E.T.S. de Ingeniería Industrial,
Informática y de Telecomunicación

Diseño y validación de un convertidor reductor para carga solar de móvil

Grado en Ingeniería Eléctrica y Electrónica

Trabajo Fin de Grado

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Control, buck, convertidor, DC/DC, almacenamiento, fotovoltaica

Resumen:

Con las tecnologías que disponemos hoy en día, se puede aprovechar la energía solar para algo tan necesario como nuestros smartphones, los cuales en momentos puntuales necesitan recargarse, y no en cualquier lugar.

Mediante la energía solar captada en los módulos fotovoltaicos, es posible recargar una batería externa que a su vez en cualquier momento podrá cargar nuestro móvil, y así poderlo tener al máximo de batería.

Esto es posible mediante el uso de dos convertidores reductores DC/DC y dos controles.

El primer convertidor está entre los módulos fotovoltaicos y la batería que acumula energía y controlará la tensión.

El segundo convertidor está entre la batería y la batería del móvil y controlará la corriente.

Abstract:

Nowadays with the technologies that we have, we can make the most of solar energy for something necessary like smartphones, which in certain moments need to be charged, and not a chosen location.

With the solar energy absorbed by the photovoltaic modules, it is possible to recharge an external battery, which in any moment will charge our phone, and this keep it fully charged.

This is possible thanks to the use of two DC/DC buck converters and two controls.

The first converter is placed between the solar modules, and the battery which collect the energy, and it will be controlled by a voltage control.

The second converter will be placed between the battery and the phone battery, and it will be controlled by a current control.

Contenido

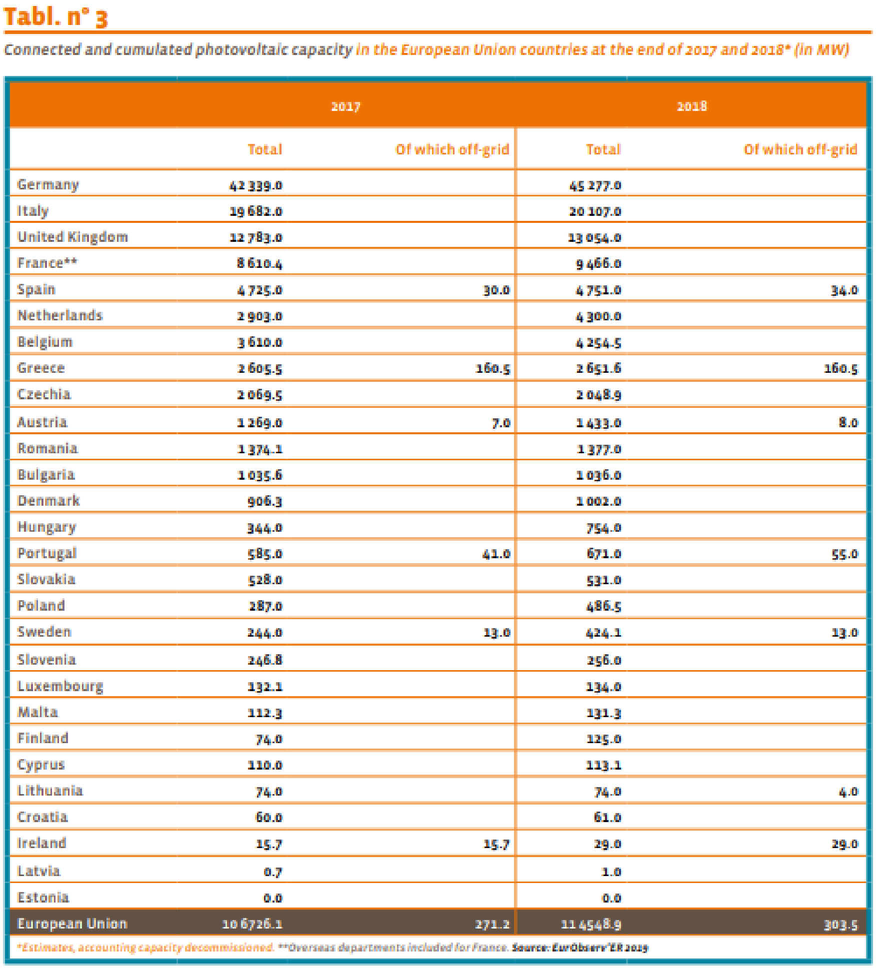
1.INTRODUCCION

1.1. LAS ENERGÍAS RENOVABLES EN EL SIGLO XXI.

Puesto que el siguiente Trabajo Fin de Estudios está totalmente relacionado con la generación de energía limpia, se comentará la actualidad de las energías renovables
Se desaprovechan muchos recursos ilimitados que ofrece la Tierra, por eso cada vez se está concienciando la gente que el futuro energético dependerá de estos recursos que son ilimitados como viento, sol, agua, etc.

Se debería fomentar más el uso de sistemas de autoconsumo en las casas o edificios, que últimamente se están construyendo con estas adaptaciones mediante las cuales se puede disfrutar de ACS, calefacción, etc.

En cuanto a superficies de generación eléctrica grandes mediante paneles fotovoltaicos, es decir, implantaciones de parques fotovoltaicos, durante estos últimos años se están realizando varias implantaciones de varios MW de potencia lo cual incrementa la Wp instalados en España en los últimos años, ya que durante los últimos años la potencia instalada en nuestro país no ha sido destacable.



Tabl. n° 3

Connected and cumulated photovoltaic capacity in the European Union countries at the end of 2017 and 2018 (in MW)*

	2017		2018	
	Total	Of which off-grid	Total	Of which off-grid
Germany	42 339.0		45 277.0	
Italy	19 682.0		20 107.0	
United Kingdom	12 783.0		13 054.0	
France**	8 610.4		9 466.0	
Spain	4 725.0	30.0	4 751.0	34.0
Netherlands	2 903.0		4 300.0	
Belgium	3 610.0		4 254.5	
Greece	2 605.5	160.5	2 651.6	160.5
Czechia	2 069.5		2 048.9	
Austria	1 269.0	7.0	1 433.0	8.0
Romania	1 374.1		1 377.0	
Bulgaria	1 035.6		1 036.0	
Denmark	906.3		1 002.0	
Hungary	344.0		754.0	
Portugal	585.0	41.0	671.0	55.0
Slovakia	528.0		531.0	
Poland	287.0		486.5	
Sweden	244.0	13.0	424.1	13.0
Slovenia	246.8		256.0	
Luxembourg	132.1		134.0	
Malta	112.3		131.3	
Finland	74.0		125.0	
Cyprus	110.0		113.1	
Lithuania	74.0		74.0	4.0
Croatia	60.0		61.0	
Ireland	15.7	15.7	29.0	29.0
Latvia	0.7		1.0	
Estonia	0.0		0.0	
European Union	10 6726.1	271.2	11 4548.9	303.5

Estimates, accounting capacity decommissioned. **Overseas departments included for France.* **Source: EurObserv'ER 2019

Fig 1.1. Capacidad fotovoltaica en la UE años 2017 y 2018[1]

Como se aprecia en la Fig 1, en el año 2017 en España había instalados 4725 MW de potencia y en el año 2018 4751 MW [1], lo que supone un incremento de 26 MW, muy poco comparándolo con el resto de países de la UE y más sabiendo que las horas equivalentes de Sol en España son mayores que al resto de países de la UE.

Según el PER en el año 2015 había instalados en España alrededor de 5500 MW y se tiene la previsión de que para el año 2020 tiene que haber 7250 MW de potencia instalados, es un aumento muy drástico y más si nos damos cuenta que la potencia instalada ha disminuido, pero teniendo en cuenta que ahora mismo se han realizado bastantes implantaciones y las que se van a realizar, la cifra de 2020 puede llegar a conseguirse.[2]

En la pg web de UNEF (Unión Española Fotovoltaica) comentan en una noticia porque se están volviendo a instalar plantas fotovoltaicas en nuestro país.

Según expertos se estima que se instalarán al menos 4000 MW a lo largo de este año, lo que supone casi duplicar las instalaciones que había hasta hace un año. [3]

1.2. TIPOS DE INSTALACIONES FOTOVOLTAICAS

Como bien se sabe hay distintas formas de conexionado e infraestructura a la hora de construir instalaciones fotovoltaicas.

Hoy en día se disponen las siguientes configuraciones:

- Conectada a red:
  El objetivo es extraer de los módulos fotovoltaicos la máxima energía posible para verterla a red.

  -Grandes plantas:
  Sistemas de gran potencia que están situadas en zonas no habitadas.

  -Comerciales/industriales:
  Instalaciones para el propio consumo de energía de la empresa

  -Autoconsumo:
  Producción de electricidad para el propio consumo en hogares.

- Aislada
  Sistemas cuya energía no se vierte a red, se utiliza para alimentar cargas que no disponen de conexión a red. Su objetivo es abastecer con fiabilidad dichas cargas.

1.3. AISLADA

Estos sistemas fotovoltaicos constan de los siguientes elementos:

- Módulos FV
- Sistemas de acumulación (baterías)
- Regulador
- Inversor FV

En la Fig 1.2. se puede apreciar las posibles configuraciones de sistemas aislados que hay.

- *Fig. 1.2. Configuraciones de sistema aislado[4].*

Las cargas que se alimentarán pueden ser tanto DC como AC, por ello si las cargas son en DC no hace falta instalar el inversor y por contrario si las cargas son en AC si será necesario.

Este tipo de instalación DC es muy parecido al nuestro, en este caso sin Inversor FV ya que nuestra carga que sería el móvil se alimenta en DC.

El regulador será el convertidor con sus controles adecuados y disponemos tanto de módulos fotovoltaicos para generar energía, como de baterías para poder acumular esa energía que luego se transfiere al smartphone.

La configuración del sistema ejecutado en el proyecto será la siguiente:

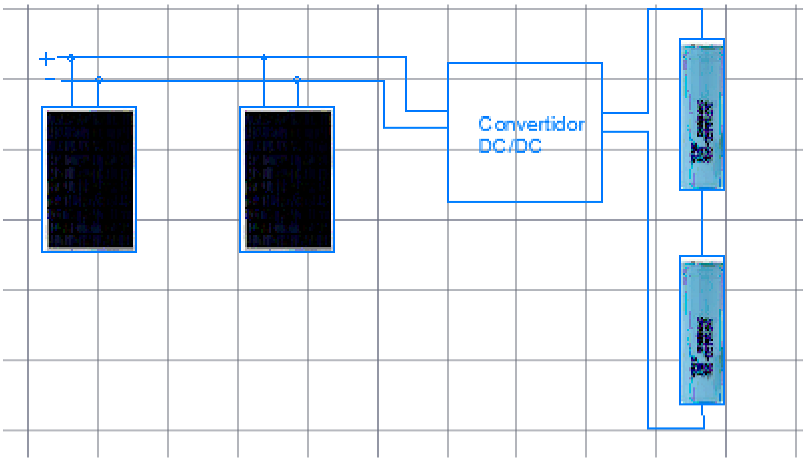


Fig. 1.3.Carga de baterías mediante módulos.

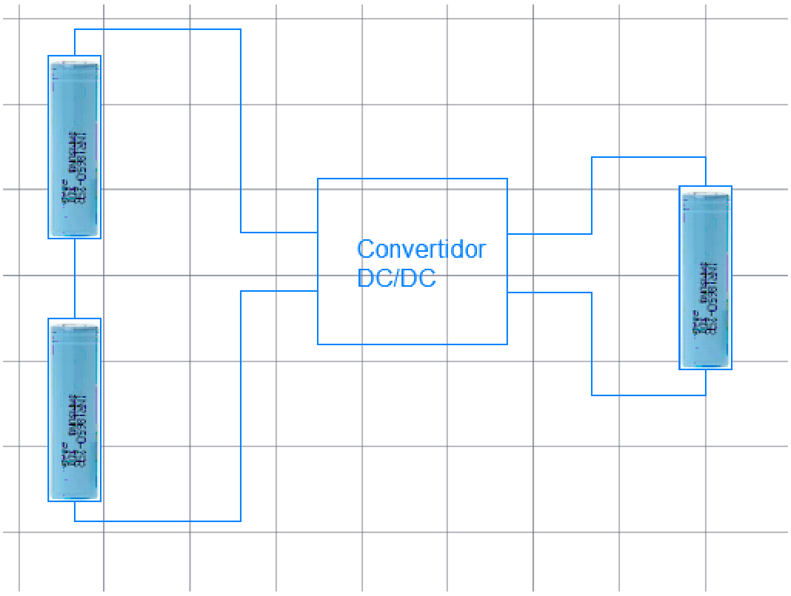


Fig. 1.4.Carga de batería del móvil mediante descarga de batería externa.

El convertidor reductor 1 controlará la tensión que den los módulos fotovoltaicos y el convertidor reductor 2 controla la corriente de carga de la batería del móvil.

2.DIMENSIONADO DEL SISTEMA

2.1. DIMENSIONADO DE LAS BATERÍAS.

Si se quiere conseguir que la carga se produzca en alrededor de dos horas y media, y las baterías de los móviles están alrededor de los 4000-4500 mAh se necesitará la siguiente corriente de carga:

$$I = \frac{4300\ mAh}{2{,}5h} = 1720\ mA$$

Es decir, se necesitarán unos 1,75 A de corriente para la carga de la batería del móvil. Las baterías elegidas tienen una capacidad de 3000 mAh ya que se quiere que al menos puedan cargar el móvil una vez y una tensión nominal de 3,6 V, pudiendo llegar a 4,2 V de voltaje máximo.
Son baterías de litio y se han elegido de este material debido a que son más seguras, tienen un voltaje mayor y la carga y descarga es más rápida que las tradicionales de plomo-ácido.

Para el proyecto se pondrán 2 baterías en serie para conseguir 7,2 V, y así poder transferir la energía de estas a la batería del móvil mediante el convertidor de una manera más sencilla, porque para que ocurra esto la tensión de las baterías en serie debe ser mayor que la tensión de la batería del móvil.

Mediante el cálculo de capacidad en Wh se puede saber cuántas cargas al móvil se pueden realizar con estas dos baterías.

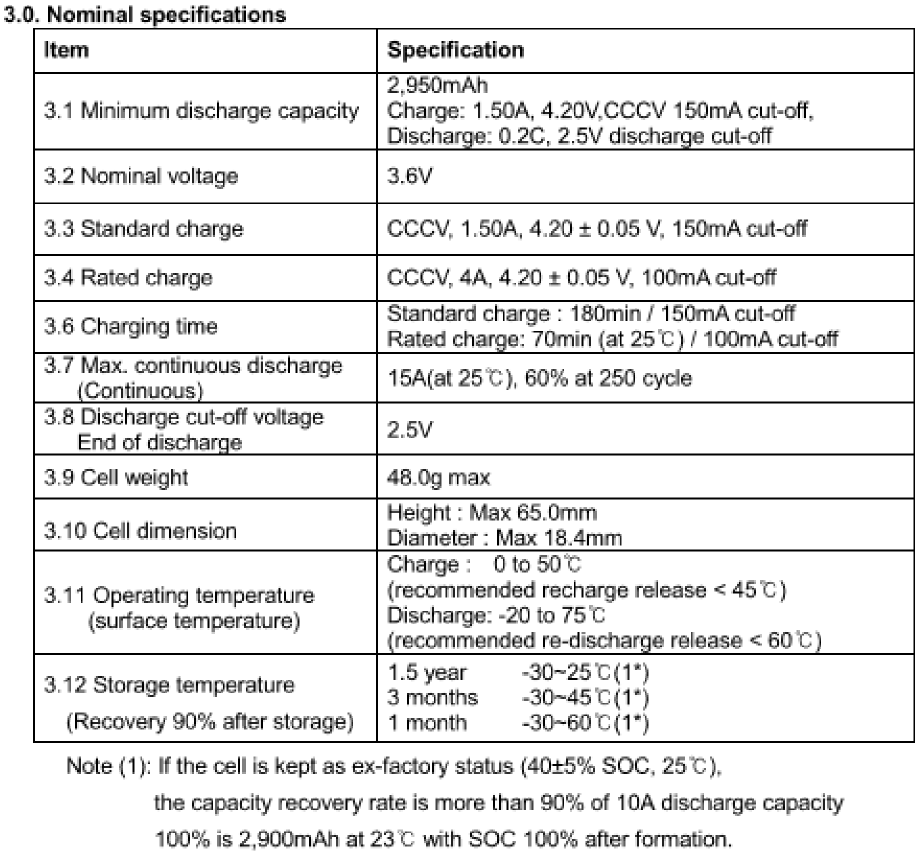
$$Ealm = 3Ah * 7{,}2V = 21{,}6\ Wh$$

$$Emovil = 4Ah * 3{,}6V = 14{,}4\ Wh$$

$$Nº\ de\ cargas = \frac{21{,}6\ Wh}{14{,}4\ Wh} = 1{,}5\ cargas$$

Por lo tanto el sistema de baterías de almacenamiento, lo que sería la batería externa recargable, debe ser capaz de cargar el móvil 1,5 veces cuando su capacidad sea máxima.

En la Fig.2.1 se pueden ver las características de las baterías elegidas.



3.0. Nominal specifications

Item	Specification
3.1 Minimum discharge capacity	2,950mAh Charge: 1.50A, 4.20V,CCCV 150mA cut-off, Discharge: 0.2C, 2.5V discharge cut-off
3.2 Nominal voltage	3.6V
3.3 Standard charge	CCCV, 1.50A, 4.20 ± 0.05 V, 150mA cut-off
3.4 Rated charge	CCCV, 4A, 4.20 ± 0.05 V, 100mA cut-off
3.6 Charging time	Standard charge : 180min / 150mA cut-off Rated charge: 70min (at 25℃) / 100mA cut-off
3.7 Max. continuous discharge (Continuous)	15A(at 25℃), 60% at 250 cycle
3.8 Discharge cut-off voltage End of discharge	2.5V
3.9 Cell weight	48.0g max
3.10 Cell dimension	Height : Max 65.0mm Diameter : Max 18.4mm
3.11 Operating temperature (surface temperature)	Charge : 0 to 50℃ (recommended recharge release < 45℃) Discharge: -20 to 75℃ (recommended re-discharge release < 60℃)
3.12 Storage temperature (Recovery 90% after storage)	1.5 year -30~25℃(1*) 3 months -30~45℃(1*) 1 month -30~60℃(1*)

Note (1): If the cell is kept as ex-factory status (40±5% SOC, 25℃),
the capacity recovery rate is more than 90% of 10A discharge capacity
100% is 2,900mAh at 23℃ with SOC 100% after formation.

Fig. 2.1. Características técnicas batería

2.2. DIMENSIONADO DEL GENERADOR FOTOVOLTAICO.

Se ha elegido un panel de pequeña potencia, el módulo elegido es el modelo 9046128 de 5W de RS Components y estas son sus características principales:

Potencia máxima (Pmax)	**5 Wp**
Tensión máxima potencia (Vmp)	**16,8 V**
Intensidad máxima potencia (Imp)	**0,3 A**
Voltaje circuito abierto (Voc)	**21 V**
Corriente de cortocircuito (Isc)	**0,39 A**
Temperatura de operación nominal (NOCT)	**48 ºC**
Coef corriente	**0,003 %A/K**

Coef voltaje	**-0,13 %V/K**
Coef potencia	**-0,675% W/K**

Tabla 1. Características técnicas en STC del modulo

El motivo por el que se elige el panel es el siguiente:

$$P = 7{,}2V * 1{,}75A = 12{,}6W\ de\ baterías.$$

Con la potencia del sistema, se puede calcular el número mínimo y máximo de paneles que se van a poner, teniendo en cuanta su potencia pico.

$$Nmin = \frac{12{,}6 * 1{,}1}{5} = 2{,}77\ paneles$$

$$Nmax = \frac{12{,}6 * 1{,}2}{5} = 3{,}024\ paneles$$

Se deben colocar 3 módulos en paralelo, pero para el sistema se colocarán finalmente 2.

Se dispondrán dos paneles fotovoltaicos en paralelo para la instalación, con una potencia de 10W, ya que con esa potencia es suficiente.
El voltaje del sistema no aumenta, pero la intensidad será el doble.
En la Fig.2.2 se muestra el conexionado de los módulos fotovoltaicos.

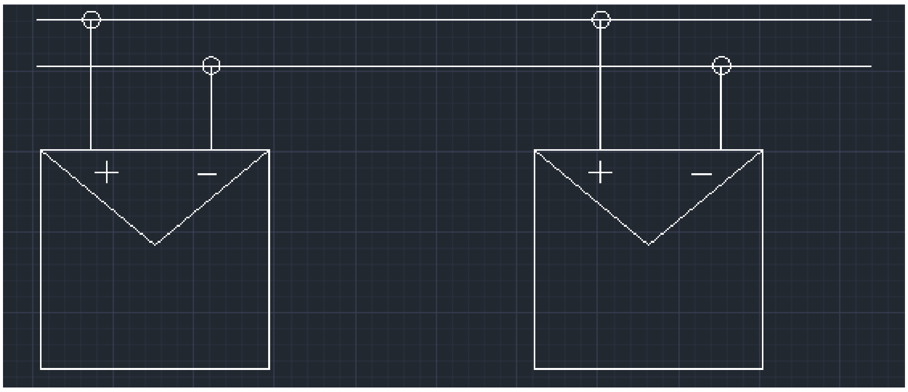


Fig. 2.2. Configuración de paneles

Mediante la simulación en PSIM se puede obtener la curva I-V del panel fotovoltaico y la de potencia como se muestra en la Fig 2.3, 2.4 y 2.5.

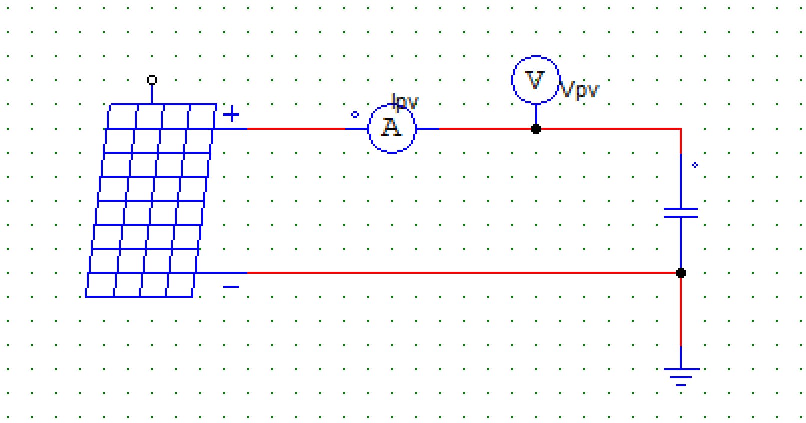


Fig. 2.3. Simulación PV en PSIM

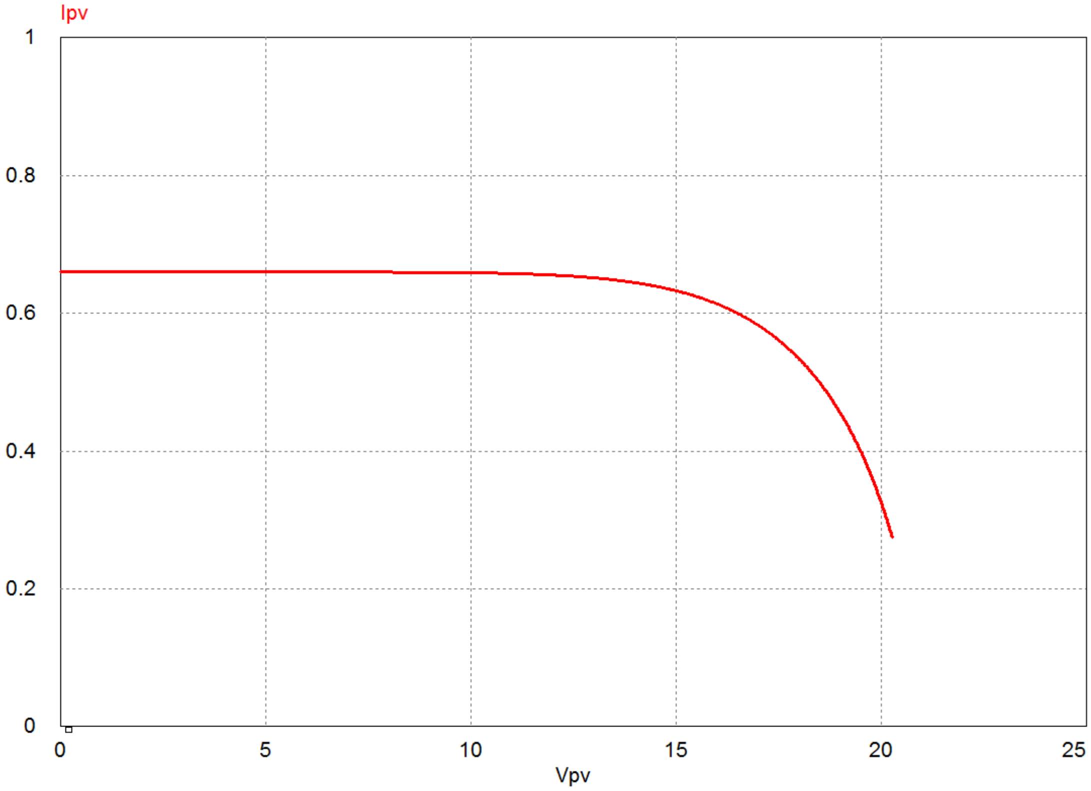


Fig. 2.4. Curva I-V paneles en paralelo

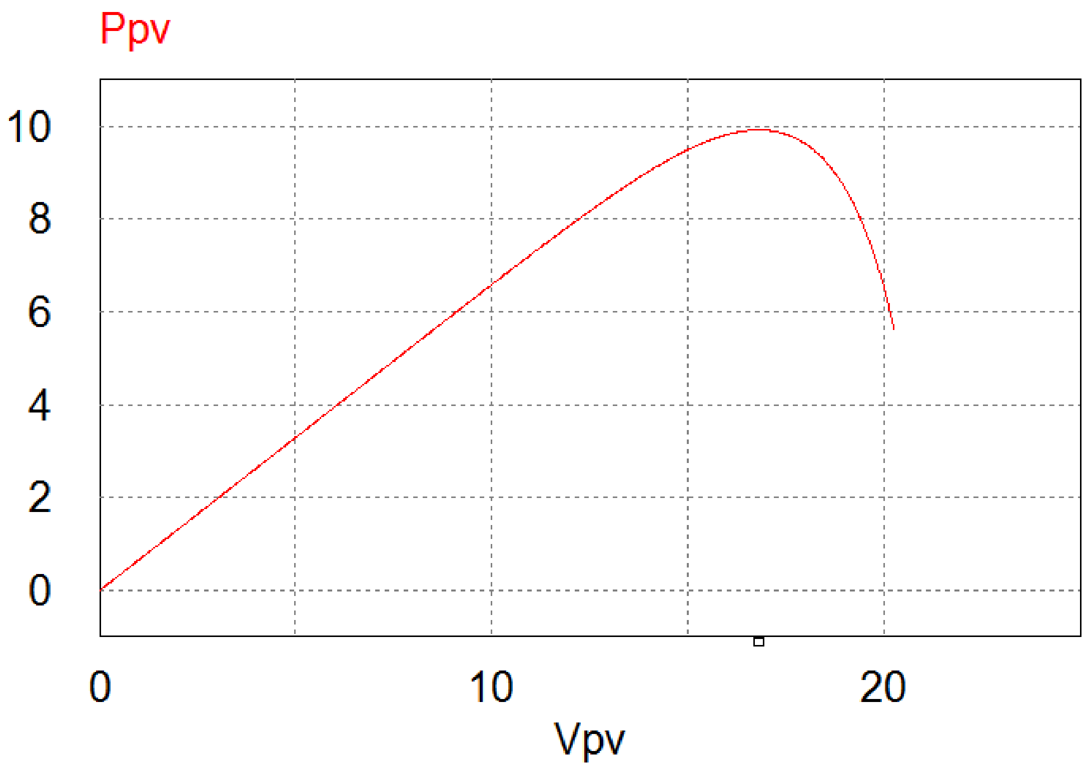


Fig. 2.5. Curva de potencia de los paneles en paralelo

Teniendo en cuenta las características técnicas del módulo que se pueden ver en la Tabla 1, se pueden calcular los valores más adversos de temperatura de la célula y el rango de voltajes que tendría el módulo con esas temperaturas más desfavorables.

Para el cálculo de la temperatura de célula, se dispondrán dos condiciones:

1- Tamb=-20 ºC y G=0 W/m^2
2- Tamb= 45 ºC y G=1000 W/m^2

Estas dos condiciones representan por un lado la condición mínima a la que se puede comenzar a generar, y la máxima a la cual podemos generar.

Para calcular la temperatura de la celda en cada caso, deberemos utilizar la siguiente fórmula:

$$Tc = \frac{G}{800} * (NOCT - 20) + Tamb \qquad \text{Ec.(1)}$$

Para la condición 1 se tendrá una temperatura mínima de célula de -20 ºC.
Para la condición 2 se tendrá una temperatura máxima de célula de 80 ºC.

Con estas dos temperaturas podemos calcular el rango de tensiones (Vmpp) que nuestro panel FV va a generar.

Para calcular la Vmpp se utilizará la siguiente ecuación:

$$Vmpp(Tc) = Vmpp + (Tc - 25) * \frac{\beta v}{100} * Vmpp \qquad \text{Ec.(2)}$$

Donde βV= -0,13 %V/K

Para una temperatura de célula de -20 ºC obtenemos una tensión de 17,78 V
Para una temperatura de célula de 80 ºC obtenemos una tensión de 15,6 V

Como se puede observar según los cálculos obtenidos cuanto mayor es la temperatura de la célula, el voltaje obtenido es menor.

Para el apartado de control de voltaje, que más adelante se comentará, utilizaremos cómo voltaje de referencia una temperatura intermedia, como 45 ºC.
Para ello realizamos el mismo cálculo que se ha hecho anteriormente, pero en este caso para Tc=45 ºC, y se obtiene un voltaje de unos 16,5 V.

3.DISEÑO DE LOS COMPONENTES

3.1 CONVERTIDOR REDUCTOR BUCK

El convertidor Buck es un convertidor DC/DC reductor con el cual a su salida se obtiene una tensión continua igual o menor a la de su entrada.
Es una fuente de alimentación conmutada mediante al menos dos semiconductores que actúan como interruptores.[5]
El objetivo es diseñar dos tipos de convertidores:

- El primer convertidor se encargará de cargar la batería portátil mediante energía solar fotovoltaica, para ello será necesario un control de tensión que haga que controle la tensión generada por los módulos fotovoltaicos.
- El segundo convertidor se encargará de mediante la batería portátil de 7,2 V, cargar la del móvil de 3,6 V, y será necesario un control de corriente de salida, ya que se quiere mantener una corriente constante y con un filtrado de su rizado en la intensidad por la bobina.

3.1.1. ELECCION DE SEMICONDUCTORES

A la hora de diseñar los convertidores se deberá elegir los semiconductores.
Hay que tener en cuenta que se trata de una configuración no reversible por lo que el flujo de potencia va a ir desde la fuente de entrada a la fuente de salida en ambos casos, por tanto la corriente en la bobina siempre va a ser positiva.
En la Fig 3.1 se puede ver la estructura que tendrán los dos convertidores DC/DC a la espera de elegir adecuadamente los semiconductores

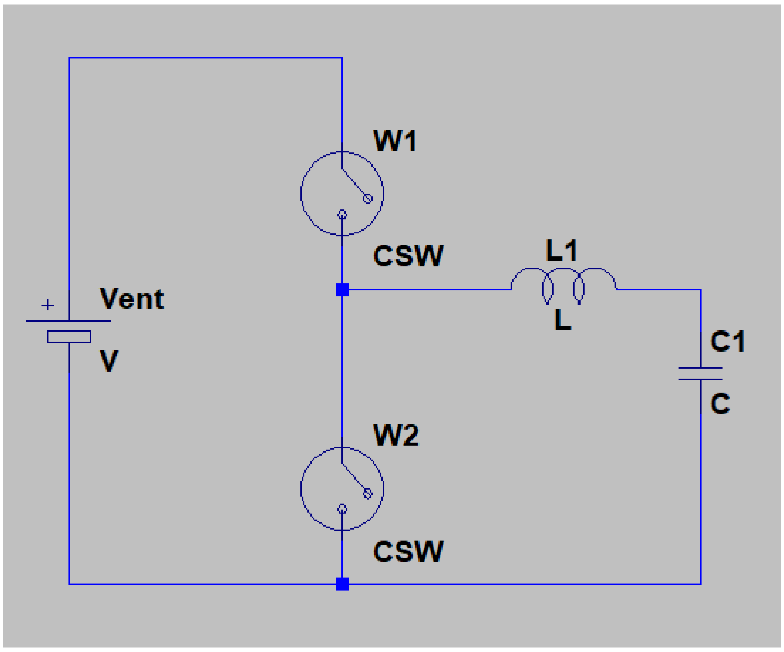


Fig.3 1Estructura del Convertidor Buck

Se debe tener en cuenta que las variables del sistema voltaje de entrada (Vent), voltaje de salida (Vsal), corriente de entrada (Ient) y corriente de salida (Isal) deben ser mayor que 0.

Para el caso en el que conduce el semiconductor 1 tenemos lo que se muestra en la Fig 3.2.

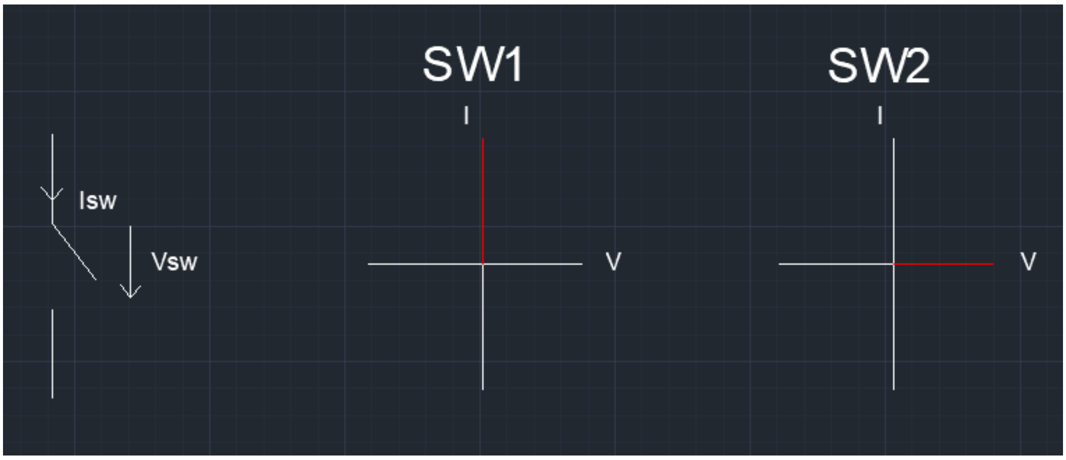


Fig.3 2 Conducción de semiconductor 1. Representación I-V

La tensión soportada por el semiconductor 1 será de 0 V y la corriente que pase por el será equivalente a la que pase por la bobina, mientras que la tensión que soportará el semiconductor 2 será la tensión de entrada (en el lado superior tiene una tensión igual que Vent y en el lado inferior tiene una tensión de 0 V) y la corriente que soporta es 0 A puesto que no circula nada al estar abierto.

SW1 ON Vsw1= 0 V Isw1= iL A
SW2 OFF Vsw2= Vent V Isw2 = 0 A

Para el caso en el que conduce el semiconductor 2 tenemos los que se muestra en la figura 3.3.

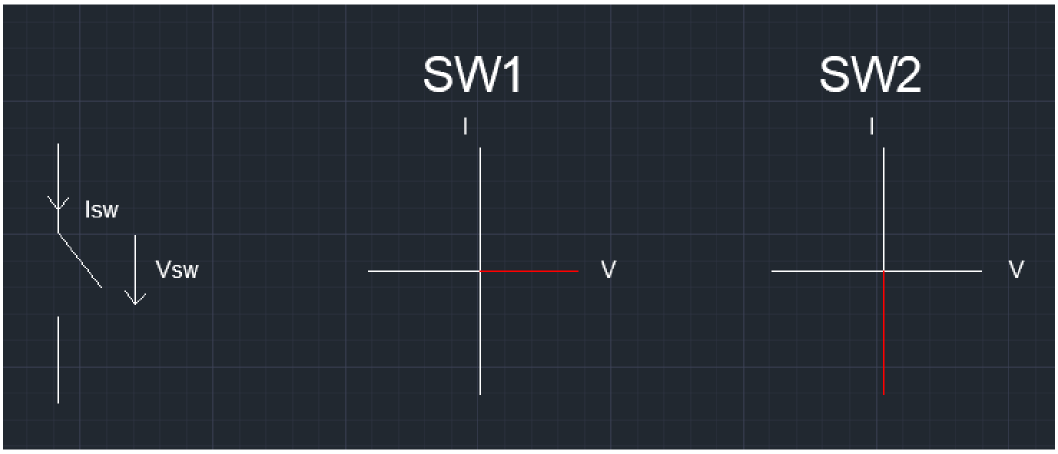


Fig.3 3Conducción del semiconductor 2. Representación I-V.

La tensión soportada por el semiconductor 1 será de la tensión de entrada V y la corriente que pase por el será de 0 A, mientras que la tensión que soportará el semiconductor 2 será de 0 V y la corriente que soporta es -iL A, ya que la corriente irá desde la salida a la entrada.

SW1	OFF	Vsw1= Vent V	Isw1= 0 A
SW2	ON	Vsw2= 0 V	Isw2 = -iL A

Si se juntan ambas gráficas quedará la siguiente configuración que se refleja en la Fig.3.4.

Fig.3 4 Tensión y corriente soportadas por los semiconductores

Se tiene un semiconductor 1 que es un transistor, se elegirá un MOSFET debido a su velocidad (se utilizarán frecuencias del orden de los 50 kHz) y el voltaje que soporta, y un semiconductor 2 que es un diodo.

Las características técnicas de estos dos elementos se visualizarán en el apartado de ANEXOS.

3.1.2. MODO CONDUCCION CONTINUA iL(t)>0 (MCC)

Teniendo en cuenta los semiconductores elegidos, la siguiente Fig.3.5. corresponde con el convertidor completo que se utilizará.

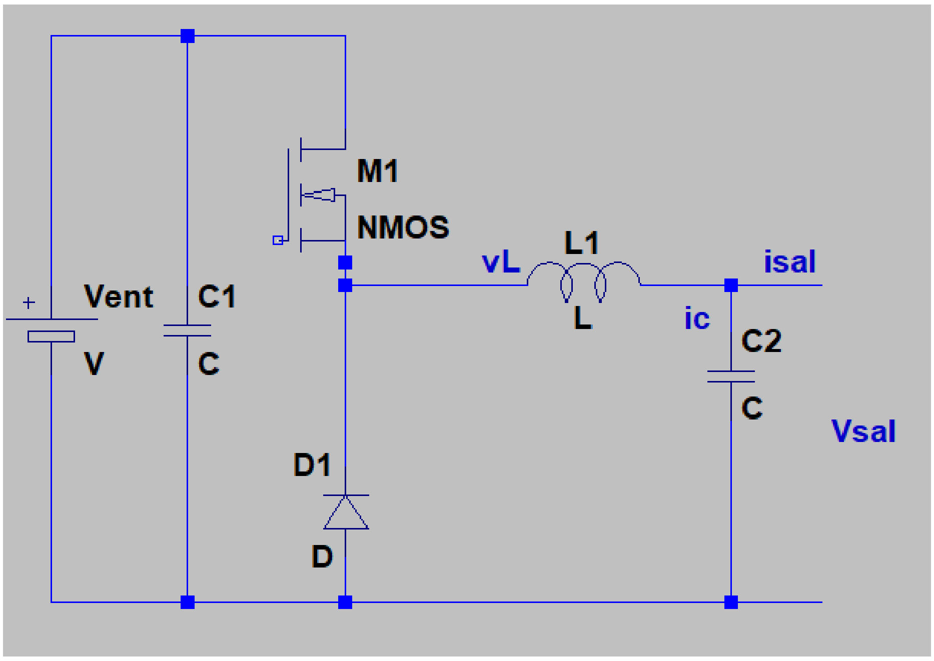


Fig.3 5 Convertidor Buck DC/DC

Se deducirá la ecuación del convertidor con las formas de onda del encendido y apagado.

Se considera que el valor medio de tensión de la bobina será 0.

$$Vl = 0 = \frac{(Vent - Vsal) * ton - Vsal * toff}{T}$$

$$(Vent - Vsal) * ton = Vsal * toff$$

$$Vent * ton - Vsal * ton = Vsal * toff$$

$$Vent * ton = Vsal(ton + toff)$$

$$Vent * ton = Vsal * T$$

$$Vsal = \frac{Vent * ton}{T}$$

Si se define el ciclo de trabajo como la siguiente expresión:

$$D = \frac{ton}{T} \quad \text{Ec. (4)}$$

Se obtiene la siguiente ecuación:

$$Vsal = Vent * D \quad \text{Ec. (5)}$$

En donde:

-Vent : Voltaje de entrada (V).

-Vsal : Voltaje de salida (V).

-ton : Tiempo que conduce el MOSFET (s).

-toff : Tiempo que no conduce el MOSFET (s).

-T : periodo de conmutación (s).

-D : ciclo de trabajo.

Esta será la ecuación fundamental del convertidor, donde D (ciclo de trabajo) solo puede tomar valores entre 0 y 1, y Vsal deberá comprenderse entre 0 y Vent, ya que al ser un reductor la salida siempre será más pequeña que la entrada.

Hay otras fórmulas, como:

- Corriente en la inductancia

$$iL = ic + isal \quad \text{Ec. (6)[5]}$$

Se supone que el valor medio de la corriente en el condensador es 0, por lo que el valor medio de iL será el valor medio de salida y queda la siguiente expresión

$$IL = Isal = \frac{D*Vent}{Rcarga} \quad \text{Ec. (7)[5]}$$

- Rizado de corriente por la bobina (ΔiL)

$$vL = L*\frac{diL}{dt} = L*\frac{\Delta iL}{\Delta t} = L*\frac{\Delta il}{ton} = Vent - Vsal$$

$$\Delta iL = \frac{(Vent - Vsal)*ton}{L} = \frac{Vent - D*Vent}{L}*ton = \frac{Vent(1-D)}{L}*\frac{T}{T}$$

$$= \frac{Vent(1-D)*D*T}{L}$$

$$\Delta iL = \frac{Vent(1-D)*D}{L*fconm} \quad \text{Ec. (8)[5]}$$

En donde:

- ΔiL : Rizado de corriente (A)
-fconm : frecuencia de conmutación (Hz)
- L : bobina (H)

Un mayor rizado en la bobina tiene ciertos efectos negativos:

-Aumento de las pérdidas magnéticas.

-Aumento de las pérdidas en el cobre (más aun en MCD).
- Aumento de las emisiones electromagnéticas (EMI).

Para paliar estos efectos negativos, hay distintas formas de hacerlo, aumentando el tamaño de la bobina (es caro) o aumentar la frecuencia de conmutación (lo cual implica más pérdidas). [4]

Si se calcula el tamaño de la bobina para el peor rizado nos dará la siguiente fórmula:

$$L \geq \frac{Vent}{4 * fconm * \Delta iLmax} \qquad \text{Ec. (9)[5]}$$

- Rizado de voltaje en el condensador de salida.

$$\Delta Vc = \frac{\Delta Q}{C}$$

$$\Delta Vc = \frac{Vent}{32 * L * C * fcon^2} \qquad \text{Ec. (10)[5]}$$

De aquí se pueden utilizar dos criterios para calcular el condensador.
Este es el primero:

$$C \geq \frac{Vent}{32 * L * \Delta Vcmax * fcon^2} \qquad \text{Ec. (11)[5]}$$

El otro hace que el filtro atenúe 1000 veces, para ello:

$$fcorte = \frac{1}{2pi * \sqrt{L * C}} \qquad \text{Ec. (12)[5]}$$

Para que atenúe 1000 veces la frecuencia de corte debe ser 0,03*fcon, y con ello la fórmula resultante que queda es la siguiente:

$$C = \frac{1}{4 * pi^2 * fcon^2 * L * 0{,}0009} \qquad \text{Ec. (13) [5]}$$

Con este segundo criterio se consiguen valores de condensador mayores.

3.1.3. MODO CONDUCCION DISCONTINUO iL(t)=0 (MCD)

Si disminuye la carga (es decir aumenta la R), la intensidad que pasa por la bobina cada vez es más pequeña pudiendo llegar a los 0 A, aunque el rizado se sigue manteniendo porque el ciclo de trabajo es constante.

Para el MCD, la ecuación del convertidor es la siguiente:

$$Vsal = \frac{D}{1-\frac{T1}{T}} * Vent \quad \text{Ec. (14)}$$

T1 es una expresión temporal que depende de la carga (la iL=0), esto típicamente se soluciona mediante el control de corriente, para ello se evita que iL=0 mediante la colocación de una resistencia puesta en paralelo a la carga, por la que discurrirá la mitad de la corriente y como esta resistencia no cambia de valor, la iL nunca será 0.
El problema de ello es que al tener un consumo permanente es una mala solución.[4]

3.1.4. MODULACION

La señal que producirá las conmutaciones en los semiconductores estará producida por modulación PWM.
La señal de control que dé el controlador se comparará con una señal triangular, que esta dará la onda que va hacia un driver que efectuará las conmutaciones del MOSFET.

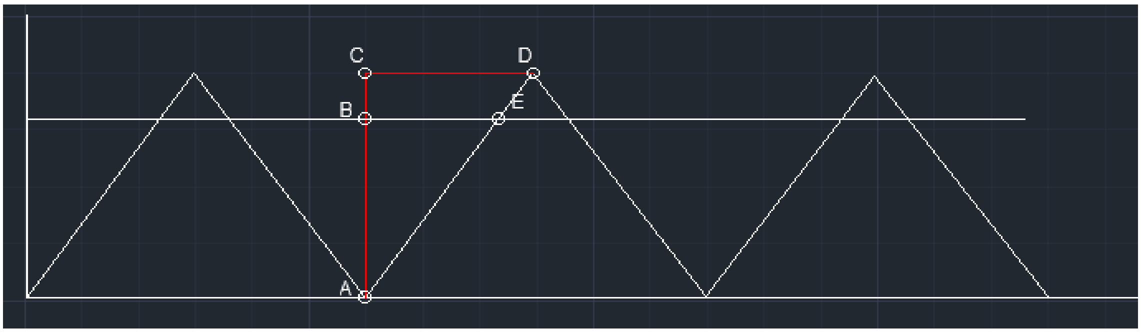


Fig.3 6 Modulación PWM

$$\frac{AB}{AC} = \frac{BE}{CD}$$

$$\frac{Vcontrol}{Vptri} = \frac{ton/2}{\frac{T}{2}} = D$$

$$Vsal = \frac{Vcontrol}{Vptri} * Vent \quad \text{Ec. (15)}$$

3.2. CALCULO DE PERDIDAS

Como todo semiconductor, se tiene pérdidas de potencia en ellos, lo normal es disponer de disipadores para poder disipar esta potencia o energía que pierden en forma de calor. El objetivo principal del cálculo es comprobar si es necesario el uso de un disipador.

Del diodo Schottky no se disponen de valores de pérdidas en el datasheet, por lo que no es posible calcularlas, pero dado que el diodo tiene bajas pérdidas y en este caso el Schottky es de gran tamaño, es posible evacuar el calor sin disponer de disipador.
De los MOSFET si se tienen valores para poder realizar el cálculo de pérdidas.

