_Celes_0 + 2;
                    }
                    if (V_3 > Auxiliar_Max)
                    {
                           Auxiliar_Max = V_3;
                           Cela_Maxima = Compt_Celes_0 + 3;
                    }
                    if (V_4 > Auxiliar_Max)
                    {
                           Auxiliar_Max = V_4;
                           Cela_Maxima = Compt_Celes_0 + 4;
                    }
                    if (V_1 < Auxiliar_Min)
                    {
                           Auxiliar_Min = V_1;
                           Cela_Minima = Compt_Celes_0 + 1;
                    }
                    if (V_2 < Auxiliar_Min)
                    {
                           Auxiliar_Min = V_2;
                           Cela_Minima = Compt_Celes_0 + 2;
                    }
```

```
                    if (V_3 < Auxiliar_Min)
                    {
                          Auxiliar_Min = V_3;
                          Cela_Minima = Compt_Celes_0 + 3;
                    }
                    if (V_4 < Auxiliar_Min)
                    {
                          Auxiliar_Min = V_4;
                          Cela_Minima = Compt_Celes_0 + 4;
                    }

                    Compt_Celes_0 += 10;
              }
       }
       if (ECanaRegs.CANRMP.bit.RMP1==1)
       {
              if (ECanaMboxes.MBOX1.MSGID.bit.STDMSGID >= 0x1802F4B0 &&
ECanaMboxes.MBOX1.MSGID.bit.STDMSGID <= 0x1802F4B8) //
              {
                    V_5 = (((long)ECanaMboxes.MBOX1.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX1.MDL.byte.BYTE1;
                    V_6 = (((long)ECanaMboxes.MBOX1.MDL.byte.BYTE2)<<8) +
(long)ECanaMboxes.MBOX1.MDL.byte.BYTE3;
                    V_7 = (((long)ECanaMboxes.MBOX1.MDH.byte.BYTE4)<<8) +
(long)ECanaMboxes.MBOX1.MDH.byte.BYTE5;
                    V_8 = (((long)ECanaMboxes.MBOX1.MDH.byte.BYTE6)<<8) +
(long)ECanaMboxes.MBOX1.MDH.byte.BYTE7;
                    if (V_5 > Auxiliar_Max)
                    {
                          Auxiliar_Max = V_5;
                          Cela_Maxima = Compt_Celes_1 + 1;
                    }
                    if (V_6 > Auxiliar_Max)
                    {
                          Auxiliar_Max = V_6;
                          Cela_Maxima = Compt_Celes_1 + 2;
                    }
                    if (V_7 > Auxiliar_Max)
                    {
                          Auxiliar_Max = V_7;
                          Cela_Maxima = Compt_Celes_1 + 3;
                    }
                    if (V_8 > Auxiliar_Max)
                    {
                          Auxiliar_Max = V_8;
                          Cela_Maxima = Compt_Celes_1 + 4;
                    }

                    if (V_5 < Auxiliar_Min)
                    {
                          Auxiliar_Min = V_5;
                          Cela_Minima = Compt_Celes_1 + 1;
                    }
                    if (V_6 < Auxiliar_Min)
                    {
                          Auxiliar_Min = V_6;
                          Cela_Minima = Compt_Celes_1 + 2;
                    }
```

```
				if (V_7 < Auxiliar_Min)
				{
					Auxiliar_Min = V_7;
					Cela_Minima = Compt_Celes_1 + 3;
				}
				if (V_8 < Auxiliar_Min)
				{
					Auxiliar_Min = V_8;
					Cela_Minima = Compt_Celes_1 + 4;
				}
				Compt_Celes_1 += 10;
			}
		}

		if (ECanaRegs.CANRMP.bit.RMP2==1)
		{
			if (ECanaMboxes.MBOX2.MSGID.bit.STDMSGID >= 0x1803F4B0 &&
ECanaMboxes.MBOX2.MSGID.bit.STDMSGID <= 0x1803F4B8) //
			{
				if (Compt_par_impar == 0)
				{
					V_9 = (((long)ECanaMboxes.MBOX2.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX2.MDL.byte.BYTE1;
					V_10 = (((long)ECanaMboxes.MBOX2.MDL.byte.BYTE2)<<8) +
(long)ECanaMboxes.MBOX2.MDL.byte.BYTE3;
					if (V_9 > Auxiliar_Max)
					{
					Auxiliar_Max = V_9;
					Cela_Maxima = Compt_Celes_2 + 1;
					}
					if (V_10 > Auxiliar_Max)
					{
					Auxiliar_Max = V_10;
					Cela_Maxima = Compt_Celes_2 + 2;
					}
					if (V_9 < Auxiliar_Min)
					{
						Auxiliar_Min = V_9;
						Cela_Minima = Compt_Celes_2 + 1;
					}
					if (V_10 < Auxiliar_Min)
					{
						Auxiliar_Min = V_10;
						Cela_Minima = Compt_Celes_2 + 2;
					}
					Compt_Celes_2 += 10;
					Compt_par_impar +=1;
				}
				if (Compt_par_impar == 1)
				{
					V_9 = (((long)ECanaMboxes.MBOX2.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX2.MDL.byte.BYTE1;
					if (V_9 > Auxiliar_Max)
					{
						Auxiliar_Max = V_9;
						Cela_Maxima = Compt_Celes_2 + 1;
					}
					if (V_9 < Auxiliar_Min)
```

ETSEIB

```
                        {
                                Auxiliar_Min = V_9;
                                Cela_Minima = Compt_Celes_2 + 1;
                        }
                        Compt_Celes_2 += 10;
                        Compt_par_impar = 0;
                }
        }
}


if (ECanaRegs.CANRMP.bit.RMP4==1)
{
        if (ECanaMboxes.MBOX1.MSGID.bit.STDMSGID >= 0x18FF01F4 &&
ECanaMboxes.MBOX1.MSGID.bit.STDMSGID <= 0x18FF02F4) //
        {

                V_11 = (((long)ECanaMboxes.MBOX1.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX1.MDL.byte.BYTE1;
                V_12 = (((long)ECanaMboxes.MBOX1.MDL.byte.BYTE2)<<8) +
(long)ECanaMboxes.MBOX1.MDL.byte.BYTE3;
                V_13 = (((long)ECanaMboxes.MBOX1.MDH.byte.BYTE4)<<8) +
(long)ECanaMboxes.MBOX1.MDH.byte.BYTE5;
                V_14 = (((long)ECanaMboxes.MBOX1.MDH.byte.BYTE6)<<8) +
(long)ECanaMboxes.MBOX1.MDH.byte.BYTE7;
                if (V_11 > Auxiliar_Max)
                {
                        Auxiliar_Max = V_11;
                        Cela_Maxima = Compt_Celes_4 + 1;
                }
                if (V_12 > Auxiliar_Max)
                {
                        Auxiliar_Max = V_12;
                        Cela_Maxima = Compt_Celes_4 + 2;
                }
                if (V_13 > Auxiliar_Max)
                {
                        Auxiliar_Max = V_13;
                        Cela_Maxima = Compt_Celes_4 + 3;
                }
                if (V_14 > Auxiliar_Max)
                {
                        Auxiliar_Max = V_14;
                        Cela_Maxima = Compt_Celes_4 + 4;
                }
                if (V_11 < Auxiliar_Min)
                {
                        Auxiliar_Min = V_11;
                        Cela_Minima = Compt_Celes_4 + 1;
                }
                if (V_12 < Auxiliar_Min)
                {
                        Auxiliar_Min = V_12;
                        Cela_Minima = Compt_Celes_4 + 2;
                }
                if (V_13 < Auxiliar_Min)
                {
                        Auxiliar_Min = V_13;
```

```
                                Cela_Minima = Compt_Celes_4 + 3;
                        }
                        if (V_14 < Auxiliar_Min)
                        {
                                Auxiliar_Min = V_14;
                                Cela_Minima = Compt_Celes_4 + 4;
                        }
                        Compt_Celes_1 += 4;
                }
        }



        if(ECanaRegs.CANRMP.bit.RMP5==1)
        {
                Lect_Consigna_BMS = ((((long)ECanaMboxes.MBOX5.MDL.byte.BYTE2)<<8) +
(long)ECanaMboxes.MBOX5.MDL.byte.BYTE3)*_IQ(0.1);
                if(Lect_Consigna_BMS > 1023) Lect_Consigna_BMS=1023;
                Consigna_BMS = Lect_Consigna_BMS << 21;
        }


        if (ECanaRegs.CANRMP.bit.RMP6==1)
        {
                Lect_Bateries = ((((long)ECanaMboxes.MBOX6.MDH.byte.BYTE4)<<8) +
(long)ECanaMboxes.MBOX6.MDH.byte.BYTE5)*_IQ(0.1);
                if(Lect_Bateries > 1023) Error_Tensio_Bateries=1;
                Tensio_Bateries = Lect_Bateries << 21;

                SOC = ((((long)ECanaMboxes.MBOX6.MDL.byte.BYTE0)<<8) +
(long)ECanaMboxes.MBOX6.MDL.byte.BYTE1)/_IQ(100.0); //SOC
        }

        if (ECanaRegs.CANRMP.bit.RMP8==1)
        {

        }

                GestioAlarmesBMS();


        if (Compt_Celes_4 >= 95 && Compt_Celes_2 >= 86 && Compt_Celes_1 >= 84 &&
Compt_Celes_0 >= 80)
        {
                MaxMinTensio();
                Compt_Celes_0 = 1;
                Compt_Celes_1 = 5;
                Compt_Celes_2 = 9;
                Compt_Celes_4 = 87;
        }

        ECanaRegs.CANTA.all=0xFFFFFFFF;
        ECanaRegs.CANRMP.all=0xFFFFFFFF;
        ECanaRegs.CANGIF0.all=0xFFFFFFFF;
        PieCtrlRegs.PIEACK.all=PIEACK_GROUP9;
        return;

