Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels
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# FINAL YEAR PROJECT

**Title:** Design of a low-cost RPAS Ground Control Station

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**Resum**


En aquest projecte s’ha dissenyat, desenvolupat i construït una Estació de Control Terrena (GCS, per les seves sigles en anglès) per a un Sistema Avió Pilotat Remotament (RPAS).

L’ECT forma part d’un sistema més ampli anomenat Sistema Avió no Tripulat (UAS) format per el propi RPAS en el segment aire, l’enllaç de comunicacions i finalment l’estació de control terrena.

Primer de tot, s’ha fet un breu estudi per a conèixer els diferents tipus d’estació terrena que existeixen actualment. Hi ha molts tipus de GCS depenent de la magnitud del RPAS que s’ha de controlar, el pressupost del projecte o els requeriments de la missió. Donades aquestes característiques, es defineix la magnitud de la GCS que serà dissenyada.

Un cop establerta la magnitud de l’estació terrena, es definiran els diferents components que en formen part. Començant pel microprocessador fins al controlador de la pantalla LCD, s’enumeraran i descriuran els diferents components utilitzats; Així com les seves característiques i avantatges davant altres opcions. A més, s’explicarà el procés seguit per tal de dissenyar algunes de les parts com per exemple el sistema de potència.

A part del hardware, l’estació terrena també necessita de softwares per operar. S’explicaran els diferents softwares i sistemes operatius instal·lats i utilitzats, així com els mètodes d’instal·lació.

Un cop les diferents parts han estat definides, s’utilitzarà el programa de disseny Solid Works® per tal d’establir el disseny físic de l’estació terrena. Considerant l’espai disponible donada la magnitud del projecte i la quantitat d’elements a encabir i interconnectar, es farà un disseny realista. Aquest disseny serà després utilitzat per tal de construir l’estació terrena real. S’explicarà el procés de construcció l’estació terrena i es testejarà.

Finalment, es farà una conclusió per tal d’establir la viabilitat del projecte, tenint en compte les plataformes ja existents així com la comparació del consum d’energia i la duració de la bateria, el pes, el preu i les característiques tècniques.

**Overview**

In this project, a Ground Control Station (GCS) for a Remotely Piloted Aircraft System (RPAS) has been designed, developed and built from scratch.

The GCS is part of a larger System called Unmanned Aircraft System (UAS) formed by the RPAS in the air segment, the communications link and the Ground Control Station.

First of all, a brief study has been done in order to know the different types of GCS that currently exist. There are lots of GCS types, depending on the scope of the RPAS that has to be controlled, the project budget or the mission requirements. Given these characteristics, the scope of the GCS will be defined.

Once stablished the scope of the GCS, its different components will be determined. From the microprocessor to the Liquid Cristal Display (LCD) controller, the components will be listed and described, as well as its characteristics and advantages against other options. Also, the process followed to design some of the parts such as the power system will be explained.

Apart from the hardware the Ground Control Station also needs software to operate. The different software and operating systems installed and used will be described onwards, as well as installation methods.

Once the different parts are defined, Solid Works® 3D design program will be used for stablishing the physical design of the GCS. Considering the available space given by the scope of the project and the amount of elements to be fitted and connected, a realistic design will be made. This design will be used later on to build the actual GCS. The building process will be briefly shown and the GCS will be tested.

Finally, a conclusion will be made in order to stablish the viability of the project, taking into account the already existing platforms currently used as well as the power consumption and battery endurance, weight, price and technical performances.

# INDEX

# I. INTRODUCTION

Nowadays, the use of Remotely Piloted Air Systems (RPAS) use is rising. Due to this fact, lots of companies are investing in this field and providing new uses for RPAS platforms. This new trend provides lots of market opportunities in this area, not only on RPAS sells but also on the surrounding systems that are needed to operate them. Here is where the Ground Control Station GCS fits in.

Along this project, a GCS will be designed not only to operate RPAS but to make a difference regarding commonly used GCSs. To do so, the current market has to be studied.

To sum it up, the GCS market is divided in three different blocks, small, medium and large RPAS GCSs.

The first ones are typical laptops with the adequate software installed and taken to the flight field. This GCSs are cheap but lack lots of useful systems that have to be added apart. Moreover, battery life not always allows to perform long range RPAS missions.

The second ones are proper GCSs equipped with systems such as First Person View (FPV). Nevertheless, they are quite expensive and not affordable for small RPAS companies or amateur users.

And last but not least, large RPAS need big GCSs, such as Ikhana's GCS provided with state of the art technology such as satellite communications. These GCS are beyond this project reach.

In this project, a medium low-cost GCS will be built. The **objective** is to achieve a fully working GCS with all the necessary systems at a lower price than existing medium GCSs and with enough battery life to operate a medium range RPAS.

Once the market opportunity is known, its different components will be selected and installed, the necessary software will be provided and the GCS will be built.

Furthermore, a brief description of the used RPAS will be made, containing the platform, hardware and software used.

Once the GCS is built, it will be tested and the objectives will be validated.

# II GCS TYPES AND PROJECT SCOPE

To begin with, a study of the currently existing Ground Control Stations has to be made in order to define the scope of this project.

From small Remotely Piloted Aircraft Systems such as quadcopters to large ones like NASA's Global Hawk, all RPAS need some kind of control station from where a pilot can control the unmanned aircraft and the mission information can be received.

Later on, different GSC types will be described in order to find the suitable scope for our GCS.

## II.I GCS Types

The GCS complexity is directly related with the mission requirements. UAS missions can be classified according to flight altitude and endurance. [1]

### II.I.I LASE: Low altitude, short endurance missions.

These are the most common missions performed by civil RPAS such as quadcopters.

There are two LASE categories, Handheld and Close missions.

On the one hand, Handheld missions reach about 600 m altitudes and 2 km ranges, these missions do not need a highly complex GCS, as the RPAS is always in the line of sight of the pilot. The GCSs general characteristics are:

- Open source software
- Open source communications protocol
- Omnidirectional antenna
- 2.4 GHz Remote control for pilots

The typical problems with this kind of GCS are the battery endurance and the communications range. It is also necessary to add extra hardware to improve these characteristics or to achieve, for instance, real time camera view.

These GCS are typically laptops with the necessary programs installed, so their price depends on the laptop used. It can be considered a 500 € cost for an average laptop price.

**Figure 2.1:** LASE Ground Control Station

On the other hand, Close missions have a larger range, up to 10 km. GCSs for this missions are more complex and have adequate systems such as directive antennas and FPV camera view.

Nevertheless, with a cost about 5000 €, these GCSs are too expensive for a small RPAS companies or amateur RPAS users

### II.I.II LALE: Low altitude, long endurance missions.

These missions are commonly performed by research or military teams with aircraft such as Predator A RPAS with up to 200 km range.

From this mission type forward, GCSs tend to be much more complex than LASE mission GCSs, having redundant systems for safety reasons and absolute control of the RPAS.

**Figure 2.2:** LALE Ground Control Station

For example, Ikhana's GCS characteristics are [2]:

- Dual pilot control station
- Electronic navigation charts
- Weather information
- Engineering, science and safety work stations
- Remote video from aircraft
- Satellite communications
- Redundant receiver and transmitters with worldwide range.

### II.I.III MALE: Medium altitude, long endurance missions.

Reaching up to 9000 m altitude and 200 km range these are high complexity missions. With RPAS such as Predator B, these missions need a considerably complex GCS, not only to maintain the communications but also the aircraft control.

Furthermore, the ground control station has to be able to control the aircraft payload, as these RPAS are used as military weapons.

**Figure 2.3:** MALE Ground Control Station

### II.I.IV HALE: High altitude, long endurance missions.

These missions can reach over 9000 m altitudes and they have an undefined ranges.

With RPAS such as Global Hawk or Ikhana (NASA), these missions have a great complexity and as a result, GCS reach the same complexity level.

Given these characteristics for both simple and complex Ground Control Stations, in this project, a LASE Close GCS will be designed.

The objective is trying to solve the current problems of LASE GCSs such as battery endurance, real-time video support and range while reducing the total cost of the system. To sum it up, in this project the gap between LASE Handheld and Close GCSs will be filled.

With these objectives in mind a GCS will be designed, trying to achieve all these functions while looking for an easy to handle format.

To achieve this format, the GCS will be built inside a typical tool suitcase, as the inside volume would be enough to fit all components easily as well as being easy to carry.

# III GCS Components

Once the objective of the project is set, it is necessary to define the components needed.

First of all, a CPU will be needed to execute the Ground Control Station software and to process the real time images from the RPAS, once a First Person View (FPV) system receives them.

Also, a power supply system has to be able to provide different voltages for different components, as well as a display has to show both the ground control station program and received images.

Finally, an Antenna Tracking system must follow the RPAS while flying in order to achieve the maximum range.

## III.I Processor

As the processor is considered the most important part of the GCS, it must be powerful enough to both run a ground station program and displaying received images.

Even though, it has to be as cheap as possible so the minimum cost is achieved.

Different suitable options were studied:

### III.I.I Mini/ Nano – ITX boards

Meaning Information Technology Extended, Mini - ITX and Nano - ITX are very small PC mother boards.

Characterized by their small footprint, these boards were designed to power low-consumption systems but have improved their performance through the years.

They are used in all kind of projects such as vehicle on-board computers and have become very popular.

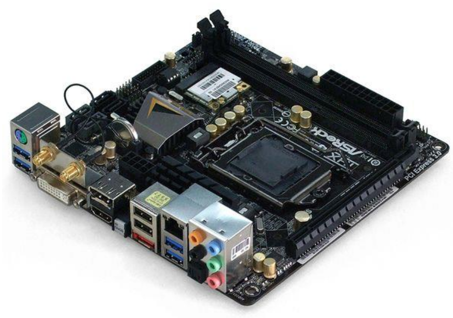

**Figure 3.1:** Mini ITX Board

Even if their performance is more than enough for this project, their price is about 100 € so they were discarded.

### III.I.II Intel Galileo [3]

Intel Galileo is an Arduino Board with an Intel CPU.

These boards are very useful to create applications and programs that use Arduino analogic and digital pins for sensors and process more data in a faster way using Intel processor.

This microprocessor boards use Windows 10® Internet of Things operating system. Given so, a personalized program or application must be created or installed.

**Figure 3.2:** Intel Galileo Board

Nevertheless, Mission Planner ground station program, that was expected to be used, was not available as a Windows 10® IoT application. (See chapter IV.I)

The price for this boards is also high, from 60 € to 90 € depending on the board model.

### III.I.III Raspberry Pi 2 Model B [4]

Raspberry Pi (RPi) is a microprocessor, a simple board computer designed to educate about computing science.

Raspberry Pi is built with all the necessary components to work as a computer, as Mini ITX or Nano ITX. Also, free software is provided as well as lots of open source programs and codes to apply this microprocessor to any project.

**Figure 3.3:** Raspberry Pi 2 Model B Board

A reduced version of Linux Operating System (OS) is available and can be installed, as well as Mission Planner software to operate the GCS for the last RPi models (RPi 2 Model B).

The price can vary depending on the model like Intel Galileo Boards, but Raspberry Pi 2 is cheaper, about 40 € for model B.

To sum it up, both Mini/Nano ITX and Raspberry Pi 2 boards can have an operating system installed capable of running Mission Planner software, but Raspberry Pi 2 is cheaper and also smaller.

To conclude, Raspberry Pi 2 board is the most suitable processor to be used in this project.

## III.II Display

As it can be supposed, a display for the GCS is needed. Even if it seems a logic choice it is not, as there are a lot of options to study.

The functions of the display are showing the GCS software and received RPAS real time images. It has to be considered if those functions will be performed by the same display or not. Also the video format given by the Raspberry Pi and Video Receiver has to be taken into account, as the microprocessor display output is a HDMI port and the receiver's is a RCA connector.

Different options were considered.

### III.II.I Two different monitors

First of all, two different displays where thought to be a good option. Each of the displays would have the appropriate connectors and would be fitted into the GCS suitcase.

The main problem for this option was the display prices. For instance, the price for a 15 inch monitor ready to be connected was about 70 €. Also the weight of a monitor is excessively heavy.

Apart from the price, the second main problem was to fit both monitors into the GCS suitcase.

For those reasons, this first option was discarded.

### III.II.II GCS monitor plus external connection

As the suitcase space was not wide enough to fit both of the monitors, it was thought to provide an external USB connection in order to display FPV images on an external device such as a smartphone.

In this case, the user would have to add this external device not included on the GCS. Apart of this issue, a third party mobile application would have to be installed on the device in order to use it as a display.

Given these inconvenient as well as the GCS monitor price, this option was also discarded.

### III.II.III Single monitor

As in the previous case an external device was needed, another option was considered.

Adding the video processing function to the processor functions, no external device was needed and a single monitor could be used. Even so, a video processing software had to be installed into the microcontroller (See chapter IV.III). Also, as the price was still an issue, another display option was considered.

In this case, a typical laptop display would be used, as they are cheaper and fully available. For example, the price for the same 15 inch size display for a Liquid Crystal Display (LCD) screen is about 25€.

Even so, the HDMI output from the Raspberry Pi 2 is not directly supported by the LCD display, so a display controller would have to be used.

This option was chosen above the others, not for its simplicity but for being the cheaper option as well as the lightest.

#### *III.II.III.ILCD interface and Display Controller*

Given the size of the GCS case, a 15 inch interface was chosen. In this case, a LP154WX4 1280x800 LCD screen. *See annex 1: LP154WX4 Liquid Crystal Display.*

Once the LCD display was chosen, a compatible controller board was purchased. In this case, an Nt68676 controller.

This controller board can support LED and LCD interfaces up to 2048x1152, more than enough for our LCD display, synchronizes automatically and supports interface options such as contrast and brightness controls. Also, different video inputs are supported, as well as an inverter output is available if the interface needs it. More characteristics can be seen on annex *2: Monitor Control Board Specidication.*

## III.III Video Receiver

In order to achieve real time images from the RPAS, a FPV system must be installed.

The different parts of the FPV systems are:

- On-board Camera
- Video transmitter
- Video receiver

While most of the system is located on the RPAS, only the receiver and its respective antenna have to be fitted in the GCS.

The function of this system is simple. A small camera located on the RPAS captures images. Those images are sent through a 5.8 GHz radiofrequency connection. The images received on the GCS are processed by the microcontroller through a RCA USB adaptor and displayed on the LCD interface.

## III.IV Power Supply System [5]

Once the rest of the GCS are chosen, a Power supply has to be designed so all the components are provided with the adequate voltages.

In this case, not only a single power source was considered but two of them.

On the one hand, the GCS is expected to use a battery to be able to work autonomously. In this case, all the systems will be powered by the battery.

On the other hand and as the battery must be charged, the power supply was designed to be able to connect with the electric network. When this happens, all the components are fed by the electric network while the battery is charged.

The next table shows the different voltages and consumptions of each component:

**Table 3.1:** Components consumption

| Component | Voltage needed | Consumption |
|---|---|---|
| Raspberry Pi 2 | 5 V | Up to 2 A |
| LDC Controller | 12 V | 1 A |
| Video Receiver | 12 V | 200 mA |

### III.IV.I Battery

Now that the components consumption is known, an adequate battery must be chosen. Both lithium polymer and lead batteries were studied:

- LiPo Battery:

This kind of battery is very light and have a very stable discharge rate, but their capacity is not enough for the GCS consumption, and the available time for the mission would be too low. Also, charging a LiPo battery is a complex function, as it may explode if overloaded.

- Lead Battery:

On the other hand, lead batteries are heavier. Even so, their capacity is greater and can be charged giving a fixed voltage between its terminals.

As in this case autonomy is more important than weight, a lead acid battery was chosen. A Ritar® RT1270 battery with 7 AH / 20 HR capacity, with a charging voltage and consumption of 13.8 V 1.4 A. This will have to be considered when designing the battery charger.

Once all the power supply functions are known and the battery to be used is chosen, the different parts can be designed.

### III.IV.II AC/DC converter

The GCS must be able to be connected to electric network, so an alternating to direct current converter must be installed.

A simple converter was designed to take 230 V 50 Hz electric network current and to give a direct 12 V output. To do so, first of all a transformer would reduce 230 V to 12 V alternating current, and then a diode bridge with two 1000 µF parallel capacitors would rectify the signal so a direct 12 V current is achieved.

The AC/DC converter scheme is shown:

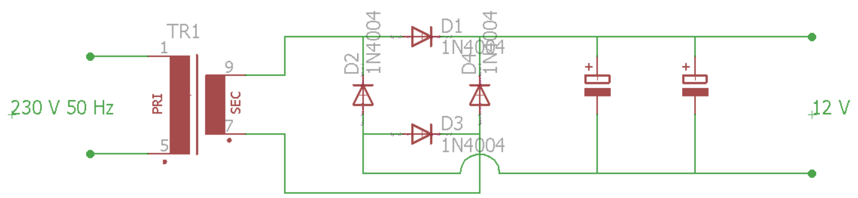


**Figure 3.4:** AD/DC converter scheme

Once the AC/DC converter is designed, the rest of the power supply components can be studied.

### III.IV.III 12 V and 5 V Voltage regulators

Even if the AC/DC output is already a 12 V direct current source, a regulator must be done in order to ensure the voltage stability, protecting the GCS components from voltage peaks. Furthermore, when using the battery as the power source, the voltage is not constant, so a 12 V regulator is needed.

On the other hand a 5 V regulator is needed in order to feed the microprocessor with the adequate voltage.

In order to design both voltage regulators, different options were considered.

### *III.IV.III.I Linear Regulators*

Linear regulators are an easy way to achieve a voltage regulator. Even so, their efficiency is lower than commutated regulators and a voltage differential (ΔV) between the input and the output is needed to make them work properly.

$$\Delta V = V_{in} - V_{out}$$

For example, a LM138/LM338 linear regulator, needs a ΔV between 5 V to 10 V in order to achieve its maximum output current as the next figure shows:

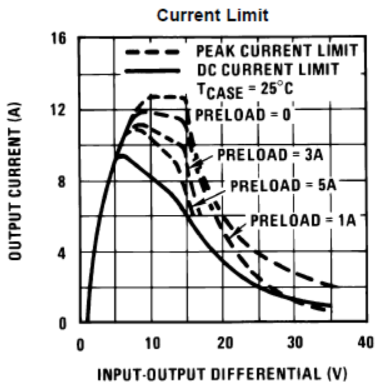


**Figure 3.5:** Output current vs Input-Output differential voltage graph

This characteristic would not be a problem for 5 V regulator, although the efficiency would be very low.

$$\eta = \frac{V_{out}}{V_{in}} * 100\% = \frac{5}{12} * 100\% = 41.67\ \%$$

Given these characteristics, a linear regulator was discarded and a switching regulator option was studied.

### *III.IV.III.II Switching Regulators*

As a linear regulator could not be used to make a 12 V regulator from a 12 V source and the 5 V regulator efficiency was very low, a switching voltage regulator was studied.

To design both 12 V and 5 V regulators, the WEBENCH® Dessigner software was used.

This software, provided by Texas Instruments Company allows to design power supply circuits in a very simple way.

By fixing input and output voltages, output current, efficiency, circuit footprint and component's cost, the program automatically designs a suitable power supply circuit, allowing to save the circuit schematic and even download a .CAD file.

By using this useful tool, the next schemes were designed:

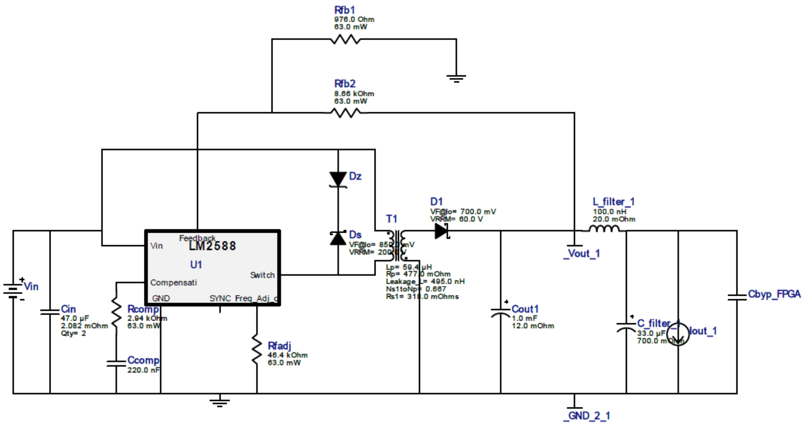


**Figure 3.6:** 12 V Switching Regulator

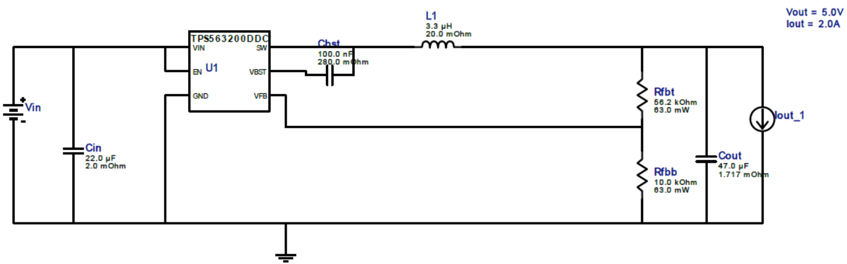


**Figure 3.7:** 5 V Switching Regulator

Apart of generating the circuit schematic, this software generates a project report with all the needed information about the circuit electronic components; as well as different graphics such as the integrated circuit duty cycle or the circuit efficiency depending on the output current. *See annex 3: Power supply voltage regulators.*

### III.IV.IV Battery Charger

As said before, it is needed to charge the battery while the GCS is connected to the electric network. To do so, a battery charger circuit was designed.

In this case, a LT1513 integrated circuit was used.

This integrated circuit is also a regulator. Nevertheless, it has a current sense feedback pin that controls the charge level of the battery, stopping the charging process once the battery is fully charged.

One of the most advantages of this charger is that its input voltage may be higher, equal or lower than the battery charger voltage, so it can be directly connected to AC/DC converter output.

This charger circuit is a simple standard circuit that can be adapted to charging voltage of the battery simply by configuring two resistors. R1 and R2. See figure 3.8:

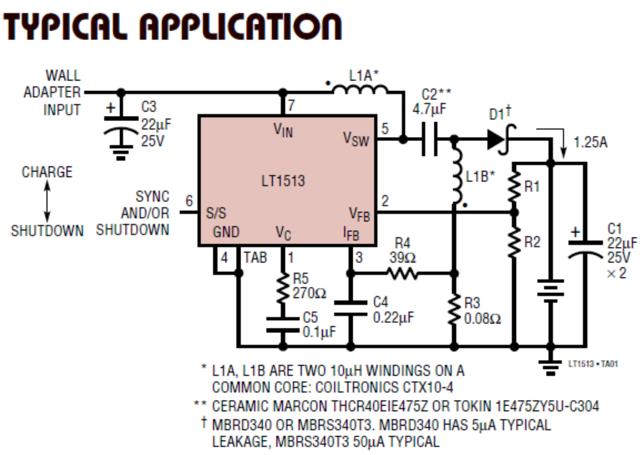


**Figure 3.8:** Battery Charger

The typical suggested value for R2 is 12.4 kΩ, so a 12 kΩ resistor will be chosen.

The value for R1 is given by the next equation:

$$R1 = \frac{R2 * (V_{bat} - 1.245)}{1.245 + R2 * 0.3\mu A} = \frac{12k\Omega * (13.8V - 1.245)}{1.245 + 12k\Omega * 0.3\mu A} = 120\ k\Omega$$

Where $V_{bat}$ is the battery float voltage, 1.245 V is the reference feedback voltage and 0.3 µA is the feedback pin bias current.

For more information about the battery charger circuit, *See annex 4: Power supply battery charger.*

## III.IV.V Final Power supply circuit

Finally, once all the different parts of the GCS power supply were defined, a global schematic was done.

As the power supply system was designed to work in two different ways, it was necessary to combine both functionalities. To do so, a relay is installed at the input of the voltage regulators.

When the GCS is not connected to the electric network, the relay is not active, and connects the battery terminals directly to the voltage regulators. When the GCS is connected, the relay is activated, commuting the input of the voltage regulators to the AC/DC converter output.

On the other hand, the battery charger input is connected only to the AC/DC converter, so when the GCS is not connected to the electric network, the charger circuit does not work.

In addition, a switch was installed between the voltage regulators and the relay, so it could be possible to charge the battery while the rest of the systems are off.

Finally, two fuses were installed at the alternative current entry and after the voltage regulators switch, in order to protect the whole power supply system against short-circuits.

When all these requirements were defined, a global scheme with the real component connections was made using Eagle® Printed Circuit Board (PCB) Design Program.

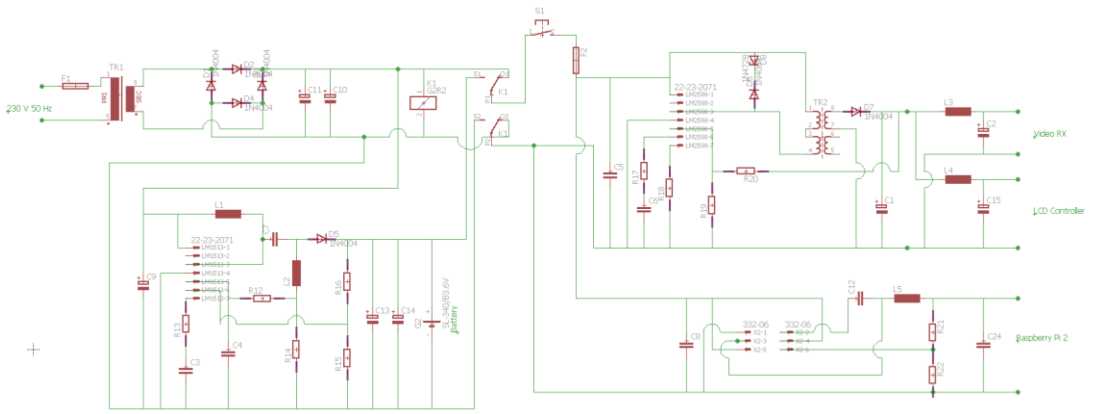


**Figure 3.9:** Final power supply circuit scheme

Once the circuit scheme is made, the PCB can be designed.

With this process, the construction of the power supply circuit is much easier, as the circuit tracks can be automatically drawn and edited if needed.

In the next figure the final PCB design and the real prototype can be seen. Note that both the battery and transformer are not on the PCB design but their connections are. This is because these components are situated separately from the power supply circuit board.

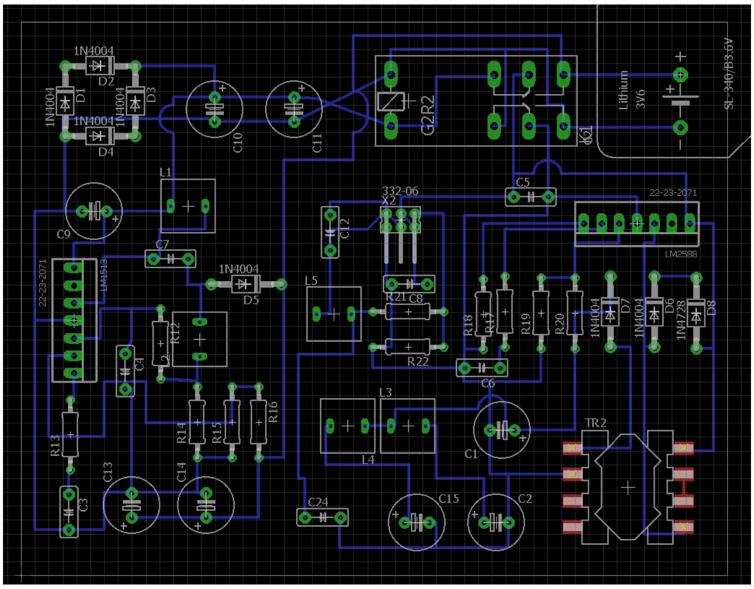

**Figure 3.10:** Final power supply circuit board

Once the PCB design is ready, the real prototype will be built. This will be explained later on chapter VI.

## III.V Antenna tracking [6]

Another of the desired characteristics of the GCS to be designed is an antenna tracking system. By providing the GCS with a directive antenna, the RPAS range can be increased.

The antenna tracking system parts are explained below:

### III.V.I Antenna

First of all, a suitable antenna must be selected.

As the telemetry data has to be sent on 433 MHz band, the antenna has to be designed to work at this frequency. Also, it has to be as light as possible to ease its transport.

However, the working frequency sets the antenna dimensions and it is not possible to change it.

In this case, a Yagi directional antenna was chosen. Measuring 74 x 47.5 cm it is a considerably large antenna. Nevertheless its weight is low as it is made of aluminium.

### III.V.II Tripod and gimbal

The antenna has to be capable to move in order to follow the RPAS. To do so, a simple tripod is provided with a gimbal pan. While the tripod ensures a good support for the antenna, the gimbal pan allows it to move.

Nevertheless, not all gimbals can be used for this purpose. Different requirements must be achieved.

- Range of movement

The gimbal must be capable to follow the RPAS as it flies. So it is necessary to know how will the RPAS fly besides the GCS and which yaw and pitch angle ranges are needed.

If the RPAS can fly in all directions, the antenna must be capable of turning 360º in yaw, but, in this case the RPAS will only fly in front of the GCS, so only a 180º range of movement is needed.

On the other hand, pitch angle range is only needed to be 90º, as the RPAS will be always at the same level or higher than the GCS.

- Power

The Gimbal must be capable of moving the antenna. If the antenna is too heavy for the gimbal, the system will not work properly.

With these characteristics taken into account, a heavy duty gimbal pan was purchased, powered by two servos with 160º angle range each. In consequence, yaw movement will be limited when designing the flight plan. Nevertheless, the 20º range difference is relatively low and is not expected to be a problem.

Once the gimbal is selected, a controller must be installed.

**Figure 3.11:** Final power supply circuit board

### III.V.III Controller

In order to move the gimbal accordingly to the RPAS position, a controller must be installed.

This controller must be able to adjust both pitch and yaw antenna angles in order to aim directly to the RPAS.

Different options were possible to achieve an antenna tracker controller.

- Arduino board

An Arduino board could be programed to read RPAS telemetry data. This data contains information about the RPAS sensors like pitch, yaw, roll, GPS position and ground speed. Knowing the RPAS and GCS position, the RPAS direction from GCS can be computed and used to aim the directional antenna.