Se diferencian dos tipos de pérdidas, las de conducción y las de conmutación.

Las de conducción se producen debido a que el MOSFET en saturación se comporta como una resistencia de valor Rds(on), por lo que las pérdidas serán:

$$Pcond = Rds(on) * Id^2 * D \quad \text{Ec. (16)}$$

Para el convertidor Buck 1, el ciclo de trabajo estará comprendido entre 0,35 y 0,5, se escogerá el peor caso.

$$Pcond = 0{,}029 * 1{,}75^2 * 0{,}5 = 44{,}4\, mW$$

Para el convertidor Buck 2, el ciclo de trabajo estará en torno a 0,5, pero como las baterías pueden llegar a tener una tensión de entre 6 V a 8,4 V, si se escoge el peor caso, que sería 6 V, dará un ciclo de trabajo de 0,62 por lo que estas son las pérdidas.

$$Pcond = 0{,}029 * 1{,}75 * 0{,}62 = 55{,}06\, mW$$

En cuanto a las pérdidas de conmutación, son las pérdidas de energía provocadas en cada conmutación y que depende de la tensión y corriente de trabajo, y también de la tensión de control y resistencia de puerta, en nuestro caso de 6,8 ohm.

En las ecuaciones Ec. (17) y (18) se puede observar cómo se calculan las pérdidas.

$$Eon(Vdc, Idc) = Eon(Vdcref, Idcref) * \left(\frac{Vdc}{Vdcref}\right) * \left(\frac{Idc}{Idcref}\right) \quad \text{Ec. (17)}$$

$$Eoff(Vdc, Idc) = Eoff(Vdcref, Idcref) * \left(\frac{Vdc}{Vdcref}\right) * \left(\frac{Idc}{Idcref}\right) \quad \text{Ec. (18)}$$

Las pérdidas en el encendido se representan con la Ec. (19):

$$Eon = \frac{Vds * Id * tr}{2} + \frac{2}{3} * Cds(Vdc) * Vdc^2 \quad \text{Ec. (19)[6]}$$

Donde tr es el tiempo de carga del condensador Cds.

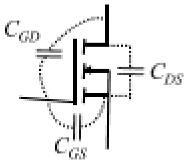
Las pérdidas en el apagado se representan con la Ec. (20):

$$Eoff = \frac{Vds * Id * tf}{2} + \frac{4}{3} * Cds(Vdc) * Vdc^2 \quad \text{Ec. (20)[6]}$$

Donde tf es el tiempo de descarga del condensador Cds.

Como se puede apreciar, en las ecuaciones aparece un capacitor nombrado como Cds.

Este capacitor es una modelización de la introducción y extracción de los electrones de las distintas capas por las que circula la corriente. [6]



$$C_{iss} = C_{GS} + C_{GD}$$
$$C_{oss} = C_{DS} + C_{GD}$$
$$C_{rss} = C_{GD}$$

Cuando el valor de tensión entre el drenador y fuente del MOSFET disminuye, el valor de las capacidades parásitas aumenta considerablemente.

Los valores de estas capacidades aparecen en el datasheet del MOSFET que se ha elegido que se incluye en al apartado de ANEXOS.

Para el convertidor Buck 1 se tendrá la siguiente ecuación:

$$Eon = \frac{30 * 5 * 5{,}6 * 10^{-8}}{2} + \frac{2}{3} * 20 * 10^{-12} * 22^2 = 4{,}26 * 10^{-7}\, J$$

$$Eoff = \frac{30 * 5 * 9{,}1 * 10^{-8}}{2} + \frac{4}{3} * 20 * 10^{-12} * 22^2 = 6{,}954 * 10^{-8}\, J$$

Para el convertidor Buck 2 se tendrá la siguiente ecuación:

$$Eon = \frac{8{,}4 * 1{,}75 * 5{,}6 * 10^{-8}}{2} + \frac{2}{3} * 20 * 10^{-12} * 8{,}4^2 = 4{,}21 * 10^{-8}\, J$$

$$Eoff = \frac{8{,}4 * 1{,}75 * 9{,}1 * 10^{-8}}{2} + \frac{4}{3} * 20 * 10^{-12} * 8{,}4^{2} = 6{,}877 * 10^{-8}\, J$$

Por tanto, se tendrán las siguientes pérdidas de conmutación en los dos convertidores según la Ec. (21).

$$Pconm = (Eon + Eoff) * fcon \quad \text{Ec. (21)[6]}$$

Buck 1:

$$Pconm = (6{,}954 * 10^{-7} + 4{,}26 * 10^{-7}) * 50000 = 56{,}07\, mW$$

Buck 2:

$$Pconm = (4{,}21 * 10^{-8} + 6{,}877 * 10^{-8}) * 50000 = 5{,}543\, mW$$

Sumando tanto pérdidas de conducción como de conmutación se tendrá lo siguiente:

Buck 1:

$$Ppérd = 44{,}4 + 56{,}07 = 100{,}07\, mW$$

Buck 2:

$$Ppérd = 55{,}06 + 5{,}543 = 60{,}6\, mW$$

Como se puede apreciar, los valores de pérdidas son insignificantes debido a que según el datasheet, la resistencia térmica dice que es de 0,01 W/ºC, y por tanto en el Buck 1 como mucho en la unión habrá 10ºC que de temperatura ambiente y en el Buck 2 como mucho habrá 6 ºC más que de temperatura ambiente.

Teniendo en cuenta que la unión del MOSFET aguanta hasta temperaturas de 150ºC, este valor no es posible alcanzarlo y por tanto no haría falta instalar un disipador de energía para las pérdidas del semiconductor.

3.3. FILTROS DE SALIDA

El Esquema que se puede ver en la Fig.3.7. es el del convertidor buck 1.

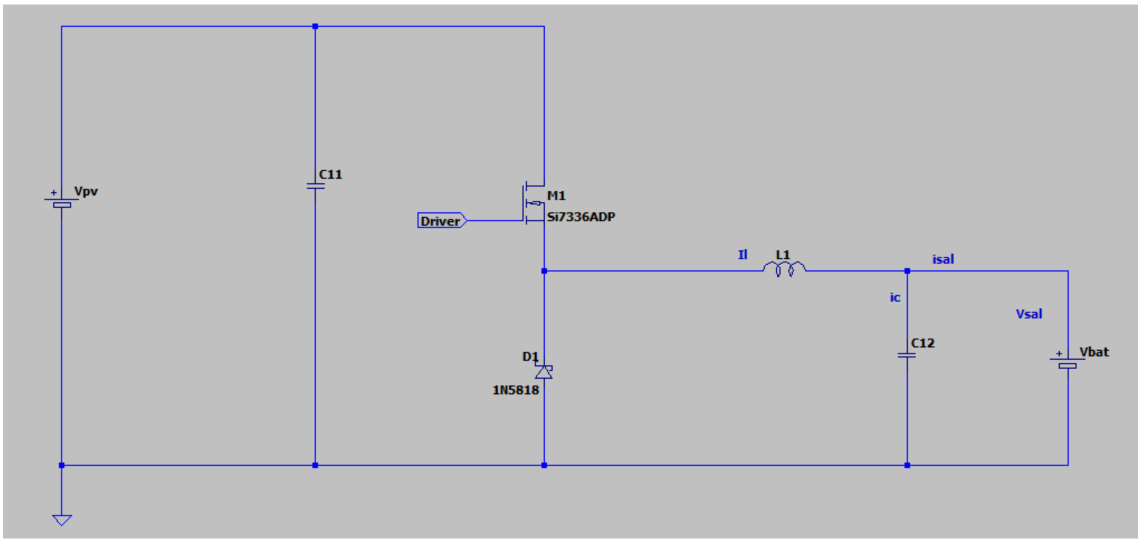


Fig.3.7 Esquema con variables del convertidor buck 1

3.3.1. CONDENSADOR ENTRADA BUCK 1

El condensador de entrada hace que, mediante su carga, posteriormente se pueda medir la tensión que tienen los módulos.

Para el cálculo de este condensador se tendrán en cuenta las siguientes consideraciones:

$$i(t) = C * \frac{dV(t)}{dt} \qquad \text{Ec. (22)}$$

$$I = C * \frac{\Delta V}{\Delta t}$$

De aquí se despeja y se obtiene que:

$$C = I * \frac{\Delta t}{\Delta V}$$

Si se tiene en cuenta que el rizado de voltaje se considera del 2% y que Δt lo tomamos como el periodo de conmutación multiplicado por el ciclo de trabajo, se consigue la siguiente expresión:

$$C = \frac{I*Tcon*D}{\Delta V} = \frac{I*D}{\Delta V*fcon} \qquad \text{Ec. (23)}$$

Si tomamos como intensidad el valor de 1,75 A, de frecuencia de conmutación 50 kHz y de ciclo de trabajo 0,5 ya que es el máximo para Vpvmin y Vbatmax, se obtiene que el valor del condensador es el siguiente:

C11=58,33µF

Para el modelado de los dos paneles en paralelo, semiconductores y filtro que se calculará en el siguiente apartado, en la Fig.3.8. se puede ver el rizado del condensador.

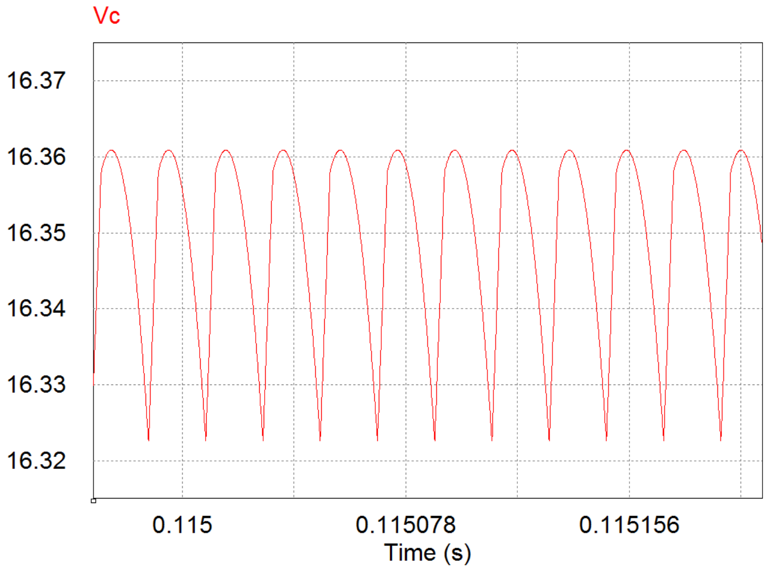


Fig.3.8. Rizado de tensión en el condensador C11

3.3.2. FILTRO SALIDA BUCK 1

Debido a que la forma de onda de salida del convertidor es cuadrada es necesario que se filtre mediante un filtro paso bajo LC, es decir, una bobina y un condensador en paralelo.

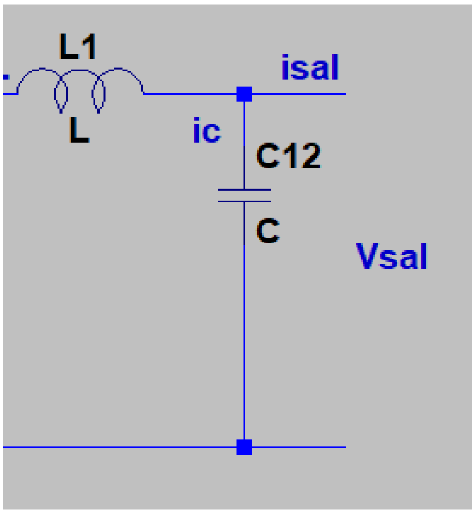


Fig.3.9. Filtro de salida del Buck 1

3.3.2.1. BOBINA

Se le ajustará a la bobina un valor de rizado del 20% es decir de 0,35 A teniendo en cuenta que la corriente máxima será de 1,75 A.

$$L1 = \frac{Vent}{4 * fcon * \Delta ilmax} = 300\mu H$$

En donde:

- Vent : Tensión de entrada
- fcon : frecuencia de conmutación
- Δilmax : rizado máximo

Para el presente proyecto se ha realizado la bobina de forma manual de la siguiente manera que se muestra a continuación.

Para el trabajo se ha optado por la creación de unas bobinas mediante unos núcleos magnéticos y un cordel de cobre.

Para ello habrá que dar las vueltas alrededor del núcleo (espiras) necesarias para conseguir el valor de inductancia deseado.

Como se quiere ser medianamente preciso con su valor ya que un mal ajuste de ellas provocará unos rizados mayores de corriente, se procederá a calcular el valor de la permeabilidad magnética del núcleo, ya que exactamente no se sabe qué valor escoger, aunque si se tiene por seguro que los núcleos son de polvo de hierro, no se tiene claro cuál es su permeabilidad relativa con exactitud.

Se alimentará un núcleo con un determinado número de espiras, en este caso 21 vueltas, a unos 4 V de tensión triangular y de frecuencia 50 kHz.
Debido a que este núcleo actúa como una resistencia, pudiendo saber el valor de corriente que circula por él, se podrá saber el valor de su inductancia.

En este caso los valores obtenidos son los siguientes:

V = 4,04 V
I = 0,371 A

Por lo que si se quiere calcular la Z:

$$Z = \frac{4{,}04}{0{,}371} = 10{,}8894\ \Omega$$

Z = L*w = L*2*π*50000

10,8894 = L*2*π*50000

L = $46{,}48*10^{-6}$.

Este es el valor de la bobina cuando el núcleo de hierro esta rodeado por 21 espiras, pero se quieren conseguir de $300*10^{-6}$ H.

Primero se deberá calcular el valor de la permeabilidad con el valor de bobina calculado anteriormente.

$$L = \frac{\mu o * \mu r * N^2 * h}{2\pi} * Ln\left(\frac{b}{a}\right) \qquad \text{Ec. (22) [7]}$$

h: altura
b: radio exterior
a: radio interior
μo: permeabilidad del vacío
μr: permeabilidad magnética.

Para la comprobación se utilizó un núcleo que tendrá las siguientes características:

a= 0,01m
b= 0,016m
h=0,012m

$$46{,}68 * 10^{-6} = \frac{4\pi * 10^{-7} * \mu r * 21^2 * 0{,}012}{2\pi} * Ln(\frac{0{,}016}{0{,}01})$$

De aquí sale que:

μr= 93,84 N/A^2.

Se puede dar veracidad al dato obtenido debido a que tiene un valor muy cercano a los que manejan los fabricantes.

$$300 * 10^{-6} = \frac{4\pi * 10^{-7} * 93{,}84 * N^2 * 0{,}012}{2\pi} * Ln(\frac{0{,}016}{0{,}01})$$

El número de espiras (N) será de 55.
También se calcula la intensidad de saturación.
Se calculará la reluctancia de la bobina de 300 μH

$$Rel = \frac{lm}{\mu r * \mu o * Anucleo} \qquad \text{Ec.(23) [7]}$$

Rel: Reluctancia
lm: longitud de la circunferencia
Anucleo: área del núcleo

$$Rel = \frac{0{,}0702}{93{,}84 * 4\pi * 10^{-7} * 3{,}485 * 10^{-4}} = 1708191\ Wb$$

$$Isat = \frac{Bsat * Anucleo * Rel}{N} \qquad \text{Ec. (24) [7]}$$

Se tomará un valor de Bsat=0,6-1,3 T, en este caso se opta por 0,8 T.

$$Isat = \frac{0{,}8 * 3{,}485 * 10^{-4} * 1708191}{55} = 8{,}65\ A$$

Por lo tanto, como se aprecia, el valor de intensidad de saturación de la bobina es superior que con el que se va a trabajar por lo que no debería haber problema alguno.

Fig.3.10. Bobina con 55 espiras.

En la siguiente Fig 3.11 se puede apreciar el rizado de la bobina L1

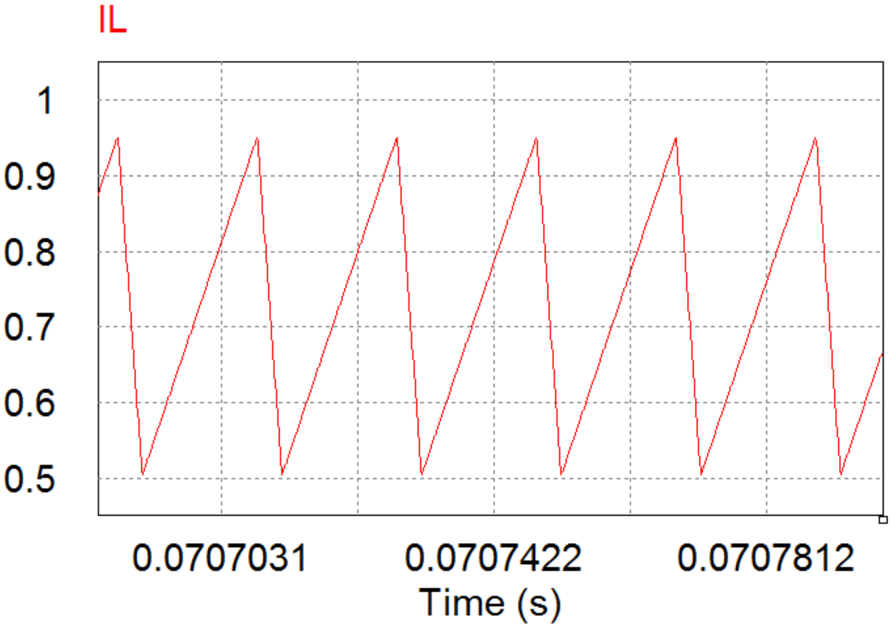


Fig.3 11 Rizado de corriente en bobina L1.

3.3.2.2.CONDENSADOR

En este caso en vez de utilizar un valor de rizado de corriente fijo para el condensador como se ha hecho para la bobina, se utilizará un valor fijo de rizado de tensión.

$$C \geq \frac{Vent}{32 * L * \Delta Vcmax * fcon^2} = \frac{22}{32 * 300 * 10^{-6} * 0{,}15 * 50000^2}$$

C12=6,11µF

En donde:

- fcon : frecuencia de conmutación
- L : valor de la bobina calculada anteriormente
- $\Delta Vcmax$: rizado de tensión tomado como el 2%

3.3.3. CONDENSADOR ENTRADA BUCK 2

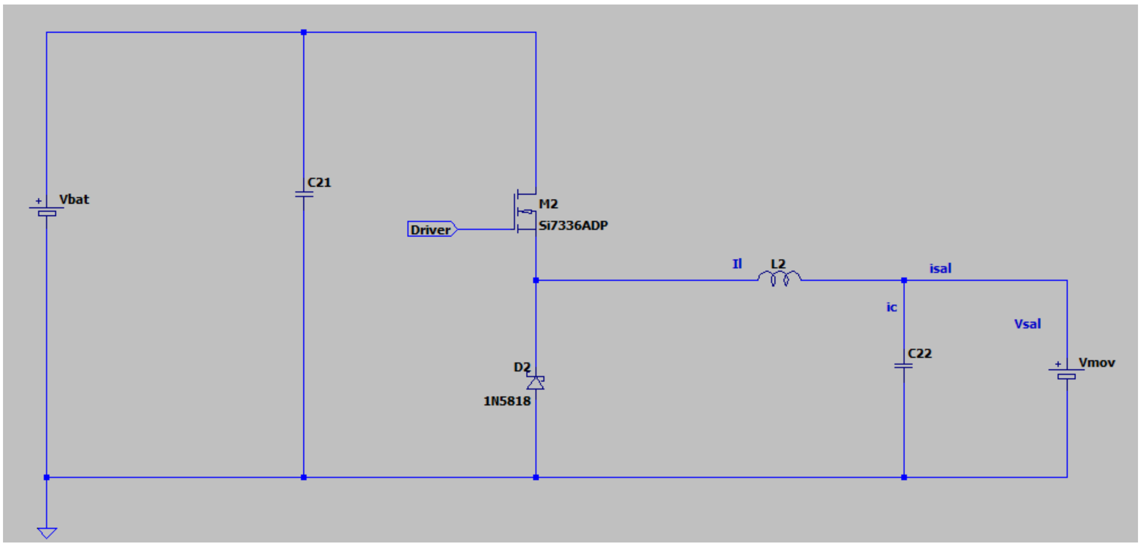


Fig.3.12 Esquema con variables del convertidor buck 1

Para el cálculo de este condensador se tendrán en cuenta las siguientes consideraciones:

$$i(t) = C * \frac{dV(t)}{dt} \qquad \text{Ec. (25)}$$

$$I = C * \frac{\Delta V}{\Delta t}$$

De aquí se despeja y se obtiene que:

$$C = I * \frac{\Delta t}{\Delta V}$$

Si se tiene en cuenta que el rizado de voltaje se considera del 2% y que Δt lo tomamos como el periodo de conmutación multiplicado por el ciclo de trabajo, se consigue la siguiente expresión:

$$C = \frac{I * Tcon * D}{\Delta V} = \frac{I * D}{\Delta V * fcon} \qquad \text{Ec. (26)}$$

Si tomamos como intensidad el valor de 1,75 A, de frecuencia de conmutación 50 kHz, de ciclo de trabajo 0,5 ya que Vent=7,2V y Vsal=3,7 por lo que si se aplica la Ec.(5) se obtiene que D=0,5, y el 2% de rizado de 8,4V se obtiene que el valor del condensador es el siguiente:

C21=104,16µF

3.3.4. FILTRO SALIDA BUCK 2

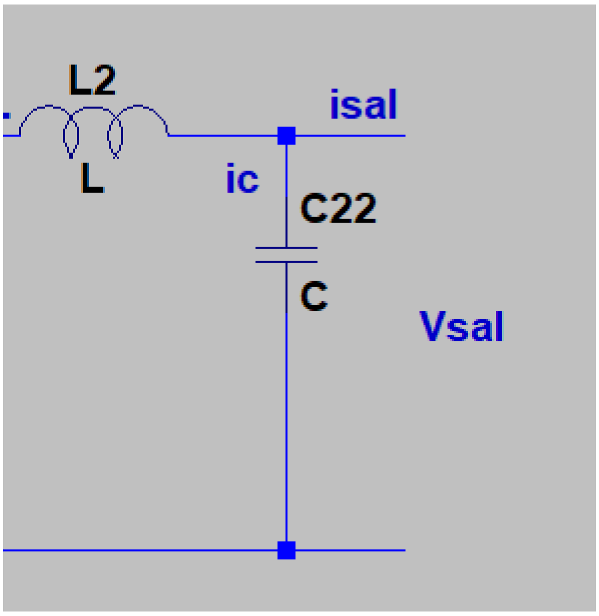


Fig.3 13 Filtro de salida del Buck 2.

3.3.4.1. BOBINA

Se le ajustará a la bobina un valor de rizado del 20% es decir de 0,35 A teniendo en cuenta que la corriente máxima será de 1,75 A.

$$L2 = \frac{Vent}{4 * fcon * \Delta ilmax} = 120\mu H$$

En donde:

- Vent : Tensión de entrada
- fcon : frecuencia de conmutación
- Δilmax : rizado máximo

Se realizará el mismo proceso inicial que en el apartado 3.3.1.1. para la fabricación de la bobina.

$$120 * 10^{-6} = \frac{4\pi * 10^{-7} * 93{,}84 * N^2 * 0{,}012}{2\pi} * Ln(\frac{0{,}016}{0{,}01})$$

El número de espiras (N) será de 34.
Se calculará la reluctancia de la bobina de 120 µH

$$Rel = \frac{lm}{\mu r * \mu o * Anucleo}$$

Rel: Reluctancia
lm: longitud de la circunferencia
Anucleo: área del núcleo

$$Rel = \frac{0{,}08168}{93{,}84 * 4\pi * 10^{-7} * 4{,}9 * 10^{-4}} = 1413329\, Wb$$

$$Isat = \frac{Bsat * Anucleo * Rel}{N}$$

Se tomará un valor de Bsat=0,6-1,3 T, pero se usará Bsat=0,8T.

$$Isat = \frac{0{,}8 * 4{,}9 * 10^{-4} * 1413329}{34} = 16{,}3\, A$$

Por lo tanto, como se aprecia, el valor de intensidad de saturación de la bobina es superior que con el que se va a trabajar por lo que no debería haber problema alguno.

Fig.3 14 Bobina con 34 espiras.

En la siguiente Fig 3.15 se puede apreciar el rizado de la bobina L1

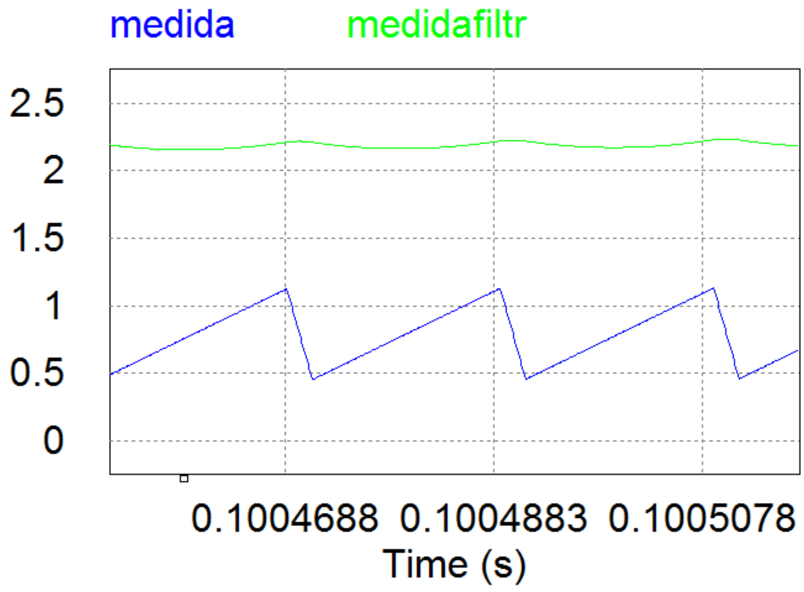


Fig.3 15 Rizado de corriente en bobina L2.

3.3.4.2.CONDENSADOR

En este caso en vez de utilizar un valor de rizado de corriente fijo para el condensador como se ha hecho para la bobina, se utilizará un valor fijo de rizado de tensión.

$$C \geq \frac{Vent}{32 * L * \Delta Vcmax * fcon^2} = \frac{8,4}{32 * 120 * 10^{-6} * 0,072 * 50000^2}$$

C22=12,15µF

En donde:

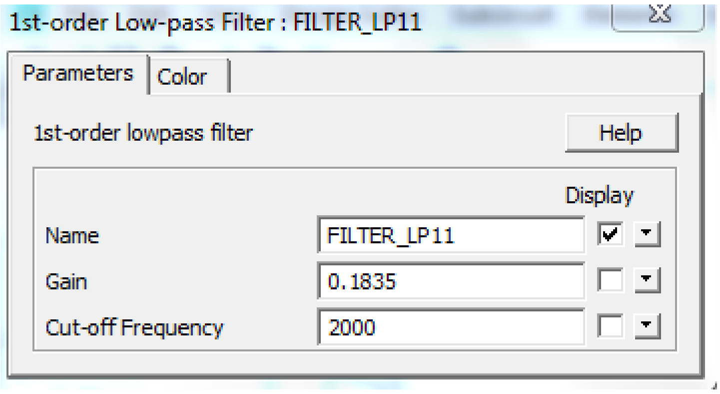
- fcon : frecuencia de conmutación
- L : valor de la bobina calculada anteriormente
- $\Delta Vcmax$: rizado de tensión tomado como el 2%

3.4. FILTROS DE MEDIDA-

3.4.1. FILTRO LAZO CONTROL TENSION

Para el filtro del lazo de control, se desea controlar la variable Vpv por lo que se obtiene una ganancia llamada Ksv de 1/5,45, ya que como se quiere fijar la referencia a 3V para cuando el módulo este dando 16,35 V (45ºC de célula), 16,35 entre 3 son estos 5,45, que realmente atenuarán la señal.

Como el lazo de control será a 50 kHz, el filtro deberá tener una frecuencia de corte al menos 8 veces inferior, por lo que la frecuencia de corte del filtro será de 2000 Hz.



1st-order lowpass filter

Name FILTER_LP11 ☑
Gain 0.1835 ☐
Cut-off Frequency 2000 ☐

Fig.3 .16 Valores introducidos en PSIM

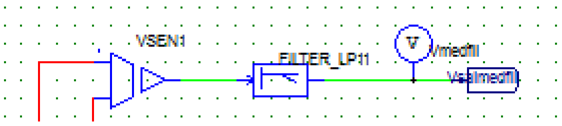


Fig.3 .17 Esquemático PSIM filtro lazo tensión

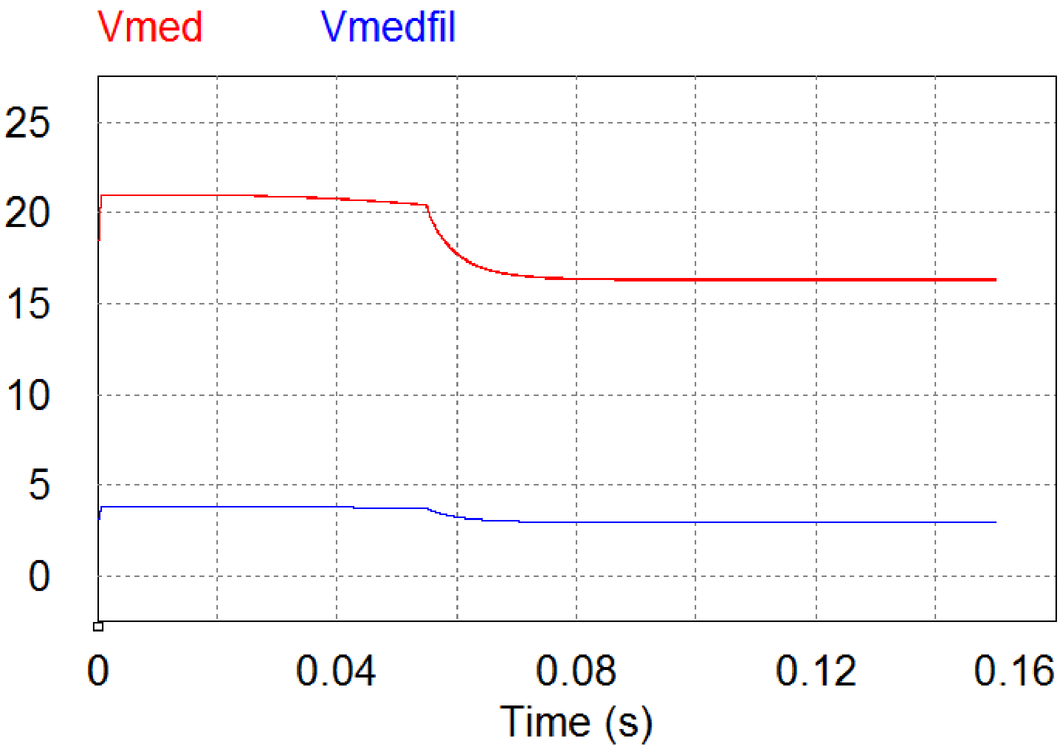


Fig.3 .18 Vmed señal roja / Vmedfil señal azul.

En la Fig.3.18 se puede ver como la señal se escala y se filtra, despareciendo el rizado.

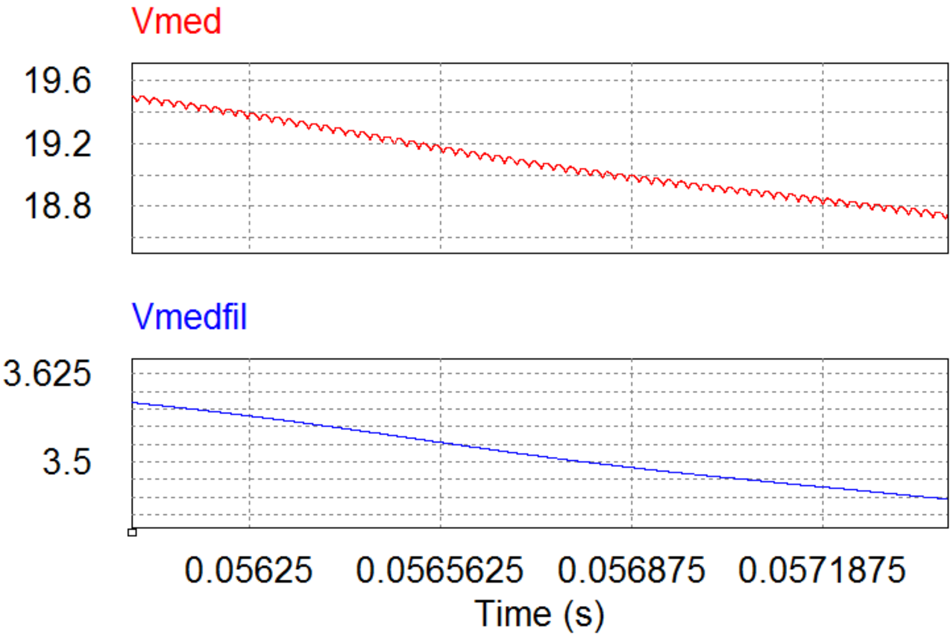


Fig.3 .19. Señal medida y señal medida y filtrada.

Como se aprecia en la Fig 3.19 el voltaje medido se escala y se filtra mediante un filtro paso bajo y un divisor de tensiones.

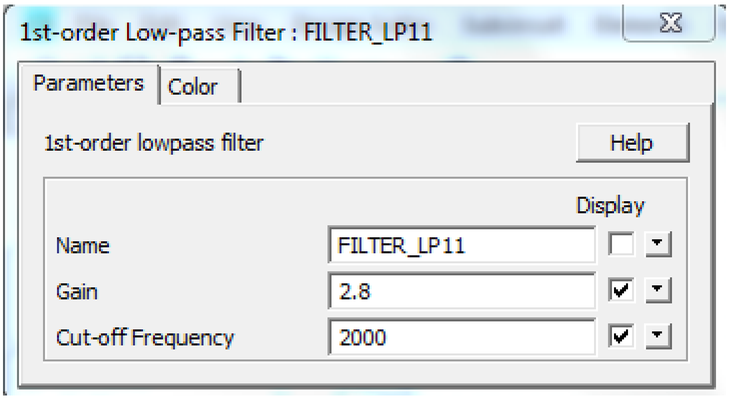
3.4.2. FILTRO LAZO CONTROL CORRIENTE

La célula LEM necesita un escalado y un filtro paso bajo para rectificar y filtrar la señal que nos devuelve de corriente en forma de tensión.

Sabiendo que el control va a ser a 50 kHz, debemos tener en cuenta que la frecuencia del filtro debe ser al menos 8 veces menor, por lo que la frecuencia de corte será de 2000 Hz.

La referencia se quiere fijar en 3V, por lo que para escalar la señal de corriente que medirá la célula LEM se deberá calcular el valor de Ksi.

$$Ksi = \frac{8,4}{3} = 2,8$$



1st-order Low-pass Filter : FILTER_LP11

1st-order lowpass filter

		Display
Name	FILTER_LP11	☐
Gain	2.8	☑
Cut-off Frequency	2000	☑

Fig.3 .20 Valores introducidos en PSIM

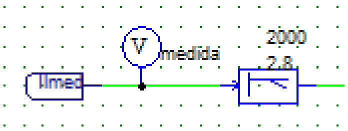


Fig.3 .21 Esquematico PSIM del filtro de medida del lazo de corriente

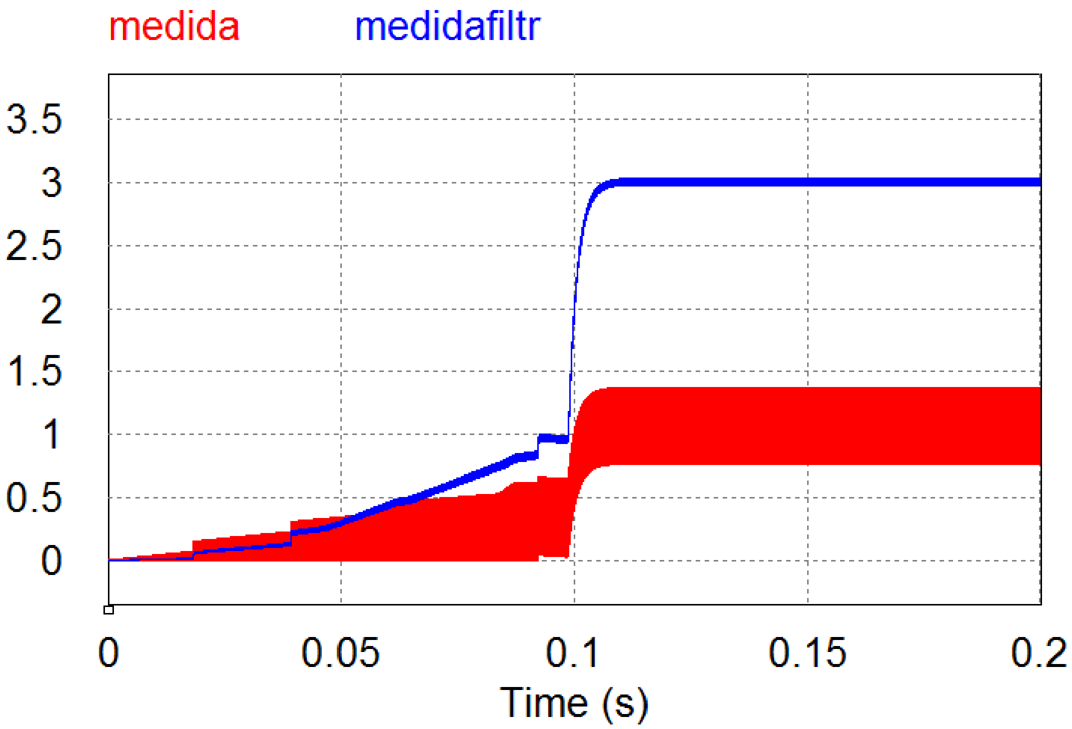


Fig.3 .22 Señal de corriente medida / filtrada

Como se aprecia en la Fig.3.22, la señal roja es la corriente medida, que debido a su paso por un filtro, se corrigen las imperfecciones y además se le da una ganancia, y como se puede ver la corriente medida y filtrada tenderá a ser del mismo valor que la de referencia, pero con su rizado particular.

El rizado de la corriente medida y filtrada deberá ser menor que el de la corriente medida, como se ve en la Fig.3.23.

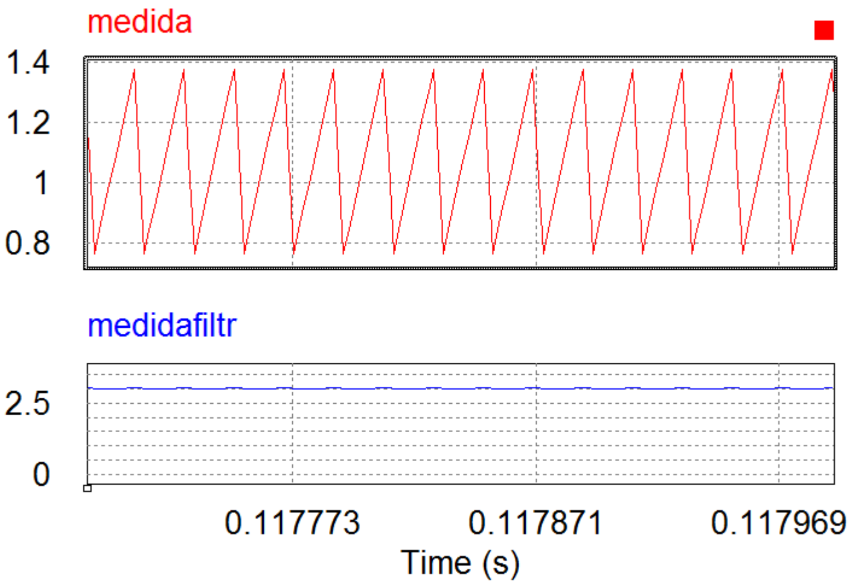


Fig.3 .23.Rizado de corriente en corriente medida y corriente medida y filtrada.

4.CONTROLES DEL CONVERTIDOR

4.1. LAZO DE CONTROL DE TENSION

Para controlar la tensión, se coloca un condensador a la entrada, por lo tanto, la tensión de bus equivaldrá al estado de carga del condensador como se muestra en la Fig.4.1.

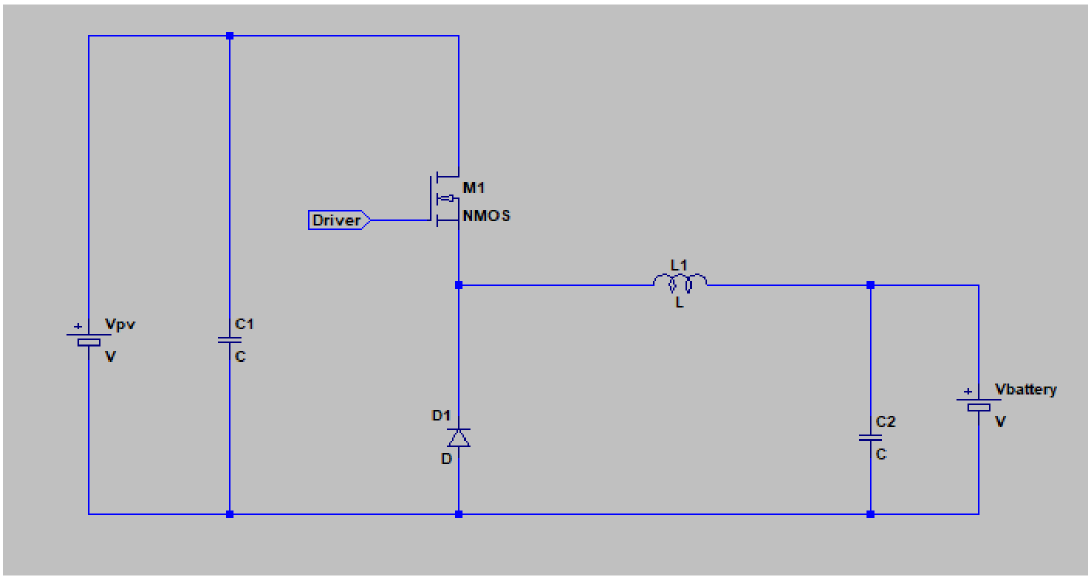


Fig 4. 1 Convertidor Buck 1

En la Fig.4.2. se muestra el lazo cerrado utilizado para controlar la tensión proporcionada por los paneles.

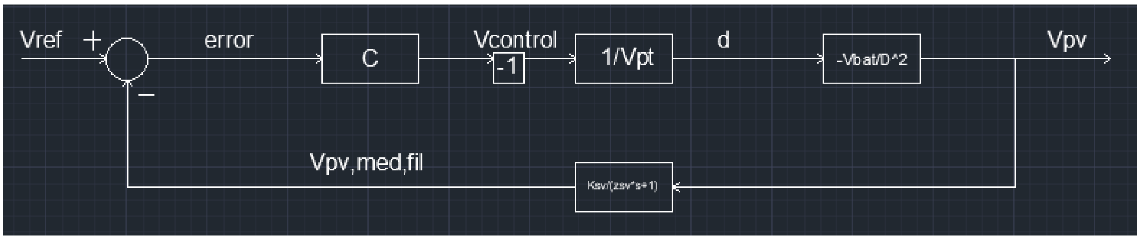


Fig 4. 2.Esquema del control de tensión en lazo cerrado

Se tiene como ventajas la precisión ya que el control se basa en el error y el MCC y MCD, y como desventajas que es más complejo y sin información acerca de la corriente.

El control de tensión tendrá una fc establecida de 40 Hz, más baja que la del filtro que será menor de 50 kHz/8, ya que con esto se consigue que el comportamiento de la planta sea lineal.

Se observa en la Fig.4.2 un cuadrado en el que aparece dibujado en su interior un -1, esto representa que ese -1 unido a la modelización de la planta, que también tiene un signo negativo, se compensará.

Para el control se establecen distintas partes:

- Referencia
- Restador
- Controlador integral
- Comparador
- Planta
- Filtro

La implementación de estos subcircuitos se explicará en el apartado de diseño de la circuitería, excepto el controlador y planta.

A continuación se presenta el modelado de la planta y el diseño de los parámetros del controlador.

4.1.1.PLANTA

La planta del sistema, al no ser un modelo lineal puesto que la tensión de entrada no es constante, se linearizará en torno a un punto de trabajo con tensión Vbat y ciclo de trabajo D.
Este valor será el siguiente:

$$\frac{dVpv}{dD} = \frac{-Vbat}{D\text{^}2}$$

$$\widehat{Vpv} = \frac{-Vbat}{D^2} * \hat{d}$$

La planta pues se tomará como una constante de valor:

$$\text{PLANTA(s)} = \text{-Vbat}/\text{D}^2$$

Esta planta a su vez es igual que:

$$\text{PLANTA(s)} = \text{Vpv}^2/\text{-Vbat}$$

Como se verá en el apartado de cálculo se escogerá la Vpv mayor y para Vbat se cogerá la menor, así se modela para la planta mayor posible.
Esto implica que se diseña para el punto más rápido y de menor estabilidad, ya que para otros puntos del siste,a será estable.

4.1.2.DISEÑO DEL CONTROLADOR INTEGRAL

Es un control basado en el cálculo de la integral mediante el circuito en el que se toma el dato del error pasado y el controlador lo va almacenando.

Cada vez que se integra el proceso hace que la señal se vaya aproximando a la señal de referencia.

Es ahí donde hay que ser eficaz y dotar a nuestro controlador de la rapidez necesaria, y esta rapidez viene dada por la expresión Ki, para acelerar o desacelerar la respuesta.

La acción del control integral viene dada por la siguiente expresión:

$$V(t) = Ki * \int_0^t e(t)dt \qquad \text{Ec. (27)[4]}$$

Para el diseño del control integral se deben tener en cuenta los siguientes valores de nuestro circuito:

Frec.conmutación	**50 kHz**
Tensión entrada	**22 V**
Cte de escalado(ksv)	**1/5,45**
Intensidad max.	**1,75 A**
Bobina 1	**300 µH**
Condensador 12	**6,11 µF**
Cte tiempo de filtro (τsv**)**	**7,957*10-5 s**
Voltaje triangular	**3,2 V**
Frecuencia corte lazo	**40 Hz**

Tabla 2. Valores para el cálculo del lazo de tensión

Para el cálculo de la constante de integración Ki y del margen de fase (MF), se deberá conocer la función de transferencia en lazo abierto del sistema que es la siguiente:

$$FTLA = \frac{Ki}{s} * \frac{1}{Vpt} * \frac{Vpv^2}{Vbat} * \frac{Ksv}{\tau sv * s + 1} \qquad \text{Ec. (28)}$$

De aquí se puede sacar el margen de fase.
MF = 180º - 90º -arctg(τsv*wcv) = 90º -1,145º = **88,854º**

Si hacemos que el valor absoluto de la función de transferencia sea 1 y a su vez que la s=w =wc, tendremos lo siguiente:

$$FTLA = \frac{Ki}{wc} * \frac{1}{Vpt} * \frac{Vpv^2}{Vbat} * \frac{Ksv}{\sqrt{\tau sv^2 * wc^2 + 1}} = 1$$

Si se despeja de ahí el valor de la constante integral se obtiene el siguiente resultado:

Ki= 54,3474

En la Fig.4.3 se muestra el modelo del controlador en el software PSIM.

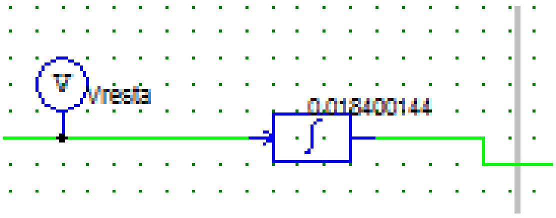


Fig 4. 3.Esquema del controlador en PSIM

Como se ve en la Fig 4.4 debido a la acción del controlador se consigue que la resta entre la referencia y la tensión medida sea 0, de esta forma se comprueba que el controlador ha actuado.