}
```

Apèndix C.

Fitxes tècniques dels següents elements del projecte:

- Cel·les Melasta SLPBA843126.
- BMS Freemens.
- Motor Emrax 228 HV.
- IMD Bender ® iso-F1 IR155-3203.
- Article sobre el balanceig actiu.

深圳鸿星聚合物锂离子电池规格书

MELASTA LITHIUM-POLYMER (LIP)BATTERY SPECIFICATIONS

MODEL NO: SLPBA843126 6350mAh 15C 3.7V

制定**(PREPARED BY):** 杜华武 日期 DATE**: 2015.05.20**

审核**(CHECKED BY):** 胡远升 日期 DATE**: 2015.05.20**

地址 ***Add:*** *中国深圳市宝安区大浪同富裕工业区*
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ISO 9001

Content

目录

1. 序言 PREFACE

此规格书适用于深圳市风云电池有限公司的锂聚合物可充电电池产品

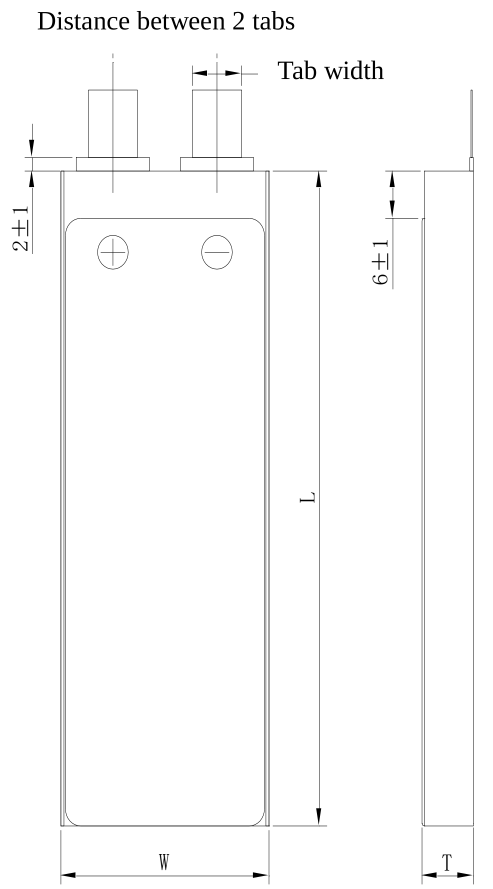
The specification is suitable for the performance of Lithium-Polymer (LIP) rechargeable battery produced by the SHENZHEN MELASTA BATTERY CO., LTD.

2. 型号 MODEL

SLPBA843126 6350mAh 15C 3.7V

3. 产品规格 SPECIFICATION

单颗电池规格 Specifications of single cell



◆标称容量 Typical Capacity①		6.35Ah
◆标称电压 Nominal Voltage		3.7V
◆ 充电条件 Charge Condition	最大电流 Max. Continuous charge Current	12.7A
	峰值充电 Peak charge current	25.4A(≤1sec)
	电压 Voltage	4.2V±0.03V
◆ 放电条件 Discharge Condition	Max Continuous Discharge Current	105A
	Peak Discharge Current	127A(≤2sec)
	Cut-off Voltage	3.0V
◆交流内阻 AC Impedance(mOHM)		<2.0
◆循环寿命【充电:1.0C,放电:15C】 Cycle Life【CHA:1.0C,DCH:15C】		>100cycles
◆使用温度 Operating Temp.	充电 Charge	0℃~45℃
	放电 Discharge	-20℃~60℃
◆ 电芯尺寸 Cell Dimensions	厚度 Thickness(T)	10.5±0.3mm
	宽度 Width(W)	42.7±0.5mm
	长度 Length(L)	127.5±0.5mm
	极耳间距 Distance between 2 tabs	21±1mm
◆ 极耳尺寸 Dimensions of Cell tabs	极耳材料 Tab Material	Pure Aluminum
	极耳宽度 Tab Width	15mm
	极耳厚度 Tab Thickness	0.2mm
	极耳长度 Tab Length	Max 30mm
◆重量 Weight(g)		131±2.0
①标称容量：0.5CmA,4.2V~3.0V@23℃±2℃ Typical Capacity:0.5CmA,4.2V~3.0V@23℃±2℃		

4.电芯性能检查及测试 BATTERY CELL PERFORMANCE CRITERIA

在进行下例各项测试前每颗电池应用 0.5C 放至 3.0V。如果没有特别规定，测试应在电池交付 1 个月内按以下各项条件进行：

Before proceed the following tests, the cells should be discharged at 0.2C to 3.0V cut off. Unless otherwise stated, tests should be done within one month of delivery under the following conditions:

环境温度 Ambient temperature: 20℃±5℃

相对湿度 Relative Humidity: 65±20%RH

注意标准充放电为 Note Standard Charge/Discharge Conditions:

充电 Charge: 以 0.5C 电流恒流充电至限制电压 4.2V 时,改为恒压充电,直到截止电流为 0.05C 时停止充电;The battery will be charged to 4.2V with 0.5C from constant current to constant voltage, when the current is 0.05C, stop to charge.;

放电 Discharge: 0.5C to 3.0V/cell

测试项目 Test	**单 位 Unit**	**规格 Specification**	**条 件 Condition**	**备 注 Remarks**
容量 Capacity	mAh	≥6350	标准充放电 Standard Charge / Discharge	允许循环 3 次 Up to 3 cycles are allowed
开路电压 Open Circuit Voltage (OCV)	V	≥4.15	标准充电后 1 个小时内 Within 1 hr after standard charge	单位颗 Unit cell
内阻 Internal Impedance (IR)	mΩ	≤2.0	充满电后用 1kHz 测试 Upon fully charge at 1kHz	*
高倍率放电 High Rate Discharge (15C)	min	≥3.6	标准充电/休息 5 分钟 用 15C 放电至 3.0V Standard Charge/rest 5min discharge at15C to 3.0V	允许循环 3 次 Up to 3 cycles are allowed
低温放电 Low Temperature Discharge	min	≥210	标准充电后贮藏在-20±2℃环境中 2 小时 然后用 0.2C 放电 Standard Charge, Storage:2hrs at-2 0±2℃ 0.2C discharge at 0±2℃	3.0V/cell Cut-off
自放电 Charge Reserve	min	≥90% （初始容量 First Capacity）	标准充满电后 20 度贮藏 30 天， 标准 0.5C 放电 Standard charge Storage at 20 degree: 30days Standard discharge (0.5C)	3.0V/cell Cut-off
寿命测试 Cycle Life Test	Cycle times	≥100	充电：1C 充电至 4.2V，放电，15C 放电至 3.0V，当放电容量降至初始容量的 80%时，所完成的循环次数定义为该电芯的循环寿命 Charge:1C to 4.2V ,Discharge: 15C to 3.0V, 80% or more of 1st cycle capacity at 15C discharge of Operation	Retention capacity 容量保持 ≥ 80% of initial capacity
短路测试 External Short Circuit	N/A	不着火不爆炸 No Fire and No Explosion	标准充电后，在 20℃±5 环境中用超过 0.75mm^2 金属丝将单颗电池短路至电池恢复到常温。 After standard charge, short-circuit the cell at 20℃±5℃ until the cell temperature returns to ambient temperature.(cross section of the wire or connector should be more than 0.75mm^2)	*

自由跌落测试 Free Falling(drop)	N/A	不着火不爆炸 No Fire and No Explosion	跌标准充电后，搁置 2 小时。从 50CM 高任意方向自由跌落 30MM 厚木板 3 次 Standard Charge,and then leave for 2hrs,check battery before / after drop Height: 50 cm Thickness of wooden board: 30mm Direction is not specified Test for 3 times	*

5. 贮存及其它事项 STORAGE AND OTHERS

5.1 环境温度 Ambient temperature: 20℃±5℃

相对湿度 Relative Humidity: 65±20%RH

5.2 请每隔 3 个月按下面方法激活电池一次:

Please activate the battery once every 3 months according to the following method:

0.2C 充电至 4.2V，休息 5 分钟，然后用 0.2C 放电至每颗电池 3.0V，休息 5 分钟，0.2C 充电 3.9V。

Charge at 0.2C to 4.2V, rest 5 min, then discharge with 0.2C to 3.0V/cell,rest 5 min, then charge at 0.2C to 3.9V.

6. 聚合物锂离子充电电芯操作指示及注意事项 HANDLING PRECAUTIONS AND GUIDLINE

声明一：

客户若需要将电芯用于超出文件规定以外的设备，或在文件规定以外的使用条件下使用电芯，应事先联系风云公司，因为需要进行特定的实验测试以核实电芯在该使用条件下的性能及安全性。

Note(1):

The customer is requested to contact MELASTA in advance, if and when the customer needs other applications or operating conditions than those described in this document. Additional experimentation may be required to verify performance and safety under such conditions.

声明二：

对于在超出文件规定以外的条件下使用电芯而造成的任何意外事故，风云公司概不负责

Note (2):

MELASTA will take no responsibility for any accident when the cell is used under other conditions than those described in this Document.

声明三：

如有必要，风云公司会以书面形式告之客户有关正确操作使用电芯的改进措施。
MELASTA will inform, in a written form, the customer of improvement(s) regarding proper use and handing of the cell, if it is deemed necessary.

6.1. 充电 Charging

6.1.1 充电电流 Charging current:

充电电流不得超过本标准书中规定的最大充电电流。使用高于推荐值电流充电将可能引起电芯的充放电性能、机械性能和安全性能的问题，并可能会导致发热或泄漏。

Charging current should be less than maximum charge current specified in the Product Specification. Charging with higher current than recommended value may cause damage to cell electrical, mechanical and safety performance and could lead to heat generation or leakage.

6.1.2. 充电电压 Charging voltage:

充电电压不得超过本标准书中规定的额定电压（4.2V/电芯）。4.25V 为充电电压最高极限，充电器的设计应满足此条件；电芯电压高于额定电压值时，将可能引起电芯的充放电性能、机械性能和安全性能的问题，可能会导致发热或泄漏。

Charging shall be done by voltage less than that specified in the Product Specification (4.2V/cell).

Charging beyond 4.25V, which is the absolute maximum voltage, must be strictly prohibited. The charger shall be designed to comply with this condition. It is very dangerous that charging with higher voltage than maximum voltage may cause damage to the cell electrical, mechanical safety performance and could lead to heat generation or leakage.

6.1.3. 充电温度 Charging temperature:

电芯必须在 0℃~45℃的环境温度范围内进行充电

The cell shall be charged within 0℃~45℃ range in the Product Specification.

6.1.4. 禁止反向充电 Prohibition of reverse charging:

正确连接电池的正负极，严禁反向充电。若电池正负极接反，将无法对电芯进行充电。同时，反向充电会降低电芯的充放电性能、安全性，并会导致发热、泄漏。

Reverse charging is prohibited. The cell shall be connected correctly. The polarity has to be confirmed before wiring, In case of the cell is connected improperly, the cell cannot be charged. Simultaneously, the reverse charging may cause damaging to the cell which may lead to degradation of cell performance and damage the cell safety, and could cause heat generation or leakage.

6.2．放电 Discharging

6.2.1. 放电电流 Discharging current

放电电流不得超过本标准书规定的最大放电电流，大电流放电会导致电芯容量剧减并导致过热。

The cell shall be discharged at less than the maximum discharge current specified in the Product Specification. High discharging current may reduce the discharging capacity significantly or cause over-heat.

6.2.2. 放电温度 Discharging temperature

电芯必须在-20℃~60℃的环境温度范围内进行放电。

The cell shall be discharged within -20℃~60℃ range specified in the Product Specification.

6.2.3. 过放电 Over-discharging:

需要注意的是，在电芯长期未使用期间，它可能会用其它自放电特性而处于某种过放电状态。为防止放电的发生，电芯应定期充电，将其电压维持在 3.6V 至 3.9V 之间。

过放电会导致电芯性能、电池功能的丧失。

充电器应有装置来防止电池放电至低于本标准书规定的截止电压。此外，充电器还应有装置以防止重复充电，步骤如下：

电池在快速充电之前，应先以一小电流（0.01C）预充电 15~30 分钟，以使（每个）电芯的电压达到 3V 以上，再进行快速充电。可用一记时器来实现该预充电步骤。如果在预充电规定时间内，（个别）电芯的电压仍未升到 3.0V 以上，充电器应能够停止下一步快速充电，并显示该电芯/电池正处于非正常状态。

It should be noted that the cell would be at over-discharged state by its self-discharge characteristics in case the cell is not used for long time. In order to prevent over-discharging, the cell shall be charged periodically to maintain between 3.6V and 3.9V.

Over-discharging may causes loss of cell performance, characteristics, or battery functions.

The charger shall be equipped with a device to prevent further discharging exceeding a cut-off voyage specified in the Product Specification. Also the charger shall be equipped with a device to control the recharging procedures as follows:

The cell battery pack shall start with a low current (0.01C) for 15-30 minutes, i.e.-charging, before rapid charging starts. The rapid charging shall be started after the (individual) cell voltage has been reached above 3V within 15-30 minutes that can be determined with the use of an appropriate timer for pre-charging. In case the (individual) cell voltage does not rise to 3V within the pre-charging time, then the charger shall have functions to stop further charging and display the cell/pack is at abnormal state.

6.3. 贮存 Storage:

电芯储存温度必须在-10℃~45℃的范围内,长期存储电池（超过 3 个月）须置于温度为 23±5℃、湿度为 65±20%RH 的环境中,贮存电压为 3.6V~3.9V

The cell shall be storied within -10℃~45℃ range environmental condition, If the cell has to be storied for a long time (Over 3 months),the environmental condition should be; Temperature: 23±5℃

Humidity: 65±20%RH, The voltage for a long time storage shall be 3.6V~3.9V range.

6.4. 电芯操作注意事项 Handling of Cells:

由于电芯属于软包装，为保证电芯的性能不受损害，必须小心对电芯进行操作。

Since the battery is packed in soft package, to ensure its better performance, it’s very important to carefully handle the battery;

6.4.1. 铝箔包装材料易被尖锐部件损伤，诸如镍片，尖针。

The soft aluminum packing foil is very easily damaged by sharp edge parts such as Ni-tabs, pins and needles.

·禁止用尖锐部件碰撞电池;

Don’t strike battery with any sharp edge parts;

·取放电芯时，请修短指甲或戴上手套;

Trim your nail or wear glove before taking battery；

·应清洁工作环境，避免有尖锐物体存在;

Clean work table to make sure no any sharp particle;

6.4.2. 禁止弯折顶封边;

Don’t bend or fold sealing edge;

6.4.3. 禁止打开或破坏折边;

Don’t open or deform folding edge;

6.4.4. 禁止弯折极片;

Don’t bend tab ;

6.4.5. 禁止坠落、冲击、弯折电芯;

Don’t Fall, hit, bend battery body;

6.4.6. 任何时候禁止短路电芯，它会导致电芯严重损坏;

Short circuit terminals of battery is strictly prohibited, it may damage battery;

6.5. 电池外壳设计 Notice Designing Battery Pack;

·电池外壳应有足够的机械强度以保证其内部电芯免受机械撞击;

Battery pack should have sufficient strength and battery should be protected from mechanical shock;

·外壳内安装电芯的部位不应有锋利的边角;

No Sharp edge components should be inside the pack containing the battery;

6.6. 电芯与外壳组装注意事项 Notice for Assembling Battery Pack

6.6.1.电芯的连接 Tab connection

建议使用超声波焊接或点焊技术来连接电芯与保护电路模块或其它部分。如使用手工锡焊，须注意以下事项，以

保证电芯的功能：

Ultrasonic welding or spot welding is recommended to connect battery with PCM or other parts.If apply manual solder method to connect tab with PCM, below notice is very important to ensure battery performance.

a) 烙铁的温度可控能防静电；

The solder iron should be temperature controlled and ESD safe

b) 烙铁温度不能超过 350℃

Soldering temperature should not exceed 350℃

c) 锡焊时间不能超过 3 秒；

Soldering time should not be longer than 3s

d) 锡焊次数不能超过 5 次；

Soldering time should not exceed 5 times Keep battery tab cold down before next time soldering

e) 必须在极片冷却后再进行二次焊接；禁止直接加热电芯，高于 100℃会导致电芯损坏。

Directly heat cell body is strictly prohibited, Battery may be damaged by heat above approx.100℃

6.6.2. 电芯的安装 Cell fixing

·应将电芯的宽面安装在外壳内；

The battery should be fixed to the battery pack by its large surface area

·电芯不得在壳内活动。

No cell movement in the battery pack should be allowed

7.其它事项 OTHERS

7.1. 防止电池内短路 Prevention of short circuit within a battery pack

使用足够的绝缘材料对线路进行保护

Enough insulation layers between wiring and the cells shall be used to maintain extra safety protection.

7.2. 严禁拆卸电芯 Prohibition of disassembly

7.2.1. 拆卸电芯可能会导致内部短路，进而引起鼓气、着火及其它问题

The disassembling may generate internal short circuit in the cell, which may cause gassing, firing, or other problems.

7.2.2. 聚合物锂电池理论上不存在流动的电解液，但万一有电解液泄漏而接触到皮肤、眼睛或身体其它部位，应立即用清水冲洗电解液并就医

LIP battery should not have liquid from electrolyte flowing, but in case the electrolyte come into contact with the skin, or eyes, physicians shall flush the electrolyte immediately with fresh water and medical advice is to be sought.

7.3. 在任何情况下，不得燃烧电芯或将电芯投入火中，否则会引起电芯燃烧，这是非常危险的，应绝对禁止

Never incinerate nor dispose the cells in fire. These may cause firing of the cells, which is very dangerous and is prohibited.

7.4 不得将电芯浸泡液体，如淡水、海水、饮料(果汁、咖啡)等

The cells shall never be soaked with liquids such as water, seawater drinks such as soft drinks, juices coffee or others.

7.5 更换电芯应由电芯供应商或设备供应商完成，用户不得自行更换

The battery replacement shall be done only by either cells supplier or device supplier and never be done by the user.

7.6 禁止使用已损坏的电芯 Prohibition of use of damaged cells

电芯在运输过程中可能因撞击等原因而损坏，若发现电芯有任何异常特征，如电芯塑料封边损坏，外壳破损，闻到电解液气体，电解液泄漏等，该电芯不得使用。

有电解液泄漏或散发电解液气味的电池应远离火源以避免着火。

The cells might be damaged during shipping by shock. If any abnormal features of the cells are found such as damages in a plastic envelop of the cell, deformation of the cell package, smelling of electrolyte, electrolyte leakage and others, the cells shall never be used any more.

The cells with a smell of the electrolyte or a leakage shall be placed away from fire to avoid firing.

Report No.：I02103022016D~1

MSDS Report

Sample Name & Model	Li-ion Polymer Cell (SLPBA843126)
Applicant	MELASTA CORPORATION LIMITED
Address	RM1006, 2ND BLDG EAST, SEG TECHNOLOGY PARK, HUAQIANG RD., FUTIAN SHENZHEN, CHINA

No.: I02103022016D
Code: o30yyl36rh

Material Safety Data Sheet

According to ISO11014:2009 & GB16483-2008

Section 1 - Chemical Product and Company Identification

Chemical product identification

Product Name: Li-ion Polymer Cell

Battery Type: SLPBA843126

Company identification

Manufacturer: SHENZHEN MELASTA BATTERY CO., LTD

Address: RM1006, 2ND BLDG EAST, SEG TECHNOLOGY PARK, HUAQIANG RD., FUTIAN SHENZHEN, CHINA

Tel: 0755-83953865

Fax: 0755-33096219

Post code: 518028

Further Information obtainable from

Emergency telephone: 0755-83953865

E-mail: info@melasta.com

Section 2 - Hazards Identification

No harm at the normal use. If contact the electrolyte in the battery, reference as follows:

Classification of the substance or mixture

Classification according to GHS

Acute toxicity, Oral (Category 4)

Acute toxicity, Dermal (Category 3)

Skin, irritate (Category 1B)

Eyes, irritate (Category 1)

Label elements

Labelling according to Regulation (EC) No 1272/2008[CLP]

Hazard pictogram(s):

Signal word: Danger

Hazard statement(s): H311: Toxic in contact with skin.
H314: Causes severe skin burns and eye damage

H302: Harmful if swallowed.

Precautionary statement(s):

Prevention: P280: Wear protective gloves/protective clothing/eye protection / face protection.

Response: P312: Call a POISON CENTER or doctor/ physician if you feel unwell.

P302 + P350 - IF ON SKIN: Gently wash with plenty of soap and water

P301 + P330 + P331 - IF SWALLOWED: rinse mouth. Do NOT induce vomiting

P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do.

Disposal: P501: Dispose of contents/container in accordance with local/national regulations

Other hazards No information available.

Section 3 - Composition, Information on Ingredients

Chemical characterization: Mixture

Chemical Composition	CAS No.	EC#	Weight (%)
Cobalt Lithium Dioxide	12190-79-3	235-362-0	20~35
Aluminium	7429-90-5	231-072-3	10~15
Lithium	7439-93-2	231-102-5	10~15
Lithium Hexafluorophosphate	21324-40-3	244-334-7	3~7
Carbon Black	1333-86-4	231-153-3	2~5
Nickel	7440-02-0	231-853-9	1~2
Polyvinylidene Fluoride	24937-79-9	200-867-7	3~6
Graphite	7782-42-5	231-955-3	10~16
Copper	7440-50-8	231-159-6	15~20

Section 4 - First Aid Measures

Description of first aid measures

General information No special measures required.

After eye contact

Flush eyes with plenty of water for several minutes while holding eyelids open. Get medical attention if irritation persists.

After skin contact

Remove contaminated clothing and shoes. Immediately wash with water and soap and rinse thoroughly. Wash clothing and shoes before reuse. If irritation occurs, get medical attention.

After inhalation

Remove victim to fresh area. Administer artificial respiration if breathing is difficult. Seek medical attention.

After swallowing

Do not induce vomiting. Get medical attention.

Information for doctor：

Indication of any immediate medical attention and special treatment needed

No further relevant information available.

Section 5 - Fire Fighting Measures

Flammability: Not available.

Extinguishing media

Suitable extinguishing agents

Use extinguishing agent suitable for local conditions and the surrounding environment . Such as dry powder , CO_2.

Special hazards arising from the substance or mixture

Cell may burst and release hazardous decomposition products when exposed to a fire situation. Lithium ion Cells contain flammable electrolyte that may vent, ignite and produce sparks when subjected to high temperature(>150℃(302℉)), when damaged or abused (e.g. mechanical damage or electrical overcharging); may burn rapidly with flare-burning effect; may ignite other cells in clothes proximity.

Advice for firefighters

Protective equipment: Wear self-contained respirator. Wear fully protective impervious suit.

Section 6 - Accidental Release Measures

Personal precautions, protective equipment and emergency procedures

Wear protective equipment. Keep unprotected persons away. Ensure adequate ventilation

Environmental precautions

Do not allow material to be released to the environment without proper governmental permits.

Steps to be taken in case material is spilled or released

Remove ignition sources, evacuate area. Sweep up using a method that does not generate dust. Collect as much of the spilled material as possible, placed the spilled material into a suitable disposal container. Keep spilled material out of sewers, ditches and bodies of water.

Waste disposal method

All waste must refer to the United Nations, the national and local regulations for disposal.

Reference to other sections

See Section 7 for information on safe handling.