Even so, a code must be created to do those functions, which increases the system complexity.

- Mini APM

Mini APM is a reduced version of an ArduPilot Mega controller board. This board was considered as a good option due to its low price and small size. Nevertheless, this controller board does not support Antenna Tracking firmware, so it was not possible to use it.

- Pixhawk

Pixhawk is a powerful programmable controller board used for controlling rovers, copters and planes. It also can be used as an antenna tracking controller.

By using Pixhawk board, there is no necessity of programing, as an already existing code can be loaded in the board. Nevertheless, Pixhawk is more expensive than any Arduino board.

**Figure 3.12:** Pixhawk controller board

In this case, the controller will be a Pixhawk clone controller board with the antenna tracker software provided by ardupilot. This open source software will be explained in chapter IV.

By using a clone board, the same characteristics are achieved but the price is lower.

### III.V.IV Power

The antenna tracking system is powered by a secondary battery. This simplifies the main power supply system as well as improves the GCS main battery life.

This secondary battery is a 11.1 V tree cell Litium Polimer battery, with a 2700 mAh capacity. Its function is to provide power to the antenna tracker controller and servos.

As in the GCS main power system, a voltage regulator is needed in order to power the Pixhawk with 5 V. Nevertheless, in this case a small ready-to-use regulator will be used. Also, a 3 A Universal Batery Eliminator Circuit (UBEC) is used to power the servos independently, as the Pixhawk board does not power them.

# IV GCS Software

At this point, all the different GCS components are defined and chosen. Nevertheless, the system can not work without the adequate software installed on the microprocessor and the different components.

In this case, a ground station and a video processing software are needed for the microcontroller. But first an operating system must be installed.

## IV.I Operating System

First of all, an operating system has to be installed on the Raspberry Pi 2. This operating system has to be powerful enough to handle ground station programs and run them properly.

Two different options were studied.

### IV.I.I Windows 10 Internet of Things [7]

Windows 10 Internet of Things (IoT) is a Windows 10 version optimized for small devices such as Intel Galileo or Raspberry Pi 2 and 3.

The main advantage of W10 IoT operating system is that the applications can be executed in all different types of Windows 10-using devices. For instance, the same application that is installed on a Windows 10 phone can be executed in a Windows 10 laptop and even a Raspberry Pi.

Nevertheless and as explained before, there is no created application of Mission Planer ground station program available in this software. Also, creating a GCS application for scratch was not an option due to the complexity of the code and no other ground station applications were available.

Due to this problem, another option was considered.

### IV.I.II Raspbian Jessie [8]

Jessie is the most recent version of Raspbian operating system based on Debian Linux, and it was created specifically for Raspberry Pi. This is the most complete and best performance Raspbian operating system nowadays.

Raspbian Jessie is an open source operating system, so lots of free content are available and can be used freely. What is more, a Mission Planner Jessie-adapted version is available.

Given these options, the chosen OS to be used is Raspbian Jessie, which can be obtained directly from Raspberry Pi web site.

#### *IV.I.II.I Raspbian Jessie Installation*

There are two methods of installing Raspbian Jessie operating system on the Raspberry Pi. “NOOBS” method and advanced method. In this case, the advanced method was used and the different steps followed will be explained below.

1. Download the image

First of all, the operating system image has to be downloaded. This is done from the official Raspberry Pi page: “wwww.raspberrypi.org/downloads/” from where Raspbian image will be downloaded.

Once downloaded, the image must be written in an SD card.

2. Writing the image to the SD card.

To do so, different methods are possible. In this case, as the computer used to write the image is using Windows operating system, a Windows tool will be used.

This tool is the Win32DiskImager. That can be obtained from “sourceforge.net/projects/win32diskimager/”.

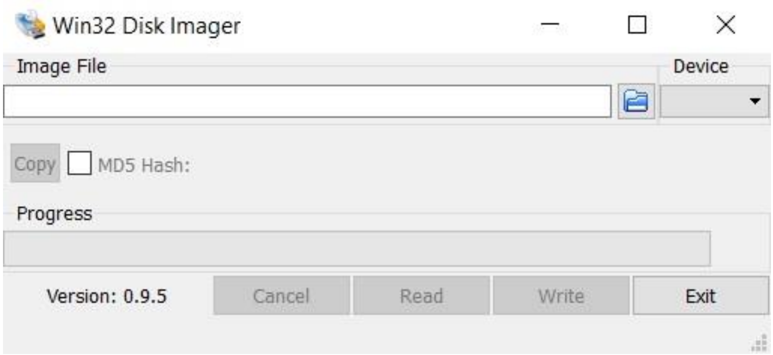


**Figure 4.1:** Win32DiskImager program window

Once the SD card is plugged into the PC, the Win32DiskImager tool is executed. The SD card and the desired image are selected and the image is automatically written into the SD card.

3. Setting up the operating system

Once the SD card is loaded with the operating system, it is plugged into the Raspberry Pi and turned on. The Raspberry Pi will automatically initiate the installation process and the operating system is ready to use.

## IV.II Ground Station software

Nowadays, there are lots of different ground station programs, from amateur programmed software to professional ones. For this project a fully operative program was needed, but a professional and expensive software could not be afforded. Nevertheless, there are different options left.

### IV.II.I QGroundControl [9]

QGroundControl is a fully operative open source ground station software, compatible with the most common flight controllers and any device using MAVLink wireless communications.

This program is available for Windows, MacOS and Linux operating systems. Some of its characteristics are listed below:

- 2D/3D Maps
- Flight plan design and load
- In-flight parameters and waypoints manipulation
- Multiple flight controller support
- Real time sensor plotting
- MAVLink protocol

This software is currently at Beta state, and it is not ensured that it is Raspbian Jessie compatible, as this is a reduced version of Linux.

However, other options were available

### IV.II.II Mission Planner [10]

Mission Planner is an open source ground station application. It has all the main functionalities that a GCS needs.

This software is capable of monitor both plane and copter RPAS or Remotely Piloted Ground Systems (RPGS) such as rovers, so our GCS will also be adaptable to any kind of RPAS.

Mission Planner is only compatible with Windows, but similar versions called APM Planner are also available for Linux or MacOS. Moreover, it is continuously upgrading and adding new features.

The APM Planner features are:

- Loading firmware to the flight controller
- Controller configuration and calibration
- Compatible with most common flight controllers
- Controller configuration and calibration
- Plan, save and load flight missions
- MAVLink protocol

As Raspberry Pi 2 will be used with a Linux based operating system, Raspbian-compatible version of Mission Planner will have to be installed. Luckily, an APM Planner experimental version designed specifically for Raspberry Pi 2 and Raspbian Jessie operating system is available, so this software will be used.

Nevertheless, the main disadvantage of open source operating systems and programs are the installation problems, which are a constant issue. Even so, APM Planner was successfully installed on the Raspberry Pi 2.

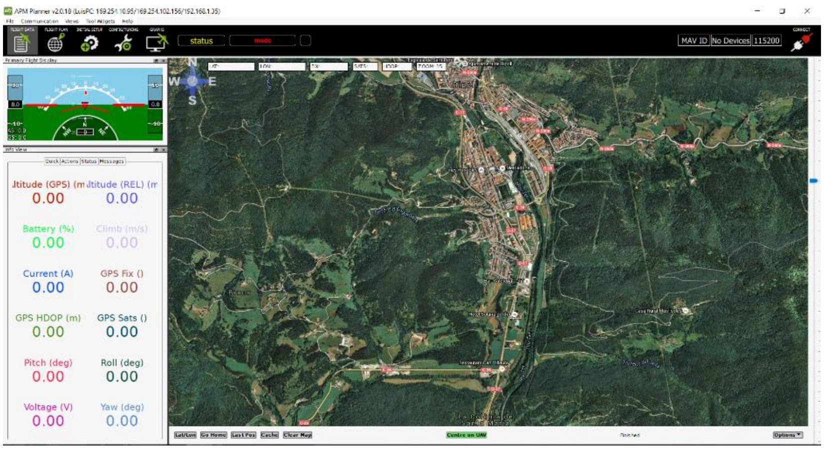


**Figure 4.2:** APM Planner 2 program window

### *IV.II.II.I APM Planner installation*

There are several ways to install APM Planner on the Raspberry Pi.

First of all, the APM Planner 2.0 Raspberry Pi Experimental was downloaded from the official web site and the installation was tried. However, there were several errors and it was not possible to make it work.

As the first option failed, it was tried to build the program from the source code. To do so, different steps were followed: [11]

1. First, the 8 GB SD card was substituted by a 32 GB one. Then, a 4GB memory swap was done, allowing the Raspberry Pi to use it and have a greater RAM memory so APM Planner program could be run.

   The different commands used to make the memory swap are the next:

- Locate an area on disk where to place the swap file, in this case /root location.
- Use the dd command to create the swap file under the desired directory: “dd if=/dev/zero of=/root/swap bs=1M count=512”
- Now it is necessary to change the permission of the file so only /root directory can access it: “chmod 600 /root/swap”
- Make a swap file of this file using mkswap command: “mkswap /root/swap”
- The created file has to be enabled: “swapon /root/swap”
- Finally, to make this file available after rebooting the Raspberry Pi, the /etc/fstab file has to be modified adding the following line: “/root/swap swap swap defaults 0 0”

Now that more RAM memory is available, the APM Planner program can be installed.

2. The required program packages have to be installed using the following command: “sudo apt-get install phonon libqt4-dev \ libphonon-dev libphonon4 phonon-backend-gstreamer \ qtcreator libsdl1.2-dev libflite1 flite1-dev build-essential \ libopenscenegraph-dev libssl-dev”.

   It is important to ensure that every package is installed, as if one of them gives an error, none of them will be installed.

3. Now the source code must be cloned in the desired directory. In this case, a workspace folder will be created in desktop: “cd ~/workspace git clone https://github.com/diydrones/apm_planner”.

4. Once the source code is cloned, it can be built. To do so, the following commands are used: “cd ~/workspace/apm_planner qmake-qt4 qgroundcontrol.pro” and “make”.

   This process can last a long time, but at the end, the program should be installed.

5. Finally, to run APM Planner, the next command is written at the terminal: “./release/apmplanner2”.

After all these steps, several errors were found and overcome but after lots of tries, it was not possible to make it work.

These kind of problems are common when working with open source programs and when building programs from the source code. Nevertheless, it is necessary to keep trying.

Due to the release of another version of the program (2.0.18), another chance was given to the first method.

The same steps were followed but, this time no errors were faced and the program was installed without any problem.

APM Planner 2 was working fluently on the Raspberry Pi 2.

## IV.III Video Processing

As explained before, in order to use a single display for the GCS, the video received from the RPAS has to be processed by the microcontroller. To do so, an RCA to USB adaptor was needed.

It is very important to know which adaptor is used, as the driver is specific for each chipset. In this case a USBTV007 EasyCap clone was used.

First of all, it was needed to know if the RCA to USB adaptor is recognized by the Raspberry Pi. To do so, the “lsusb” command is used to list all available USB devices. If this command is done, the device should be recognized as “Bus 001 Device 012: ID 1b71:3002”.

Once recognized, to be able to see the images coming from the video receiver, a compatible program must be installed on the microcontroller. As usual in open-source operating systems, a bit of research was needed to find the adequate program to use. For this purpose, some options were tried.

### IV.III.I Luvcview

Luvcview is a simple viewing application that recognize video signals from USB ports and displays them in the Raspberry Pi screen. This program does not support audio, However, in this case is not needed.

The program was easily installed using an installing command: “sudo apt-get install luvcview”

Nevertheless, this program only supports up to 640x480 pixel images and the received video was 720x480. Furthermore, it would not recognize the USB device, so other programs were tried.

### IV.III.II MPlayer

MPlayer stands for Media Player. This program does the same function as Luvcview, but it also supports audio.

As in the previous case, a simple command line was used to install it: “sudo apt-get install mplayer”.

Once the program was installed and executed, another command has to be typed to make it run:
"mplayer tv:// -tv device=/dev/video0 -hardframedrop".

This command calls mplayer tv function (-tv) and gives it an input identification (/dev/video0) with an additional option (-hardframedrop).

Using this command a real time video is successfully displayed in the Raspberry Pi screen.

## IV.IV Antenna tracking [6]

Antenna tracking software, as mission planner, is an open source software provided by ardupilot.

The way this program works is simple. The antenna receives the telemetry data from the RPAS, which goes through the antenna tracking controller to the GCS by an USB cable. Also, the controller uses this information to adjust the servo position in order to correct the aim and be able to follow the RPAS track.

The antenna tracking software was installed using the Windows version of Mission Planner. A simple step by step installation and configuration can be done.

1. First, the gimbal servos, GPS and external compass were connected.

   Note that the servos must be fed independently with a BEC/ESC regulator, as explained in chapter III.V.IV.

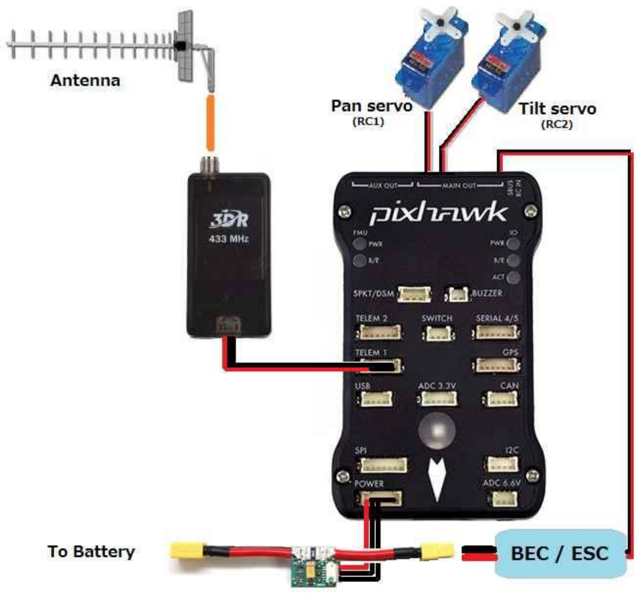


**Figure 4.3:** Antenna tracking controller board mounting

2. Then, the Pixhawk clone was connected via USB with the PC, and the antenna tracker firmware was loaded into the board.

3. Once connected, the Antenna tracker was configured.

   - If the controller is not aligned with the antenna direction, it is necessary to set the actual orientation when configuring. In this case, this is not necessary.

   - Compass orientation has also to be set if not aligned with the antenna direction. In this case, a 180 yaw orientation is set.

   - Once correctly oriented, compass is calibrated using Mission Planner live calibration. This calibration records different points while moving the compass to compute the compass offsets.

   - Next, the servo pitch and yaw range of movement is set. To do so, the Extended Tunning page of Mission Planner calibration tab is used. By modifying the maximum and minimum Pulse Width Modulation signal, the maximum range of movement is set.

When these characteristics are set, the antenna tracking is ready to use.

# V Mechanical Design and Component Integration

Once all the components are defined, properly power supplied and all the software is installed and working, the GCS physical design must be done.

Solid Works® design software was used to build a 3D model of the GCS, also helping to define the components distribution inside the GCS.

It is important to fit all the components in an easy to handle case, in order to ease its transportation and use. For this project a LASE GCS was intended to be created, so a suitcase was chosen to be used as container.

Next, the different steps followed to design the GCS and Build it are explained.

## V.I Component Measurements

First of all, all the component sizes had to be measured and written down, so the better component distribution could be found and the Solid Works® design was as realistic as possible.

All the component sizes, from the LCD display to the AC/DC converter transformer are listed below.

Note that these are the most representative measurements. Other measurements such as suitcase rounded edge radius are also used but are not represented in the table.

**Table 5.1:** Component measurements

| Parts | Length (cm) | | Width (cm) | | Height (cm) | |
|---|---|---|---|---|---|---|
| **Suitcase** | 43.5 | 45.6 | 31.3 | 33.2 | 10.2 | 5.1 |
| **Raspberry Pi 2** | 10 | | 5.6 | | 1.7 | |
| **Display** | 34.5 | | 0.7 | | 22.3 | |
| **LCD Controller** | 14 | | 5.8 | | 1.5 | |
| **LCD Inverter** | 12.3 | | 2.75 | | 1.2 | |
| **LCD Options board** | 11 | | 1.9 | | 0.8 | |
| **Video RX** | 8 | | 6.5 | | 1.5 | |
| **Keyboard** | 35.5 | | 14.2 | | 2.1 | |
| **Power supply circuit** | 15.5 | | 9 | | 4 | |
| **Transformer** | 7 | | 5 | | 6 | |
| **Battery** | 15 | | 6.5 | | 9.2 | |
| **Fan** | 5 | | 1 | | 5 | |

With these measures, the internal configuration can be done.

## V.II Internal components configuration

Before all the measures were taken, lots of configurations were considered. But once the power supply circuit and other initially unknown measurements were known, the possible configurations were reduced. Next, two of these configurations are explained.

### V.II.I First Component Configuration

As the battery is the heaviest component of the GCS, it was located at the bottom of the suitcase, so its weight is supported by the suitcase itself and not the interior structure. The transformer is heavy as well, and in a first instance was located next to the battery.

Placing all the heavy components at the bottom of the suitcase makes the GCS transportation much more comfortable.

The power supply circuit and the microprocessor were thought to be placed side by side, installing one fan at each end. With this configuration, an air flow would refrigerate both components.

The microprocessor's USB and Ethernet connections were thought to be accessible from the outside, so the Raspberry Pi was located at the suitcase side.

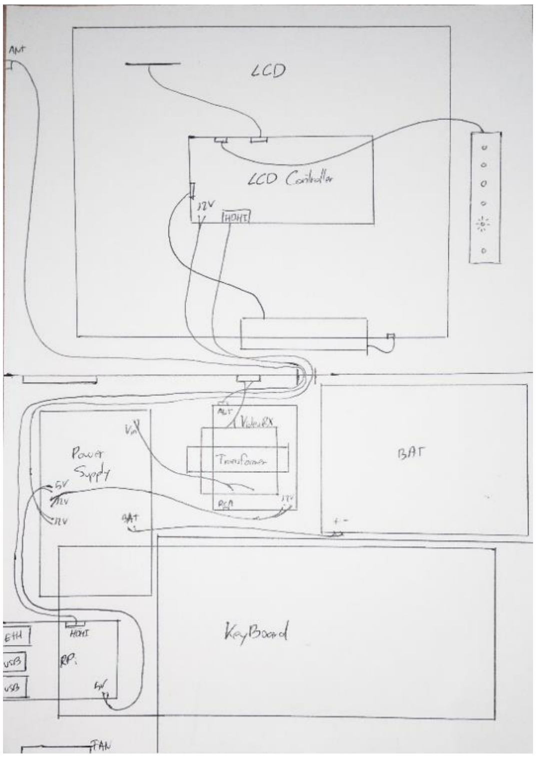


**Figure 5.1:** First component configuration design

Also, a storage compartment was considered in order to store the different removable pieces such as the power cable or the Video 5.8 GHz antenna.

On the other hand, all the related LCD components and the video receiver antenna were located on the suitcase upper side, connected with microprocessor video output, power supply and video receiver by the corresponding cables. This way, the antenna is not shielded by the suitcase itself and the signal is not interfered.

Finally the keyboard and the video receiver were located at the suitcase base, on top of the other components.

This first design scheme is shown in figure 5.1.

Besides all the design considerations, there were some troubles.

First of all, some of the microprocessor USB connections were to be used by the keyboard and the RCA to USB adaptor, so it would not be useful to connect and disconnect these components every time the GCS had to be transported.

Furthermore, the HDMI cable connected to the Raspberry Pi was too big and interfered with the power supply circuit.

Due to this troubles, another internal configuration was considered.

### V.II.II Second Component Configuration

By using a USB Hub and an Ethernet cable, the microprocessor was no longer needed to be accessible from the outside. Then, it was relocated so the HDMI cable was not an issue.

As it can be seen, the Raspberry Pi is now located at the back, and connected with the USB and Ethernet external connectors.

The transformer was also relocated, so all the power supply system was located together at the left side of the suitcase. Moreover, an external alternate current connector was located next to the transformer.

In this case, the air flow does not refrigerate the microprocessor, but this is not a problem as it refrigerates the power supply circuit.

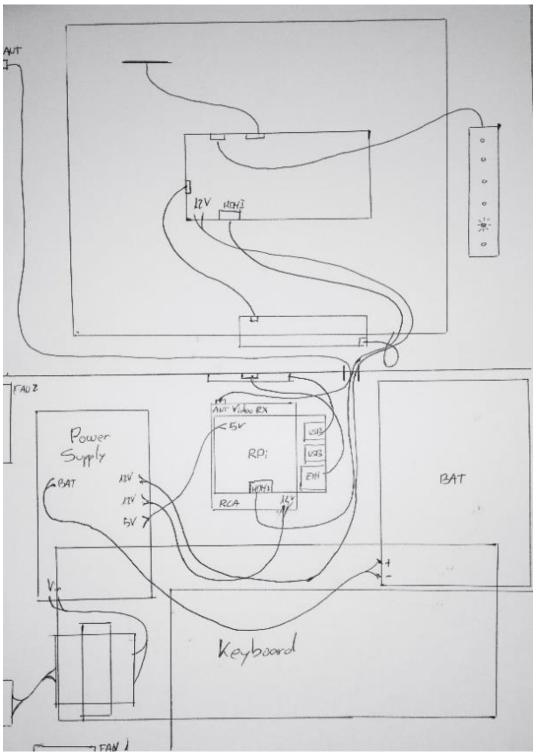


**Figure 5.2:** Second component configuration design

Furthermore, one of the fans was relocated as it interfered with the suitcase hinge.

With this configuration, the suitcase bottom was divided in four compartments.

- Power supply compartment
- Microprocessor compartment
- Battery compartment
- Storage compartment

In this case, the storage compartment was reduced due to the battery position. Nevertheless there was more space for internal components such as the RCA to USB adaptor.

In the other hand, the upper side components, keyboard and video receiver positions had no issues, so the same configuration was maintained.

In figure 5.2, a simple scheme shows the final configuration chosen.

## V.III Solid Works® Design

Now that the internal configuration is defined, it is time to start the Solid Works® design.

First of all, a base was made at the suitcase bottom in order to fix the different circuits and components with screws.

At the base, the four different compartments and five separators were made. Four of the five separators would be used to fix the cover in place, while the one at the bottom right corner would be used as a support for the storage compartment cover.

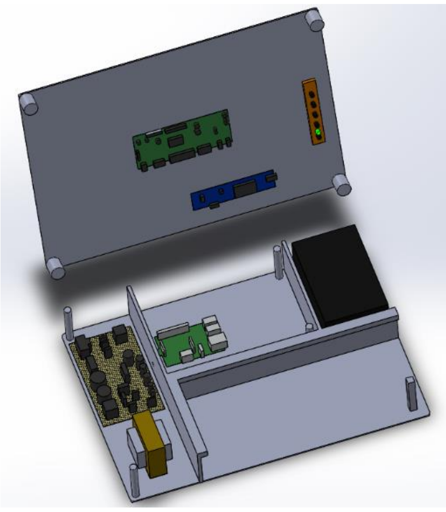

**Figure 5.3:** Solid Works® internal structure design

Once all the different components were put in place, the bottom cover was placed so the inner components were hidden. The cover would be drilled and lowered in some areas so the keyboard and video receiver fit in their place, and the storage compartment side would be cut apart so it could be opened independently.

Different apertures were done in the suitcase sides in order to fit the fans and make connectors accessible from the outside. These connectors are a USB hub and Ethernet connection at the back of the suitcase and the alternating current input at the left side.

The same process was done at the upper side of the suitcase, but a thinner base was made, as the components weight it has to support was lower.

In this case no compartments were made, and four separators provide enough space to fit the LCD controller boards.

On top of the separators, a cover was made to hold both the display and the menu buttons board in place.

Once completed, different material appearances were added to the different components, so a more real design is achieved.

**Figure 5.4:** Solid Works® final design

In figure 5.3, it can be seen the different components and compartment separators, while in figure 5.4 the final 3D design is shown.

# VI GCS Construction

In this chapter, the construction of all the different parts of the Ground Control Station will be shown.

The main objective of this project was not only to design a GCS but also to build it, so a physical result could be achieved.

## VI.I Power supply

As explained in chapter III, the GCS power supply circuit was designed specifically for this project. Thus, it was built from scratch.

First of all, the needed electronic components had to be bought. It has to be considered that the exact resistor needed value is rarely found, so the most similar value was taken. Even so, capacitor and inductance values were easily found.

Moreover, different capacitor types are used for different purposes, so the adequate ceramic, electrolytic or tantalum capacitor must be chosen.

Some of the components were only available in Surface Mounted Device (SMD) format. Although this fact, the adequate adaptation was made to be able to use them.

Once all the components were purchased and adapted if needed, the power supply circuit could be mounted.

To do so, the board scheme created with Eagle® program was used. All the components were soldered manually and, later on, the different circuit parts (battery charger, 5 V and 12 V regulators) were tested.

In figure 6.1, the final result can be seen:

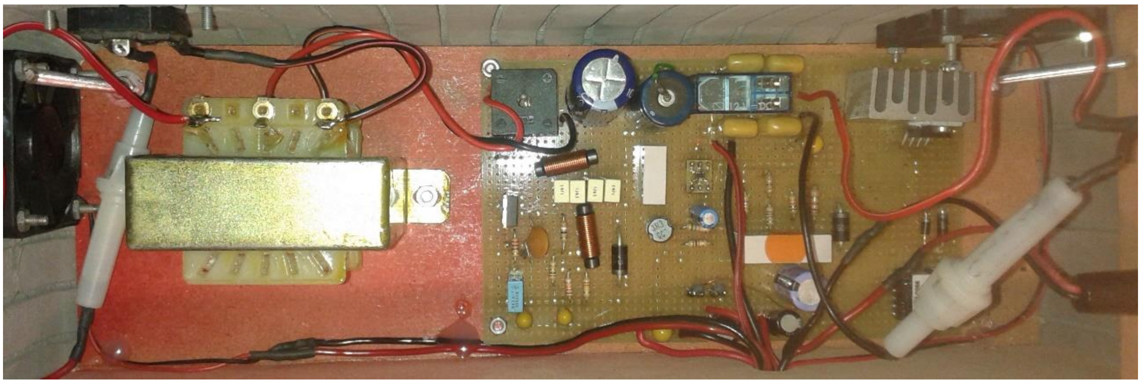

**Figure 6.1:** Power Supply Circuit

As it can be seen, the fans were installed and connected directly to the 12 V regulator output. This is because the circuit heated in excess, so an air flow was created to constantly refrigerate the power supply circuit.

## VI.II GCS structure

In the first place, the inner structure of the GCS was intended to be 3D printed. Nevertheless, it was not possible due to 3D printer and time limits.

The available 3D printer allows to print in a 20 cm edge cube. This forces the structure to be divided in smaller parts and complicates the design. Furthermore, it could be possible to have not expected troubles while printing, so a more hand-made version was built.

Although if it was not possible to 3D print the GCS, the construction process was done following the Solid Works® design.

First of all, a wood base was made to fit in the suitcase base. Different holes were drilled in order to fix the components to the base with screws. Moreover, the suitcase sides were perforated in order to fit the different connectors.

**Figure 6.2:** GCS bottom internal structure

Later on, the compartment separators were cut from a larger piece of wood following the design measures and glued in place.

Finally the cover was made. By superposing different wood sheets with the adequate forms, the keyboard and Video receiver slots were made, and the switch and light holes were drilled.

Once the suitcase base structure was finished, the upper side was built.

Another wood base was constructed to fit in the suitcase upper part and drilled in order to fix LCD controller boards. Four separators were screwed and glued in place and the upper part cover was made to fit both the LCD display and display buttons.

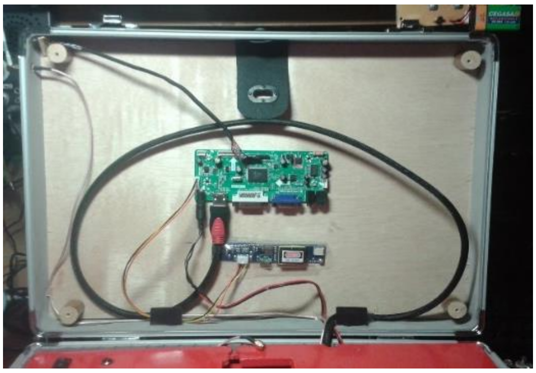

**Figure 6.3:** GCS top internal structure

Finally, the different visible parts were painted, all components were put in place and fixed and the covers were screwed in place.

The final result can be seen in figure 6.4.

**Figure 6.4:** Final GCS

## VI.III Antenna Tracking System

As well as the GCS itself, the antenna tracking system was also built up once all the components were chosen.

It is important to achieve a structure as light as possible, in order to minimize the gimbal servos work load.

First of all, the gimbal was fixed to the tripod. To do so, an aluminium structure was made and screwed on the tripod, later the gimbal was fixed to this base using screws. In figure 6.5 this structure can be seen.

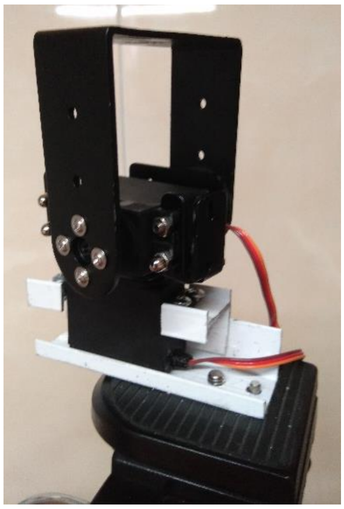

**Figure 6.5:** Gimbal aluminium fix

Once the gimbal is fixed, the antenna and the controller must be put in place. All these components must move together, so an aluminium base was screwed on the gimbal so all the components could be fitted in the most efficient way.

It has to be considered that the total system centre of gravity must not be far from the gimbal, as it would increase the gimbal work load.

Finally, the antenna was fixed and the controller components such as the pixhawk or the battery were attached with Velcro. This way, the mounting process is fast and easy.

In figure 6.6, the final antenna tracking system can be seen.