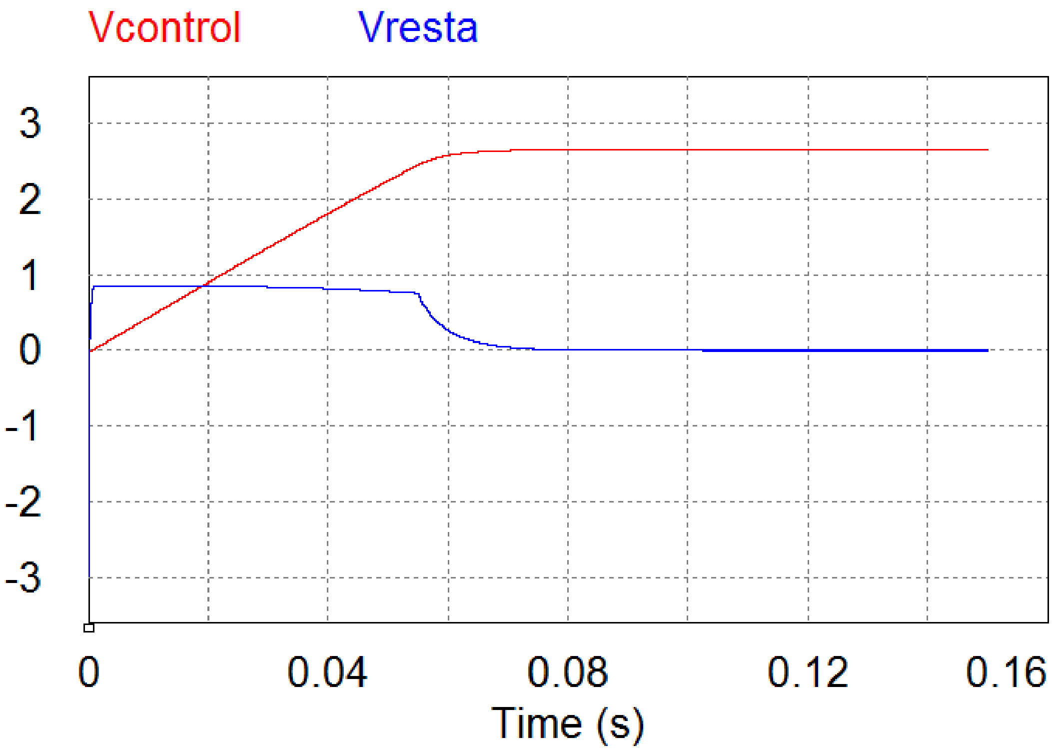


Fig 4.4.Señal de control y resta entre referencia y medición

Como se ha comentado anteriormente, en este lazo se ha trabajado a 40 Hz y con un modulado de planta que era el máximo, si se hubiese trabajado con el mínimo se habría obtenido la siguiente frecuencia.

$$wc^4 = \frac{Vpv^4 * Ksv^2 * Ki^2}{Vpt^2 * Vbat^2}$$

$$wc^4 = \sqrt[4]{6967{,}4} = 9{,}137\frac{rad}{s}$$

Donde se obtiene una f= 1,45 Hz

4.2. LAZO DE CONTROL DE CORRIENTE

Se debe contralar la corriente que se transmite desde las baterías hasta el móvil y para que no exceda de sus valores predeterminados se debe hacer un control de corriente.

En la Fig.4.5 se muestra es convertidor reductor DC/DC 2

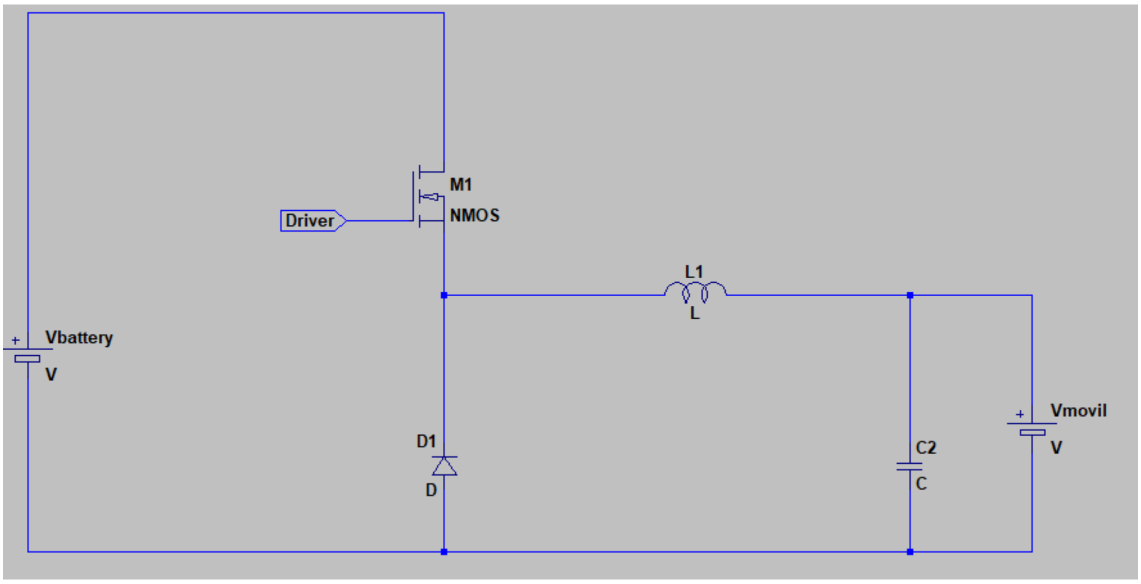


Fig 4. 5.Convertidor Buck 2

En la Fig.4.6 se ve el lazo utilizado para controlar la corriente de carga del móvil.

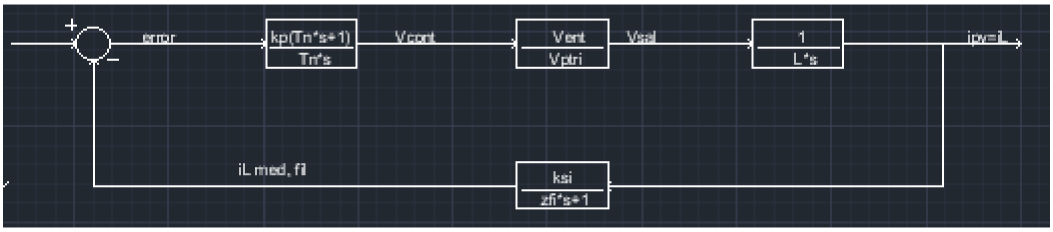


Fig 4.6Esquema del control de corriente lazo cerrado

Se tiene como ventajas del control de corriente que es muy preciso, se protege contra intensidades de la bobina muy altas y sirve para MCC y MCD, pero como desventajas se tiene que es más caro y complejo.

Para el control se establecen distintas partes:

- Referencia
- Restador
- Controlador proporcional integral (PI)

- Comparador
- Planta
- Filtro

La implementación de estos subcircuitos se explicará en el apartado de diseño de la circuitería, excepto el controlador y planta.

A continuación se presenta el modelado de la planta y el diseño de los parámetros del controlador.

4.2.1.PLANTA

Al ser la corriente que pasa por la bobina la fórmula de la planta es la siguiente:

$$PLANTA(s) = \frac{1}{L * s}$$

Como se verá en el apartado de cálculos, el valor de L será la bobina del convertidor, y la s supondrá un integrador, el cual aporta fase negativa de -90º clave para calcular la Tn del PI.

4.2.2.DISEÑO DEL CONTROLADOR PROPORCIONAL – INTEGRAL (PI)

El controlador PI tiene como misión disminuir y eliminar el error en estado estacionario.
El control integral actúa cuando hay una desviación entre la variable y el punto de control, es decir, cuando hay error, que lo integra en el tiempo y suma esta acción integral a la proporcional.

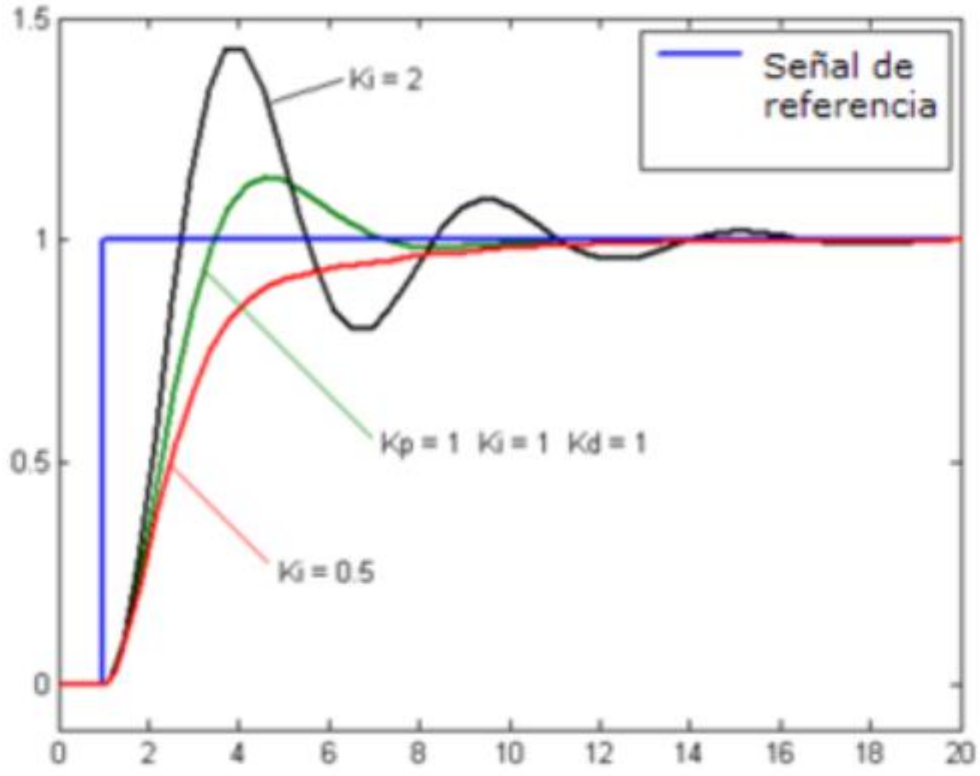


Fig 4.7 Respuestas de un controlador PI ante una referencia en función de sus cte.

La ecuación del controlador PI es la suma del control proporcional y del control integral y queda reflejada del siguiente modo:

$$PI(s) = Kp + \frac{Ki}{s}$$

$$PI(s) = Kp * \left(1 + \frac{Ki}{Kp * s}\right)$$

$$PI(s) = Kp * \left(1 + \frac{1}{Tn * s}\right)$$

$$Ki = \frac{Kp}{Tn}$$

$$PI(s) = Kp * \left(\frac{Tn*s+1}{Tn*s} \right) \quad \text{Ec. (29) [4]}$$

Donde la Kp es la ganancia del controlador y Tn es el tiempo de integración.

Para el diseño del control proporcional-integral se deben tener en cuenta los siguientes valores de nuestro circuito:

Frec.conmutación	**50 kHz**
Tensión entrada	**8,4V**
Cte de escalado(ksi)	**2,8**
Intensidad max.	**1,75 A**
Bobina 2	**120 µH**
Condensador 12	**12,16 µF**
Cte tiempo de filtro (τsv)	**7,957*10-5 s**
Voltaje triangular	**3,2 V**
Frecuencia corte lazo	**200 Hz**

Para el cálculo de la constante de integración Ki y de Tn se deberá conocer la función de transferencia en lazo abierto del sistema que es la siguiente:

$$FTLA = \frac{1}{s^2} * \frac{Kp(Tn*s+1)}{Vpt} * \frac{Vent}{L*Tn} * \frac{Ksi}{\tau sv*s+1} \quad \text{Ec. (28)}$$

Supondremos un margen de fase de 60º, valor en el cual tenemos estabilidad y rapidez suficiente.

60º = MF = 180º - 180º -arctg(τsv*wci)+arctg(Tn*wci)

$$60º+5,71º= \arctg(Tn*200*2*\pi)$$

Si se despeja, la Tn tendrá el siguiente valor:

$$Tn=1,763*10^{-3}s$$

Si hacemos que el valor absoluto de la función de transferencia sea 1 y a su vez que la s=w =wc, tendremos lo siguiente:

$$FTLA = \frac{Kp}{wc^2} * \frac{Ksi}{Vpt * L} * \frac{Vent}{Vbat} * \frac{\sqrt{Tn^2 * wc^2 + 1}}{\sqrt{\tau sv^2 * wc^2 + 1}} = 1$$

Si se despeja de ahí el valor de la constante proporcional se obtiene el siguiente resultado:

$$Kp=0,018793$$

En la Fig.4.8. se muestra el modelado del controlador PI en PSIM.

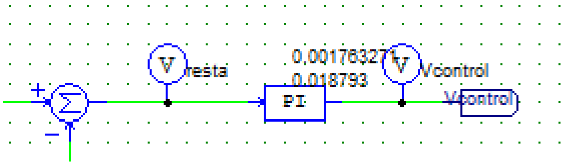


Fig 4.8 Esquema del controlador en PSIM

En la Fig.4.9. se aprecia como la resta entre la referencia y la corriente medida es 0, debido a la acción de nuestro controlador PI.

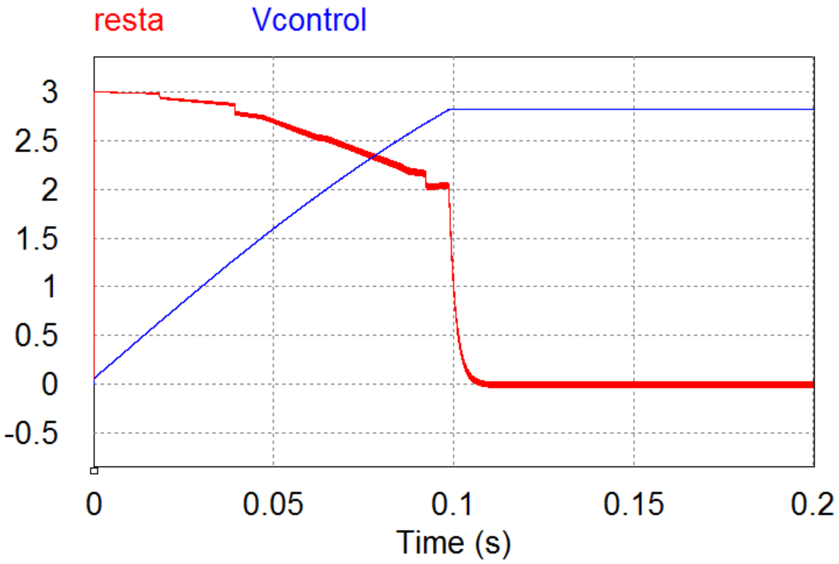


Fig 4.9.Señal de control y resta entre referencia y medición.

5.DISEÑO DE LA CIRCUITERIA

5.1.FUENTE DE ALIMENTACIÓN AISLADA

Antes de exponer la circuitería de los distintos sistemas, es preciso indicar como se van a alimentar.

En el apartado de ANEXOS se incluirá el datasheet correspondiente a la fuente de alimentación.

Esta fuente de alimentación se alimentará entre 4,5-10 V, ese voltaje será dado por las baterías de almacenamiento que se recuerda que tienen una tensión de 7,2 V.

Esta fuente de alimentación tiene dos salidas, una positiva de 5 V y otra negativa de -5V con las cuales se alimentarán los amplificadores operacionales TL081IP.

Estos voltajes se pueden ver en la Fig 5.1 y Fig 5.2 que se muestran a continuación.

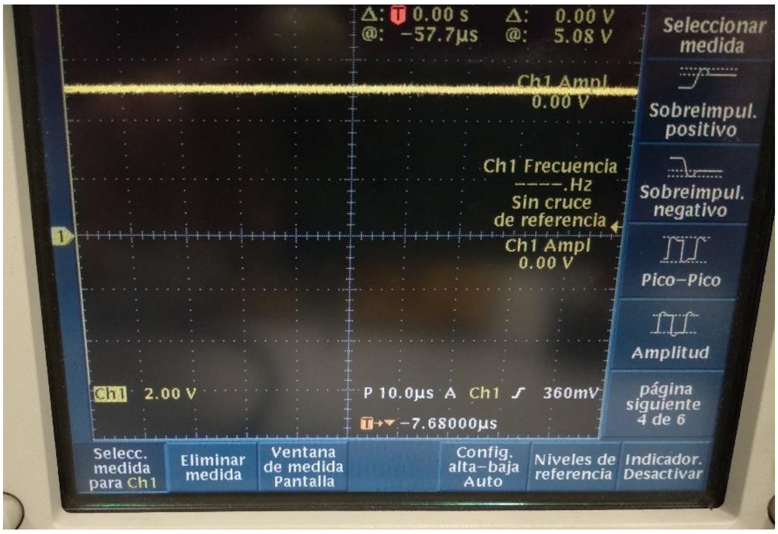
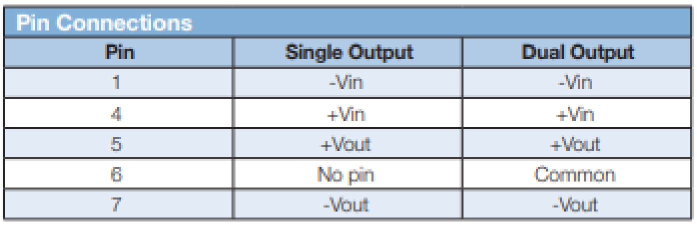


Fig.5 1. Salida positiva de 5V de la fuente

Fig.5 2. Salida negativa de -5V de la fuente



Pin Connections

Pin	Single Output	Dual Output
1	-Vin	-Vin
4	+Vin	+Vin
5	+Vout	+Vout
6	No pin	Common
7	-Vout	-Vout

Fig.5 3. Pines de conexión de la fuente [9].

5.2 CIRCUITOS DEL CONTROL DE TENSION

5.2.1.REFERENCIA

Se trata de configurar una señal a un valor predeterminado y constante, con el cual luego se comparará la señal de entrada que nos generen los paneles fotovoltaicos.

Se utilizará una resistencia unida a un potenciómetro, así se afinará más para buscar el valor deseado.

Del punto medio de los elementos mencionados anteriormente se unirá a un operacional, que actúa en forma de seguidor emisor, esto hace que la tensión de entrada sea igual que la tensión de salida debido a que se modifica la impedancia entre circuitos, aumentando la impedancia de entrada y disminuyendo la de salida para aislar los circuitos entre sí.

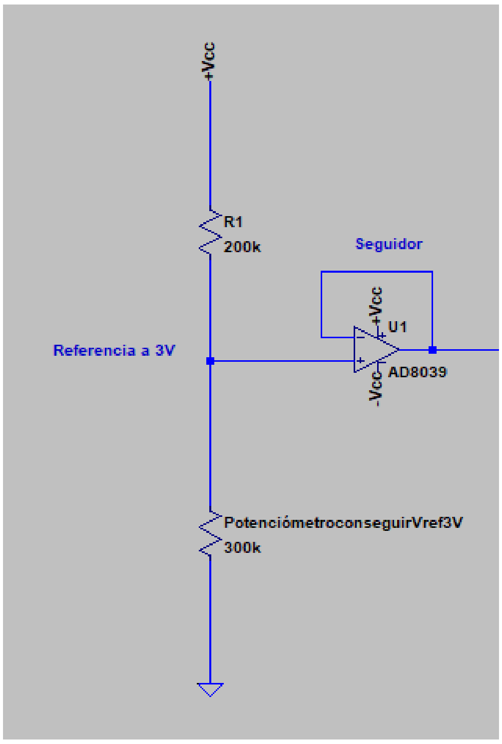


Fig.5 4. Circuito de tensión de referencia .

Para crear la referencia, se deberá escalar el voltaje que nos proporcionan los paneles, en este caso queremos que con 16,5 V la tensión sea de 3 V, es decir nuestra referencia, por lo que ksv=3/16,5,es decir, 1/5,45.

Como en todos los circuitos que se van a desarrollar, no se quieren tener pérdidas de potencia por lo que se dimensionaran para intensidades relativamente bajas del entorno de 0,01 mA- 1mA.

Para crear nuestra referencia, bastará con una resistencia conectada a 5 V de unos 200k y otra conectada a tierra de 300k.
Como normalmente las resistencias tienen tolerancias altas, será mejor poner un potenciómetro abajo para hilar más fino con el valor de referencia.
A la salida de la referencia, se deberá incluir un AO en forma de seguidor que actúa como aislador de circuitos, ya que el AO tiene alta impedancia de entrada y baja o nula de salida.

5.2.2.RESTADOR

Es un circuito mediante el cual se van a comparar la tensión de referencia y la tensión de panel medida y filtrada, esto se hace para poder calcular el error y así mediante la acción del controlador modificar los parámetros necesarios.

La fórmula de restador con realimentación negativa es la siguiente:

$$v0 = \left(1 + \frac{R2}{R1}\right) * \frac{R4}{R3+R4} * v1 - \frac{R2}{R1} * v2 \qquad \text{Ec. (29)[8]}$$

Si se considera que:

$$\frac{R2}{R1} = \frac{R4}{R3}$$

Se queda una expresión tal que:

$$v0 = \frac{R2}{R1}(v1 - v2) \qquad \text{Ec. (30)[8]}$$

Como no se quiere tener ningún tipo de ganancia, todas las resistencias serán iguales, en este caso de 250k.

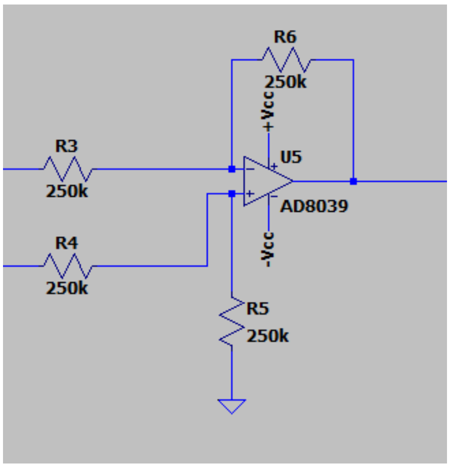


Fig.5 5. Circuito restador entre referencia y tensión medida .

En la Fig.5.6. se ve como la señal azul equivale a la referencia, la señal roja al voltaje medido y filtrado, y la señal verde a la resta de ambos, como se ve la resta tiende a estabilizarse en 0 V, sinónimo de que el controlador ha actuado.

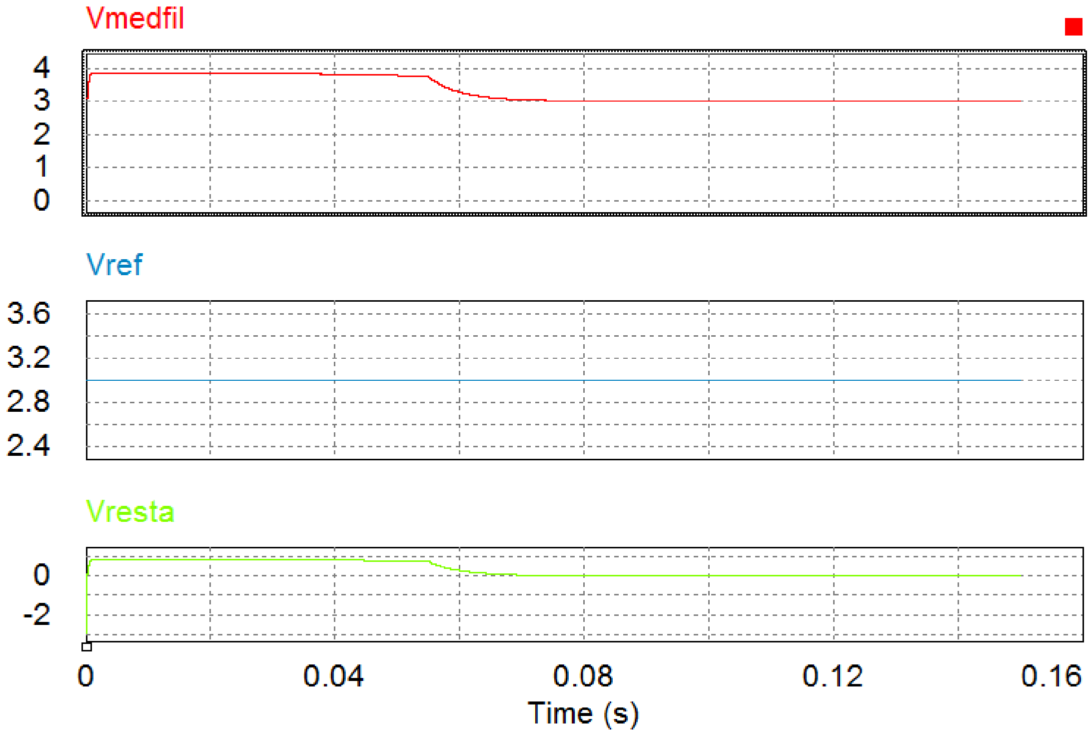


Fig.5 6.Simulación en PSIM del valor final de resta, señal de color verde .

5.2.3.COMPARADOR

Es un operacional al cual le llega a sus entradas dos señales analógicas, en este caso una será la acción integral y la otra será una señal triangular que define la frecuencia de conmutación del MOSFET.
De esta comparación se consigue a la salida una señal digital llamada DutyCycle, si la acción integral es mayor que la triangular el valor será alto y si ocurre lo contrario el valor será bajo.

El conjunto de estas ondas forma lo que es llamado PWM (Modulación por anchura de pulso), que sirve para encender y apagar los semiconductores, el MOSFET, para obtener una tensión troceada, ya que interesa recibir el valor medio de esta tensión.

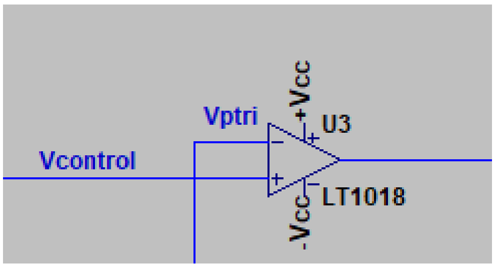


Fig.5 7.Circuito comparador.

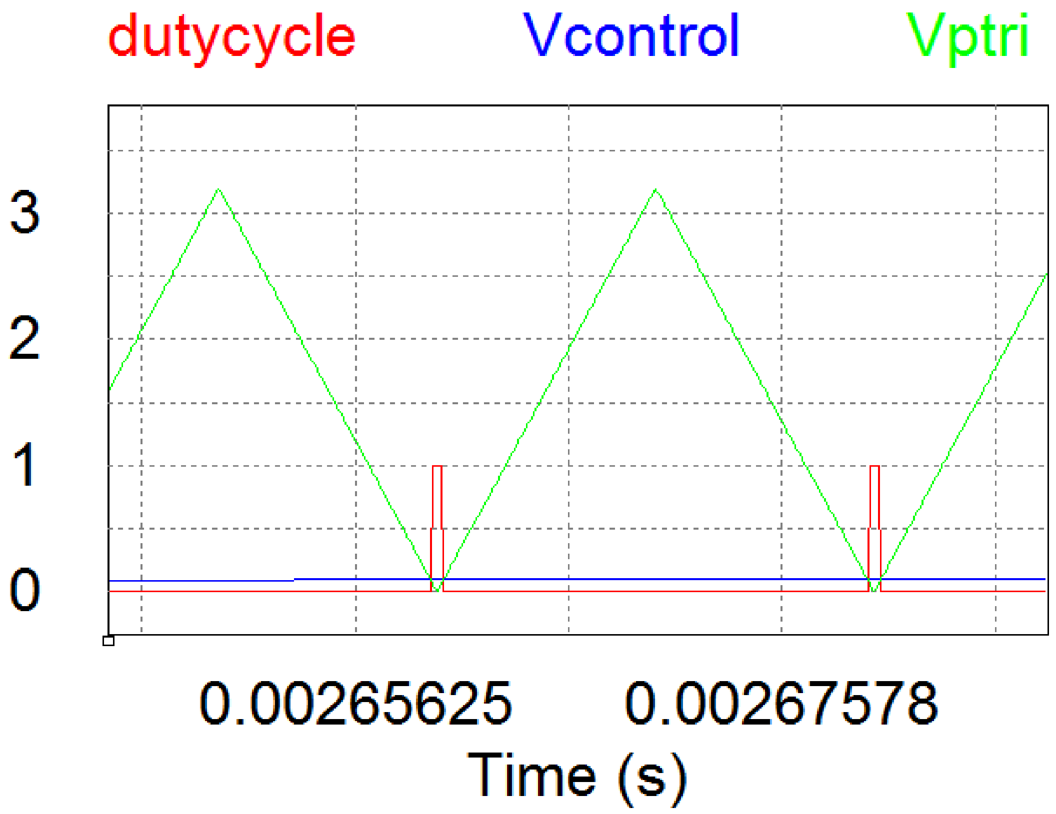


Fig.5 8.Simulación PSIM comienzo del lazo control de tensión

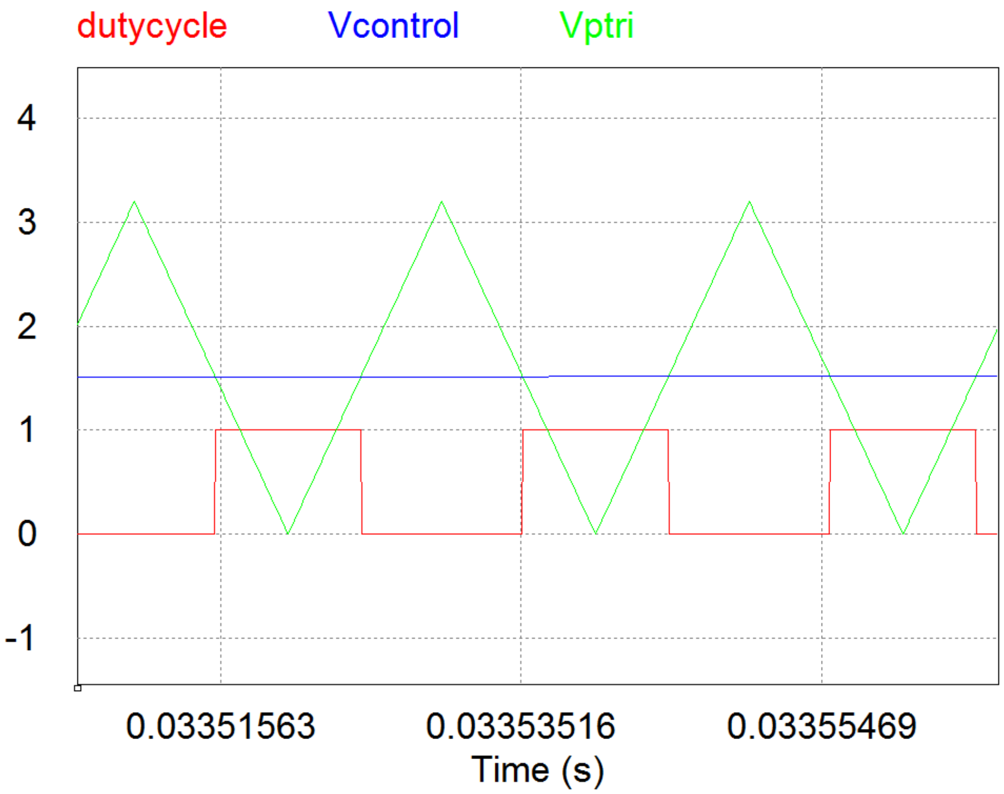


Fig.5 9.Simulación PSIM del lazo control de tensión de una zona intermedia.

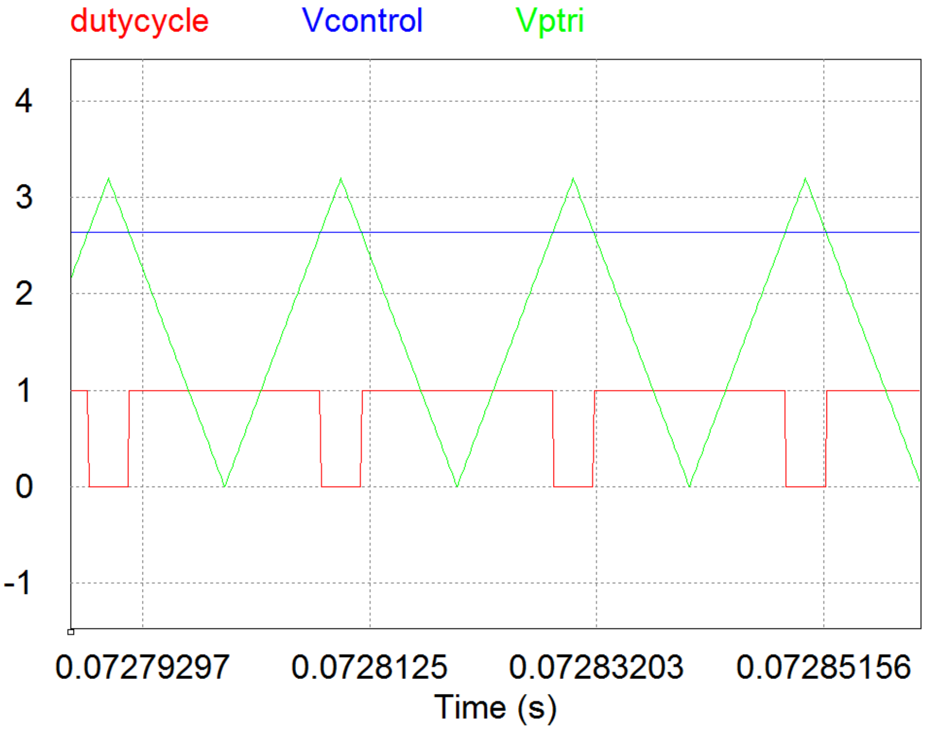


Fig.5 10.Simulación PSIM del lazo control de tensión de una zona final.

Como se aprecia en las figuras 5.8, 5.9 y 5.10, se ve como la señal modulante que le llega al mosfet va cambiando debido al control del controlador integral.

El ciclo de trabajo aumenta de un valor bajo a uno mayor, en este caso es inversamente proporcional.

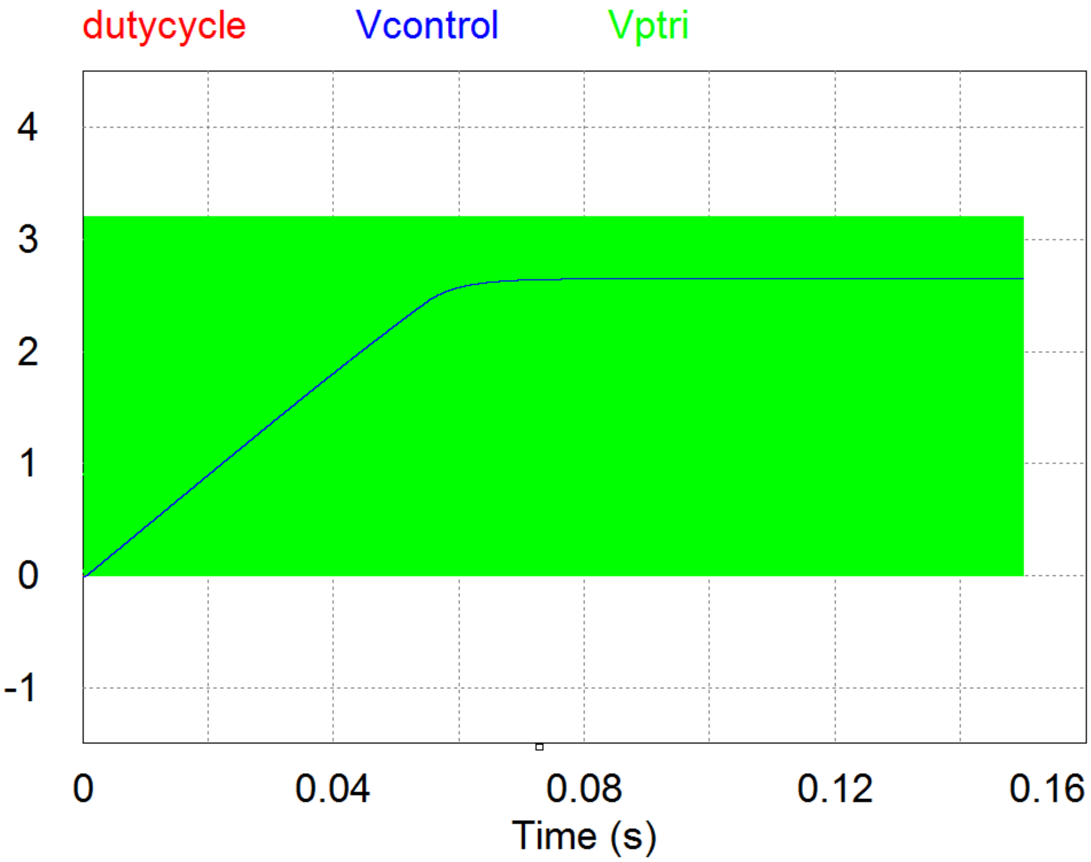


Fig.5 11.Simulación PSIM del lazo control de corriente.

5.2.4.FILTRO +SENSOR

La señal de voltaje proporcionada por los paneles deberá ser filtrada para adecuarla a valores en los que no se dañen los equipos de medida ya que hay que filtrar componentes de la señal que no se desean.

El filtro será de paso bajo y RC y se resolverá mediante la siguiente fórmula:

$$Wcf = \frac{1}{Rf * Cf} \quad \text{Ec. (31)}$$

Primero se deberá conseguir es el escalado, para ello se deberá amplificar la señal medida por un valor 1/5,45.

Para ello se crea un divisor resistivo, por el cual se consigue el escalado necesario con los valores de resistencia que aparecen en la Fig.5.12.

Para los valores del filtro supondremos un valor de condensador de 22nF y con ello se calcula el valor de resistencia, ya que el valor de frecuencia es de 2000 Hz.

$$Rf = \frac{1}{22 * 10^{-9} * 2000 * 2\pi} = 3620\ ohmnios$$

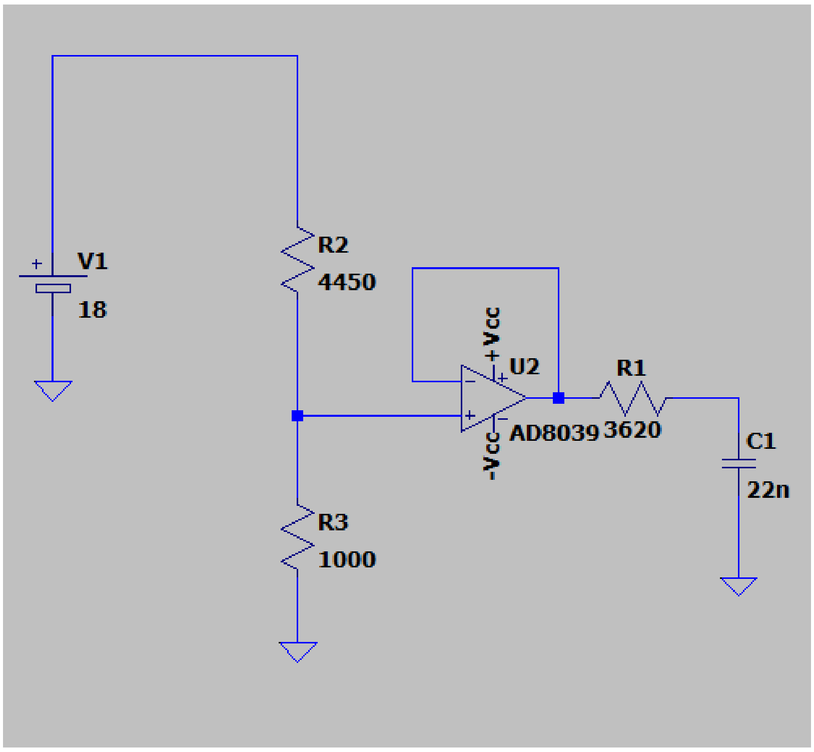


Fig.5 12.Circuito de escalado y filtrado

5.2.4.CONTROLADOR INTEGRAL

El controlador integral se podrá implementar mediante el valor de Ki que se obtuvo en el apartado 4.1.2. de 54,3474

$$Ki = \frac{1}{R * C}$$

Para ello se fija un valor de condensador de 330µF y con ello se calcula el valor de R.

$$R2 = \frac{1}{330 * 10^{-9} \ * 54{,}3474} = 55758\ ohmnios$$

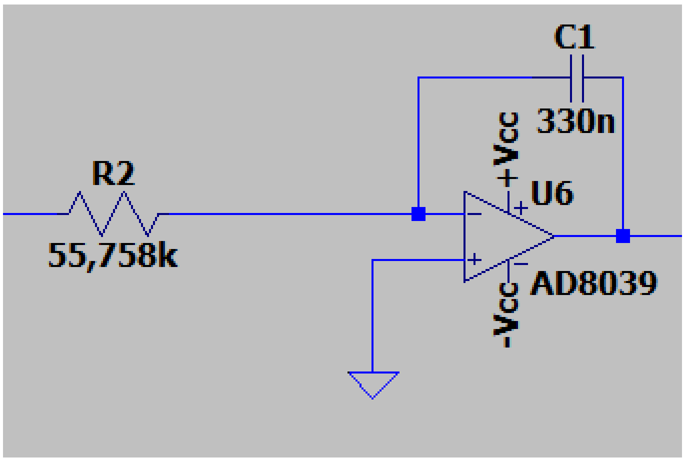


Fig.5 13.Circuito del controlador integral.

5.3.CIRCUITOS DEL CONTROL DE CORRIENTE

5.3.1.REFERENCIA

Se trata de configurar una señal a un valor predeterminado y constante, que equivale a un valor de intensidad, es decir, para este control el valor de las variables será voltaje, pero las variables son de corriente.

Se utilizará una resistencia unida a un potenciómetro, así se afinará más para buscar el valor deseado.

Del punto medio de los elementos mencionados anteriormente se unirá a un operacional, que actúa en forma de seguidor emisor, esto hace que la tensión de entrada sea igual que la tensión de salida debido a que se modifica la impedancia entre circuitos, aumentando la impedancia de entrada y disminuyendo la de salida para aislar los circuitos entre sí.

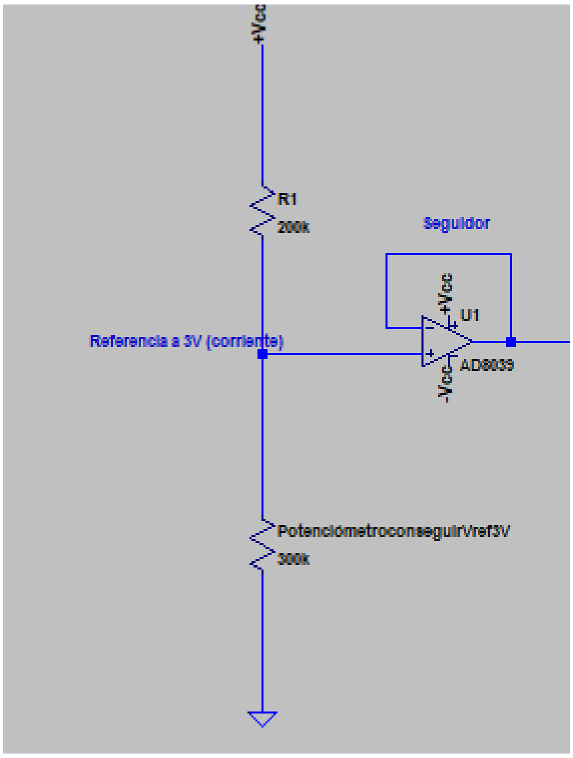


Fig.5 14.Circuito de referencia del control de corriente.

Se quiere conseguir una referencia de 3V que equivalen a la intensidad de referencia, que se restará a la señal medida ya acondicionada.

Es un valor óptimo debido a que la señales deberán ser más bajas de 5 V.

Con las resistencias y el emisor-seguidor propuesto en la Fig.5.14 se consiguen estos 3 V de referencia.

5.3.2.RESTADOR

Es un circuito mediante el cual se van a comparar la tensión de referencia(equivalente a la intensidad de la bobina tomada como referencia) y la corriente medida y filtrada de la bobina, esto se hace para poder calcular el error y así mediante la acción del controlador modificar los parámetros necesarios.

La fórmula de restador con realimentación negativa es la siguiente:

$$v0 = \left(1 + \frac{R2}{R1}\right) * \frac{R4}{R3 + R4} * v1 - \frac{R2}{R1} * v2$$

Si se considera que:

$$\frac{R2}{R1} = \frac{R4}{R3}$$

Se queda una expresión tal que:

$$v0 = \frac{R2}{R1}(v1 - v2)$$

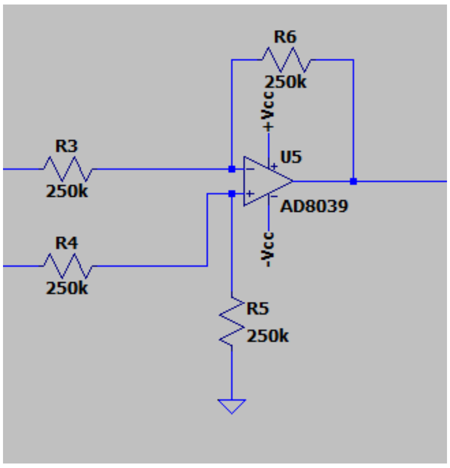


Fig.5 15.Circuito restador entre corriente de referencia y corriente medida y filtrada.

En la Fig.5.16. se puede ver las señales que corresponden a la resta.

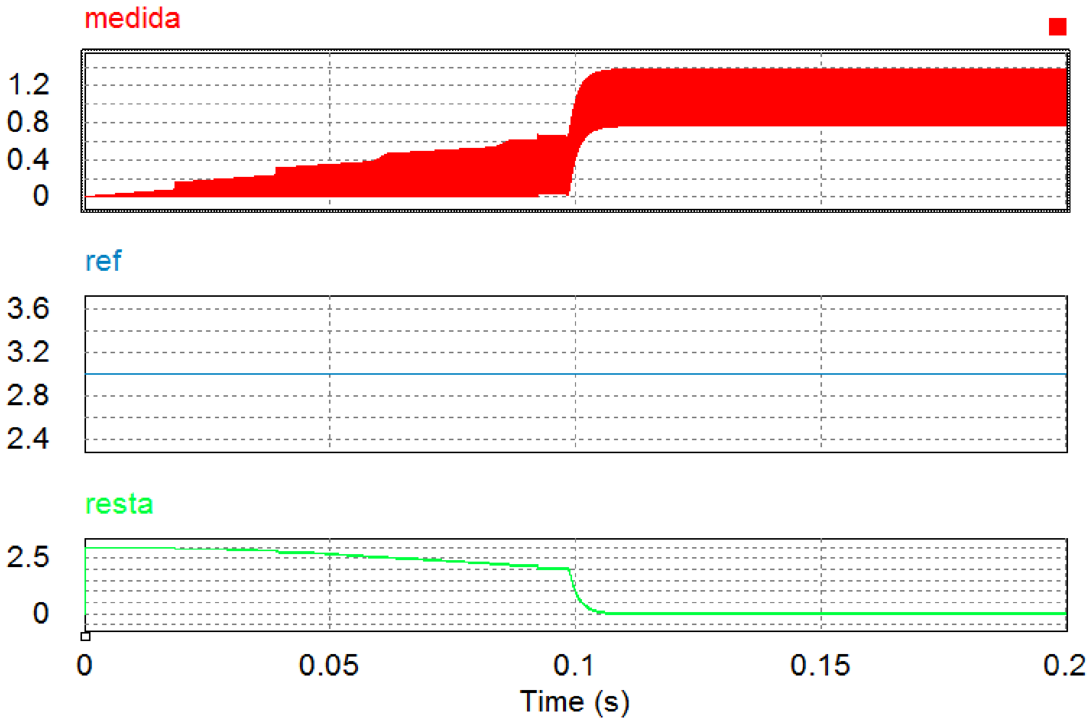


Fig.5 16. Formas de onda de la referencia (roja), resta (verde) y Il medida (azul).