See Section 8 for information on personal protection equipment.

See Section 13 for disposal information.

Section 7 - Handling and Storage

Handling

Precautions for safe handling

Consumption of food and beverage should be avoided in work areas.

Wash hands with soap and water before eating, drinking.

Ground containers when transferring liquid to prevent static accumulation and discharge.

Information about fire and explosion protection

Cells may explode or cause burns, if disassembled, crushed or exposed to fire or high temperatures. Do not short or install with incorrect polarity.

Conditions for safe storage, including any incompatibilities

Requirements to be met by storerooms and receptacles

Store in a cool, dry, well-ventilated place.

Information about storage in one common storage facility

Keep away from heat, avoiding the long time of sunlight.

Further information about storage conditions

Keep container tightly sealed.

Specific and use

No further relevant information available.

Section 8 - Exposure Controls, Personal Protection

Control parameters

Ingredients with limit values that require monitoring at the workplace:	
12190-79-3 Lithium Cobalt Oxide	
TLV (USA)	0.02mg/m^3.
MAK(Germany)	0.1mg/m^3.

Exposure controls

Personal protective equipment

General protective and hygienic measures

The usual precautionary measures for handling chemicals should be followed.

Keep away from foodstuffs, beverages and feed.

Remove all soiled and contaminated clothing immediately.

Wash hands before breaks and at the end of work.

Respiratory Protection

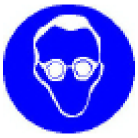
Use suitable respirator when high concentrations are present.

Personal Protection

Protection of hands

Protective gloves

Eye protection



Tightly sealed goggles

Section 9 - Physical and Chemical Properties

Information on basic physical and chemical properties

General information

Appearance:	White.
Form:	Prismatic.
Odour:	Odorless.

pH:	Not available.
Change in condition	
Melting point:	Not available.
Boiling point:	Not available.
Freezing point	Not available.
Flash point:	Not available.
Flammability:	Not available.
Ignition temperature:	Not available.
Decomposition temperature:	Not available.
Self-igniting:	Not available.
Danger of explosion:	Not available.
Explosion limits	
Lower:	Not available.
Upper:	Not available.
Oxidizing properties:	Not available.
Vapour pressure:	Not available.
Density:	Not available.
Relative density:	Not available.
Vapour density:	Not available.
Evaporation rate:	Not available.
Solubility in/Miscibility with water:	Not available.
n-octanol/water partition coefficient:	Not available.
Viscosity	Not available.
Dynamic:	Not available.
Kinematic:	Not available.
Other information:	
Voltage	3.7V
Electric capacity	6350mAh

Section 10 - Stability and Reactivity

Reactivity: Data not available.

Chemical stability: Stable**.**

Possibility of hazardous reactions: Data not available.

Conditions to Avoid

Flames, sparks, and other sources of ignition, incompatible materials.

Incompatibilities

Oxidizing agents, acid, base.

Hazardous Combustible Products

Carbon monoxide, carbon dioxide, lithium oxide fumes.

Hazardous Polymerization

N/A.

Section 11 - Toxicological Information

Information on toxicological effects

Acute toxicity

LD/LC50 Values relevant for classification:
Not available.

Primary irritant effect

No further relevant information available.

Sensitization:

No further relevant information available.

Additional toxicological information:

Toxicological, metabolism and distribution:

No further relevant information available.

Acute effects (acute toxicity, irritation and corrosivity):

No further relevant information available.

CMR effects (carcinogenity, mutagenicity and toxicity for reproduction):

No further relevant information available.

Section 12 - Ecological Information

Toxicity

Aquatic toxicity: No further relevant information available.

Persistence and degradability: No further relevant information available.

Behaviour in environmental systems

Bioaccumulative potential: No further relevant information available.

Mobility in soil: No further relevant information available.

Ecological effects

Additional ecological information

General notes:

Do not allow material to be released to the environment without proper governmental permits.

Other adverse effects: No further relevant information available.

Section 13 - Disposal Considerations

Waste treatment methods

Recommendation:

Consult state, local or national regulations to ensure proper disposal.

Uncleaned packaging

Recommendation: Disposal must be made according to official regulations.

Section 14 - Transport Information

UN Number	
IATA	UN3480
IMDG	None
Model Regulation	None
UN Proper shipping name	
IATA	Lithium Ion Cells
IMDG	None
Model Regulation	None
Transport hazard class(es)	
IATA	9
IMDG	None
Model Regulation	None
Packing group	
IATA	None
IMDG	None
Model Regulation	None
Environmental hazards	
Marine pollutant:	No
Special precautions for user	Not applicable.

Transport information: The Li-ion Polymer Cell (SLPBA843126) has passed the test UN38.3, according to the report ID: H01233042321D and H01233042321D~1.
According to the Packing Instruction 965 section IA of IATA DGR 55th Edition for transportation.
According to the special provision 188 of IMDG (36-12) or the <<Recommendations On The Transport Of Dangerous Goods-Model Regulations>> (18th). The Watt-hour exceeds the standard, so it belongs to dangerous goods.

More information concerning shipping, testing, marking and packaging can be obtained from Label master at http://www.labelmaster.com.
Separate Lithium-ion cells when shipping to prevent short-circuiting. They should be packed in strong packaging for support during transport. Take in a cargo of them without falling, dropping, and breakage. Prevent collapse of cargo piles and wet by rain.

Transport Fashion: By air, by sea, by railway, by road.

Section 15 - Regulatory Information

This Material Safety Data Sheet complies with the requirements of Regulation (EC) No. 1907/2006.

Safety, health and environmental regulations/legislation specific for the substance or mixture

Composition	CAS#	TSCA	EC#	EINECS
Cobalt Lithium Dioxide	12190-79-3	Listed	235-362-0	Listed
Aluminium	7429-90-5	Listed	231-072-3	Listed
Lithium	7439-93-2	Listed	231-102-5	Listed
Lithium Hexafluorophosphate	21324-40-3	Listed	244-334-7	Listed
Carbon Black	1333-86-4	Listed	231-153-3	Listed
Nickel	7440-02-0	Listed	231-853-9	Listed
Polyvinylidene Fluoride	24937-79-9	Listed	200-867-7	Listed
Graphite	7782-42-5	Listed	231-955-3	Listed
Copper	7440-50-8	Listed	231-159-6	Listed

Section 16 - Additional Information

Abbreviations and acronyms

CLP:	EU regulation (EC) No 1272/2008 on classification, labelling and packaging of chemical substances and mixtures.
CAS:	Chemical Abstracts Service (Division of the American Chemical Society).
ACGIH:	American Conference of Governmental Industrial Hygienists
TLV:	Threshold Limit Value
IATA:	International Air Transport Association
IMDG:	International Maritime Dangerous Goods
LC50:	lethal concentration, 50 percent kill
LD50:	lethal dose, 50 percent kill
TWA	Time Weighted Average
TSCA	United States Toxic Substances Control Act Section 8(b) Inventory
EINECS	European Inventory of Existing Commercial Chemical Substances

Declare to reader

The above information is based on the data of which we are aware and is believed to be correct as of the data hereof. Since this information may be applied under conditions beyond our control and with which may be unfamiliar and since data made available subsequent to the data hereof may suggest modifications of the information, we do not assume any responsibility for the results of its use. This information is furnished upon condition that the person receiving it shall make his own determination of the suitability of the material for his particular purpose.

Prepared by: Zuojingjing Checked by: zhengpeng Approved by: Liyou

MSDS Creation Date: February 13, 2014

End of report

Engineering tomorrow's energy

FreeSafe FS02-M/S

Battery Management System

Features

- **Manages from 2 to 12 battery cells per device (cell voltage up to 5V)**
- **Stackable architecture up to 600V battery pack**
- **Supports multiple battery chemistries and supercapacitors**
- **Redundant analog and digital protections**
- **Below 400µA power saving mode supply current**
- **Embedded smart power supply**
- **State of charge (SoC) and state of health (SoH) estimations based on advanced algorithms**
- **Stores up to 10 years of data history**
- **CAN-bus interface to adjacent devices**
- **Wi-Fi 802.11 monitoring capabilities (M-Series)**
- **Operates with FreeSB (Freemens Smart Breaker) battery circuit breaker**
- **Fully configurable with proprietary software "FreeLab" (Freemens Battery Management Software)**
- Embedded passive cell balancing up to 1W per cell
- Ability to drive external passive or active balancing devices
- Onboard temperature sensor and thermistor inputs
- Safe with random connection of cells
- Built-in self - tests
- High EMI immunity

Applications

Mobility and stationary electrical storages such as :

- Electric and hybrid electric vehicles
- High power portable equipment
- Backup battery systems
- Electric bicycles, motorcycles, scooters

Description

FreeSafe is a 2nd generation battery management system which provides high standard of security, optimal battery life-span and precise SOC (state of charge) and SOH (state of health) estimations.

FreeSafe provides an easy to use solution to manage large packs of Li-Ion batteries. FreeSafe boards are easy and safe to connect or disconnect from the batteries. Multiple FreeSafe boards can be used together to manage any number of cells in series for up to 600V battery stack.

FreeSafe protects the batteries from over-voltage and under-voltage using redundant analog and digital safety features

To ensure that the battery has been used properly, FreeSafe records all activities in an up to 10 years data history file. Communication between FreeSafe and others devices can be accomplished through CAN bus and 802.11 physical layers. FreeSafe includes a comprehensive and universal CANopen application layer and Wi-Fi protocol application libraries.

FreeSafe built-in high efficiency smart DC converter enables self-sufficient operations without the need of external power supply. It also spares energy consumption by adapting to the battery conditions of use, down to 15mW in a fully loaded 12 cells battery stack configuration.

While FreeSafe devices are "plug and play" for LiFePO4 batteries, specific applications and other chemistries require custom settings. FreeSafe parameters can be easily adapted with a step-by-step configuration manager provided in our PC software FreeLab.

FreeSafe devices are compliant with FreeData technology allowing a remote data management. New embedded software release will enable remote firmware upgrade, calibration and predictive maintenance.

Typical Application

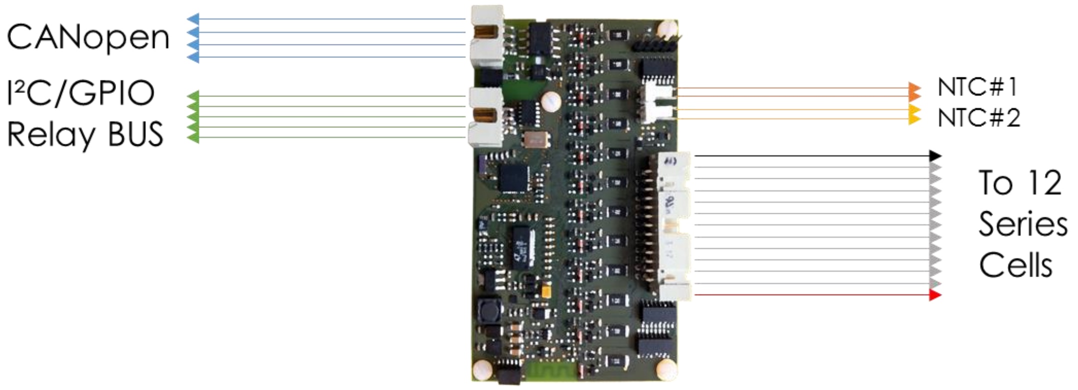


Figure 1: Battery management solution with 3 stacked FreeSafe boards and a FreeSB–PR relay driver

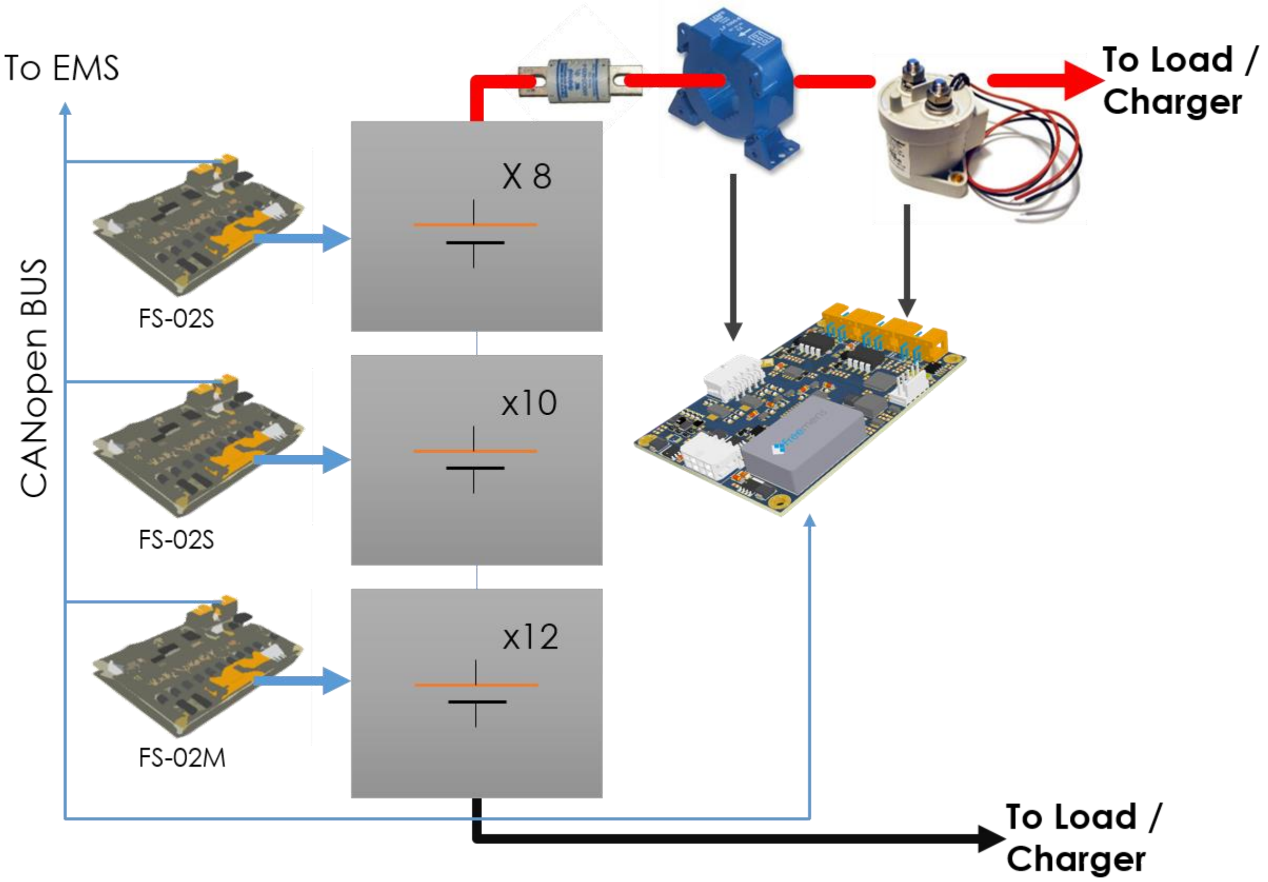


Figure 2 : Typical application, light electric vehicle with 100V LFP battery

Absolute Maximum Ratings

Parameter	Symbol	Value	Units
Maximum Cells Voltage	V_{celln}	–0.3V to Min (8 • n, 75)	V
Maximum Balancing Control Voltage	B_{Cn}	–0.3V to Min (8 • n, 75)	V
Maximum Current Measurement Input Voltage	I_{mes}	3.3	V
Operating Temperature Range	T_{range}	-40 to 105	°C
Maximum CAN-bus supply current	I_{can}	250	mA
Maximum Voltage on Imes input	I_{mes}	3.6	V
Maximum Balancing Power Dissipation per Cell	P_{bal}	1.5	W
Maximum Total Power Dissipation	P_{balmax}	5	W

Electrical Characteristics

The following specifications apply over the full operating temperature range

Voltage Monitoring

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Battery Stack Voltage	V_{bat}		10		55	V
Measurement Resolution	V_{lsb}			1.5		mV/Bit
ADC Offset			-0.5		0.5	mV
ADC Gain Error			-0.22		0.22	%
Total Measurement Error	V_{err}	V_{cell} <5V	-9	+-2.5	9	mV
Cell Voltage Range	V_{cell}		-0.3		5	V
Supply Current	I_s	Sleep Mode (12 cells)	7	10	15	mW
		Long Cycle (12 cells)	20	25	35	mW
		Short Cycle (12 cells)	0.9	1	1.2	W

Cell Balancing

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Internal Balancing Resistor	R_{bal}	T_{amb} = 25°C		10		Ω
Maximum Internal Balancing current	I_{bal}	T_{amb} = 25°C ; V_{cell} =3.6V	340	360	385	mA
External Balancing Control Voltage	$SV_{bal}n$	Output High Level without common mode		$V_{cell}n$		V
		Output Low Level without common mode		0		V
External Balancing Control Current	$SI_{bal}n$	Sourced Current T_{amb} = 25°C ; V_{cell} =3.6V		1.2		mA
		Sinked Current T_{amb} = 25°C ; V_{cell} =3.6V		1.2		mA

CANBUS

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Supply Voltage (Bus side)	V_{bus}	Power on the bus is provided by the first BMS of the string	3		5.5	V
Can Bus Output Voltage (dominant)	CAN_H	Rl=60 Ohm	2.9	3.5	4.5	V
	CAN_L	Rl=60 Ohm	0.8	1.2	1.5	V
Can Bus Output Voltage (recessive)		Rl=60 Ohm	2	2.3	3	V
Can Bus Output Current	I_{can}	Rl=60 Ohm				
Can Bus Rate of Operation	F_{can}			250		Kbps

External Coulomb Counting

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Analog to digital converter resolution	AD_{res}	A_{Vdd}=3.3V A_{vss}=0V		10		bits
ADC Integral Nonlinearity	AD_{In}	A_{Vdd}=3.3V A_{vss}=0V	-1.5		+1.5	LSb
ADC Differential Nonlinearity	AD_{Dn}	A_{Vdd}=3.3V A_{vss}=0V	>-1		<1	LSb

ADC Gain Error	AD_{Ge}	A_{Vdd}=3.3V A_{vss}=0V		3	6	LSb
ADC Offset Error	AD_{Oe}	A_{Vdd}=3.3V A_{vss}=0V		2	5	LSb
ADC Input Voltage	AD_{Vin}	A_{Vdd}=3.3V A_{vss}=0V	-0.3		3.6	V
Recommended Impedance of Analog Voltage Source	I_{can}	R_{l}=60 Ohm		200		Ohm
Can Bus Rate of Operation	F_{can}			1		Mbps

Mechanical Characteristics (millimeters)

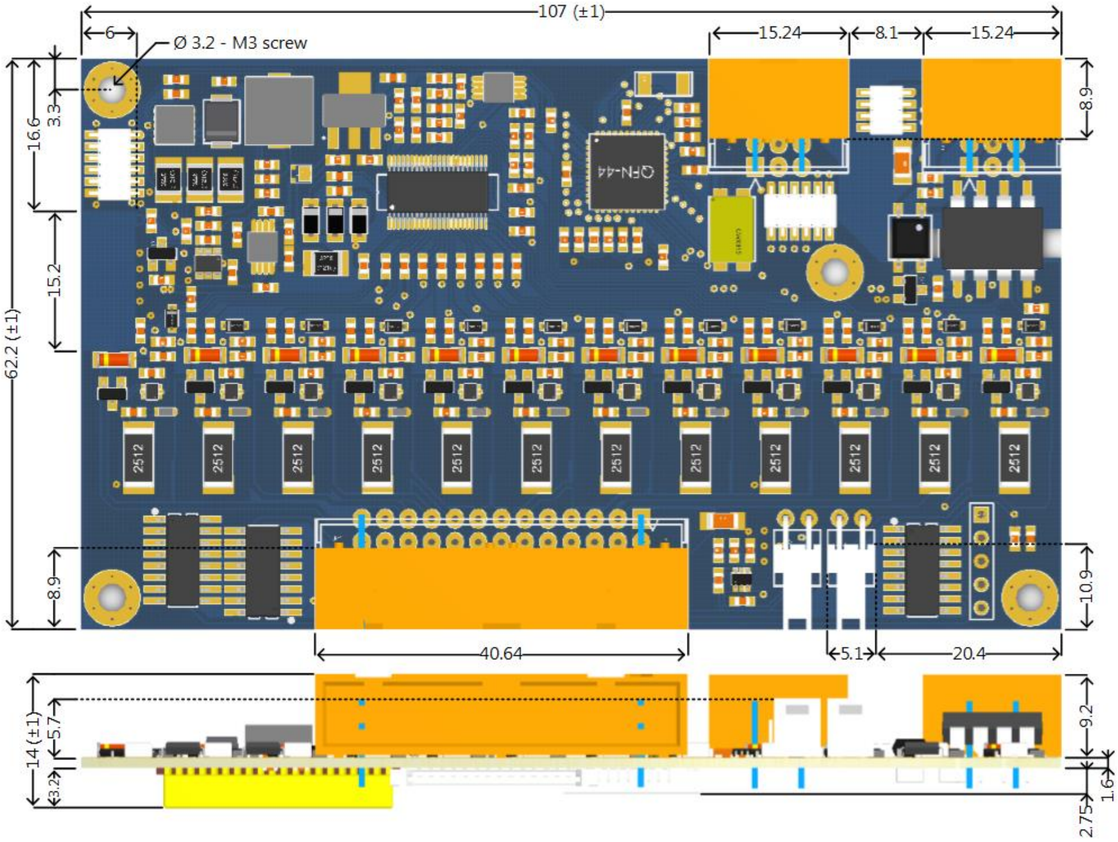


Figure 3: Mechanical views (side, top)

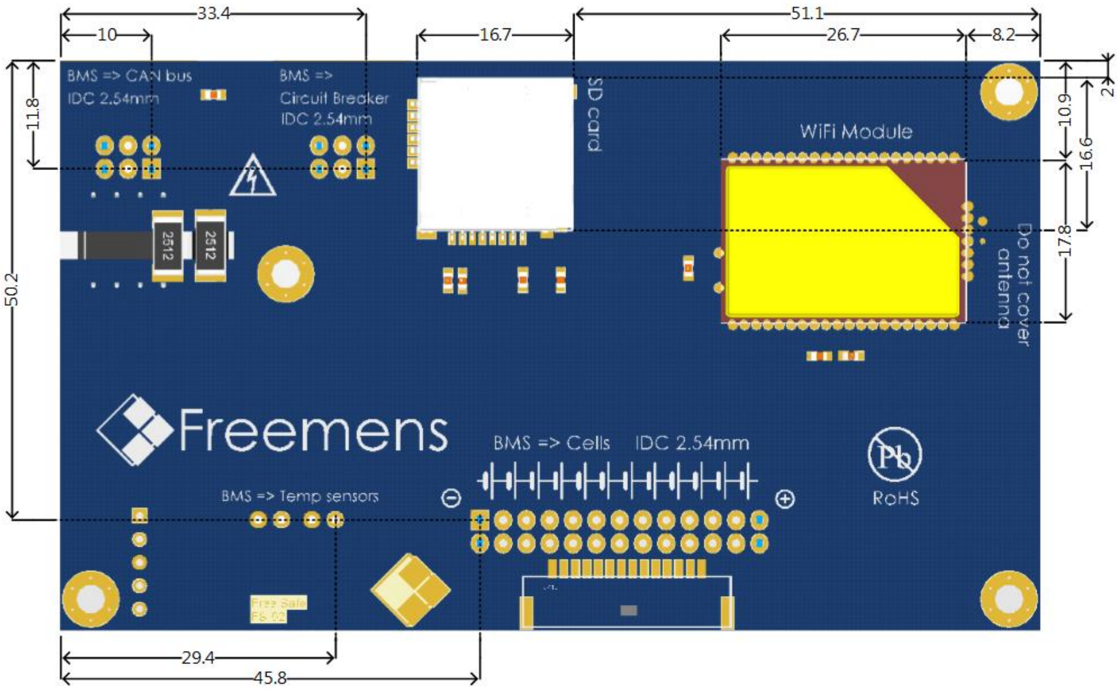


Figure 4: Mechanical view bottom side

General description

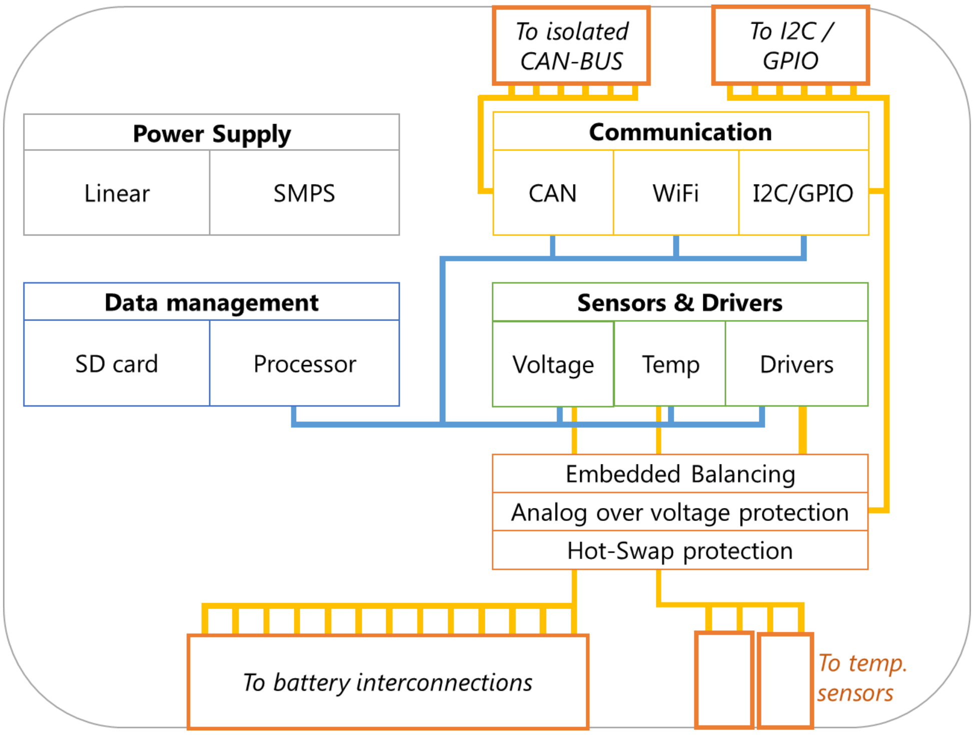


Figure 5 : Functional diagram

The following functional blocs are presented

- Data Management
- Sensors & Drivers
- Embedded Balancing
- Redundant Analog Protection
- Power Supply
- Communication

Data management

A power full 16bits DSC (Digital Signal Controller) is used for the data processing. The DSC is the core of the system where most of the algorithms are implemented. It communicates and controls the other function of the BMS.

- Regulation of power consumption and power supply strategy
- Measurements acquisition from all the sensors
- Algorithms computing
- Wired system level communications
- Wireless communications
- Balancing control

FreeSafe includes mass data storage capabilities to keep the available information related to the battery and the BMS operations. Based on an embedded micro SD card of 4Gbits (default configuration), FreeSafe is able to record up to 10 years of data. Remote access is possible for battery fleet control & monitoring thought proprietary FreeLab application and FreeData database. Data can also be retrieved and decrypted directly from the SD card if wireless connectivity is an issue.

Sensors & Drivers

The Sensors & Drivers block provides precise and reliable measurements related to the operation conditions. As a result, FreeSafe is able to sense from 2 up to 12 cell voltages and up to 3 temperatures per device. Current measurement is usually retrieved numerically through a FreeSB device, but can be additionally sampled by an analog input located in the GPIO port. In addition, the sensors measure the self-power consumption and the board level temperature.

Embedded Balancing

FreeSafe includes a low power Embedded Balancing Unit able to dissipate up to 1 W per cell at 25°C ambient temperature. The balancing is made by connecting power resistors to over-charged battery cell. The balancing control is obtained at the processor level based on the individual cell SOC estimation rather than the voltage comparison. With each resistor able to dissipate up to 1W, the thermal regulation at the board level is provided to reach an optimal balancing capacity and to ensure the device integrity. The maximum balancing current of 400mA requires the use of adapted wiring between FreeSafe devices and the battery stack.

Redundant Analog Protection

The over-voltage detection is achieved both at digital and analog level. If the sensors or processors fail to detect an overvoltage situation, a hard wired analog detection system will trigger a 3.3V TTL level on the GPIO port.

Power supply unit

FreeSafe integrates its own Power Supply Unit DSU as a default configuration making the board fully standalone once connected to the battery. In addition, it performs optimal supply thanks to an intelligent control and extensive use of switch mode power supplies with efficiencies above 85%. This feature makes FreeSafe a low power BMS device capable of ultra-low power operation. On board supplies are 12V DC, 5V DC and 3.3V DC. To operate, the DSU must be connected to a battery with at least 9V output DC voltage and up to 55V.

Communication

FreeSafe includes several hardware and corresponding communication protocols in order to facilitate and open wide the communication between the BMS and the other control or power interfaces of the system. In particular, FreeSafe integrates an Isolated CAN Bus, which allows to stack BMS devices at no risk for the hardware but also for the data. In addition and for local and wired communication, FreeSafe integrates I2C and SPI protocols. Finally, for remote or wireless access to the battery BMS, FreeSafe includes a Wi-Fi hardware and software interface. Thanks to these extensive communications FreeSafe can receive control orders, updated programs and parameters. FreeSafe can communicate through wired isolated or non-isolated communication interfaces to drive and sense FreeSafe units or associated FreeSB smart breaker and almost any device implementing CAN, I2C, SPI or Wi-Fi.