**Figure 6.6:** Final Antenna Tracking System

# VII Remotely Piloted Air System

In this project, not only a GCS has been designed and built, but also a Remotely Piloted Air System (RPAS) has been built in order to test the GCS. This part of the project is not so complex, as all RPAS components were purchased and not specifically designed.

This system needs some characteristics to properly test the GCS, such as real time video transmission or autopilot.

In this chapter, a RPAS platform will be chosen, its different components will be listed and explained, as well as the needed software to be installed.

## VII.I RPAS Platform

To choose a RPAS Platform it is needed to know the kind of mission that the RPAS will perform.

Nowadays, multirotor copters have popularized in the RPAS sector. Their ability to both take off and land vertically discards the need of a runway to perform missions. Also, as multicopters keep getting bigger, their payloads keep growing as well. Nevertheless, these big multicopters are expensive and not accessible to everybody, and the mission endurance is very short.

In this project another option has been considered and a fixed wing RPAS will be used.

Fixed wing RPAS have been commonly used in MALE and HALE missions such as Ikhana and Global Hawk from NASA. But nowadays there are not used for small LASE missions.

The usage of fixed wing RPAS allows to increase mission time, as the RPAS does not have to lift its total weight but only propel itself in order to generate lift. Furthermore, a plane moves faster than a multicopter and can cover a larger area.

Moreover, the RPAS platform has to be large enough to fit all the components inside. To do so a 1.5m wingspan cargo plane was chosen.

## VII.II RPAS Components

Once the RPAS platform is chosen, it has to be provided with the necessary components.

### VII.II.I Flight control system

As the RPAS has to be able to fly autonomously, a flight control system has to be installed. The different parts of this system are explained below.

#### *VII.II.I.I Autopilot*

The autopilot is the most important part of the RPAS. It has to be capable not only to control the aircraft but also to fly loaded flight plans. Moreover, it has to communicate with the GCS and switch flight modes in order to control the aircraft manually if needed.

To do so, an Arducopter controller board was installed.

Arducopter is a white label version of Ardupilot controller board. It is an identical board that can be loaded with the necessary software provided by ardupilot.

#### *VII.II.I.II GPS and Compass*

In order to know the actual position of the RPAS, a GPS and compass must be installed. In this case, an Arducopter-compatible GPS/compass board was installed and connected to the autopilot.

#### *VII.II.I.III Telemetry radios*

These radios are used to communicate the RPAS with the GCS. This allows the GCS to know about the RPAS state as well as loading and modifying flight plans.

Using these radios, the RPAS is always under control. Also, if the wireless link is lost an automatic fail-safe response ensures the safety of the RPAS by returning to launch location.

#### *VII.II.I.IV Power supply*

All these systems are powered by a voltage regulator that reduces to 5 V the battery voltage. These power supply is also used to feed the 2.4 GHz radio receiver and the different servos that move the aircraft control surfaces.

### VII.II.II 2.4 GHz Receiver and Servos

A RPAS has to be manually controllable in order to ensure its safety and avoid accidents caused by flight control failure. To do so, a 2.4 GHz radio receiver is installed.

This receiver is connected to the aircraft servos through the autopilot. This way, the autopilot is capable of both controlling the airplane autonomously and switch to manual mode if required.

In the other hand, the RPAS flight control surfaces are moved by servo motors. These motors are controlled with a Pulse Width Modulation (PWM) signal provided by both the receiver and autopilot.

In figure 7.1, all the flight control components and receiver are shown inside the RPAS Platform.

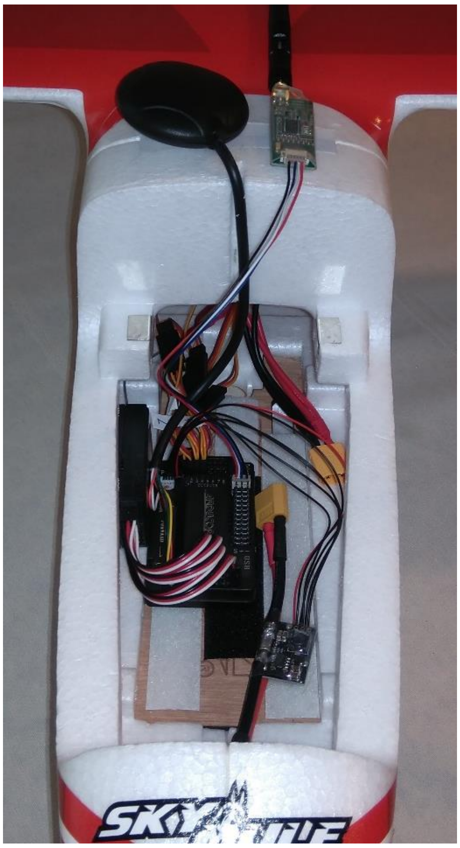

**Figure 7.1:** Flight control components

### VII.II.III Video Transmitter

As in the GCS a video receiver has been installed, a video transmitter must be installed in the RPAS too, in order to test its functionality.

In this case, a small camera aiming the ground is connected to the 5.8 GHz video transmitter, which is located outside the RPAS fuselage in order to maximize the signal range.

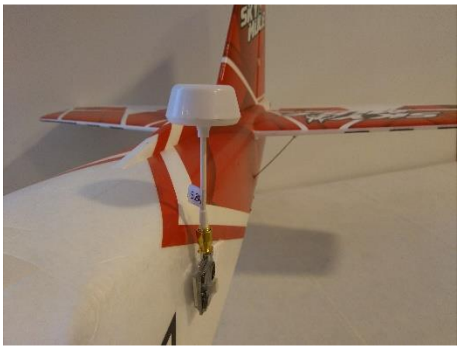

**Figure 7.2:** Video transmitter and antenna

### VII.II.IV Battery

Finally, a battery must be installed to power all the systems above.

As explained before in chapter III.IV.I, there are different battery types. In this case, the battery weight is more critical than its capacity, so a LiPo battery will be used. A high capacity (5200 mAh) LiPo battery was installed in order to achieve the maximum battery life and, in consequence, the maximum mission time.

In order to power the video transmission system, a smaller battery was installed. In this case, a 2650 mAh LiPo battery.

## VII.III RPAS Software

As in the GCS, the installed components on the RPAS are not useful if the adequate software is not installed. In this case, only the autopilot is needed to be loaded with the adequate firmware.

The used platform is a fixed wing RPAS, so an open source fixed wing controller software will be installed.

As Mission Planner or Antenna tracking, this program called APM Plane is provided by Ardupilot.

This free firmware can be installed in all types of compatible controller boards, in this case an Arducopter board. APM Plane gives a fixed wing RPAS full of autonomous capability. With the capacity of loading hundreds of waypoints, large flight plans can be made, as well as being compatible with various GCS software by using MAVLink communications protocol.

Once all the different components are chosen and the adequate software is installed, it can all be mounted on the RPAS platform, achieving a fully functional RPAS.

In the next figure, the final RPAS is shown.


**Figure 7.3:** Final RPAS platform

# VIII System Verification

## VIII.I Power consumption

One of the most critical specifications of the GCS is the power consumption. It has to be as low as possible in order to achieve the maximum battery life. Nevertheless, all components must be on while using the GCS.

It has to be considered that the antenna tracking system is powered by a secondary LiPo battery.

In the next graph, the different components maximum consumption is shown in order to stablish the main and secondary battery lives.

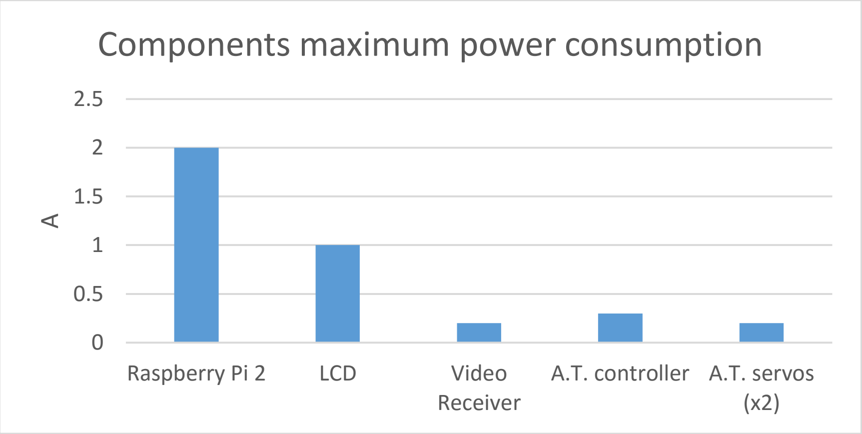


**Figure 8.1:** Components maximum power consumption

Also, it has to be taken into account that both LCD controller and video receiver work at 12 V while the Raspberry Pi 2 works at 5 V.

Considering that all the GCS components are working at the same time, the total power consumption is:

$$P_{total} = I_{RPi} * V_{RPi} + I_{LCDC} * V_{LCDC} + I_{Video\ RX} * V_{Video\ RX}$$

$$P_{total} = 2 * 5 + 1 * 12 + 0.2 * 12 = 24\ W$$

Note that these computations are made in the worst case where all the components are consuming the maximum power.

Considering the lead acid main battery at maximum charge, the GCS battery life can be computed with a simple equation.

$$time\ (h) = \frac{battery\ power\ capacity\ (Wh)}{power\ consumption\ (W)}$$

$$\frac{7\,Ah * 12V}{24\,W} = \frac{84\,Wh}{24W} = 3.5\,h = 3h\;30min$$

On the other hand, the antenna tracker system components consumption is very low, as only a microcontroller and two servos are working. In this case the total power consumption is:

$$I_{total} = 0.350 + 0.2 * 2 = 0.750\,A = 750\,mA$$

In this case the battery endurance is:

$$\frac{2700\,mAh}{750\,mA} = 3.6\,h = 3h\;36\,min$$

Note that the computation is made using intensity and not power. This is because the used voltages for the Antenna Tracker controller and servos is the same.

As it can be seen, the antenna tracking system battery life is similar to the GCS main battery life, even so, the most restricting system is the GCS.

It has to be considered that the used RPAS endurance is about 20 minutes, so the GCS battery life would be more than enough for a mission or two.

Considering that an average laptop battery life is between two and three hours, the GCS battery life is approximately the same, and it is enough to perform a few missions. Also, GCS battery can also be substituted, allowing to double or triple its battery life depending on the available batteries.

Comparing with similar Ground Control Stations such as Helipse GCS [12] or UAV Factory GCS [13], it can be seen that battery life is also between 2 and 3 hours. It can be concluded than battery life may not be improved, but it is within the typical ranges.

## VIII.II Weight

As explained before, this project was designed to be an easy to handle ground control station. Being small and light was one of the main objectives in order to make this GCS as easy to transport and comfortable as possible.

With these characteristics in mind, the different components were chosen to minimize the total weight. Nevertheless, components such as the lead acid battery or the AC/DC converter circuit transformer can not be avoided to use and increase the GCS weight.

Moreover, the GCS was finally hand-made using wood sheets as light as possible instead of 3D-printed plastic. The use of a 3D printer allows to determine the pieces density and also the weight, but this was not possible and the total weight was increased.

Finally, the total GCS suitcase and the antenna tracking weights are 8.6 kg and 2.7 kg respectively.

Considering that an average laptop weight is about 2.5 kg, the GSC is heavier. Nevertheless, the typical weight of a GCS is between 18 and 20 kg. [12][13] Thus, the achieved weight is around 10 kg lower, making the designed GCS lighter than the already existing ones.

## VIII.III Cost

The cost has been one of the principal design criteria for this project. By reducing the price of the components, a total cost reduction was expected to be achieved.

In this section, a summary of all the components' cost will be made to show the total price of this GCS.

**Table 8.1:** GCS cost itemisation and total sum

<table>
<tr><th colspan="3">GCS Components</th><th>Cost (€)</th></tr>
<tr><td colspan="3">Suitcase</td><td>29.95</td></tr>
<tr><td colspan="3">Raspberry Pi 2</td><td>41.31</td></tr>
<tr><td colspan="3">LCD Display</td><td>15</td></tr>
<tr><td colspan="3">LCD Controller</td><td>59.99</td></tr>
<tr><td rowspan="4">Power supply circuit</td><td>Passive Components</td><td>17.801</td><td rowspan="4">62.175</td></tr>
<tr><td>Active Components</td><td>23.934</td></tr>
<tr><td>Prototype Board</td><td>5.44</td></tr>
<tr><td>Transformer</td><td>15</td></tr>
<tr><td colspan="3">Battery</td><td>22.99</td></tr>
<tr><td colspan="3">FPV Kit</td><td>57.84</td></tr>
<tr><td colspan="3">Keyboard</td><td>19.95</td></tr>
<tr><td rowspan="3">Cable adapters and connectors</td><td>RCA to USB</td><td>10.49</td><td rowspan="3">21</td></tr>
<tr><td>Antenna cable</td><td>3.56</td></tr>
<tr><td>HDMI cable</td><td>5</td></tr>
<tr><td colspan="3">Directive Antenna</td><td>15.04</td></tr>
<tr><td colspan="3">Tripod</td><td>21.90</td></tr>
<tr><td colspan="3">Gimbal</td><td>14.90</td></tr>
<tr><td colspan="3">Pixhawk clone</td><td>90</td></tr>
<tr><td rowspan="3">A.T. Power supply</td><td>Secondary battery</td><td>34.50</td><td rowspan="3">56.82</td></tr>
<tr><td>BEC</td><td>12.90</td></tr>
<tr><td>Voltage regulator</td><td>9.42</td></tr>
<tr><td colspan="3">TOTAL</td><td>528.865</td></tr>
</table>

**Table 8.2:** RPAS cost itemisation and total sum

| RPAS Components | Cost (€) |
|---|---|
| Platform | 194.05 |
| Battery | 31.79 |
| 2.4GHz radios | 71.81 |
| Autopilot | 49.06 |
| **TOTAL** | **346.71** |

As it can be seen, the total GCS cost is quite high and the RPAS platform is also expensive.

If we compare the GCS cost with an average laptop price, it is quite similar. Neverteless, this is a lot cheaper than a built GCS, typically worth about 5000 € [14]. Although the number of hours dedicated on the GCS have not been considered when computing the total cost.

Moreover, the final price of the RPAS is lower than the average ready-to-fly RPAS available on the market. For instance, Tarot 680 ready-to-fly hexacopter is worth about 850 € [15]. If comparing with a fixed wing RPAS, the price difference is much higher.

It can be concluded that both the GCS and the RPAS designed are considerably cheaper than the already built ones. Even so, not only GCS battery life, weight and price must be compared but also its performance.

## VIII.IV Performances

One of the main goals of these project was to improve Handheld LASE Ground Control Station performances while reducing costs. In order to properly compare different GCS performances, a list with the achieved characteristics must be done.

The GCS designed in this project performances are:

- RPAS full control
- RPAS calibration
- Mission planning with GPS waypoints
- Real time video display
- Improved range using Antenna Tracking
- Over-voltage protection
- Storage compartment

In this case, two main differences regarding laptop GCSs are achieved: real time video display and range improvement.

On the other hand, similar GCSs available in the market performances are:

Example 1: Helipse GCS performances [12]:

- Ground Station Computer fully rugged laptop with software license.
- Long range telemetry system.
- Control system for payloads.
- HD and A/V video receivers with a 12" screen.
- HD Video recorder system.
- Bidirectional full duplex communication system between operator and pilot.


**Figure 8.2:** Helipse GCS

Example 2: UAV factory GCS main performances [13]:

- Based on fully ruggedized Panasonic CF-31 Toughbook
- Two Hot-swappable lithium batteries
- User-dedicated modular electronics compartment
- Super bright 17” and 13” touch screen displays
- Intuitive power monitoring display
- Over-voltage, overcurrent, reverse polarity protection
- Battery over-discharge protection
- User-serviceable fuses
- Removable Cordura bag for accessories

**Figure 8.3:** UAV factory GCS

As it can be seen, both GCSs are based on laptops, providing additional characteristics like video receivers, touch screens, storage compartments or long range telemetry systems. These characteristics are also provided by the designed GCS.

On the other hand, other characteristics like control system for payloads, power monitoring display or battery over-discharge protection are not fulfilled.

Nevertheless, it can be concluded that the main characteristics of a GCS are achieved with approximately an order of magnitude less in the final price, with the same battery life and lower weight.

# IX Test

The final part of every development project is to test the final result. To do so, different steps were taken.

## IX.I Independent testing

First of all, an independent testing is needed in order to ensure the functionality of the different systems before the final assembly is made.

### IX.I.I LCD Controller

Although being tested during the development, the LCD controller board was tested once mounted on place. The three boards (controller, inverter and buttons) were connected to the monitor and powered.

As it can be seen on figure 9.1, the controller and the LCD display works perfectly.

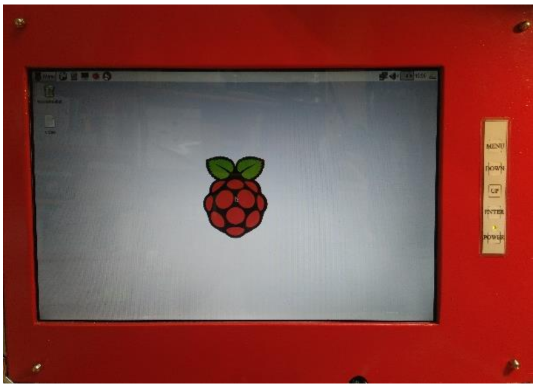

**Figure 9.1:** Running Liquid Cristal Display

### IX.I.II Raspberry Pi 2

The microprocessor was tested both while being used to install the needed software and after the final assembling. Also, the installed software was tested and both the APM Planner and the real time video processing were completely functional.

In figure 9.2 it can be seen the APM Planner and the video processing running on Raspberry Pi 2.

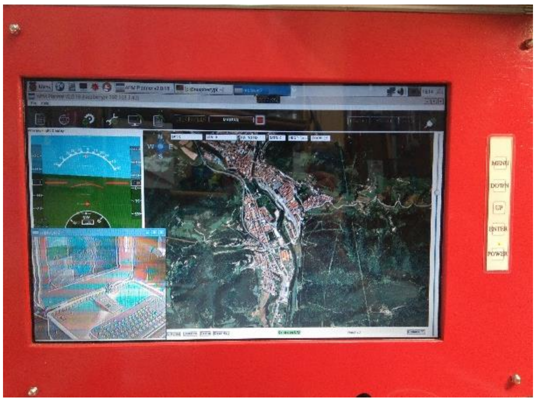

**Figure 9.2:** Running Raspberry Pi 2

### IX.I.III Power Supply Circuit

When building the power control circuit, lots of testing were needed in order to check its functionality and to search for possible errors to fix. After many revisions and fixed errors, the circuit was properly working. Nevertheless, if no load is applied at the 12 V output the output voltage value is higher, in particular, 15.72 V.

Figure 9.3 shows the measured values of the 5 V and 12 V regulators and battery charger circuit respectively.


**Figure 9.3:** Power Supply Circuit measurements

### IX.I.IV Antenna Tracking

The antenna tracking system was tested too when installing the necessary software and calibrating the maximum ranges of the gimbal servos.

Moreover, once APM Planner was installed on the Raspberry Pi, the antenna tracker was connected via USB to ensure the compatibility of both systems. It was checked that the system worked as it was supposed to.

In figure 9.4, the APM Planner screen is shown when connected to the antenna tracking system.

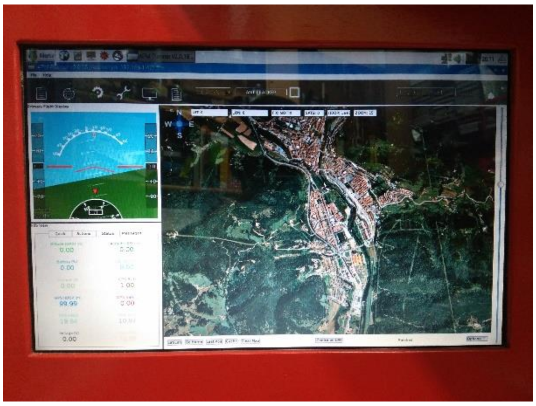

**Figure 9.4:** Antenna tracker connected to APM Planner

### IX.I.V RPAS Testing

As antenna tracking system, the RPAS was tested while configuring its internal components such as the flight controller. It was also tested using a laptop to ensure the wireless link was working as well as gps and video transmitter.

In addition, it was connected to the Rasperry Pi once APM Planner was installed to ensure the compatibility of both systems and the proper functionality of APM Planner program.

## IX.II Global testing

Knowing that all the different components worked perfectly on their own, the global testing could be done. All the components were mounted in their place, all connections were made and the system was powered up. However, different problems were faced.

### IX.II.I Battery charger circuit

In the first place and just after powering up, the power system circuit failed. In particular, the battery charger 22 μF 25 V tantalum input capacitor, exploded.

This problem is thought to be caused because the battery charging circuit design was not prepared for voltage peaks when powering up. However, the circuit can properly work without this component, as the output measure remains the same.

Even so, one possible solution to avoid this problem is to increase the capacitor voltage resistance. In this case, the capacitor was replaced for a 22 μF 63 V electrolytic capacitor.

### IX.II.II 12 V regulator output voltage

The next problem encountered is that the LCD display background light will do not turn completely on, and only half the LCD is illuminated. After taking different measures with different loads on the 12 V regulator circuit, it can be seen that the output voltage reduces drastically to 6.98 V when all the components are working.

This problem can be caused because the LCD initial consumption may be higher than expected when designing the power supply circuit. Also, both the fans and power light consumptions were not considered. Given so, the voltage regulator circuit can not provide enough power.

Due to these problems, whole system could not be globaly tested on the field.

### IX.II.III Real GCS consumptions

Once the GCS was assembled, the different components' consumption was measured. In the next table the different values can be seen:

**Table 9.1:** Real components' consumption

| Component | Consumption (mA) |
|---|---|
| Raspberry Pi | 560 |
| Video Receiver | 230 |
| LCD controllers and display | 800 |

As it can be seen, the most power consuming component is the LCD controller and the monitor. Even so, the consumption is lower than it was expected when designing the power supply system in chapter III.IV. This should allow a longer battery life, but does not explain why the power supply circuit can not power all the systems properly.

## IX.III Future improvements

Due to the lack of time remaining, it was not possible to fix the power supply system, as probably a new circuit should be made.

However, in order to test the GCS and all its systems with the already built RPAS, an alternative power supply could be added, such as a PC power supply. Using these alternative, the GCS could be used while connected to the electric network.

As the 12 V regulator can work properly if the load is not high, the most consuming load (in this case the display screen) could be powered by an alternative power source. Meanwhile, the designed power supply circuit would power the rest of the loads.

Another option could be to connect directly the 12 V battery to the 12 V powered circuits, only using a voltage regulator for 5 V systems. This way, the system could be tested on the field. Even so, the battery voltage would not be regulated or the circuits protected from over-voltages.

With a new fully-working power supply system, the GCS and the rest of the systems could be properly tested.

# X Conclusions

In this project, a low cost GCS has been designed from scratch.

From defining the project scope to the construction of the GCS, Lots of different possibilities have been studied. The pros and cons for each case were given and the best option was chosen among the others.

Lots of setbacks have been encountered during the design process. Not compatible controller boards, continuous troubles when installing the necessary software, and so on. Even so, a successful result has been achieved.

A fully operable RPAS has also been built. With all the necessary equipment to test the designed GCS.

The GCS final performances have been compared with market available GCSs in terms of battery life, weight, price and performance. Concluding that the designed GCS functionalities are at the same level as existing GCSs but at a lower price.

Finally, the GCS test has been done. The different GCS parts have been tested independently and globally and even if the results are not as good as expected to be, future improvements have been listed and different alternative options have been shown.

It can be concluded that the designed GCS is a success, given battery life, weight, cost and achieved performances. However, different improvements would have to be done so a proper test could be done and the GCS would work as it should.

# XI References

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# ANNEX 1: LP14WX4 LIQUID CRYSTAL DYSPLAY

( ◆ ) **Preliminary Specification**

(    ) **Final Specification**

| Title | 15.4" WXGA TFT LCD |
|---|---|

| Customer | Quanta |
|---|---|
| MODEL | |

| SUPPLIER | LG.Philips LCD Co., Ltd. |
|---|---|
| *MODEL | LP154WX4 |
| Suffix | TLC1 |

*When you obtain standard approval,
please use the above model name without suffix

| APPROVED BY | SIGNATURE |
|---|---|
| / | |
| / | |
| / | |

Please return 1 copy for your confirmation with your signature and comments.

| APPROVED BY | SIGNATURE |
|---|---|
| C. S. Jung / S.Manager | |
| **REVIEWED BY** | |
| C. I. Kim / Manager | |
| **PREPARED BY** | |
| H. M. Yoon / Engineer<br>C. H. Lee / Engineer | |

**Products Engineering Dept.**
**LG. Philips LCD Co., Ltd**

# Contents

# RECORD OF REVISIONS

| Revision No | Revision Date | Page | Description | EDID ver |
|---|---|---|---|---|
| 0.0 | Apr. 13. 2007 | - | First Draft (Preliminary Specification) | 0.0 |
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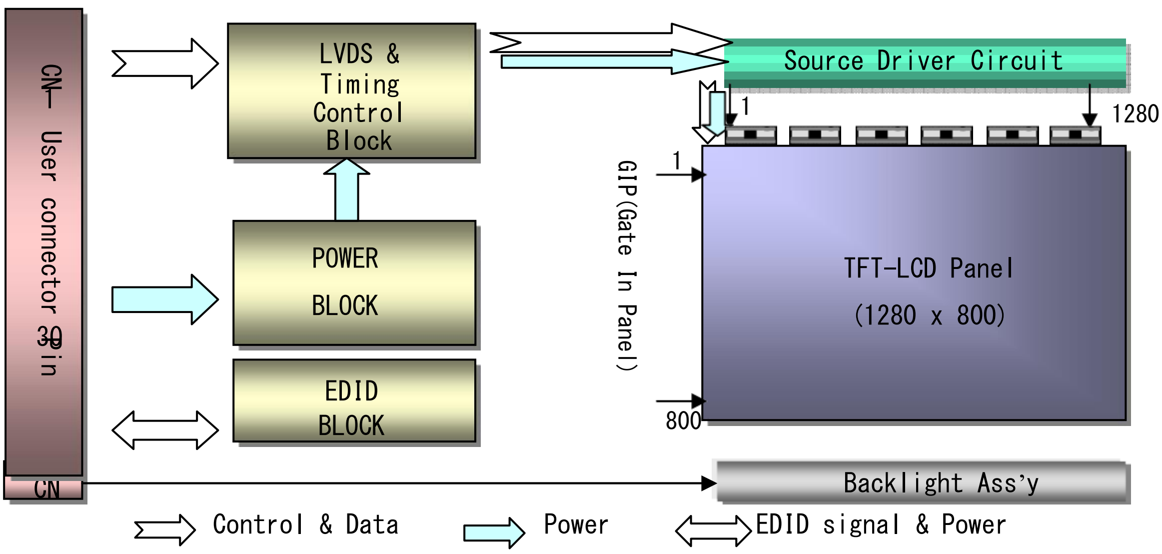
## 1. General Description

The LP154WX4 is a Color Active Matrix Liquid Crystal Display with an integral Cold Cathode Fluorescent Lamp (CCFL) backlight system. The matrix employs a-Si Thin Film Transistor as the active element. It is a transmissive type display operating in the normally white mode. This TFT-LCD has 15.4 inches diagonally measured active display area with WXGA resolution(800 vertical by 1280 horizontal pixel array). Each pixel is divided into Red, Green and Blue sub-pixels or dots which are arranged in vertical stripes. Gray scale or the brightness of the sub-pixel color is determined with a 6-bit gray scale signal for each dot, thus, presenting a palette of more than 262,144 colors.

The LP154WX4 has been designed to apply the interface method that enables low power, high speed, low EMI.

The LP154WX4 is intended to support applications where thin thickness, low power are critical factors and graphic displays are important. In combination with the vertical arrangement of the sub-pixels, the LP154WX4 characteristics provide an excellent flat display for office automation products such as Notebook PC.




## General Features

| | |
|---|---|
| Active Screen Size | 15.4 inches diagonal |
| Outline Dimension | 344.0(H, typ) × 222.0(V, typ) × 6.2(D, typ) [mm] |
| Pixel Pitch | 0.25875mm × 0.25875 mm |
| Pixel Format | 1280 horiz. By 800 vert. Pixels RGB strip arrangement |
| Color Depth | 6-bit, 262,144 colors |
| Luminance, White | 200 cd/m$^2$(Typ.5 point) |
| Power Consumption | Total 5.6 Watt(Typ.) @ LCM circuit 1.4Watt(Typ.), B/L input 4.2Watt(Typ.) |
| Weight | 575 g (Max.), 560g(Typ.) |
| Display Operating Mode | Transmissive mode, normally white |
| Surface Treatment | Glare treatment of the front polarizer |
| RoHS Comply | Yes |

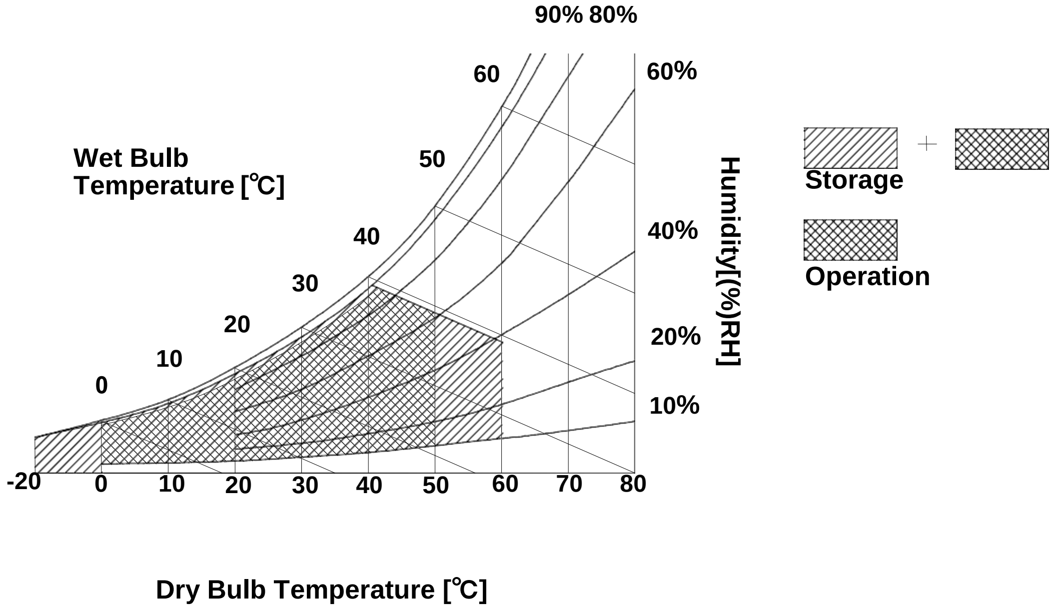
## 2. Absolute Maximum Ratings

The following are maximum values which, if exceeded, may cause faulty operation or damage to the unit.