Como se aprecia en la Fig.5.17., la corriente medida tendrá un rizado provocado por las conmutaciones.

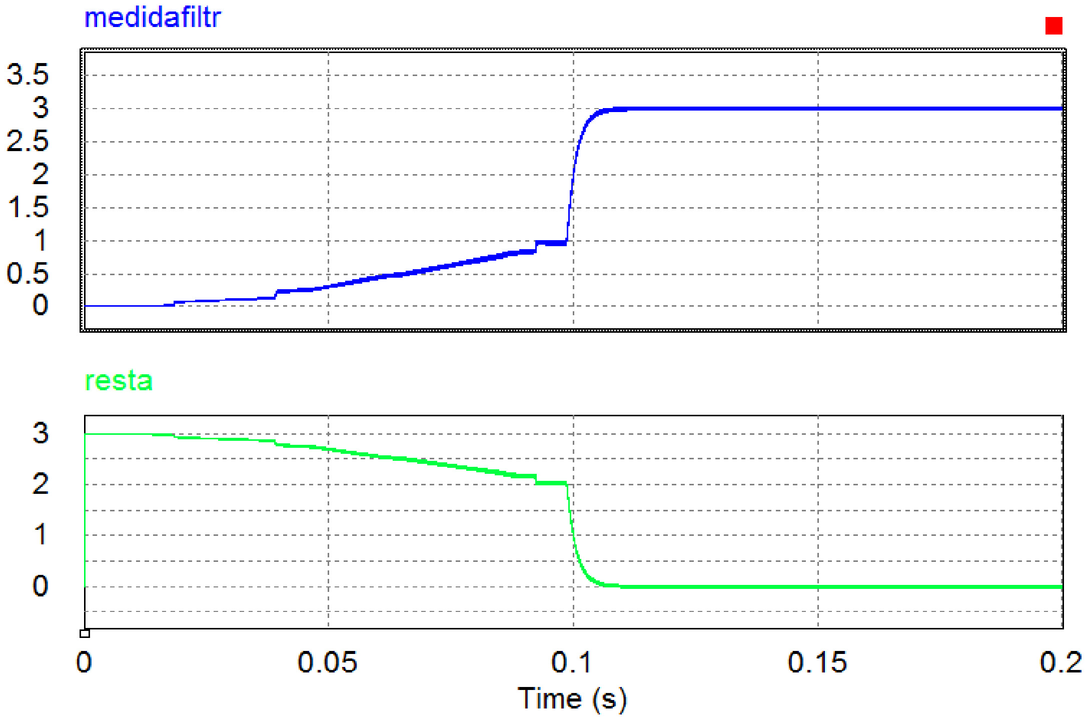


Fig.5 17. Formas de onda de Il medida y filtrada (roja), resta (azul).

5.3.3.COMPARADOR

Es un operacional al cual le llega a sus entradas dos señales analógicas, en este caso una será la señal del PI y la otra será una señal triangular que define la frecuencia de conmutación del MOSFET.

De esta comparación se consigue a la salida una señal digital llamada DutyCycle (senalmosf), si salida del PI es mayor que la triangular el valor será alto y si ocurre lo contrario el valor será bajo.

El conjunto de estas ondas forma lo que es llamado PWM (Modulación por anchura de pulso), que sirve para encender y apagar los semiconductores, el MOSFET, para obtener una tensión troceada, ya que interesa recibir el valor medio de esta tensión.

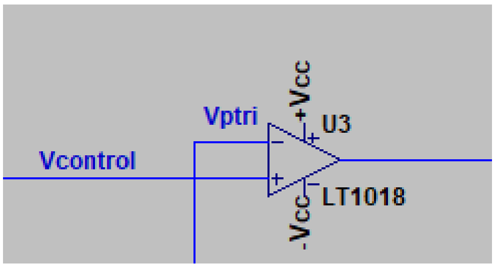


Fig.5 18. Circuito comparador entre la Vcontrol del PI y la señal triangular.

Como se puede ver en las figuras 5.19, 5.10 y 5.21, el ciclo de trabajo irá aumentando para conseguir que la corriente medida sea igual que la referencia.

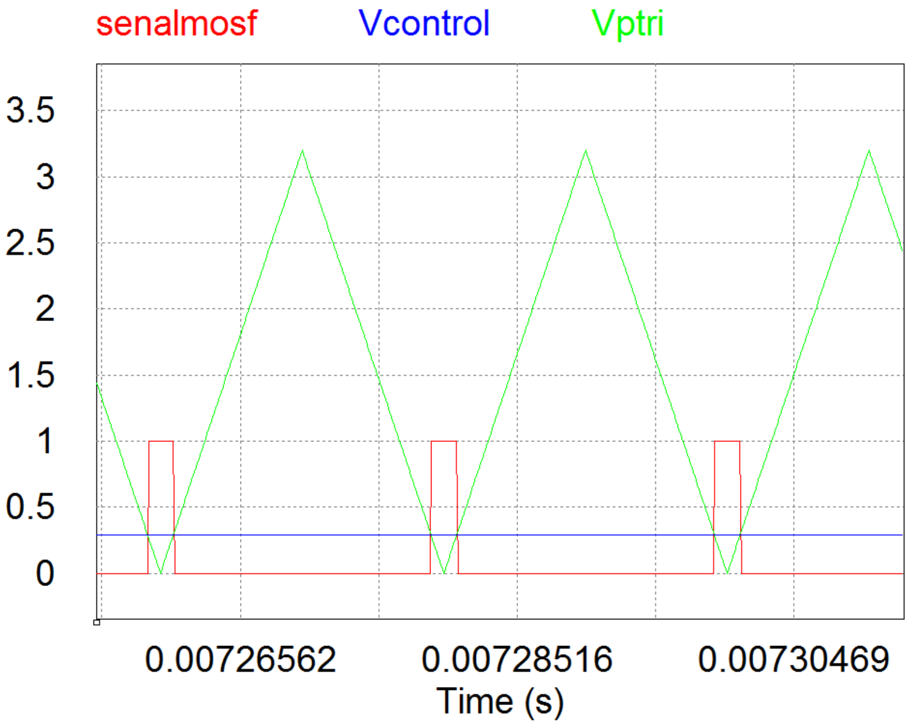


Fig.5 19. Simulación en PSIM de una zona inicial.

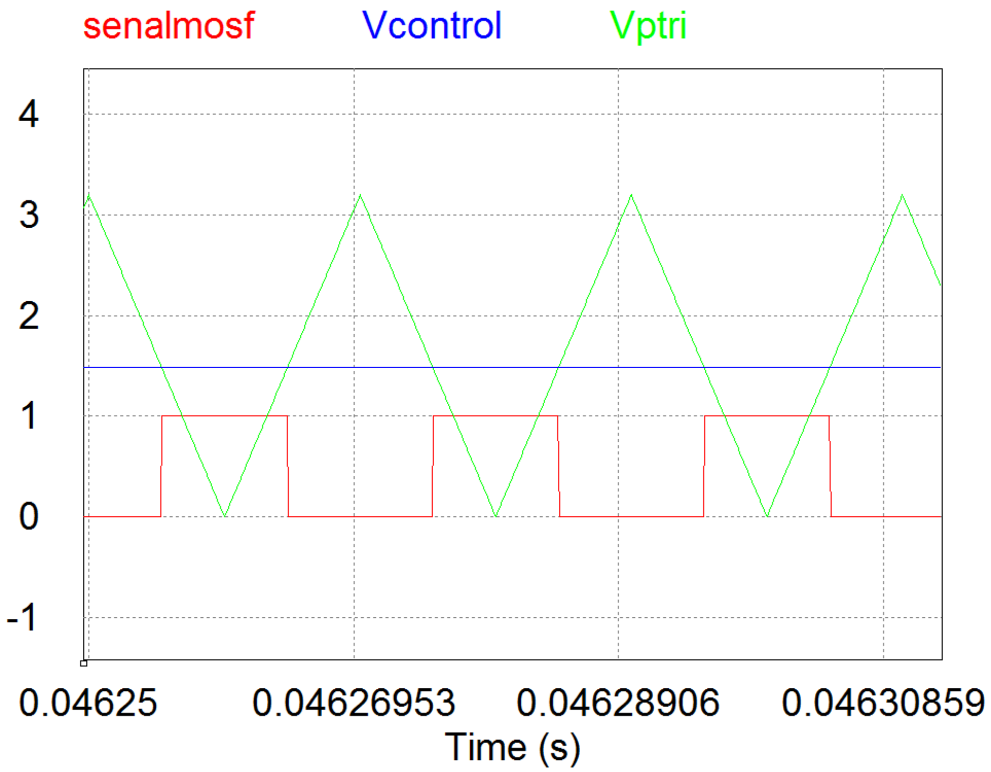


Fig.5 20. Simulación en PSIM de una zona intermedia.

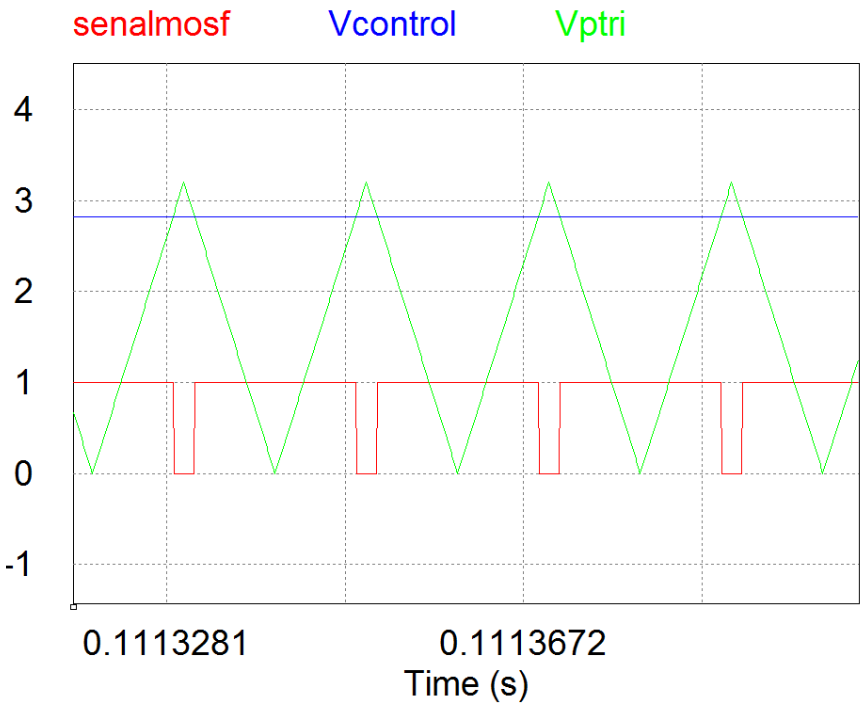


Fig.5 21. Simulación en PSIM de una zona final del control de corriente.

5.3.4.FILTRO + SENSOR

La corriente que pasa por la bobina deberá ser medida para que actue el control sobre ella, para ello mediante una célula LEM de efecto Hall, efecto mediante el cual aparece un campo magnético en el interior de un conductor por el que circula una corriente.
El sensor da un valor en tensión de la corriente que pasa por el conductor, que deberá ser filtrado.

Para los valores del filtro supondremos un valor de condensador de 22nF y con ello se calcula el valor de resistencia, ya que el valor de frecuencia es de 2000 Hz.

$$Rf = \frac{1}{22 * 10^{-9} * 2000 * 2\pi} = 3618\ ohmnios$$

Con este filtro se atenuarán todas aquellas señales a partir de 2000 Hz.

Para el escalado, la corriente medida deberá amplificarse en 2,8 veces para dar un valor de tensión.

La Ec. (32) muestra la ganancia del circuito:

$$Vo = \left(1 + \frac{R5}{R4}\right) * V2$$

Como se quiere conseguir una ganancia de 2,8, la relación entre R5 y R4 deberá ser que R5 será 1,8 veces mayor que R4, por ello se considerarán los valores que se comentan en la Fig 5.22

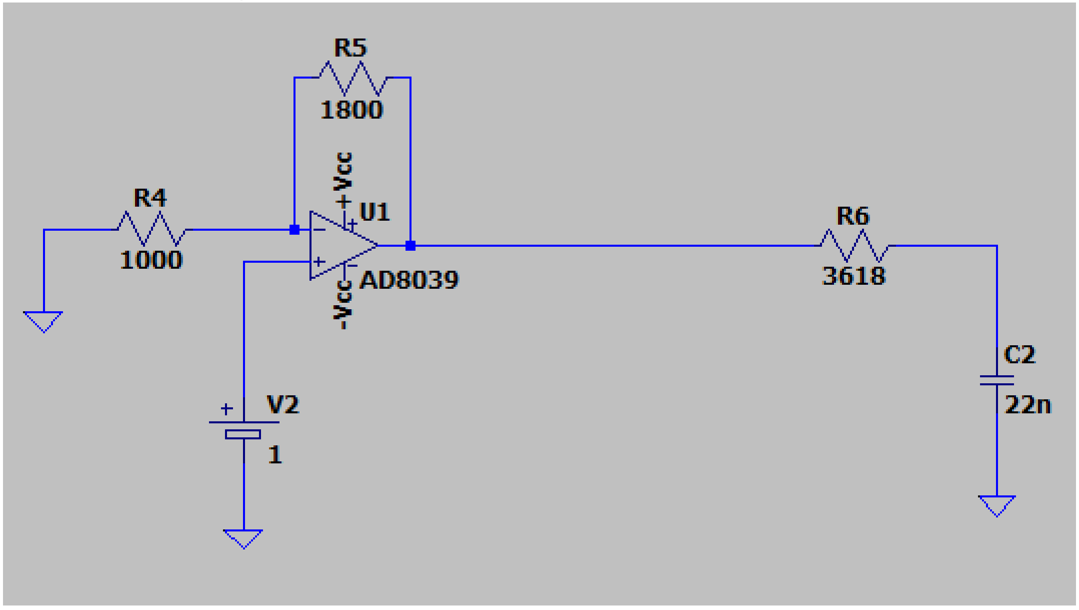


Fig.5 22. Circuito de filtrado+sensor del control de corriente

En la Fig.5.23. se ve como el rizado disminuye y el escalado aumenta la señal en 2,8 veces.

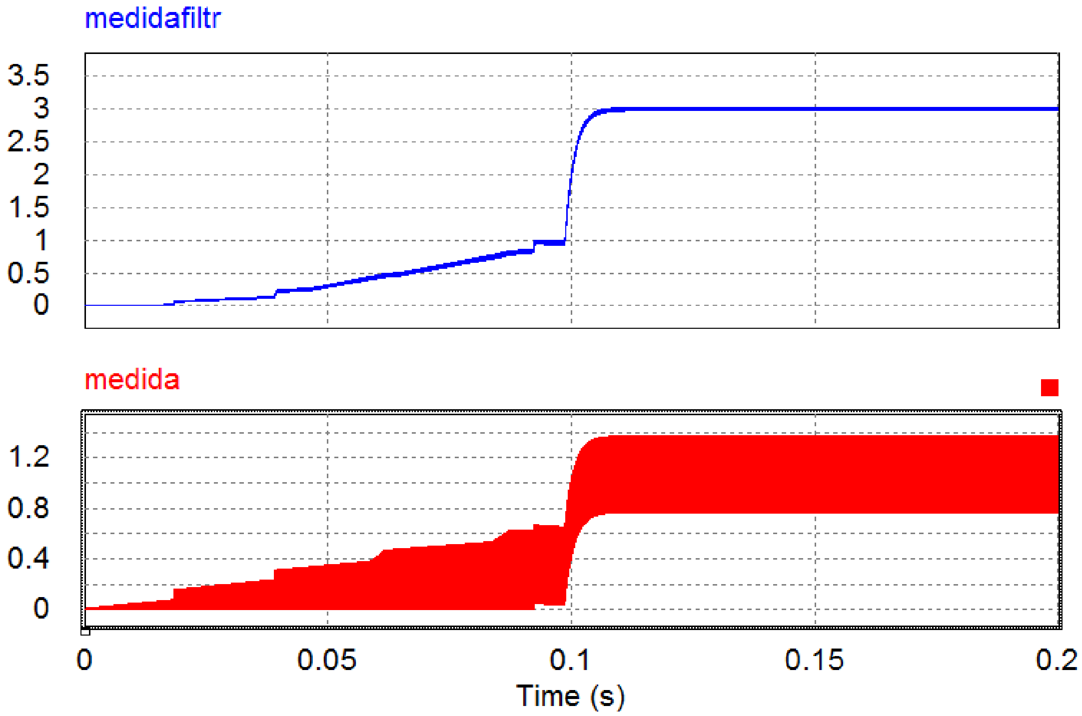


Fig.5 22. Simulación en PSIM de la corriente medida (rojo) y de la corriente medida y filtrada (azul)

Como se aprecia en la imagen, la señal roja es la corriente medida, que debido a su paso por un filtro, se corrigen las imperfecciones y además se le da una ganancia, y como se puede ver la corriente medida y filtrada tenderá a ser del mismo valor que la de referencia, pero con su rizado particular.

5.3.5.CONTROLADOR PROPORCIONAL INTEGRAL

El controlador integral se podrá implementar mediante el valor de Ki que se obtuvo en el apartado 4.2.2. de 0,018793 y de Tn de 1,763*10^{-3}.

$$Ki = \frac{Kp}{Tn} \qquad \text{Ec.(32)}$$

$$Ki = \frac{0{,}018793}{1{,}763 * 10^{-3}} = 10{,}66$$

Para ello se fija un valor de condensador de 330µF y con ello se calcula el valor de R.

$$R1 = \frac{1}{2{,}2 * 10^{-6} \ * 10{,}66} = 42640 \ ohmnios$$

Sabiendo el valor de R1, se puede calcular el valor de R2 según la siguiente expresión:

$$R2 = Kp * R1 \qquad \text{Ec.(33)[4]}$$

En la Fig.5.13. se puede observar la implementación del controlador PI.

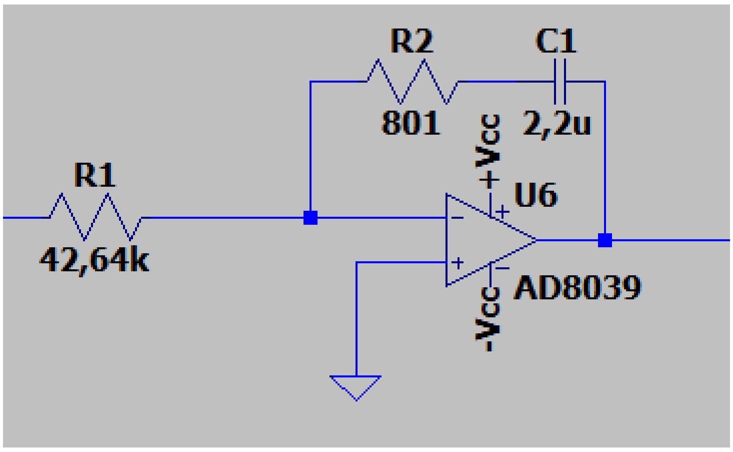


Fig.5 23.Circuito del controlador integral.

5.4.ONDA TRIANGULAR

Para poder realizar la modulación PWM es necesario comparar la señal de control con otra señal triangular.

Esta señal triangular se ha de realizar mediante herramientas que disponemos, y ha de ser de la frecuencia establecida para el control.

5.4.1.GENERADOR DE ONDA TRIANGULAR

Para poder realizar la señal, primeramente se conseguirá una señal cuadrada mediante la configuración por histéresis del AO, con el cual dará una señal cuadrada entre 5 V y -5V. Debido a las no idealidades del AO y que este al ser alimentado a 5 V se saturará a unos 4 V, la onda cuadrada será de +4 V/-4 V.

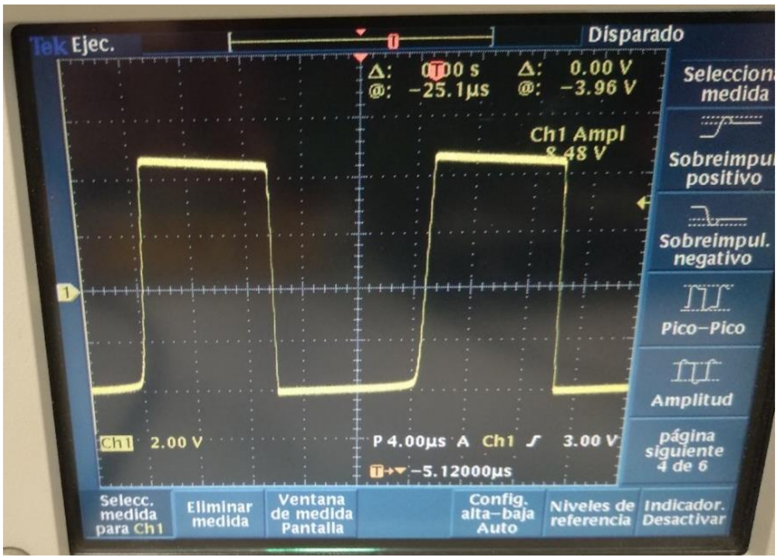


Fig.5 24.Medida de señal proporcionada por la histéresis.

Esta señal cuadrada pasa a un AO configurado en modo de integrador, por lo que integra la señal dando lugar a una señal triangular de 3,2V y -3,2V.
Este valor de señal triangular es el que se ha elegido, debido a que si se acerca mucho al valor máximo podría tender a saturarse y no se quiere llegar a eso.

El valor de la señal se puede ver en la Fig.5.25 representada a continuación.

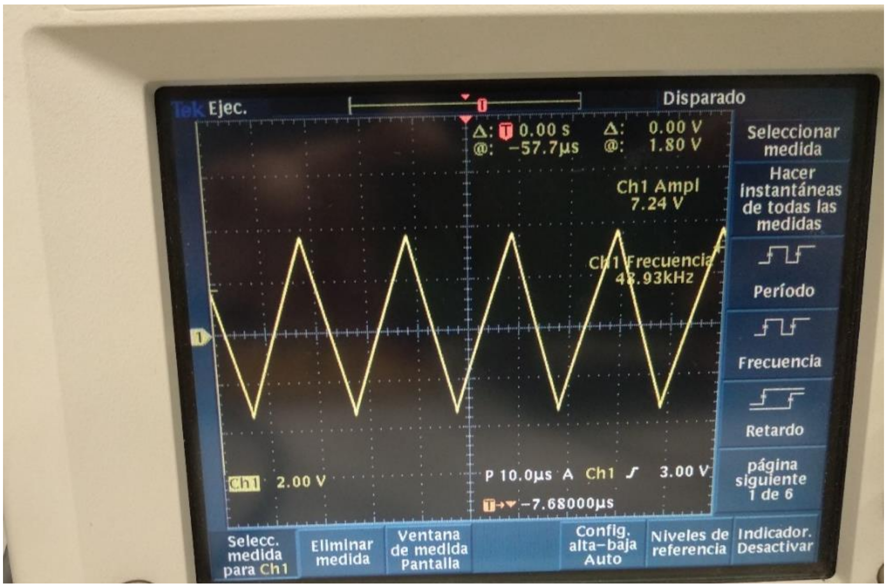


Fig.5.25.Señal triangular entre +3,2 V y -3,2 V.

Al tener únicamente valores de tensión de control positivas, la parte negativa de la señal triangular no interesa ya que, teniendo valores negativos y positivos, cuando la señal de control es de valor 0 V, el ciclo de trabajo será del 50% y no se quiere conseguir eso, por lo que se intentará conseguir una señal triangular de +3,2 V valor máximo y 0 V valor mínimo.

Para ello a la salida del circuito integrador, se hará que la señal se “divida” en dos mediante un divisor de tensiones, por lo que la señal pasará a ser de +1,6 V/-1,6 V, y a continuación se creará una referencia de valor 1,6 V, que mediante la acción de un amplificador operacional en modo sumador, sumará tanto la señal triangular como la referencia, dando lugar a la señal triangular que se desea conseguir.

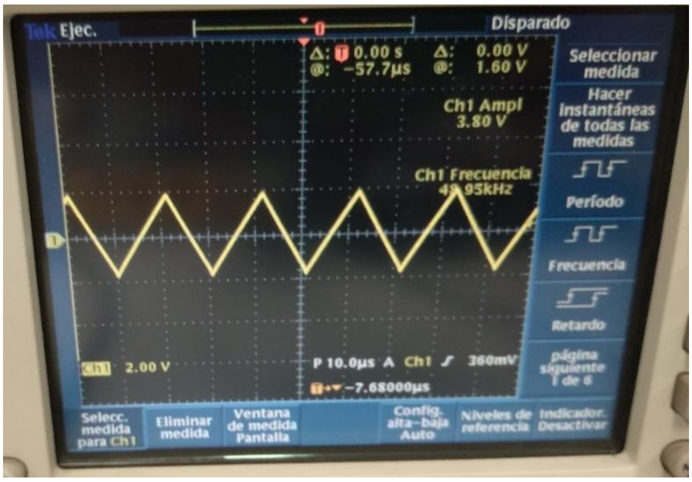


Fig.5 26.Señal triangular entre +1,6 V y -1,6 V

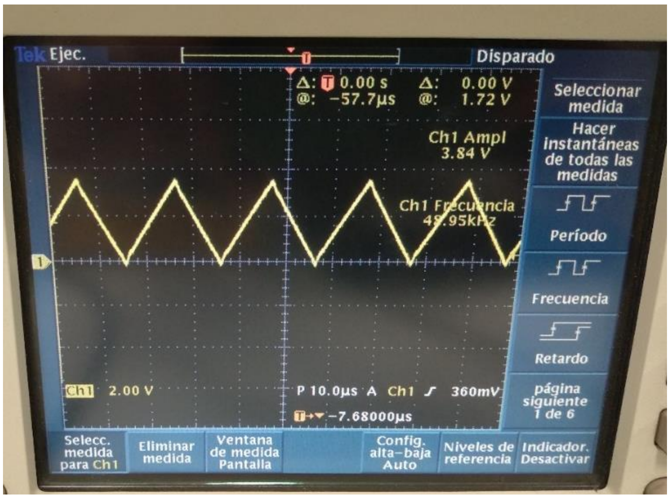


Fig.5 27.Señal triangular entre +3,6 V y 0 V.

Para poder tener la señal reflejada en la Fig.5.27, se ha debido crear el siguiente circuito representado en la Fig.5.28 y 5.29.

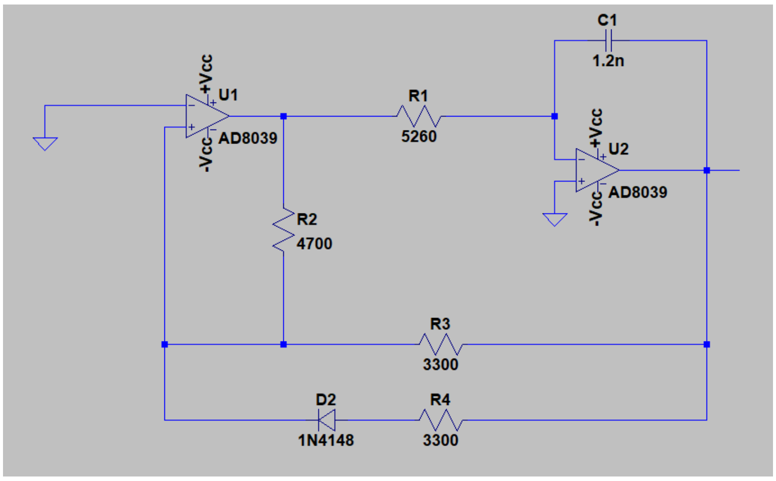


Fig.5 28.Predictor de Schmitt. [10]

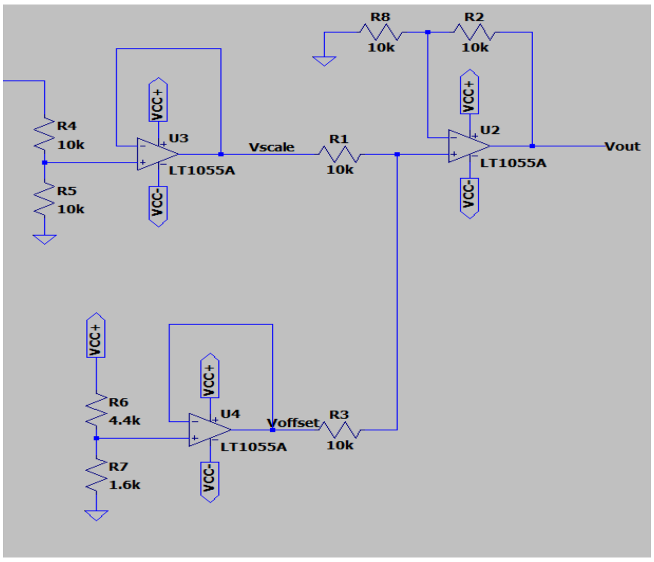


Fig.5 29.Acondicionamientos para lograr señal triangular entre +3,6 V y 0V.

Para poder llegar a conseguir la onda triangular se han debido implementar distintos subcircuitos como se ve en la Fig.5.28 y 5.29.

El dimensionado de los elementos ha seguido los siguientes criterios:

Para lograr la señal triangular mediante el predictor de Schmitt, lo primero que se realizó fue ver que saturación tenían los operacionales tanto en la alimentación positiva como en la negativa.

Los valores obtenidos fueron de +4,1 V de saturación en la alimentación positiva y de -3,9 V en la alimentación negativa, por lo que al no saturarse perfectamente fue necesario el uso de un diodo y una resistencia en paralelo a R3 como se ve en la Fig.5.28.

Como el valor de saturación es de alrededor de 4 V, se ha querido modelizar una señal triangular de 3,2 V.

Se toma R3 y R4 con un valor de 3,3K y mediante este valor y la tensión de saturación se puede sacar la relación con las otras resistencias.

$$R2 = \frac{4{,}1V}{3{,}2\ V} * 3{,}3K = 4{,}3K$$

En el laboratorio de la UPNA el valor más cercano es de 4,7 K asique usaremos ese valor para el cálculo.

Para el divisor resistivo con dos resistencias del mismo valor con tolerancias pequeñas se puede conseguir que la señal triangular se divida entre dos.

La señal de referencia será ajustada con un potenciómetro para que nos dé un valor positivo de 1,6 V.

El circuito sumador será el representado como en la Fig.5.29 y con todas las resistencias iguales de 10k, ya que no se quiere obtener ganancia.

La suma de la mitad de la señal triangular inicial y de la referencia hará que la señal triangular final tenga la forma de onda deseada y con una frecuencia de 50 kHz que es la de conmutación.

6. VALIDACIONES

En el siguiente apartado se comentaran las formas de onda obtenidas y se contrastarán con las obtenidas en simulaciones.

6.1.BUCK 1

Como se ve en la Fig.6.1. la tensión que otorgan los paneles (Vpv) es muy baja, debido a que las pruebas se han realizado en el laboratorio, donde apenas hay luz solar.

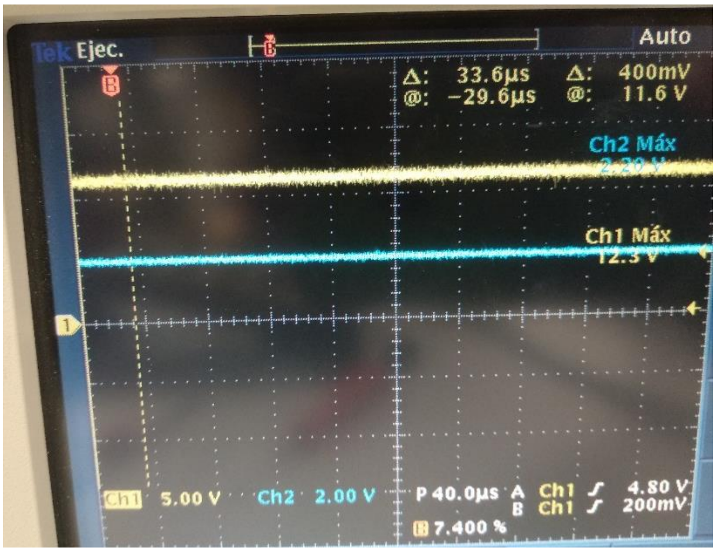


Fig.6.1. señal amarilla Vpv y señal azul Vpv,med,fil

Esta tensión es de 12,3 V, como nuestra Ksv era de 1/5,45, el voltaje medido y filtrado nos debe salir de 2,25 V.

En la Fig.6.1. se ve que el valor de tensión medida y filtrada es de 2,20 V, un valor bastante aproximado al deseado.

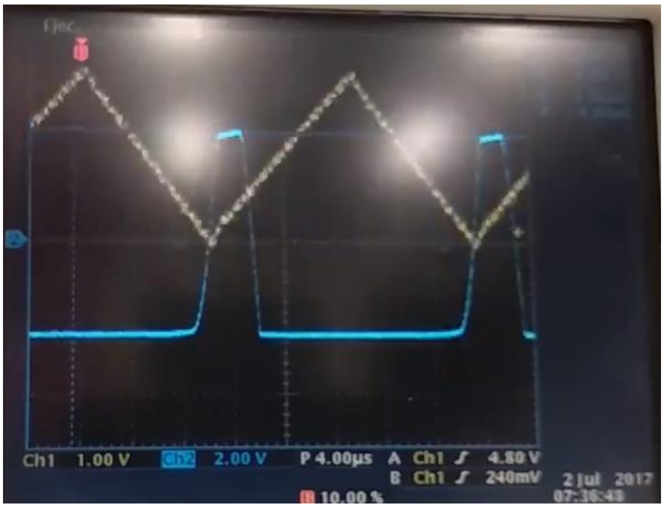


Fig.6.2. Señal triangular y señal de salida del MOSFET

En la Fig.6.2. se puede ver un momento en el que se ha conseguido capturar la señal de salida del MOSFET.

La señal amarilla es la señal triangular de 50 kHz y la señal azul es la señal de salida del MOSFET.

Normalmente las señales modulantes que les llegaban eran las siguientes representadas en las Fig.6.3. y 6.4. La señal azul corresponde con la señal que envía el comparador al driver.

Fig.6.3. Señal triangular y señal del comparador.

Como se aprecia, la señal que marca el ciclo de trabajo es una señal continua a 5 V (hay que fijarse que la escala entre el canal 1 y 2 no es la misma).

Esto puede ser debido a algún problema de saturación en el controlador o en el comparador.

En la Fig.6.4 se ve como también se produce una saturación negativa en -5 V.

Fig.6.4. Señal triangular y señal del comparador.

6.2.BUCK 2

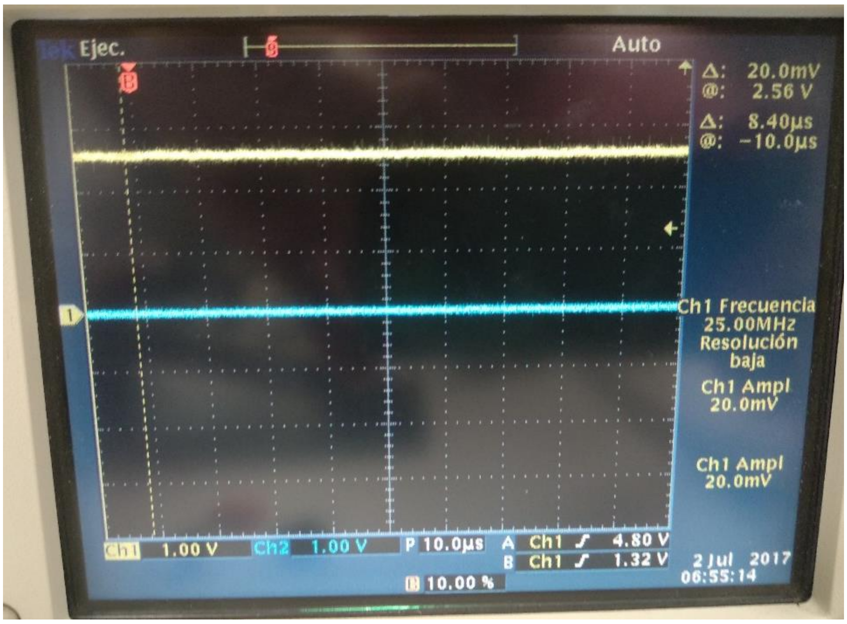


Fig.6.5. Señal medida y filtrada de corriente

Como se ve en la Fig.6.6, el valor que tenemos de tensión es de 2,56 V.

Este valor ha sido amplificado para pasarlo a tensión en 2,8 veces, por lo que si se quiere saber la intensidad que está pasando realmente:

$$Imed = \frac{2{,}56}{2{,}8} = 0{,}92A$$

Si nos fijamos en el la Fig.5.22 el valor que sale de intensidad medida es de 1 A y con un importante rizado, lo cual da veracidad a la medida realizada del convertidor.

No se han podido conseguir los 1,75 A esperados debido a posibles pérdidas, conmutaciones del MOSFET no adecuadas, componentes con tolerancias que han provocado desajustes, se ha infradimensionado el proyecto, etc.

Como se aprecia en la Fig.6.6. se ven claramente las conmutaciones que se producen en el MOSFET.

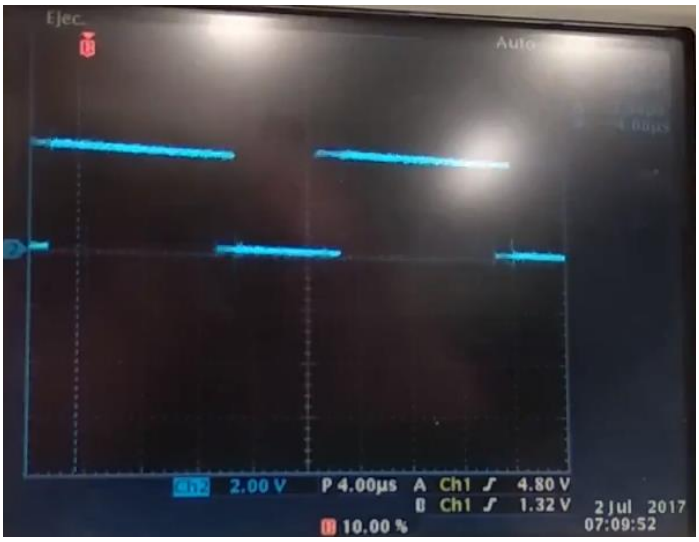


Fig.6.6. Conmutaciones en el MOSFET.

En la Fig.6.7. se puede ver cómo hemos comentado antes en las validaciones del BUCK 1, el problema que ocurre con el convertidor o lazo, en este caso en el BUCK 2 o lazo de corriente.

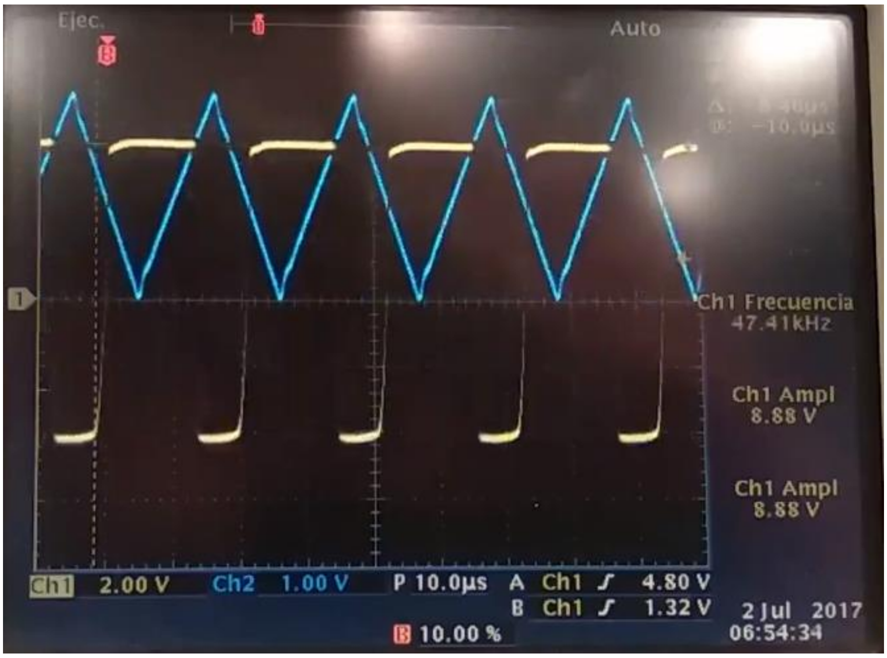


Fig.6.7. Conmutaciones en el MOSFET.

Se ve claramente como la señal de ciclo de trabajo va desde un valor de +5 V a un valor de -5 V.

Como se comentó anteriormente lo más probable es algún problema de saturación en los operacionales del controlador proporcional-integral o en el comparador, ya que la tensión de alimentación de estos está restringida a +5 V y -5V por el tipo de fuentes que se han usado, haciendo que las tensiones de saturación sean de valores cercanos a +4 V y -4 V, y por tanto, como se están controlando tensiones en muy poca amplitud, cualquier pequeño cambio o brusquedad hace que se saturen y no funcione el sistema.

En las Fig.6.8., 6.9. y 6.10. se muestran los circuitos de control y señales utilizados para las validaciones del proyecto.

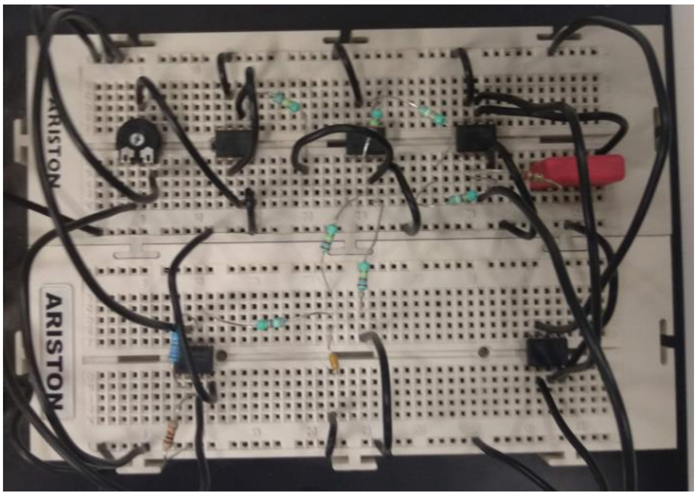


Fig.6.8. Circuito de lazo de corriente

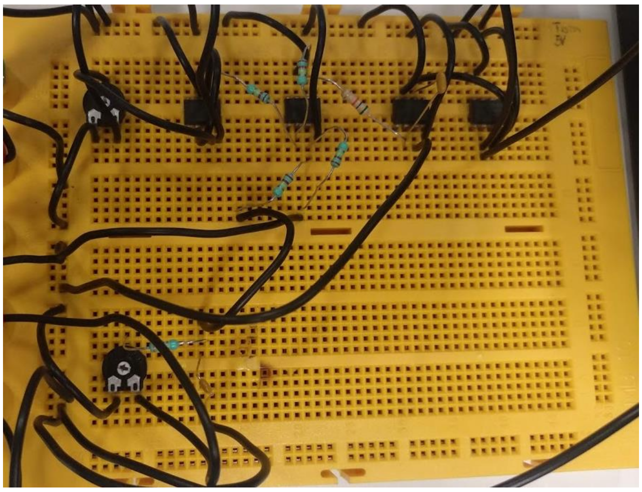


Fig.6.9. Circuito de lazo de tensión.

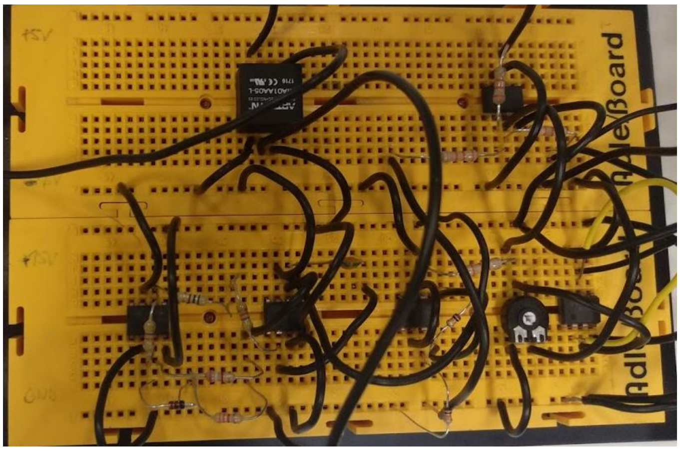


Fig.6.10. Circuitos de alimentación y señal triangular

7. DISEÑO DE PCB

El diseño de la PCB se ha realizado mediante el software DesignSpark, un programa que se utilizó en la asignatura Tarjetas Electrónicas del Grado de Ingeniería Eléctrica y Electrónica.
Los motivos por el cual se ha realizado una PCB son los siguientes:

- MOSFET muy pequeño y además diseñado para soldarlo mediante soldadura superficial, por lo que sus pines no están diseñados para su uso en protoboards.
- Integrar la etapa de potencia por separado de la etapa de los lazos de control. En la misma PCB se han separado los dos convertidores, de tal forma que se puede usar cada uno por separado.

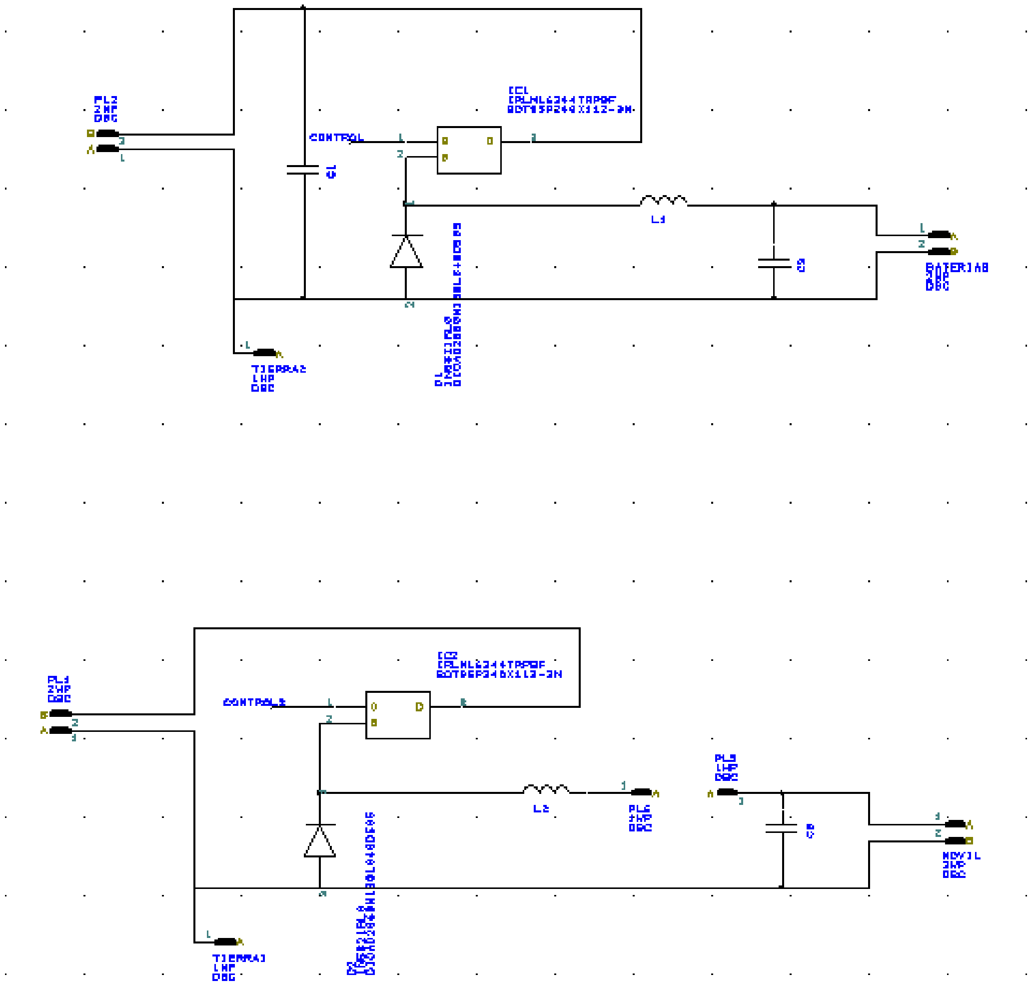


Fig.7.1. Esquema eléctrico de los convertidores.