Pin Configuration and connectors

Two connector configurations are available.

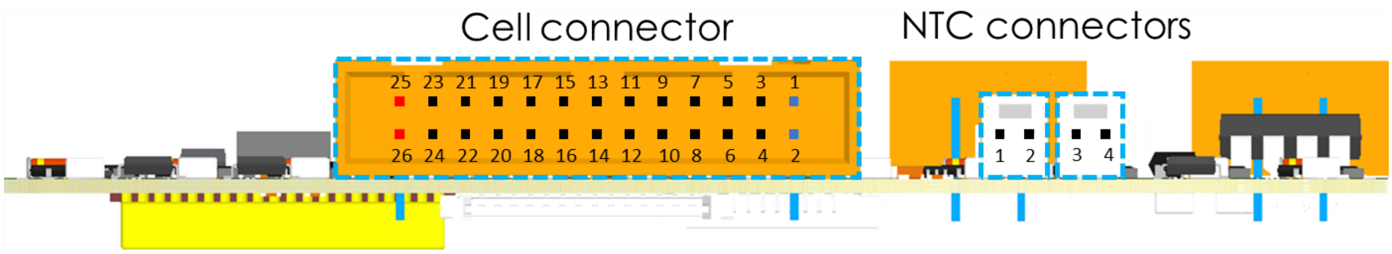


Figure 6: FreeSafe FS02-M front side

Figure 7: FreeSafe FS02-S back-side

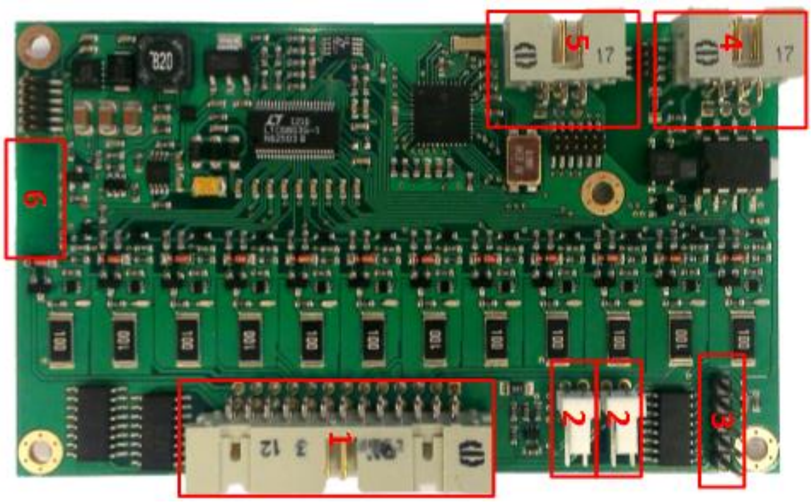


Figure 8: FreeSafe top side

Table 1: FreeSafe pins & connectors

Num.	Connector	Pin	Description
1	**Cell connector**	26	Connect to battery cell terminals
2	**NTC connector # 1**	2	Connect to 10k NTC resistor
2 bis	**NTC connector # 2**	2	Connect to 10k NTC resistor
3	**CAN-bus connector**	6	Connect to CAN-bus
4	**I2C/GPIO connector**	6	Connect to I2C/Reset/Wake-up
5	**Programming connector**	5	-
6	**Wi-Fi antenna**	1	Onboard printed Wi-Fi antenna. Do not cover.

Table 2: Recommended complementary connectors for onboard connector version

Onboard connector			Recommended complementary connector	
N°	Manufacturer	Part number	Manufacturer	Part number
1	Harting	09 18 526 7323	Harting	09 18 526 7813
			3M (or AMPHENOL SPECTRA-STRIP)	3365/06-100 (or 191-2801-126)
2	TE CONNECTIVITY	640457-2	TE CONNECTIVITY	3-640441-2
			AVX	ND06P00103K
3 & 4	Harting	09 18 506 7323	Harting	ND06P00103K
			3M	09 18 506 7803
5	Harwin Inc	M20-9990546	Molex	22-01-2057
			Molex	08-50-0114

Cell connector

Figure 9: Cell connector front side

See Figure 14: Incorrect & correct wiring to cell stack for additional connection information.

Table 3: Cell connector pins description

Pins	Description
1 – 2	Cell 1 -
3 – 4	Cell 1 + / Cell 2 -
5 – 6	Cell 2 + / Cell 3 -
7 – 8	Cell 3 + / Cell 4 -
9 – 10	Cell 4 + / Cell 5 -
11 – 12	Cell 5 + / Cell 6 -
13 – 14	Cell 6 + / Cell 7 -
15 – 16	Cell 7 + / Cell 8 -
17 – 18	Cell 8 + / Cell 9 -
19 – 20	Cell 9 + / Cell 10 -
21 – 22	Cell 10 + / Cell 11 -
23 – 24	Cell 11 + / Cell 12 -
25 – 26	Cell 12 +

NTC connectors

NTC resistor terminals can be connected indiscriminately to connector pins.

CAN-connector

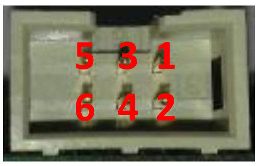


Figure 10: CAN-bus connector front side

Table 4: CAN-bus connector pins description

Pins	Description
1 – 2	5V
3	CAN L
4	CAN H
5 – 6	Cell 1 Negative terminal

I2C/GPIO connector

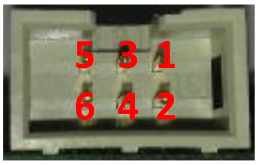


Figure 11: I2C/GPIO connector front side

Table 5: I2C/GPIO connector pins description

Pins	Description
1	Analog OverVoltage signal
2	SDA
3	Digital I/O
4	SCL
5	Analog / digital I/I
6	NC

Programming connector

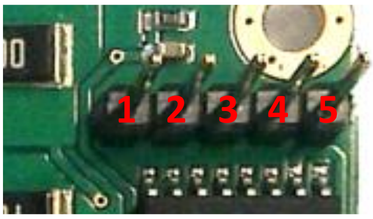


Figure 12: Programming connector front side

Table 6: Programming connector pins description

Pins	Description
1	Reset
2	3.3V
3	Cell 1 Negative terminal
4	PGD
5	PGC

Connection procedure

Step	Connector	Comment
1	2, 3&4	No particular steps are required for these connectors. FreeSafe will not start or power up before the Cell connector is connected to the battery cells.
2	1	Balancing LEDs may blink at the connection before the initialization routine.
Caution	5	Programming connector is only used when firmware update is necessary. Notice that pin 3 is referenced to the negative terminal of the lowest stack cell. Caution must be taken when connecting a non-isolated debugger or programmer

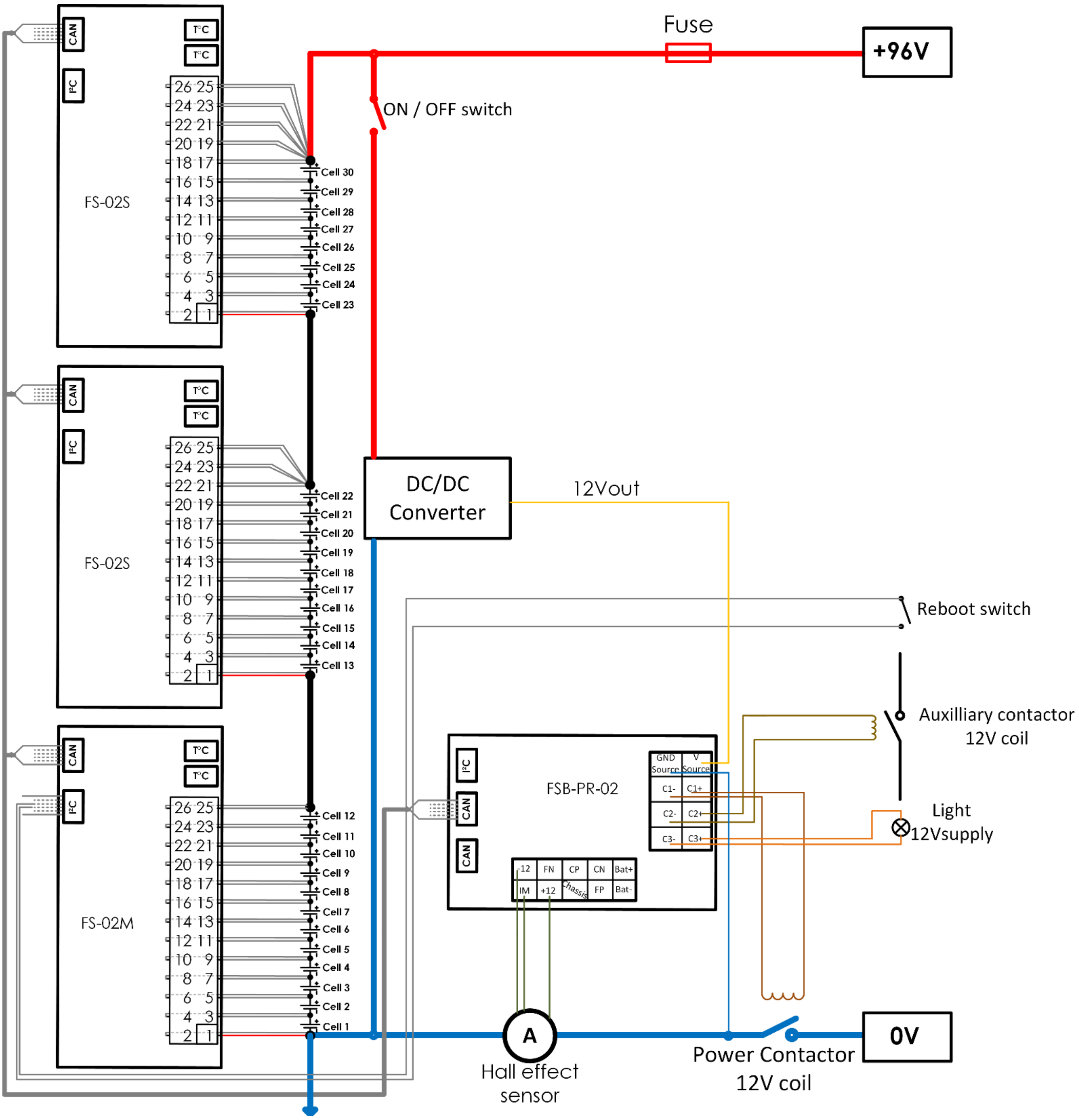


Figure 13: Typical Battery management system connection diagram for a 100V application

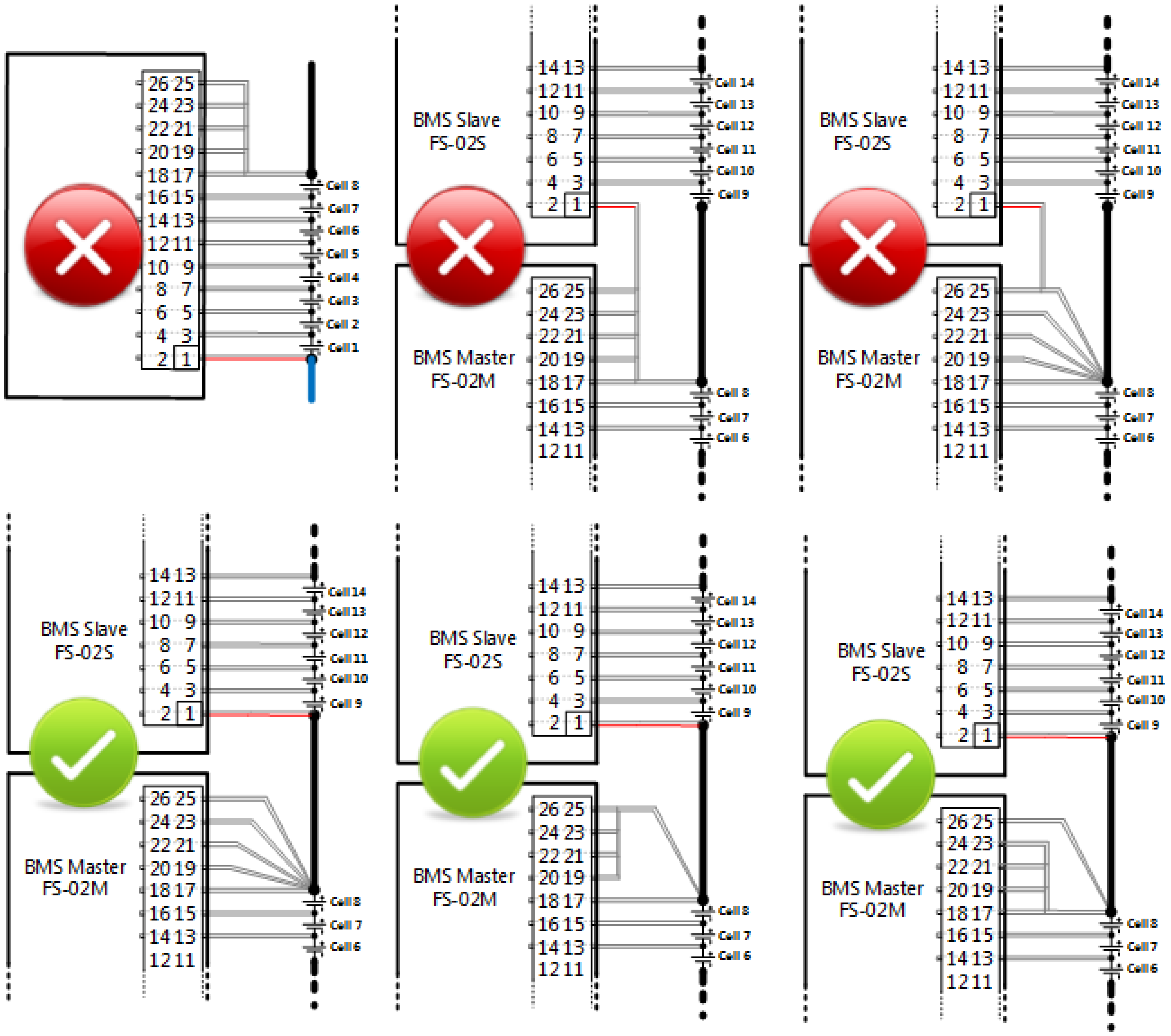


Figure 14: Incorrect & correct wiring to cell stack

The unused cell connector pins must be connected in short circuit to the last positive cell terminal. Cell 1- & Cell 12+ must always be directly connected as close as possible to the cell terminal with a dedicated wire.

To ensure correct voltage readings, all the **cell connector** pins must be connected as close as possible to the cell terminals.

Operation

Running modes

Running modes enable better power consumption control by minimizing FreeSafe activity when heavy algorithm such as SOC estimation, balancing control or wireless communication are not needed.

FreeSafe is able to select the mode of operation to improve battery autonomy and self-preservation during storage or long term non-use.

There are two modes of operation:

- Normal Mode
- Power Saving Mode

By default, FreeSafe will run in Normal Mode when connected to the battery stack for the first time. After POWER_SAVING_TIMER seconds of inactivity, the BMS will go into Power Saving Mode.
When FreeSafe is in Normal mode, the subsequent events will reset the inactivity timer:

- Current detected on the power line.
- Active Wi-Fi communication
- Short circuit between pin 2 & 4 of I2C GPIO connector
- Balancing activation

The inactivity timer will be held in reset in these states:

- Short circuit between pin 2 & 4 of I2C GPIO connector and FORCE_PWR_SAVING option is set to 0 (default is 1).
- Balancing is active

When FreeSafe is in Power Saving Mode, the subsequent events will wake up the module:

- Balancing activation
- Short circuit between pin 2 & 4 of I2C GPIO connector and FORCE_PWR_SAVING option is set to 0 (default is 1).

Stimuli thresholds and mode durations are fully configurable within the BMS configuration file.

Table 7: Functions overview in normal and power saving modes

Function	Mode	
	Normal	Power saving
Voltage acquisition period	1s	POWERSAVING_DURATION
Balancing actualization period	1s	✖
Current acquisition period	100ms	✖
State of charge actualization period	1s	✖
5V Canbus power supply	✔	20ms/min (if Slave)
Wi-Fi Module	✔	✖
Typical power consumption	320mW	20mW

Normal mode

In Normal mode, FreeSafe performs all the monitoring and communication tasks at maximum speed. Cell voltages, current and state of charge can be refreshed up to 1 time per second.

In this mode, FreeSafe will become an Access Point for Wi-Fi devices. The Android FreeSafe application will automatically connect to the BMS and display the variables in real-time.

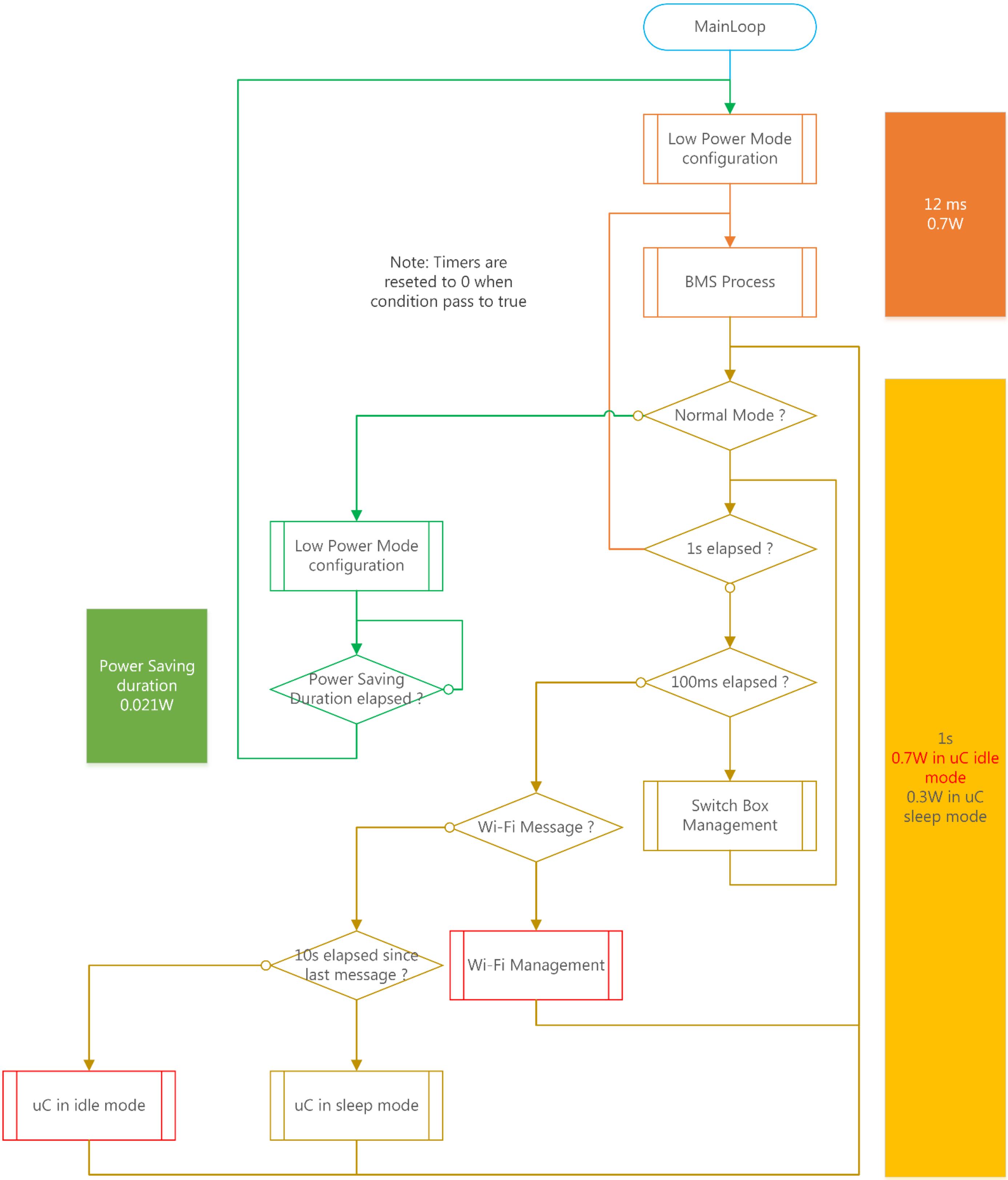


Figure 15: Global process diagram

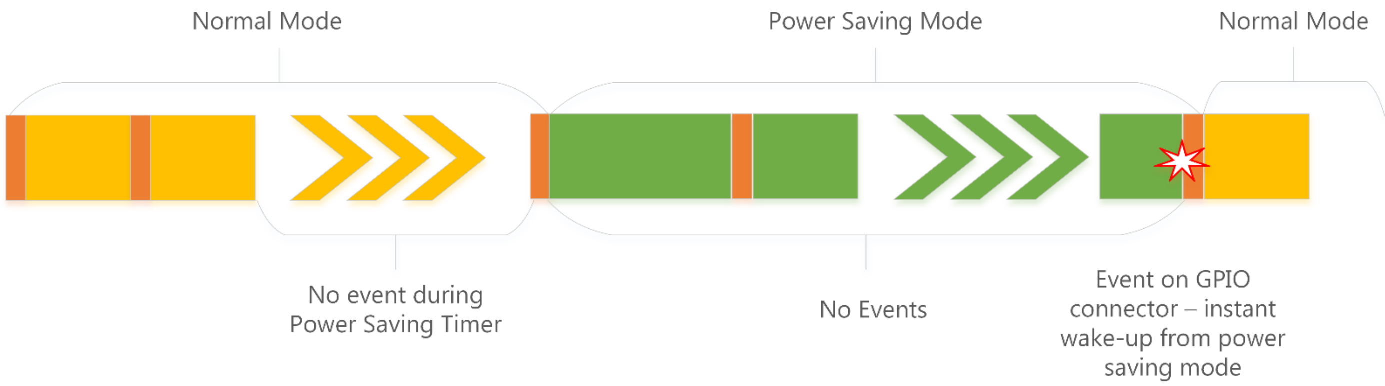


Figure 16: Global process typical timeline

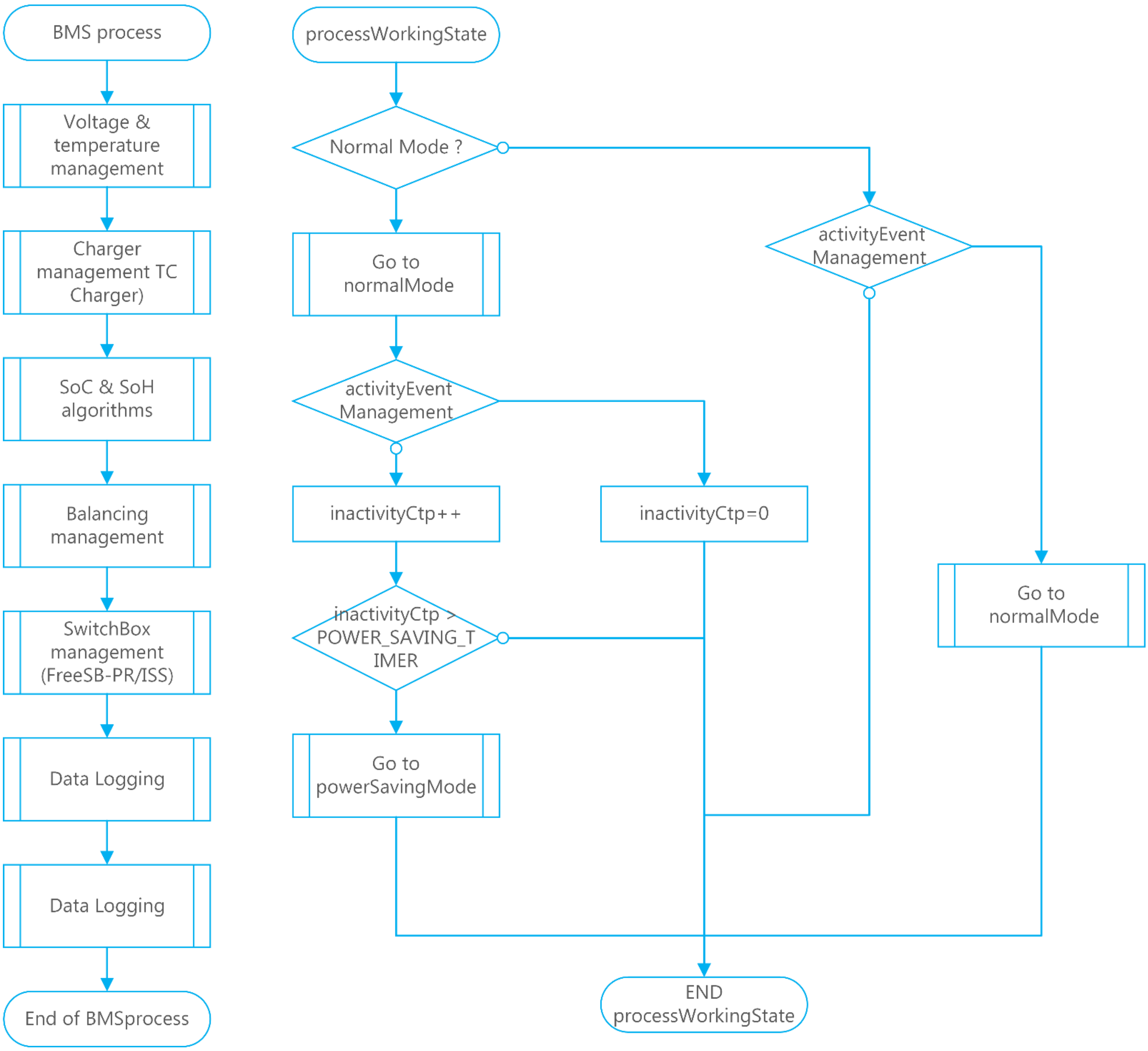


Figure 17: Operation flow-chart of the BMS process

Power Saving mode

In Long Sleep mode, FreeSafe will perform a basic checkup on the battery variables every POWERSAVING_DURATION seconds.

In this mode, FreeSafe will be unreachable via Wi-Fi until the BMS returns in Full Speed or Short Sleep Mode.

It is recommended to install a switch dedicated to wake up the battery when needed between the pin 2 & 4 of the I2C/GPIO connector.

Configuration

FreeSafe can be easily configured to fit precisely to the needs of various applications. All the editable parameters of the BMS are grouped in a XML configuration file stored on the SD card. At initialization the configuration file is parsed by FreeSafe and all the parameters are loaded into the embedded software. If the configuration file is corrupted or missing, the initialization process will enter a fail and retry mode.

In this section, all the parameters of the BMS will be detailed for the 100V LIFEPO4 LEV scenario. Additional scenarios can be found on our website www.freemens.fr on the FreeSafe webpage.

Battery specifications

The parameters in this section are used to configure the expected number of cells [CELL_NUMBER] and the global distribution of slave boards [SLAVE NUMBER]. These parameters are used at the primary initialization. If the number of cells does not match the configuration, FreeSafe will periodically reboot until the correct amount of cells is detected. The configured number of slave is used to guarantee that all the boards are correctly configured and operational. The last parameter is the initial nominal capacity of each parallel string [D1C]. It is used for SOC and SOH calculations. See

Table 8: Battery Configuration

Name	id	Unit	Type	Example	Range	Comment
CELL_NUMBER	0	-	int	30	4-96	Number of series cells
SLAVE_NUMBER	1	-	int	2	0-15	Number of FreeSafe Slaves
D1CAP	2	Ah	int	100	0-10000	Initial nominal battery capacity

Power Management

These parameters control the length of the loop in the power saving mode and the minimum inactivity timeframe that will put FreeSafe in this mode. Adjusting POWER_SAVING_DURATION will allow to reduce the overall power consumption but will slow down the refresh rate of the voltage and temperature and their recording on the SD card.

In our example the power consumption in power saving mode will be:

$$EnergyConsumed = \frac{SleepPower * SleepTime + ProcessPower * ProcessTime}{SleepTime + ProcessTime}$$

During the sleeping period, the current is supplied with a low quiescent linear regulator:

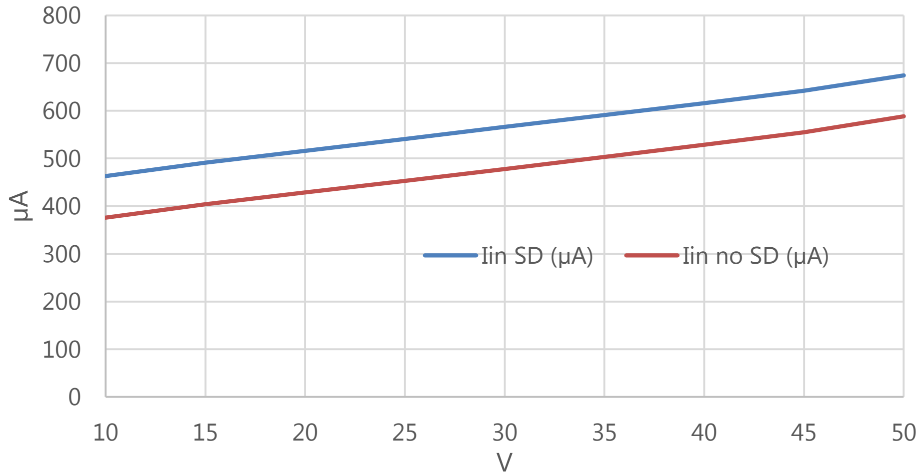


Figure 18: Consumption in sleep during power saving mode

$$SleepPower = SleepCurrent * Battery\ Voltage$$

For a mean 35V per board:

$$SleepPower = 600 * 35 = 0.021W$$

In this example the power consumption in power saving mode will be:

$SleepPower = 0.021W$

$SleepTime = POWER\_SAVING\_DURATION$

$ProcessPower = 0.75W$

$ProcessTime = 20ms$

$$EnergyConsumed = \frac{0.021 * 5 + 0.75 * 0.02}{5{,}02} = 0.023W$$

Table 9: Power management configuration

Name	id	Unit	Type	Example	Range	Comment
POWER_SAVING_TIMER	3	s	int	300	10-10000	Inactivity duration before going into power saving mode
POWER_SAVING_DURATION	4	s	int	5	10-1000	Interval between voltage and temperature refresh in power saving mode
ON_OFF_CAN_BUS	5	-	bool	0	0 - 1	Reserved

Data Logging

FreeSafe master supports up to 32Go SDHC card to store configuration file, data and events recordings.

Recommended SDHC card models:

- KINGSTON 4GB MICROSDHC CLASS 4
- KINGSTON 8GB MICROSDHC CLASS 4
- KINGSTON 4GB MICROSDHC CLASS 10
- KINGSTON 8GB MICROSDHC CLASS 10

To avoid redundant data and to save memory space, new data will be saved only if the variation between two measurements exceeds a configurable threshold. The following parameters will be saved:

- Voltage
- Current
- Temperature
- SOC
- SOH

It is recommended to keep the default parameters.

Table 10: Data logging configuration

Name	id	Unit	Type	Example	Range	Comment
CURRENT _MEAS_CONVENTION	8	-	String	OUT	OUT/IN	Current is counted positively in discharge (OUT) or charge (IN)
VOLTAGE_DIFFERENCE	9	mV	Uint	6	3-10000	Minimal difference between two voltage measurements which triggers a SD-Card data recording.
TEMPERATURE_DIFFERENCE	10	°C	Uint	2	2-10000	Minimal difference between two temperature measurements which triggers a SD-Card data recording.

CURRENT_DIFFERENCE	11	A	float	0,1	0,1-1000	Minimal difference between two current measurements which triggers a SD-Card data recording.
SOC_DIFFERENCE	12	%	float	0,5	0,5-100	Minimal difference between two SOC measurements which triggers a SD-Card data recording.
SOH_DIFFERENCE	13	%	Uint	1000	0-1000	Reserved
BACKUP_PERIOD		s	Uint	3600	10-10000	Maximum permitted period between two recordings

Balancing management

Passive balancing can be configured according to two methods used independently and simultaneously. It can be activated upon reaching a voltage threshold with the FORCE_BALANCING parameter. It can also be activated upon reaching a voltage difference between any cell of the battery and the one with the lowest voltage superior to BALANCING_DELTA_LIMIT_UP. In this case, passive balancing will be disabled when the voltage difference decreases below the BALANCING_DELTA_LIMIT_DOWN threshold. Balancing will never occur if the cells voltage is below the STOP_BALANCING value. Over temperature will prevent balancing if it exceeds 80°C.

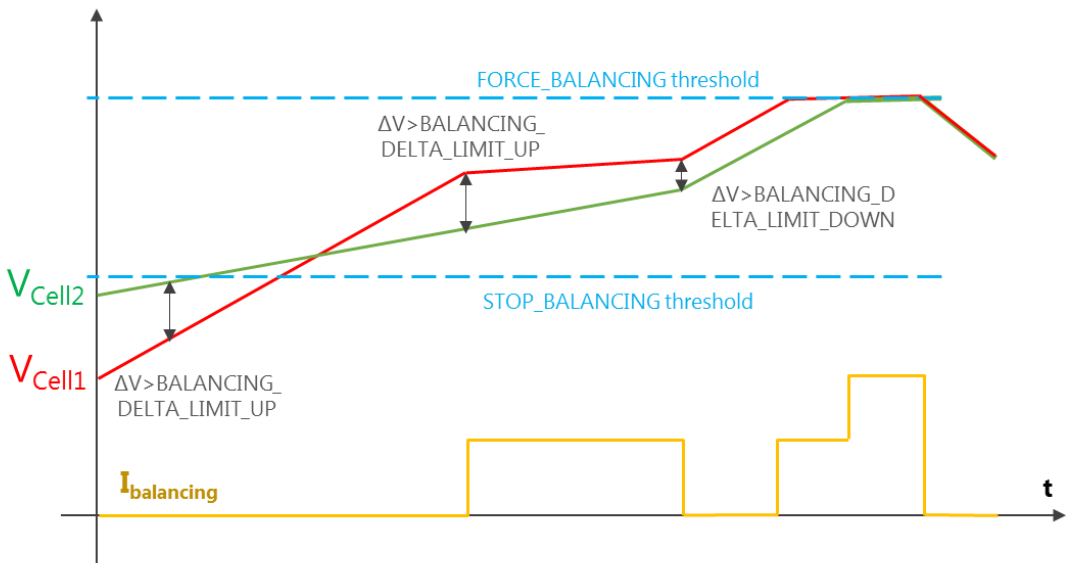


Figure 19: Balancing management

Table 11: Balancing configuration

Name	id	Unit	Type	Example	Range	Comment
BALANCING_DELTA_LIMIT_UP	14	mV	int	10	0-10000	Activation of balancing threshold
BALANCING _DELTA_LIMIT_DOWN	15	mV	int	2	0-10000	Deactivation of balancing threshold
FORCE_BALANCING	18	mV	int	3650	0-10000	Cell voltage threshold triggering forced balancing
STOP_BALANCING	19	mv	int	3300	0-10000	Cell voltage threshold at which passive balancing is disabled

Voltage management

The over and under voltage thresholds are mandatory to operate lithium batteries. Extra care must be taken when modifying these parameters. Default values are recommended for LiFePO4 batteries. If these thresholds are reached, FreeSafe will ask FreeSB to cutoff the battery from the application/charger. V_CAL_BOT and V_CAL_SUP are used to recalibrate SOC and SOH estimations. Default values recommended for LiFePO4 batteries are shown in Table 12: Voltage management configuration

Table 12: Voltage management configuration

Name	id	Unit	Type	Example	Range	Comment
MAX_VOLTAGE	16	mV	int	3650	0-10000	Over voltage threshold
MIN_VOLTAGE	17	mV	int	2600	0-10000	Under voltage threshold
V_CAL_SUP	20	mV	int	3620	0-10000	Cell voltage threshold used to recalibrate SOC and SOH
V_CAL_BOT	21	mV	int	2620	0-10000	Cell voltage threshold used to recalibrate SOC and SOH

Current Management

For more information please refer to FreeSB datasheet. For parameters example see Table 13: Current management configuration

Table 13: Current management configuration

Name	id	Unit	Type	Example	Range	Comment
CURRENT_PIC	26	A	int	250	0-32766	Positive instantaneous current limit
CURRENT_LIMIT	27	A	int	120	0-32766	Positive over current reference
CURRENT_PIC_NEG	28	A		-250	0-32766	Negative instantaneous current limit
CURRENT_LIMIT_NEG	29	A		-120	0-32766	Negative over current reference
CURRENT_NOMINAL		A	int	80	0-32766	Positive nominal current
CURRENT_NOMINAL_NEG		A	int	80	0-32766	Negative nominal current
CURRENT_LIMIT_TIME	30	A		10	0-32766	Thermal time reference
LEGACY_GAIN	31	-	Int	1		Legacy
LEGACY_R_SHUNT	32	-	Int	1		Legacy
FSB_PR_LEM_GAIN	33	-	Int	1000	0-32766	LEM current sensor gain for FreeSB-PR application

Thermal management

The over and under temperature thresholds are mandatory to operate lithium batteries. Extra care must be taken when modifying these parameters. Default values are recommended for LiFePO4 batteries. To ensure correct temperature readings, sensors must be placed as close as possible to the monitored cell. For example, they can be directly placed onto screws used for power connection. Parameters example for AVX – ND06P00103K thermistor (Figure 18) are given in Table 14: Thermal management configuration.

Figure 20: AVX - ND06P00103K

Table 14: Thermal management configuration

Name	id	Unit	Type	Example	Range	Comment
MAX_TEMP	22	°C	Uint	50	-180 - 180	Over Temperature threshold
MIN_TEMP	23	°C	int	-10	-180 - 180	Under Temperature threshold
MAX_BOARD_TEMP		°C	Uint	60	0 - 95	Over Temperature threshold on FreeSafe boards

R0	24	-	int	10000	0-32766	External temperature sensor parameter
BETA	25	-	int	4220	0-32766	External temperature sensor parameter

Wi-Fi access point

The accessibility parameters for Wi-Fi in local mode can be modified to fit customer and application requirements. FreeSafe automatically activates the access point while in normal mode. Peripheral such as android mobile phone or tablet (with FreeView application) are then able to reach FreeSafe by connecting to the corresponding SSID name. Communications over Wi-Fi are considered as "wake-up events" preventing FreeSafe from entering in Power Saving Mode. In power saving mode, the Wi-Fi is disabled. Protocol in local AP mode is described in the communication section.

Table 15: WiFi configuration in local mode

Name	id	Unit	Type	Example	Range	Comment
ACCESS_POINT_NAME	6	-	String	FreeSafeAP	Char[33] a-z;0-9	Wi-Fi SSID name of the BMS in access point mode.
ACCESS_POINT_PWD	7	-	String	freemens	Char[33] a-z;0-9	Channel of emission in AP Mode
CHANEL_EMISSION	8	-	String	1	Char[3]	Channel of emission in AP Mode

All parameters are written with the following tags:

<variable name="NAME" id=ID_NUMBER value="VALUE">

Implemented in future software release						
HYSTERESIS_LOW_CHARGER	34	mV	Int	3400	0-32766	Charger cutoff voltage threshold
WLAN_SSID	35	-	String	D-LinkAP		SSID name of target infrastructure access point
AUTH_MODE	36	-	String	WPA2		Authentication mode of target infrastructure access point
WLAN_PASS	37	-	String	azerty00		Password of target infrastructure access point
WLAN_CHAN	38	-	Int	0		Channel of target infrastructure access point
FTP_ADDR	39	-	String	192.168.0.100		FTP address of target server
FTP_USER	40	-	String	boris		FTP login of target server
FTP_PASS	41	-	String	freemens		FTP password of target server
FTP_DIR	42	-	String	.		FTP directory of target server
TIMER_FTP_UPLOAD	43	-	Int	7		Reserved
SIZE_FTP_UPLOAD	44	-	int	50		Reserved

Communication

Wi-Fi Infrastructure Mode

In this mode, FreeSafe connects to an Access Point provided it is reachable and correctly configured (SSID, authentication mode, key/password and channel) in the SD Card.

Multiple authentication modes are supported:

- WEP64 & WEP128
- WPA-PSK

- WPA1-PSK (TKIP only)
- WPA2-PSK (AES only)

FreeSafe IP-address is provided by the Access point and can be retrieved in the router connected devices list. Infrastructure Mode is required for Internet connectivity and Remote operation with online databases.

Wi-Fi Access Point Mode

In this mode, FreeSafe will provide an open Wi-Fi access point for adjacent portable devices such as mobile phones and tablets. These devices will be able to connect to the BMS via the IP-address: 1.2.3.4 and to communicate through TCP protocol

Command	Name	Unit	Type	Description
get raw param+	D1C	Ah	Int	Cell nominal capacity
	maxCurrent	A	Int	Over current threshold
	maxVoltage	mV	Int	Cell over voltage threshold
	minVoltage	mV	Int	Cell under voltage threshold
	maxTemp	°C	Int	Over temperature threshold
	minTemp	°C	Int	Under temperature threshold
	slaveNumber	-	Int	Number of connected FreeSafe slaves
get SOC+	SOC unit	-	float	Returns SOC
get raw temp+	numTemp	-	int	Returns the number of temperature sensors
	valueTemp	C°	int[numTemp]	Temperature value
get volt+	numCell	-	int	Returns the number of cells