**Table 1. ABSOLUTE MAXIMUM RATINGS**

| Parameter | Symbol | Values | | Units | Notes |
|---|---|---|---|---|---|
| | | Min | Max | | |
| Power Input Voltage | VCC | -0.3 | 4.0 | Vdc | at 25 ± 5°C |
| Operating Temperature | TOP | 0 | 50 | °C | 1 |
| Storage Temperature | HST | -20 | 60 | °C | 1 |
| Operating Ambient Humidity | HOP | 10 | 90 | %RH | 1 |
| Storage Humidity | HST | 10 | 90 | %RH | 1 |

Note : 1. Temperature and relative humidity range are shown in the figure below.
Wet bulb temperature should be 39°C Max, and no condensation of water.



# 3. Electrical Specifications

## 3-1. Electrical Characteristics

The LP154WX4 requires two power inputs. One is employed to power the LCD electronics and to drive the TFT array and liquid crystal. The second input which powers the CCFL, is typically generated by an inverter. The inverter is an external unit to the LCD.

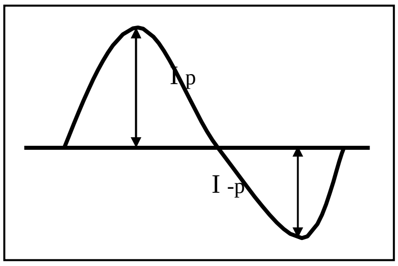
**Table 2. ELECTRICAL CHARACTERISTICS**

| Parameter | Symbol | Values | | | Unit | Notes |
|---|---|---|---|---|---|---|
| | | Min | Typ | Max | | |
| MODULE : | | | | | | |
| Power Supply Input Voltage | VCC | 3.0 | 3.3 | 3.6 | $V_{DC}$ | |
| Power Supply Input Current | $I_{CC}$ | 340 | 400 | 460 | mA | 1 |
| Power Consumption | Pc | - | 1.4 | 1.6 | Watt | 1 |
| Differential Impedance | Zm | 90 | 100 | 110 | Ohm | 2 |
| LAMP : | | | | | | |
| Operating Voltage | $V_{BL}$ | 665(6.8mA) | 690(6.0mA) | 830(3.0mA) | $V_{RMS}$ | |
| Operating Current | $I_{BL}$ | 3.0 | 6.0 | 6.8 | $mA_{RMS}$ | 3 |
| Power Consumption | $P_{BL}$ | - | 4.2 | 4.6 | | |
| Operating Frequency | $f_{BL}$ | 45 | 60 | 80 | kHz | |
| Discharge Stabilization Time | Ts | - | - | 3 | Min | 4 |
| Life Time | | 12,000 | - | - | Hrs | 5 |
| Established Starting Voltage at 25℃ / at 0 ℃ | Vs | | | 1200<br>1500 | $V_{RMS}$<br>$V_{RMS}$ | |

Note)
1. The specified current and power consumption are under the Vcc = 3.3V , 25℃, fv = 60Hz condition whereas full black pattern is displayed and fv is the frame frequency.
2. This impedance value is needed to proper display and measured form LVDS Tx to the mating connector.
3. The typical operating current is for the typical surface luminance ($L_{WH}$) in optical characteristics.
4. Define the brightness of the lamp after being lighted for 5 minutes as 100%, Ts is the time required for the brightness of the center of the lamp to be not less than 95%.
5. The life time is determined as the time at which brightness of lamp is 50% compare to that of initial value at the typical lamp current.
6. The output of the inverter must have symmetrical(negative and positive) voltage waveform and symmetrical current waveform.(Asymmetrical ratio is less than 10%) Please do not use the inverter which has asymmetrical voltage and asymmetrical current and spike wave.
   Lamp frequency may produce interface with horizontal synchronous frequency and as a result this may cause beat on the display. Therefore lamp frequency shall be as away possible from the horizontal synchronous frequency and from its harmonics in order to prevent interference.
7. It is defined the brightness of the lamp after being lighted for 5 minutes as 100%.
   $T_S$ is the time required for the brightness of the center of the lamp to be not less than 95%.
8. The lamp power consumption shown above does not include loss of external inverter.
   The applied lamp current is a typical one.

Note)

9. Requirements for a system inverter design, which is intended to have a better display performance, a better power efficiency and a more reliable lamp, are following.
   It shall help increase the lamp lifetime and reduce leakage current.
   a. The asymmetry rate of the inverter waveform should be less than 10%.
   b. The distortion rate of the waveform should be within √2 ±10%.
      * Inverter output waveform had better be more similar to ideal sine wave.




* Asymmetry rate:

  $| I_p - I_{-p} | / I_{rms} * 100\%$

* Distortion rate

  $I_p$ (or $I_{-p}$) / $I_{rms}$

※ Do not attach a conducting tape to lamp connecting wire.
If the lamp wire attach to a conducting tape, TFT-LCD Module has a low luminance and the inverter has abnormal action. Because leakage current is occurred between lamp wire and conducting tape.

## 3-2. Interface Connections

This LCD employs two interface connections, a 30 pin connector is used for the module electronics interface and the other connector is used for the integral backlight system.
The electronics interface connector is a model GT101-30S-HR11 manufactured by LSC.

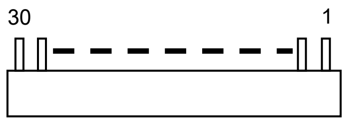
**Table 3. MODULE CONNECTOR PIN CONFIGURATION (CN1)**

| Pin | Symbol | Description | Notes |
|---|---|---|---|
| 1 | GND | Ground | |
| 2 | VCC | Power Supply, 3.3V Typ. | |
| 3 | VCC | Power Supply, 3.3V Typ. | |
| 4 | V EEDID | DDC 3.3V power | |
| 5 | NC | Reserved for supplier test point | |
| 6 | Clk EEDID | DDC Clock | |
| 7 | DATA EEDID | DDC Data | |
| 8 | $R_{IN}$ 0- | Negative LVDS differential data input | |
| 9 | $R_{IN}$ 0+ | Positive LVDS differential data input | |
| 10 | GND | Ground | |
| 11 | $R_{IN}$ 1- | Negative LVDS differential data input | |
| 12 | $R_{IN}$ 1+ | Positive LVDS differential data input | |
| 13 | GND | Ground | |
| 14 | $R_{IN}$ 2- | Negative LVDS differential data input | |
| 15 | $R_{IN}$ 2+ | Positive LVDS differential data input | |
| 16 | GND | Ground | |
| 17 | CLKIN- | Negative LVDS differential clock input | |
| 18 | CLKIN+ | Positive LVDS differential clock input | |
| 19 | GND | Ground | |
| 20 | NC | No Connect | |
| 21 | NC | No Connect | |
| 22 | GND | Ground | |
| 23 | NC | No Connect | |
| 24 | NC | No Connect | |
| 25 | GND | Ground | |
| 26 | NC | No Connect | |
| 27 | NC | No Connect | |
| 28 | GND | Ground | |
| 29 | NC | No Connect | |
| 30 | NC | No Connect | |

Notes:

1, Interface chips
  1.1 LCD : SW, SW0604_M (LCD Controller)
      including LVDS Receiver
  1.2 System : ? or equivalent
    * Pin to Pin compatible with LVDS

2. Connector
  2.1 LCD :IS100-C30R-C15 ,UJU Elec.
      GT101-30S-HR11,LS Cable
      its compatibles
  2.2 Mating : FI-X30M or equivalent.
  2.3 Connector pin arrangement




[LCD Module Rear View]

The backlight interface connector is a model BHSR-02VS-1, manufactured by JST or Compatible.
The mating connector part number is AMP1674817-2 or equivalent.

**Table 5. BACKLIGHT CONNECTOR PIN CONFIGURATION (J3)**

| Pin | Symbol | Description | Notes |
|---|---|---|---|
| 1 | HV | Power supply for lamp (High voltage side) | 1 |
| 2 | LV | Power supply for lamp (Low voltage side) | 1 |

Notes : 1. The high voltage side terminal is colored Pink and the low voltage side terminal is White.

## 3-3. Signal Timing Specifications

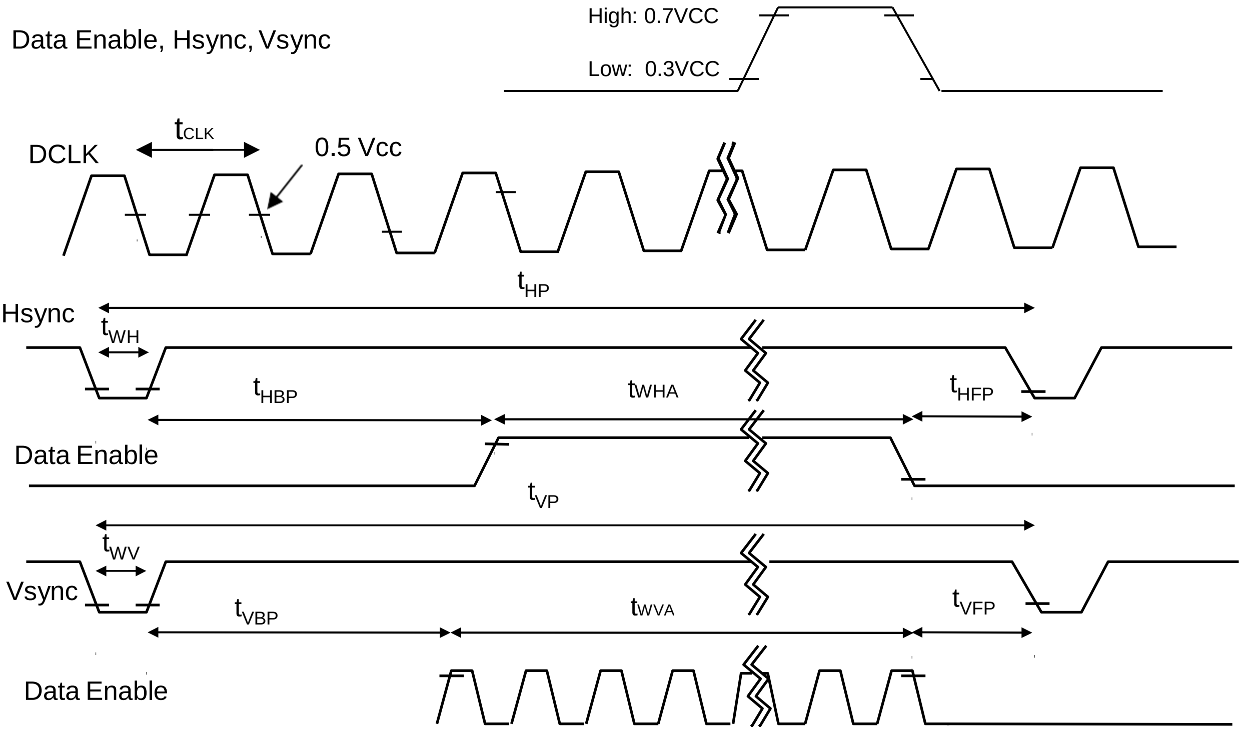
This is the signal timing required at the input of the User connector. All of the interface signal timing should be satisfied with the following specifications and specifications of LVDS Tx/Rx for its proper operation.

**Table 6. TIMING TABLE**

| ITEM | Symbol | | Min | Typ | Max | Unit | Note |
|---|---|---|---|---|---|---|---|
| DCLK | Frequency | $f_{CLK}$ | 66.0 | 71.0 | 76.0 | MHz | |
| Hsync | Period | Thp | 1360 | 1440 | 1480 | tCLK | |
| | Width | $t_{WH}$ | 16 | 32 | 48 | | |
| | Width-Active | $t_{WHA}$ | 1280 | 1280 | 1280 | | |
| Vsync | Period | $t_{VP}$ | 809 | 823 | 860 | tHP | |
| | Width | $t_{WV}$ | 2 | 6 | 10 | | |
| | Width-Active | $t_{WVA}$ | 800 | 800 | 800 | | |
| Data Enable | Horizontal back porch | $t_{HBP}$ | 40 | 80 | 96 | tCLK | |
| | Horizontal front porch | $t_{HFP}$ | 24 | 48 | 56 | | |
| | Vertical back porch | $t_{VBP}$ | 6 | 14 | 32 | tHP | |
| | Vertical front porch | $t_{VFP}$ | 1 | 3 | 18 | | |

## 3-4. Signal Timing Waveforms

Condition : VCC =3.3V



## 3-5. Color Input Data Reference

The brightness of each primary color (red,green and blue) is based on the 6-bit gray scale data input for the color ; the higher the binary input, the brighter the color. The table below provides a reference for color versus data input.

**Table 7. COLOR DATA REFERENCE**

| Color | | Input Color Data | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RED | | | | | | GREEN | | | | | | BLUE | | | | | |
| | | MSB | | | | | LSB | MSB | | | | | LSB | MSB | | | | | LSB |
| | | R 5 | R 4 | R3 | R2 | R1 | R0 | G 5 | G 4 | G3 | G2 | G1 | G0 | B 5 | B 4 | B 3 | B 2 | B 1 | B 0 |
| Basic Color | Black | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Red | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Green | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Blue | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Cyan | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Magenta | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Yellow | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | White | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RED | RED (00) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | RED (01) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | … | … | | | | | | … | | | | | | … | | | | | |
| | RED (62) | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | RED (63) | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GREEN | GREEN (00) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | GREEN (01) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | ... | … | | | | | | … | | | | | | … | | | | | |
| | GREEN (62) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | GREEN (63) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| BLUE | BLUE (00) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | BLUE (01) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | … | … | | | | | | … | | | | | | … | | | | | |
| | BLUE (62) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| | BLUE (63) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

## 3-6. Power Sequence

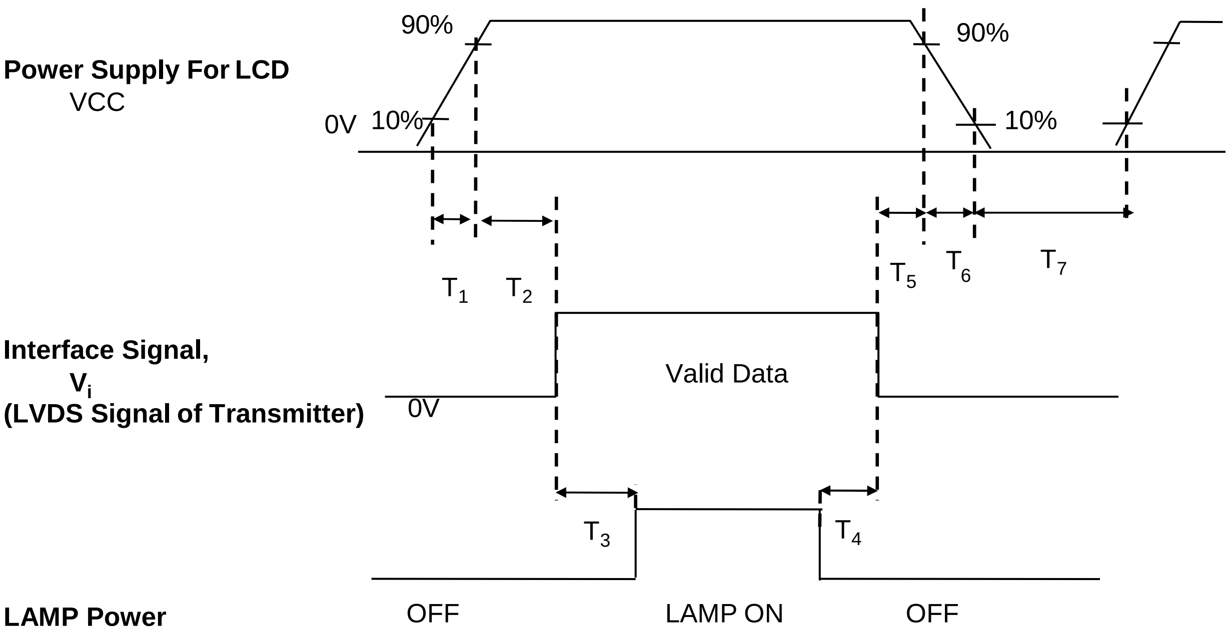



**Table 8. POWER SEQUENCE TABLE**

| Parameter | Value | | | Units |
|---|---|---|---|---|
| | Min. | Typ. | Max. | |
| $T_1$ | 0.5 | - | 10 | (ms) |
| $T_2$ | 0 | - | 50 | (ms) |
| $T_3$ | 200 | - | - | (ms) |
| $T_4$ | 200 | - | - | (ms) |
| $T_5$ | 0 | - | 50 | (ms) |
| $T_6$ | 0 | - | 10 | (ms) |
| $T_7$ | 200 | - | - | (ms) |

Note)
1. Please avoid floating state of interface signal at invalid period.
2. When the interface signal is invalid, be sure to pull down the power supply for LCD VCC to 0V.
3. Lamp power must be turn on after power supply for LCD and interface signal are valid.

## 4. Optical Specification

Optical characteristics are determined after the unit has been 'ON' and stable for approximately 30 minutes in a dark environment at 25°C. The values specified are at an approximate distance 50cm from the LCD surface at a viewing angle of Φ and Θ equal to 0°.
FIG. 1 presents additional information concerning the measurement equipment and method.

**FIG. 1 Optical Characteristic Measurement Equipment and Method**

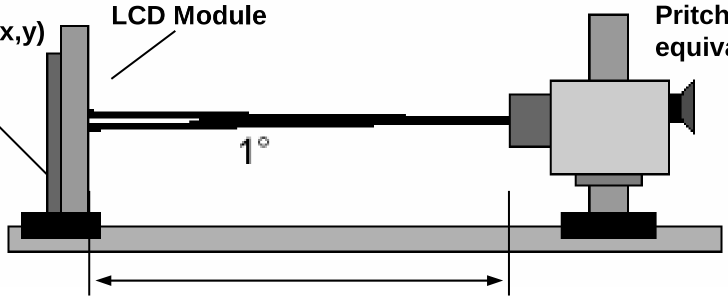



**Table 9. OPTICAL CHARACTERISTICS**

Ta=25°C, VCC=3.3V, fv=60Hz, $f_{CLK}$= 71.0MHz, $I_{BL}$= 6.0mA

| Parameter | | Symbol | Values | | | Units | Notes |
|---|---|---|---|---|---|---|---|
| | | | Min | Typ | Max | | |
| Contrast Ratio | | CR | 400 | 600 | - | | 1 |
| Surface Luminance, white | | $L_{WH}$ | 170 | 200 | - | cd/m² | 2 |
| Luminance Variation | | $\delta_{WHITE}$ | - | 1.4 | 1.6 | | 3 |
| Response Time | | $Tr_R + Tr_D$ | | 16 | | ms | 4 |
| Color Coordinates | | | | | | | |
| | RED | RX | 0.570 | 0.600 | 0.630 | | |
| | | RY | 0.321 | 0.351 | 0.381 | | |
| | GREEN | GX | 0.295 | 0.325 | 0.355 | | |
| | | GY | 0.524 | 0.554 | 0.584 | | |
| | BLUE | BX | 0.124 | 0.154 | 0.184 | | |
| | | BY | 0.115 | 0.145 | 0.175 | | |
| | WHITE | WX | 0.283 | 0.313 | 0.343 | | |
| | | WY | 0.299 | 0.329 | 0.359 | | |
| Viewing Angle | | | | | | | 5 |
| | x axis, right(Φ=0°) | Θr | 40 | 45 | - | degree | |
| | x axis, left (Φ=180°) | Θl | 40 | 45 | - | degree | |
| | y axis, up (Φ=90°) | Θu | 10 | 15 | - | degree | |
| | y axis, down (Φ=270°) | Θd | 30 | 35 | - | degree | |
| Gray Scale | | | | | | | 6 |

Note)

1. Contrast Ratio(CR) is defined mathematically as

$$\text{Contrast Ratio} = \frac{\text{Surface Luminance with all white pixels}}{\text{Surface Luminance with all black pixels}}$$

2. Surface luminance is the average of 5 point across the LCD surface 50cm from the surface with all pixels displaying white. For more information see FIG 1.

$$L_{WH} = \text{Average}(L_1, L_2, \ldots L_5)$$

3. The variation in surface luminance , The panel total variation ($\delta_{WHITE}$) is determined by measuring $L_N$ at each test position 1 through 13 and then defined as followed numerical formula.
For more information see FIG 2.

$$\delta_{WHITE} = \frac{\text{Maximum}(L_1, L_2, \ldots L_{13})}{\text{Minimum}(L_1, L_2, \ldots L_{13})}$$

4. Response time is the time required for the display to transition from white to black (rise time, $Tr_R$) and from black to white(Decay Time, $Tr_D$). For additional information see FIG 3.

5. Viewing angle is the angle at which the contrast ratio is greater than 10. The angles are determined for the horizontal or x axis and the vertical or y axis with respect to the z axis which is normal to the LCD surface. For more information see FIG 4.

6. Gray scale specification * $f_V$ = 60Hz

| Gray Level | Luminance [%] (Typ) |
|---|---|
| L0 | 0 |
| L7 | 0. 80 |
| L15 | 4. 25 |
| L23 | 10. 9 |
| L31 | 21. 0 |
| L39 | 34. 8 |
| L47 | 52. 5 |
| L55 | 74. 2 |
| L63 | 100 |

**FIG. 2 Luminance**

<measuring point for surface luminance & measuring point for luminance variation>

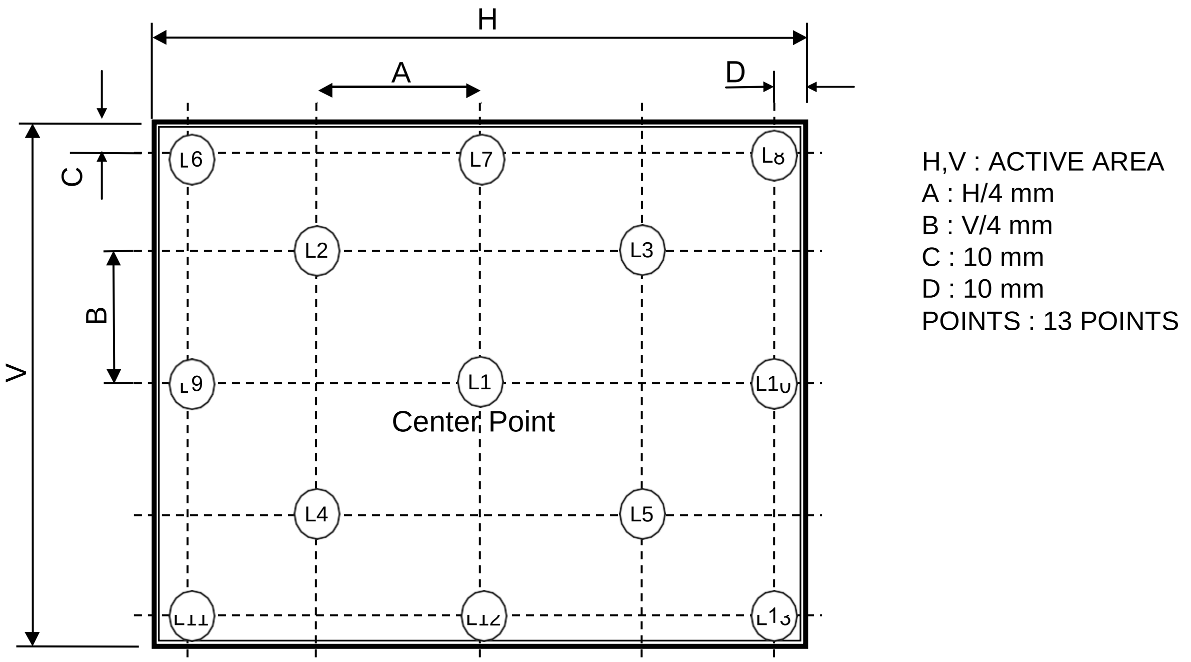



**FIG. 3 Response Time**

The response time is defined as the following figure and shall be measured by switching the input signal for “black” and “white”.

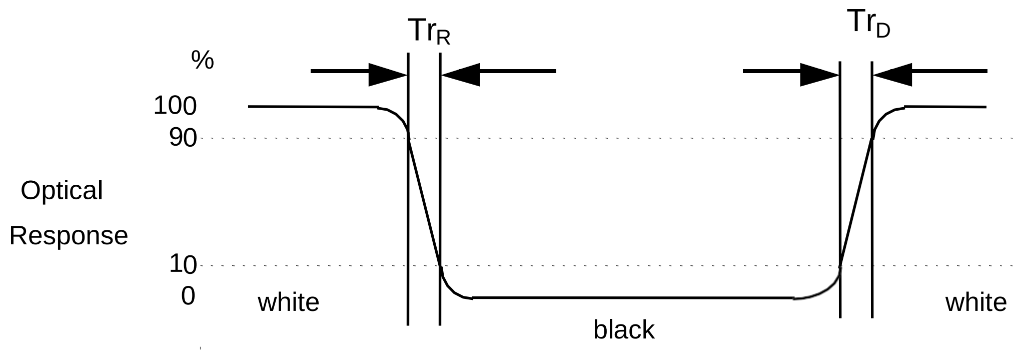
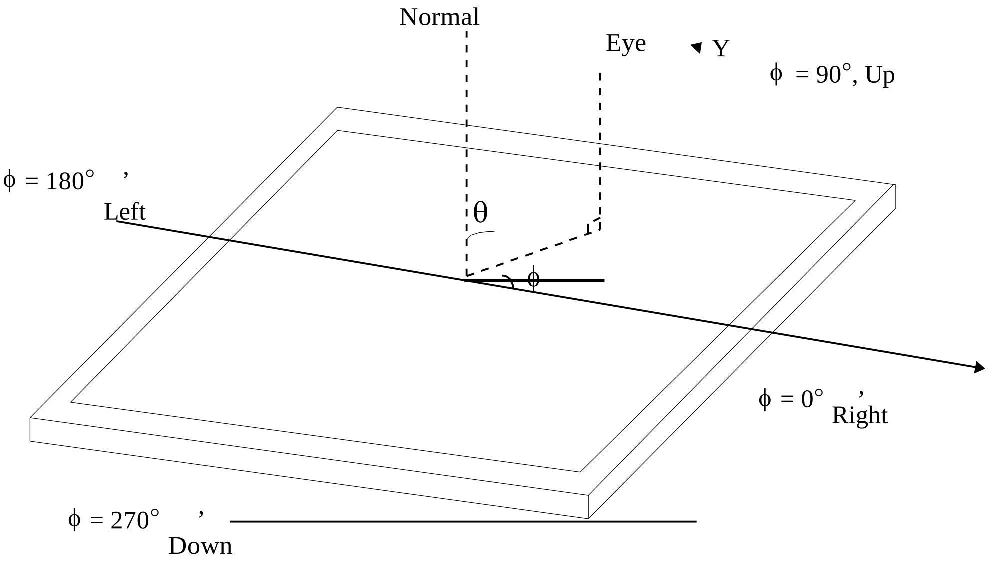


**FIG. 4 Viewing angle**

<Dimension of viewing angle range>



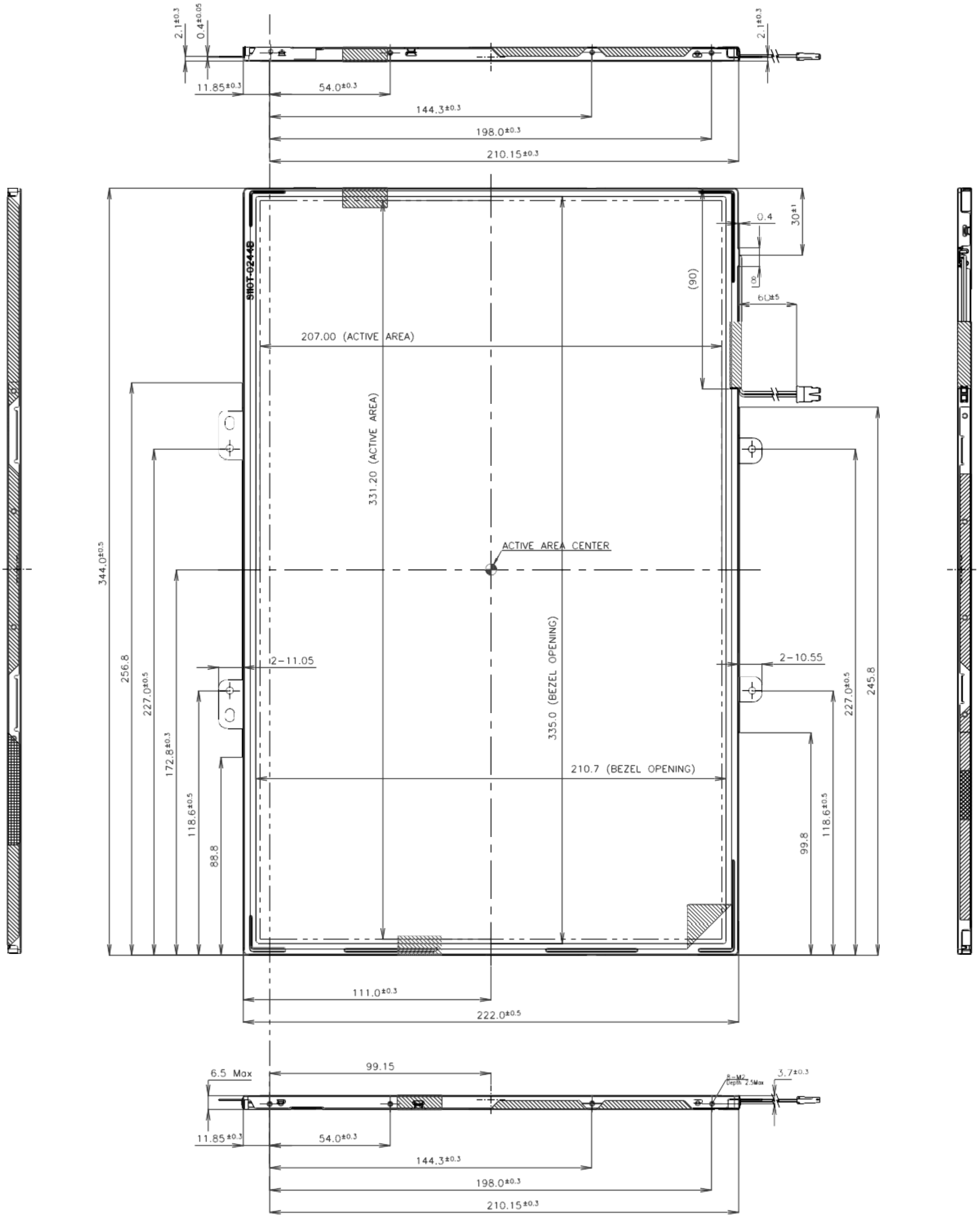
## 5. Mechanical Characteristics

The contents provide general mechanical characteristics for the model LP154WX4. In addition the figures in the next page are detailed mechanical drawing of the LCD.