En el diseño de la PCB también se han incluido los drivers y la célula LEM como se verá en las Fig.7.2, 7.3 y 7.4.

El driver no tenía huella PCB para cogerlo desde la librería, por lo que se tuvo que diseñar en la página web que ofrece RS COMPONENTS. [11]

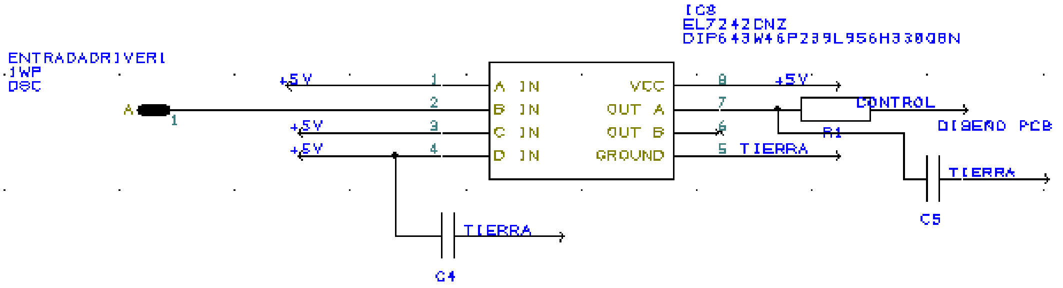


Fig.7.2. Diseño del driver 1.

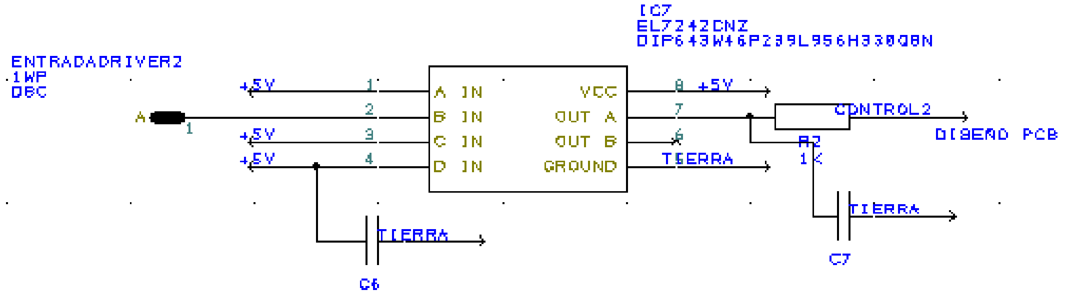


Fig.7.3. Diseño del driver 2.

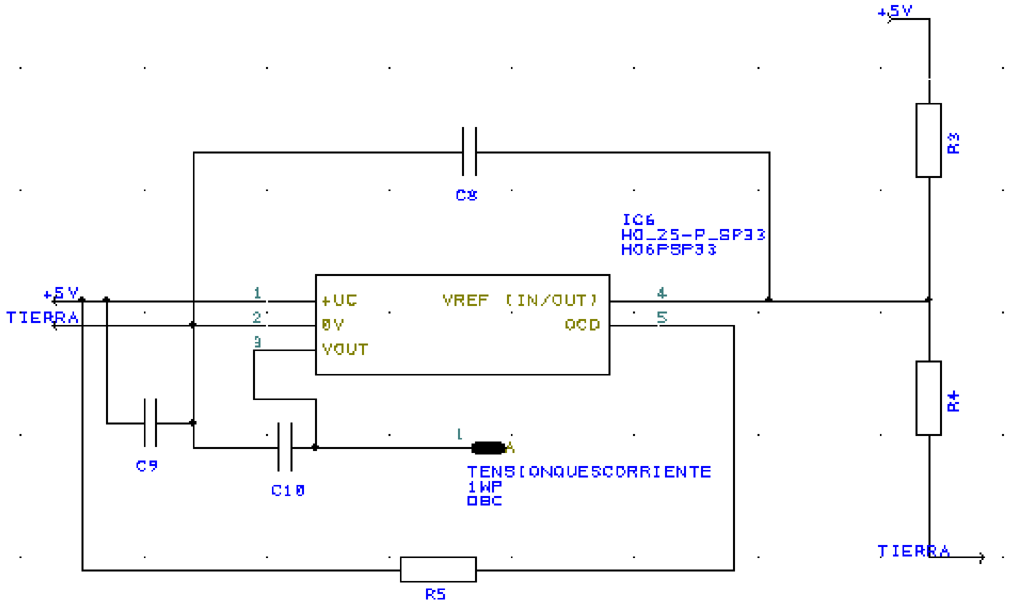


Fig.7.4. Diseño de la célula LEM.

Para evitar demasiadas pistas, se creó una capa de cobre por cada lado de la PCB, la superior es la de tierra como se ve en la Fig.7.5. y la inferior la de Vcc (5 V) como se ve en la Fig.7.6.

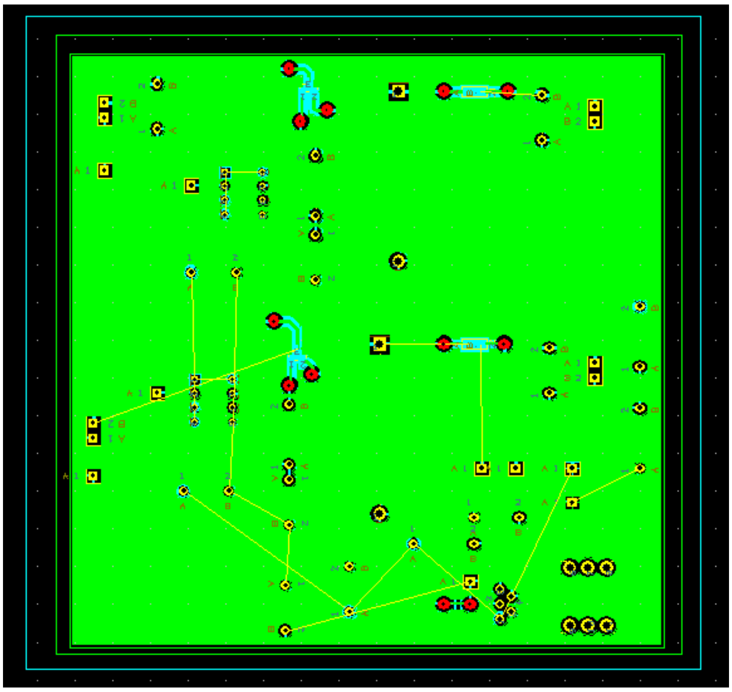


Fig.7.5. Capa superior con área de cobre que es la tierra.

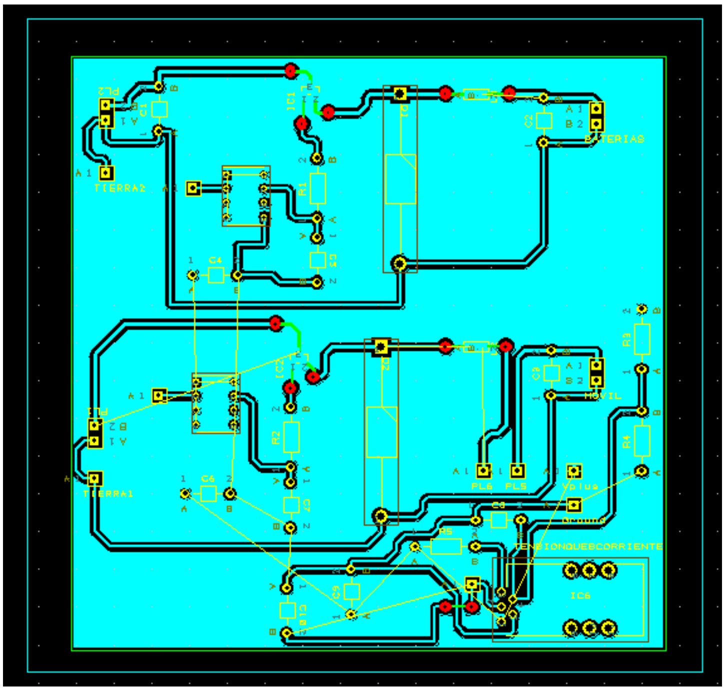


Fig.7.6. Capa inferior con área de cobre que es Vcc.

Mediante el software DesignSpark se pueden sacar imágenes 3D de cómo quedará la futura PCB, como se ve en las Fig.7.7 y 7.8.

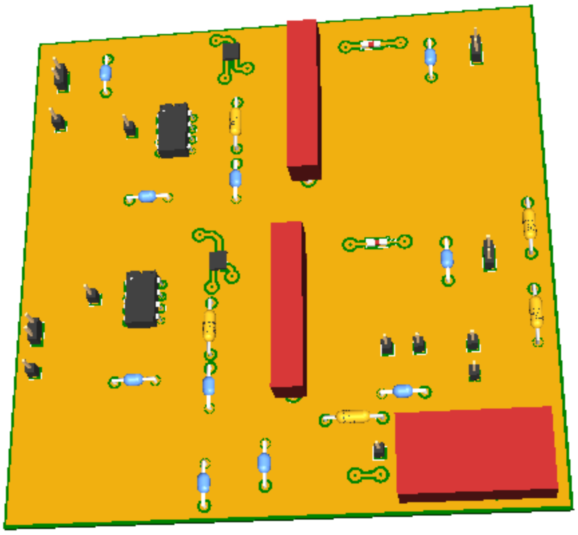


Fig.7.7. Capa superior de la PCB con los elementos.

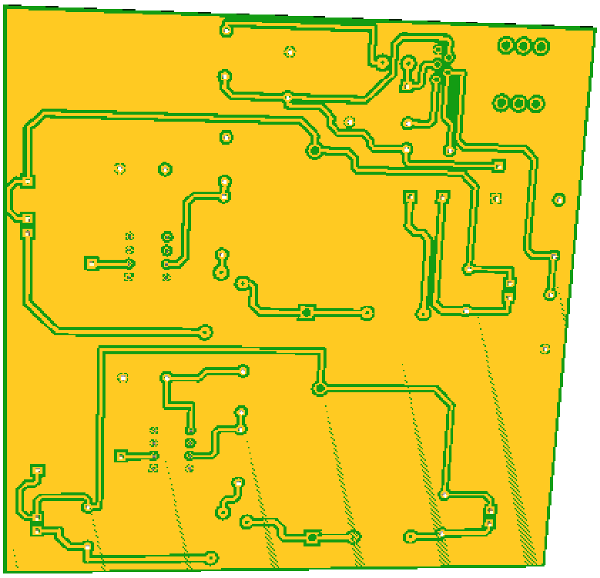


Fig.7.6. Capa inferior de la PCB con las pistas.

Después de diseñar la PCB se colocó un condensador de unos pF entre la placa Vcc y tierra, esto evitará posibles acoplamientos.

El resultado final de la PCB será el siguiente mostrado en la Fig.7.7.

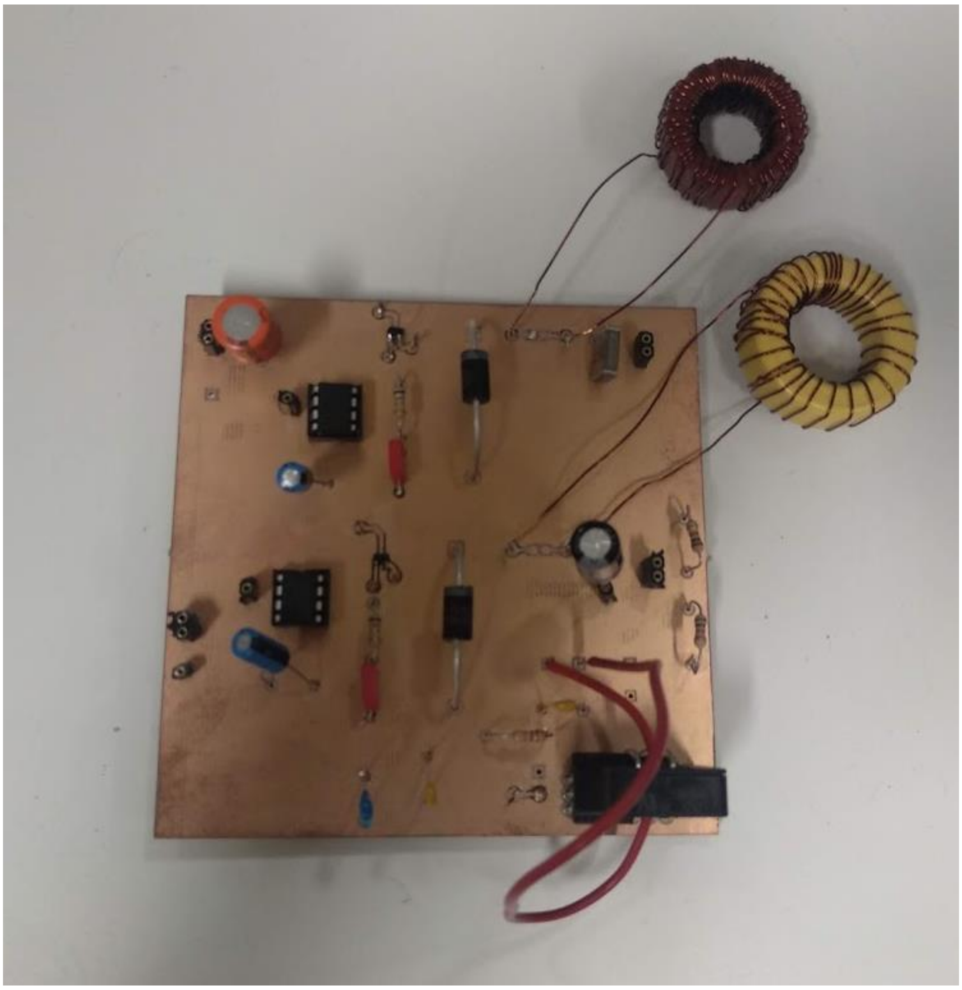


Fig.7.7. PCB de la instalación.

8. PRESUPUESTO

	UNIDADES	PRECIO UNITARIO	TOTAL
MOSFET	2	0,267	0,534
DRIVER	2	6,94	13,88
PANEL	2	17,222	34,444
OP_AMP	14	0,402	5,628
FUENTE ALIM	2	18,5	37
CEL.LEM	1	8,87	8,87
DIODO	2	0,328	0,656
		TOTAL SIN IVA (€)	101,012

Tabla 3. Presupuesto sin IVA.

Hay que tener en cuenta que dentro de este presupuesto no se han considerado los siguientes elementos:

- PCB
- Condensadores
- Resistencias
- Pines de conexión
- Cableado
- Cobre
- Núcleos de polvo de hierro
- Baterías
- Zócalos

Lo cual incrementaría el precio del sistema que se ha realizado, aunque tampoco en gran cantidad, ya que son elementos de bajo coste.

9. REFERENCIAS

[1] Photovoltaic barometer European Union [En línea] https://www.eurobserv-er.org/category/all-photovoltaic-barometers/

[2] Ernesto Barrios Rípodas. "Estado actual y perspectivas de las Energías Renovables". Dpto. de Ing. Eléctrica y Electrónica de la UPNA, 2016.

[3] UNEF why solar energy is back from the death in Spain https://unef.es/2019/04/why-solar-energy-is-back-from-the-dead-in-spain/

[4] Ernesto Barrios Rípodas "Fundamentos de los sistemas fotovoltaicos" Dpto de Ingeniería Eléctrica y Electrónica de la UPNA, 2016.

[5] Javier Marcos "Convertidores DC/DC" Dpto de Ingeniería Eléctrica y Electrónica de la UPNA, 2015.

[6] Javier Marcos y Luis Marroyo "Semiconductores de potencia" Dpto de Ingeniería Eléctrica y Electrónica de la UPNA, 2015.

[7] R.W. Erickson, and D. Maksimovi, "Fundamentals of Power Electronics : Magnetics", Kluwer Academic Publishers, 2nd Ed, 2001.

[8] Javier Goicoetxea "Electrónica Analógica" Dpto de Ingeniería Eléctrica y Electrónica de la UPNA, 2016.

[9] Componentes electrónicos elegidos www.rscomponents.com

[10] Borja Ororbia Payán, "Diseño y montaje de una instalación fotovoltaica de 200W con convertidor multifuncional", TFE de la UPNA 2018.

[11] Huellas para PCB y esquemas www.componentsearchengine.com

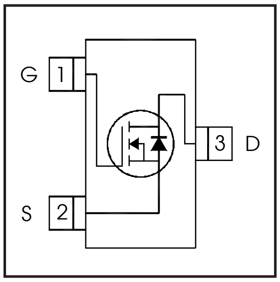
10. ANEXOS

International
IOR Rectifier

IRLML6344TRPbF

HEXFET® Power MOSFET

V_{DS}	**30**	**V**
$V_{GS\ Max}$	**± 12**	**V**
$R_{DS(on)\ max}$ (@V_{GS} = 4.5V)	**29**	**mΩ**
$R_{DS(on)\ max}$ (@V_{GS} = 2.5V)	**37**	**mΩ**



Micro3^{TM} (SOT-23)
IRLML6344TRPbF

Application(s)

- Load/ System Switch

Features and Benefits

Features		Benefits
Low R_{DSon} (<29mΩ)	results in	Lower Conduction Losses
Industry-standard SOT-23 Package		Multi-vendor compatibility
RoHS compliant containing no lead, no bromide and no halogen		Environmentally friendly
MSL1, Consumer Qualification		Increased Reliability

Base Part Number	Package Type	Standard Pack		Orderable Part Number
		Form	Quantity	
IRLML6344TRPbF	Micro3™(SOT-23)	Tape and Reel	3000	IRLML6344TRPbF

Absolute Maximum Ratings

Symbol	Parameter	Max.	Units
V_{DS}	Drain-Source Voltage	30	V
I_D @ T_A = 25°C	Continuous Drain Current, V_{GS} @ 10V	5.0	A
I_D @ T_A = 70°C	Continuous Drain Current, V_{GS} @ 10V	4.0	
I_{DM}	Pulsed Drain Current	25	
P_D @T_A = 25°C	Maximum Power Dissipation	1.3	W
P_D @T_A = 70°C	Maximum Power Dissipation	0.8	
	Linear Derating Factor	0.01	W/°C
V_{GS}	Gate-to-Source Voltage	± 12	V
T_J, T_{STG}	Junction and Storage Temperature Range	-55 to + 150	°C

Thermal Resistance

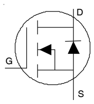
Symbol	Parameter	Typ.	Max.	Units
$R_{\theta JA}$	Junction-to-Ambient ③	——	100	°C/W
$R_{\theta JA}$	Junction-to-Ambient (t<10s) ④	——	99	

ORDERING INFORMATION:
See detailed ordering and shipping information on the last page of this data sheet.

Electric Characteristics @ T_J = 25°C (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	30	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.02	—	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	22	29	mΩ	V_{GS} = 4.5V, I_D = 5.0A ②
		—	27	37		V_{GS} = 2.5V, I_D = 4.0A ②
$V_{GS(th)}$	Gate Threshold Voltage	0.5	0.8	1.1	V	V_{DS} = V_{GS}, I_D = 10μA
I_{DSS}	Drain-to-Source Leakage Current	—	—	1.0	μA	V_{DS} =24V, V_{GS} = 0V
		—	—	150		V_{DS} = 24V, V_{GS} = 0V, T_J = 125°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 12V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -12V
R_G	Internal Gate Resistance	—	1.7	—	Ω	
gfs	Forward Transconductance	19	—	—	S	V_{DS} = 10V, I_D = 5.0A
Q_g	Total Gate Charge	—	6.8	—	nC	I_D = 5.0A
Q_{gs}	Gate-to-Source Charge	—	0.3	—		V_{DS} =15V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	2.4	—		V_{GS} = 4.5V ②
$t_{d(on)}$	Turn-On Delay Time	—	4.2	—	ns	V_{DD} =15V②
t_r	Rise Time	—	5.6	—		I_D = 1.0A
$t_{d(off)}$	Turn-Off Delay Time	—	22	—		R_G = 6.8Ω
t_f	Fall Time	—	9.1	—		V_{GS} = 4.5V
C_{iss}	Input Capacitance	—	650	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	65	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	46	—		f = 1.0MHz

Source - Drain Ratings and Characteristics

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	1.3	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①	—	—	25		
V_{SD}	Diode Forward Voltage	—	—	1.2	V	T_J = 25°C, I_S = 5.0A, V_{GS} = 0V ②
t_{rr}	Reverse Recovery Time	—	10	15	ns	T_J = 25°C, V_R = 15V, I_F=1.3A
Q_{rr}	Reverse Recovery Charge	—	3.8	5.7	nC	di/dt = 100A/μs ②

Notes ① through ④ are on page 10

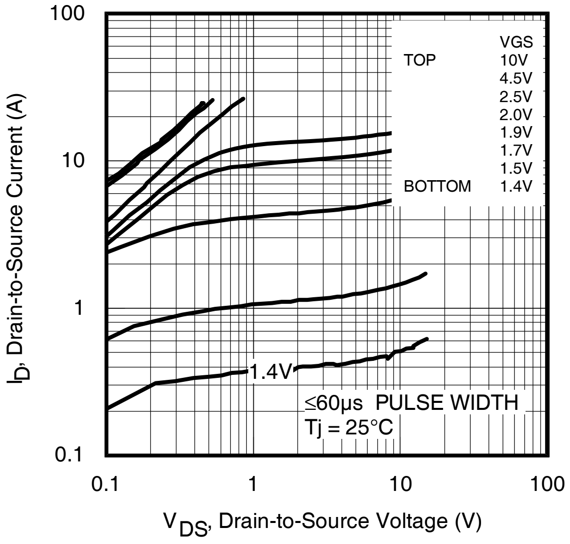


Fig 1. Typical Output Characteristics

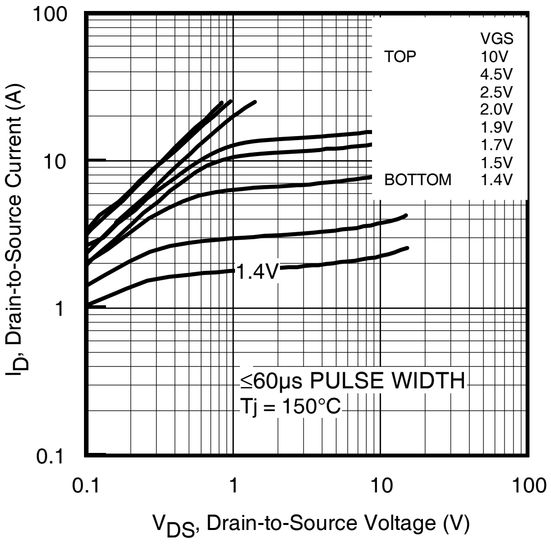


Fig 2. Typical Output Characteristics

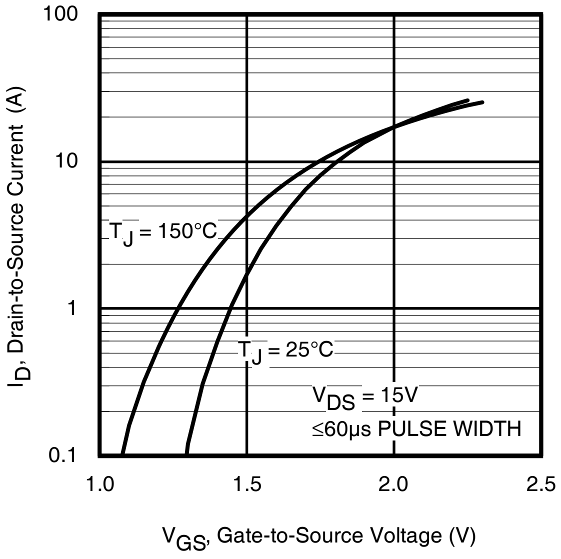


Fig 3. Typical Transfer Characteristics

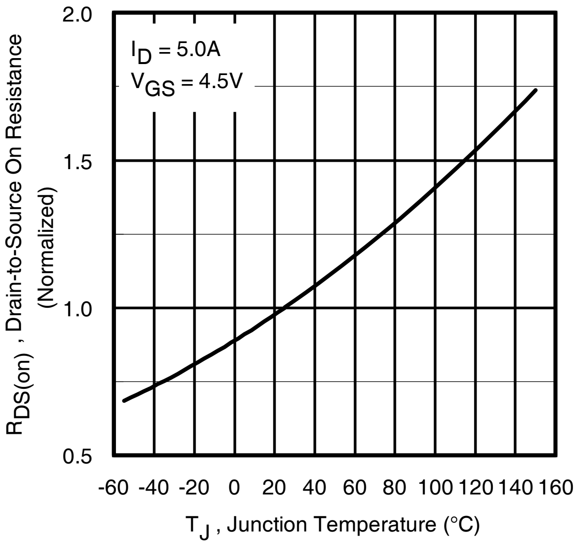


Fig 4. Normalized On-Resistance Vs. Temperature

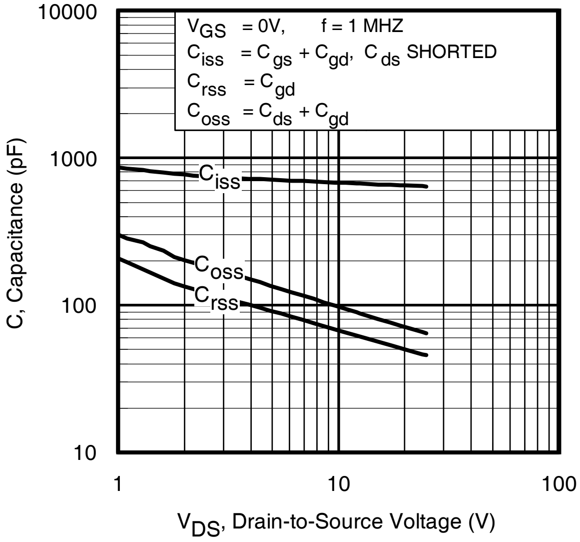


Fig 5. Typical Capacitance Vs. Drain-to-Source Voltage

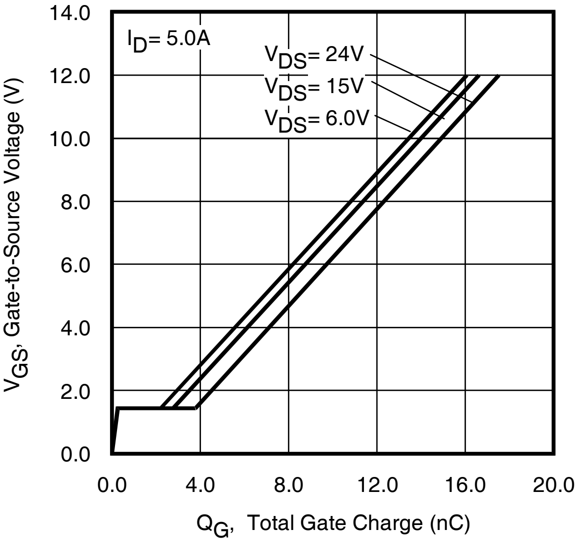


Fig 6. Typical Gate Charge Vs. Gate-to-Source Voltage

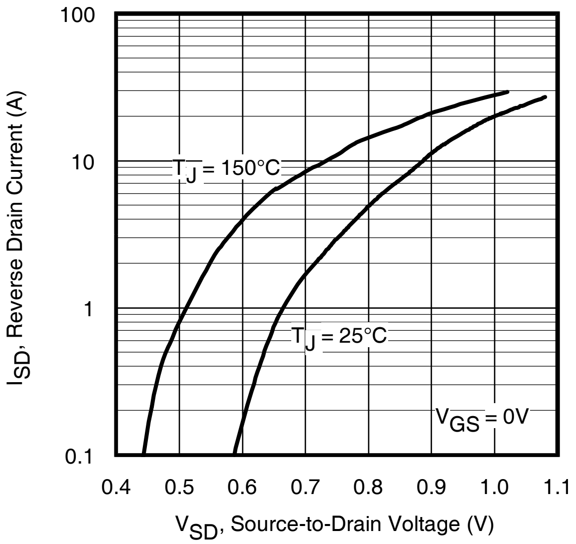


Fig 7. Typical Source-Drain Diode Forward Voltage

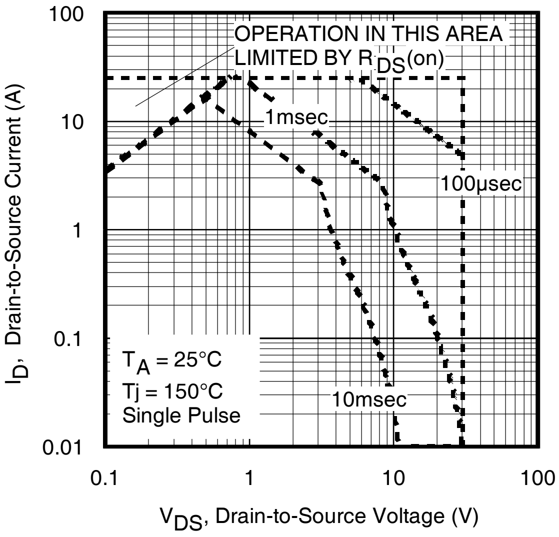


Fig 8. Maximum Safe Operating Area

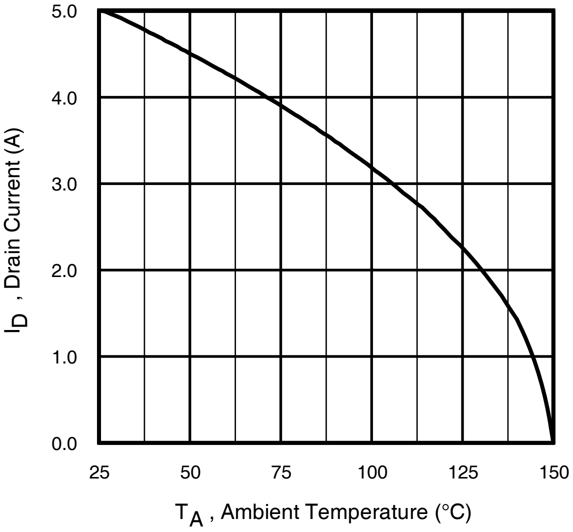


Fig 9. Maximum Drain Current Vs. Ambient Temperature

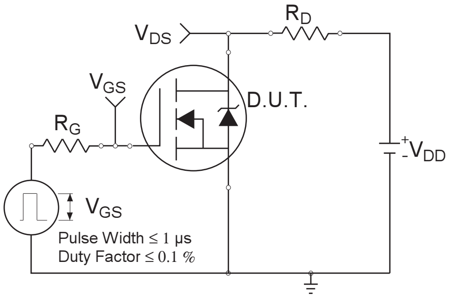


Fig 10a. Switching Time Test Circuit

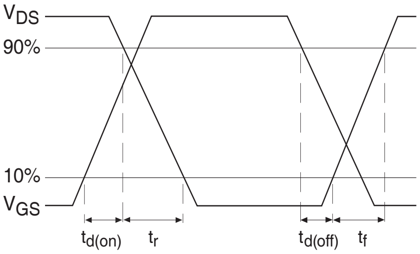


Fig 10b. Switching Time Waveforms

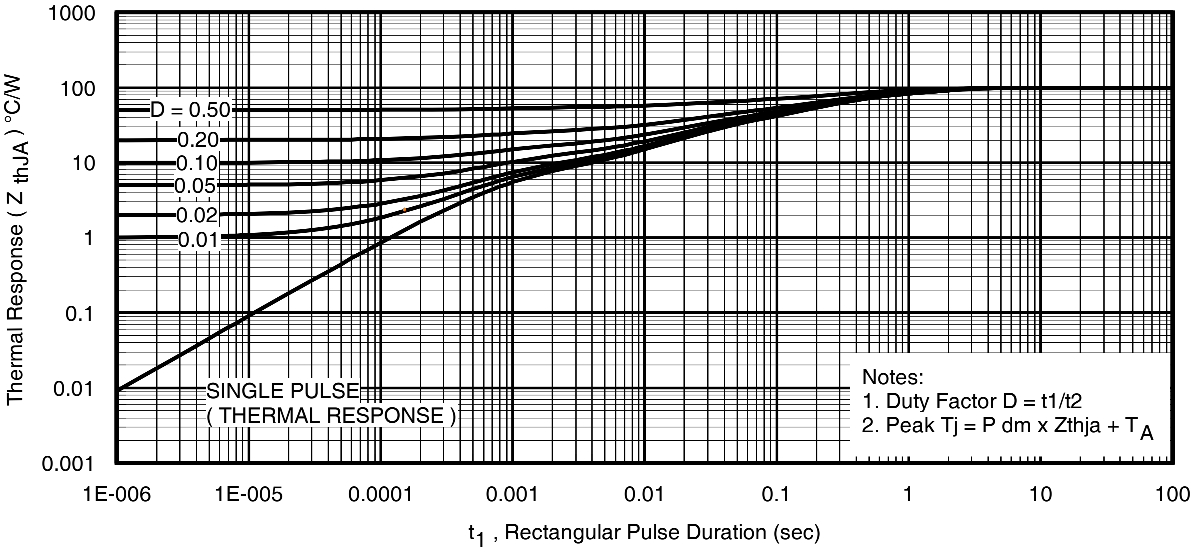


Fig 11. Typical Effective Transient Thermal Impedance, Junction-to-Ambient

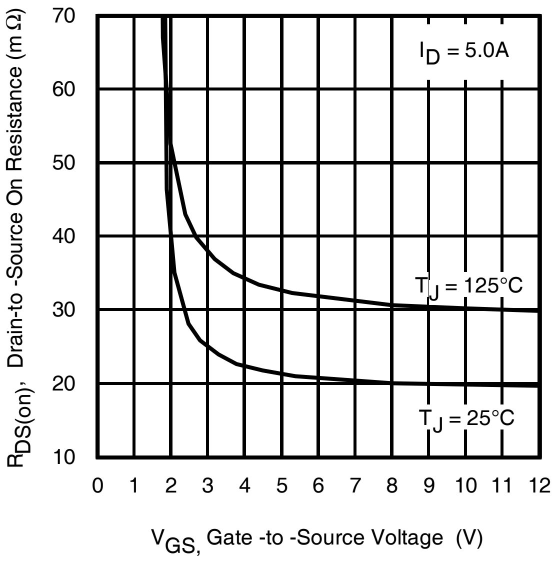


Fig 12. Typical On-Resistance Vs. Gate Voltage

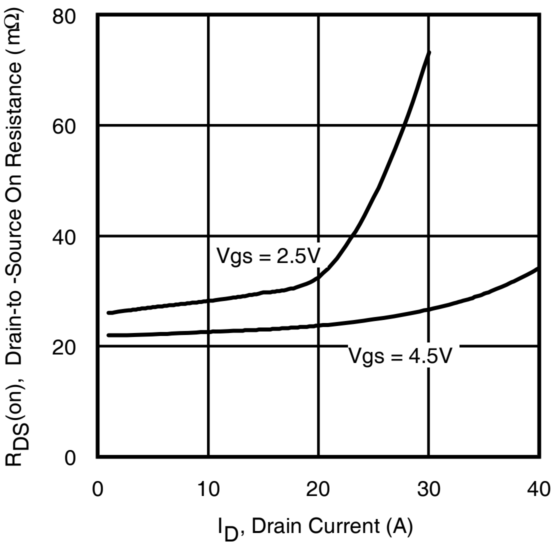


Fig 13. Typical On-Resistance Vs. Drain Current

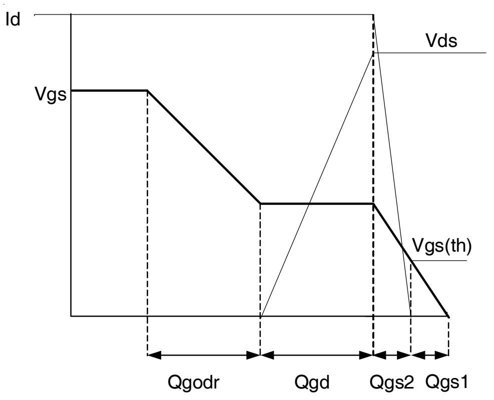


Fig 14a. Basic Gate Charge Waveform

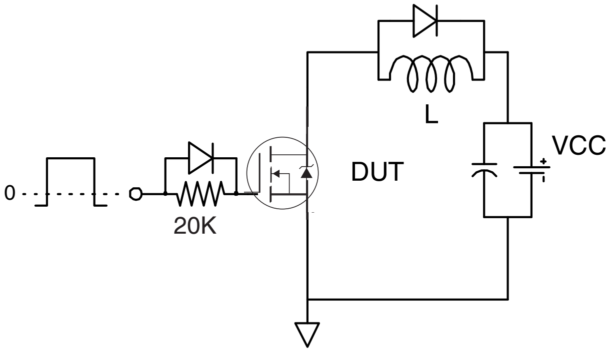


Fig 14b. Gate Charge Test Circuit

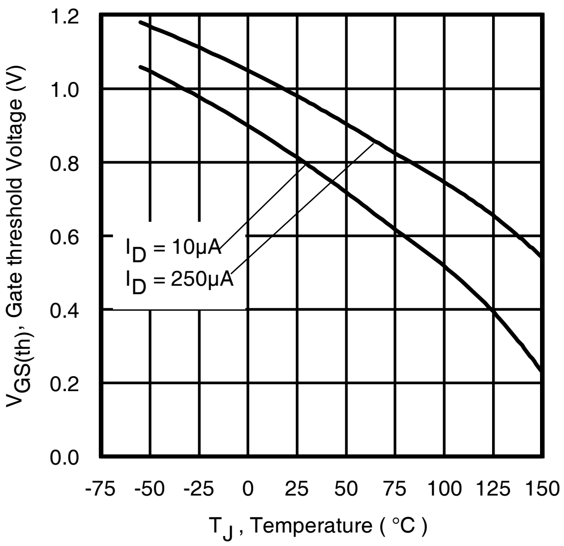


Fig 15. Typical Threshold Voltage Vs. Junction Temperature

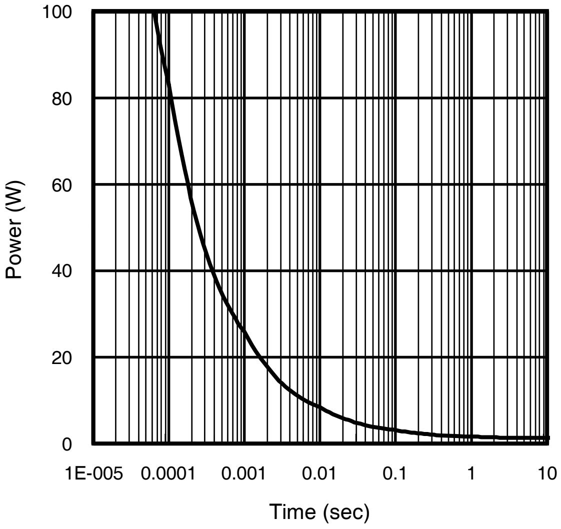
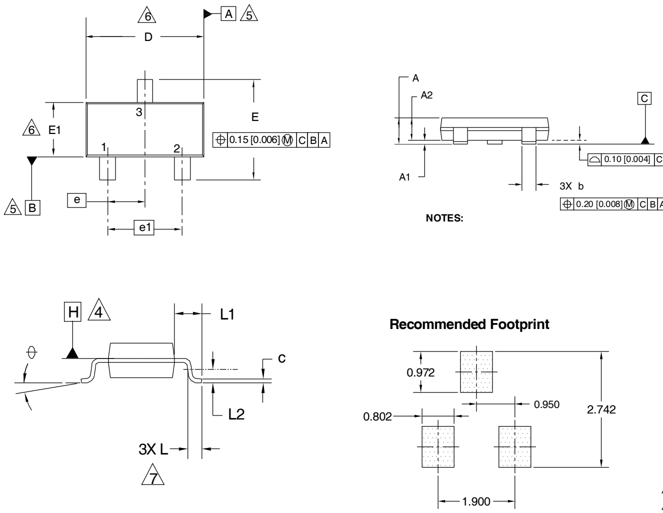


Fig 16. Typical Power Vs. Time

Micro3™(SOT-23) Package Outline

Dimensions are shown in millimeters (inches)



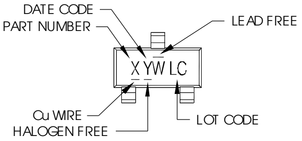
Recommended Footprint

SYMBOL	DIMENSIONS			
	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	0.89	1.12	0.035	0.044
A1	0.01	0.10	0.0004	0.004
A2	0.88	1.02	0.035	0.040
b	0.30	0.50	0.012	0.020
c	0.08	0.20	0.003	0.008
D	2.80	3.04	0.110	0.120
E	2.10	2.64	0.083	0.104
E1	1.20	1.40	0.047	0.055
e	0.95	BSC	0.037	BSC
e1	1.90	BSC	0.075	BSC
L	0.40	0.60	0.016	0.024
L1	0.54	REF	0.021	REF
L2	0.25	BSC	0.010	BSC
θ	0	8	0	8

1. DIMENSIONING & TOLERANCING PER ANSI Y14.5M-1994
2. DIMENSIONS ARE SHOWN IN MILLIMETERS [INCHES].
3. CONTROLLING DIMENSION: MILLIMETER.
△4 DATUM PLANE H IS LOCATED AT THE MOLD PARTING LINE.
△5 DATUM A AND B TO BE DETERMINED AT DATUM PLANE H.
△6 DIMENSIONS D AND E1 ARE MEASURED AT DATUM PLANE H. DIMENSIONS DOES NOT INCLUDE MOLD PROTRUSIONS OR INTERLEAD FLASH. MOLD PROTRUSIONS OR INTERLEAD FLASH SHALL NOT EXCEED 0.25 MM [0.010 INCH] PER SIDE.
△7 DIMENSION L IS THE LEAD LENGTH FOR SOLDERING TO A SUBSTRATE.
8. OUTLINE CONFORMS TO JEDEC OUTLINE TO-236 AB.

Micro3™(SOT-23) Part Marking Information

Notes : This part marking information applies to devices produced after 02/26/2001



X = PART NUMBER CODE REFERENCE:

A = IRLML2402
B = IRLML2803
C = IRLML6302
D = IRLML5103
E = IRLML6402
F = IRLML6401
G = IRLML2502
H = IRLML5203
I = IRLML0030
J = IRLML2030
K = IRLML0100
L = IRLML0060
M = IRLML0040
N = IRLML2060
P = IRLML9301
R = IRLML9303
S = IRLML6244
T = IRLML6246
U = IRLML6344
V = IRLML6346
W = IRFML8244
X = IRLML2244
Y = IRLML2246
Z = IRFML9244

Note: A line above the work week
(as shown here) indicates Lead - Free.

DATE CODE MARKING INSTRUCTIONS

WW = (1-26) IF PRECEDED BY LAST DIGIT OF CALENDAR YEAR

YEAR		Y	WORK WEEK	W
2011	2001	1	01	A
2012	2002	2	02	B
2013	2003	3	03	C
2014	2004	4	04	D
2015	2005	5	↓	↓
2016	2006	6		
2017	2007	7		
2018	2008	8		
2019	2009	9		
2020	2010	0	24	X
			25	Y
			26	Z

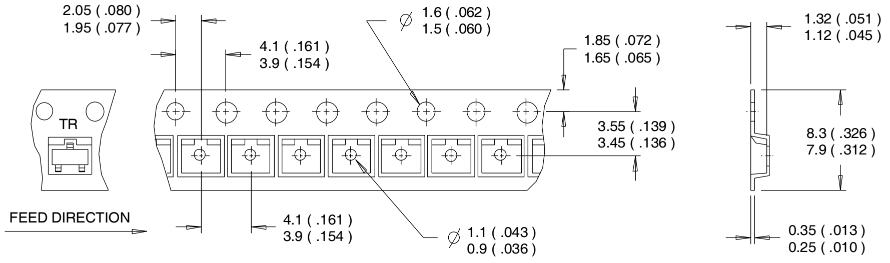
WW = (27-52) IF PRECEDED BY A LETTER

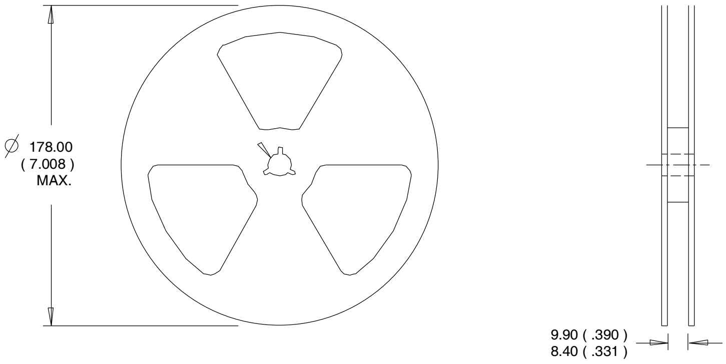
YEAR		Y	WORK WEEK	W
2011	2001	A	27	A
2012	2002	B	28	B
2013	2003	C	29	C
2014	2004	D	30	D
2015	2005	E	↓	↓
2016	2006	F		
2017	2007	G		
2018	2008	H		
2019	2009	J		
2020	2010	K	50	X
			51	Y
			52	Z

Note: For the most current drawing please refer to IR website at: http://www.irf.com/package/

Micro3™(SOT-23) Tape & Reel Information

Dimensions are shown in millimeters (inches)





NOTES:
1. CONTROLLING DIMENSION : MILLIMETER.
2. OUTLINE CONFORMS TO EIA-481 & EIA-541.

Note: For the most current drawing please refer to IR website at: http://www.irf.com/package/

Qualification information[†]

Qualification level	Consumer[††] (per JEDEC JESD47F[†††] guidelines)	
Moisture Sensitivity Level	Micro3™(SOT-23)	MSL1 (per IPC/JEDEC J-STD-020D[†††])
RoHS compliant	Yes	

[†] Qualification standards can be found at International Rectifier's web site http://www.irf.com/product-info/reliability

[††] Higher qualification ratings may be available should the user have such requirements. Please contact your International Rectifier sales representative for further information: http://www.irf.com/whoto-call/salesrep/

[†††] Applicable version of JEDEC standard at the time of product release.

Notes:

① Repetitive rating; pulse width limited by max. junction temperature.
② Pulse width ≤ 400µs; duty cycle ≤ 2%.
③ Surface mounted on 1 in square Cu board
④ Refer to application note #AN-994.