	valueVoltage	mV	int[numCell]	Returns the voltage of all the cells
get curr+	valueCurrent	A	Float	Returns the value of the ingoing or outgoing current
get CCS flag+	TCchargerFlag	-	int	Returns 1 if the charger is connected, 0 else.
get file confbms.xml				Returns configuration file
get file event.txt				Returns events file
get file info.txt				Returns information file

CAN-bus

FreeSafe uses the **SAEJ1939 Standard**. This standard is based on the 2.0B physical layer and transmits "**Extended Data Frame**" messages. The bus frequency is set at **250Kbps**.

Table16: CAN 2.0B Message Frame

SOF (1 bit)	ARBITRATION (32 bits)	CONTROL (6 bits)	DATA (0-64 bits)	CRC (16 bits)	ACK (2 bits)	EOF (7 bits)

Table 17: CAN 2.0B Message Frame (detailed)

	Field	Size (bits)	Description	Default
ARBITRATION	ID	11	Message identifier (part 1)	
	SRR	1	Substitute remote request	1
	IDE	1	Identifier Extension	1
	Ext ID	18	Message identifier (part 2)	
	RTR	1	Remote Transmit Request	0
CONTROL	RB0	1		
	RB1	1		0
	DLC	4	Data length code	
DATA	DATA	DLC*8	Data bytes	
CRC	CRCS	15	CRC	
	CRCD	1	CRC Delimiter	
ACK	ACKS	1	Used for receiver to ACK msg. Sent as recessive.	
	ACKD	1	ACK Delimiter	
EOF	EOF	7	End of Frame. Sent as recessive	

Table 18: SAE J1939 Message Frame Identifier

ID						Extended ID			
Priority	**R**	**DP**	**PF** (<7:2>)	**SRR**	**IDE**	**PF** (<1:0>)	**PS**	**SA**	**RTR**
(3 bits)	(1 bit)	(1 bits)	(8 bits)				(8 bits)	(8 bits)	

	Values	Description
Priority	0 - 7	8 priority levels. 0 : highest, 7 : lowest
Reserved	0	0 is mandatory
Data Page	0 - 1	Page format selection. Stays at 0 for our internal protocol
PDU Format (PF)	0 - 255	Message type
PDU Specific (PS)	0 - 255	If PF > 240(0xF0): the message is a broadcast, PS will be used as PF extension. Si PF < 240(0xF0): the message is peer to peer, PS will be used as destination address.
Source Address (SA)	0 - 255	Source address of controller application

The resulting ID will be as follow:

ID					
Priority	R	DP	PF	PS	SA
Priority	PGN				SA

PGN (Parameter Group Number) identifies a Parameter Group. A Parameter Group defines the characteristics of a message type (PF) (Number of bytes, bytes descriptions, periodicity, priority, etc...).

Table 19: Reserved peripheral addresses

Peripheral	Adress	Hex value
Custom LCD Display	160	A0
FreeSafe S	176-191	B0-BF
FreeSB	192	C0
Reserved	193-207	C1-CF
TC Charger	229	E5

FreeSafe M	244	F4
FreeFlex	255	FF

Typical Internal Canbus operations

In a 36 cells battery configuration, 3 FreeSafe boards are used (1 Master & 2 Slaves) with a FreeSB PR (Smart Breaker for Power relays). FreeSafe M will initiate every CANbus communication by sending message frames (except initialization requests from certain peripherals). FreeSafe Slave and FreeSB PR will only acknowledge and answer to those requests. Also FreeSafe M will provide a 5 V power supply for each isolated drivers of Freemens peripherals.

/!\ the 5 V CANbus power supply provided by FreeSafe M should not be used to power foreign peripherals.

Communication FreeSafe Master – FreeSafe Slave

At FreeSafe master powers up, an initialization message is sent to the slaves to check the battery pack global integrity.

Table 20: Identifier description: Cell number verification request

Period : Once at startup		Value (Hex)	Comment
ID = 18 04 B0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	04	Number of connected cells verification request
	PS	B0	FreeSafe S Address
	SA	F4	FreeSafe M Address
DATA = 0 Byte			

Table 21: Identifier description: Cell number verification answer

Period : Once at startup		Value (Hex)	Comment
ID = 18 05 F4 B0	P	6	Default Value
	R	0	-
	DP	0	-
	PF	05	Number of connected cells verification request
	PS	F4	FreeSafe M Address
	SA	B0	FreeSafe S Address
DATA = 3 Bytes			
	Bytes 1 & 2	xx x0	**Bit Field** Bit 0: **1 : cell 1 detected** / **0 : no cell** Bit 1: 1 : cell 2 detected / 0 : no cell Bit 11: 1 : cell 12 detected / 0 : no cell -
	Byte 3	xx	Total number of connected cells to the FreeSafe S Board

In Normal and Power Saving mode, FreeSafe M will periodically ask each slave of its cells voltages and temperatures.

Table 22: Identifier description: voltage and temperature request

Period : 1s / xxs		Value (Hex)	Comment
ID = 18 01 B0 F4	**P**	6	Default Value
	R	0	-
	DP	0	-
	PF	01	Voltage and temperature request

	PS	B0	FreeSafe S Address
	SA	F4	FreeSafe M Address
DATA = 0 Bytes			

Table 23: Identifier description: voltage and temperature answer (Frame 1)

Period : 1s / xxs		Value (Hex)	Comment
ID = 18 01 F4 B0	P	6	Default Value
	R	0	-
	DP	0	-
	PF	01	voltage and temperature answer (Frame 1)
	PS	F4	FreeSafe M Address
	SA	B0	FreeSafe S Address
DATA = 8 Bytes			
	Byte 1 & 2	0x xx	Cell 1 Voltage of Slave SA (big endian)
	Byte 3 & 4	0x xx	Cell 2 Voltage of Slave SA (big endian)
	Byte 5 & 6	0x xx	Cell 3 Voltage of Slave SA (big endian)
	Byte 7 & 8	0x xx	Cell 4 Voltage of Slave SA (big endian)

Table 24: Identifier description: voltage and temperature answer (Frame 2)

Period : 1s / xxs		Value (Hex)	Comment
ID = 18 02 F4 B0	P	6	Default Value
	R	0	-
	DP	0	-
	PF	02	voltage and temperature answer (Frame 2)
	PS	F4	FreeSafe M Address
	SA	B0	FreeSafe S Address
DATA = 8 Bytes			
	Byte 1 & 2	0x xx	Cell 5 Voltage of Slave SA (big endian)
	Byte 3 & 4	0x xx	Cell 6 Voltage of Slave SA (big endian)
	Byte 5 & 6	0x xx	Cell 7 Voltage of Slave SA (big endian)
	Byte 7 & 8	0x xx	Cell 8 Voltage of Slave SA (big endian)

Table 25: Identifier description: voltage and temperature answer (Frame 3)

Period : 1s / xxs		Value (Hex)	Comment
ID = 18 03 F4 B0	P	6	Default Value
	R	0	-
	DP	0	-
	PF	03	voltage and temperature answer (Frame 3)
	PS	F4	FreeSafe M Address
	SA	B0	FreeSafe S Address
DATA = 8 Bytes			

	Byte 1 & 2	0x xx	Cell 9 Voltage of Slave SA (big endian)
	Byte 3 & 4	0x xx	Cell 10 Voltage of Slave SA (big endian)
	Byte 5 & 6	0x xx	Cell 11 Voltage of Slave SA (big endian)
	Byte 7 & 8	0x xx	Cell 12 Voltage of Slave SA (big endian)

Table 26: Identifier description: voltage and temperature answer (Frame 4)

Period : 1s / xxs		Value (Hex)	Comment
ID = 18 04 F4 B0	P	6	Default Value
	R	0	-
	DP	0	-
	PF	04	voltage and temperature answer (Frame 4)
	PS	F4	FreeSafe M Address
	SA	B0	FreeSafe S Address
DATA = 8 Bytes			
	Byte 1 & 2	0x xx	External temperature sense 1 (big endian)
	Byte 3 & 4	0x xx	External temperature sense 2 (big endian)
	Byte 5 & 6	0x xx	Internal slave board temperature (big endian)
	Byte 7 & 8	0x xx	Cell 12 Voltage of Slave SA (big endian)

After an internal processing the FreeSafe Master Board will dispatch the balancing orders if required.

Table 27: Identifier description: Balancing orders dispatching

Period : 1s / xxs		Value (Hex)	Comment
ID = 18 20 B0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	20	Balancing Order
	PS	B0	FreeSafe S Address
	SA	F4	FreeSafe M Address
DATA = 2 Bytes			
	Byte 1 & 2	0x xx	**Bit Field** Bit 0: 1 : Balance Cell 1 / 0 : no balancing Bit 1: 1 : Balance Cell 2 / 0 : no balancing Bit 11: 1 : Balance Cell 3 / 0 : no balancing -

Communication FreeSafe Master – FreeSB PR

When FreeSB is powered up and connected to CANbus, it will begin its initialization by requesting the configuration parameters from the FreeSafe Master.

Table 28: Identifier description: FreeSB initialization request

Period : Once at startup		Value (Hex)	Comment
ID = 18 06 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	06	Initialization request

	PS	F4	FreeSafe M Address
	SA	C0	FreeSB PR Address
DATA = 0 Byte			

Table 29 Identifier description: FreeSB initialization answer (frame 1)

Period : Once at startup		Value (Hex)	Comment
ID = 18 06 C0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	06	Initialization Parameters (frame 1)
	PS	C0	FreeSB PR Address
	SA	F4	FreeSafe M Address
DATA = 8 Bytes			
	Byte 1 & 2	0x xx	Charge over current limit (A) (big endian)
	Byte 3 & 4	0x xx	Discharge over current limit (A) (big endian)
	Byte 5 & 6	0x xx	Positive instantaneous current limit (A)
	Byte 7 & 8	0x xx	Negative instantaneous current limit (A)

Table 30: Identifier description: FreeSB initialization answer (frame 2)

Period : Once at startup		Value (Hex)	Comment
ID = 18 07 C0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	07	Initialization Parameters (frame 2)
	PS	C0	FreeSB PR Address
	SA	F4	FreeSafe M Address
DATA = 8 Bytes			
	Byte 1 & 2	0x xx	Over current time limit (s) (big endian)
	Byte 3 & 4	0x xx	Battery capacity (Ah) (big endian)
	Byte 5 & 8	0x xx	Shunt value (float, Ohm, big endian)

Table 31 : Identifier description: FreeSB initialization answer (frame 3)

Period : Once at startup		Value (Hex)	Comment
ID = 18 08 C0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	08	Initialization Parameters (frame 3)
	PS	C0	FreeSB PR Address
	SA	F4	FreeSafe M Address
DATA = 6 Bytes			

	Byte 1 & 2	0x xx	State of change sampling rate (sample/s, big endian)
	Byte 3 & 6	0x xx	Current Sense Gain (big endian float)

When FreeSafe is in normal mode, it will request an update every 100ms of current value. At the same time FreeSafe will communicate its state to FreeSB.

Table 32: Identifier description: current value request

Period : 100ms		Value (Hex)	Comment
ID = 18 0A C0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	0A	Current value request
	PS	C0	FreeSB PR Address
	SA	F4	FreeSafe M Address
DATA = 1 Byte			
	Byte 1	0x xx	Bit field corresponding to various FreeSafe state flags

Table 33: Identifier description: current value answer

Period : 100ms		Value (Hex)	Comment
ID = 18 0A F4C0	P	6	Default Value
	R	0	-
	DP	0	-
	PF	0A	Current value
	PS	F4	FreeSafe M Address
	SA	C0	FreeSB PR Address
DATA = 3 Bytes			
	Byte 1&2	xx xx	Current value (10mA, big endian)
	Byte 3	xx xx	Bit Field corresponding to various FreeSB state flags

Every Second FreeSafe M requests an updated value of FreeSB coulomb counting

Table 34: Identifier description: coulomb counting value request

Period : 100ms		Value (Hex)	Comment
ID = 18 09 C0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	09	Coulomb counting value
	PS	C0	FreeSB PR Address
	SA	F4	FreeSafe M Address
DATA = 1 Byte			
	Byte 1	0x xx	Bit field corresponding to various FreeSafe state flags

Table 35: Identifier description: coulomb counting value answer

Period : 100ms		Value (Hex)	Comment
ID = 18 0A F4C0	P	6	Default Value
	R	0	-
	DP	0	-
	PF	0A	Coulomb Counting value
	PS	F4	FreeSafe M Address
	SA	C0	FreeSB PR Address
DATA = 3 Bytes			
	Byte 1 - 4	xx xx xx xx	Coulomb counting value (C, big endian, float)

Communication FreeSafe Master – LCD Display

FreeSafe master will periodically send a message frame that will refresh the LCD display parameters.

Table 36 : Identifier description: LCD display parameters

Period : 100ms		Value (Hex)	Comment
ID = 18 0A A0 F4	P	6	Default Value
	R	0	-
	DP	0	-
	PF	0A	LCD display parameters
	PS	A0	LCD Display Address
	SA	F4	FreeSafe M Address
DATA = 6 Bytes			
	Byte 1	xx	**Bit Field** Bit 0: 1: Under Voltage, 0: - Bit 1: 1: Low SOC (10%), 0: - -
	Byte 2	xx	SOC Value (%, big endian)
	Byte 3-4	xx xx	Total battery voltage (V*10, big endian)
	Byte 5-6	xx xx	Battery current (A*10, big endian)

Broadcast messages

When FreeSafe is in power saving mode, it will poll every slaves periodically in order to refresh the battery parameters. To reduce the power consumption after the data has been retrieved, it will shut down the CANbus power supply. Before doing so a broadcast message is sent to warn all the peripheral powered by FreeSafe M that the bus will go offline.

Table 37 : Identifier description: CANbus shutdown broadcast

Period : 100ms		Value (Hex)	Comment
ID = 18	P	6	Default Value
	R	0	-
	DP	0	-

	PF	FF	CANbus shutdown Broadcast warning
	PS	AA	
	SA	F4	FreeSafe M Address
DATA = 0 Byte			

FreeSB FSB-PR-02

Power Relay Management

Features

- **Manages up to 3 independent power outputs (DC coil contactor, fans...)**
- **Supports wide DC contactor coil voltage levels (2 ranges depending of supply reference: from 9V to 36V or from 18V to 75V)**
- **Supports wide input voltage levels from 10V to 75V**
- **Current measurement through external Hall effect current sensor**
- **Isolated CAN bus interface to adjacent devices**
- **Compliant with FreeSafe (Freemens Battery Management System) for complete battery management solution**
- Non isolated I^2C communication
- Contactor and fuse continuity tester
- Built-in self-tests
- High EMI immunity

Applications

- Electric and Hybrid Electric Vehicles
- High Power Portable Equipments
- Backup Battery Systems
- Electric Bicycles, Motorcycles, Scooters

Description

FreeSB-PR is a smart circuit breaker especially designed for high currents. FreeSB-PR can drive up to 3 external devices such as power switches or fans, powered by the supply dedicated to the circuit breaker (e.g. it is possible to wire two contactors and one light).

FreeSB-PR provides an easy to use solution to manage large packs of Li-Ion batteries. FreeSB-PR boards are easy and safe to connect or disconnect. FreeSB-PR supports a wide voltage supply range in order to drive a large range of DC contactor coils.

Current measurement is assured using external Hall effect sensor that must have a current output for the measurement. The accuracy of the measurements depends on the accuracy of the sensor. A ±12 V power supply is available for the sensor.

FreeSB-PR cuts off the current when a short circuit is detected: the cut off time depends on the switch off time of the power switch. FreeSB-PR can also react on over-current or over-temperature: these parameters are programmable as well as the time to react. FreeSB-PR protects the battery cells from over and under voltage based on the data received from FreeSafe Battery Management System.

The circuit breaker is continuously testing the fuse and power switch in order to assure the integrity of these devices.

To ensure that the battery is used properly, FreeSB-PR sends all the data to FreeSafe, which records all activities in an up to 10 years long data history file. The communication between FreeSafe and FreeSB-PR is realized through CAN bus. FreeSB-PR is delivered with a comprehensive CAN application layer.

While FreeSB-PR devices are "plug and play" for LFP batteries, specific applications and other chemistries require custom settings. FreeSB-PR parameters can be easily changed.

Typical Application

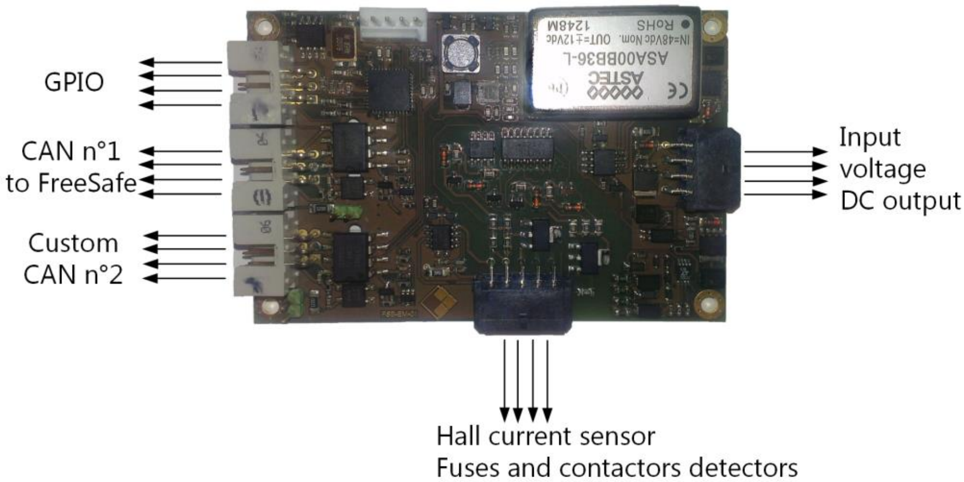


Figure 1 - FSB-PR board inputs and outputs

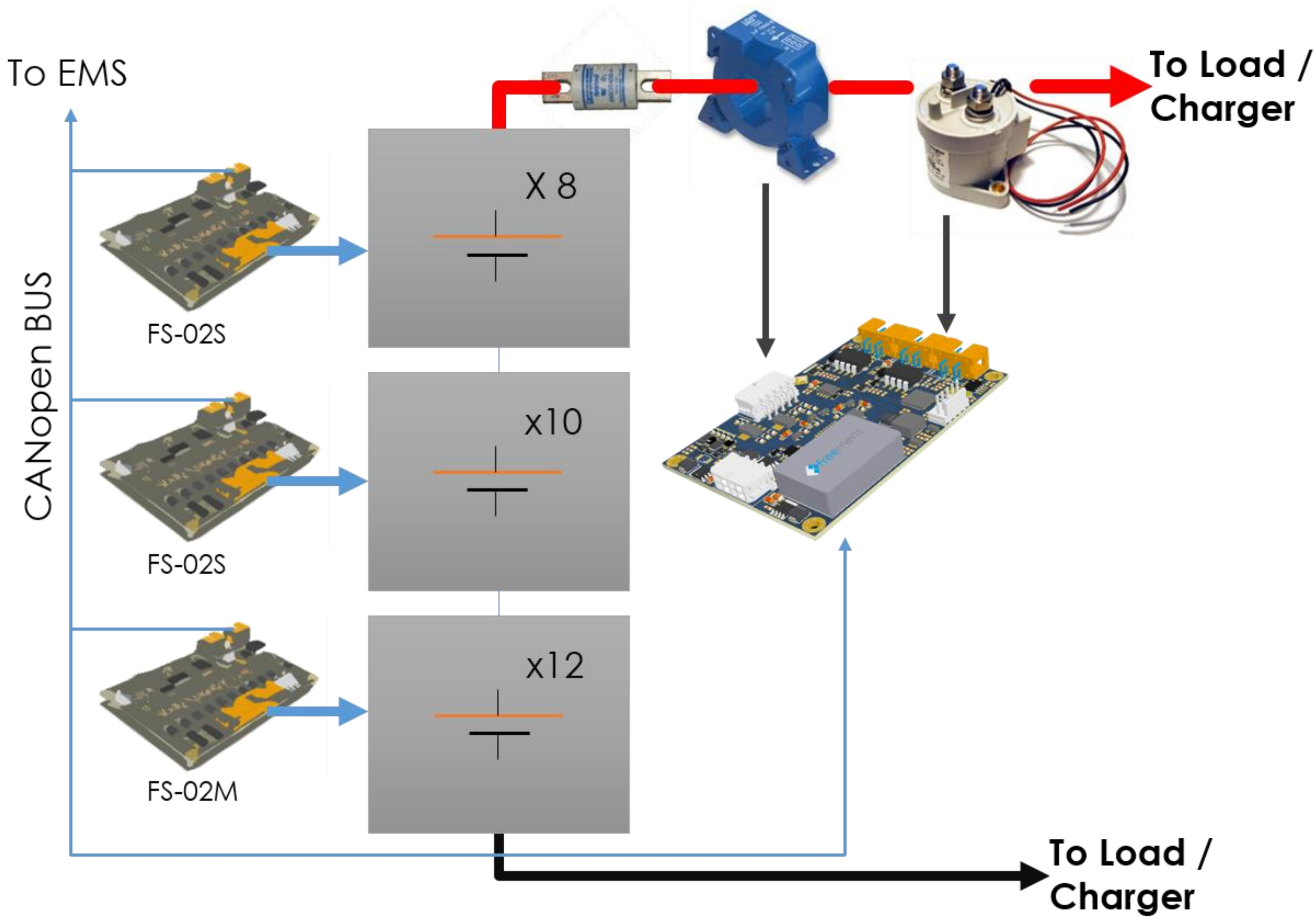


Figure 2 - Example of a battery management solution with 3 stacked FreeSafe boards, a FreeSB-PR and its peripherals

Absolute Maximum Ratings

Parameter	Symbol	Value	Units
Maximum input supply voltage Maximum DC contactor coil voltage	Vin	36 or 75 *	V
Maximum allowed inrush current per power output		15	A
Maximum input current measurement provided by a Hall Effect sensor		±110	mA
Operating temperature range		-40 to 85	°C
Maximum CANbus supply current		200	mA
Maximum voltage for isolated continuity testers		400	V

* Input voltage is either 9-36V or 18-75V according to the supply reference onboard.

General description

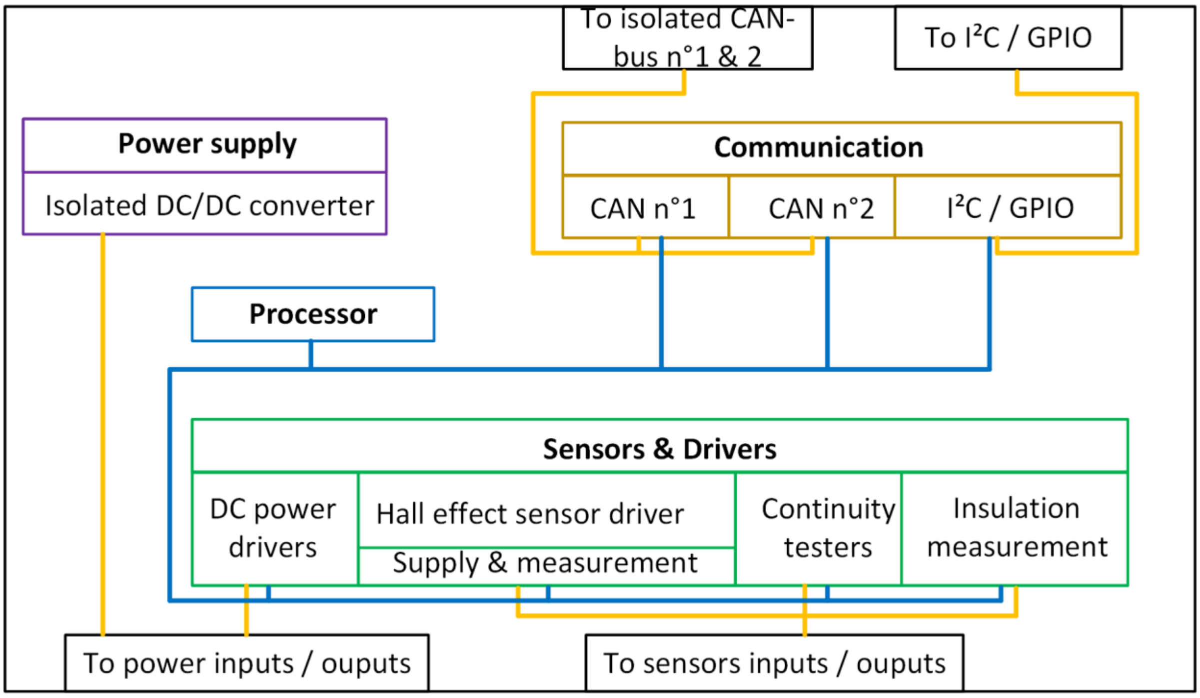


Figure 3 - Functional diagram

The following functional blocs are presented:

- Management (processor)
- Sensors & Drivers
- Power Supply
- Communication

Power supply unit

FreeSB-PR integrates its own Power Supply Unit (PSU) making the board fully standalone once connected to a wide range of DC sources. On board supplies are isolated ±12V_{DC}, 5V_{DC} and 3.3V_{DC}. By default, the PSU must be connected to a source with a voltage range between 18V and 75V. FreeSB-PR can also accept an input between 9V and 36V, if the reference of the PSU is adapted.

DC source design choices

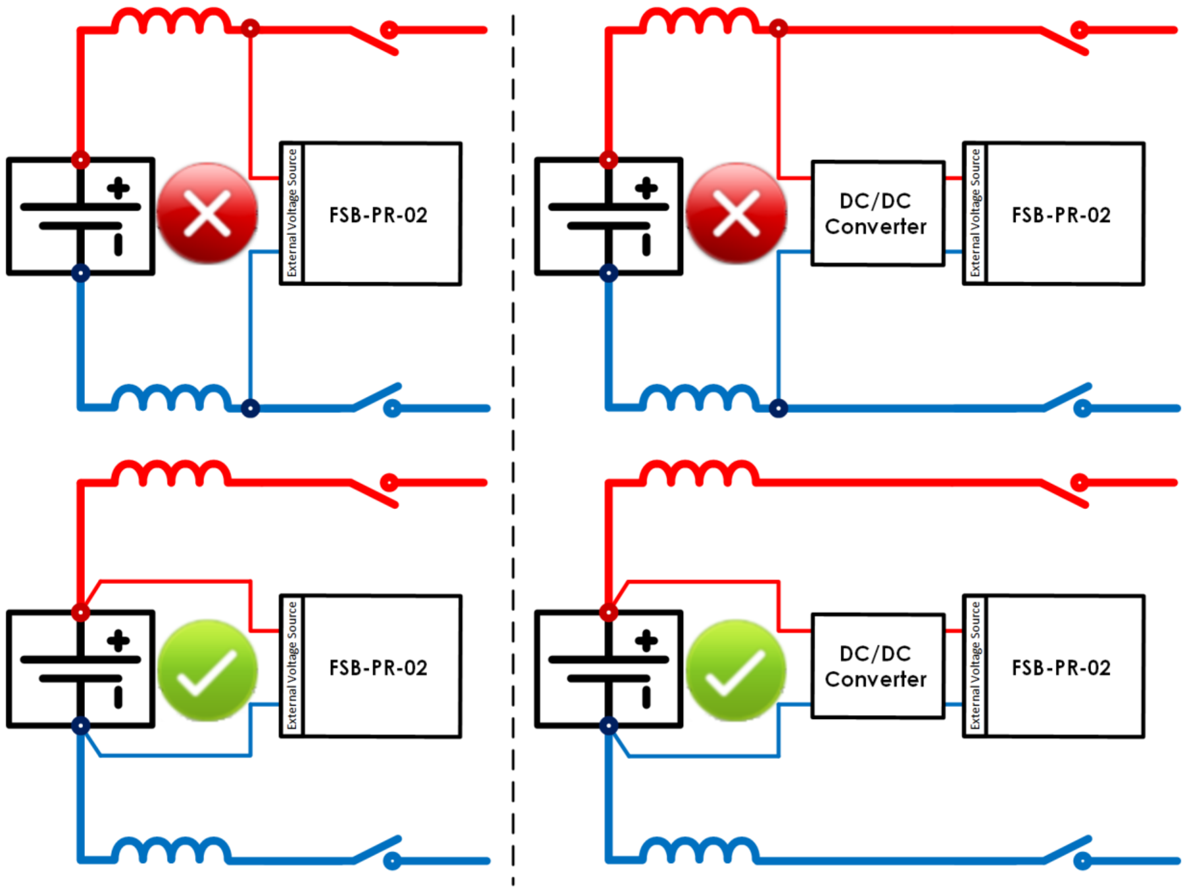
The DC source of FSB-PR must provide any voltage between 18V and 75V (or 9V and 36V). At least 6Wmax are needed to supply all the electronics on the board. The DC source must also provide enough current to be able to withstand the inrush current when driving DC contactor coils. The standard solution is a DC/DC converter directly plugged on the battery and designed to provide enough power. Another solution could be to plug FSB-PR directly to the main battery if the voltage concurs with the input limits. It is possible to use an intermediate point on the main battery as a DC source - for instance connecting FSB-PR between the ground and the 8th cell of a 15 cells 48V LiFePO4 battery provides a 20V to 29.2V supply. But this will unbalance the firsts 8 cells of the pack and an equalizer such as a FreeFlex (Freemens Flexible Power Supply) will be required.

There is another constraint in the choice of the DC source: the driving voltage of the DC contactor coil. The supply voltage will be directly reused to drive the contactor, so **all the devices must work with the same voltage level (source, contactor, fans, lamp, etc).**

Connecting FSB-PR to the DC source

The DC source must ensure a stable input voltage in the specified input range. For that the connection between FSB-PR and its source must be carefully considered.

If the DC source is the battery or a DC/DC converter (isolated or not) whose input is the battery, the connection to FSB-PR has to be a star connection as shown on the next figure. This star connection guarantees that the power current flowing to the application, or from the charger, will not trouble the input of FSP-PR from wire inductive or resistive perturbation.



Using the battery as the DC source for FSPB-PR-02:

Direct use if 9V<Vbat<75V — Through a DC/DC converter

Figure 4 – Connection of the DC source to FSB-PR

Sensors & Drivers

The Sensors & Drivers block provides precise and reliable measurements related to the operating conditions. As a result, FreeSB-PR is able to sense power current and drives up to 3 independent power outputs. Current measurement is retrieved through an analog to digital conversion of the measurement given by a Hall Effect sensor device. In addition, FreeSB-PR includes sensors that measure the insulation resistor between the chassis and the battery contacts and also continuity testers that detect a fuse or power contactor fault.