| | | |
|---|---|---|
| Outline Dimension | Horizontal | 344.0 ± 0.5mm |
| | Vertical | 222.0 ± 0.5mm |
| | Thickness | 6.5mm (max) |
| Bezel Area | Horizontal | 335.0 ± 0.5mm |
| | Vertical | 210.7 ± 0.5mm |
| Active Display Area | Horizontal | 331.2 mm |
| | Vertical | 207.0 mm |
| Weight | 560g(Typ.), 575g (Max.) | |
| Surface Treatment | Glare treatment of the front polarizer | |

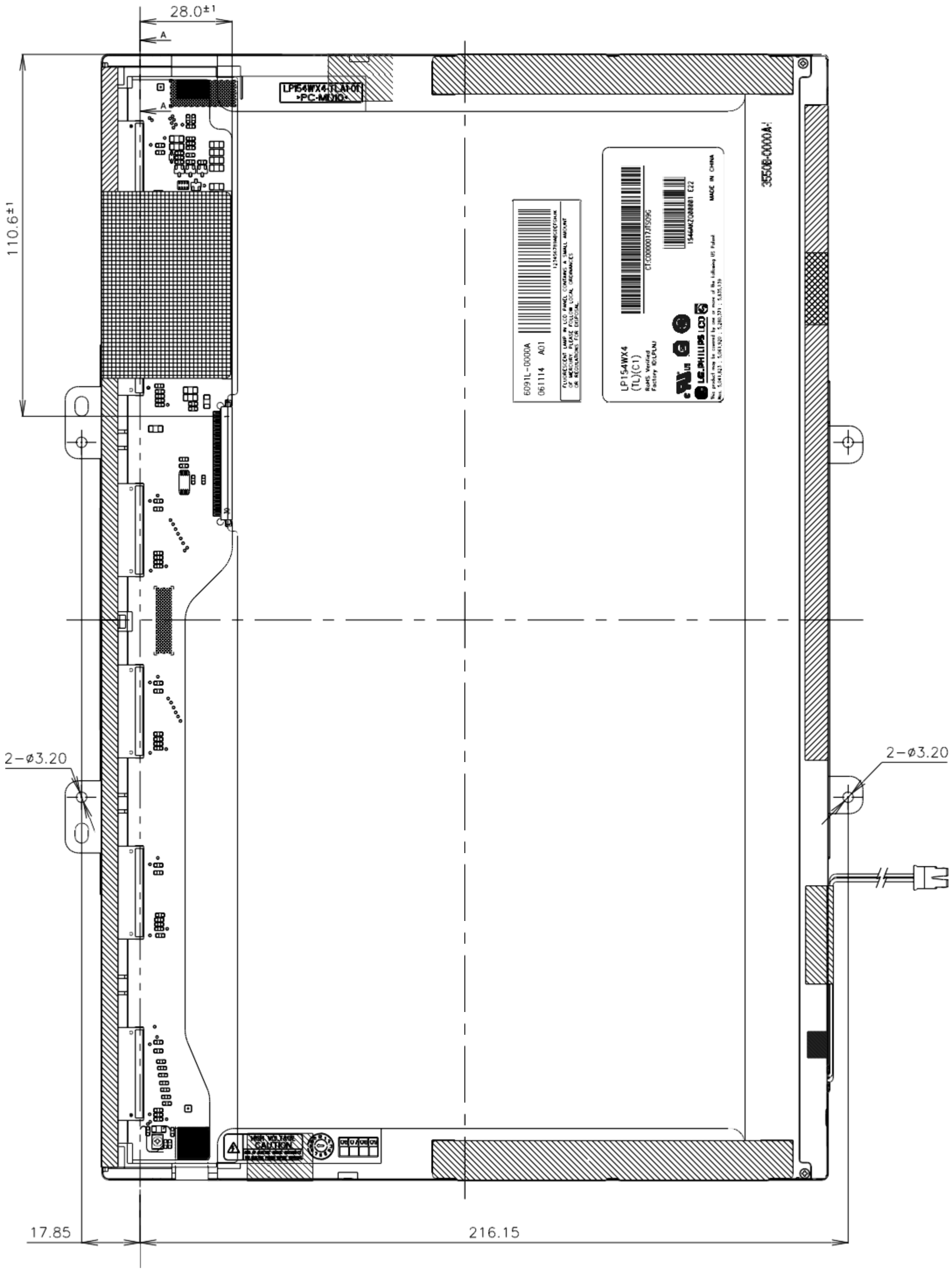
<FRONT VIEW>

Note) Unit:[mm], General tolerance: ±0.5mm

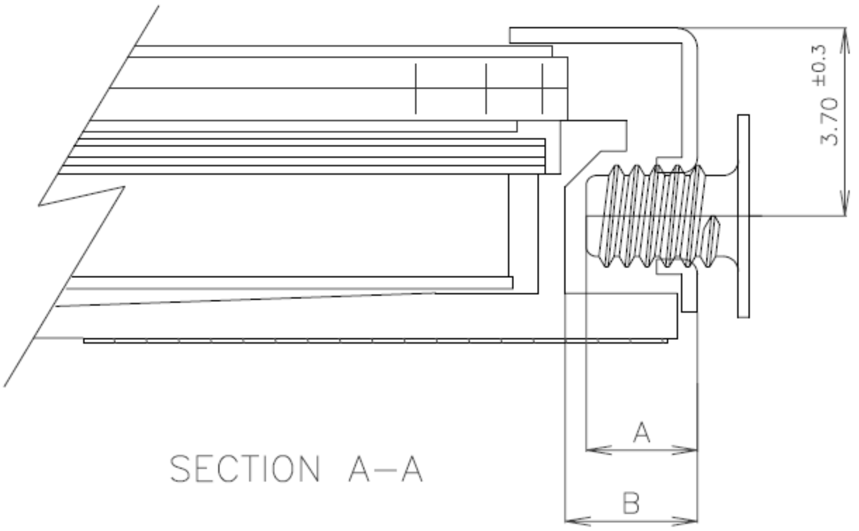


<REAR VIEW>

Note) Unit:[mm], General tolerance: ±0.5mm



[ DETAIL DESCRIPTION OF SIDE MOUNTING SCREW ]




* Mounting Screw Length (A)
  = 2.0(Min) / 2.5(Max)
* Mounting Screw Hole Depth (B)
  = 2.5(Min)
* Mounting hole location : 3.7(typ.)
* Torque : 2.5 kgf.cm(Max)
  (Measurement gauge : torque meter)

Notes : 1. Screw plated through the method of non-electrolytic nickel plating is preferred to reduce possibility that results in vertical and/or horizontal line defect due to the conductive particles from screw surface.

# 6. Reliability

Environment test condition

| No. | Test Item | Conditions |
|---|---|---|
| 1 | High temperature storage test | Ta= 60°C, 240h |
| 2 | Low temperature storage test | Ta= -20°C, 240h |
| 3 | High temperature operation test | Ta= 50°C, 50%RH, 240h |
| 4 | Low temperature operation test | Ta= 0°C, 240h |
| 5 | Vibration test (non-operating) | Sine wave, 10 ~ 500 ~ 10Hz, 1.5G, 0.37oct/min<br>3 axis, 1hour/axis |
| 6 | Shock test (non-operating) | Half sine wave, 180G, 2ms<br>one shock of each six faces(I.e. run 180G 6ms for all six faces) |
| 7 | Altitude operating<br>storage / shipment | 0 ~ 10,000 feet (3,048m) 24Hr<br>0 ~ 40,000 feet (12,192m) 24Hr |

{ Result Evaluation Criteria }
There should be no change which might affect the practical display function when the display quality test is conducted under normal operating condition.

# 7. International Standards

## 7-1. Safety

a) UL 60950-1:2003, First Edition, Underwriters Laboratories, Inc.,
Standard for Safety of Information Technology Equipment.
b) CAN/CSA C22.2, No. 60950-1-03 1st Ed. April 1, 2003, Canadian Standards Association,
Standard for Safety of Information Technology Equipment.
c) EN 60950-1:2001, First Edition,
European Committee for Electrotechnical Standardization(CENELEC)
European Standard for Safety of Information Technology Equipment.

## 7-2. EMC

a) ANSI C63.4 "Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electrical Equipment in the Range of 9kHZ to 40GHz. "American National Standards Institute(ANSI), 1992
b) C.I.S.P.R "Limits and Methods of Measurement of Radio Interface Characteristics of Information Technology Equipment." International Special Committee on Radio Interference.
c) EN 55022 "Limits and Methods of Measurement of Radio Interface Characteristics of Information Technology Equipment." European Committee for Electrotechnical Standardization.(CENELEC), 1998
( Including A1: 2000 )

# 8. Packing

## 8-1. Designation of Lot Mark

a) Lot Mark

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G | H | I | J | K | L | M |

A,B,C : SIZE(INCH)
D : YEAR
E : MONTH
F ~ M : SERIAL NO.

Note

1. YEAR

| Year | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mark | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 0 |

2. MONTH

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mark | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C |

b) Location of Lot Mark

Serial No. is printed on the label. The label is attached to the backside of the LCD module.
This is subject to change without prior notice.

## 8-2. Packing Form

a) Package quantity in one box : 20pcs

b) Box Size : 441mm × 373mm ×348mm

# 9. PRECAUTIONS

Please pay attention to the followings when you use this TFT LCD module.

## 9-1. MOUNTING PRECAUTIONS

(1) You must mount a module using holes arranged in four corners or four sides.
(2) You should consider the mounting structure so that uneven force (ex. Twisted stress) is not applied to the module. And the case on which a module is mounted should have sufficient strength so that external force is not transmitted directly to the module.
(3) Please attach the surface transparent protective plate to the surface in order to protect the polarizer. Transparent protective plate should have sufficient strength in order to the resist external force.
(4) You should adopt radiation structure to satisfy the temperature specification.
(5) Acetic acid type and chlorine type materials for the cover case are not desirable because the former generates corrosive gas of attacking the polarizer at high temperature and the latter causes circuit break by electro-chemical reaction.
(6) Do not touch, push or rub the exposed polarizers with glass, tweezers or anything harder than HB pencil lead. And please do not rub with dust clothes with chemical treatment.
Do not touch the surface of polarizer for bare hand or greasy cloth.(Some cosmetics are detrimental to the polarizer.)
(7) When the surface becomes dusty, please wipe gently with absorbent cotton or other soft materials like chamois soaks with petroleum benzene. Normal-hexane is recommended for cleaning the adhesives used to attach front / rear polarizers. Do not use acetone, toluene and alcohol because they cause chemical damage to the polarizer.
(8) Wipe off saliva or water drops as soon as possible. Their long time contact with polarizer causes deformations and color fading.
(9) Do not open the case because inside circuits do not have sufficient strength.

## 9-2. OPERATING PRECAUTIONS

(1) The spike noise causes the mis-operation of circuits. It should be lower than following voltage :
V=± 200mV(Over and under shoot voltage)

(2) Response time depends on the temperature.(In lower temperature, it becomes longer.)
(3) Brightness depends on the temperature. (In lower temperature, it becomes lower.)
And in lower temperature, response time(required time that brightness is stable after turned on) becomes longer.
(4) Be careful for condensation at sudden temperature change. Condensation makes damage to polarizer or electrical contacted parts. And after fading condensation, smear or spot will occur.
(5) When fixed patterns are displayed for a long time, remnant image is likely to occur.
(6) Module has high frequency circuits. Sufficient suppression to the electromagnetic interference shall be done by system manufacturers. Grounding and shielding methods may be important to minimized the interference.

## 9-3. ELECTROSTATIC DISCHARGE CONTROL

Since a module is composed of electronic circuits, it is not strong to electrostatic discharge. Make certain that treatment persons are connected to ground through wrist band etc. And don't touch interface pin directly.

## 9-4. PRECAUTIONS FOR STRONG LIGHT EXPOSURE

Strong light exposure causes degradation of polarizer and color filter.

## 9-5. STORAGE

When storing modules as spares for a long time, the following precautions are necessary.

(1) Store them in a dark place. Do not expose the module to sunlight or fluorescent light. Keep the temperature between 5°C and 35°C at normal humidity.
(2) The polarizer surface should not come in contact with any other object.
It is recommended that they be stored in the container in which they were shipped.

## 9-6. HANDLING PRECAUTIONS FOR PROTECTION FILM

(1) When the protection film is peeled off, static electricity is generated between the film and polarizer. This should be peeled off slowly and carefully by people who are electrically grounded and with well ion-blown equipment or in such a condition, etc.
(2) The protection film is attached to the polarizer with a small amount of glue. If some stress is applied to rub the protection film against the polarizer during the time you peel off the film, the glue is apt to remain on the polarizer.
Please carefully peel off the protection film without rubbing it against the polarizer.
(3) When the module with protection film attached is stored for a long time, sometimes there remains a very small amount of glue still on the polarizer after the protection film is peeled off.
(4) You can remove the glue easily. When the glue remains on the polarizer surface or its vestige is recognized, please wipe them off with absorbent cotton waste or other soft material like chamois soaked with normal-hexane.

## APPENDIX A. Enhanced Extended Display Identification Data (EEDID™) 1/3

### LP154WX4-TLC1 E-EDID DATA (ver0.0)

2007.04.13

| Byte# (decimal) | Byte# (HEX) | Field Name and Comments | Value (HEX) | | Value (binary) | |
|---|---|---|---|---|---|---|
| 0 | 00 | Header | 0 | 0 | 0000 0000 | **Header** |
| 1 | 01 | | F | F | 1111 1111 | |
| 2 | 02 | | F | F | 1111 1111 | |
| 3 | 03 | | F | F | 1111 1111 | |
| 4 | 04 | | F | F | 1111 1111 | |
| 5 | 05 | | F | F | 1111 1111 | |
| 6 | 06 | | F | F | 1111 1111 | |
| 7 | 07 | | 0 | 0 | 0000 0000 | |
| 8 | 08 | EISA manufacturer code = LPL | 3 | 2 | 0011 0010 | **Vender/ Product ID** |
| 9 | 09 | | 0 | C | 0000 1100 | |
| 10 | 0A | Product code = 00DB | 0 | 0 | 0000 0000 | |
| 11 | 0B | (Hex, LSB first) | D | B | 1101 1011 | |
| 12 | 0C | 32-bit serial number | 0 | 0 | 0000 0000 | |
| 13 | 0D | | 0 | 0 | 0000 0000 | |
| 14 | 0E | | 0 | 0 | 0000 0000 | |
| 15 | 0F | | 0 | 0 | 0000 0000 | |
| 16 | 10 | Week of manufacture | 0 | 0 | 0000 0000 | |
| 17 | 11 | Year of manufacture = 2006 | 1 | 0 | 0001 0000 | |
| 18 | 12 | EDID Structure version # = 1 | 0 | 1 | 0000 0001 | **EDID Version/ Revision** |
| 19 | 13 | EDID Revision # = 3 | 0 | 3 | 0000 0011 | |
| 20 | 14 | Video input definition = Digital I/p,non TMDS CRGB | 8 | 0 | 1000 0000 | **Display Parameter** |
| 21 | 15 | Max H image size(㎝) = 33.12㎝(33) | 2 | 1 | 0010 0001 | |
| 22 | 16 | Max V image size(㎝) = 20.7㎝(21) | 1 | 5 | 0001 0101 | |
| 23 | 17 | Display gamma = 2.20 | 7 | 8 | 0111 1000 | |
| 24 | 18 | Feature support(DPMS) = Active off, RGB Color | 0 | A | 0000 1010 | |
| 25 | 19 | Red/Green low Bits | B | 3 | 1011 0011 | **Color Characteristic** |
| 26 | 1A | Blue/White Low Bits | 4 | 0 | 0100 0000 | |
| 27 | 1B | Red X Rx = 0.600 | 9 | 9 | 1001 1001 | |
| 28 | 1C | Red Y Ry = 0.351 | 5 | 9 | 0101 1001 | |
| 29 | 1D | Green X Gx = 0.325 | 5 | 3 | 0101 0011 | |
| 30 | 1E | Green Y Gy = 0.554 | 8 | D | 1000 1101 | |
| 31 | 1F | Blue X Bx = 0.154 | 2 | 7 | 0010 0111 | |
| 32 | 20 | Blue Y By = 0.145 | 2 | 5 | 0010 0101 | |
| 33 | 21 | White X Wx = 0.313 | 5 | 0 | 0101 0000 | |
| 34 | 22 | White Y Wy = 0.329 | 5 | 4 | 0101 0100 | |
| 35 | 23 | Established Timing I | 0 | 0 | 0000 0000 | **Established Timings** |
| 36 | 24 | Established Timing II | 0 | 0 | 0000 0000 | |
| 37 | 25 | Manufacturer's Timings | 0 | 0 | 0000 0000 | |
| 38 | 26 | Standard Timing Identification 1 was not used | 0 | 1 | 0000 0001 | **Standard Timing ID** |
| 39 | 27 | Standard Timing Identification 1 was not used | 0 | 1 | 0000 0001 | |
| 40 | 28 | Standard Timing Identification 2 was not used | 0 | 1 | 0000 0001 | |
| 41 | 29 | Standard Timing Identification 2 was not used | 0 | 1 | 0000 0001 | |
| 42 | 2A | Standard Timing Identification 3 was not used | 0 | 1 | 0000 0001 | |
| 43 | 2B | Standard Timing Identification 3 was not used | 0 | 1 | 0000 0001 | |
| 44 | 2C | Standard Timing Identification 4 was not used | 0 | 1 | 0000 0001 | |
| 45 | 2D | Standard Timing Identification 4 was not used | 0 | 1 | 0000 0001 | |
| 46 | 2E | Standard Timing Identification 5 was not used | 0 | 1 | 0000 0001 | |
| 47 | 2F | Standard Timing Identification 5 was not used | 0 | 1 | 0000 0001 | |
| 48 | 30 | Standard Timing Identification 6 was not used | 0 | 1 | 0000 0001 | |
| 49 | 31 | Standard Timing Identification 6 was not used | 0 | 1 | 0000 0001 | |
| 50 | 32 | Standard Timing Identification 7 was not used | 0 | 1 | 0000 0001 | |
| 51 | 33 | Standard Timing Identification 7 was not used | 0 | 1 | 0000 0001 | |
| 52 | 34 | Standard Timing Identification 8 was not used | 0 | 1 | 0000 0001 | |
| 53 | 35 | Standard Timing Identification 8 was not used | 0 | 1 | 0000 0001 | |

## APPENDIX A. Enhanced Extended Display Identification Data (EEDID™) 2/3

| Byte# (decimal) | Byte# (HEX) | Field Name and Comments | Value (HEX) | | Value (binary) | |
|---|---|---|---|---|---|---|
| 54 | 36 | 1280 X 800 @ 60Hz mode : pixel clock = 71.00MHz | B | C | 1011 1100 | Timing Descriptor #1 |
| 55 | 37 | (Stored LSB first) | 1 | B | 0001 1011 | |
| 56 | 38 | Horizontal Active = 1280 pixels | 0 | 0 | 0000 0000 | |
| 57 | 39 | Horizontal Blanking = 160 pixels | A | 0 | 1010 0000 | |
| 58 | 3A | Horizontal Active : Horizontal Blanking = 1280 : 160 | 5 | 0 | 0101 0000 | |
| 59 | 3B | Vertical Avtive = 800 lines | 2 | 0 | 0010 0000 | |
| 60 | 3C | Vertical Blanking = 23 lines | 1 | 7 | 0001 0111 | |
| 61 | 3D | Vertical Active : Vertical Blanking = 800 : 23 | 3 | 0 | 0011 0000 | |
| 62 | 3E | Horizontal Sync. Offset = 48 pixels | 3 | 0 | 0011 0000 | |
| 63 | 3F | Horizontal Sync Pulse Width = 32 pixels | 2 | 0 | 0010 0000 | |
| 64 | 40 | Vertical Sync Offset = 3 lines, Sync Width = 6 lines | 3 | 6 | 0011 0110 | |
| 65 | 41 | Horizontal Vertical Sync Offset/Width upper 2bits = 0 | 0 | 0 | 0000 0000 | |
| 66 | 42 | Horizontal Image Size = 331.2mm(331) | 4 | B | 0100 1011 | |
| 67 | 43 | Vertical Image Size = 207.0mm(207) | C | F | 1100 1111 | |
| 68 | 44 | Horizontal & Vertical Image Size | 1 | 0 | 0001 0000 | |
| 69 | 45 | Horizontal Border = 0 | 0 | 0 | 0000 0000 | |
| 70 | 46 | Vertical Border = 0 | 0 | 0 | 0000 0000 | |
| 71 | 47 | Non-interlaced,Normal display,no stereo,Digital separate sync,H/V pol negatives | 1 | 9 | 0001 1001 | |
| 72 | 48 | Detailed Timing Descriptor #2 | 0 | 0 | 0000 0000 | Detailed Timing Description #2 |
| 73 | 49 | | 0 | 0 | 0000 0000 | |
| 74 | 4A | | 0 | 0 | 0000 0000 | |
| 75 | 4B | | 0 | 0 | 0000 0000 | |
| 76 | 4C | | 0 | 0 | 0000 0000 | |
| 77 | 4D | | 0 | 0 | 0000 0000 | |
| 78 | 4E | | 0 | 0 | 0000 0000 | |
| 79 | 4F | | 0 | 0 | 0000 0000 | |
| 80 | 50 | | 0 | 0 | 0000 0000 | |
| 81 | 51 | | 0 | 0 | 0000 0000 | |
| 82 | 52 | | 0 | 0 | 0000 0000 | |
| 83 | 53 | | 0 | 0 | 0000 0000 | |
| 84 | 55 | | 0 | 0 | 0000 0000 | |
| 85 | 55 | | 0 | 0 | 0000 0000 | |
| 86 | 56 | | 0 | 0 | 0000 0000 | |
| 87 | 57 | | 0 | 0 | 0000 0000 | |
| 88 | 58 | | 0 | 0 | 0000 0000 | |
| 89 | 59 | | 0 | 0 | 0000 0000 | |
| 90 | 5A | Detailed Timing Descriptor #3 | 0 | 0 | 0000 0000 | Detailed Timing Description #3 |
| 91 | 5B | | 0 | 0 | 0000 0000 | |
| 92 | 5C | | 0 | 0 | 0000 0000 | |
| 93 | 5D | | F | E | 1111 1110 | |
| 94 | 5E | | 0 | 0 | 0000 0000 | |
| 95 | 5F | L | 4 | C | 0100 1100 | |
| 96 | 60 | G | 4 | 7 | 0100 0111 | |
| 97 | 61 | P | 5 | 0 | 0101 0000 | |
| 98 | 62 | h | 6 | 8 | 0110 1000 | |
| 99 | 63 | i | 6 | 9 | 0110 1001 | |
| 100 | 64 | l | 6 | C | 0110 1100 | |
| 101 | 65 | i | 6 | 9 | 0110 1001 | |
| 102 | 66 | p | 7 | 0 | 0111 0000 | |
| 103 | 67 | s | 7 | 3 | 0111 0011 | |
| 104 | 68 | L | 4 | C | 0100 1100 | |
| 105 | 69 | C | 4 | 3 | 0100 0011 | |
| 106 | 6A | D | 4 | 4 | 0100 0100 | |
| 107 | 6B | LF | 0 | A | 0000 1010 | |

# APPENDIX A. Enhanced Extended Display Identification Data (EEDID™) 3/3

| Byte# (decimal) | Byte# (HEX) | Field Name and Comments | Value (HEX) | | Value (binary) | |
|---|---|---|---|---|---|---|
| 108 | 6C | Detailed Timing Descriptor #4 | 0 | 0 | 0000 0000 | Detailed Timing Description #4 |
| 109 | 6D | | 0 | 0 | 0000 0000 | |
| 110 | 6E | | 0 | 0 | 0000 0000 | |
| 111 | 6F | | F | E | 1111 1110 | |
| 112 | 70 | | 0 | 0 | 0000 0000 | |
| 113 | 71 | L | 4 | C | 0100 1100 | |
| 114 | 72 | P | 5 | 0 | 0101 0000 | |
| 115 | 73 | 1 | 3 | 1 | 0011 0001 | |
| 116 | 74 | 5 | 3 | 5 | 0011 0101 | |
| 117 | 75 | 4 | 3 | 4 | 0011 0100 | |
| 118 | 76 | W | 5 | 7 | 0101 0111 | |
| 119 | 77 | X | 5 | 8 | 0101 1000 | |
| 120 | 78 | 4 | 3 | 4 | 0011 0100 | |
| 121 | 79 | - | 2 | D | 0010 1101 | |
| 122 | 7A | T | 5 | 4 | 0101 0100 | |
| 123 | 7B | L | 4 | C | 0100 1100 | |
| 124 | 7C | C | 4 | 3 | 0100 0011 | |
| 125 | 7D | 1 | 3 | 1 | 0011 0001 | |
| 126 | 7E | Extension flag = 00 | 0 | 0 | 0000 0000 | Extension Flag |
| 127 | 7F | Checksum | 4 | 6 | 0100 0110 | Checksum |

# ANNEX 2: MONITOR CONTROL BOARD SPECIFICATION

**MODEL: M.NT68676.2A**

Part Number: NT-11112749

AUTHOR: 2011.12.27 19:31:11 +08'00'

CHECKED BY: 2011.12.27 21:26:32 +08'00'

RECHECKED BY: zhp 2011.12.27 22:20:03 +08'00'

APPROVED BY: 2011.12.27 22:31:57 +08'00'

PUBLISHED DATE: 2011-12-27

# CONTENT



# REVISION HISTORY

| VERSION | DATE | BOARD ID | PAGE | DESCRIPTION | AUTHOR |
|---|---|---|---|---|---|
| V1.0 | 2011.12.27 | M.NT68676.2A 11486 | All | First issued. | Linda |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

# 1. GENERAL DESCRIPTION

**M.NT68676.2A** is a monitor control board, which is suitable for Asia-Pacific market. It can support LED/LCD panels which resolution is up to 2048×1152.

**M.NT68676.2A** can synchronize with computer automatically. Synchronization requires the synchronous signal which horizontal and vertical sync are separated.

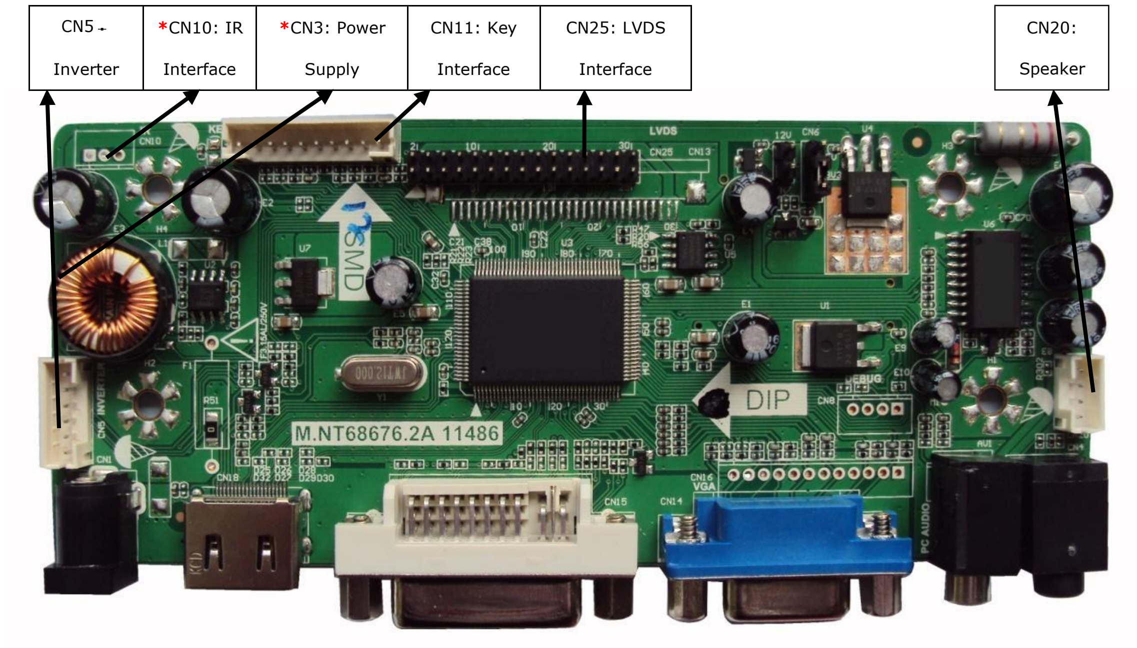
**M.NT68676.2A** can support dynamic contrast control, headphone input and Digital volume control simultaneously.