Revision History

Date	Comment
12/19/2014	• Formatted the data sheet using the IR Corporate template. • Updated part marking on page 8. • Corrected Typical Output curve Fig.2 on page 3 (used to be exact same as Fig.1)

International
IOR Rectifier

IR WORLD HEADQUARTERS: 101 N. Sepulveda Blvd., El Segundo, California 90245, USA
To contact International Rectifier, please visit http://www.irf.com/whoto-call/

1N5820, 1N5821, 1N5822

1N5820 and 1N5822 are Preferred Devices

Axial Lead Rectifiers

This series employs the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features chrome barrier metal, epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

Features

- Extremely Low V_F
- Low Power Loss/High Efficiency
- Low Stored Charge, Majority Carrier Conduction
- Shipped in plastic bags, 500 per bag
- Available in Tape and Reel, 1500 per reel, by adding a “RL” suffix to the part number
- Pb-Free Packages are Available*

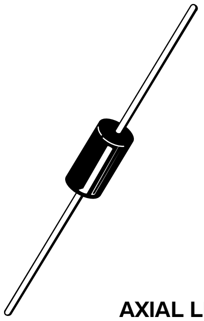
Mechanical Characteristics:

- Case: Epoxy, Molded
- Weight: 1.1 Gram (Approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
- Lead Temperature for Soldering Purposes: 260°C Max. for 10 Seconds
- Polarity: Cathode indicated by Polarity Band

ON Semiconductor®

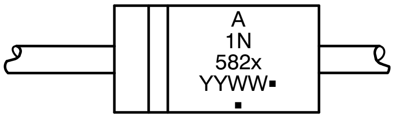
http://onsemi.com

SCHOTTKY BARRIER RECTIFIERS 3.0 AMPERES 20, 30, 40 VOLTS



AXIAL LEAD
CASE 267-05
(DO-201AD)
STYLE 1

MARKING DIAGRAM



A = Assembly Location
1N582x = Device Code
x = 0, 1, or 2
YY = Year
WW = Work Week
▪ = Pb-Free Package
(Note: Microdot may be in either location)

ORDERING INFORMATION

See detailed ordering and shipping information on page 3 of this data sheet.

Preferred devices are recommended choices for future use and best overall value.

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*For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

December, 2007 − Rev. 10

MAXIMUM RATINGS

Rating	Symbol	1N5820	1N5821	1N5822	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	V
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	V
RMS Reverse Voltage	$V_{R(RMS)}$	14	21	28	V
Average Rectified Forward Current (Note 1) $V_{R(equiv)} \le 0.2\ V_{R(dc)}$, $T_L = 95°C$ ($R_{\theta JA}$ = 28°C/W, P.C. Board Mounting, see Note 5)	I_O	← 3.0 →			A
Ambient Temperature Rated $V_{R(dc)}$, $P_{F(AV)} = 0$ $R_{\theta JA}$ = 28°C/W	T_A	90	85	80	°C
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions, half wave, single phase 60 Hz, T_L = 75°C)	I_{FSM}	80 (for one cycle)			A
Operating and Storage Junction Temperature Range (Reverse Voltage applied)	T_J, T_{stg}	−65 to +125			°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

*THERMAL CHARACTERISTICS (Note 5)

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction-to-Ambient	$R_{\theta JA}$	28	°C/W

*ELECTRICAL CHARACTERISTICS (T_L = 25°C unless otherwise noted) (Note 1)

Characteristic	Symbol	1N5820	1N5821	1N5822	Unit
Maximum Instantaneous Forward Voltage (Note 2)	V_F				V
(i_F = 1.0 Amp)		0.370	0.380	0.390	
(i_F = 3.0 Amp)		0.475	0.500	0.525	
(i_F = 9.4 Amp)		0.850	0.900	0.950	
Maximum Instantaneous Reverse Current @ Rated dc Voltage (Note 2)	i_R				mA
T_L = 25°C		2.0	2.0	2.0	
T_L = 100°C		20	20	20	

1. Lead Temperature reference is cathode lead 1/32″ from case.
2. Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

*Indicates JEDEC Registered Data for 1N5820-22.

ORDERING INFORMATION

Device	Package	Shipping†
1N5820	Axial Lead	500 Units/Bag
1N5820G	Axial Lead (Pb-Free)	500 Units/Bag
1N5820RL	Axial Lead	1500/Tape & Reel
1N5820RLG	Axial Lead (Pb-Free)	1500/Tape & Reel
1N5821	Axial Lead	500 Units/Bag
1N5821G	Axial Lead (Pb-Free)	500 Units/Bag
1N5821RL	Axial Lead	1500/Tape & Reel
1N5821RLG	Axial Lead (Pb-Free)	1500/Tape & Reel
1N5822	Axial Lead	500 Units/Bag
1N5822G	Axial Lead (Pb-Free)	500 Units/Bag
1N5822RL	Axial Lead	1500/Tape & Reel
1N5822RLG	Axial Lead (Pb-Free)	1500/Tape & Reel

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

NOTE 3 — DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.1 V_{RWM}. Proper derating may be accomplished by use of equation (1).

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}P_{F(AV)} - R_{\theta JA}P_{R(AV)} \quad (1)$$

where $T_{A(max)}$ = Maximum allowable ambient temperature
$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest)
$P_{F(AV)}$ = Average forward power dissipation
$P_{R(AV)}$ = Average reverse power dissipation
$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1, 2, and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2).

$$T_R = T_{J(max)} - R_{\theta JA}P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2, and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2, and 3 is based upon dc conditions. For use in common rectifier circuits, Table 1 indicates suggested factors for an equivalent dc voltage to use for conservative design, that is:

$$V_{R(equiv)} = V_{(FM)} \times F \quad (4)$$

The factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

EXAMPLE: Find $T_{A(max)}$ for 1N5821 operated in a 12-volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 2.0 A ($I_{F(AV)}$ = 1.0 A), $I_{(FM)}/I_{(AV)}$ = 10, Input Voltage = 10 $V_{(rms)}$, $R_{\theta JA}$ = 40°C/W.

Step 1. Find $V_{R(equiv)}$. Read F = 0.65 from Table 1,

$$\therefore V_{R(equiv)} = (1.41)(10)(0.65) = 9.2\text{ V.}$$

Step 2. Find T_R from Figure 2. Read T_R = 108°C

@ V_R = 9.2 V and $R_{\theta JA}$ = 40°C/W.

Step 3. Find $P_{F(AV)}$ from Figure 6. **Read $P_{F(AV)}$ = 0.85 W

$$@\frac{I_{(FM)}}{I_{(AV)}} = 10 \text{ and } I_{F(AV)} = 1.0\text{ A.}$$

Step 4. Find $T_{A(max)}$ from equation (3).

$$T_{A(max)} = 108 - (0.85)(40) = 74°\text{C.}$$

**Values given are for the 1N5821. Power is slightly lower for the 1N5820 because of its lower forward voltage, and higher for the 1N5822. Variations will be similar for the MBR-prefix devices, using $P_{F(AV)}$ from Figure 6.

Table 1. Values for Factor F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped*†	
Load	**Resistive**	**Capacitive***	**Resistive**	**Capacitive**	**Resistive**	**Capacitive**
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{R(PK)} \approx 2.0\ V_{in(PK)}$.
†Use line to center tap voltage for V_{in}.

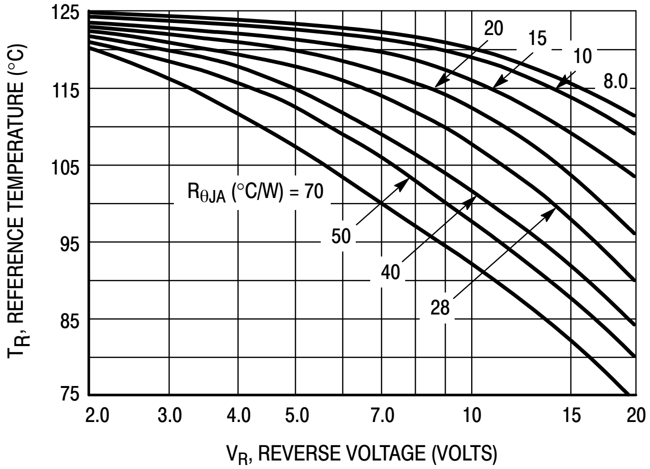


Figure 1. Maximum Reference Temperature 1N5820

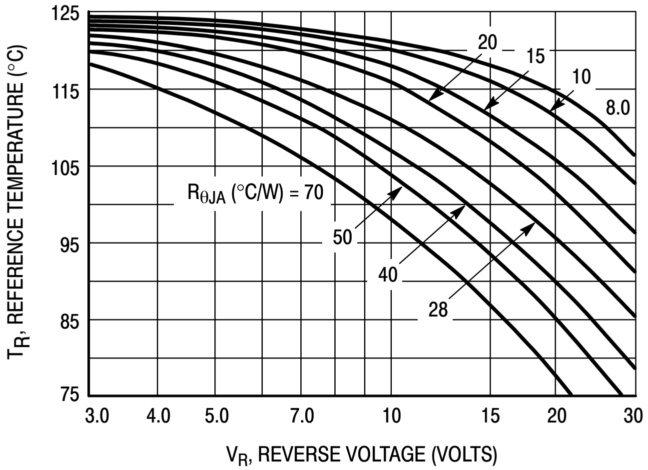


Figure 2. Maximum Reference Temperature 1N5821

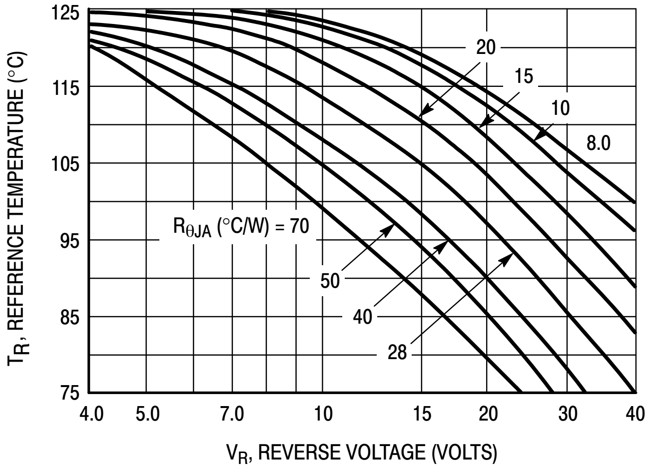


Figure 3. Maximum Reference Temperature 1N5822

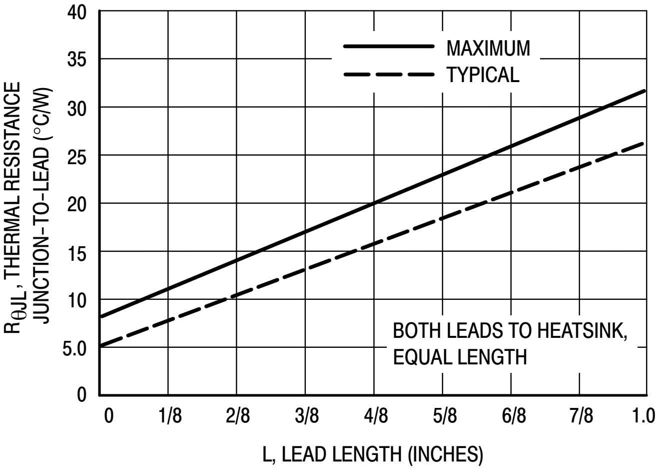
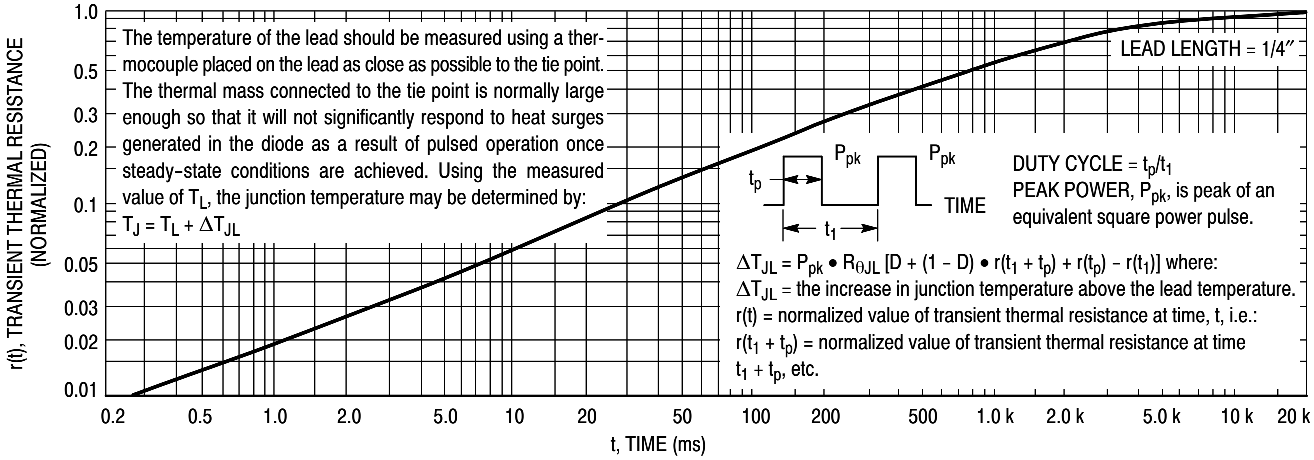


Figure 4. Steady−State Thermal Resistance



The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady−state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

$T_J = T_L + \Delta T_{JL}$

DUTY CYCLE = t_p/t_1
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

$\Delta T_{JL} = P_{pk} \bullet R_{\theta JL} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$ where:
ΔT_{JL} = the increase in junction temperature above the lead temperature.
r(t) = normalized value of transient thermal resistance at time, t, i.e.:
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$, etc.

Figure 5. Thermal Response

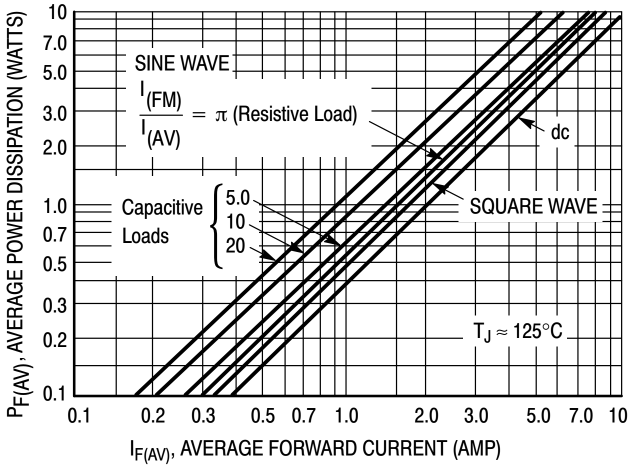
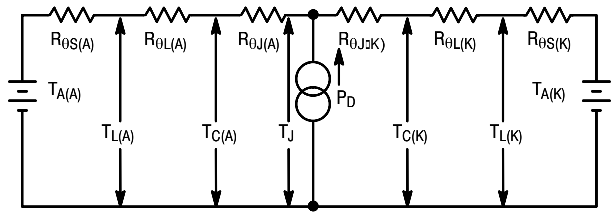


Figure 6. Forward Power Dissipation 1N5820−22

NOTE 4 − APPROXIMATE THERMAL CIRCUIT MODEL



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature T_C = Case Temperature
T_L = Lead Temperature T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heatsink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead−to−Heatsink
$R_{\theta J}$ = Thermal Resistance, Junction−to−Case
P_D = Total Power Dissipation = $P_F + P_R$
P_F = Forward Power Dissipation
P_R = Reverse Power Dissipation

(Subscripts (A) and (K) refer to anode and cathode sides, respectively.) Values for thermal resistance components are:

$R_{\theta L}$ = 42°C/W/in typically and 48°C/W/in maximum
$R_{\theta J}$ = 10°C/W typically and 16°C/W maximum

The maximum lead temperature may be found as follows:

$T_L = T_{J(max)} - \Delta T_{JL}$
where $\Delta T_{JL} \approx R_{\theta JL} \cdot P_D$

NOTE 5 — MOUNTING DATA

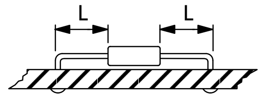
Data shown for thermal resistance junction−to−ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering, or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

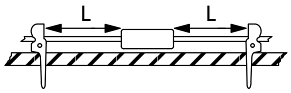
Mounting Method	Lead Length, L (in)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3	28				°C/W

Mounting Method 1

P.C. Board where available copper surface is small.



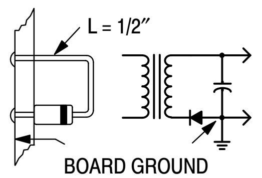
Mounting Method 2



VECTOR PUSH−IN TERMINALS T−28

Mounting Method 3

P.C. Board with 2−1/2, x 2−1/2, copper surface.



BOARD GROUND PLANE

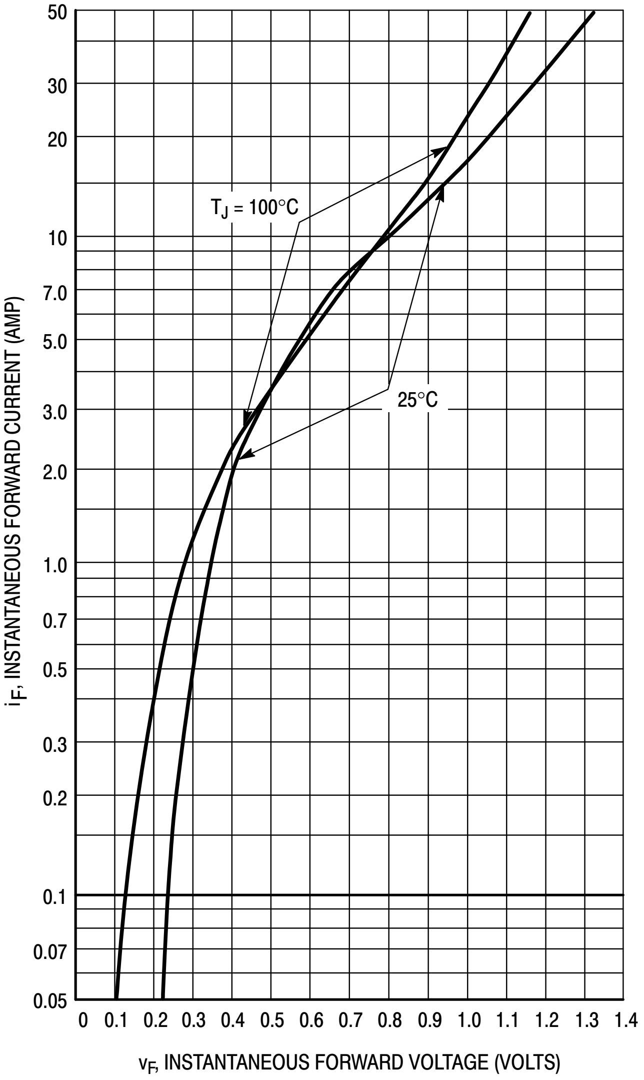


Figure 7. Typical Forward Voltage

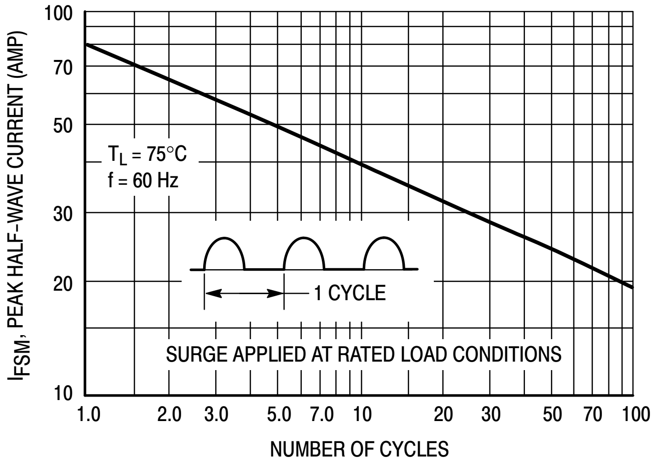


Figure 8. Maximum Non-Repetitive Surge Current

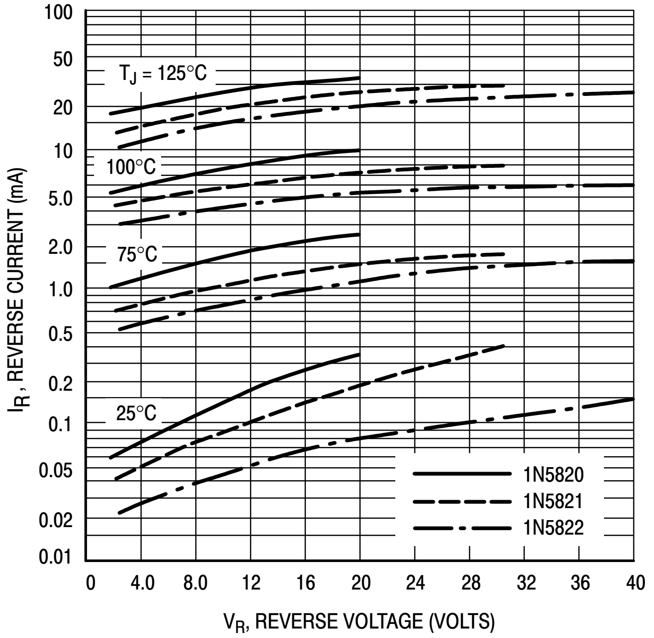


Figure 9. Typical Reverse Current

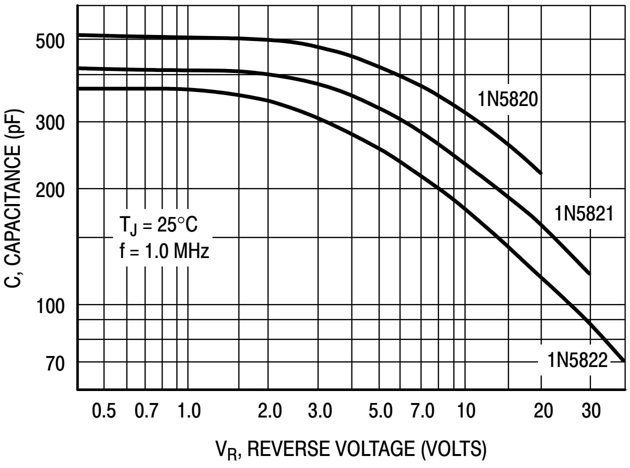


Figure 10. Typical Capacitance

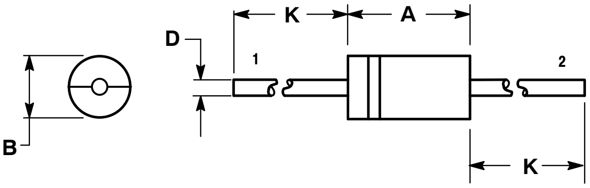
NOTE 6 — HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 10.)

PACKAGE DIMENSIONS

AXIAL LEAD

CASE 267-05
(DO-201AD)
ISSUE G



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.287	0.374	7.30	9.50
B	0.189	0.209	4.80	5.30
D	0.047	0.051	1.20	1.30
K	1.000	---	25.40	---

STYLE 1:
PIN 1. CATHODE (POLARITY BAND)
2. ANODE

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Current Transducer HO-P series

I_{PN} = 6, 10, 25 A

Ref: HO 6-P, HO 10-P, HO 25-P

For the electronic measurement of current: DC, AC, pulsed..., with galvanic separation between the primary and the secondary circuit.

Features

- Hall effect measuring principle
- Galvanic separation between primary and secondary circuit
- Insulated test voltage 4300 V
- Low power consumption
- Single power supply +5 V
- Fixed offset & sensitivity
- Over-current detect 2.63 × I_{PN} (peak value)
- Memory check.

Advantages

- Small size and space saving
- Only one design for wide primary current range
- High immunity to external interference
- 8 mm creepage /clearance
- High insulation capability
- Fast response.

Applications

- AC variable speed drives
- Static converters for DC motor drives
- Battery supplied applications
- Uninterruptible Power Supplies (UPS)
- Switched Mode Power Supplies (SMPS)
- Power supplies for welding applications
- The solar inverter on DC side of the inverter (MPPT)
- Combiner box.

Standards

- EN 50178: 1997
- IEC 61010-1: 2010
- IEC 61326-1: 2012
- UL 508: 2010.

Application Domain

- Industrial.

Absolute maximum ratings

Parameter	Symbol	Unit	Value
Supply voltage (not operating)	U_C	V	6.5
Primary conductor temperature	T_B	°C	125
ESD rating, Human Body Model (HBM)	U_{ESD}	kV	2

Stresses above these ratings may cause permanent damage. Exposure to absolute maximum ratings for extended periods may degrade reliability.

UL 508: Ratings and assumptions of certification

File # E189713 Volume: 2 Section: 5

Standards

- CSA C22.2 NO. 14-10 INDUSTRIAL CONTROL EQUIPMENT - Edition 11 - Revision Date 2011/08/01
- UL 508 STANDARD FOR INDUSTRIAL CONTROL EQUIPMENT - Edition 17 - Revision Date 2010/04/15

Ratings

Parameter	Symbol	Unit	Value
Primary involved potential		V AC/DC	600
Max surrounding air temperature	T_A	°C	105
Primary current	I_P	A	According to series primary currents
Secondary supply voltage	U_C	V DC	5
Output voltage	V_{out}	V	0 to 5

Conditions of acceptability

When installed in the end-use equipment, consideration shall be given to the following:

1 - *These devices have been evaluated for overvoltage category III and for use in pollution degree 2 environment.*
2 - *A suitable enclosure shall be provided in the end-use application.*
3 - *The terminals have not been evaluated for field wiring.*
4 - *These devices have been evaluated for use in 105°C maximum surrounding air temperature.*
5 - *The secondary (Sensing) circuit is intended to be supplied by a Isolated Secondary Circuit - Limited voltage circuit defined by UL 508 paragraph 32.5. The maximum open circuit voltage potential available to the circuit and overcurrent protection shall be evaluated in the end use application.*
6 - *These devices are intended to be mounted on a printed wiring board of end-use equipment. The suitability of the connections (including spacings) shall be determined in the end-use application.*
7 - *Any surface of polymeric housing have not been evaluated as insulating barrier.*
8 - *Low voltage circuits are intended to be powered by a circuit derived from an isolating source (such as a transformer, optical isolator, limiting impedance or electro-mechanical relay) and having no direct connection back to the primary circuit (other than through the grounding means).*

Marking

Only those products bearing the UL or UR Mark should be considered to be Listed or Recognized and covered under UL's Follow-Up Service. Always look for the Mark on the product.

Insulation coordination

Parameter	Symbol	Unit	Value	Comment
RMS voltage for AC isolation test 50/60 Hz/1 min [1]	U_d	kV	4.3	
Impulse withstand voltage 1.2/50 µs	$\hat{U}_W$	kV	8	
Partial discharge extinction voltage @ 10 pC (rms)	U_e	V	1650	
Clearance (pri. - sec.)	d_{Cl}	mm	8	Shortest distance through air
Creepage distance (pri. - sec.)	d_{Cp}	mm	8	Shortest path along device body
Case material			V0 according to UL 94	
Comparative tracking index	*CTI*		600	
Application example	-	-	600 V CAT III PD2	Reinforced insulation, non uniform field according to EN 50178
Application example	-	-	300 V CAT III PD2	Reinforced insulation, non uniform field according to IEC 61010
Application example	-	-	1000 V CAT III PD2	Simple insulation, non uniform field according to EN 50178, IEC 61010

Environmental and mechanical characteristics

Parameter	Symbol	Unit	Min	Typ	Max	Comment
Ambient operating temperature	T_A	°C	-40		105	
Ambient storage temperature	T_S	°C	-40		105	
Surrounding temperature according to UL 508		°C			105	
Mass	*m*	g		10		

Note: [1] Voltage of Retention pins has to be consider. If it is same as primary electrical potential, insulation is no issue. If it is same as secondary electrical potental, insulation of primary bus bar has to be considered.

Electrical data I_{PN} = 6 A

At T_A = 25 °C, U_C = +5 V, N_P = 1 turn, R_L = 10 KΩ unless otherwise noted (see Min, Max, typ. definition paragraph in page 7).

Parameter	Symbol	Unit	Min	Typ	Max	Comment
Primary nominal rms current	I_{PN}	A		6		
Primary current, measuring range	I_{PM}	A	-20		20	
Supply voltage	U_C	V	4.5	5	5.5	
Current consumption	I_C	mA		19	25	
Reference voltage	V_{ref}	V	2.475	2.5	2.525	Internal reference
External reference voltage	V_{ref}	V	0.5		2.65	
Output voltage range @ I_{PM}	$V_{OUT} - V_{ref}$	V	-2		2	
Output voltage @ I_P = 0 A	V_{OUT}	V		$V_{ref} + V_{OE}$		
Electrical offset voltage	V_{OE}	mV	-10		10	
Temperature coefficient of V_{REF}	TCV_{ref}	ppm/K			±160	-20 °C .. 85 °C Internal reference
					±190	-40 °C .. 105 °C Internal reference
Temperature coefficient of V_{OE}	TCV_{OE}	mV/K			±0.14	-20 °C .. 85 °C
						-40 °C .. 105 °C
Theoretical sensitivity	G_{th}	mV/A		100		600 mV/ I_{PN} @ U_C = 5 V
Sensitivity error	ε_G	%			±0.85	Factory adjustement
Temperature coefficient of G	TCG	ppm/K			±250	
Linearity error 0 .. I_{PN}	ε_L	% of I_{PN}			±0.5	@ U_C = 5 V
Linearity error 0 .. I_{PM}	ε_L	% of I_{PM}			±0.8	@ U_C = 5 V
Gain error with respect to U_C ±10 %		%/%			±0.05	Gain error per U_C drift
Magnetic offset voltage @ I_P = 0 after 2.5 × I_{PN}	V_{OM}	mV			±5	
Reaction time @ 10 % of I_{PN}	t_{ra}	µs			2	di/dt = I_{PN}/µs
Response time @ 90 % of I_{PN}	t_r	µs			3.5	di/dt = I_{PN}/µs
Frequency bandwidth (-3 dB)	BW	kHz		250		
Output voltage noise (spectral density) (DC .. 100 kHz)	e_{no}	µVrms/√Hz			32.9	@ U_C = 5 V
Output voltage noise (DC .. 20 MHz)	V_{no}	mVpp		80		
Over-current detect		V	2.6 × I_{PN}	2.9 × I_{PN}	3.2 × I_{PN}	peak value
Accuracy @ I_{PN}	X	% of I_{PN}			±1.35	$\varepsilon_G + \varepsilon_L$
Accuracy @ I_{PN} @ T_A = +85°C	X	% of I_{PN}			±4.25	See formula note [1]
Accuracy @ I_{PN} @ T_A = +105°C	X	% of I_{PN}			±5.22	See formula note [1]

Note: [1] Accuracy @ I_P and $X_{TA} = \pm [X + (TCG/10000) \cdot (T_A - 25) + TCV_{OE} \cdot 100 \cdot (T_A - 25) / (G_{th} \cdot I_P)]$.

Electrical data I_{PN} = 10 A

At T_A = 25 °C, U_C = +5 V, N_P = 1 turn, R_L = 10 KΩ unless otherwise noted (see Min, Max, typ. definition paragraph in page 7).

Parameter	Symbol	Unit	Min	Typ	Max	Comment
Primary nominal rms current	I_{PN}	A		10		
Primary current, measuring range	I_{PM}	A	-25		25	
Supply voltage	U_C	V	4.5	5	5.5	
Current consumption	I_C	mA		19	25	
Reference voltage	V_{ref}	V	2.475	2.5	2.525	Internal reference
External reference voltage	V_{ref}	V	0.5		2.65	
Output voltage range @ I_{PM}	$V_{OUT} - V_{ref}$	V	-2		2	
Output voltage @ I_P = 0 A	V_{OUT}	V		$V_{ref} + V_{OE}$		
Electrical offset voltage	V_{OE}	mV	-10		10	
Temperature coefficient of V_{ref}	TCV_{ref}	ppm/K			±160	-20 °C .. 85 °C Internal reference
					±190	-40 °C .. 105 °C Internal reference
Temperature coefficient of V_{OE}	TCV_{OE}	mV/K			±0.12	
Theoretical sensitivity	G_{th}	mV/A		80		800 mV/ I_{PN}, @ U_C = 5 V
Sensitivity error	ε_G	%			±0.85	Factory adjustement
Temperature coefficient of G	TCG	ppm/K			±250	
Linearity error 0 .. I_{PN}	ε_L	% of I_{PN}			±0.5	@ U_C = 5 V
Linearity error 0 .. I_{PM}	ε_L	% of I_{PM}			±0.8	@ U_C = 5 V
Gain error with respect to U_C ±10 %		%/%			±0.05	Gain error per U_C drift
Magnetic offset voltage @ I_P = 0 after 2.5 × I_{PN}	V_{OM}	mV			±6	
Reaction time @ 10 % of I_{PN}	t_{ra}	µs			2	$di/dt = I_{PN}$/µs
Response time @ 90 % of I_{PN}	t_r	µs			3.5	$di/dt = I_{PN}$/µs
Frequency bandwidth (-3 dB)	BW	kHz		250		
Output voltage noise (spectral density) (DC .. 100 MHz)	e_{no}	µVrms/√Hz			17.5	
Output voltage noise (DC .. 20 MHz)	V_{no}	mVpp		50		
Over-current detect		V	2.6 × I_{PN}	2.9 × I_{PN}	3.2 × I_{PN}	peak value
Accuracy @ I_{PN}	X	% of I_{PN}			±1.35	$\varepsilon_G + \varepsilon_L$
Accuracy @ I_{PN} @ T_A = +85 °C	X	% of I_{PN}			±3.75	See formula note [1]
Accuracy @ I_{PN} @ T_A = +105 °C	X	% of I_{PN}			±4.55	See formula note [1]

Note: [1] Accuracy @ I_P and $X_{TA} = \pm [X + (TCG/10000) \cdot (T_A - 25) + TCV_{OE} \cdot 100 \cdot (T_A - 25) / (G_{th} \cdot I_P)]$.

Electrical data I_{PN} = 25 A

At T_A = 25 °C, U_C = +5 V, N_P = 1 turn, R_L = 10 KΩ unless otherwise noted (see Min, Max, typ. definition paragraph in page 7).

Parameter	Symbol	Unit	Min	Typ	Max	Comment
Primary nominal rms current	I_{PN}	A		25		
Primary current, measuring range	I_{PM}	A	-62.5		62.5	
Supply voltage	U_C	V	4.5	5	5.5	
Current consumption	I_C	mA		19	25	
Reference voltage	V_{ref}	V	2.475	2.5	2.525	Internal reference
External reference voltage	V_{ref}	V	0.5		2.65	
Output voltage range @ I_{PM}	$V_{OUT} - V_{ref}$	V	-2		2	
Output voltage @ I_P = 0 A	V_{OUT}	V		$V_{ref} + V_{OE}$		
Electrical offset voltage	V_{OE}	mV	-10		10	
Temperature coefficient of V_{ref}	TCV_{ref}	ppm/K			±160	-20 °C .. 85 °C Internal reference
					±190	-40 °C .. 105 °C Internal reference
Temperature coefficient of V_{OE}	TCV_{OE}	mV/K			±0.075	
Theoretical sensitivity	G_{th}	mV/A		32		800 mV/ I_{PN} @ U_C = 5 V
Sensitivity error	ε_G	%			±0.85	Factory adjustement
Temperature coefficient of G	TCG	ppm/K			±250	
Linearity error 0 .. I_{PN}	ε_L	% of I_{PN}			±0.5	@ U_C = 5 V
Linearity error 0 .. I_{PM}	ε_L	% of I_{PM}			±0.8	@ U_C = 5 V
Gain error with respect to U_C ±10 %		%/%			±0.05	Gain error per U_C drift
Magnetic offset voltage @ I_P = 0 after 2.5 × I_{PN}	V_{OM}	mV			±7	
Reaction time @ 10 % of I_{PN}	t_{ra}	µs			2	$di/dt = I_{PN}/\mu s$
Response time @ 90 % of I_{PN}	t_r	µs			3.5	$di/dt = I_{PN}/\mu s$
Frequency bandwidth (-3 dB)	BW	kHz		250		
Output voltage noise (spectral density) (DC .. 100 MHz)	e_{no}	µVrms/√Hz			10.5	
Output voltage noise (DC .. 20 MHz)	V_{no}	mVpp		30		
Over-current detect		V	2.6 × I_{PN}	2.9 × I_{PN}	3.2 × I_{PN}	peak value
Accuracy @ I_{PN}	X	% of I_{PN}			±1.35	$\varepsilon_G + \varepsilon_L$
Accuracy @ I_{PN} @ T_A = +85 °C	X	% of I_{PN}			±3.42	See formula note [1]
Accuracy @ I_{PN} @ T_A = +105 °C	X	% of I_{PN}			±4.1	See formula note [1]

Note: [1] Accuracy @ I_P and $X_{TA} = \pm\ [X + (TCG/10000) \cdot (T_A - 25) + TCV_{OE} \cdot 100 \cdot (T_A - 25) / (G_{th} \cdot I_P)]$.

Definition of typical, minimum and maximum values

Minimum and maximum values for specified limiting and safety conditions have to be understood as such as well as values shown in “typical” graphs. On the other hand, measured values are part of a statistical distribution that can be specified by an interval with upper and lower limits and a probability for measured values to lie within this interval.

Unless otherwise stated (e.g. “100 % tested”), the LEM definition for such intervals designated with “min” and “max” is that the probability for values of samples to lie in this interval is 99.73 %. For a normal (Gaussian) distribution, this corresponds to an interval between -3 sigma and +3 sigma. If “typical” values are not obviously mean or average values, those values are defined to delimit intervals with a probability of 68.27 %, corresponding to an interval between -sigma and +sigma for a normal distribution.
Typical, maximal and minimal values are determined during the initial characterization of a product.

Maximum continuous DC primary current

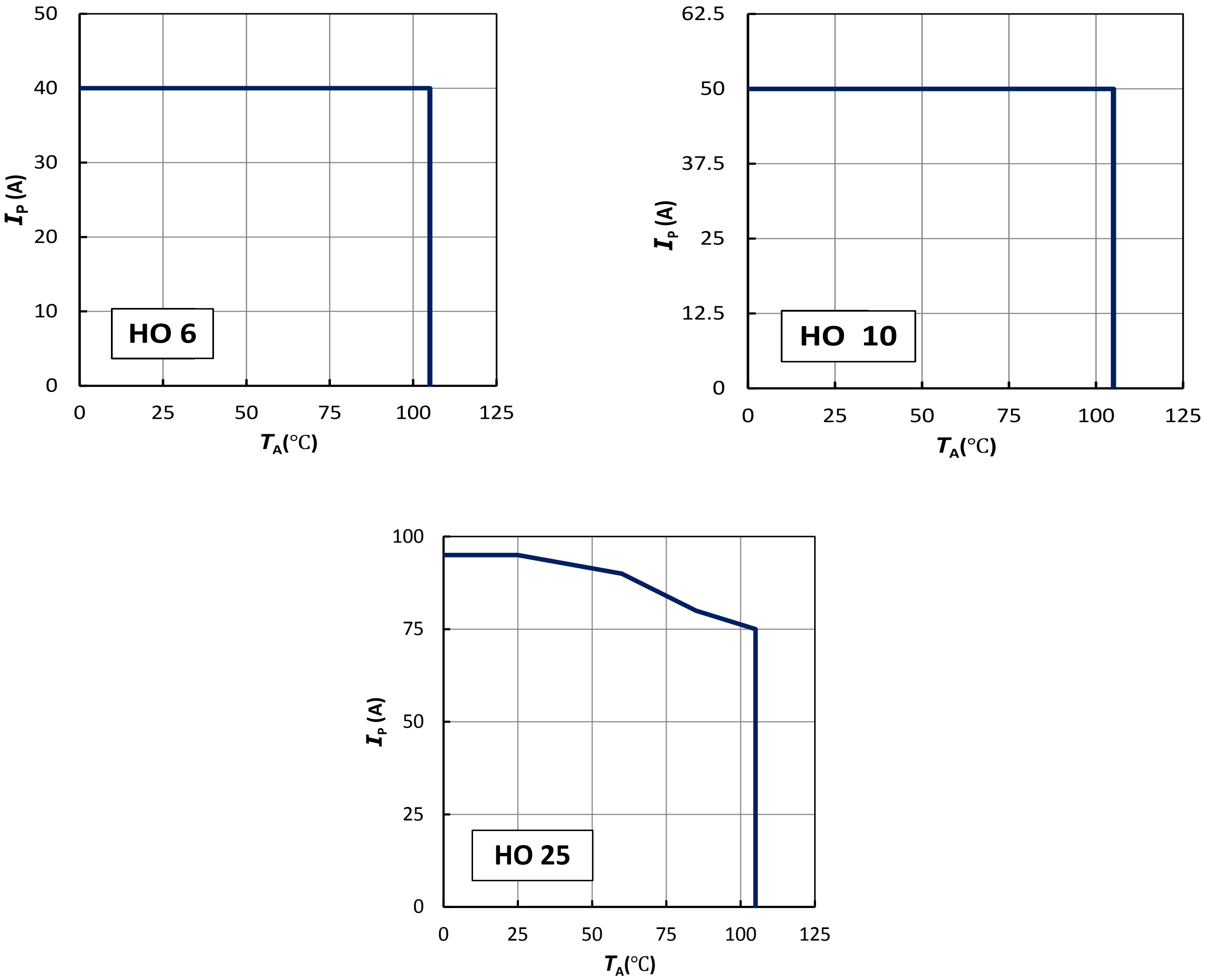
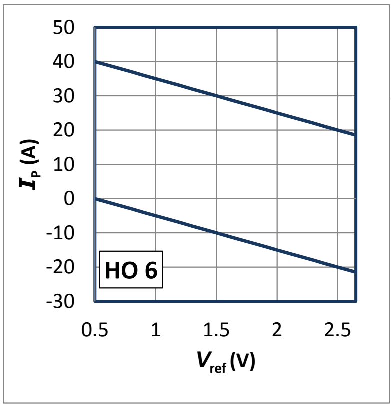


Figure 1: I_P vs T_A for HO series

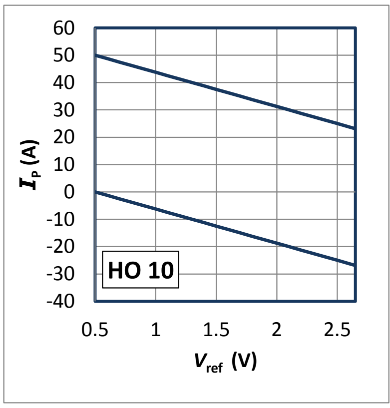
Important notice: whatever the usage and/or application, the primary conductor temperature shall not go above the maximum rating of 125 °C as stated in page 2 of this datasheet.

Measuring range with external reference voltage



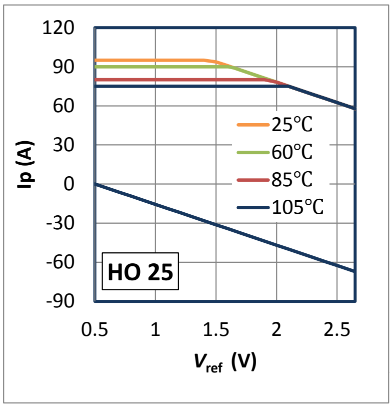
Upper limit: $I_P = -10 \times V_{ref} + 45$ (V_{ref} = 0.5 .. 2.65 V)

Lower limit: $I_P = -10 \times V_{ref} + 5$ (V_{ref} = 0.5 .. 2.65 V)



Upper limit: $I_P = -12.5 \times V_{ref} + 56.25$ (V_{ref} = 0.5 .. 2.65 V)

Lower limit: $I_P = -12.5 \times V_{ref} + 6.25$ (V_{ref} = 0.5 .. 2.65 V)



Upper limit:

T_A = 105 °C: $I_P = 75$ (V_{ref} = 0.5 ..2.1 V)
$I_P = 31.25 \times V_{ref} + 140.63$ (V_{ref} = 2.1 .. 2.65 V)

T_A = 85 °C: $I_P = 80$ (V_{ref} = 0.5 ..1.94 V)
$I_P = 31.25 \times V_{ref} + 140.63$ (V_{ref} = 1.94 .. 2.65 V)

T_A = 60 °C: $I_P = 90$ (V_{ref} = 0.5 ..1.62 V)
$I_P = 31.25 \times V_{ref} + 140.63$ (V_{ref} = 1.62 .. 2.65 V)

T_A = 25 °C: $I_P = 95$ (V_{ref} = 0.5 ..1.46 V)
$I_P = 31.25 \times V_{ref} + 140.63$ (V_{ref} = 1.46 .. 2.65 V)

Lower limit: $I_P = -31.25 \times V_{ref} + 15.63$ (V_{ref} = 0.5 .. 2.65 V)

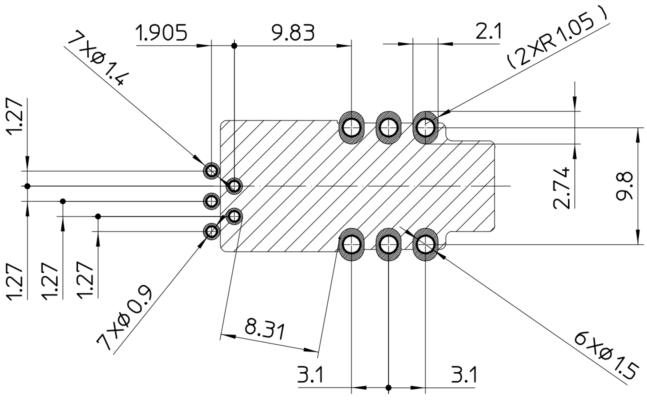
Example with V_{ref} *= 0.5 V:*

- The 6 A version has a measuring range from 0 A to 40 A
- The 10 A version has a measuring range from 0 A to 50 A
- The 25 A version has a measuring range from 0 A to 75 A at T_A = 105 °C

Example with V_{ref} *= 1.5 V:*

- The 6 A version has a measuring range from -10 A to 30 A
- The 10 A version has a measuring range from -18.7 A to + 56.3 A
- The 25 A version has a measuring range from -31.2 A to + 80 A at T_A = 85 °C

PCB Footprint



Assembly on PCB

• Recommended PCB hole diameter	1.5 mm for retention pin 0.9 mm for secondary pin
• Maximum PCB thickness	2.4 mm
• Wave soldering profile No clean process only	maximum 260 °C, 10 s

Safety

This transducer must be used in limited-energy secondary circuits according to IEC 61010-1.

This transducer must be used in electric/electronic equipment with respect to applicable standards and safety requirements in accordance with the manufacturer’s operating instructions.

Caution, risk of electrical shock.
When operating the transducer, certain parts of the module can carry hazardous voltage (e.g. primary bus bar, power supply).
Ignoring this warning can lead to injury and/or cause serious damage.
This transducer is a build-in device, whose conducting parts must be inaccessible after installation.
A protective housing or additional shield could be used.
Main supply must be able to be disconnected.

Performance parameters definition

Ampere-turns and amperes

The transducer is sensitive to the primary current linkage Θ_P (also called ampere-turns).

$\Theta_P = N_P \cdot I_P$ (At)
Where N_P is the number of primary turn (depending on the connection of the primary jumpers)

Caution: As most applications will use the transducer with only one single primary turn ($N_P = 1$), much of this datasheet is written in terms of primary current instead of current linkages. However, the ampere-turns (At) unit is used to emphasis that current linkages are intended and applicable.