Hall Effect sensor design choices

Two constraints guide the choice of a Hall Effect sensor working with FSB-PR. The first one is that the supply voltage provided by the board is a ±12V dual supply (±250mA max). The second one is that the sensor must be a current transducer that will provide an output current measurement, which is an image of the power current. This current measurement must be ±110mA max, otherwise, the measure will exceed the full scale measurement because of the default amplification gain on FSB-PR.

The gain of the Hall Effect sensor can be configured through the configuration file of FreeSafe. To modify the gain of the FSB-PR board – in order to change the limit of the full-scale measurement – a custom PCB design will be needed.

Example of recommended Hall Effect sensors:

- LEM LS 205-S/SP3: ±100A nominal current measurement, ±12V supply, closed loop current transducer (1:1000 ratio).

Datasheet: http://www.lem.com/docs/products/lf%20205-s%20sp3.pdf

- Tamura S23P50/100D15M1 with similar characteristics.

Datasheet: http://www.tamuracorp.com/clientuploads/pdfs/engineeringdocs/S23PXXXD15M1.pdf

Contactor (or fan or other peripheral) design choices

The power DC contactor as shown in Figure 5, must be designed to withstand the battery voltage, the nominal power current and to be able to cut over current or even, if needed, short-circuit current. The driving voltage of the coil and the supply voltage of the board must be the same. The maximum inrush current that drives the coil must be less than 15A during 100ms and the maximum continuous driving current must be less than 3.75A if only one output is supplying the current and 2.1A per output if all three outputs are working in the same time. Following these recommendations ensure the proper use of FSB-PR and its functions.

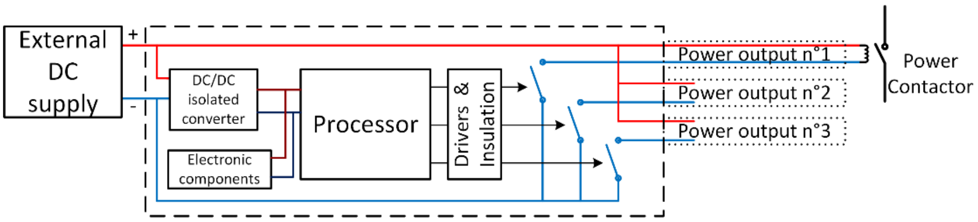


Figure 5 - functional diagram of the 3 DC power outputs and their supply

Example of recommended DC contactor:

- TE connectivity Kilovac EV200: 900Vdc max, 500Amax, 9V to 95V coil voltage. Datasheet:

http://www.te.com/catalog/pn/fr/1618002-7

Management

A powerful 16bits DSC (Digital Signal Controller) is used for the data processing. The DSC is the core of the system where most of the algorithms are implemented. It communicates and controls the other function of the BMS:

- Driving the 3 power outputs to change the states of the contactors, fans, etc.
- Measurements retrieval from all the sensors
- Estimators computing
- Wired system level communications

FreeSB-PR transmits its data (e.g. current measurement or events) to FreeSafe through CAN communications. All data related to the battery and the BMS operations are then stored and kept available for future use. Based on an embedded micro SD card of 4Gbits (default configuration), FreeSafe is able to record up to 10 years of data. Remote access is possible for the battery fleet control & monitoring thought proprietary FreeLab application and FreeData database.

Communication

FSB-PR includes hardware for CAN bus communication protocols to facilitate the communication between the BMS and the other control or power interfaces of the system. In particular, FreeSB-PR integrates an isolated CAN Bus allowing to communicate with other Freemens products (the FreeSafe solutions for instance). For the communication with other external devices, a second CAN bus is provided but this feature needs a custom development to implement the desired communication protocol. The extensive communication techniques allow FreeSB-PR to receive control orders, updated programs and parameters.

Connectors' Configuration

Two variants of the connectors' configuration of FSB-PR are possible. The first one is a version with wire-to-board connector and is designed for general use. The alternate version has board-to-board connectors and is designed to be plugged on a mother board. Between the two variants, all the connectors have the same pins configurations, the difference is based on the footprint and the mechanical characteristics of the connectors.

Wire-to-board version

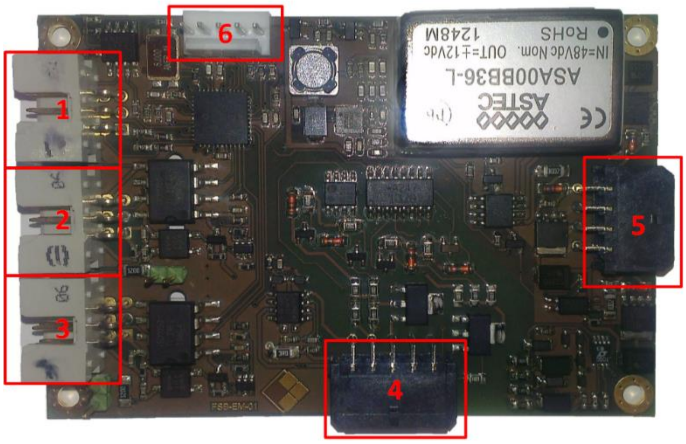


Figure 6 - FreeSB-PR top side view

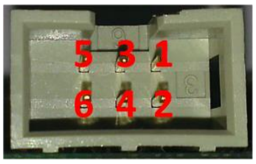
Connectors' description

Connector	**Description**
1	I^2C / GPIO connector
2	CAN bus n°1. Main CAN connected to FreeSafe Boards
3	CAN bus n°2. Secondary CAN for custom protocols
4	Connector for Hall sensor, continuity tester, insulation measurement
5	Input supply and output to contactors or fans
6	Programming connector

Connectors' references

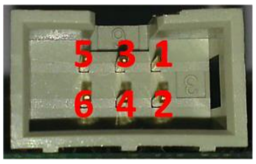
N°	**Onboard connector**		**Recommended complementary connector**	
	Manufacturer	Reference	Manufacturer	Reference
1, 2 & 3	Harting	09 18 506 7323	Harting	09 18 506 7803
			3M	3365/06
4	Molex	43045-1000	Molex	43025-1000
			Molex	46235-0001
5	Molex	43045-0800	Molex	43025-0800
			Molex	46235-0001

Connector n°1 - I²C / GPIO



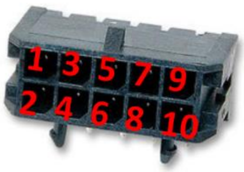
Pins	Description
1	Over Voltage signal
2	SDA
3	Digital I/O
4	SCL
5	Analog or digital I/O
6	NC

Connector n°2 & n°3 – CAN BUS



Pins	Description
1 – 2	5V output up to 200 mA
3	CAN L
4	CAN H
5 – 6	GND

Connector n°4 – Sensors inputs & outputs



Pins	Description
1	-12V output up to -250 mA
2	IM – Input measurement for Hall Effect sensor
3	Fn – Continuity testing input
4	+12V output up to 250 mA
5	Cp – Continuity testing input
6	Chassis
7	Cn – Continuity testing input
8	Fp – Continuity testing input
9	Bat+ – Continuity testing input
10	Bat- – Continuity testing input

Connector n°5 – Power inputs & outputs

Pins	Description
1	Power output negative – C3-
2	Power output positive - C3+
3	Power output negative - C2-
4	Power output positive - C2+
5	Power output negative- C1-
6	Power output positive - C1+
7	GNDsource
8	Vsource

Connector n°6 – Programming connector

Pins	Description
1	Reset
2	3.3V
3	GND
4	PGD
5	PDC

Alternative connector version

In this FreeSB-PR version, all connectors are replaced with standard pitch .100" (2.54mm) terminal strips enabling simple board-to-board interfacing. The pin configuration between the different versions is identical.

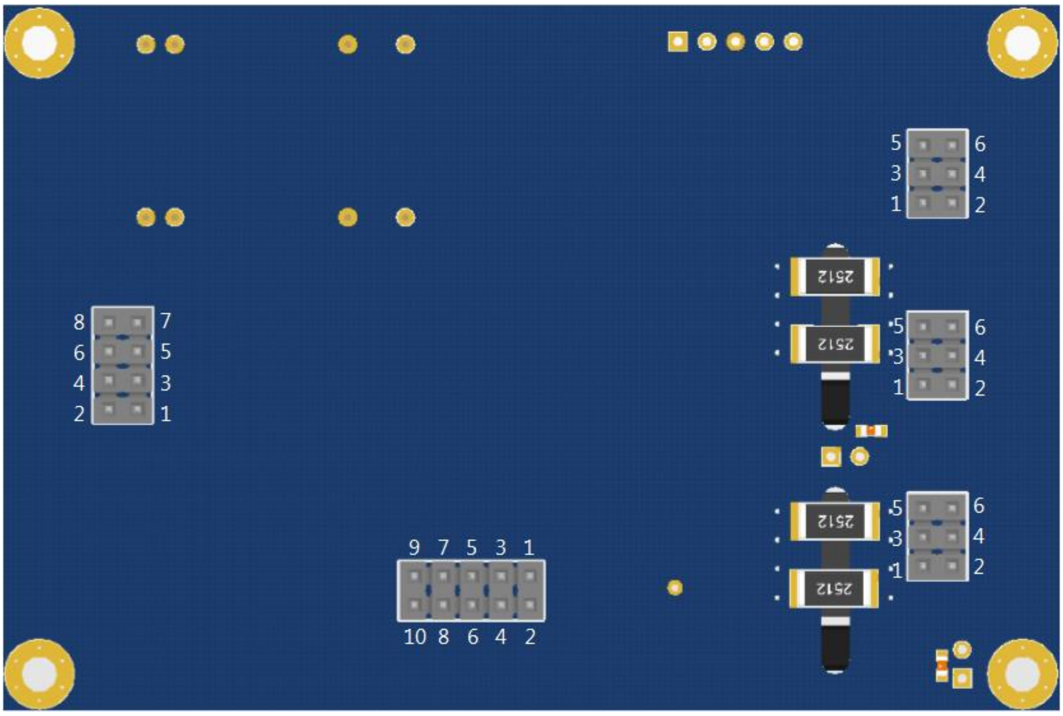


Figure 7 - FSB-PR alternate connector version. Bottom view.

	Onboard connector		Recommended complementary connector	
N°	Manufacturer	Part number	Manufacturer	Part number
1, 2 & 3	SAMTEC	TSW-103-07-T-D	SAMTEC	SSW-103-07-T-D
4	SAMTEC	TSW-105-07-T-D	SAMTEC	SSW-105-07-T-D
5	SAMTEC	TSW-104-07-T-D	SAMTEC	SSW-104-07-T-D
6	SAMTEC	TSW-105-07-T-S	SAMTEC	SSW-105-07-T-S

Connection procedure

Step	Connector	Comment
1	1, 2, 3 & 4	No particular steps are required for these connectors. FreeSB-PR will not start or power up before the power connector (n°5) is connected to the supply.
2	5	1 second after the connection, the initialization routine will close the main power contactor if no fault is detected.
Caution	6	Programming connector is only used when firmware update is necessary. Notice that pin 3 is referenced to the chassis terminal of the 4th connector. Caution must be taken when connecting a non-isolated debugger or programmer

Connection to the battery management system

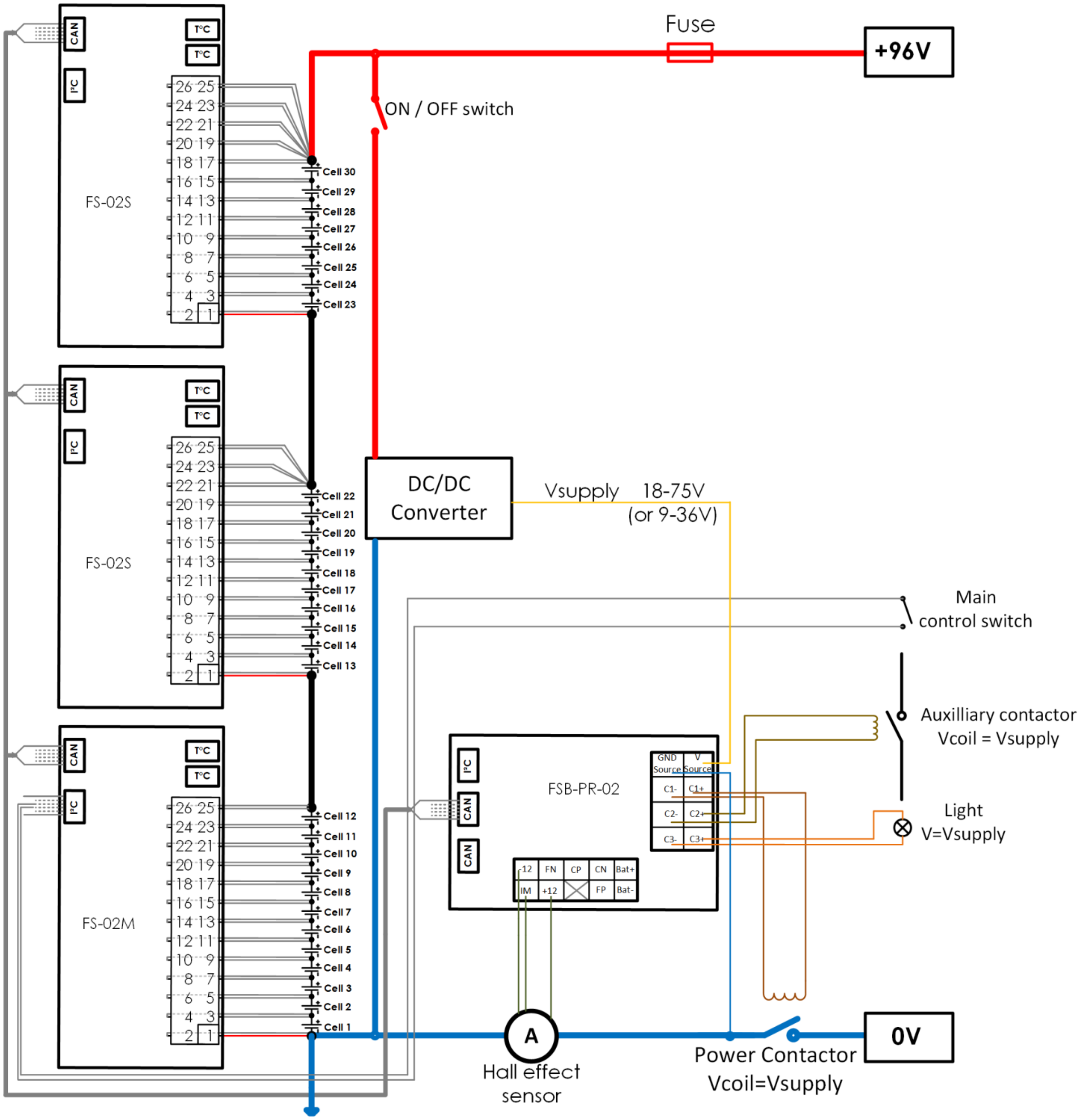


Figure 8 - A typical application for a 30 cells $LiFePO_4$ battery (96V), 12V DC contactors (power and auxiliary), warning light and on/off switch

Electrical Characteristics

The following specifications apply to the full operating temperature range

Supply

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Input Voltage	V_{in}		10		75	V
Supply Current[1]	I_s	Sleep Mode (Vin = 10 V)		29		mA
		Normal Mode (Vin = 10 V)	29,5	30	31	mA
		Sleep Mode (Vin = 75 V)	6,5			mA
		Normal Mode (Vin = 75 V)[2]	5	7	8	mA

[1] More details on the current consumption are shown on Figure 9 below.

[2] Temperature max on the board: 35°C. The ambient temperature is 25°C.

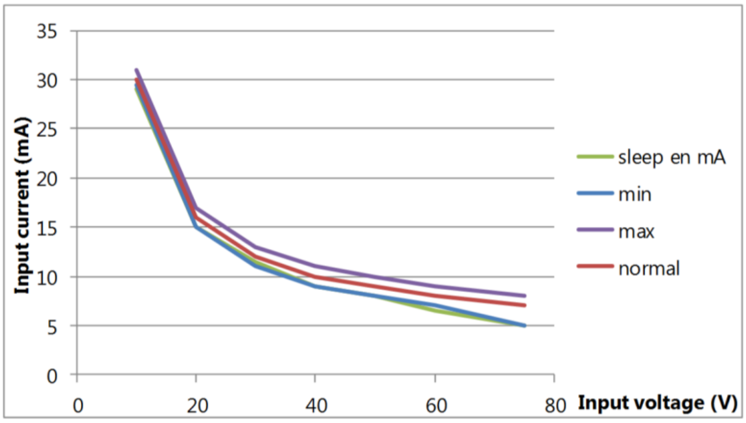


Figure 9 - Supply current vs input voltage

DC power output (for driving contactor, fan or other dc peripherals)

Parameter	Symbol	Conditions		Min	Typ	Max	Units
Output Voltage	V_{out}	$V_{out}=V_{in}$		10		75	V
Max peak current per output	I_{outmax}	Non repetitive t_{peak}=100ms				15	A
Max continuous current **per output**	I_{out}	Only **one** output working	T_{amb} =25°C			3.75	A
		All three outputs are working				2.1	A

CANBUS (main and custom secondary)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Supply Voltage (Bus side)	V_{bus}	Power on the bus is provided by the first BMS of the string		5		V
Can Bus Output Voltage **(dominant)**	CAN_H	Vi = 0 V, R_L=60 Ohm	2.9	3.5	4.5	V
	CAN_L		0.8	1.2	1.5	V
Can Bus Output Voltage **(recessive)**		Vi = 2 V, R_L=60 Ohm	2	2.3	3	V
Can Bus High-level output current	I_{OH}	Driver	-70			mA
		Receiver	- 4			mA
Can Bus Low-level output current	I_{OL}	Driver			70	mA
		Receiver			4	mA
Can Bus Rate of Operation	F_{can}			1		Mbps

I²C / GPIO (not isolated)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Max input / output voltage[3]				3.3	3.6	V
Min input / output voltage[3]			0			V

[3] inputs or outputs in 3.3V logic.

Hall Effect sensor

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Supply voltage	V_{hall}	Dual voltage supply	±11.6	±12	±12.4	V
Voltage ripple				120mV		
Max supply current[4]		Current consumption of Hall Effect sensor on ±12V supply			±250	mA
Max input current on FSB-PR	I_{hall}	Mandatory use of a current transducer Hall effect sensor			±110	mA
Internal ADC precision[5]		Output current of Hall sensor converted by a 12 bits ADC		0.054		mA

[4] the ±12V supply is short-circuit protected.

[5] the resolution of the conversion of the output current provided by the Hall Effect sensor. The 110mA max converted by a 12 bits ADC gives $110/2^{12}$=0.054mA/bit.

Operation

Standard peripherals

The use of FreeSB-PR requires the following devices:

- A configured FreeSafe system.

- A main contactor to allow or not the use of the battery. Connected on C1+ & C1- of connector n°5.

- A Hall Effect Sensor to measure the power current, to protect the battery and its application and to estimate some state indicators such as the State Of Charge (SOC) or the State Of Health (SOH) of the battery. Connected on ±12V & Im on connector n°4.

- Optional elements, such as an auxiliary contactor (connected on C2+ & C2- of connector n°5) to drive the external battery charger or a lamp indicator (connected on C3+ & C3- of the 5th connector) which is lighted when the SOC is less than 10%, are already provided in the standard operating version. If other functions are needed - e.g. fan driving or other operating logic for the contactors (power or auxiliary) - a custom firmware design will be necessary. The behavior of the peripherals on C2 and C3 output can easily be configured upon request before the firmware is loaded in the FSB-PR board. Further ongoing development will allow a fast configuration and reconfiguration through parameters stored on the memory card of FreeSafe without having to reload a new firmware.

Switches can be wired on FreeSafe to ensure some additional functionalities. The description of these functions are described in the FreeSafe datasheet and are resumed below.

- A switch to control the state of the main power contactor, the shutdown state and to re-engage the system when it enters in protection mode after a fault detection. The faults management is described in the section p14 "Fault management process". It is connected on the connector n°5 of FS-02M, between pins 2 and 3 (or between pin 2 and GND)

- An optional switch dedicated to the wake up function if needed by the application (example: the connection of a charger wakes the system up through the use of this function).

First connection

After its first connection to the main elements of the system (cf previous paragraph), the system starts if it is supplied. If no fault is detected - proper communication with the rest of the system, no over or under voltage or no over or under temperature of the battery - and if the main switch enable its operation, the main power contactor is driven and its contacts are closed to allow the use of the battery. Depending on the battery state (SOC<100% and no over voltage detected), the auxiliary contactor (if connected) is closed to allow a charge by the external charger. The lamp (if connected) is lighted as soon as the SOC falls under 10%. 10% is the default threshold, any over value can be configured before loading the firmware.

Tuning of the Hall Effect current sensor

The configuration file in the memory card of FreeSafe contains a few parameters enabling the current measurement:

- Id 9, CURRENT_MEAS_CONVENTION), enables the change of the convention sign of the current measurement. The convention for the current measurement of FSB-PR is to count positively the current that charge the battery and negatively the current that discharge the battery.

- Id 38, FSB_PR_LEM_GAIN, settles the gain of the chosen current sensor. For instance, with the LF 205-S/SP3 from LEM, FSB_PR_LEM_GAIN = 1000.
- Id 51, FSB_PR_REF_CURRENT, is the parameter that sets the value of the current reference to ensure that the measurement of a zero current value is truly on the 0A operating point.

The need of adjustment of the current measurement can be required in two cases. First, the sign of the current measurement does not match to the convention that the current charging the battery has to be positive. Second, the current measurement is not 0A when the power contactor is opened and must be adjusted.

In the first case, there are two solution: the current sensor can be re-wired in the other direction to be rotated by 180°, or the parameter CURRENT_MEAS_CONVENTION in the configuration file can be modified to fit the convention.

For the second case, the parameter FSB_PR_REF_CURRENT will be used to settle the internal reference of FSB-PR to get the right zero current measurement. The following method has to be applied:

- Ensure that no current is flowing in the battery through the current sensor
- Read the value of the current measured *Imes* (average value on a few seconds)
- Modify the parameter FSB_PR_REF_CURRENT in the configuration file according to the formula bellow

$$\mathrm{FSB\_PR\_REF\_CURRENT}\ (new\ value) = \mathrm{FSB\_PR\_REF\_CURRENT}\ (previous\ value) + \frac{Imes * 18618}{\mathrm{FSB\_PR\_LEM\_GAIN}}$$

- Reset FreeSafe to force the loading of the new value
- Check the modification by reading the new value of the 0A.

N.B. 1: after the modification of one or several parameters in the configuration file, a reset of FreeSafe is mandatory to insure that the new parameters are loaded.

N.B. 2: very low current values, under 1% of the nominal current, can be subject to noise perturbations and are not measured.

The battery is then ready to be used in its standard operation.

Standard operation

After the first connection, if no action on the battery (current consumption for example) is detected during 60 seconds, FreeSB-PR enters in a standby mode and the 3 power outputs are turned OFF to save energy. To exit the standby mode, the wake up switch or the main switch must be activated. It is also possible to activate the main switch to wake the system up and to turn the main contactor ON again.

When the battery is ready to be used, any current can be applied to charge or discharge it. Every 100ms, the state of the battery (including current measurement, coulomb counting and fault detection) is transmitted and updated between FreeSafe and FreeSB-PR via CAN communication.

The main switch has three functions. The first one is to change the state of the main power contactor (closed or opened). The second one affects the default mode and allows the user to restart the contactor after a fault management. This function is described in the section “Fault management process” below. The last function is to wake up the system or allow its shutdown.

Fault management process

Whenever a fault is detected (e.g over current or communication error), the standard fault management is started. The main power contactor is opened to protect the battery and its application. A manual action from the user - to acknowledge the fault detection, to find the error and if needed, to repair it - will be requested via the main control switch to allow FreeSB-PR to resume its operation.

There are three fault managements that are not included in this process: the short circuit, the under voltage and the communication faults. They are described in the next paragraphs.

Short circuit (i.e. hard current limit) management

Among the configuration parameters available in FreeSafe, a pair sets the positive and negative hard current limit ("**CURRENT_PIC**" and "**CURRENT_PIC_NEG**"). Beyond these limits, FreeSB-PR instantaneously opens the main DC contactor to protect the system. The time response of this protection depends on two elements: the response time of the current sensor chain and the response time of the contactor.

- Response time of the Hall Effect sensor. If the selected device has similar characteristics to the ones proposed in the "Sensors and drivers" section, it will be <10µs – they have a measurement bandwidth of 100 kHz.
- Response time of the analog to digital conversion and processor decision management. It will be less than 100µs as the whole process is calibrated to work at 10 kHz.
- Response time of the power DC contactor. If the selected device has similar characteristics to the one proposed in the "Sensors and drivers" section, it will be less than 12ms.

After detecting a short circuit and opening the power DC contactor, FreeSB-PR waits for the reboot switch to be activated in order to re-engage the power contactor and resume its operation.

Under voltage management