# 2. FUNCTION LAYOUT

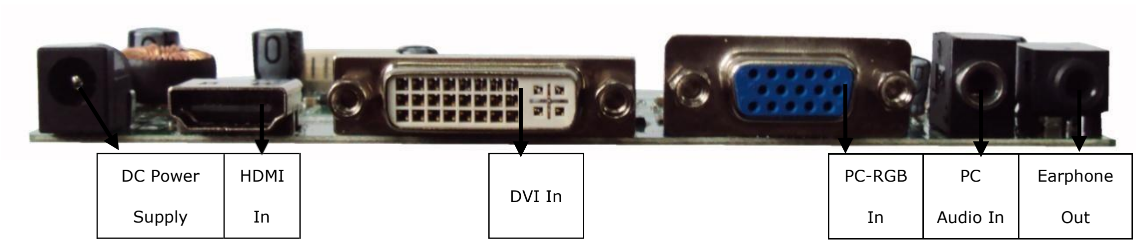
The picture is for a reference only, the actual item is the standard.

The optional connectors and terminals are marked with "*".

## TOP VIEW OF M.NT68676.2A




## FRONT VIEW OF M.NT68676.2A



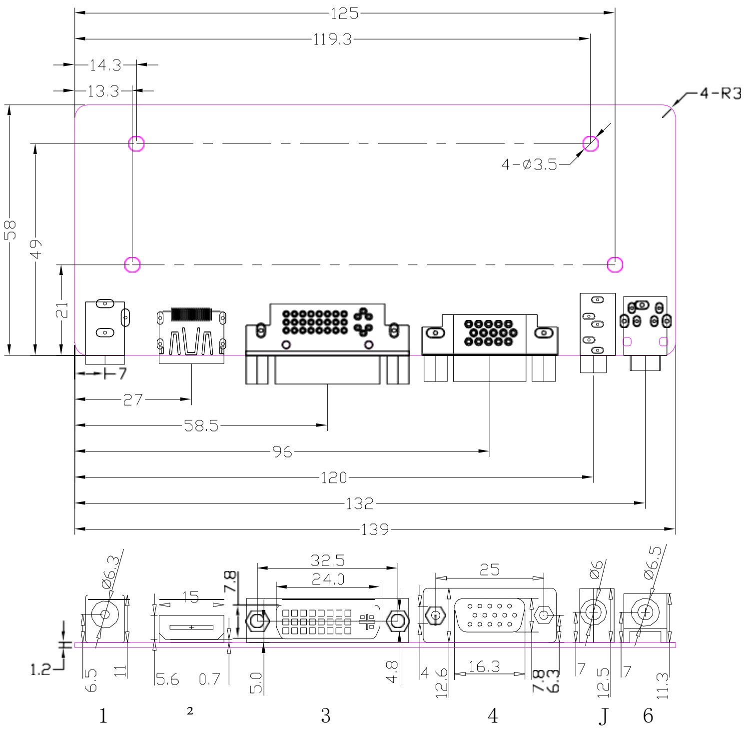
# 3. FEATURES

| | | | |
|---|---|---|---|
| **CHIPSET** | NT68676(UFG) | | |
| **MARKET AREA** | Asia-Pacific | | |
| **OSD LANGUAGE** | Simplified Chinese, Traditional Chinese, English, French, German, Italian, Spanish, Portuguese, Japanese, Korean (optional) | | |
| **PANEL** | Panel Type | LED/LCD | |
| | Interface | Single/Dual LVDS (8bit) | |
| | Max Resolution | 2048×1152 | |
| **VIDEO INPUT** | PC-RGB | Format | Up to 2048×1152@60Hz |
| | HDMI | 480i, 480p, 576i, 576p, 720p, 1080i, 1080p | |
| **AUDIO INPUT** | PC Audio | Earphone Input | 0.2 ~ 2.0 $V_{RMS}$ |
| **AUDIO OUTPUT** | Frequency Response | 100Hz~15KHz @±3dB (1KHz, 0dB reference signal) | |
| | Max Output power | 2×1W(8Ω) THD+N<10%@1KHz (Power Supply: 12V, Audio Input: 0.5$V_{RMS}$) | |
| **POWER** | Requirement | 12V DC/12V(built)/12V,5V(built in)/12V,5V,5VSB(built in) | |
| | To Panel | 3.3V/5V/12V | |
| | Management | Standby Power Consumption < 0.5W(Board Only) | |
| **KEY FUNCTION** | POWER,MENU,VOL+,VOL-,ADJUST/EXIT | | |

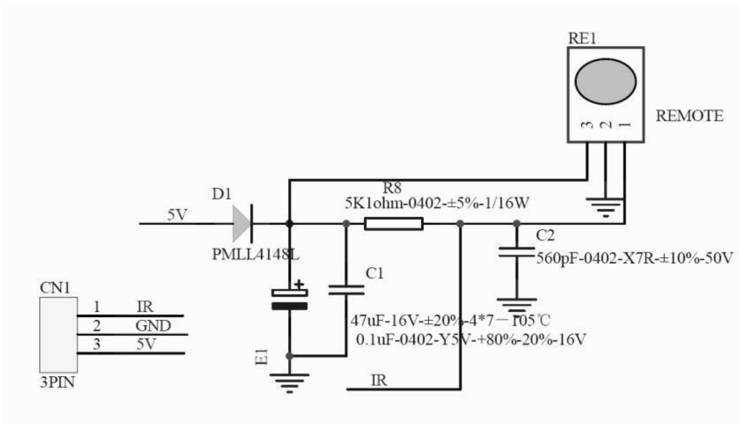
# 4. PCB DIMENSIONS

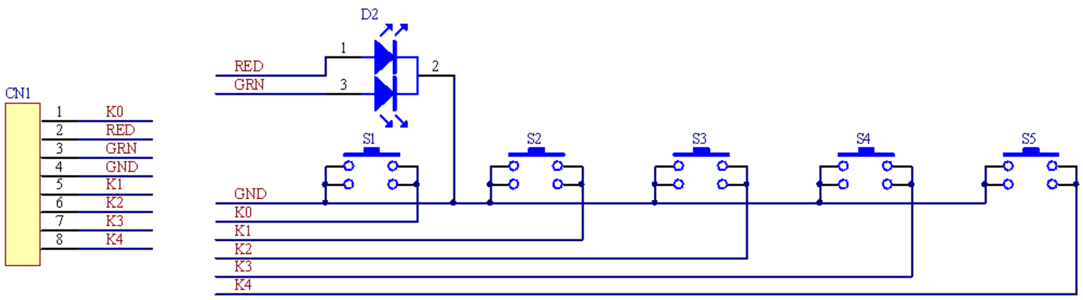
**The size of M.NT68676.2A is 139mm(L)*58mm(W)*17mm(H).**

| 9HU | 91.0 |
|---|---|
| 12. | 'HVFULSWLRQ |
| 1 | '& ,1 |
| 2 | +'0, ,1 |
| 3 | '9, ,1 |
| 4 | 9*$ ,1 |
| J | 3& $8',2 ,1 |
| 6 | ($53+21( 287 |



# 5. SCHEMATICS OF IR BOARD & KEY BOARD




# 6. INTERFACE DEFINITION

The optional connectors are marked with "*".

### ξ CN5(6PIN/2.0): INVERTER CONNECTOR

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 1 | 12V | +12V DC Power Supply |
| 2 | 12V | |
| 3 | BLO | Back-Light ON/OFF Control for Panel |
| 4 | ADJ | Brightness Adjustment for Panel |
| 5 | GND | Ground |
| 6 | GND | |

### ξ *CN10(3PIN/2.0): IR INTERFACE CONNECTOR

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 1 | IR | IR Receiver |
| 2 | GND | Ground |
| 3 | 5V | +5V DC Power Supply |

### ξ *CN3(6PIN/2.0): POWER SUPPLY CONNECTOR

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 1 | PWON | Power On/Off |
| 2 | 5VSB | +5V DC Power Supply for Standby Mode |
| 3 | 5V | +5V DC Power Supply |

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 4 | 5V | |
| 5 | GND | Ground |
| 6 | GND | |

## ε CN11(10PIN/2.0): KEY INTERFACE CONNECTOR

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 1 | K0 | Key0 |
| 2 | RED | Red Indicator |
| 3 | GRN | Green Indicator |
| 4 | GND | Ground |
| 5 | K1 | Key1 |
| 6 | K2 | Key2 |
| 7 | K3 | Key3 |
| 8 | K4 | Key4 |
| 9 | K5 | Key5 |
| 10 | K6 | Key6 |

## ε CN25(2×15PIN/2.0): LVDS INTERFACE CONNECTOR

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 1 | VSEL | Power Supply for Panel |
| 2 | VSEL | |
| 3 | VSEL | |
| 4 | GND | Ground |
| 5 | GND | |
| 6 | GND | |
| 7 | TXO0- | LVDS ODD 0- Signal |
| 8 | TXO0+ | LVDS ODD 0+ Signal |
| 9 | TXO1- | LVDS ODD 1- Signal |
| 10 | TXO1+ | LVDS ODD 1+ Signal |
| 11 | TXO2- | LVDS ODD 2- Signal |
| 12 | TXO2+ | LVDS ODD 2+ Signal |
| 13 | GND | Ground |
| 14 | GND | |
| 15 | TXOC- | LVDS ODD Clock- Signal |
| 16 | TXOC+ | LVDS ODD Clock+ Signal |
| 17 | TXO3- | LVDS ODD 3- Signal |
| 18 | TXO3+ | LVDS ODD 3+ Signal |
| 19 | TXE0- | LVDS EVEN 0- Signal |
| 20 | TXE0+ | LVDS EVEN 0+ Signal |
| 21 | TXE1- | LVDS EVEN 1- Signal |
| 22 | TXE1+ | LVDS EVEN 1+ Signal |
| 23 | TXE2- | LVDS EVEN 2- Signal |
| 24 | TXE2+ | LVDS EVEN 2+ Signal |

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 25 | GND | Ground |
| 26 | GND | |
| 27 | TXEC- | LVDS EVEN Clock- Signal |
| 28 | TXEC+ | LVDS EVEN Clock+ Signal |
| 29 | TXE3- | LVDS EVEN 3- Signal |
| 30 | TXE3+ | LVDS EVEN 3+ Signal |

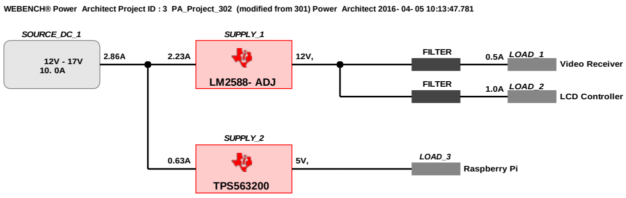
### ε CN20 (4PIN/2.0): SPEAKER CONNECTOR

| NO. | SYMBOL | DESCRIPTION |
|---|---|---|
| 1 | LO | Audio Left Channel Output |
| 2 | GND | Ground |
| 3 | GND | |
| 4 | RO | Audio Right Channel Output |

# 7. CONFIGURATION & GENERAL PRECAUTIONS

- **Relative humidity: ≤ 80%.**
- **Storage temperature: -10~60°C.**
- **Operation temperature: 0~40°C.**
- **Protect the board from static electricity in case of damage to the IC.**
- **Keep the board away from conductor when it is working.**
- **Don’t push or pull the connectors when the board is working.**
- **Don’t press , distort or disassemble the board.**
- **Clean the board with soft dry cloth when it’s dirty.**
- **Don’t wire in the board to power supply before panel is correctly connected.**

Texas Instruments




# ANNEX 3: POWER SUPPLY VOLTAGE REGULATORS

## WEBENCH® Power Architect

### Project Report

Project : 4311631/3 : PA_Project_302 (modified from 301)
Created : 2016-04-05 10:13:47.781
Optimize project optFactor=3

Project Summary

| | | |
|---|---|---|
| 1. | Total System Efficiency | 75.064 % |
| 2. | Total System BOM Count | 25.0 |
| 3. | Total System Footprint | 1.492 kmm2 |
| 4. | Total System BOM Cost | $12.92 |
| 5. | Total System Power Dissipation | 9.302 W |

--> Launch WEBENCH Power Architect.

## Sequencer Flag Table

| Supply | Sequencer Flag | Load | Load Name |
|---|---|---|---|
| SUPPLY_1 | 0 | LOAD_1 | Video Receiver |
| SUPPLY_1 | 0 | LOAD_2 | LCD Controller |
| SUPPLY_2 | 0 | LOAD_3 | Raspberry Pi 2 |

## Power Supplies

| # | Name | NSID | Description | Vout | Iout | Efficiency | Foot-print | Cost | Design Page | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | SUPPLY_1 | LM2588-ADJ | Switcher : SIMPLE SWITCHER(r) Flyback Converter | 12 V | 1.5 A | 67.9% | 1347 | $11.65 | 22 | 4 |
| 2. | SUPPLY_2 | TPS563200 | Switcher : 17V, 3A,6-pin, Low Iq Synchronous buck converter with Advanced Eco-mode | 5 V | 2.0 A | 93.6% | 145 | $1.27 | 23 | 11 |

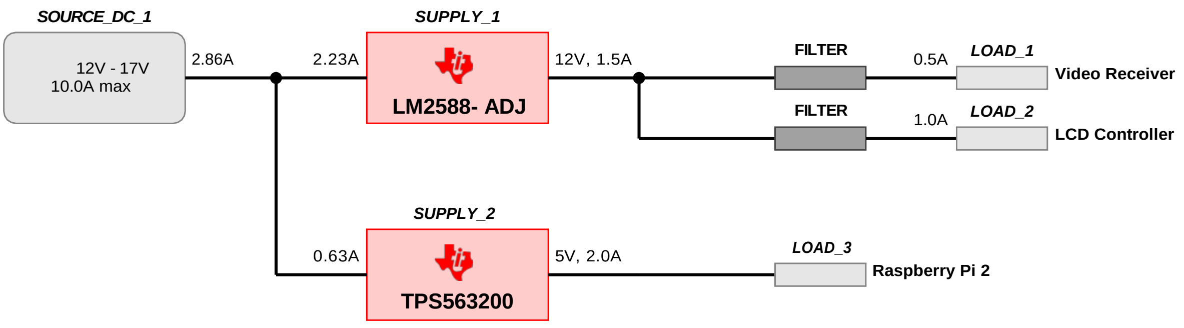
## Power Loads

| # | Name | VLoad | ILoad | Description |
|---|---|---|---|---|
| 1 | Video Receiver | 12 V | 0.5 A | VoutRipple=10%, Filter required |
| 2 | LCD Controller | 12 V | 1 A | VoutRipple=10%, Filter required |
| 3 | Raspberry Pi 2 | 5 V | 2 A | VoutRipple=10% |

.

## Project Diagram

WEBENCH® Power Architect Project ID : 3 PA_Project_302 (modified from 301) Power Architect 2016- 04- 05 10:13:47.781



## Electrical Procurement BOM

| Manufacturer | Part Number | Description | Quantity | Budgetary Price | Footprint (mm²) |
|---|---|---|---|---|---|
| AVX | 08053C104KAT2A | 0805 | 1 | $0.01 | 7 |
| Panasonic | 16SVPF1000M | CAPSMT_62_F12 | 1 | $0.74 | 151 |
| Aavid | 576602B00000G | 576602 | 1 | $0.63 | 403 |
| Diodes Inc. | B560C-13-F | SMC | 1 | $0.17 | 83 |
| TDK | C3216JB1A476M | 1206 | 1 | $0.34 | 11 |
| TDK | C3216X5R1E476M160AC | 1206 | 2 | $0.35 | 11 |
| Vishay-Dale | CRCW040210K0FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW04022K94FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW040246K4FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW040256K2FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW04028K66FKED | 0402 | 1 | $0.01 | 3 |
| Vishay-Dale | CRCW0402976RFKED | 0402 | 1 | $0.01 | 3 |
| Diodes Inc. | DFLS1200-7 | PowerDI123 | 1 | $0.21 | 13 |
| Panasonic | EEE-FK1E330UR | SM_RADIAL_C | 2 | $0.11 | 124 |
| MuRata | GRM155C80G224KE01D | 0402 | 1 | $0.01 | 3 |
| MuRata | GRM32ER61E226KE15L | 1210 | 1 | $0.16 | 15 |
| Texas Instruments | LM2588T-ADJ/NOPB | TA07B | 1 | $4.25 | 121 |
| TDK | NLCV32T-R10M-PFR | NLCV32 | 2 | $0.10 | 27 |
| Bourns | SDR0805-3R3ML | SDR0805 | 1 | $0.22 | 96 |
| Micro Commercial Components | SMBJ5365B-TP | SMB | 1 | $0.23 | 44 |
| Texas Instruments | TPS563200DDCR | DDC0006A | 1 | $0.52 | 10 |
| Coiltronics | VPH2-0066-R | VP2 | 1 | $4.25 | 344 |
| **Total** | | | 25 | $12.81 | 1491.3700999999999 |

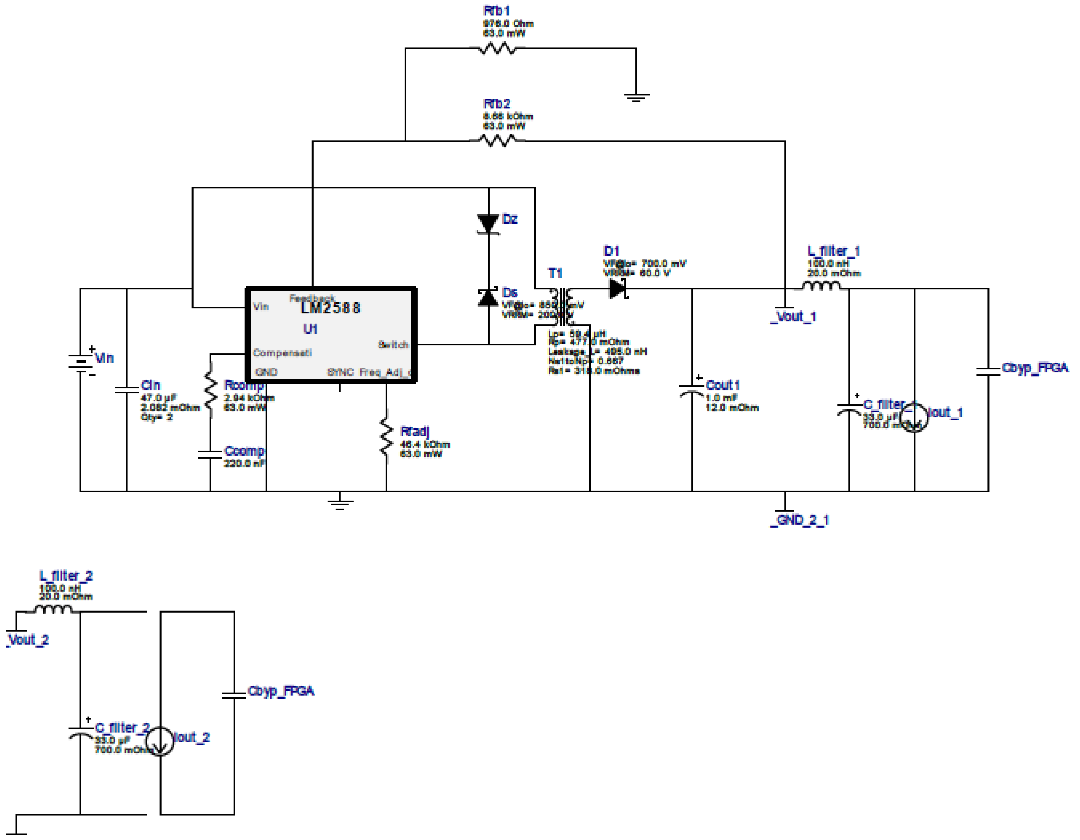
TEXAS INSTRUMENTS

# WEBENCH ® Design Report

Vout = 12.0V
Iout = 1.5A

Device = LM2588T-ADJ/NOPB
Topology = Flyback
Created = 4/5/16 10:13:47 AM
BOM Cost = $11.65
BOM Count = 18
Total Pd = 8.62W

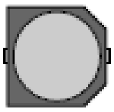
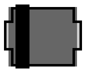
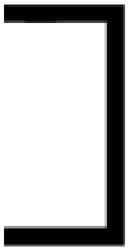
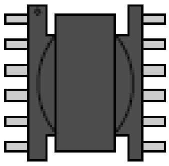
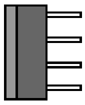
Design : 4311631/22 LM2588T-ADJ/NOPB
LM2588T-ADJ/NOPB 12.0V-17.0V to 12.00V @ 1.5A

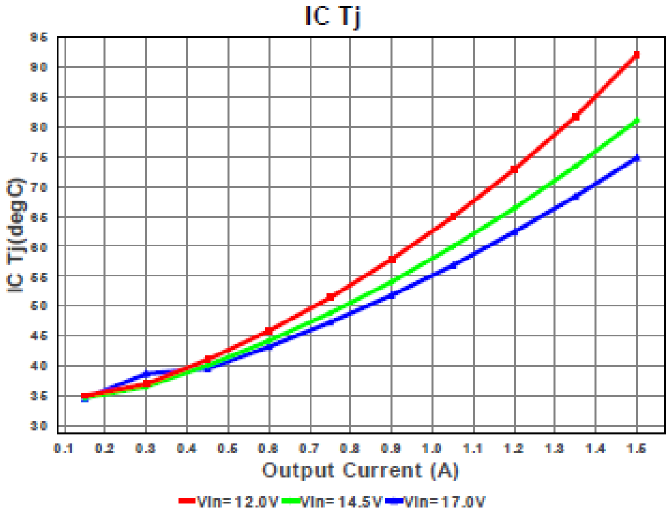


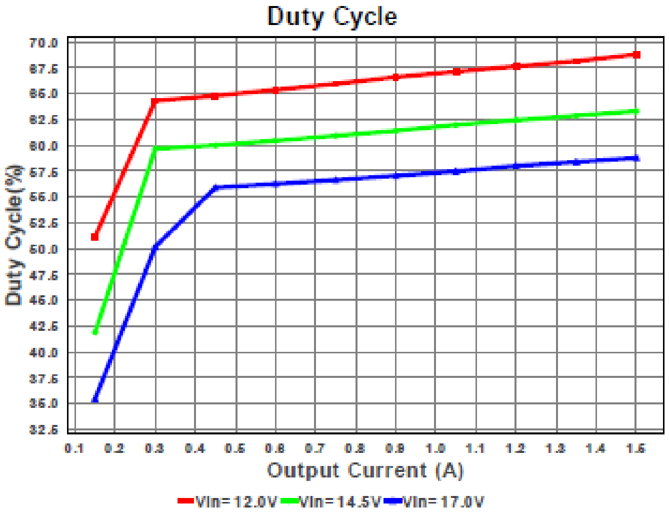

## Electrical BOM

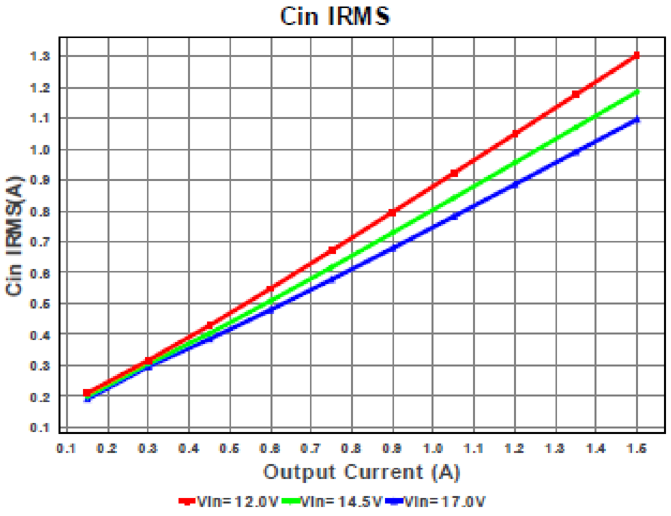
| # | Name | Manufacturer | Part Number | Properties | Qty | Price | Footprint |
|---|---|---|---|---|---|---|---|
| 1. | C_filter_1 | Panasonic | EEE-FK1E330UR<br>Series= FK | Cap= 33.0 uF<br>ESR= 700.0 mOhm<br>VDC= 25.0 V<br>IRMS= 160.0 mA | 1 | $0.11 | SM_RADIAL_C 62 $mm^2$ |
| 2. | C_filter_2 | Panasonic | EEE-FK1E330UR<br>Series= FK | Cap= 33.0 uF<br>ESR= 700.0 mOhm<br>VDC= 25.0 V<br>IRMS= 160.0 mA | 1 | $0.11 | SM_RADIAL_C 62 $mm^2$ |
| 3. | Ccomp | MuRata | GRM155C80G224KE01D<br>Series= X6S | Cap= 220.0 nF<br>VDC= 4.0 V<br>IRMS= 0.0 A | 1 | $0.01 | 0402 3 $mm^2$ |
| 4. | Cin | TDK | C3216X5R1E476M160AC<br>Series= X5R | Cap= 47.0 uF<br>ESR= 2.082 mOhm<br>VDC= 25.0 V<br>IRMS= 5.0279 A | 2 | $0.35 | 1206 11 $mm^2$ |

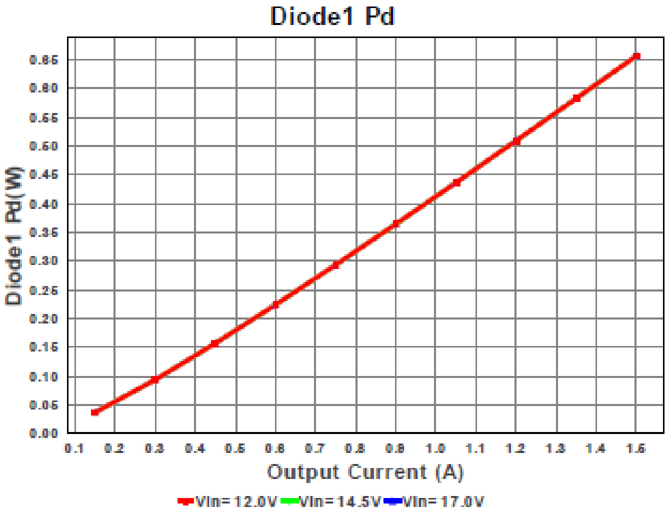
20.0 m Ohm

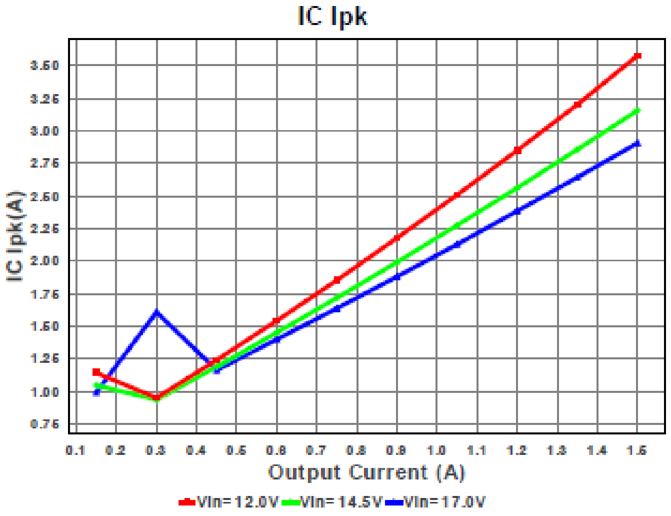
| # | Name | Manufacturer | Part Number | Properties | Qty | Price | Footprint |
|---|---|---|---|---|---|---|---|
| 5. | Cout1 | Panasonic | 16SVPF1000M<br>Series= SVPF | Cap= 1.0 mF<br>ESR= 12.0 mOhm<br>VDC= 16.0 V<br>IRMS= 5.4 A | 1 | $0.74 | <br>CAPSMT_62_F12 151 mm² |
| 6. | D1 | Diodes Inc. | B560C-13-F | VF@Io= 700.0 mV<br>VRRM= 60.0 V | 1 | $0.17 | <br>SMC 63 mm² |
| 7. | Ds | Diodes Inc. | DFLS1200-7 | VF@Io= 850.0 mV<br>VRRM= 200.0 V | 1 | $0.21 | PowerDI123 13 mm² |
| 8. | Dz | Micro Commercial Components | SMBJ5365B-TP | Zener | 1 | $0.23 | <br>SMB 44 mm² |
| 9. | HeatSink | Aavid | 576602B00000G | Heatsink | 1 | $0.63 | <br>576602 403 mm² |
| 10. | L_filter_1 | TDK | NLCV32T-R10M-PFR | L= 100.0 nH<br>DCR= 20.0 mOhm | 1 | $0.10 | <br>NLCV32 13 mm² |
| 11. | L_filter_2 | TDK | NLCV32T-R10M-PFR | L= 100.0 nH<br>DCR= 20.0 mOhm | 1 | $0.10 | <br>NLCV32 13 mm² |
| 12. | Rcomp | Vishay-Dale | CRCW04022K94FKED<br>Series= CRCW..e3 | Res= 2.94 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| 13. | Rfadj | Vishay-Dale | CRCW040246K4FKED<br>Series= CRCW..e3 | Res= 46.4 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| 14. | Rfb1 | Vishay-Dale | CRCW0402976RFKED<br>Series= CRCW..e3 | Res= 976.0 Ohm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| 15. | Rfb2 | Vishay-Dale | CRCW04028K66FKED<br>Series= CRCW..e3 | Res= 8.66 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| 16. | T1 | Coiltronics | VPH2-0066-R | Lp= 59.4 µH<br>Rp= 477.0 mOhm<br>Leakage_L= 495.0 nH<br>Ns1toNp= 0.667<br>Rs1= 318.0 mOhms | 1 | $4.25 | <br>VP2 344 mm² |
| 17. | U1 | Texas Instruments | LM2588T-ADJ/NOPB | Switcher | 1 | $4.25 | <br>TA07B 121 mm² |