Transducer simplified model

The static model of the transducer at temperature T_A is:
$V_{out} = G \cdot \Theta_P$ + overall error (mV)
In which error =
$\varepsilon_G \cdot \Theta_P \cdot G + \varepsilon_L \cdot \cdot \Theta_P \cdot G + TCG \cdot (T_A - 25) \cdot \Theta_P \cdot G + V_{OE} + TCV_{OE} \cdot (T_A - 25)$ (mV)

With:

$\Theta_P = N_P \cdot I_P$	: primary current linkage (At)
$\Theta_{P\ max}$	: max primary current linkage applied to the transducer (A/t)
V_{out}	: output voltage (V)
T_A	: ambient operating temperature (°C)
V_{OE}	: electrical offset voltage (V)
TCV_{OE}	: temperature coefficient of V_{OE} (mV/K)
G	: sensitivity of the transducer (V/At)
TCG	: temperature coefficient of G *(%/K)*
ε_G	: sensitivity error (%)
ε_L	: linearity error for Θ_P (%)

This model is valid for primary ampere-turns Θ_P between $-\Theta_{P\ max}$ and $+\Theta_{P\ max}$ only.

Sensitivity and linearity

To measure sensitivity and linearity, the primary current (DC) is cycled from 0 to I_P, then to $-I_P$ and back to 0 (equally spaced I_P/10 steps). The sensitivity G is defined as the slope of the linear regression line for a cycle between ± I_{PN}.
The linearity error ε_L is the maximum positive or negative difference between the measured points and the linear regression line, expressed in % of I_{PN}.

Magnetic offset

The magnetic offset voltage V_{OM} is the consequence of a current on the primary side ("memory effect" of the transducer's ferro-magnetic parts). It is measured using the following primary current cycle. V_{OM} depends on the current value I_{P1} ($I_{P1} > I_{PM}$).

$$V_{OM} = \frac{V_{out}(t_1) - V_{out}(t_2)}{2}$$

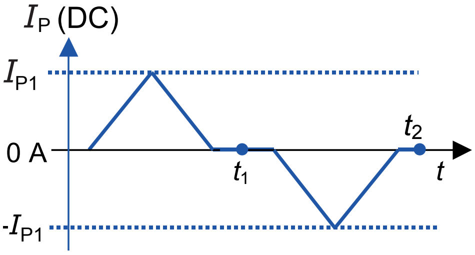


Figure 2: Current cycle used to measure magnetic and electrical offset (transducer supplied)

Electrical offset

The electrical offset V_{OE} can either be measured when the ferro-magnetic parts of the transducer are:

- completely demagnetized, which is difficult to realize,
- or in a known magnetization state, like in the current cycle shown in figure 2.

$$V_{OE} = \frac{V_{out}(t_1) + V_{out}(t_2)}{2}$$

Using the current cycle shown in figure 18, the electrical offset is:
Note: the transducer has to be demagnetized prior to the application of the current cycle (for example with a demagnetization tunnel).

Overall accuracy

The overall accuracy at 25 °C X_G is the error in the $-I_{PN}$ .. $+I_{PN}$ range, relative to the rated value I_{PN}.
It includes:

- the electrical offset V_{OE}
- the sensitivity error ε_G
- the linearity error ε_L (to I_{PN}) (%)

Response and reaction times

The response time t_r and the reaction time t_{ra} are shown in figure 18.
Both depend on the primary current d*i*/d*t*. They are measured at nominal ampere-turns.

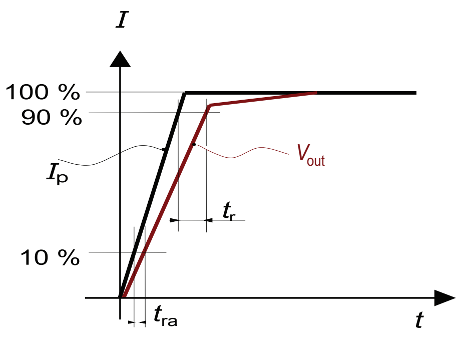
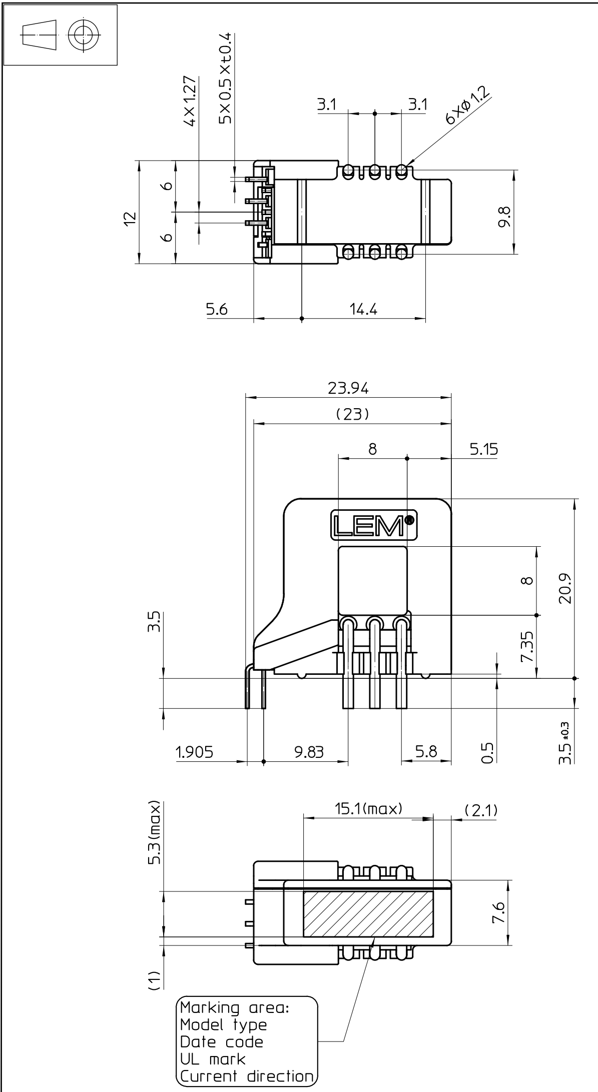
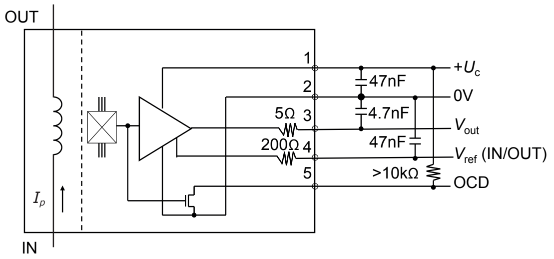


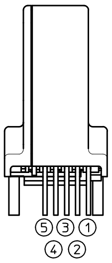
Figure 3: Response time t_r and reaction time t_{ra}

Dimensions HO 6-P, HO 10-P, HO 25-P (mm, general linear tolerance ±0.5 mm)



Operation principle





① : $+U_c$
② : 0V
③ : V_{out}
④ : V_{ref} (IN/OUT)
⑤ : OCD

	d_{Cl} (mm)	d_{Cp} (mm)
note1)	8.0	8.0

1) Minimum distance from the primary to the core

Remarks

·There are 6 retention pins which have to be used only for retention as well as into the section called "Assembly on PCB".
·The pimary conductor to be measured should go through the aperture 8 × 8 mm.

EL7242, EL7252

Data Sheet November 14, 2005 FN7285.2

Dual Input, High Speed, Dual Channel Power MOSFET Driver

The EL7242/EL7252 dual input, 2-channel drivers achieve the same excellent switching performance of the EL7212 family while providing added flexibility. The 2-input logic and configuration is applicable to numerous power MOSFET drive circuits. As with other Elantec drivers, the EL7242/EL7252 are excellent for driving large capacitive loads with minimal delay and switching times. “Shoot-thru” protection and latching circuits can be implemented by simply “cross-coupling” the 2-channels.

Ordering Information

PART NUMBER	PART MARKING	TAPE & REEL	PACKAGE	PKG. DWG. #
EL7242CN	EL7242CN	-	8-Pin PDIP	MDP0031
EL7242CNZ (See Note)	EL7242CNZ	-	8-Pin PDIP* (Pb-free)	MDP0031
EL7242CS	7242CS	-	8-Pin SOIC	MDP0027
EL7242CS-T7	7242CS	7”	8-Pin SOIC	MDP0027
EL7242CS-T13	7242CS	13”	8-Pin SOIC	MDP0027
EL7242CSZ (See Note)	7242CSZ	-	8-Pin SOIC (Pb-free)	MDP0027
EL7242CSZ-T7 (See Note)	7242CSZ	7”	8-Pin SOIC (Pb-free)	MDP0027
EL7242CSZ-T13 (See Note)	7242CSZ	13”	8-Pin SOIC (Pb-free)	MDP0027
EL7252CN	EL7252CN	-	8-Pin PDIP	MDP0031
EL7252CS	7252CS	-	8-Pin SOIC	MDP0027
EL7252CS-T7	7252CS	7”	8-Pin SOIC	MDP0027
EL7252CS-T13	7252CS	13”	8-Pin SOIC	MDP0027
EL7252CSZ (See Note)	7252CSZ	-	8-Pin SOIC (Pb-free)	MDP0027
EL7252CSZ-T7 (See Note)	7252CSZ	7”	8-Pin SOIC (Pb-free)	MDP0027
EL7252CSZ-T13 (See Note)	7252CSZ	13”	8-Pin SOIC (Pb-free)	MDP0027

*Pb-free PDIPs can be used for through hole wave solder processing only. They are not intended for use in Reflow solder processing applications.

NOTE: Intersil Pb-free plus anneal products employ special Pb-free material sets; molding compounds/die attach materials and 100% matte tin plate termination finish, which are RoHS compliant and compatible with both SnPb and Pb-free soldering operations. Intersil Pb-free products are MSL classified at Pb-free peak reflow temperatures that meet or exceed the Pb-free requirements of IPC/JEDEC J STD-020.

Features

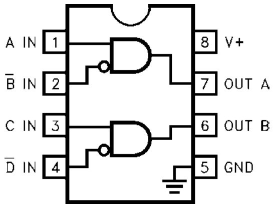
- Logic AND/NAND input
- 3V and 5V Input compatible
- Clocking speeds up to 10MHz
- 20ns Switching/delay time
- 2A Peak drive
- Isolated drains
- Low output impedance
- Low quiescent current
- Wide operating voltage — 4.5V to 16V
- Pb-free plus anneal available (RoHS compliant)

Applications

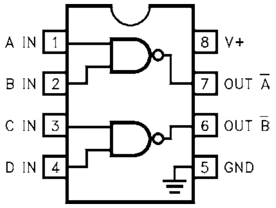
- Short circuit protected switching
- Under-voltage shut-down circuits
- Switch-mode power supplies
- Motor controls
- Power MOSFET switching
- Switching capacitive loads
- Shoot-thru protection
- Latching drivers

Pinouts

EL7242
(8-PIN PDIP, SOIC)
TOP VIEW



EL7252
(8-PIN PDIP, SOIC)
TOP VIEW



Manufactured under U.S. Patent Nos. 5,334,883, #5,341,047

Absolute Maximum Ratings (T_A = 25°C)

Supply (V+ to Gnd) 16.5V
Input Pins. . . . . -0.3V to +0.3V above V+
Combined Peak Output Current. 4A
Storage Temperature Range . . . .-65°C to +150°C

Ambient Operating Temperature . . . . -40°C to +85°C
Operating Junction Temperature . . . . 125°C
Power Dissipation
SOIC 570mW
PDIP* 1050mW

*Pb-free PDIPs can be used for through hole wave solder processing only. They are not intended for use in Reflow solder processing applications.

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

IMPORTANT NOTE: All parameters having Min/Max specifications are guaranteed. Typical values are for information purposes only. Unless otherwise noted, all tests are at the specified temperature and are pulsed tests, therefore: $T_J = T_C = T_A$

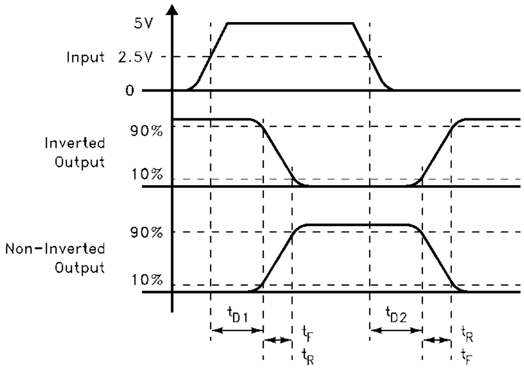
DC Electrical Specifications T_A = 25°C, V = 15V unless otherwise specified

PARAMETER	DESCRIPTION	TEST CONDITIONS	MIN	TYP	MAX	UNITS
INPUT						
V_{IH}	Logic "1' Input Voltage		2.4			V
I_{IH}	Logic "1' Input Current	@V+		0.1	10	µA
V_{IL}	Logic "0' Input Voltage				0.8	V
I_{IL}	Logic "0' Input Current	@0V		0.1	10	µA
V_{HVS}	Input Hysteresis			0.3		V
OUTPUT						
R_{OH}	Pull-Up Resistance	I_{OUT} = -100mA		3	6	Ω
R_{OL}	Pull-Down Resistance	I_{OUT} = +100mA		4	6	Ω
I_{PK}	Peak Output Current	Source Sink		2 2		A
I_{DC}	Continuous Output Current	Source/Sink	100			mA
POWER SUPPLY						
I_S	Power Supply Current	Inputs High		1	2.5	mA
V_S	Operating Voltage		4.5		16	V

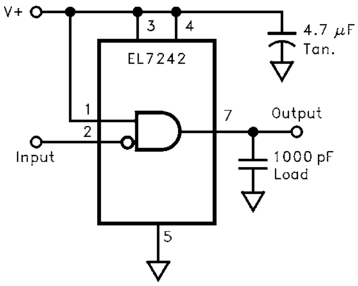
AC Electrical Specifications T_A = 25°C, V = 15V unless otherwise specified

PARAMETER	DESCRIPTION	TEST CONDITIONS	MIN	TYP	MAX	UNITS
SWITCHING CHARACTERISTICS						
t_R	Rise Time	C_L = 500pF C_L = 1000pF			10 20	ns
t_F	Fall Time	C_L = 500pF C_L = 1000pF			10 20	ns
t_{D-ON}	Turn-On Delay Time			20	25	ns
t_{D-OFF}	Turn-Off Delay Time			20	25	ns

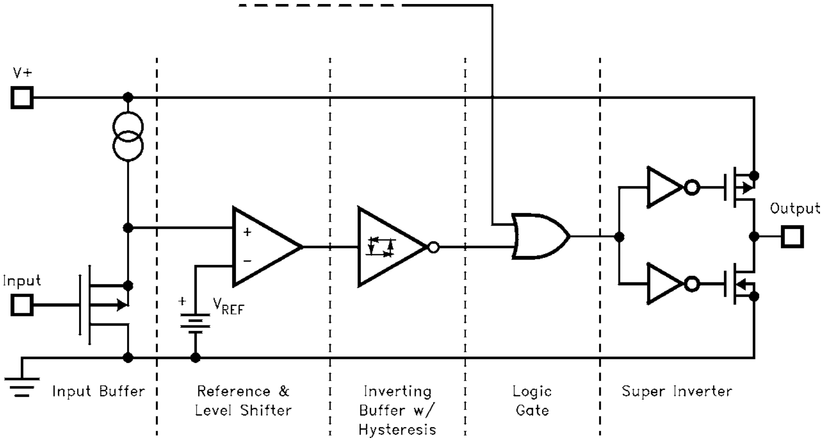
Timing Table



Standard Test Configuration

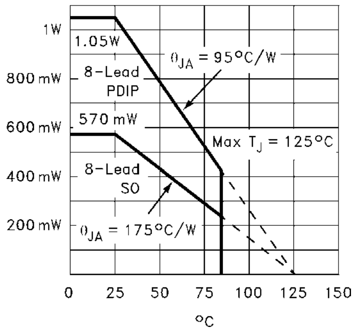


Simplified Schematic

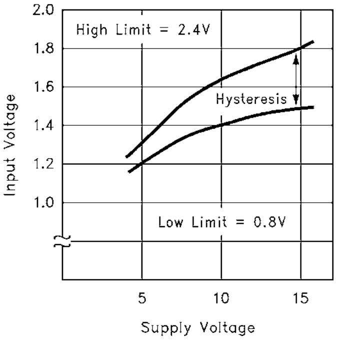


Typical Performance Curves

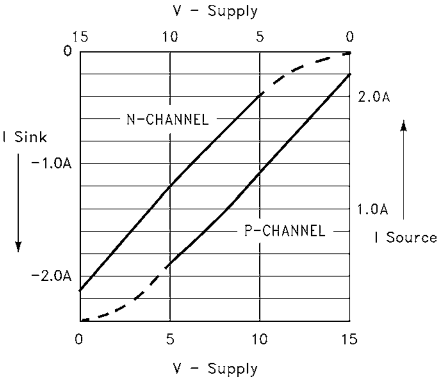
Max Power/Derating Curves



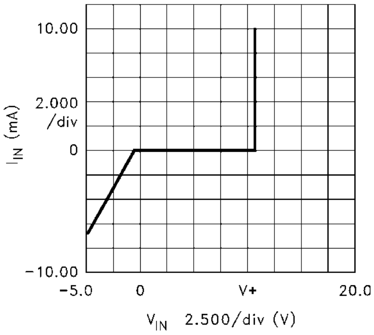
Switch Threshold vs Supply Voltage



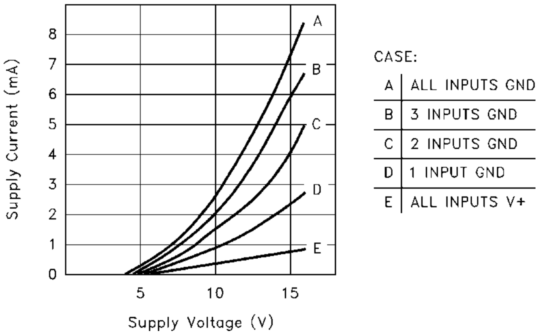
Peak Drive vs Supply Voltage



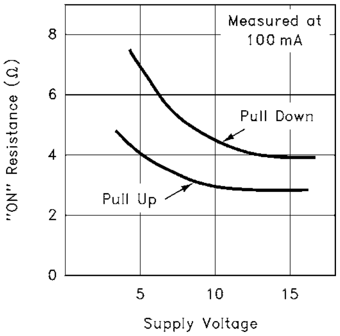
Input Current vs Voltage



Quiescent Supply Current

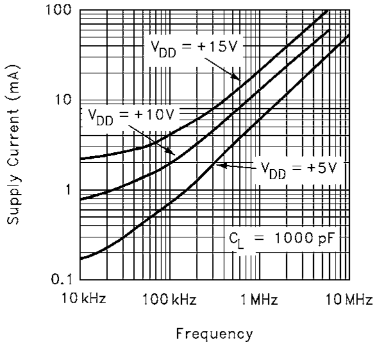


“ON' Resistance vs Supply Voltage

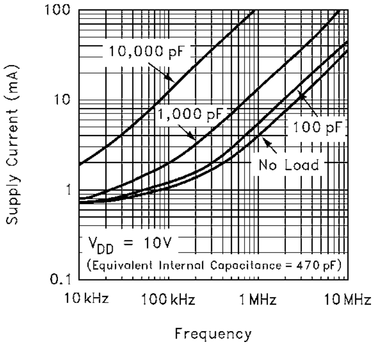


Typical Performance Curves (Continued)

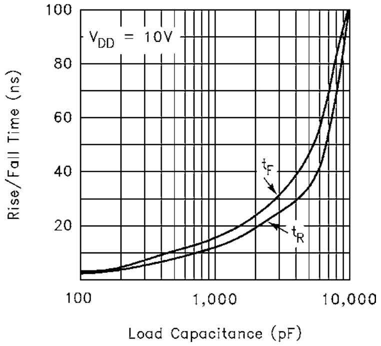
Average Supply Current vs Voltage and Frequency



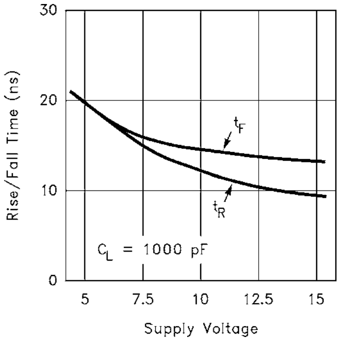
Average Supply Current vs Capacitive Load



Rise/Fall Time vs Load

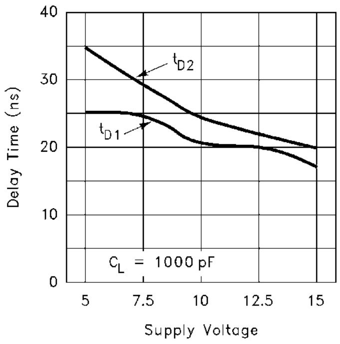


Rise/Fall Time vs Supply Voltage

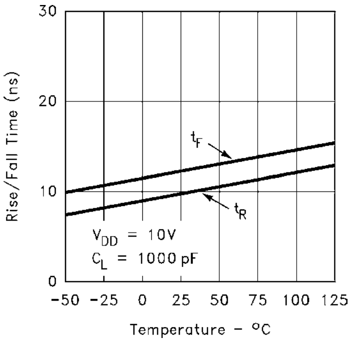


Typical Performance Curves (Continued)

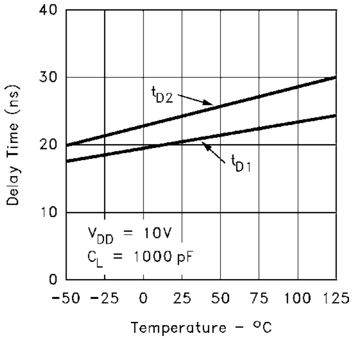
Rise/Fall Time vs Temperature



Propagation Delay vs Supply Voltage



Delay vs Temperature



AYA Series

3 Watts

Data Sheet

Total Power: 3 W
Input Voltage: 5, 12, 24, 48 V
# of Outputs: Single and Dual

SPECIAL FEATURES

- Ultra compact DIP package (14 x 14 x 8.0 mm; 0.55 x 0.55 x 0.31 inches)
- Efficiency up to 87%
- I/O-isolation 1500 VDC
- Wide 2:1 input range
- Operating temperature range -40 °C to +85 °C (with derating)
- Three year product warranty
- UL/cUL/IEC/EN 60950-1 Safety Approval, CE Mark

SAFETY

- cUL/UL 60950-1 recognition
- CE Mark

Electrical Specifications

Input	
Input range	4.5 - 10 Vdc; 9 - 18 Vdc; 18 - 36 Vdc; 36 - 75 Vdc
Efficiency	87% @ 12 Vo
Output	
Voltage tolerance	±1.5%
Line regulation	±0.2%
Load regulation	1.0%
Noise/ripple	70 mV
Overload protection	170% typ of Io max, foldback
Short circuit protection	Continuous, automatic recovery
Switching frequency	100 kHz
Isolation	
I/O isolation	I/O: 1500 Vdc
Insulation resistance	1000 Mohm
Insulation capacitance	100 pF

Environmental Specifications

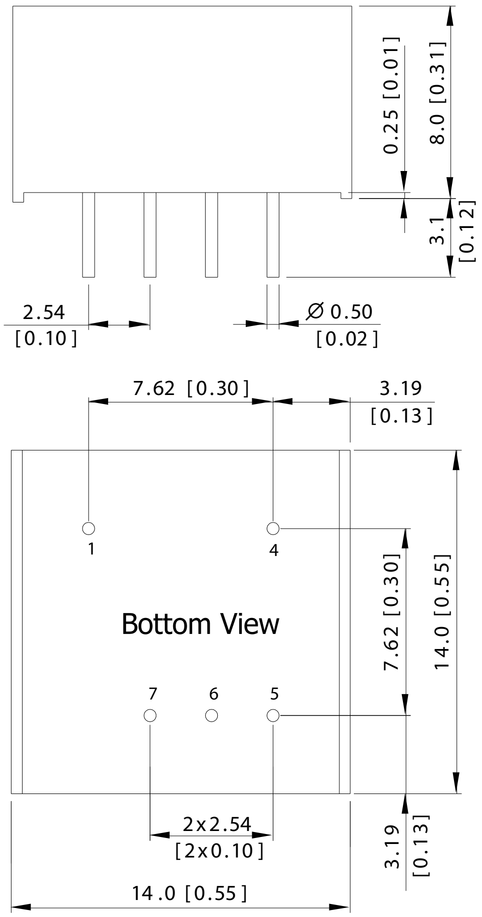
Operating ambient temperature range	-40 °C to +85 °C
Storage temperature	-50 °C to +125 °C
Humidity	5% to 95% non-condensing
MTBF	3.5 Mhrs calculated

ARTESYN™
EMBEDDED TECHNOLOGIES

Ordering Information

Part Number	Input Voltage	Output Voltage	Output Current	Efficiency	Power
AYA01F05-L	4.5 - 10 Vdc	3.3 V	0.6 A	79%	2 W
AYA01A05-L	4.5 - 10 Vdc	5 V	0.6 A	81%	3 W
AYA01B05-L	4.5 - 10 Vdc	12 V	0.25 A	85%	3 W
AYA01C05-L	4.5 - 10 Vdc	15 V	0.2 A	85%	3 W
AYA01AA05-L	4.5 - 10 Vdc	±5 V	±0.3 A	82%	3 W
AYA01BB05-L	4.5 - 10 Vdc	±12 V	±0.125 A	84%	3 W
AYA01CC05-L	4.5 - 10 Vdc	±15 V	±0.1 A	85%	3 W
AYA01F12-L	9 - 18 Vdc	3.3 V	0.6 A	80%	2 W
AYA01A12-L	9 - 18 Vdc	5 V	0.6 A	83%	3 W
AYA01B12-L	9 - 18 Vdc	12 V	0.25 A	87%	3 W
AYA01C12-L	9 - 18 Vdc	15 V	0.2 A	87%	3 W
AYA01AA12-L	9 - 18 Vdc	±5 V	±0.3 A	84%	3 W
AYA01BB12-L	9 - 18 Vdc	±12 V	±0.125 A	86%	3 W
AYA01CC12-L	9 - 18 Vdc	±15 V	±0.1 A	87%	3 W
AYA01F24-L	18 - 36 Vdc	3.3 V	0.6 A	80%	2 W
AYA01A24-L	18 - 36 Vdc	5 V	0.6 A	83%	3 W
AYA01B24-L	18 - 36 Vdc	12 V	0.25 A	87%	3 W
AYA01C24-L	18 - 36 Vdc	15 V	0.2 A	87%	3 W
AYA01AA24-L	18 - 36 Vdc	±5 V	±0.3 A	84%	3 W
AYA01BB24-L	18 - 36 Vdc	±12 V	±0.125 A	86%	3 W
AYA01CC24-L	18 - 36 Vdc	±15 V	±0.1 A	87%	3 W
AYA01F48-L	36 - 75 Vdc	3.3 V	0.6 A	79%	2 W
AYA01A48-L	36 - 75 Vdc	5 V	0.6 A	82%	3 W
AYA01B48-L	36 - 75 Vdc	12 V	0.25 A	86%	3 W
AYA01C48-L	36 - 75 Vdc	15 V	0.2 A	86%	3 W
AYA01AA48-L	36 - 75 Vdc	±5 V	±0.3 A	82%	3 W
AYA01BB48-L	36 - 75 Vdc	±12 V	±0.125 A	85%	3 W
AYA01CC48-L	36 - 75 Vdc	±15 V	±0.1 A	85%	3 W

Mechanical Dimensions



Pin Connections

Pin	Single Output	Dual Output
1	-Vin	-Vin
4	+Vin	+Vin
5	+Vout	+Vout
6	No pin	Common
7	-Vout	-Vout

- All dimensions in mm (inches)
- Tolerance: X.X±0.5 (X.XX±0.02)
  X.XX±0.25 (X.XXX±0.01)
- Pin diameter Ø 0.5 ±0.05 (0.02±0.002)

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EMBEDDED TECHNOLOGIES

www.artesyn.com

For more information: www.artesyn.com/power
For support: productsupport.ep@artesyn.com

Datasheet

ENGLISH

12V Solar Panels

BENEFITS

Reliable and Robust Design

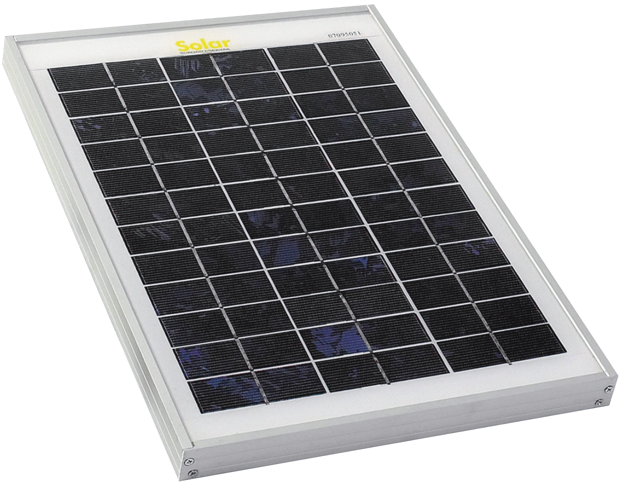
Proven materials, tempered front glass, and a sturdy anodized frame allow panels to operate reliably in multiple mounting configurations.

Classic Design

Combines high efficiency and attractive crystalline cells give an elegant appearance.

More Power

Using industry leading 17.0% efficiency solar cells delivers incredible performance.



(10WP Panel shown)

MONO & POLY-CRYSTALLINE (12 VOLT) SILICONE SOLAR CELL MODULES

5WP – 150WP

Features

- Modules are designed in accordance with IEC61215:1993 standards, manufactured with proven materials and tested to ensure electrical performance and service life.
- SiN film deposited on the front surface by PECVD acts as anti- reflection coating and gives a uniform dark blue appearance.
- Cells are laminated between highly transparent low-iron 3mm tempered glass, TPT and two layers of EVA to prevent moisture penetrating the module.
- Heavy duty anodized aluminium frame provides high wind resistance and convenient mounting access.
- Waterproof junction box and terminals allows for quick and simple connection.
- Modules will either be supplied with no cable, cable supplied but not connected to the junction box or fully fitted – depending on the option selected. Supplied cables guarantee excellent power transmission throughout the year.
- There is no current requirement for the STI Solar Modules to comply with ROHS.
- 20 year power output transferable warranty

RS PRO

ENGLISH

PV MODULES MADE WITH IEC 61215 CERTIFICATION

Model	Output Wp	Size mm	Weight Kgm	Pmax W	Vmp V	Imp A	Voc V	Isc A
9046128	**5**	306 x 218 x 25	1.0	5	16.8	0.3	21	0.39
9046121	**10**	397 x 280 x 25	1.5	10	16.8	0.59	21	0.66
9046125	**20**	638 x 278 x 25	2.2	20	17.5	1.15	22	1.27
9046134	**30**	660 x 380 x 25	2.8	30	17.5	1.72	22	1.90
9046137	**45**	634 x 535 x 25	4.5	45	17.5	2.58	22	2.86
9046131	**60**	685 x 670 x 35	6.0	60	17.2	3.49	21.6	3.97
9046140	**80**	815 x 670 x 35	7.8	80	17.2	4.65	21.6	5.00
9046143	**100**	1055 x 670 x 35	8.0	100	19.55	5.12	23.15	5.45
9046147	**120**	1250 x 670 x 35	12.0	120	17.2	6.98	21.6	7.93
9046156	**150**	1490 x 670 x 35	15.2	150	17.2	8.72	21.6	9.72

ABSOLUTE MAXIMUM LIMITS

PARAMETERS	RATING	UNIT
Operating temperature	–40 to +85	°C
Storage temperature	–40 to +85	°C
Dielectric voltage withstood	3000max	V-DC
NOCT	48	°C

TEMPERATURE COEFFICIENTS

Current temperature coefficient	dIsc/dT	+0.003A/K
Voltage temperature coefficient	dVoc/dT	– 0.13V/K
Power temperature coefficient	dPm/dT	– 0.675W/K

CERTIFICATIONS

ISO9001 (2008)	1014QMO5
TUV / IEC61215	PV60040905
IEC61710 (Salt Mist Corrosion Test)	4786191107-NABL-S1
CE	G4M20301-0199-E-16

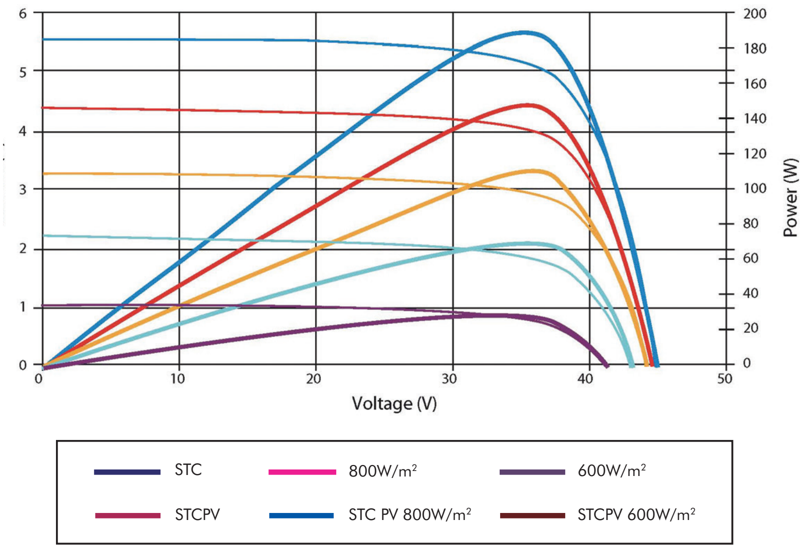
MATERIALS

Frame	Aluminium 6063 T5
Front Cover	High-transmission Glass

WARRANTY

All RS Components solar modules are supplied with a 20 year limited peak power warranty. The warranty claim will deemed to be valid if within 20 years any solar module exhibits power output at less than 80% of minimum 'Peak Power Standard Test Conditions' as noted on the data plate of each module and/or any fault is determined to be the cause of defects in materials and workmanship but not where interference with the module/s by an unauthorised person (of RS Components) has caused the fault or defect. The warranty includes any call outs, labour and other expenses associated with the repair or replacement of the defective part module. RS Components may, at its discretion offer one of the following remedies in the event of a successful claim against the module performance warranty: 1) to replace the defective module/s 2) refund the percentage of the cost of the module to the customer representing the percentage of the power output less than 80% of the minimum. RS Components endeavours to but is not bound by its commitment to rectify any fault within 7 days of notification.

IV CURVE



ALL FIGURES TAKEN UNDER THE FOLLOWING STANDARD TEST CONDITIONS:
IRRADIANCE 1000W/M², MODULE TEMPERATURE 25°C, AM=1.5

(All technical data subject to changes without prior notice)

RS, Professionally Approved Products, gives you professional quality parts across all products categories. Our range has been testified by engineers as giving comparable quality to that of the leading brands without paying a premium price.

Spec. No.	INR18650-30Q	Version No.	1.0	Wanmook, Lim

SPECIFICATION OF PRODUCT

Lithium-ion rechargeable cell for power tools

Model name : INR18650-30Q

Feb, 2015

Samsung SDI Co., Ltd.

Energy Business Division

Revision history

Revision No.	Date(‘yr-m-d)	Page	Item	Description	Changes / Author
v1.0	‘15-02-02			First Edition	Wan-Mook Lim

1.0. Scope

This product specification has been prepared to specify the rechargeable lithium-ion cell ('cell') to be supplied to the customer by Samsung SDI Co., Ltd.

2.0. Description and model

2.1 Description	lithium-ion rechargeable cell
2.2 Model name	INR18650-30Q

3.0. Nominal specifications

Item	**Specification**
3.1 Minimum discharge capacity	2,950mAh Charge: 1.50A, 4.20V,CCCV 150mA cut-off, Discharge: 0.2C, 2.5V discharge cut-off
3.2 Nominal voltage	3.6V
3.3 Standard charge	CCCV, 1.50A, 4.20 ± 0.05 V, 150mA cut-off
3.4 Rated charge	CCCV, 4A, 4.20 ± 0.05 V, 100mA cut-off
3.6 Charging time	Standard charge : 180min / 150mA cut-off Rated charge: 70min (at 25℃) / 100mA cut-off
3.7 Max. continuous discharge (Continuous)	15A(at 25℃), 60% at 250 cycle
3.8 Discharge cut-off voltage End of discharge	2.5V
3.9 Cell weight	48.0g max
3.10 Cell dimension	Height : Max 65.0mm Diameter : Max 18.4mm
3.11 Operating temperature (surface temperature)	Charge : 0 to 50℃ (recommended recharge release < 45℃) Discharge: -20 to 75℃ (recommended re-discharge release < 60℃)
3.12 Storage temperature (Recovery 90% after storage)	1.5 year -30~25℃(1*) 3 months -30~45℃(1*) 1 month -30~60℃(1*)

Note (1): If the cell is kept as ex-factory status (40±5% SOC, 25℃),
the capacity recovery rate is more than 90% of 10A discharge capacity
100% is 2,900mAh at 23℃ with SOC 100% after formation.

4.0 Outline dimensions

See the attachment (Fig. 1)

5.0. Appearance

There shall be no such defects as scratch, rust, discoloration, leakage which may adversely affect commercial value of the cell.

6.0. Standard test conditions

6.1 Environmental conditions

Unless otherwise specified, all tests stated in this specification are conducted at temperature 23±3°and humidity under 65%.

6.2 Measuring equipment

(1) Amp-meter and volt-meter

The amp-meter and volt-meter should have an accuracy of the grade 0.5mA and mV or higher.

(2) Slide caliper

The slide caliper should have 0.01 mm scale.

(3) Impedance meter

The impedance meter with AC 1kHz should be used.

7.0. Characteristics

7.1 Standard charge

This "Standard charge" means charging the cell CCCV with charge current 0.5CmA (1,500mA), constant voltage 4.2V and 150mA cut-off in CV mode at 23℃ for capacity.

.

7.2 Rated charge

Rated charge means charging the cell CCCV with charge current 4A and 100mA cut-off at 23℃

7.3 Standard discharge capacity

The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 600mA(0.2C) with 2.5V cut-off at 23℃ within 1hour after the standard charge.

Nominal discharge capacity ≥ 2,950mAh

Which complying to the minimum capacity of IEC61960 standard.

7.4 Rated discharge capacity

The rated discharge is the discharge capacity of the cell, which is measured with discharge current of 10A with 2.5V cut-off at 23℃ within 1hour after the rated charge.

Standard rated discharge capacity ≥ 2,900mAh

7.5 Initial internal impedance

Initial internal impedance measured at AC 1kHz after standard charge

Initial internal impedance ≤ 26mΩ

7.6 Temperature dependence of discharge capacity

Capacity comparison at each temperature, measured with discharge constant current 10A and 2.5V cut-off after the rated charge is as follows.

Discharge temperature				
-20℃	-10℃	0℃	23℃	60℃
60%	75%	80%	100%	95%

Note: If charge temperature and discharge temperature is not the same, the interval for temperature change is 3 hours.

Percentage index of the discharge at 23℃ at 10A (=2,900mAh) is 100%.

7.7 Temperature dependence of charge capacity

Capacity comparison at each temperature, measured with discharge constant current 10A and 2.5V cut-off after the rated charge is as follows.

	Charge temperature					Discharge temperature
	0℃	5℃	23℃	45℃	50℃	23℃
Relative capacity	80%	90%	100%	95%	95%	

Note: If charge temperature and discharge temperature is not the same, the interval for temperature change is 3 hours.

Percentage index of the discharge at 23℃ at 10A (=2,900mAh) is 100%.

7.8 Charge rate capabilities

Discharge capacity is measured with constant current 10A and 2.5V cut-off after the cell is charged with 4.2V as follows.

	Charge condition	
Current	Standard 1.5A	Maximum rapid charge 4A
Cut-off	150mA	100mA
Relative Capacity	100%	100%

Note: Percentage index of the discharge at 23℃ at 10A (=2,900mAh) is 100%.

7.9 Discharge rate capabilities

Discharge capacity is measured with the various currents in under table and 2.5V cut-off after the rated charge.

	Discharge condition				
Current	0.6A	5A	10A	15A	20A
Relative Capacity	100%	97%	100%	97%	95%

Percentage index of the discharge at 25℃ at 10A (=2,900mAh) is 100%.

7.10 Cycle life

With standard charge and maximum continuous discharge.

Capacity after 250cycles,

Capacity ≥ 1,800mAh (60% of the nominal capacity at 23℃)

7.11 Storage characteristics

Standard rated discharge capacity after storage for 1 month at 60℃ from the standard charged state is ≥ 90% of the initial 10A discharge capacity at 23℃

7.12 Status of the cell as of ex-factory

The cell should be shipped in 3.620V to 3.690V charging voltage range.

8.0. Mechanical Characteristics

8.1 Drop test

Test method: Each fully charged cell or battery is dropped three times from a height of 1.0 m onto a concrete floor. The cells or batteries are dropped so as to obtain impacts in random orientations. After the test, the sample shall be put on rest for a minimum of one hour and then a visual inspection shall be performed.

Criteria: No fire, no explosion.

Drop test shall be performed with the IEC62133 standard

8.2 Vibration test

Test method: As to the UN transportation regulation(UN38.3), for each axis (X and Y axis with cylindrical cells) 7Hz→200Hz→7Hz for 15min, repetition 12 times totally 3hours, the acceleration 1g during 7 to 18Hz and 8g (amplitude 1.6mm) up to 200Hz.

Criteria: No leakage, with less than 10% of OCV drop

Vibration test shall be performed with the UN38.3 standard

9.0. Safety

9.1 Overcharge test

Test method: Cell is to be discharged at a constant current of 0.6A to 2.5V. The cell is then to be charged with a 20V and 20A. Charging duration is to be 7 h.

Criteria: No fire, and no explosion.

Overcharge test shall be performed with the UL1642 standard

9.2 External short-circuit test

Test method: Fully rated charged cell is to be short-circuited by connecting the positive and negative terminals of the battery with a circuit load having a resistance load of 80 ±20 mΩ. The battery is to discharge until a fire or explosion is obtained, or until it has reached a completely discharged state of less than 0.2 V and the battery case temperature has returned to ±10°C of ambient temperature. The return to near ambient of the battery (cell) casing in an indication of ultimate results.

Tests are to be conducted at 20 ±5°C and at 55 ±5°C.

Criteria: No fire, and no explosion

External short-circuit test shall be performed with the UL1642 standard

9.3 Forced discharge test

Test method: A discharged cell is subjected to a reverse charge at 1.0C (3.0A) for 90 min.

Criteria: No fire, and no explosion.

Forced discharge test shall be performed with the IEC62133 standard

9.4 Heating test

Test method: To heat up the standard charged cell at heating rate 5℃ per minute up to 130℃ and keep the cell in oven for 1hr.

Criteria: No fire, and no explosion.

10.0. Warranty

Samsung SDI will be responsible for replacing the cell against defects or poor workmanship for 15months from the date of shipping. Any other problem caused by malfunction of the equipment or mix-use of the cell is not under this warranty.

The warranty set forth in proper using and handling conditions described above and excludes in the case of a defect which is not related to manufacturing of the cell.

11.0. Others

11.1 Storage for a long time

If the cell is kept for a long time (3 months or more), It is strongly recommended that the cell is preserved at dry and low-temperature.

11.2 Others

Any matters that specifications do not have, should be conferred with between the both parties.

12.0. Packing

See Fig.2,
Package Drawing

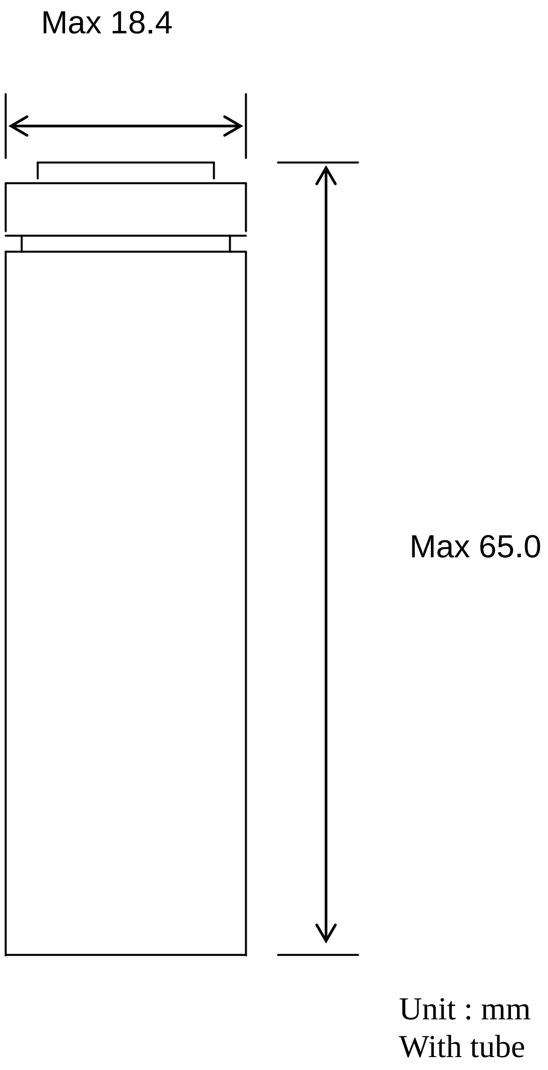
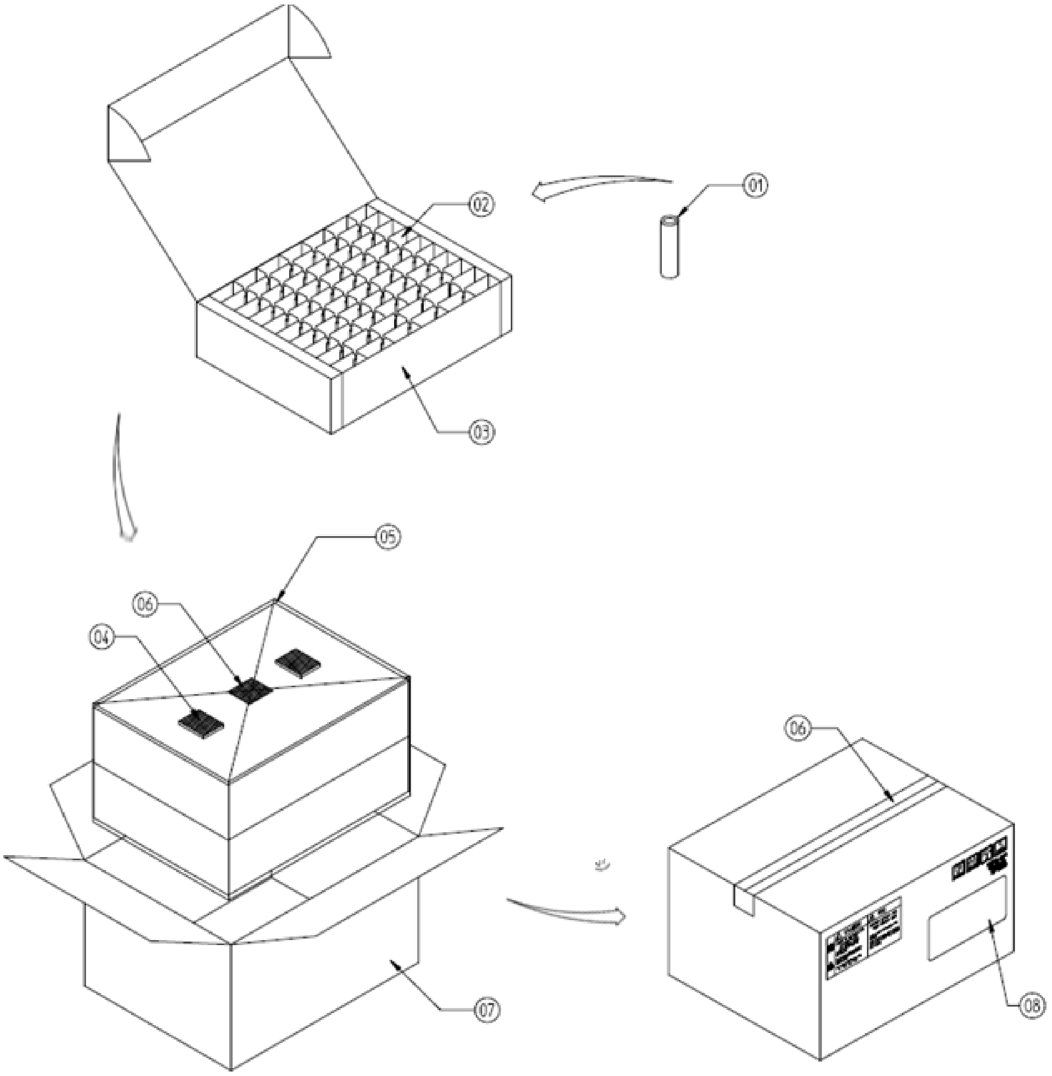


Fig.1. Outline dimensions of INR18650-30Q



NO	PART NAME	MATERIAL	MATERIAL DIM	Q'TY	TREATMENT
01	INR18650(Ref. Model List)	BARE CELL	ø18, H65	200	NONE
02	PACKING GUIDE	MANILA	L192×W191×H67	200	NONE
03	PACKING CASE IN	SW-1(B FLUTE)	L192×W192×H68	2	NONE
04	SILICAGEL	SI	L50×W50,3G	2	NONE
05	PE BAG(LARGE)	PE	L500×W450×T0.028	1	NONE
06	TAPE	PE(OPP)	W50×T0.05	1	NONE
07	PACKING CASE OUT	DW-1(BA FLUTE)	L225×W214×H164	1	NONE
08	LABEL	ART PAPER	L52×W100	1	NONE

Fig.2. Package drawing

Proper use and handling of lithium ion cells

See before using lithium-ion cell
Supplied by
Samsung SDI Co., Ltd.