Like any over error, the standard fault management is applied. Normally, after a voltage fault the voltage returns to the standard values: for an overvoltage, as soon as the current stops, the cells' voltages decrease and stabilize to a value under the overvoltage limit. The same applies for the under voltage limit, as soon as the current stops, the cells' voltages rise and stabilize to a value higher than the under voltage limit.

When there are devices that cannot be disconnected by the main power contactor (for instance any critical device which must not be shut down like the battery management system or an emergency power supply), a problem with the under voltage management appears. Even if the main power contactor is opened, there is still some current that can be drawn and keep the battery cells under the voltage limit. The main contactor cannot be closed automatically and so it will not be possible to charge the battery without an external action from the user: the switch must be used to force the circuit closure. The contactor will be opened 60 seconds later if no charge current is measured. Any discharge current detected during this forced closure will lead to an immediate opening of the contactor to protect the battery.

Communication error management

If a communication error is detected, a retry is attempted 5 times, each 10ms. One second later, if FreeSB-PR still cannot exchange any information with FreeSafe, it will assume a communication fault and to protect the system will open the main power contactor until the communication is reestablished.

Over current (i.e. soft current limit) management

There are 3 configurable parameters: "**CURRENT_LIMIT**", "**CURRENT_TIME**" and "**CURRENT_NOMINAL**" for positive current and "**CURRENT_LIMIT_NEG**", "**CURRENT_TIME_NEG**" and "**CURRENT_NOMINAL_NEG**" for negative current.

CURRENT_NOMINAL is used to define the nominal current at which the system is designed to be used (i.e thermally stable). It can be the nominal current of the battery itself or the nominal current of its application.

CURRENT_TIME defines the allowed time of an overcurrent that exceeds the CURRENT_LIMIT value.

See chapter "Features being developed for next firmware release" for more details about the overcurrent management in the next firmware release.

Configuration

Thanks to the configuration file hosted on FreeSafe and its communication via CAN BUS, various software elements of FreeSB-PR can be configured. Among all the available parameters, the following list gives and briefly describes the ones related to FreeSB-PR configuration. The complete list of the parameters with their full description is available in the FreeSafe datasheet (section "configuration", table 13 in page 20 in the FreeSafe datasheet).

Mechanical Characteristics

This section presents the mechanical data of the two connector variants of FreeSB-PR: the wire-to-board connectors and the standard board-to-board. 100" pitch connector.

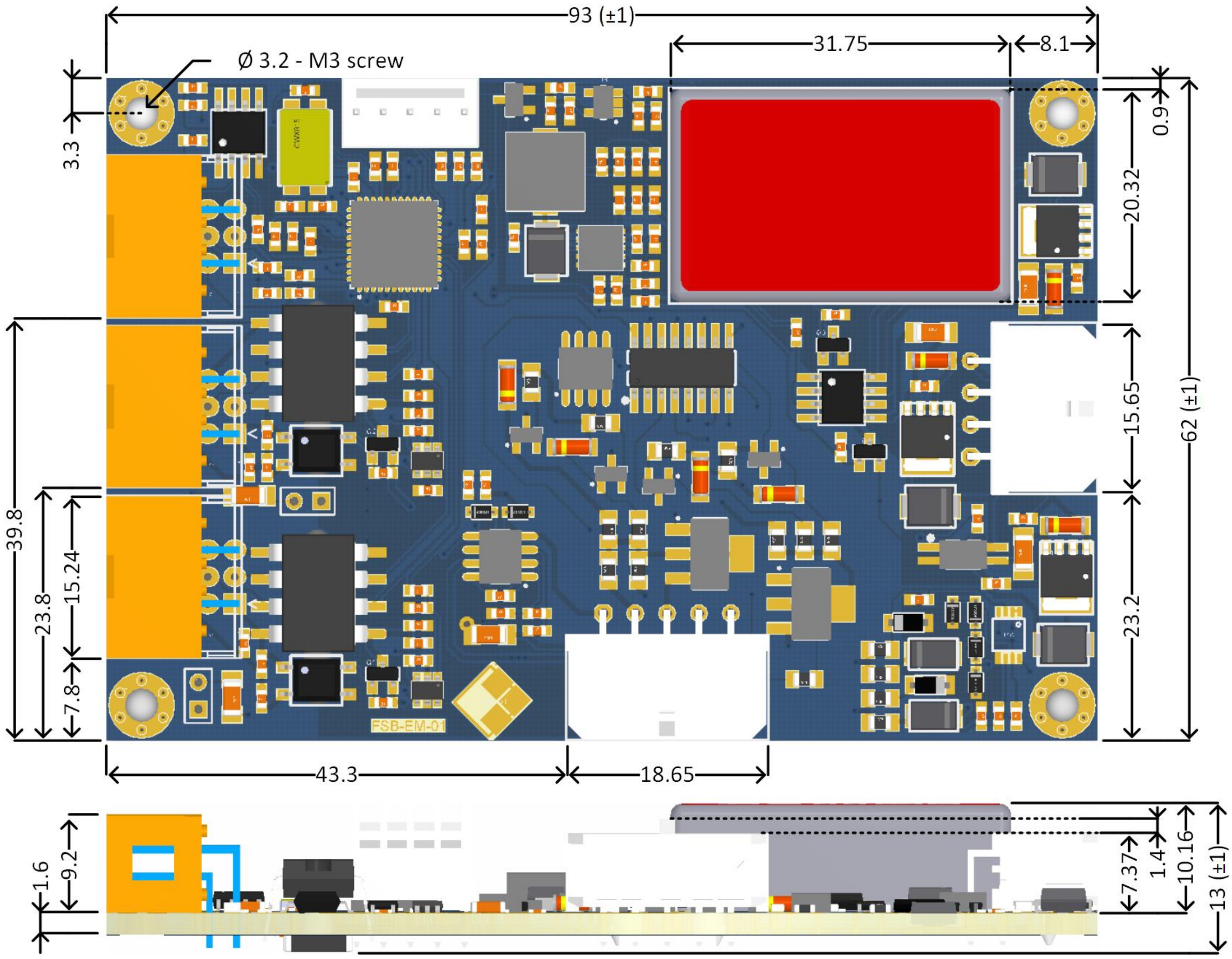


Figure 10 - Mechanical views (top and side views) of FSB-PR. Wire-to-board connector version. All dimensions are in mm.

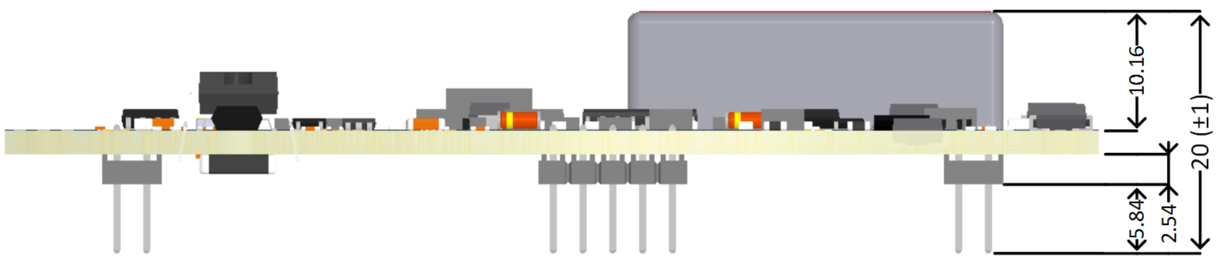
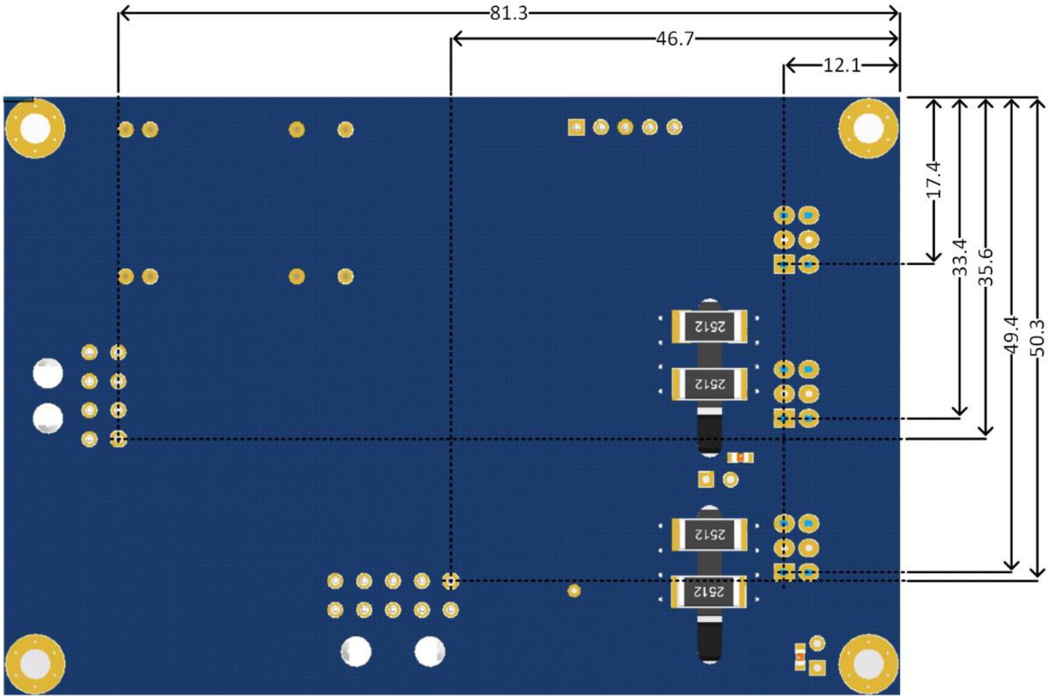


Figure 11 -Mechanical view (side view) of FSB-PR. Board-to-board connector version. All dimensions are in mm.

Wire-to-board version



Board-to-board version

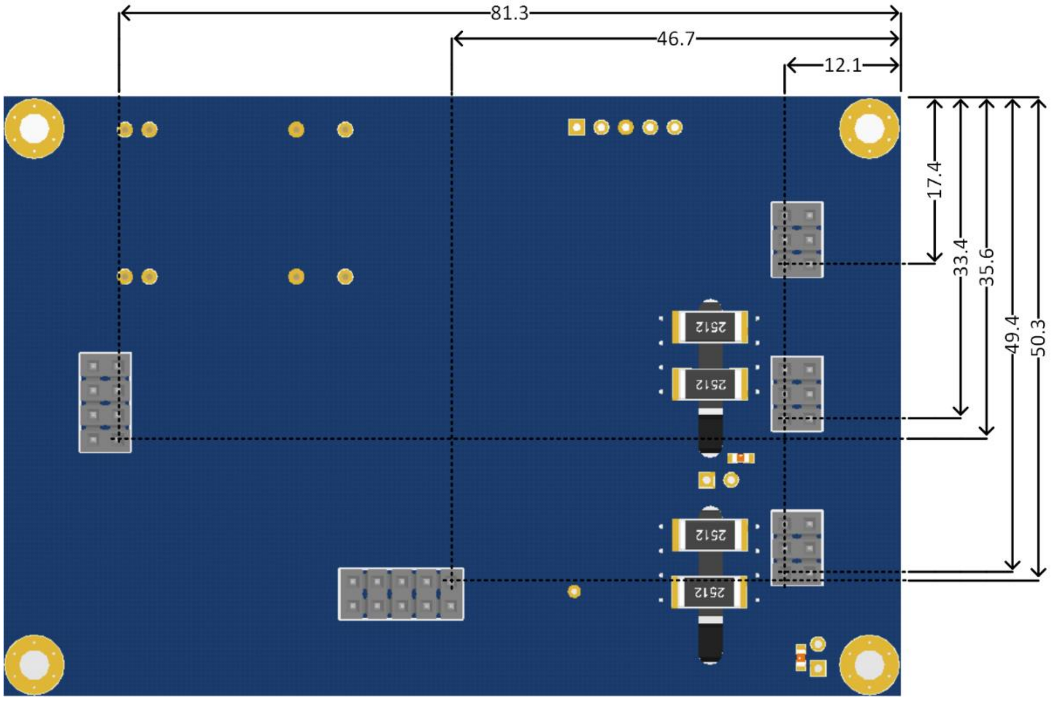


Figure 12 -Coordinates of the pin n°1 of each connector for the two connectors' variants. All dimensions are in mm.

The coordinates of the pins n°1 of each connector are the same for the two FSB-PR variants (wire-to-board and board-to-board). The differences occur on the pitch of the connectors: for connectors n°4 & 5 (power inputs & outputs and sensors & drivers) the pitch is 3mm for the wire-to-board version or 2.54mm for the board-to-board version.

Features being developed for the next firmware release

Fuse and contactor continuity tester

The continuity testers available in FSB-PR are specially designed to detect a continuity break on the positive or negative power line of the battery.

To use the continuity testers, some potentials must be wired to the system and are limited to the two power lines of the battery. In fact, the continuity between the Bat+ and Fp, Bat+ and Cp for the positive power line is tested. For the negative power line, the continuity between Bat- and Fn, Bat- and Cn is tested. Figure 13 shows a typical application with fuse and contactor protection on each power line.

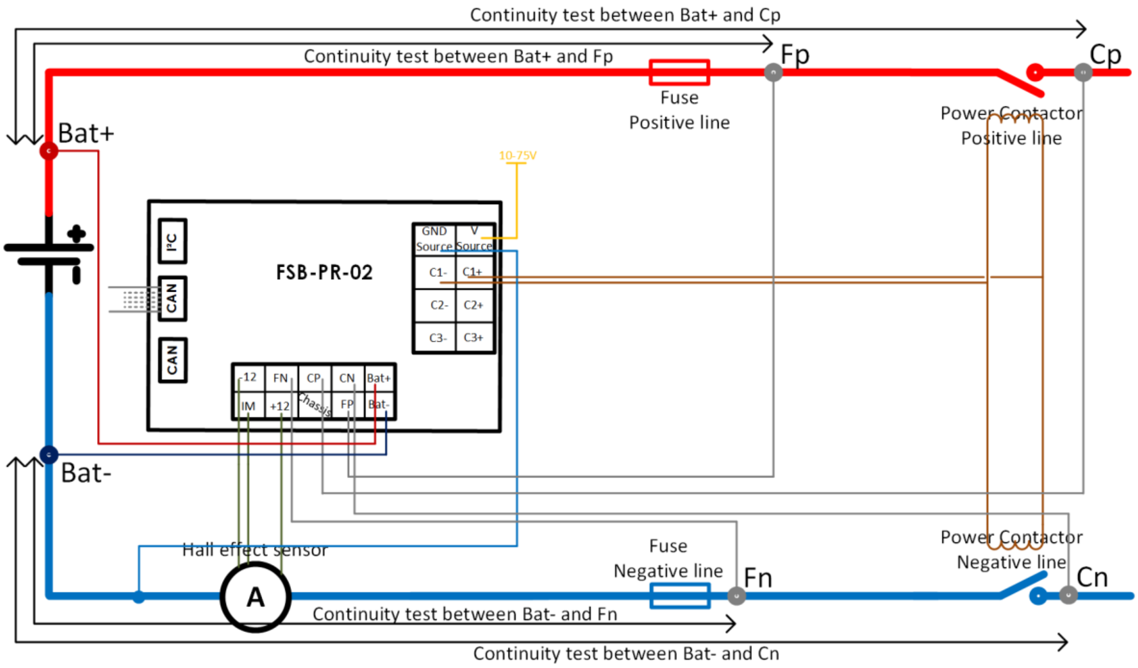


Figure 13 - Wiring (in grey lines) to test the fuse and contactor continuity with FSB-PR

As shown on Figure 13, there is a priority in the continuity of the tests. If the first element (tested between Bat+ and Fp) is opening the circuit, the second (tested between Bat+ and Cp) will be seen as opened even if it is closed. The table below summarizes these events. D_Fp is the logic output of the continuity tester on Fp (0 means no discontinuity detected, 1 means discontinuity detected), D_Cp for Cp, etc.

D_Fp	D_Cp	Positive fuse state	Positive contactor State
0	0	ON	ON
0	1	ON	OFF
1	X	OFF	X

D_Fn	D_Cn	Negative fuse state	Negative contactor State
0	0	ON	ON
0	1	ON	OFF
1	X	OFF	X

Standard operation of continuity testing

Each time after driving the main power contactor to close, a continuity test is performed. If a continuity fault is detected, it is transferred to FreeSafe, saved in its memory and the standard fault management is engaged.

In order to configure the continuity tester inside the FSB-PR software, there is a variable in the configuration file of FreeSafe: “**CONTINUITY_TEST**”. It is a 4 bits variable where each bit corresponds to a continuity test on Fp, Cp, Fn or Cn. 0 means the test is disabled and 1 means the test is enabled.

CONTINUITY_TEST	Bit 0	Bit 1	Bit 2	Bit 3
Enable test on	Fp	Cp	Fn	Cn

To disable the continuity test functions, it is recommended to set CONTINUITY_TEST=0000 and not to connect Bat+, Bat-, Fp, Cp, Fn and Cn. N.B: if the insulation measurement function is used, Bat+ and Bat- MUST be connected.

Over current (i.e. soft current limit) management

There are 3 configurable parameters: "**CURRENT_LIMIT**", "**CURRENT_TIME**" and "**CURRENT_NOMINAL**" for positive current and "**CURRENT_LIMIT_NEG**", "**CURRENT_TIME_NEG**" and "**CURRENT_NOMINAL_NEG**" for negative current.

CURRENT_NOMINAL is used to define the nominal current at which the system is designed to be used (i.e thermally stable). It can be the nominal current of the battery itself or the nominal current of its application.

CURENT_LIMIT defines an authorized pulse of constant current over the nominal current for a set CURRENT_TIME time.

To facilitate the writing of the used equation, the parameters are named in this document as following:

I_{nom} is the nominal current ("CURRENT_NOMINAL" parameter)

I_{oc} is the overcurrent limit ("CURRENT_LIMIT" parameter)

t_{oc} is the overcurrent allowed time ("CURRENT_TIME" parameter)

Isc is the short circuit limit ("CURRENT_PIC" parameter)

The management of overcurrent follows an I^2t logic. The parameters given in the initial configuration are used to set the reference: $(I_{oc} - I_{nom})^2 \cdot t_{oc}$, and then for any continuous current, it is possible to determine the maximum allowed time with $(I(t) - I_{nom})^2 \cdot t = (I_{oc} - I_{nom})^2 \cdot t_{oc}$. The next paragraph and Figure 14 show an example in order to support the comprehension.

For non-constant current, the I^2t logic is still followed thanks to the implemented integral method. It consists on the comparison between the reference $I_{oc}^2 t_{oc}$ and the integration of the measured current over time.

Example of hard and soft current limit management

We define a battery with I_{nom}=100A, I_{oc}=**150A**, t_{oc}=**10s** and the hard current limit I_{sc}=200A for its discharge characteristics. With only these parameters, FreeSB-PR can manage the overcurrent according to the explained method. For any constant current, the behavior of FreeSB-PR is resumed on the following curves Figure 14.

- Any current below the nominal current can operate for an infinite time – the safe operating area under the blue line in Figure 14.
- Any current between I_{nom} and I_{oc} can be maintained for a short amount of time – the overcurrent management area between the blue and red lines in Figure 14**Erreur ! Source du renvoi introuvable.**. For instance a 110A current (10% over the nominal) is allowed for 250s while a 175A current (75% over the nominal) is allowed for only 4.5s. This red curve is defined from I_{nom}, I_{oc} and t_{oc} parameters: $I(t) = \sqrt{\frac{(I_{oc}-I_{nom})^2 t_{oc}}{t}} - I_{nom}$ - comes from : $(I(t) - I_{nom})^2 \cdot t = (I_{oc} - I_{nom})^2 \cdot t_{oc}$

- Any current over the hard current limit (200A) is in the protected area where the power DC contactor is opened.

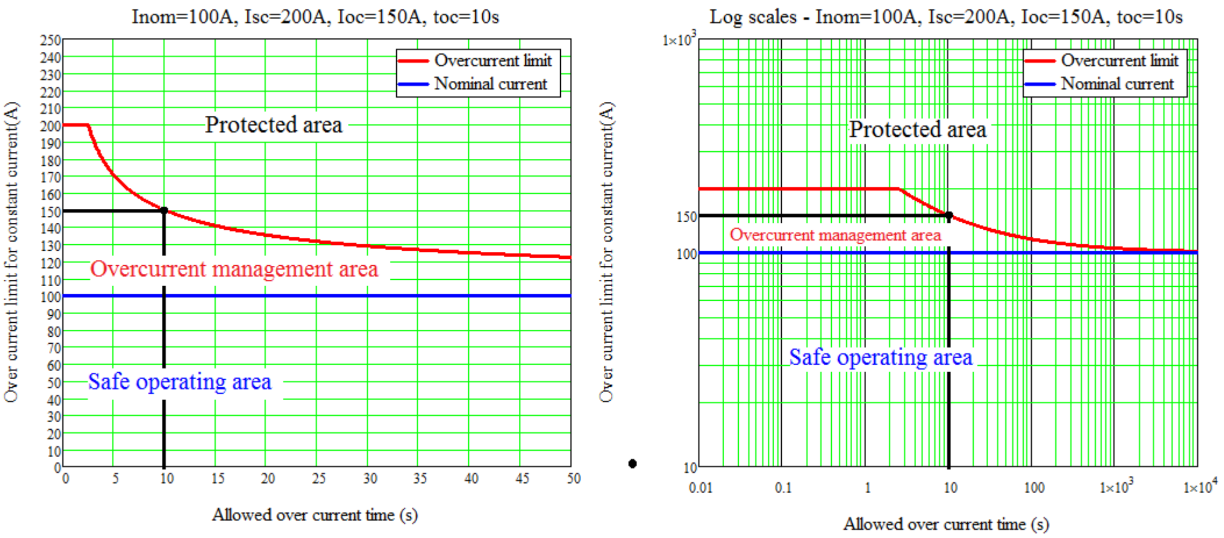


Figure 14 - Example of overcurrent management curves for constant current

Type / Technical data	EMRAX 228 High Voltage		EMRAX 228 Medium Voltage		EMRAX 228 Low Voltage	
Cooling (AC – Air Cooled; LC – Liquid Cooled)	**LC**	**AC**	**LC**	**AC**	**LC**	**AC**
Cooling medium spec.	water flow speed 0,2 l/s; 20 °C	air flow speed 25 m/s; 20 °C	water flow speed 0,2 l/s; 20 °C	air flow speed 25 m/s; 20 °C	water flow speed 0,2 l/s; 20 °C	air flow speed 25 m/s; 20 °C
Weight [kg]	12,3	12,0	12,3	12,0	12,3	12,0
Diameter ø / width [mm]	228 / 86					
Battery voltage range [Vdc]	50 – 400 (*600)		50 – 350 (*450)		24 – 100 (*140)	
Peak motor power (few min at cold start / few seconds at hot start) [kW]	**100**					
Continuous motor power (depends on the motor RPM) [kW]	30 - 50	25 - 40	30 - 50	25 - 40	30 - 50	25 – 40
Maximal rotation speed [RPM]	4000 (*5000) (**6000)					
Maximal motor current (for 2 min if cooled as described in Manual for EMRAX) [Arms]	240		320		900	
Continuous motor current [Arms]	115		160		450	
Maximal motor torque (for a few seconds) [Nm]	240					
Continuous motor torque [Nm]	125					
Torque / motor current [Nm/1Aph rms]	**1,1**		**0,75**		**0,27**	
Maximal temperature of the copper windings in the stator and also max. temp. of the magnets [°C]	120					
Motor efficiency [%]	93 - 97					
Internal phase resistance at 25 °C [mΩ]	18		8,0		1,12	
Input phase wire cross-section [mm^2]	10,2		15,2		38	
Induction in Ld/Lq [µH]	175/180		75/80		10,6/11,2	
Controller / motor signal	sine wave					
Specific idle speed (no load RPM) [RPM/1Vdc]	9,8		14		40	
Specific load speed (depends on the controller settings) [RPM/1Vdc]	8 – 9,8		11 – 14		34 – 40	
Magnetic field weakening (for higher RPM at low torque) [%]	up to 50					
Magnetic flux – axial [Vs]	0,0542		0,0355		0,0131	
Temperature sensor in the motor	kty 81/210					
Number of pole pairs	10					
Rotor inertia (mass dia=175mm, m=5,5kg) [kg*cm²]	421					
Bearings SKF _ FAG	**R/R 6206/6206** or R/AR 6206/7206 or AR/AR 7206/7206 (»O« orientation)					
Ingress protection	IP21 / IP54***/IP64***	IP21	IP21 / IP54***/IP64***	IP21	IP21 / IP54***/IP64***	IP21

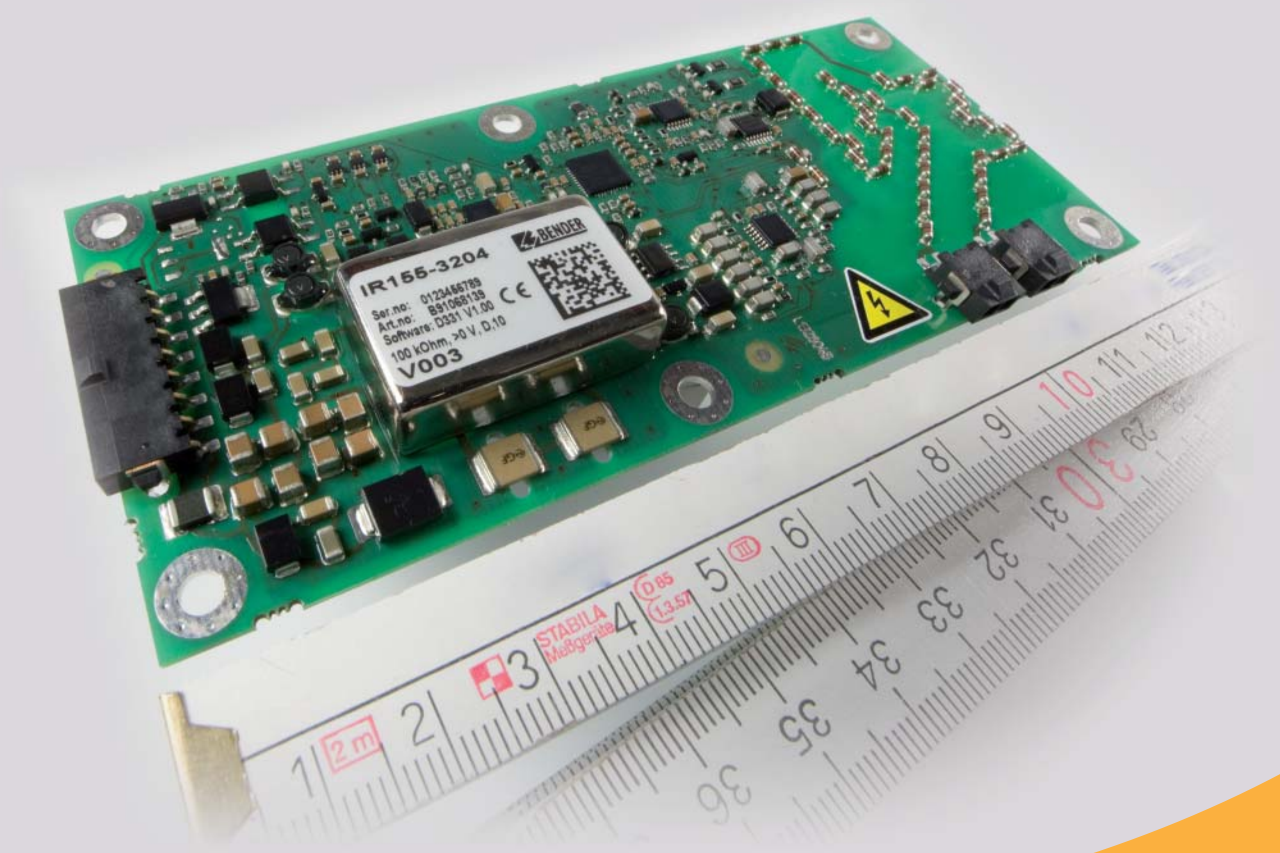
*Tested in Enstroj for a few minutes.
**Tested in Enstroj for a few seconds.
***EMRAX with IP54 has shorter load time and continuous power is approximately 20 to 30% lower compared to EMRAX with IP21. Peak power is the same. EMRAX with IP64 has additional cooling, so the performances are the same as EMRAX with IP21. This is valid only for liquid cooled motors. Dimensions of EMRAX with IP64 are a little bigger (drawing is published on our web site).

These data are valid for the motors, which were sold after January 2014.

A-ISOMETER® IR155-3203 / IR155-3204

Insulation monitoring device (IMD) for unearthed DC drive systems (IT systems) in electric vehicles

Preliminary data sheet



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A-ISOMETER® IR155-3203 / IR155-3204

Insulation monitoring device (IMD) for unearthed DC drive systems (IT systems) in electric vehicles

A-ISOMETER® IR155-3204

Device features

- Suitable for 12 V and 24 V systems
- Automatic device self test
- Continous measurement of insulation resistance 0…10 MΩ
  - Response time < 2 s after power on for first estimated insulation resistance (SST)
  - Response time < 20 s for measured insulation resistance (DCP)
- Automatic adaptation to the existing system leakage capacitance (≤1 µF)
- Detection of ground faults and lost ground line
- Isolation monitoring of AC and DC insulation faults for unearthed systems (IT systems) 0 V…1000 V peak
- Low voltage detection for voltages below 500 V (value configurable EOL Bender)
- Short protected outputs for:
  - Fault detection (high side output)
  - Measurement value (PWM 5 % … 95 %) & status (f = 10 Hz…50 Hz) at high or inverted low side driver (M_{HS} / M_{LS} output)
- Conformal coating (SL1301ECO-FLZ)

Product description

The A-ISOMETER® iso-F1 IR155-3203/-3204 monitors the insulation resistance between the insulated and active HV-conductors of an electrical drive system (U_n = DC 0 V…1000 V) and the reference earth (chassis ground ▸ Kl.31). The patented measurement technology is used to monitor the condition of the insulation on the DC side as well as on the AC motor side of the electrical drive system. Existing insulations faults will be signalised reliably even under high system interferences which can be caused by motor control processes, accelerating, energy recovering etc.

Due to its space saving design and optimised measurement technology, the device is optimised for use in hybrid or fully electric vehicles. The device meets the increased automotive requirements with regard to the environmental conditions (e.g. temperatures and vibration, EMC…).

The fault messages (insulation fault at the HV-system, connection or device error of the IMD) will be provided at the integrated and galvanic isolated interface (high- resp. low-side driver). The interface consists of a status output (OK_{HS} output) and a measurement output (M_{HS} / M_{LS} output). The status output signalises errors resp. the “good” condition. The measurement output signalises the actual insulation resistance. Furthermore it’s possible to distinguish between different fault messages and device conditions, which are base frequency encoded.

Function

The A-ISOMETER® iso-F1 IR155-3203/-3204 generates a pulsed measuring voltage, which is superimposed on the IT system by the terminals L+/L- and E/KE. The currently measured insulation condition is available as a pulse-width-modulated signal at the terminals M_{HS} resp. M_{LS}. The connection between the terminals E/KE and the chassis ground (▸ Kl.31) is continuously monitored. Therefore it’s necessary to install two separated conductors from the terminals E resp. KE to chassis ground.

Once power is switched on, the device performs an initialisation and starts the SST measurement. The device provides the first estimated insulation resistance during a maximum time of 2 sec. The DCP measurement (▸ continuous measurement method) starts subsequently. Faults in the connecting wires or functional faults will be automatically recognised and signalled.

During operation, a self test is carried out automatically every fife minutes. The interfaces will not be influenced by these self tests.

Standards

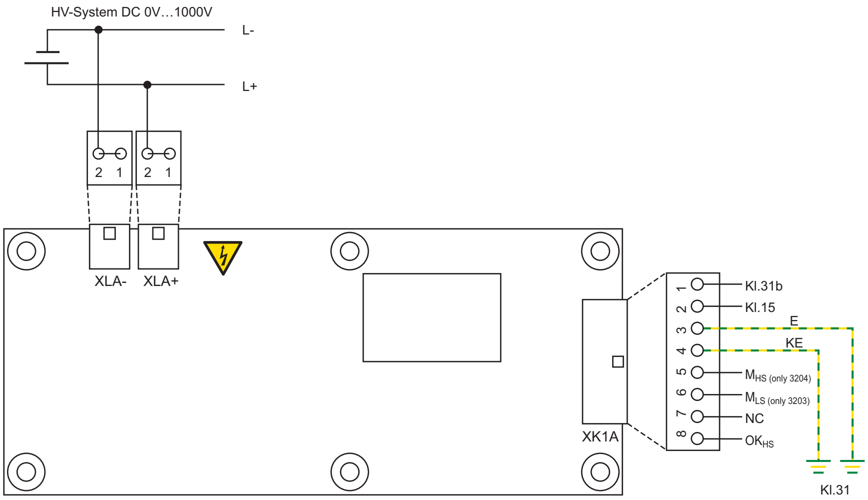
Corresponding norms and regulations

IEC 61557-1	2007-01
IEC 61557-8	2007-01
ISO 6469-3	2001-11
ISO 23273-3	2006-11
ISO 16750	2006 (E)
IEC 61010-1	2001-02
IEC 60664-1	2007-04
IEC 61326-2-4	2010
e1 acc. 72/245/EWG/EEC	

Abbreviations

DCP	Direct Current Pulse
SST	Speed Start Measuring

Wiring diagrams



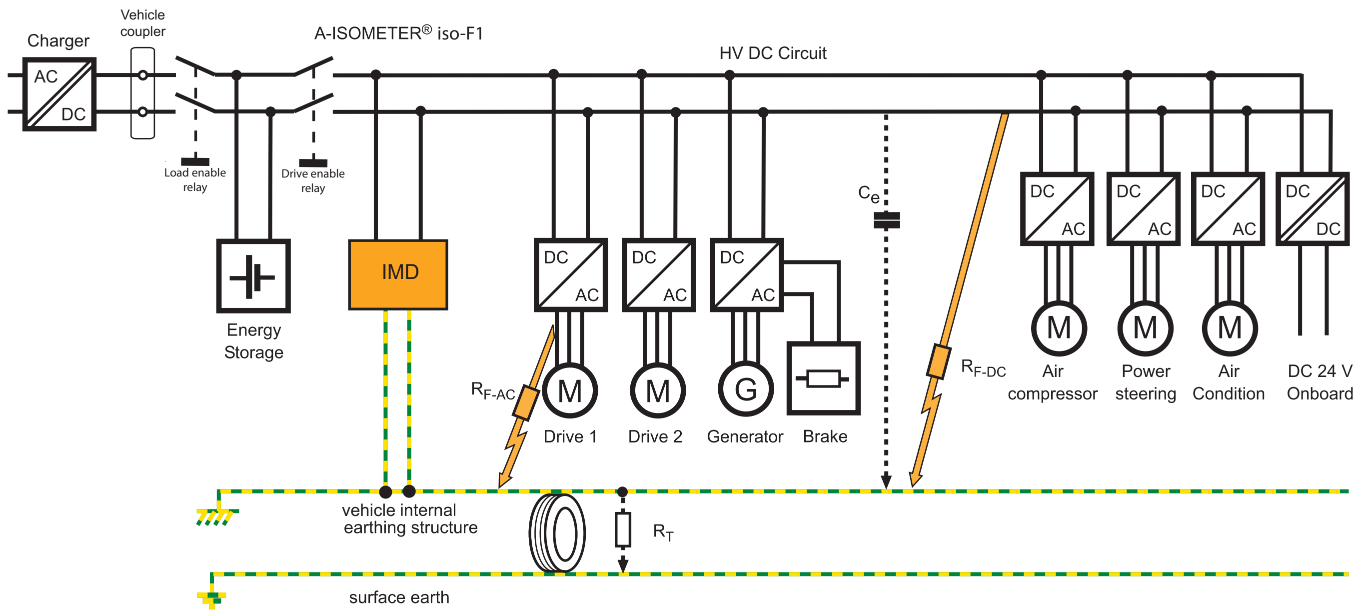
Connector XLA+
Pin 1+2 L+ Line voltage

Connector XLA-
Pin 1+2 L- Line voltage

Connector XK1A

Pin 1	Kl. 31b	Electronic ground
Pin 2	Kl. 15	Supply voltage
Pin 3	Kl. 31	Chassis ground
Pin 4	Kl. 31	Chassis ground (sep. line)
Pin 5	M_{HS}	Data Out, PWM (high side)
Pin 6	M_{LS}	Data Out, PWM (low side)
Pin 7	n.c.	
Pin 8	OK_{HS}	Status Output (high side)

Typical application

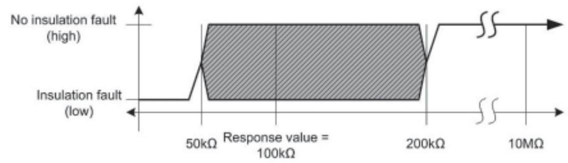


Technical data

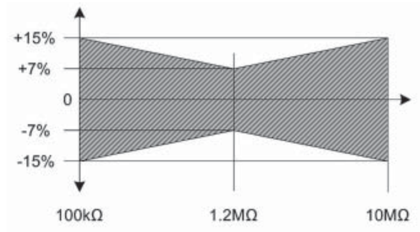
Supply voltage U_S	DC 10…36 V
Nominal supply voltage	DC 12 V / 24 V
Voltage range	10 V…36 V
Max. operational current I_S	150 mA
Max. current I_k	2 A 6 A / 2 ms Rush-In current
Power dissipation P_S	< 2 W
Line L+ / L- Voltage U_n	AC 0 V…1000 V peak; 0 V…660 V rms (10 Hz…1 kHz) DC 0 V…1000 V
Protective separation (reinforced insulation) between	(L+ / L-) – (Kl.31b, Kl.15, E, KE, M_{HS}, M_{LS}, OK_{HS})
Voltage test	AC 3500 V / 1 min
Under voltage detection	0 V…500 V; Default: 0 V (inactive)
System leakage capacity C_e	≤ 1 µF
Measuring voltage U_m	+/- 40 V
Measuring current I_m at $R_F = 0$	+/- 33 µA
Impedance Z_i at 50 Hz	≥ 1.2 MΩ
Internal resistance R_i	≥ 1.2 MΩ
Measurement range	0…10 MΩ
Measurement method	Bender DCP technologie
Factor averaging F_{ave} (Output M)	1…10 (default: 10; EOL Bender)
Relative error at SST (≤ 2s)	Good > 2 * R_{an}; Bad < 0.5 * R_{an}
Relative error at DCP	0…85 kΩ ▶ +/-20 kΩ 100 kΩ…10 MΩ ▶ +/-15 %
Relative error Output – M (base frequencies)	+/- 5 % at each frequency (10 Hz; 20 Hz; 30 Hz; 40 Hz; 50 Hz)
Relative error under voltage detection	U_n ≥100 V ▶ +/-10 %; at U_n ≥300 V ▶ +/-5 %
Response value hysteresis (DCP)	25 %
Response value R_{an}	100 kΩ…1 MΩ ▶ higher tolerances at R_{an} < 85 kΩ; (Default: 100 kΩ)
Response time t_{an} (OK_{HS}; SST)	t_{an} ≤ 2 s (typ. < 1 s at U_n > 100 V)
Response time t_{an} (OK_{HS}; DCP) (Changeover R_F: 10 MΩ ▶ R_{an}/2; at C_e = 1 µF; U_n = 1000 V DC)	t_{an} ≤ 20 s (at F_{ave} = 10*) t_{an} ≤ 17.5 s (at F_{ave} = 9) t_{an} ≤ 17.5 s (at F_{ave} = 8) t_{an} ≤ 15 s (at F_{ave} = 7) t_{an} ≤ 12.5 s (at F_{ave} = 6) t_{an} ≤ 12.5 s (at F_{ave} = 5) t_{an} ≤ 10 s (at F_{ave} = 4) t_{an} ≤ 7.5 s (at F_{ave} = 3) t_{an} ≤ 7.5 s (at F_{ave} = 2) t_{an} ≤ 5 s (at F_{ave} = 1) during self test ▶ t_{an} + 10 s