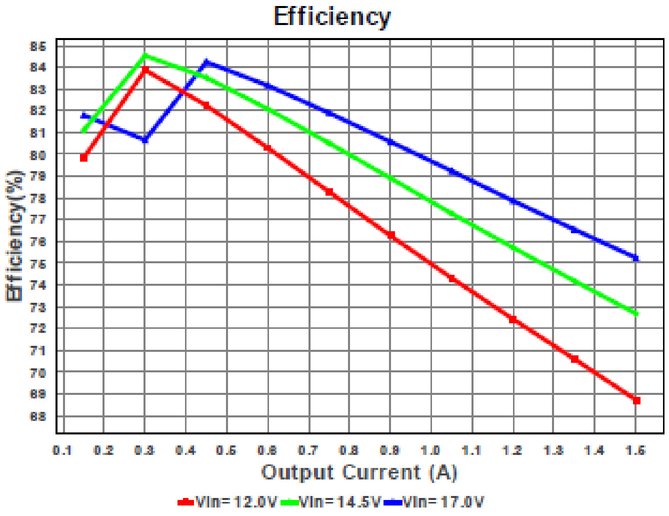

IC Tj
IC Tj(degC)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

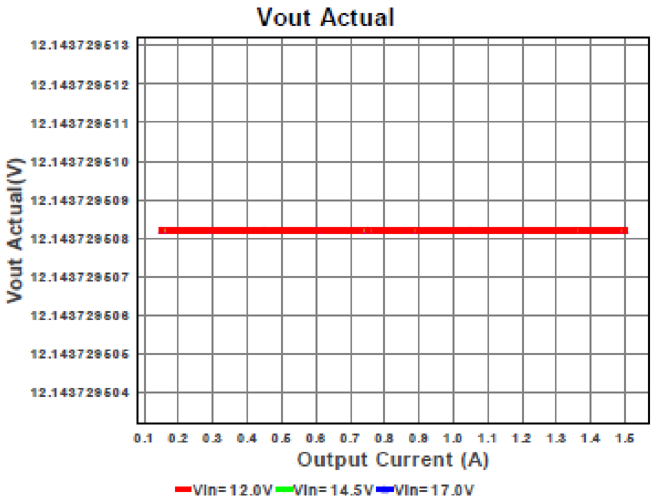

Duty Cycle
Duty Cycle(%)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

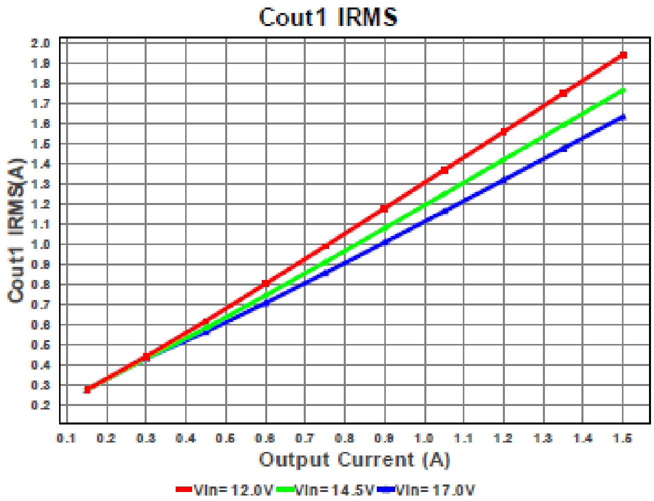

Cin IRMS
Cin IRMS(A)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

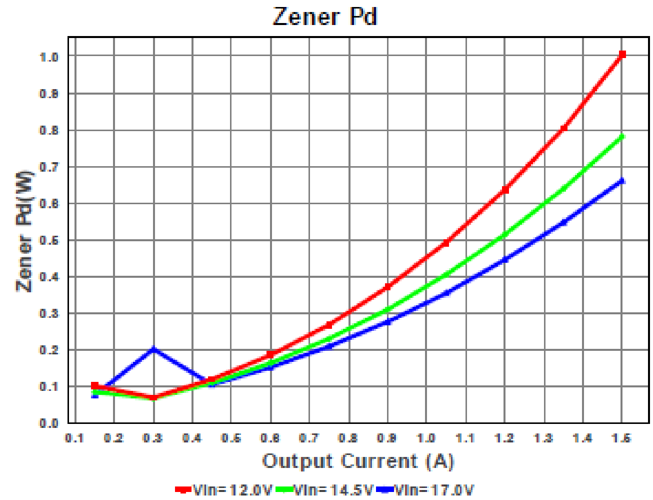

Diode1 Pd
Diode1 Pd(W)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

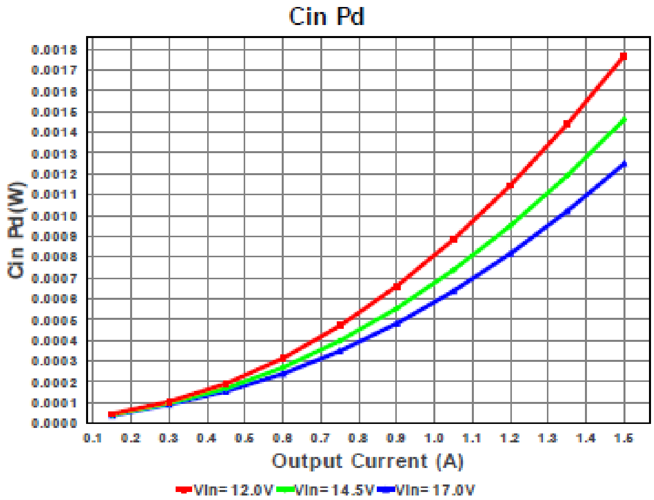

IC Ipk
IC Ipk(A)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

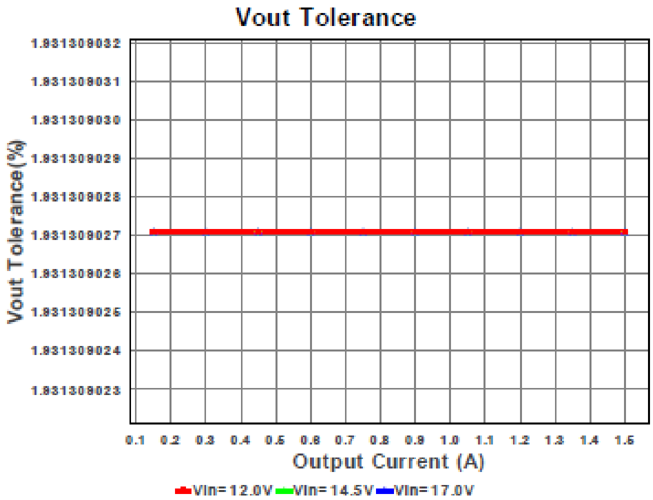

Efficiency
Efficiency(%)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

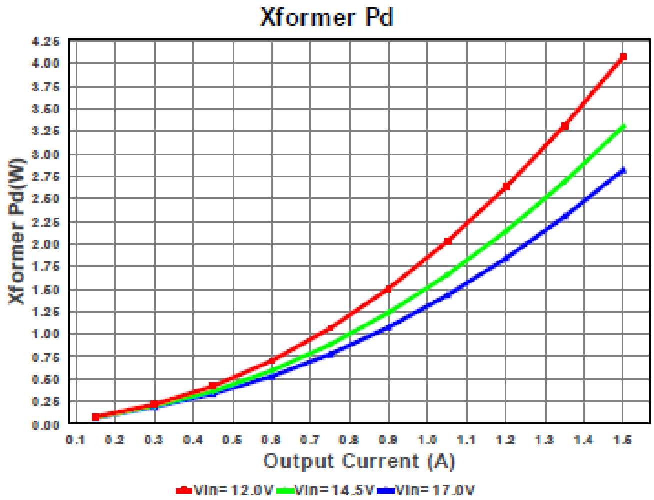

Vout Actual
12.143729513
12.143729512
12.143729511
12.143729510
12.143729509
12.143729508
12.143729507
12.143729506
12.143729505
12.143729504
Vout Actual(V)
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

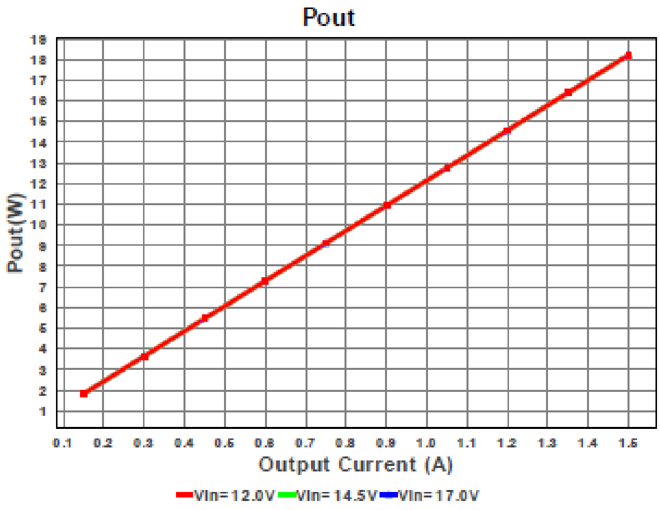

Cout1 IRMS
2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2
Cout1 IRMS(A)
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

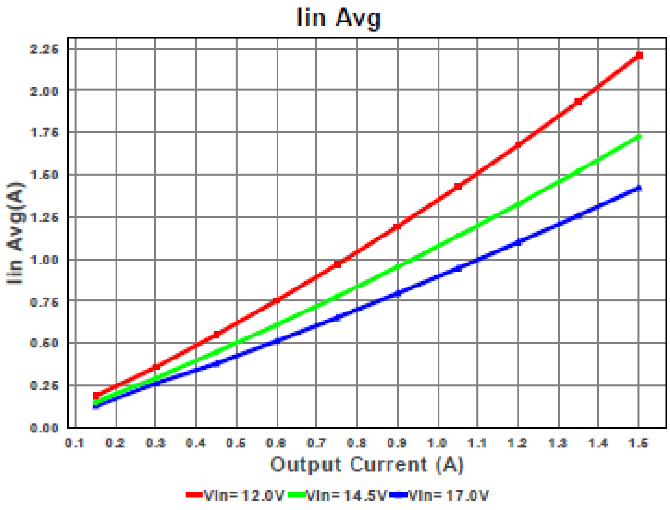

Zener Pd
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
Zener Pd(W)
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

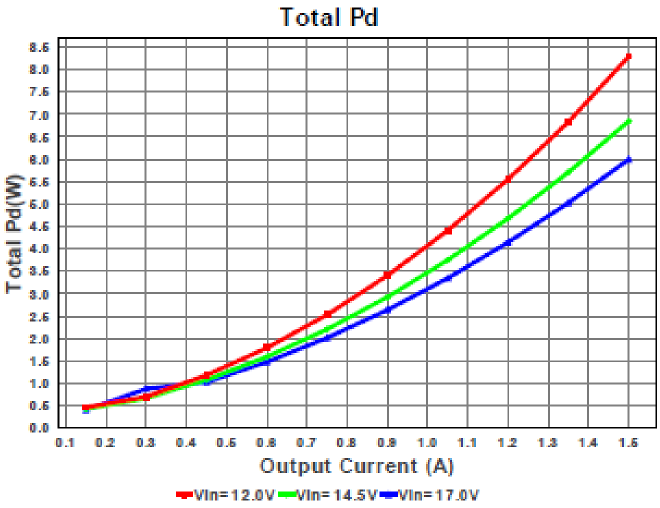

Cin Pd
0.0018 0.0017 0.0016 0.0015 0.0014 0.0013 0.0012 0.0011 0.0010 0.0009 0.0008 0.0007 0.0006 0.0005 0.0004 0.0003 0.0002 0.0001 0.0000
Cin Pd(W)
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

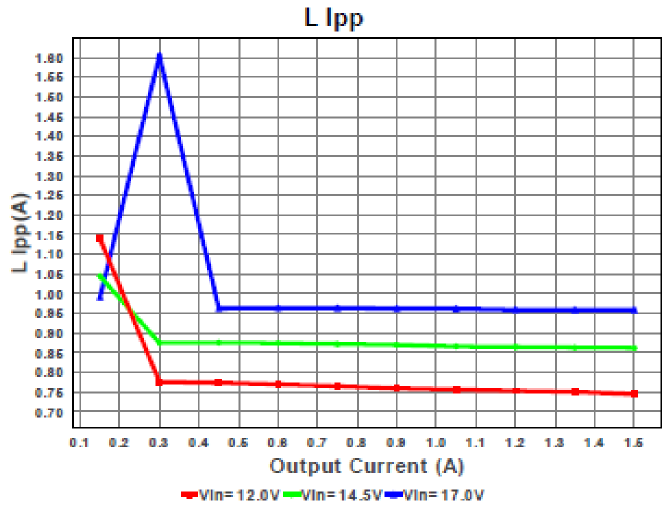

Vout Tolerance
1.931309032
1.931309031
1.931309030
1.931309029
1.931309028
1.931309027
1.931309026
1.931309025
1.931309024
1.931309023
Vout Tolerance(%)
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

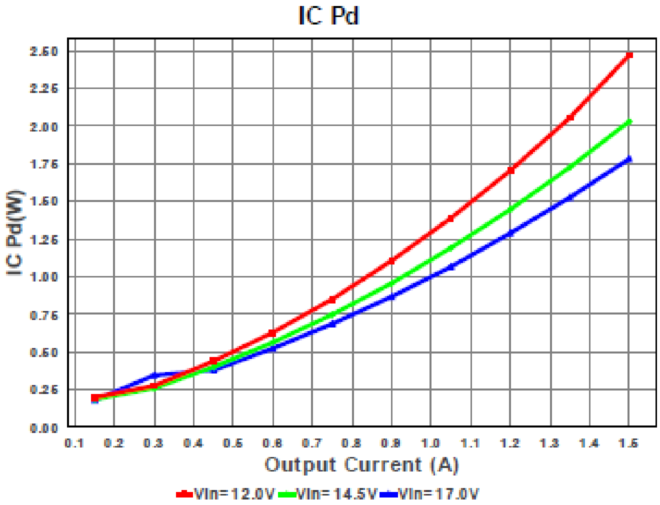

Xformer Pd
4.25 4.00 3.75 3.50 3.25 3.00 2.75 2.50 2.25 2.00 1.75 1.50 1.25 1.00 0.75 0.50 0.25 0.00
Xformer Pd(W)
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

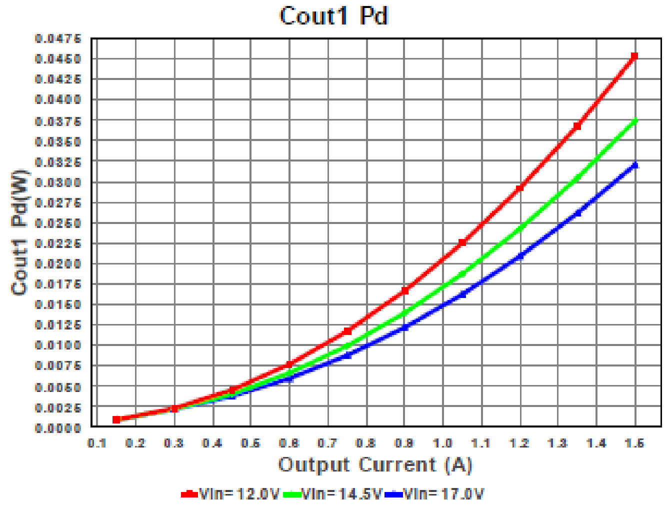

Pout
Pout(W)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

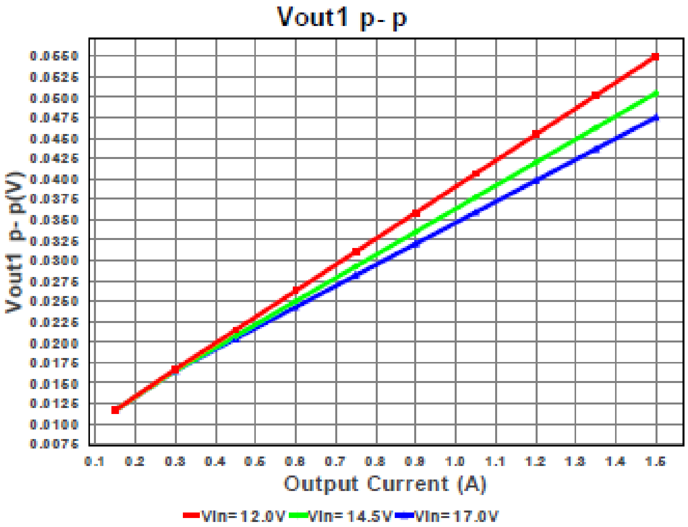

Iin Avg
Iin Avg(A)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V


Total Pd
Total Pd(W)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V


L Ipp
L Ipp(A)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V


IC Pd
IC Pd(W)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V


Cout1 Pd
Cout1 Pd(W)
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V




## Operating Values

| # | Name | Value | Category | Description |
|---|---|---|---|---|
| 1. | Cin IRMS | 1.329 A | Current | Input capacitor RMS ripple current |
| 2. | Cout1 IRMS | 1.982 A | Current | Output capacitor1 RMS ripple current |
| 3. | IC Ipk | 3.611 A | Current | Peak switch current |
| 4. | Iin Avg | 2.234 A | Current | Average input current |
| 5. | L Ipp | 759.79 mA | Current | Peak-to-peak inductor ripple current |
| 6. | filter_1 attenuation Factor | 500.0 m | Filter | Attenuation factor |
| 7. | filter_1 target Vpp | 0.0 V | Filter | Target voltage ripple through filter filter_1 |
| 8. | filter_2 attenuation Factor | 500.0 m | Filter | Attenuation factor |
| 9. | filter_2 target Vpp | 0.0 V | Filter | Target voltage ripple through filter filter_2 |
| 10. | BOM Count | 18 | General | Total Design BOM count |
| 11. | FootPrint | 1.347 k $mm^2$ | General | Total Foot Print Area of BOM components |
| 12. | Frequency | 151.071 kHz | General | Switching frequency |
| 13. | IC Tolerance | 22.0 mV | General | IC Feedback Tolerance |
| 14. | Pout | 18.216 W | General | Total output power |
| 15. | Total BOM | $11.65 | General | Total BOM Cost |
| 16. | Vout Actual | 12.144 V | Op_Point | Vout Actual calculated based on selected voltage divider resistors |
| 17. | filter_1 cut-off freq | 87.612 kHz | Op_Point | Filter cut off frequency filter_1 |
| 18. | filter_1 voltage drop | 10.0 mV | Op_Point | Voltage drop through filter filter_1 |
| 19. | filter_2 cut-off freq | 87.612 kHz | Op_Point | Filter cut off frequency filter_2 |
| 20. | filter_2 voltage drop | 20.0 mV | Op_Point | Voltage drop through filter filter_2 |
| 21. | Duty Cycle | 69.047 % | Op_point | Duty cycle |
| 22. | Efficiency | 67.871 % | Op_point | Steady state efficiency |
| 23. | IC Tj | 93.864 degC | Op_point | IC junction temperature |
| 24. | ICThetaJA | 25.157 degC/W | Op_point | IC junction-to-ambient thermal resistance |
| 25. | IOUT_OP | 1.5 A | Op_point | Iout operating point |
| 26. | VIN_OP | 12.0 V | Op_point | Vin operating point |
| 27. | Vout1 OP | 12.144 V | Op_point | Operational Voltage 1 |
| 28. | Vout1 p-p | 56.237 mV | Op_point | Peak-to-peak output1 ripple voltage |
| 29. | Cin Pd | 1.839 mW | Power | Input capacitor power dissipation |
| 30. | Cout1 Pd | 47.118 mW | Power | Output capacitor1 power dissipation |
| 31. | Cout1 Pd | 47.118 mW | Power | Output capacitor1 power dissipation |
| 32. | Diode1 Pd | 656.605 mW | Power | Diode1 power dissipation |
| 33. | IC Pd | 2.539 W | Power | IC power dissipation |
| 34. | Total Pd | 8.623 W | Power | Total Power Dissipation |
| 35. | Xformer Pd | 4.261 W | Power | Transformer power dissipation |
| 36. | Zener Pd | 1.078 W | Power | Zener power dissipation |
| 37. | filter_1_Pd | 5.0 mW | Power | Filter Power Loss filter_1 |
| 38. | filter_2_Pd | 20.0 mW | Power | Filter Power Loss filter_2 |
| 39. | Vout Tolerance | 1.931 % | | Vout Tolerance based on IC Tolerance and voltage divider resistors if applicable |

## Design Inputs

| # | Name | Value | Description |
|---|---|---|---|
| 1. | Iout | 1.5 | Maximum Output Current |
| 2. | VinMax | 17.0 | Maximum input voltage |
| 3. | VinMin | 12.0 | Minimum input voltage |
| 4. | Vout | 12.0 | Output Voltage |
| 5. | base_pn | LM2588 | Base Product Number |
| 6. | source | DC | Input Source Type |

| # | Name | Value | Description |
|---|---|---|---|
| 7. | Ta | 30.0 | Ambient temperature |

## Design Assistance

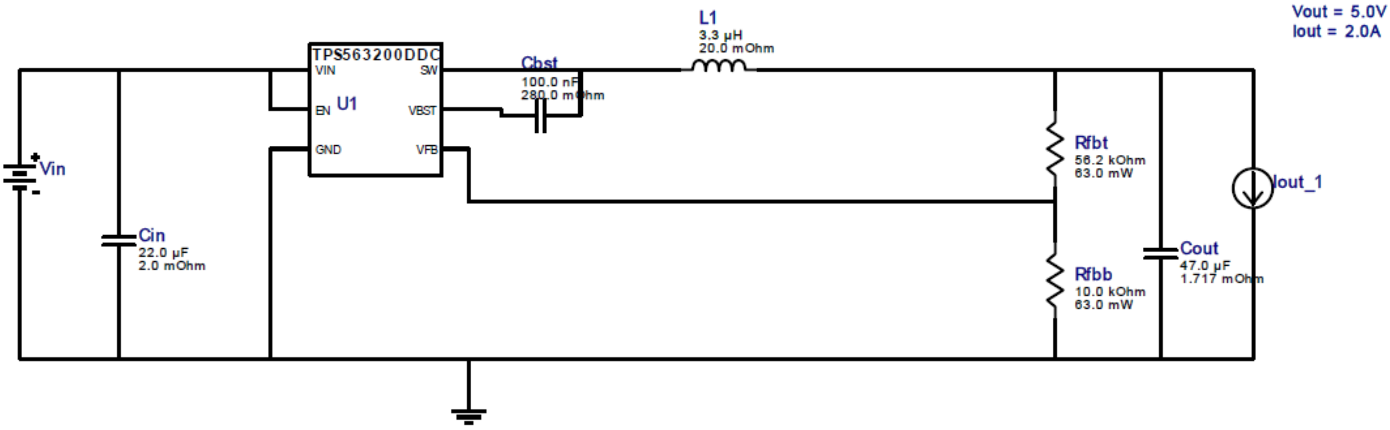
1. **LM2588** Product Folder : http://www.ti.com/product/LM2588 : contains the data sheet and other resources.

# WEBENCH ® Design Report

Vout = 5.0V
Iout = 2.0A

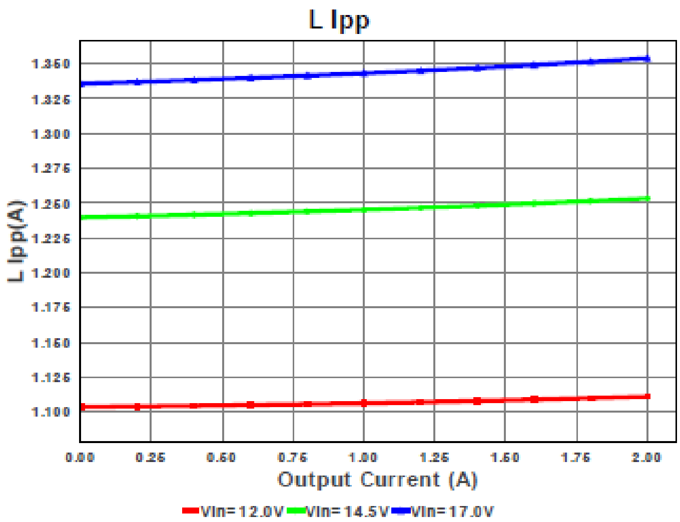
Device = TPS563200DDCR
Topology = Buck
Created = 4/5/16 10:13:47 AM
BOM Cost = $1.27
BOM Count = 7
Total Pd = 0.68W

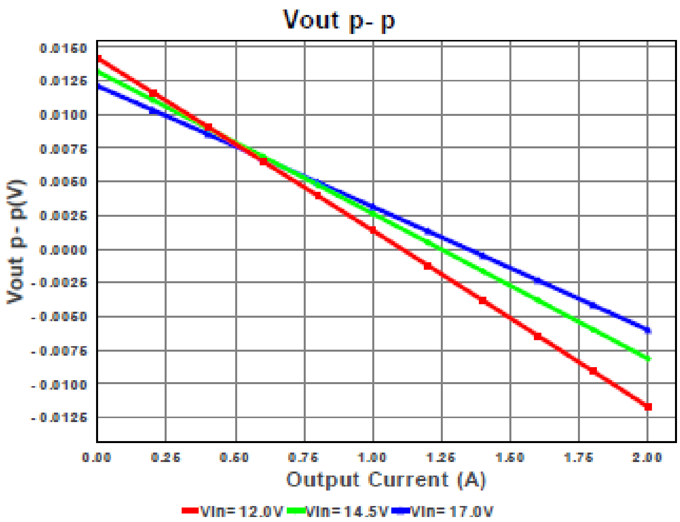
Design : 4311631/23 TPS563200DDCR
TPS563200DDCR 12.0V-17.0V to 5.00V @ 2.0A

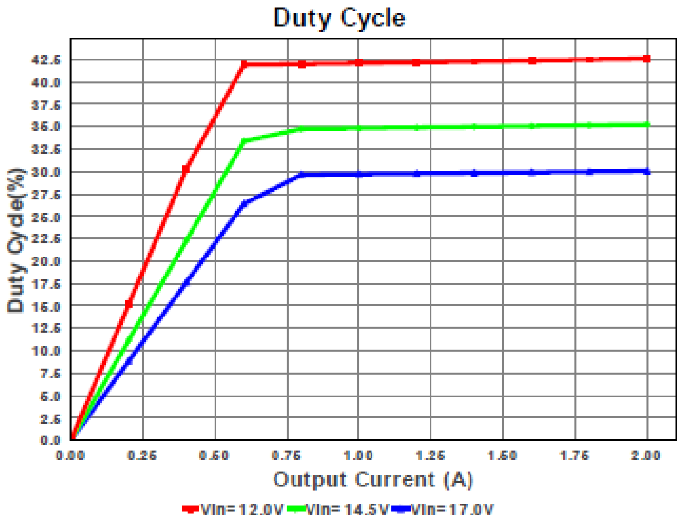


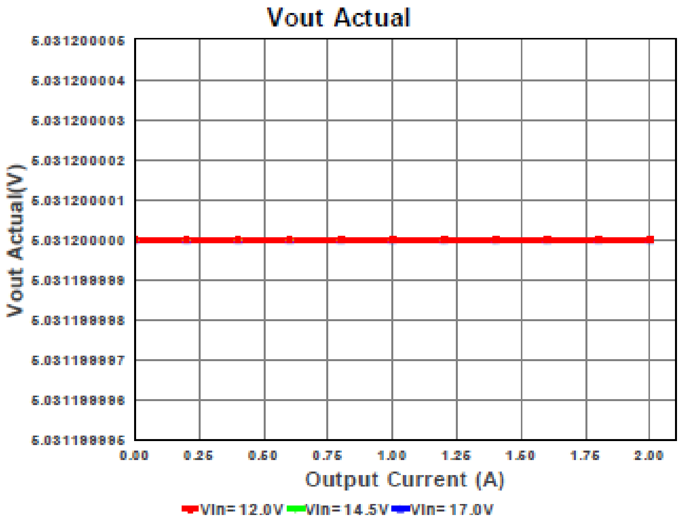

## Electrical BOM

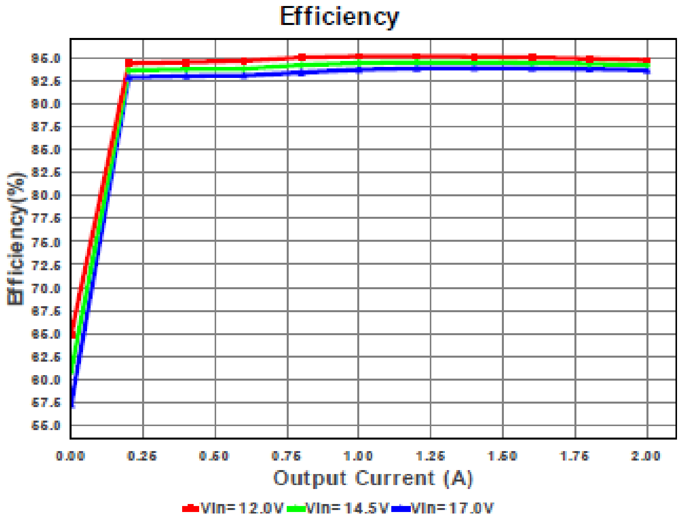
| # | Name | Manufacturer | Part Number | Properties | Qty | Price | Footprint |
|---|---|---|---|---|---|---|---|
| 1. | Cbst | AVX | 08053C104KAT2A<br>Series= X7R | Cap= 100.0 nF<br>ESR= 280.0 mOhm<br>VDC= 25.0 V<br>IRMS= 0.0 A | 1 | $0.01 | 0805 7 mm² |
| 2. | Cin | MuRata | GRM32ER61E226KE15L<br>Series= X5R | Cap= 22.0 uF<br>ESR= 2.0 mOhm<br>VDC= 25.0 V<br>IRMS= 3.67 A | 1 | $0.16 | 1210 15 mm² |
| 3. | Cout | TDK | C3216JB1A476M<br>Series= JB | Cap= 47.0 uF<br>ESR= 1.717 mOhm<br>VDC= 10.0 V<br>IRMS= 0.0 A | 1 | $0.34 | 1206 11 mm² |
| 4. | L1 | Bourns | SDR0805-3R3ML | L= 3.3 µH<br>DCR= 20.0 mOhm | 1 | $0.22 | SDR0805 96 mm² |
| 5. | Rfbb | Vishay-Dale | CRCW040210K0FKED<br>Series= CRCW..e3 | Res= 10.0 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| 6. | Rfbt | Vishay-Dale | CRCW040256K2FKED<br>Series= CRCW..e3 | Res= 56.2 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| 7. | U1 | Texas Instruments | TPS563200DDCR | Switcher | 1 | $0.52 | DDC0006A 10 mm² |