1.0. General

This document has been prepared to describe the appropriate cautions and prohibitions, which the customer should take or employ when the customer uses and handles the lithium ion cell to be manufactured and supplied by Samsung SDI Co., Ltd., in order to obtain optimal performance and safety.

2.0. Charging

2.1 Charging current

Charging current shall be less than maximum charge current specified in the product specification.

2.2 Charging voltage

Charging shall be done by voltage less than that specified in the product specification.

2.3 Charging time

Continuous charging under specified voltage does not cause any loss of performance characteristics. However, the charge timer is recommended to be installed from a safety consideration, which shuts off further charging at time specified in the product specification.

2.4 Charging temperature

The cell shall be charged within a range of specified temperatures in the specification.

2.5 Reverse charging

The cell shall be connected, confirming that its poles are correctly aligned.
Inverse charging shall be strictly prohibited. If the cell is connected improperly, it may be damaged.

3.0. Discharging

3.1 Discharging

3.1.1 The cell shall be discharged continuously at less than maximum discharge current specified in the product specification. In case of the higher discharge current should be set, it shall be discussed together with SDI.

3.2 Discharging temperature

3.2.1 The cell shall be discharged within a range of temperatures specified in the product specification.

3.2.2 Otherwise, it may cause loss of performance characteristics.

3.3 Over-discharging

3.3.1 The system should equip with a device to prevent further discharging exceeding discharging cut-off voltage specified in the product specification.

3.3.2 Over-discharging may cause loss of performance characteristics of battery.

3.3.3 Over-discharging may occur by self-discharge if the battery is left for a very long time without any use.

3.3.4 The charger should equip with a device to detect voltage of cell block and to determine recharging procedures.

4.0. Storage

4.1 Storage conditions

4.1.1 The cell should be stored within a range of temperatures specified in the product specification.

4.1.2 Otherwise, it may cause loss of performance characteristics, leakage and/or rust.

4.2 Long-term storage

4.2.1 The cell should be used within a short period after charging because long-term storage may cause loss of capacity by self-discharging.

4.2.2. If long-term storage is necessary, the cell should be stored at lower voltage within a range specified in the product specification, because storage with higher voltage may cause more loss of performance characteristics.

5.0. Cycle life

5.1 Cycle life performance

5.1.1 The cell can be charged/discharged repeatedly up to times specified in the product specification with a certain level of capacity specified in the product specification.

5.1.2 Cycle life may be determined by conditions of charging, discharging, operating temperature and/or storage.

6.0. Design of system

6.1 Connection between the cell and the battery

6.1.1 The cell should not be soldered directly with other cells. Namely, the cell should be welded with leads on its terminal and then be soldered with wire or leads to solder.

6.1.2 Otherwise, it may cause damage of component, such as separator and insulator, by heat generation.

6.2 Positioning the battery in the system

6.2.1 The battery should be positioned as possible as far from heat sources and high temperature components.

6.2.2 Otherwise, it may cause loss of characteristics.

6.2.3 The recommended spacing between the cells is more than 1mm.

6.3 Mechanical shock protection of the battery

6.3.1 The battery should be equipped with appropriate shock absorbers in the pack in order to minimize shock, which can damage the cells.

6.3.2 Otherwise, it may cause shape distortion, leakage, heat generation and/or rupture and/or open circuit.

6.4 Short-circuit protection of the cell

6.4.1 The cell equips with an insulating sleeve to protect short-circuit which may occur during transportation, battery assembly and /or system operation.

6.4.2 If the cell sleeve is damaged by some cause such as outside impact, it may cause short-circuit with some wiring inside the battery.

6.5 Connection between the battery and charger/system

6.5.1 The battery should be designed to be connected only to the specified charger and system.

6.5.2 A reverse connection of the battery, even in the specified system, should be avoided by employing special battery design such as a special terminals.

6.6 Pack design

6.6.1 The current consumption of the battery pack should be under 10uA at sleep mode.

6.6.2 Cell voltage monitoring system.
The system (charger or pack) should be equipped with a device to monitor each voltage of cell block to avoid cell imbalance which can cause damage to the cells.

6.6.4 The battery pack or system should have warning system such as over temperature, over voltage, over current, and so on.

7.0. Battery pack assembly

7.1 Prohibition of usage of damaged cell

7.1.1 The cell should be inspected visually before battery assembly.

7.1.2 The cell should not be used if sleeve-damage, can-distorsion and/or electrolyte-smell is detected.

7.2 Terminals handling

7.2.1 Excessive force on the negative terminal should be avoided when external strip terminal is welled.

7.3 Transportation

7.3.1 If the cell is necessary to be transported to such as the battery manufacturer, careful precautions should be taken to avoid damage of cell.

8.0. Others

8.1 Disassembly

8.1.1 The cell should not be dismantled from the battery pack.

8.1.2 Internal short-circuit caused by disassembly may lead to heat generation and/or venting.

8.1.3 When the electrolyte is coming in contact with the skin or eyes, flush immediately with fresh water and seek medical advice.

8.2 Short-circuiting

8.2.1 Short-circuit results in very high current which leads to heat generation.

8.2.3 An appropriate circuitry should be employed to protect accidental short-circuiting.

8.3 Incineration

8.3.1 Incinerating and disposing of the cell in fire are strictly prohibited, because it may cause rupture and explosion.

8.4 Immersion

8.4.1 Soaking the cell in water is strictly prohibited, because it may cause corrosion and leakage of components to be damaged to functions

8.5 Mixing use

8.5.1 Different types of cell, or same types but different cell manufacturer's shall not be used, which may lead to cell imbalance, cell rupture or damage to system due to the different characteristics of cell.

8.6 Battery exchange

8.6.1 Although the cell contains no environmentally hazardous component, such as lead or cadmium, the battery shall be disposed according to the local regulations when it is disposed.

8.6.2 The cell should be disposed with a discharged state to avoid heat generation by an inadvertent short-circuit.

8.7 Caution

The Battery used in this device may present a risk of fire or chemical burn if mistreated.

Do not disassemble, expose to heat above 100℃ or incinerate it.

Replace battery with those of Samsung SDI only.

Use of another battery may cause a risk of fire or explosion.
Dispose of used battery promptly.
Keep battery away from children.
Do not disassemble and do not dispose of battery in fire.

8.8 Warning – Attached

▣ Pack Design Guideline (For electrical design)

Item		Portable IT	Power-Tool	Medical	E-Bike	E-Scooter	EV/LEV	ESS/UPS
☐ Standard charging voltage (4.20V cell)		4.20V	4.20V	**4.10V**	**4.10V**	**4.10V**	**4.10V**	**4.00V (4.05V)**
☐ Standard charging voltage (4.35V cell)		4.35V	4.35V	**4.20V**	**4.20V**	**4.20V**	**4.20V**	**4.00V (4.05V)**
☐ Charging method		CC-CV	CC-CV	CC-CV	CC-CV	CC-CV	CC-CV	CC-CV
☐ Full-charging cut-off current*		0.05C	0.05C	0.025C	0.025C	0.025C	0.025C	0.025C (Continous)
☐ Voltage of Re-charging (4.20V cell)		4.10V	4.10V	4.05V	4.05V	4.05V	4.05V	4.00V (4.05V)
☐ Voltage of Re-charging (4.35V cell)		4.25V	4.25V	4.10V	4.10V	4.10V	4.10V	4.00V (4.05V)
LCO LMO	☐ Min. voltage of terminate discharging	3.00V	2.50V	3.00V	3.00V	3.00V	3.00V	3.00V
	☐ Min. voltage of over-discharging protection	2.50V	2.00V	2.50V	2.50V	2.50V	2.50V	2.50V
NCA NCM	☐ Min. voltage of terminate discharging	2.50V	2.50V	2.50V	2.50V	2.50V	2.50V	2.50V
	☐ Min. voltage of over-discharging protection	2.30V	2.00V	2.50V	2.50V	2.50V	2.50V	2.50V
☐ BMS Shut Down Voltage**		2.00V	2.00V	2.00V	2.00V	2.00V	2.00V	2.00V
☐ Max. consumption current of BMS after shut down		10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell
☐ Do not charge***		↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V
☐ Pre-charging voltage range****		1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V
☐ Current range of Pre-charging		0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C

Remark:

* Current of cell which full-charging shall be terminated.

** Voltage condition of BMS which shall be shut down.

*** Under 1.0V voltage, do not charge the cell.

**** Voltage range of cell which shall be charged by Pre-charging.

**If a customer's battery pack cannot meet the requirements above,
SDI cannot take responsibility for a quality issue about a battery cell.**

▣ Pack Design Guideline (For mechanical design)

Item	Portable IT	Power-Tool	Medical	E-Bike	E-Scooter	EV/LEV	ESS/UPS
☐ Need partitions(separator) between BMS and a Cell	◎	◎	◎	◎	◎	◎	◎
☐ Need to check if the pack is designed to be able to avoid thermal runaway (1KWh ↑)					◎	◎	◎
☐ Need to analyze the battery pack's thermal distribution and its effect on the pack's life cycle					◎	◎	◎
☐ Need to use a non-flammable (VO level) case	◎	◎	◎	◎	◎	◎	◎
☐ Need to apply improved material (Steel) to the case						◎	◎
☐ Need to analyze the battery pack's structure, system, installation status and use environment						◎	◎

If a customer’s battery pack cannot meet the requirements above,
SDI cannot take responsibility for a quality issue about a battery cell.

Handling precaution and prohibitions of lithium Ion rechargeable cells and batteries

Inaccurate handling of lithium ion and lithium ion polymer rechargeable battery may cause leakage, heat, smoke, an explosion, or fire.

This could cause deterioration of performance or failure. Please be sure to follow instructions carefully.

1.1 Storage

Store the battery at low temperature (below 25℃ is recommended), low humidity, no dust and no corrosive gas atmosphere.

1.2 Safety precaution and prohibitions

To assure product safety, describe the following precautions in the instruction manual of the application.

[Danger!]

■ Electrical misusage

Use stipulated charger.

Use or charge the battery only in the stipulated application.

Don't charge the battery by an electric outlet directly or a cigarette lighter charger.

Don't charge the battery reversely.

■ Environmental misusage

Don't leave the battery near the fire or a heated source.

Don't throw the battery into the fire.

Don't leave, charge or use the battery in a car or similar place where inside of temperature may be over 60℃.

Don't immerse, throw, wet the battery in water / sea water.

■ others

Don't fold the battery cased with laminated film such as pouch and polymer.

Don't store the battery in a pocket or a bag together with metallic objects such as keys, necklaces, hairpins, coins, or screws.

Don't short circuit (+) and (-) terminals with metallic object intentionally.

Don't pierce the battery with a sharp object such as a needle, screw drivers.

Don't heat partial area of the battery with heated objects such as soldering iron.

Don't hit with heavy objects such as a hammer, weight.

Don't step on the battery and throw or drop the battery on the hard floor to avoid mechanical shock.

Don't disassemble the battery or modify the battery design including electric circuit.

Don't solder on the battery directly.

Don't use seriously scared or deformed battery.

Don't put the battery into a microwave oven, dryer or high-pressure container.

Don't use or assemble the battery with other makers' batteries, different types and/or models of batteries such as dry batteries, nickel-metal hydride batteries, or nickel-cadmium batteries.

Don't use or assemble old and new batteries together.

[Warning!]

Stop charging the battery if charging isn't completed within the specified time.

Stop using the battery if the battery becomes abnormally hot, order, discoloration, deformation, or abnormal conditions is detected during use, charge, or storage.

Keep away from fire immediately when leakage or foul odors are detected. If liquid leaks onto your skin or cloths, wash well with fresh water immediately.

If liquid leaking from the battery gets into your eyes, don't rub your eyes and wash them with clean water and go to see a doctor immediately.

If the terminals of the battery become dirty, wipe with a dry cloth before using the battery.

The battery can be used within the following temperature ranges. Don't exceed these ranges.

The operating temperature is based on the cell surface temperature in hottest position in pack.

Charge temperature ranges : 0℃ ~ 50℃
Discharge Temperature ranges : -20℃ ~ 75℃

Store the battery at temperature below 60℃

Cover terminals with proper insulating tape before disposal.

[Caution!]

■ Electrical misusage

Battery must be charged with constant current-constant voltage (CC/CV).

Charge current must be controlled by specified value in cell specification.

Cut-off voltage of charging must be less than 4.2 + 0.05V

Charger must stop charging battery by detecting either charging time or current specified in cell's specification.

Discharge current must be controlled by specified value in cell's specification.

Cut-off voltage of full discharging and recharging must be over 2.5V.

■ others

Keep the battery away from babies and children to avoid any accidents such as swallow.

If younger children use the battery, their guardians should explain the proper handling method and precaution before using.

Before using the battery, be sure to read the user's manual and precaution of it's handling.

Before using charger, be sure to read the user's manual of the charger.

Before installing and removing the battery from application, be sure to read user's manual of the application.

Replace the battery when using time of battery becomes much shorter than usual.

Cover terminals with insulating tape before proper disposal.

If the battery is needed to be stored for an long period, battery should be removed from the application and stored in a place where humidity and temperature are low.

While the battery is charged, used and stored, keep it away from object materials with static electric chargers.

Safety handling procedure for the transporter

■ Quarantine

Packages that are crushed, punctured or torn open to reveal contents should not be transported. Such packages should be isolated until the shipper has been consulted, provided instructions and, if appropriate, arranged to have the product inspected and repacked.

■ Spilled product

In the event that damage to packaging results in the release of cells or batteries, the spilled products should be promptly collected and segregated and the shipper should contact for instructions.

Design of positioning the battery pack in application and charger

To prevent the deterioration of the battery performance caused by heat, battery shall be positioned away from the area where heat is generated in the application and the charger.

Design of the battery pack

Be sure adopting proper safe device such as PTC specified type or model in Cell Specification. If you intend to adopt different safety device which is not specified in Cell Specification, please contact Samsung SDI to investigate any potential safety problem.

Be sure designing 2nd protective devices such as PCM at the same time to protect cell just in case one protective device is fault.

Please contact following offices when you need any help including safety concerns.

Samsung SDI emergency contact information

■ **Samsung SDI Headquarters.**
150-20, Gongse-ro, Giheung-gu, Yongin-si, Gyeonggi-do
Tel:(+82) 31-8006-3100 Fax:(+82) 31-210-7887

■ **Samsung SDI Cheonan factory CS group.**
508, Sungsung-dong, Cheonan-si, Chungnam, Korea
Tel:(+82)70-7125-1860 Fax:(+82)41-560-3695

■ **Samsung SDI Germany office.**
Oskar messter strasse 29 85737 Ismaning Germany
Tel:(+49) 8992-9277-9971 Fax:（+ 49)8992-9277-9999

■ **Samsung SDI America office.**
601 McCarthy Blvd Milpitas CA 95034
Tel:(+1) 408-544-4528 Fax:(+1) 408-544-4961

Spec. No.	INR18650-30Q	Version No.	1.0	Wanmook, Lim

SPECIFICATION OF PRODUCT

Lithium-ion rechargeable cell for power tools

Model name : INR18650-30Q

Feb, 2015

Samsung SDI Co., Ltd.

Energy Business Division

Spec. No.	INR18650-30Q	Version No.	1.0	Wanmook, Lim

Revision history

Revision No.	Date(‘yr-m-d)	Page	Item	Description	Changes / Author
v1.0	‘15-02-02			First Edition	Wan-Mook Lim

1.0. Scope

This product specification has been prepared to specify the rechargeable lithium-ion cell ('cell') to be supplied to the customer by Samsung SDI Co., Ltd.

2.0. Description and model

2.1 Description	lithium-ion rechargeable cell
2.2 Model name	INR18650-30Q

3.0. Nominal specifications

Item	**Specification**
3.1 Minimum discharge capacity	2,950mAh Charge: 1.50A, 4.20V,CCCV 150mA cut-off, Discharge: 0.2C, 2.5V discharge cut-off
3.2 Nominal voltage	3.6V
3.3 Standard charge	CCCV, 1.50A, 4.20 ± 0.05 V, 150mA cut-off
3.4 Rated charge	CCCV, 4A, 4.20 ± 0.05 V, 100mA cut-off
3.6 Charging time	Standard charge : 180min / 150mA cut-off Rated charge: 70min (at 25℃) / 100mA cut-off
3.7 Max. continuous discharge (Continuous)	15A(at 25℃), 60% at 250 cycle
3.8 Discharge cut-off voltage End of discharge	2.5V
3.9 Cell weight	48.0g max
3.10 Cell dimension	Height : Max 65.0mm Diameter : Max 18.4mm
3.11 Operating temperature (surface temperature)	Charge : 0 to 50℃ (recommended recharge release < 45℃) Discharge: -20 to 75℃ (recommended re-discharge release < 60℃)
3.12 Storage temperature (Recovery 90% after storage)	1.5 year -30~25℃(1*) 3 months -30~45℃(1*) 1 month -30~60℃(1*)

Note (1): If the cell is kept as ex-factory status (40±5% SOC, 25℃),
the capacity recovery rate is more than 90% of 10A discharge capacity
100% is 2,900mAh at 23℃ with SOC 100% after formation.

4.0 Outline dimensions

See the attachment (Fig. 1)

5.0. Appearance

There shall be no such defects as scratch, rust, discoloration, leakage which may adversely affect commercial value of the cell.

6.0. Standard test conditions

6.1 Environmental conditions

Unless otherwise specified, all tests stated in this specification are conducted at temperature 23±3°and humidity under 65%.

6.2 Measuring equipment

(1) Amp-meter and volt-meter

The amp-meter and volt-meter should have an accuracy of the grade 0.5mA and mV or higher.

(2) Slide caliper

The slide caliper should have 0.01 mm scale.

(3) Impedance meter

The impedance meter with AC 1kHz should be used.

7.0. Characteristics

7.1 Standard charge

This "Standard charge" means charging the cell CCCV with charge current 0.5CmA (1,500mA), constant voltage 4.2V and 150mA cut-off in CV mode at 23℃ for capacity.

.

7.2 Rated charge

Rated charge means charging the cell CCCV with charge current 4A and 100mA cut-off at 23℃

7.3 Standard discharge capacity

The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 600mA(0.2C) with 2.5V cut-off at 23℃ within 1hour after the standard charge.

Nominal discharge capacity ≥ 2,950mAh

Which complying to the minimum capacity of IEC61960 standard.

7.4 Rated discharge capacity

The rated discharge is the discharge capacity of the cell, which is measured with discharge current of 10A with 2.5V cut-off at 23℃ within 1hour after the rated charge.

Standard rated discharge capacity ≥ 2,900mAh

7.5 Initial internal impedance

Initial internal impedance measured at AC 1kHz after standard charge

Initial internal impedance ≤ 26mΩ

7.6 Temperature dependence of discharge capacity

Capacity comparison at each temperature, measured with discharge constant current 10A and 2.5V cut-off after the rated charge is as follows.

Discharge temperature				
-20℃	-10℃	0℃	23℃	60℃
60%	75%	80%	100%	95%

Note: If charge temperature and discharge temperature is not the same,
the interval for temperature change is 3 hours.
Percentage index of the discharge at 23℃ at 10A (=2,900mAh) is 100%.

7.7 Temperature dependence of charge capacity

Capacity comparison at each temperature, measured with discharge constant current 10A and 2.5V cut-off after the rated charge is as follows.

	Charge temperature					Discharge temperature
	0℃	5℃	23℃	45℃	50℃	23℃
Relative capacity	80%	90%	100%	95%	95%	

Note: If charge temperature and discharge temperature is not the same,
the interval for temperature change is 3 hours.
Percentage index of the discharge at 23℃ at 10A (=2,900mAh) is 100%.

7.8 Charge rate capabilities

Discharge capacity is measured with constant current 10A and 2.5V cut-off after the cell is charged with 4.2V as follows.

	Charge condition	
Current	Standard 1.5A	Maximum rapid charge 4A
Cut-off	150mA	100mA
Relative Capacity	100%	100%

Note: Percentage index of the discharge at 23℃ at 10A (=2,900mAh) is 100%.

7.9 Discharge rate capabilities

Discharge capacity is measured with the various currents in under table and 2.5V cut-off after the rated charge.

	Discharge condition				
Current	0.6A	5A	10A	15A	20A
Relative Capacity	100%	97%	100%	97%	95%

Percentage index of the discharge at 25℃ at 10A (=2,900mAh) is 100%.

7.10 Cycle life

With standard charge and maximum continuous discharge.

Capacity after 250cycles,

Capacity ≥ 1,800mAh (60% of the nominal capacity at 23℃)

7.11 Storage characteristics

Standard rated discharge capacity after storage for 1 month at 60℃ from the standard charged state is ≥ 90% of the initial 10A discharge capacity at 23℃

7.12 Status of the cell as of ex-factory

The cell should be shipped in 3.620V to 3.690V charging voltage range.

8.0. Mechanical Characteristics

8.1 Drop test

Test method: Each fully charged cell or battery is dropped three times from a height of 1.0 m onto a concrete floor. The cells or batteries are dropped so as to obtain impacts in random orientations. After the test, the sample shall be put on rest for a minimum of one hour and then a visual inspection shall be performed.

Criteria: No fire, no explosion.

Drop test shall be performed with the IEC62133 standard

8.2 Vibration test

Test method: As to the UN transportation regulation(UN38.3), for each axis (X and Y axis with cylindrical cells) 7Hz→200Hz→7Hz for 15min, repetition 12 times totally 3hours, the acceleration 1g during 7 to 18Hz and 8g (amplitude 1.6mm) up to 200Hz.

Criteria: No leakage, with less than 10% of OCV drop

Vibration test shall be performed with the UN38.3 standard

9.0. Safety

9.1 Overcharge test

Test method: Cell is to be discharged at a constant current of 0.6A to 2.5V. The cell is then to be charged with a 20V and 20A. Charging duration is to be 7 h.

Criteria: No fire, and no explosion.
Overcharge test shall be performed with the UL1642 standard

9.2 External short-circuit test

Test method: Fully rated charged cell is to be short-circuited by connecting the positive and negative terminals of the battery with a circuit load having a resistance load of 80 ±20 mΩ. The battery is to discharge until a fire or explosion is obtained, or until it has reached a completely discharged state of less than 0.2 V and the battery case temperature has returned to ±10°C of ambient temperature. The return to near ambient of the battery (cell) casing in an indication of ultimate results.
Tests are to be conducted at 20 ±5°C and at 55 ±5°C.

Criteria: No fire, and no explosion
External short-circuit test shall be performed with the UL1642 standard

9.3 Forced discharge test

Test method: A discharged cell is subjected to a reverse charge at 1.0C (3.0A) for 90 min.

Criteria: No fire, and no explosion.
Forced discharge test shall be performed with the IEC62133 standard

9.4 Heating test

Test method: To heat up the standard charged cell at heating rate 5℃ per minute up to 130℃ and keep the cell in oven for 1hr.
Criteria: No fire, and no explosion.

10.0. Warranty

Samsung SDI will be responsible for replacing the cell against defects or poor workmanship for 15months from the date of shipping. Any other problem caused by malfunction of the equipment or mix-use of the cell is not under this warranty.
The warranty set forth in proper using and handling conditions described above and excludes in the case of a defect which is not related to manufacturing of the cell.

11.0. Others

11.1 Storage for a long time

If the cell is kept for a long time (3 months or more), It is strongly recommended that the cell is preserved at dry and low-temperature.

11.2 Others

Any matters that specifications do not have, should be conferred with between the both parties.

12.0. Packing

See Fig.2,

Package Drawing

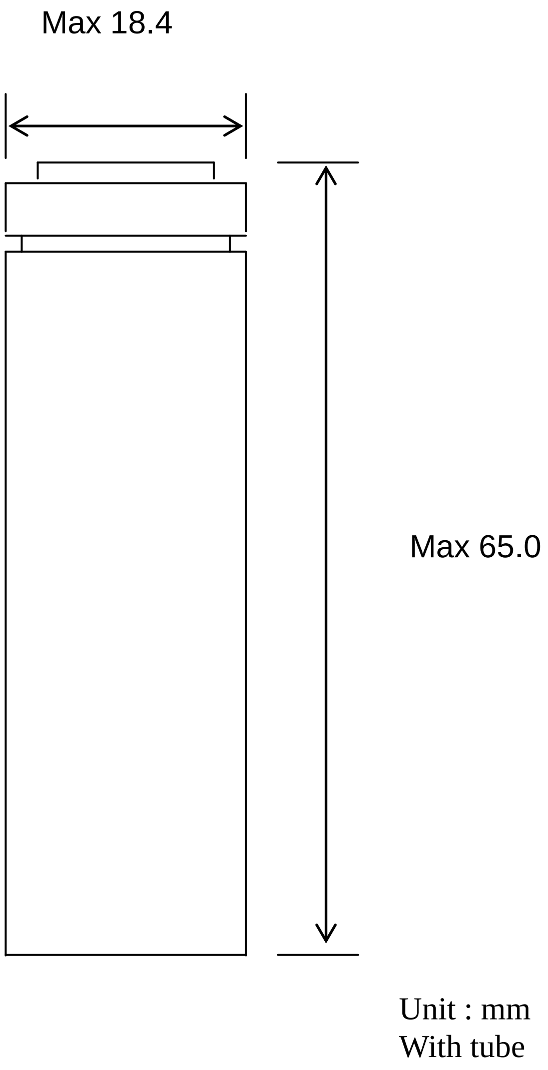
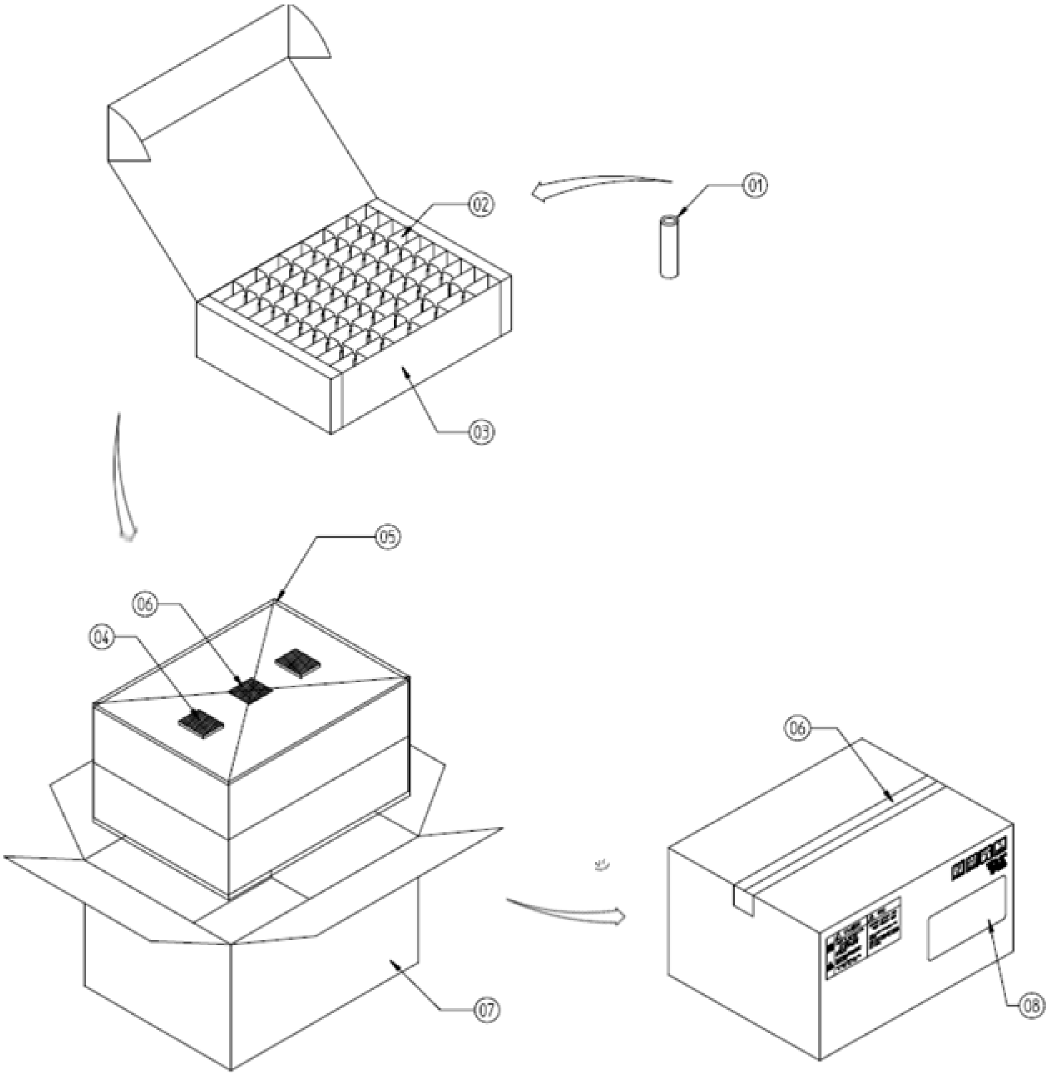
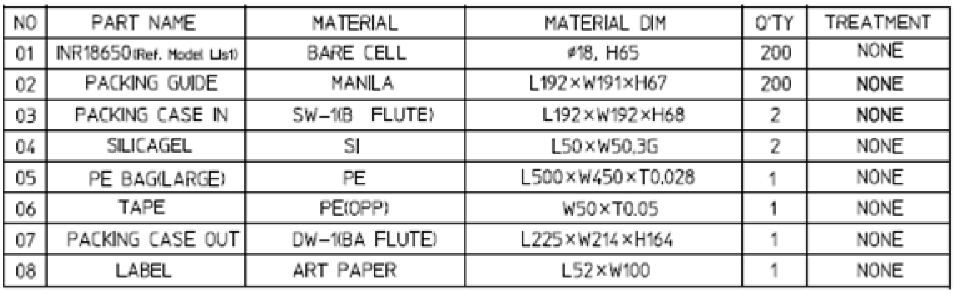


Fig.1. Outline dimensions of INR18650-30Q





NO	PART NAME	MATERIAL	MATERIAL DIM	Q'TY	TREATMENT
01	INR18650(Ref. Model List)	BARE CELL	ø18, H65	200	NONE
02	PACKING GUIDE	MANILA	L192×W191×H67	200	NONE
03	PACKING CASE IN	SW-1(B FLUTE)	L192×W192×H68	2	NONE
04	SILICAGEL	SI	L50×W50,3G	2	NONE
05	PE BAG(LARGE)	PE	L500×W450×T0.028	1	NONE
06	TAPE	PE(OPP)	W50×T0.05	1	NONE
07	PACKING CASE OUT	DW-1(BA FLUTE)	L225×W214×H164	1	NONE
08	LABEL	ART PAPER	L52×W100	1	NONE

Fig.2. Package drawing

Proper use and handling of lithium ion cells

See before using lithium-ion cell
Supplied by
Samsung SDI Co., Ltd.

1.0. General

This document has been prepared to describe the appropriate cautions and prohibitions, which the customer should take or employ when the customer uses and handles the lithium ion cell to be manufactured and supplied by Samsung SDI Co., Ltd., in order to obtain optimal performance and safety.

2.0. Charging

2.1 Charging current

Charging current shall be less than maximum charge current specified in the product specification.

2.2 Charging voltage

Charging shall be done by voltage less than that specified in the product specification.

2.3 Charging time

Continuous charging under specified voltage does not cause any loss of performance characteristics. However, the charge timer is recommended to be installed from a safety consideration, which shuts off further charging at time specified in the product specification.

2.4 Charging temperature

The cell shall be charged within a range of specified temperatures in the specification.

2.5 Reverse charging

The cell shall be connected, confirming that its poles are correctly aligned.
Inverse charging shall be strictly prohibited. If the cell is connected improperly, it may be damaged.

3.0. Discharging

3.1 Discharging

3.1.1 The cell shall be discharged continuously at less than maximum discharge current specified in the product specification. In case of the higher discharge current should be set, it shall be discussed together with SDI.

3.2 Discharging temperature

3.2.1 The cell shall be discharged within a range of temperatures specified in the product specification.

3.2.2 Otherwise, it may cause loss of performance characteristics.

3.3 Over-discharging

3.3.1 The system should equip with a device to prevent further discharging exceeding discharging cut-off voltage specified in the product specification.

3.3.2 Over-discharging may cause loss of performance characteristics of battery.

3.3.3 Over-discharging may occur by self-discharge if the battery is left for a very long time without any use.

3.3.4 The charger should equip with a device to detect voltage of cell block and to determine recharging procedures.

4.0. Storage

4.1 Storage conditions

4.1.1 The cell should be stored within a range of temperatures specified in the product specification.

4.1.2 Otherwise, it may cause loss of performance characteristics, leakage and/or rust.

4.2 Long-term storage

4.2.1 The cell should be used within a short period after charging because long-term storage may cause loss of capacity by self-discharging.

4.2.2. If long-term storage is necessary, the cell should be stored at lower voltage within a range specified in the product specification, because storage with higher voltage may cause more loss of performance characteristics.

5.0. Cycle life

5.1 Cycle life performance

5.1.1 The cell can be charged/discharged repeatedly up to times specified in the product specification with a certain level of capacity specified in the product specification.

5.1.2 Cycle life may be determined by conditions of charging, discharging, operating temperature and/or storage.

6.0. Design of system

6.1 Connection between the cell and the battery

6.1.1 The cell should not be soldered directly with other cells. Namely, the cell should be welded with leads on its terminal and then be soldered with wire or leads to solder.

6.1.2 Otherwise, it may cause damage of component, such as separator and insulator, by heat generation.

6.2 Positioning the battery in the system

6.2.1 The battery should be positioned as possible as far from heat sources and high temperature components.

6.2.2 Otherwise, it may cause loss of characteristics.

6.2.3 The recommended spacing between the cells is more than 1mm.

6.3 Mechanical shock protection of the battery

6.3.1 The battery should be equipped with appropriate shock absorbers in the pack in order to minimize shock, which can damage the cells.

6.3.2 Otherwise, it may cause shape distortion, leakage, heat generation and/or rupture and/or open circuit.

6.4 Short-circuit protection of the cell

6.4.1 The cell equips with an insulating sleeve to protect short-circuit which may occur during transportation, battery assembly and /or system operation.

6.4.2 If the cell sleeve is damaged by some cause such as outside impact, it may cause short-circuit with some wiring inside the battery.

6.5 Connection between the battery and charger/system

6.5.1 The battery should be designed to be connected only to the specified charger and system.

6.5.2 A reverse connection of the battery, even in the specified system, should be avoided by employing special battery design such as a special terminals.

6.6 Pack design

6.6.1 The current consumption of the battery pack should be under 10uA at sleep mode.

6.6.2 Cell voltage monitoring system.
The system (charger or pack) should be equipped with a device to monitor each voltage of cell block to avoid cell imbalance which can cause damage to the cells.

6.6.4 The battery pack or system should have warning system such as over temperature, over voltage, over current, and so on.

7.0. Battery pack assembly

7.1 Prohibition of usage of damaged cell

- 7.1.1 The cell should be inspected visually before battery assembly.
- 7.1.2 The cell should not be used if sleeve-damage, can-distorsion and/or electrolyte-smell is detected.

7.2 Terminals handling

- 7.2.1 Excessive force on the negative terminal should be avoided when external strip terminal is welled.

7.3 Transportation

- 7.3.1 If the cell is necessary to be transported to such as the battery manufacturer, careful precautions should be taken to avoid damage of cell.

8.0. Others

8.1 Disassembly

- 8.1.1 The cell should not be dismantled from the battery pack.
- 8.1.2 Internal short-circuit caused by disassembly may lead to heat generation and/or venting.
- 8.1.3 When the electrolyte is coming in contact with the skin or eyes, flush immediately with fresh water and seek medical advice.

8.2 Short-circuiting

- 8.2.1 Short-circuit results in very high current which leads to heat generation.
- 8.2.3 An appropriate circuitry should be employed to protect accidental short-circuiting.

8.3 Incineration

- 8.3.1 Incinerating and disposing of the cell in fire are strictly prohibited, because it may cause rupture and explosion.

8.4 Immersion

- 8.4.1 Soaking the cell in water is strictly prohibited, because it may cause corrosion and leakage of components to be damaged to functions

8.5 Mixing use

- 8.5.1 Different types of cell, or same types but different cell manufacturer's shall not be used, which may lead to cell imbalance, cell rupture or damage to system due to the different characteristics of cell.

8.6 Battery exchange

- 8.6.1 Although the cell contains no environmentally hazardous component, such as lead or cadmium, the battery shall be disposed according to the local regulations when it is disposed.
- 8.6.2 The cell should be disposed with a discharged state to avoid heat generation by an inadvertent short-circuit.

8.7 Caution

The Battery used in this device may present a risk of fire or chemical burn if mistreated.

Do not disassemble, expose to heat above 100℃ or incinerate it.

Replace battery with those of Samsung SDI only.

Use of another battery may cause a risk of fire or explosion.
Dispose of used battery promptly.
Keep battery away from children.
Do not disassemble and do not dispose of battery in fire.

8.8 Warning – Attached

▣ Pack Design Guideline (For electrical design)

Item		**Portable IT**	**Power-Tool**	**Medical**	**E-Bike**	**E-Scooter**	**EV/LEV**	**ESS/UPS**
☐ Standard charging voltage (4.20V cell)		4.20V	4.20V	**4.10V**	**4.10V**	**4.10V**	**4.10V**	**4.00V** **(4.05V)**
☐ Standard charging voltage (4.35V cell)		4.35V	4.35V	**4.20V**	**4.20V**	**4.20V**	**4.20V**	**4.00V** **(4.05V)**
☐ Charging method		CC-CV	CC-CV	CC-CV	CC-CV	CC-CV	CC-CV	CC-CV
☐ Full-charging cut-off current*		0.05C	0.05C	0.025C	0.025C	0.025C	0.025C	0.025C (Continous)
☐ Voltage of Re-charging (4.20V cell)		4.10V	4.10V	4.05V	4.05V	4.05V	4.05V	4.00V (4.05V)
☐ Voltage of Re-charging (4.35V cell)		4.25V	4.25V	4.10V	4.10V	4.10V	4.10V	4.00V (4.05V)
LCO LMO	☐ Min. voltage of terminate discharging	3.00V	2.50V	3.00V	3.00V	3.00V	3.00V	3.00V
	☐ Min. voltage of over-discharging protection	2.50V	2.00V	2.50V	2.50V	2.50V	2.50V	2.50V
NCA NCM	☐ Min. voltage of terminate discharging	2.50V	2.50V	2.50V	2.50V	2.50V	2.50V	2.50V
	☐ Min. voltage of over-discharging protection	2.30V	2.00V	2.50V	2.50V	2.50V	2.50V	2.50V
☐ BMS Shut Down Voltage**		2.00V	2.00V	2.00V	2.00V	2.00V	2.00V	2.00V
☐ Max. consumption current of BMS after shut down		10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell	10μA/Cell
☐ Do not charge***		↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V	↓ 1.00V
☐ Pre-charging voltage range****		1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V	1.0V ~ 3.0V
☐ Current range of Pre-charging		0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C	0.1C ~ 0.5C

Remark:

* Current of cell which full-charging shall be terminated.

** Voltage condition of BMS which shall be shut down.

*** Under 1.0V voltage, do not charge the cell.

**** Voltage range of cell which shall be charged by Pre-charging.

If a customer’s battery pack cannot meet the requirements above,
SDI cannot take responsibility for a quality issue about a battery cell.

▣ Pack Design Guideline (For mechanical design)

Item	Portable IT	Power-Tool	Medical	E-Bike	E-Scooter	EV/LEV	ESS/UPS
☐ Need partitions(separator) between BMS and a Cell	◎	◎	◎	◎	◎	◎	◎
☐ Need to check if the pack is designed to be able to avoid thermal runaway (1KWh ↑)					◎	◎	◎
☐ Need to analyze the battery pack's thermal distribution and its effect on the pack's life cycle					◎	◎	◎
☐ Need to use a non-flammable (VO level) case	◎	◎	◎	◎	◎	◎	◎
☐ Need to apply improved material (Steel) to the case						◎	◎
☐ Need to analyze the battery pack's structure, system, installation status and use environment						◎	◎

**If a customer's battery pack cannot meet the requirements above,
SDI cannot take responsibility for a quality issue about a battery cell.**

Handling precaution and prohibitions of lithium Ion rechargeable cells and batteries

Inaccurate handling of lithium ion and lithium ion polymer rechargeable battery may cause leakage, heat, smoke, an explosion, or fire.

This could cause deterioration of performance or failure. Please be sure to follow instructions carefully.

1.1 Storage

Store the battery at low temperature (below 25℃ is recommended), low humidity, no dust and no corrosive gas atmosphere.

1.2 Safety precaution and prohibitions

To assure product safety, describe the following precautions in the instruction manual of the application.

[Danger!]

■ Electrical misusage

Use stipulated charger.

Use or charge the battery only in the stipulated application.

Don't charge the battery by an electric outlet directly or a cigarette lighter charger.

Don't charge the battery reversely.

■ Environmental misusage

Don't leave the battery near the fire or a heated source.

Don't throw the battery into the fire.

Don't leave, charge or use the battery in a car or similar place where inside of temperature may be over 60℃.

Don't immerse, throw, wet the battery in water / sea water.

■ others

Don't fold the battery cased with laminated film such as pouch and polymer.

Don't store the battery in a pocket or a bag together with metallic objects such as keys, necklaces, hairpins, coins, or screws.

Don't short circuit (+) and (-) terminals with metallic object intentionally.

Don't pierce the battery with a sharp object such as a needle, screw drivers.

Don't heat partial area of the battery with heated objects such as soldering iron.

Don't hit with heavy objects such as a hammer, weight.

Don't step on the battery and throw or drop the battery on the hard floor to avoid mechanical shock.

Don't disassemble the battery or modify the battery design including electric circuit.

Don't solder on the battery directly.

Don't use seriously scared or deformed battery.

Don't put the battery into a microwave oven, dryer or high-pressure container.

Don't use or assemble the battery with other makers' batteries, different types and/or models of batteries such as dry batteries, nickel-metal hydride batteries, or nickel-cadmium batteries.

Don't use or assemble old and new batteries together.

[Warning!]

Stop charging the battery if charging isn't completed within the specified time.

Stop using the battery if the battery becomes abnormally hot, order, discoloration, deformation, or abnormal conditions is detected during use, charge, or storage.

Keep away from fire immediately when leakage or foul odors are detected. If liquid leaks onto your skin or cloths, wash well with fresh water immediately.

If liquid leaking from the battery gets into your eyes, don't rub your eyes and wash them with clean water and go to see a doctor immediately.

If the terminals of the battery become dirty, wipe with a dry cloth before using the battery.

The battery can be used within the following temperature ranges. Don't exceed these ranges.

The operating temperature is based on the cell surface temperature in hottest position in pack.

Charge temperature ranges : 0℃ ~ 50℃

Discharge Temperature ranges : -20℃ ~ 75℃

Store the battery at temperature below 60℃

Cover terminals with proper insulating tape before disposal.

[Caution!]

■ Electrical misusage

Battery must be charged with constant current-constant voltage (CC/CV).

Charge current must be controlled by specified value in cell specification.

Cut-off voltage of charging must be less than 4.2 + 0.05V

Charger must stop charging battery by detecting either charging time or current specified in cell’s specification.

Discharge current must be controlled by specified value in cell’s specification.

Cut-off voltage of full discharging and recharging must be over 2.5V.

■ others

Keep the battery away from babies and children to avoid any accidents such as swallow.

If younger children use the battery, their guardians should explain the proper handling method and precaution before using.

Before using the battery, be sure to read the user's manual and precaution of it's handling.

Before using charger, be sure to read the user's manual of the charger.

Before installing and removing the battery from application, be sure to read user's manual of the application.

Replace the battery when using time of battery becomes much shorter than usual.

Cover terminals with insulating tape before proper disposal.

If the battery is needed to be stored for an long period, battery should be removed from the application and stored in a place where humidity and temperature are low.

While the battery is charged, used and stored, keep it away from object materials with static electric chargers.

Safety handling procedure for the transporter

■ Quarantine

Packages that are crushed, punctured or torn open to reveal contents should not be transported. Such packages should be isolated until the shipper has been consulted, provided instructions and, if appropriate, arranged to have the product inspected and repacked.

■ Spilled product

In the event that damage to packaging results in the release of cells or batteries, the spilled products should be promptly collected and segregated and the shipper should contact for instructions.

Design of positioning the battery pack in application and charger

To prevent the deterioration of the battery performance caused by heat, battery shall be positioned away from the area where heat is generated in the application and the charger.

Design of the battery pack

Be sure adopting proper safe device such as PTC specified type or model in Cell Specification. If you intend to adopt different safety device which is not specified in Cell Specification, please contact Samsung SDI to investigate any potential safety problem.

Be sure designing 2nd protective devices such as PCM at the same time to protect cell just in case one protective device is fault.

Please contact following offices when you need any help including safety concerns.

Samsung SDI emergency contact information

■ **Samsung SDI Headquarters.**
150-20, Gongse-ro, Giheung-gu, Yongin-si, Gyeonggi-do
Tel:(+82) 31-8006-3100 Fax:(+82) 31-210-7887

■ **Samsung SDI Cheonan factory CS group.**
508, Sungsung-dong, Cheonan-si, Chungnam, Korea
Tel:(+82)70-7125-1860 Fax:(+82)41-560-3695

■ **Samsung SDI Germany office.**
Oskar messter strasse 29 85737 Ismaning Germany
Tel:(+49) 8992-9277-9971 Fax: （+ 49)8992-9277-9999

■ **Samsung SDI America office.**
601 McCarthy Blvd Milpitas CA 95034
Tel:(+1) 408-544-4528 Fax:(+1) 408-544-4961