* F_{ave} = 10 is recommended for electric vehicles

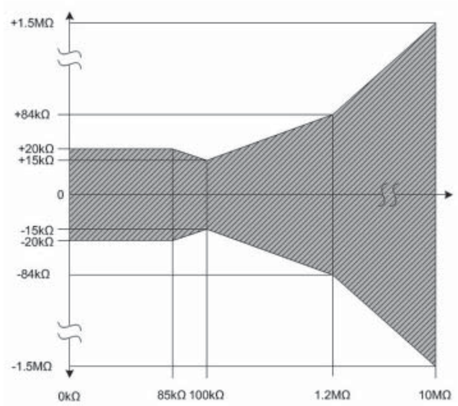
Switch-off time t_{ab} (OK_{HS}; DCP) (Changeover R_F: $R_{an/2}$ ▶ 10 MΩ; at C_e =1 µF; U_n = 1000V DC)	t_{ab} ≤ 40 s (at F_{ave} = 10) t_{ab} ≤ 40 s (at F_{ave} = 9) t_{ab} ≤ 33 s (at F_{ave} = 8) t_{ab} ≤ 33 s (at F_{ave} = 7) t_{ab} ≤ 33 s (at F_{ave} = 6) t_{ab} ≤ 26 s (at F_{ave} = 5) t_{ab} ≤ 26 s (at F_{ave} = 4) t_{ab} ≤ 26 s (at F_{ave} = 3) t_{ab} ≤ 20 s (at F_{ave} = 2) t_{ab} ≤ 20 s (at F_{ave} = 1) during self test ▶ t_{ab} + 10 s
Self test time	10 s (every 5 minutes; has to be added to t_{an} / t_{ab})
Relative error (SST)	"Good-Value" ≥ 2 * R_{an} "Bad-Value" ≤ 0.5 * R_{an}



Relative error (DCP)	100 kΩ ▶ +/-15 % 100 kΩ…1.2 MΩ ▶ +/-15 % to +/-7 % 1.2 MΩ ▶ +/-7 % 1.2 MΩ…10 MΩ ▶ +/-7 % to +/-15 % 10 MΩ ▶ +/-15 %



Absolute error (DCP)	0 Ω…85 kΩ ▶ +/-20 kΩ



Measurement Output (M)

M_{HS} switches to U_S – 2 V (3204)
(external load to ground necessary)

M_{LS} switches to Kl.31b +2 V (3203)
(external load to U_b necessary)

0 Hz ▶ Hi > short to U_b+ (Kl.15); Low > IMD off or short to Kl.31

10 Hz ▶ Normal Condition
Insulation measuring DCP;
starts 2 s after Power-On;
first successful insulation measurement at ≤ 17.5 s
PWM active 5 %…95 %

20 Hz ▶ Under voltage condition
Insulation measuring DCP (correct measurement);
starts 2 s after Power-On;
PWM active 5 %…95 %
first successful insulation measurement at ≤ 17.5 s
Under voltage detection 0 V…500 V
(EOL Bender configurable).

30 Hz ▶ Speed Start
Insulation measuring (only good/bad estimation);
Starts directly after Power-On; response time ≤ 2 s;
PWM 5 %…10 % (good) and 90 %…95 % (bad)

40 Hz ▶ IMD Error
IMD error detected; PWM 47.5%…52.5%

50 Hz ▶ Ground error
Error on measurement ground line (Kl. 31) detected
PWM 47.5%…52.5%

OK_{HS} Output

OK_{HS} switches to U_S – 2V
(external load to ground necessary)

High ▶ No fault; R_F > response value
Low ▶ Insulation resistance ≤ response value detected; IMD error; ground error, under voltage detected or IMD off
(ext. pull-down resistor required)

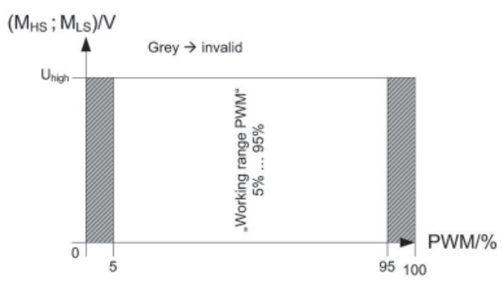
Operating principle PWM- driver

- Condition "Normal" and "Under voltage detected" (10Hz; 20Hz)

Duty cycle ▶ 5 % = >50 MΩ (∞)
Duty cycle ▶ 50 % = 1200 kΩ
Duty cycle ▶ 95 % = 0 kΩ

$$R_F = \frac{90\% \times 1200\ k\Omega}{dc_{meas} - 5\%} - 1200\ k\Omega$$

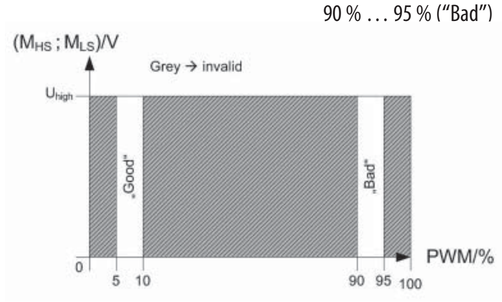
dc_{meas} = measured duty cycle (5 %…95 %)



Operating principle PWM- driver

- Condition "SST" (30Hz)

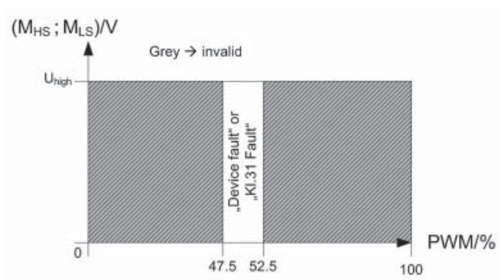
Duty cycle ▶ 5 %…10 % ("Good")
90 % … 95 % ("Bad")



Operating principle PWM- driver

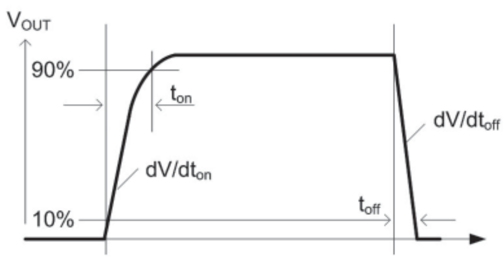
- Condition "Device error" and "Kl.31 fault" (40Hz; 50Hz)

Duty cycle ▶ 47.5 % … 52.5 %



Load current I_L	20 mA
Turn-on time ▶ to 90 % V_{OUT}	Max. 125 µs
Turn-off time ▶ to 10 % V_{OUT}	Max. 175 µs
Slew rate on ▶ 10 to 30 % V_{OUT}	Max. 6 V/µs
Slew rate off ▶ 70 to 40 % V_{OUT}	Max. 8 V/µs

Timing 3204 (inverse of 3203)



Connectors	TYCO-MICRO MATE-N-LOK 1 x 2-1445088-8 (Kl.31b, Kl.15, E, KE, M_{HS}, M_{LS}, OK_{HS}) 2 x 2-1445088-2 (L+, L-)
Crimp contacts	TYCO MICRO MATE-N-LOK Gold 14x 1-794606-1
Necessary crimp tongs (TYCO)	91501-1
Operating mode / mounting	Continuous operation / any position
Temperature range	-40 °C…+105 °C
Voltage dropout	≤ 2 ms
Fire protection class acc. UL94	V 0

ESD protection

Contact discharge – directly to terminals	≤ 10 kV
Contact discharge – indirectly to environment	≤ 25 kV
Air discharge – handling of the PCB	≤ 6 kV

Mounting

Screw mounting: M4 metal screws with locking washers between screw head and PCB.

Torx, T20 with a max. tightening torque of 4 Nm for the screws. Furthermore max. 10 Nm pressure to the PCB at the mounting points.

Screw and washer kit attached. The max. diameter of the mounting points is 10 mm. Before mounting the device, ensure sufficient insulation between the device and the vehicle resp. the mounting points (min. 11.4 mm to other parts). If the IMD is mounted on a metal or conductive subsurface, this subsurface has to get ground potential (Kl.31; vehicle mass).

Deflection	max. 1 % of the length resp. width of the PCB
Conformal coating	Thick-Film-Laequer
Weight	52 g +/-2 g

Ordering information

Type		Art.No
IR155-3203	Fixed default parameters R_{an}: 100 kΩ Under voltage detection: 300 V F_{ave}: 10 Measurement output low side	B 9106 8138
IR155-3203	Parameters can be customised R_{an}: 100 kΩ…1 MΩ Under voltage detection: 0 V…500 V F_{ave}: 1…10 Measurement output low side	B 9106 8138C
IR155-3204	Fixed default parameters R_{an}: 100 kΩ Under voltage detection: 0 V (inactive) F_{ave}: 10 Measurement output high side	B 9106 8139
IR155-3204	Parameters can be customised R_{an}: 100 kΩ…1 MΩ Under voltage detection: 0 V…500 V F_{ave}: 1…10 Measurement output high side	B 9106 8139C

Example for ordering

IR155-3204-100kΩ-0V + B 9106 8139

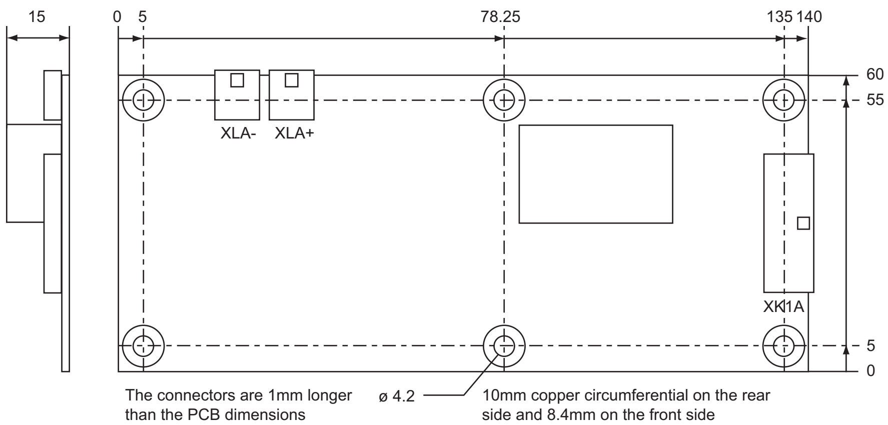
IR155-3204-200kΩ-100V + B 9106 8139C

The parameters acc. response value and under voltage protection have always to be added or included to an order.

Dimension diagram

Dimensions in mm

PCB dimensions (L x W x H) 140 mm x 60 mm x 15 mm



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Integrated interleaved active balancing converter for battery management applications

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Abstract This paper presents an efficient and innovative concept for the optimal management of electrochemical storage systems. The basic idea is to introduce a compact and highly reliable silicon integrated real time active balancing converter into the battery, thus allowing efficient energy transfer between the series connected battery cells. The presented concept allows to guarantee permanent and real time SOC equalization among the cells while maximizing the energy potential of the battery pack as well as its lifetime extension. The design of a silicon integrated CMOS multiple legs power converter is presented. First experimental results are provided and discussed, highlighting the advantages of the proposed concept.

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Introduction

The constantly growing needs of the portable and embedded power applications have led to the expansion of the lithium batteries market. Furthermore, lithium batteries are known as being extremely sensitive to overcharges and over-discharges and therefore require efficient battery management systems to prevent early state of health reduction and failure occurrence. Battery Management Systems are intended to observe and act on battery cells to keep them balanced and correctly used. Real time active balancing rise the opportunity to permanently keep the battery cells with identical State of Charge (SOC), simplifying significantly the battery pack management. Various balancing methods can be considered [1, 2, 3] to guarantee the voltage balance among the cells of the pack. Nevertheless, only a few topologies can meet the objectives of being simple to integrate and implement while being able to carry large currents and to perform real time active balancing. Recently, an innovative active balancing topology was proposed [4] allowing to transfer high energy quantities form any overcharged cell(s) to any undercharged cell(s), under any operating conditions applied to the stack, charge or discharge, high or low rates. In order to greatly reduce the volume of the inverter, an interleaved converter approach was also presented. Nevertheless, in that case many inverter arms are needed, thus leading to complex implementation and reliability problems due to the increased amount of active devices, drivers, supplies and interconnections. A possible solution to this issue is the monolithic integration of the active devices, their drivers and associated functions [5, 6].

This paper presents deeper investigation of this original approach for lithium battery real time active balancing. The paper focuses on the monolithic integration of an interleaved converter allowing a significant simplification of the implementation of the battery itself as well as its management system (BMS). The paper will first briefly recall the cell balancing operating principle and the topology of the active balancing converter. Then, the design of the proposed integrated converter will be presented and the resulting advantages will be discussed. The second part of the paper is dedicated to the perspective of a high level integration of the balancing converter. The design of a silicon integrated CMOS multiple power converters integrated circuit is also presented. First experimental results are provided and discussed, highlighting the advantages of the proposed concept. The last section of the paper is dedicated to the evolutions of the battery management system thanks to the introduction of real time active balancing architectures within the battery stack.

Active balancing

Real time active balancing is considered to guarantee voltage and/or SOC balance among series connected cells while offering access to all available energy in the stack even if the elementary cells are non-identical in terms of storage capability. There are many families of equalizing topologies for active balancing that can operate under natural or forced balancing control schemes. The natural balancing operation allows natural transfer of energy to where it is needed, without any control and measuring. The forced balancing mode controls the currents that flow inside the equalizer and the energy is delivered to the most undercharged cells. This paper focuses on a particular topology that can operate both in natural and forced cell balancing principles. The cell balancing circuit (Fig. 1) is composed of *N-1* parallel converter legs, where *N* is also the number of cells in the pack. Each phase is connected at the potential available between two consecutive battery cells through an inductor and is able to maintain and regulate its potential as a fraction of the total voltage available across the battery stack. The cell balancing operating principle of this structure is presented with more details in [4].

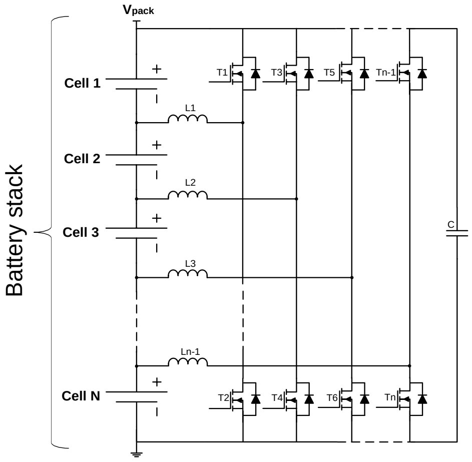
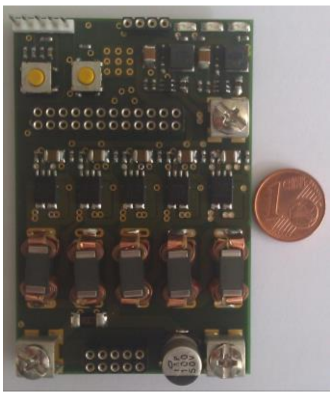


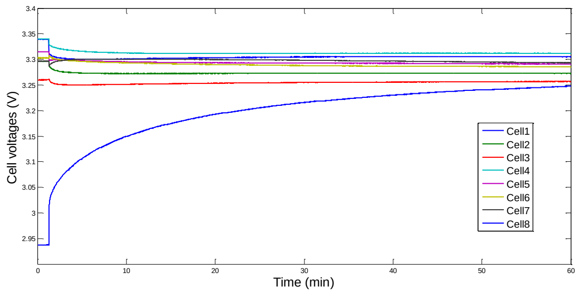
Fig. 1: Initial active balancing topology

The structure main advantages concern the bidirectional energy transfer from any cell(s) to any cell(s), the choice of natural or forced operating mode, as well as the ease of implementation and the integration feasibility due to the generic arrangement of the power devices. As for the disadvantages, the structure has very large amount of components and it presents non-optimal volume and size due to the design constraints of the passive components. Based on this consideration, it is clear that the design of the inductors must be a subject of an important optimization effort.

An interesting approach that can be considered is the interleaving of the cell balancing device with coupled inductances. Considering that the duty cycles of each leg in the initial topology will operate at or near a fraction k/N, k being an integer from 1 to N-1, the interleaved coupled inductors can be greatly optimized [4]. In order to demonstrate the operation of the proposed concept, Fig.2.a) shows the practical realization with discrete devices.



a)



b)

Fig. 2: a) Photograph of an interleaved leg (40Vmax, 10Amax) of the balancing topology and b) practical results of voltage (V) as function of time (min) during natural equalization of an 8 cell battery pack.

With the proposed interleaved converter the total volume of the passive components is 5 times smaller compared to ones needed for the basic converter topology (under comparable design ratings and switching frequency). As it is for the operation of the converter Fig.2.b) shows the experimental results for 60min of running the converter under natural balancing mode for a 24V - 10A.h Li-ion battery stack of 8cells with one cell fully discharged compared to the others. The results correspond to what is expected of the interleaved active balancing converter. 60 minutes after the beginning of the experimental measurement, all cells have a voltage difference of less than 100mV.

Integration motivation

Multiphase converters [7] offer the possibility to replace the standard magnetic cores with coupled inductors in order to reduce the inductors size and the total volume of the converter. The efficient current sharing and the better thermal management due to the sharing of the current and the resulting conduction and switching losses between the different active devices are also key advantages of these power electronic architectures. Nevertheless, as shown in Fig. 3, in that case the numbers of the active devices and the interconnections are significantly increased leading to very complex implementation and reliability problems. The solution to this issue is the monolithic integration of the active devices, their drivers and associated functions. This leads to a significant reduction of the number of power dies, drivers and PCB interconnections.

Fig.3 shows a schematic view of a battery pack composed of four battery cells needed to achieve the required voltage level for the portable applications. Four inverter legs are interconnected between two neighbour cells. The required power converter is therefore composed of twelve inverter legs.

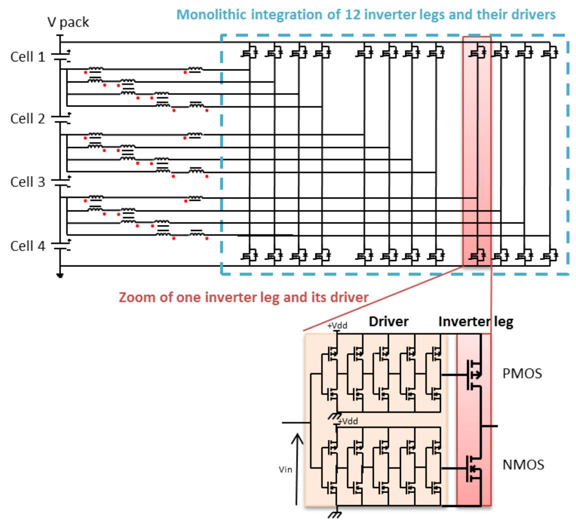


Fig. 3: An interleaved cell balancing topology

Design and realization of the integrated active balancing converter

The integrated converter was designed to contain 12 CMOS inverter legs based on the 0.35µm CMOS high- voltage technology (20V up to 50V) from Austria Microsystems (ams). The CMOS transistors were designed with nominal current through each inverter leg of about 0,5A allowing a current flow among the cells in the range of 2A. The maximum battery stack voltage level must be kept below 20V.

Fig.4 shows a photograph of the integrated active balancing converter assembled in QFN package.

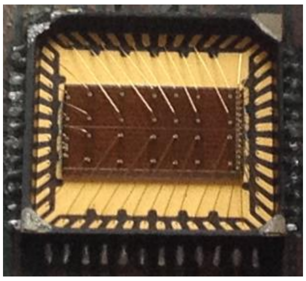


Fig. 4: Photograph of the 12 inverter legs all integrated in a single die, including drivers and level shifters (the die is 5*2.5mm)

Practical results

A prototype for four cells balancing was realized for the practical validation of the operation of the integrated active balancing converter. The prototype is shown on Fig.5. It is made out of three integrated converters allowing to perform active balancing currents up to 6A per inverter leg. The PCB integrates on one side the passive components and on the other side, the integrated converters, the microcontroller, voltage and current sensors and the required supplies.

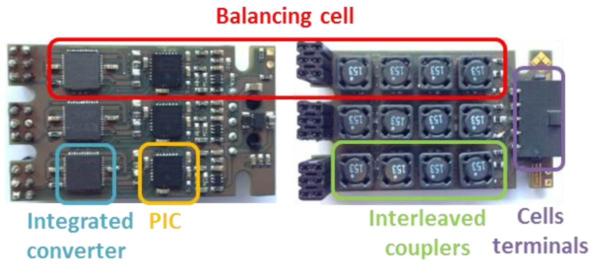


Fig. 5: Photograph of the active balancing converter

Fig.6 shows the results of the realized practical tests. The characterization is focused on the top balancing structure, implemented between Cell1 and Cell2. The battery stack voltage is 12V. The structure is operating at 500kHz switching frequency with a duty cycle of 0.75.

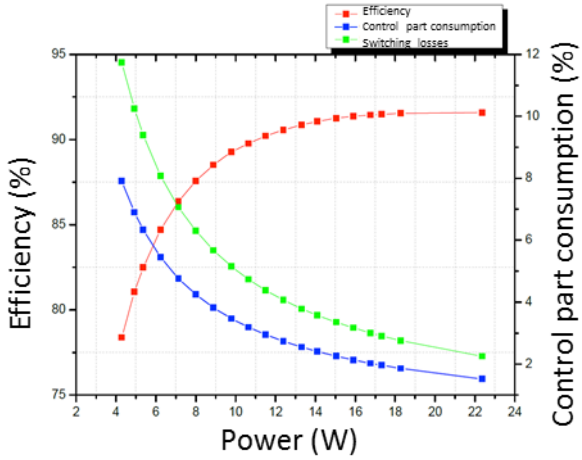


Fig. 6: Practical results (efficiency: red curve, switching losses: green curve, control part consumption: blue curve)

The balancing current is 2.5A, the power transferred by the converter is 22W and as shown in Fig.6 the efficiency reached at this point is 91%. From a global point of view, the active balancing circuit power density is 3.5kW/L.

Benefits of real time active balancing for battery management

Real time active balancing enables to maximize the available energy from the battery stack. Moreover, it perfectly compensates cells' State of Health (SOH) disparities by maintaining permanently their respective SOC equal. This feature is a key factor for the secure operation and optimal use of the battery. But the most unexpected benefit relies on the resulting simplification of the battery management needs. Since all battery cells are kept equally charged, no matter their operating conditions, the energy management of the battery itself can be greatly simplified. For instance, the charging unit only needs to monitor the battery stack voltage to determine correctly the level of charge of all cells. In such a way, there is no risk to overcharge the weakest element, or to enter in deep discharge when the battery is completely emptied. Real time active balancing definitively maximizes the safe operation of the battery as long as it performs effective SOC equalization among the cells of the battery stack. If this work has outlined that active balancing hardware can be a reality, its qualification still needs to be carried out. This will be further presented at the conference.

Conclusions

This paper presented the interest of the introduction of an integrated active balancing converter for battery management application. The active balancing topology allows to transfer high energy quantities form any overcharged cell(s) to any undercharged cell(s), under any operating conditions, thus preventing early state of health reduction and failure occurrence of the electrochemical storage equipment.

In order to greatly reduce the size of the passive components an interleaved converter topology is proposed. Nevertheless, the increase of the number of the active devices in this case leads to reliability problems. Thus, a monolithic integrated version of the active balancing converter is proposed. The concept is based on the integration of the active devices and their associated drivers in the same silicon die. The practical results demonstrated that proposed active balancing concept is a key enabling factor for optimal battery management, maximizing the safe operation of the battery stack.

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