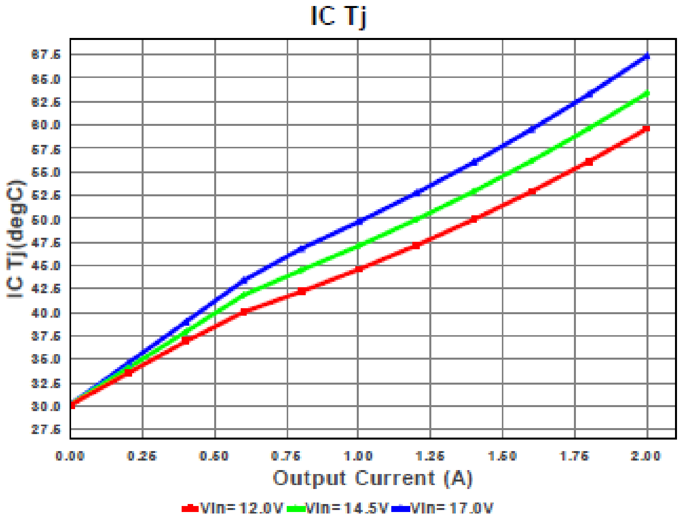

L Ipp
L Ipp(A)
1.350 1.325 1.300 1.275 1.250 1.225 1.200 1.175 1.150 1.125 1.100
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

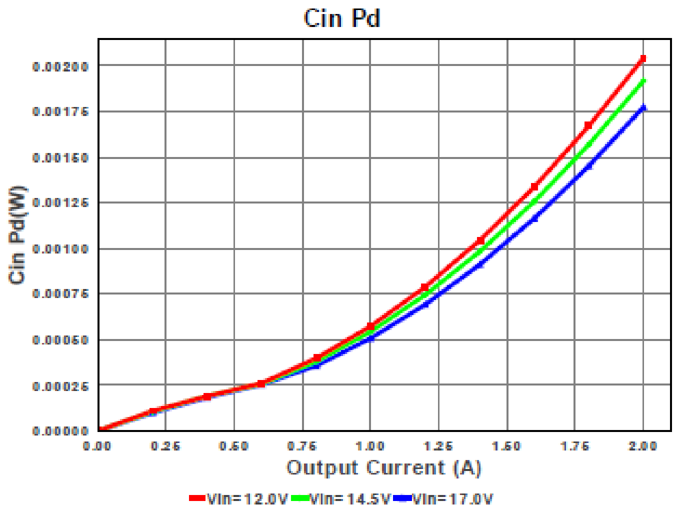

Vout p- p
Vout p- p(V)
0.0150 0.0125 0.0100 0.0075 0.0050 0.0025 0.0000 - 0.0025 - 0.0050 - 0.0075 - 0.0100 - 0.0125
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

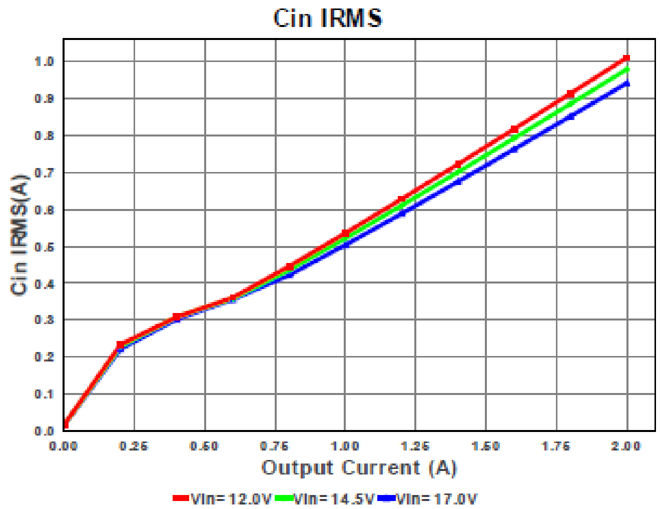

Duty Cycle
Duty Cycle(%)
42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5 10.0 7.5 5.0 2.5 0.0
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

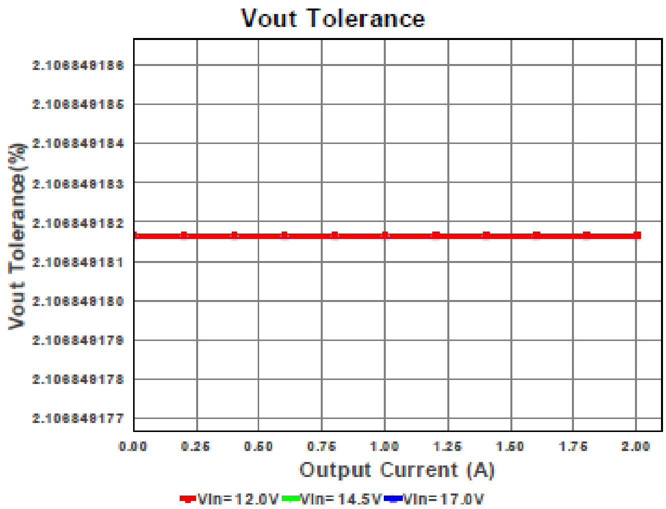

Vout Actual
Vout Actual(V)
5.031200005 5.031200004 5.031200003 5.031200002 5.031200001 5.031200000 5.031199999 5.031199998 5.031199997 5.031199996 5.031199995
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

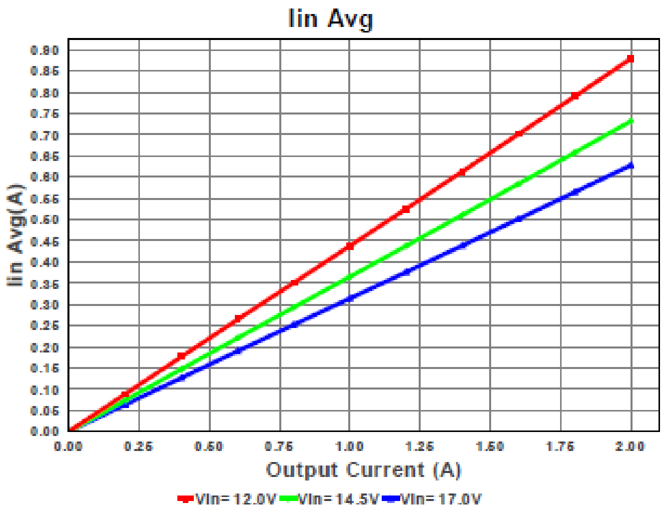

Efficiency
Efficiency(%)
95.0 92.5 90.0 87.5 85.0 82.5 80.0 77.5 75.0 72.5 70.0 67.5 65.0 62.5 60.0 57.5 55.0
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

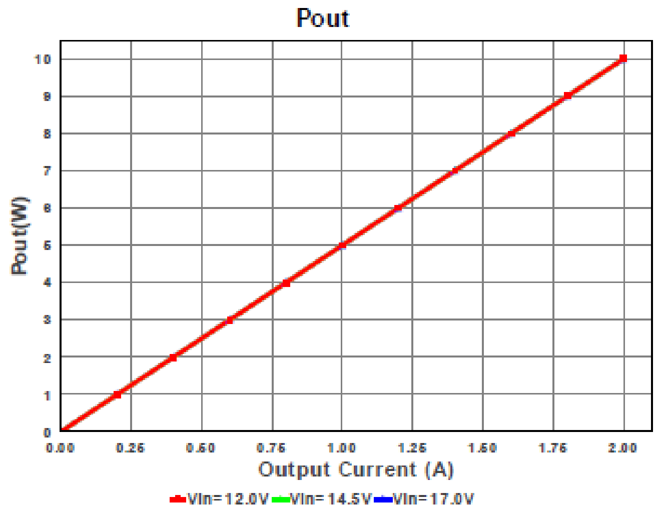

IC Tj
IC Tj(degC)
67.5 65.0 62.5 60.0 57.5 55.0 52.5 50.0 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin= 12.0V Vin= 14.5V Vin= 17.0V

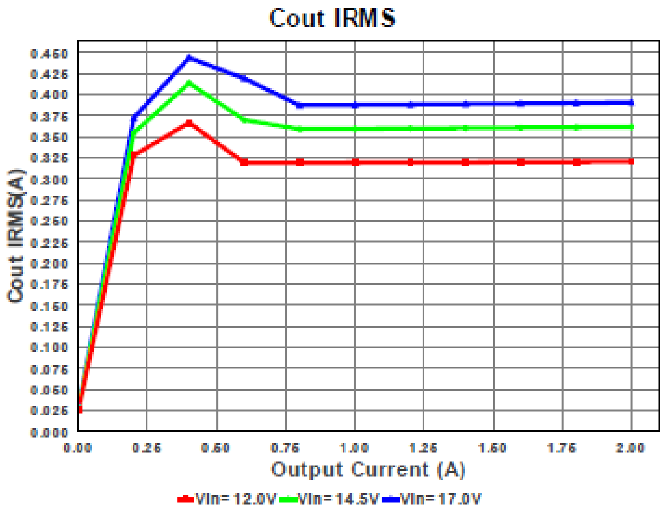

Cin Pd
Cin Pd(W)
Output Current (A)
Vin=12.0V Vin=14.5V Vin=17.0V

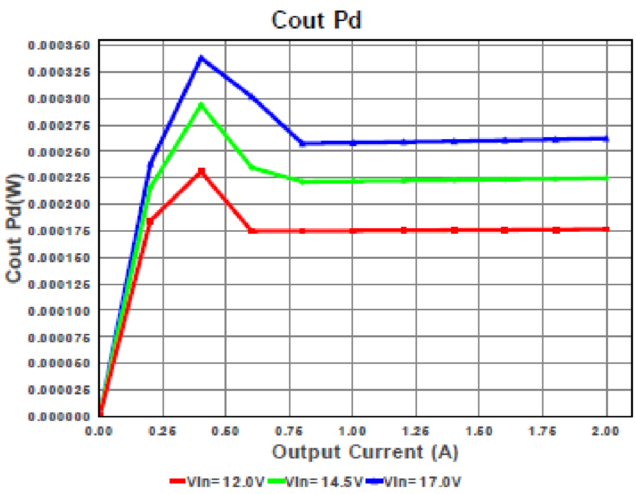

Cin IRMS
Cin IRMS(A)
Output Current (A)
Vin=12.0V Vin=14.5V Vin=17.0V

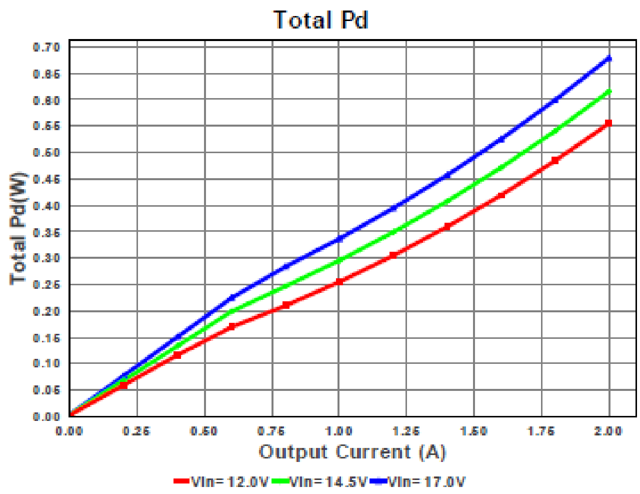

Vout Tolerance
Vout Tolerance(%)
Output Current (A)
Vin=12.0V Vin=14.5V Vin=17.0V

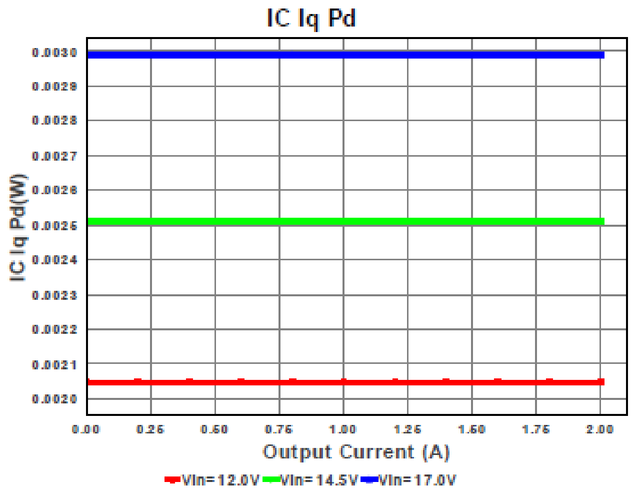

Iin Avg
Iin Avg(A)
Output Current (A)
Vin=12.0V Vin=14.5V Vin=17.0V

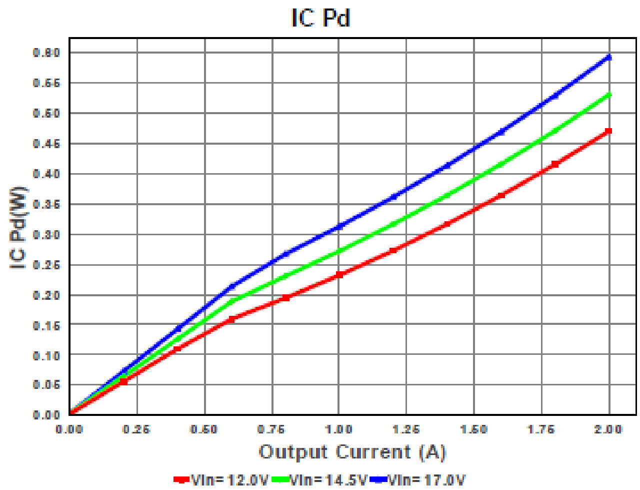

Pout
Pout(W)
Output Current (A)
Vin=12.0V Vin=14.5V Vin=17.0V

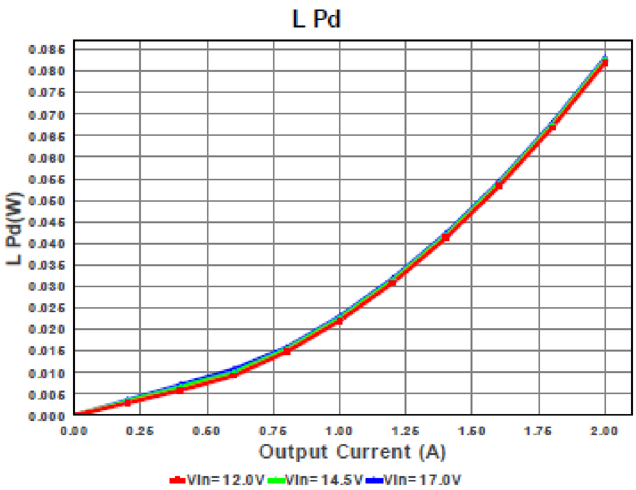

Cout IRMS
Cout IRMS(A)
Output Current (A)
Vin=12.0V Vin=14.5V Vin=17.0V

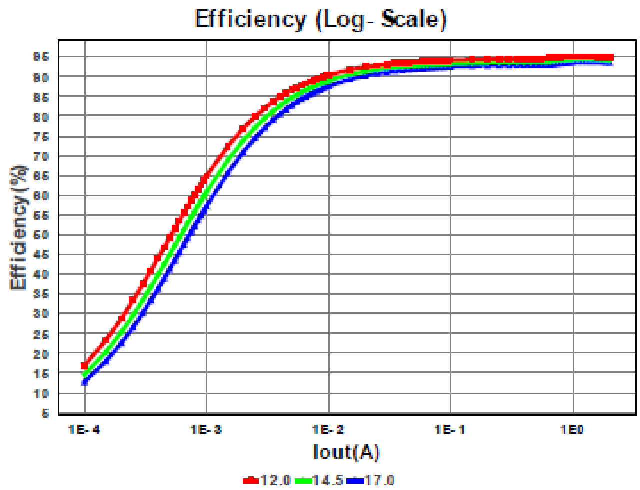



## Operating Values

| # | Name | Value | Category | Description |
|---|---|---|---|---|
| 1. | Cin IRMS | 941.774 mA | Current | Input capacitor RMS ripple current |
| 2. | Cout IRMS | 390.783 mA | Current | Output capacitor RMS ripple current |
| 3. | Iin Avg | 628.17 mA | Current | Average input current |
| 4. | L Ipp | 1.354 A | Current | Peak-to-peak inductor ripple current |
| 5. | BOM Count | 7 | General | Total Design BOM count |
| 6. | FootPrint | 145.0 $mm^2$ | General | Total Foot Print Area of BOM components |
| 7. | Frequency | 798.64 kHz | General | Switching frequency |
| 8. | Pout | 10.0 W | General | Total output power |
| 9. | Total BOM | $1.27 | General | Total BOM Cost |
| 10. | Vout Actual | 5.031 V | Op_Point | Vout Actual calculated based on selected voltage divider resistors |
| 11. | Vout OP | 5.0 V | Op_Point | Operational Output Voltage |

| # | Name | Value | Category | Description |
|---|---|---|---|---|
| 12. | Duty Cycle | 30.064 % | Op_point | Duty cycle |
| 13. | Efficiency | 93.642 % | Op_point | Steady state efficiency |
| 14. | IC Tj | 67.331 degC | Op_point | IC junction temperature |
| 15. | ICThetaJA | 62.9 degC/W | Op_point | IC junction-to-ambient thermal resistance |
| 16. | IOUT_OP | 2.0 A | Op_point | Iout operating point |
| 17. | VIN_OP | 17.0 V | Op_point | Vin operating point |
| 18. | Vout p-p | 5.534 mV | Op_point | Peak-to-peak output ripple voltage |
| 19. | Cin Pd | 1.774 mW | Power | Input capacitor power dissipation |
| 20. | Cout Pd | 262.206 µW | Power | Output capacitor power dissipation |
| 21. | IC Iq Pd | 2.988 mW | Power | IC Iq Pd |
| 22. | IC Pd | 593.498 mW | Power | IC power dissipation |
| 23. | L Pd | 83.054 mW | Power | Inductor power dissipation |
| 24. | Total Pd | 678.964 mW | Power | Total Power Dissipation |
| 25. | Vout Tolerance | 2.107 % | | Vout Tolerance based on IC Tolerance and voltage divider resistors if applicable |

## Design Inputs

| # | Name | Value | Description |
|---|---|---|---|
| 1. | Iout | 2.0 | Maximum Output Current |
| 2. | VinMax | 17.0 | Maximum input voltage |
| 3. | VinMin | 12.0 | Minimum input voltage |
| 4. | Vout | 5.0 | Output Voltage |
| 5. | base_pn | TPS563200 | Base Product Number |
| 6. | source | DC | Input Source Type |
| 7. | Ta | 30.0 | Ambient temperature |

## Design Assistance

1. **TPS563200** Product Folder : http://www.ti.com/product/TPS563200 : contains the data sheet and other resources.

# ANNEX 4: POWER SUPPLY BATTERY CHARGER

## FEATURES

- **Charger Input Voltage May Be Higher, Equal to or Lower Than Battery Voltage**
- Charges Any Number of Cells Up to 20V
- 1% Voltage Accuracy for Rechargeable Lithium Batteries
- 100mV Current Sense Voltage for High Efficiency (LT1513)
- 0mV Current Sense Voltage for Easy Current Programming (LT1513-2)
- **Battery Can Be Directly Grounded**
- **500kHz Switching Frequency Minimizes Inductor Size**
- Charging Current Easily Programmable or Shut Down

## APPLICATIONS

- Charging of NiCd, NiMH, Lead-Acid or Lithium Rechargeable Cells
- Precision Current Limited Power Supply
- Constant-Voltage/Constant-Current Supply
- Transducer Excitation
- Universal Input CCFL Driver

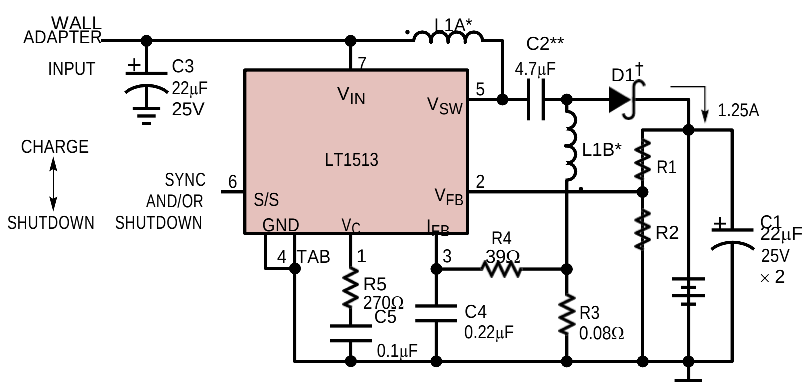
## DESCRIPTION

The LT®1513 is a 500kHz current mode switching regulator specially configured to create a constant- or programmable-current/constant-voltage battery charger. In addition to the usual voltage feedback node, it has a current sense feedback circuit for accurately controlling output current of a flyback or SEPIC (Single-Ended Primary Inductance Converter) topology charger. These topologies allow the current sense circuit to be ground referred and completely separated from the battery itself, simplifying battery switching and system grounding problems. In addition, these topologies allow charging even when the input voltage is lower than the battery voltage. The LT1513 can also drive a CCFL Royer converter with high efficiency in floating or grounded mode.

Maximum switch current on the LT1513 is 3A. This allows battery charging currents up to 2A for a single lithium-ion cell. Accuracy of 1% in constant-voltage mode is perfect for lithium battery applications. Charging current can be easily programmed for all battery types.



## TYPICAL APPLICATION



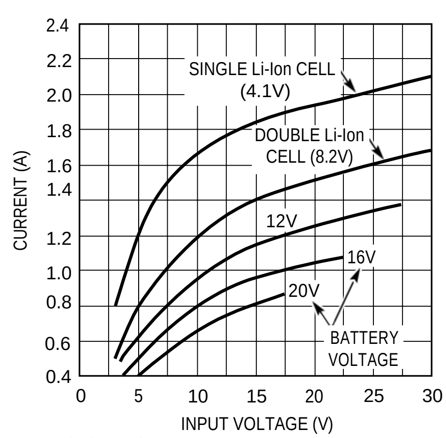

* L1A, L1B ARE TWO 10µH WINDINGS ON A COMMON CORE: COILTRONICS CTX10-4

** CERAMIC MARCON THCR40EIE475Z OR TOKIN 1E475ZY5U-C304

† MBRD340 OR MBRS340T3. MBRD340 HAS 5µA TYPICAL LEAKAGE, MBRS340T3 50µA TYPICAL

**Figure 1. SEPIC Charger with 1.25A Output Current**

**Maximum Charging Current**



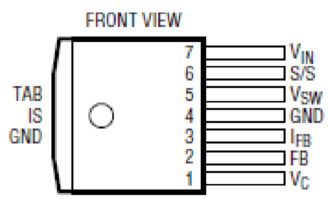

INDUCTOR = 10µH
ACTUAL PROGRAMMED CHARGING CURRENT WILL BE INDEPENDENT OF INPUT VOLTAGE IF IT DOES NOT EXCEED VALUES SHOWN

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage ...................................................... 30V
Switch Voltage ....................................................... 40V
S/S Pin Voltage ...................................................... 30V
FB Pin Voltage (Transient, 10ms) ......................... ±10V
$V_{FB}$ Pin Current .................................................. 10mA
$I_{FB}$ Pin Voltage (Transient, 10ms) ......................... ±10V

Operating Junction Temperature Range
  LT1513C ............................................. 0°C to 125°C
  LT1513I ......................................... – 40°C to 125°C
  Short Circuit ........................................ 0°C to 150°C
Storage Temperature Range ................ – 65°C to 150°C
Lead Temperature (Soldering, 10 sec) ................. 300°C

## PACKAGE/ORDER INFORMATION

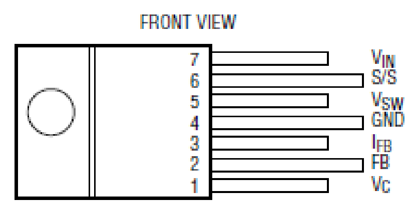



R PACKAGE
7-LEAD PLASTIC DD

$T_{JMAX}$ = 125°C, $\theta_{JA}$ = 30°C/W

WITH PACKAGE SOLDERED TO 0.5INCH² COPPER AREA OVER BACKSIDE GROUND PLANE OR INTERNAL POWER PLANE, $\theta_{JA}$ CAN VARY FROM 20°C/W TO > 40°C/W DEPENDING ON MOUNTING TECHNIQUE

| ORDER PART NUMBER |
|---|
| LT1513CR |
| LT1513-2CR |
| LT1513IR |
| LT1513-2IR |




T7 PACKAGE
7-LEAD TO-220

$T_{JMAX}$ = 125°C, $\theta_{JA}$ = 50°C/W, $\theta_{JC}$ = 4°C/W

| ORDER PART NUMBER |
|---|
| LT1513-2CT7 |
| LT1513-2IT7 |

Consult factory for Military grade parts.

## ELECTRICAL CHARACTERISTICS

**$V_{IN}$ = 5V, $V_C$ = 0.6V, $V_{FB}$ = $V_{REF}$, $I_{FB}$ = 0V, $V_{SW}$ and S/S pins open, unless otherwise noted.**

| SYMBOL | PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| $V_{REF}$ | FB Reference Voltage | Measured at FB Pin<br>$V_C$ = 0.8V | <br>● | 1.233<br>1.228 | 1.245<br>1.245 | 1.257<br>1.262 | V<br>V |
| | FB Input Current | $V_{FB}$ = $V_{REF}$ | <br>● | | 300 | 550<br>600 | nA<br>nA |
| | FB Reference Voltage Line Regulation | 2.7V ≤ $V_{IN}$ ≤ 25V, $V_C$ = 0.8V | ● | | 0.01 | 0.03 | %/V |
| $V_{IREF}$ | $I_{FB}$ Reference Voltage (LT1513) | Measured at $I_{FB}$ Pin<br>$V_{FB}$=0V, $V_C$=0.8V | <br>● | – 107<br>–110 | – 100<br>– 100 | – 93<br>– 90 | mV<br>mV |
| | $I_{FB}$ Input Current | $V_{IFB}$ = $V_{IREF}$ (Note 2) | ● | 10 | 25 | 35 | µA |
| | $I_{FB}$ Reference Voltage Line Regulation | 2.7V ≤ $V_{IN}$ ≤ 25V, $V_C$ = 0.8V | ● | | 0.01 | 0.05 | %/V |
| $I_{FBVOS}$ | $I_{FB}$ Voltage Offset (LT1513-2) (Note 3) | $I_{VFB}$ = 60µA (Note 4) | ● | – 7.5 | 2.5 | 12.5 | mV |
| | $I_{FB}$ Input Current | $V_{IFB}$ = $V_{IREF}$ | ● | – 200 | – 10 | 0 | nA |
| | $V_{FB}$ Source Current | $V_{IREF}$ = – 10mV, $V_{FB}$ = 1.2V | ● | – 700 | – 300 | – 100 | µA |
| $g_m$ | Error Amplifier Transconductance | $\Delta I_C$ = ±25µA | <br>● | 1100<br>700 | 1500 | 1900<br>2300 | µmho<br>µmho |
| | Error Amplifier Source Current | $V_{FB}$ = $V_{REF}$ – 150mV, $V_C$ = 1.5V | ● | 120 | 200 | 350 | µA |
| | Error Amplifier Sink Current | $V_{FB}$ = $V_{REF}$ + 150mV, $V_C$ = 1.5V | ● | | 1400 | 2400 | µA |

## ELECTRICAL CHARACTERISTICS

**$V_{IN}$ = 5V, $V_C$ = 0.6V, $V_{FB}$ = $V_{REF}$, $I_{FB}$ = 0V, $V_{SW}$ and S/S pins open, unless otherwise noted.**

| SYMBOL | PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| | Error Amplifier Clamp Voltage | High Clamp, $V_{FB}$ = 1V<br>Low Clamp, $V_{FB}$ = 1.5V | | 1.70<br>0.25 | 1.95<br>0.40 | 2.30<br>0.52 | V<br>V |
| $A_V$ | Error Amplifier Voltage Gain | | | | 500 | | V/ V |
| | $V_C$ Pin Threshold | Duty Cycle = 0% | | 0.8 | 1 | 1.25 | V |
| f | Switching Frequency | $2.7V \le V_{IN} \le 25V$<br>$0°C \le T_J \le 125°C$<br>$T_J < 0°C$ | | 450<br>430<br>400 | 500<br>500 | 550<br>580<br>580 | kHz<br>kHz<br>kHz |
| | Maximum Switch Duty Cycle | | • | 85 | 95 | | % |
| | Switch Current Limit Blanking Time | | | | 130 | 260 | ns |
| BV | Output Switch Breakdown Voltage | $0°C \le T_J \le 125°C$<br>$T_J < 0°C$ | | 40<br>35 | 47 | | V<br>V |
| | | | | | | | |
| $V_{SAT}$ | Output Switch ON Resistance | $I_{SW}$ = 2A | • | | 0.25 | 0.45 | Ω |
| $I_{LIM}$ | Switch Current Limit | Duty Cycle = 50%<br>Duty Cycle = 80% (Note 1) | •<br>• | 3.0<br>2.6 | 3.8<br>3.4 | 5.4<br>5.0 | A<br>A |
| $\Delta I_{IN}/\Delta I_{SW}$ | Supply Current Increase During Switch ON Time | | | | 15 | 25 | mA/A |
| | Control Voltage to Switch Current Transconductance | | | | 4 | | A/V |
| | Minimum Input Voltage | | • | | 2.4 | 2.7 | V |
| $I_Q$ | Supply Current | $2.7V \le V_{IN} \le 25V$ | • | | 4 | 5.5 | mA |
| | Shutdown Supply Current | $2.7V \le V_{IN} \le 25V$, $V_{S/S} \le 0.6V$, $T_J \ge 0°C$<br>$T_J < 0°C$ | • | | 12 | 30<br>50 | µA<br>µA |
| | Shutdown Threshold | $2.7V \le V_{IN} \le 25V$ | • | 0.6 | 1.3 | 2 | V |
| | Shutdown Delay | | • | 5 | 12 | 25 | µs |
| | S/S Pin Input Current | $0V \le V_{S/S} \le 5V$ | • | – 10 | | 15 | µA |
| | Synchronization Frequency Range | | • | 600 | | 800 | kHz |

The • denotes specifications which apply over the full operating temperature range.

**Note 1:** For duty cycles (DC) between 50% and 85%, minimum guaranteed switch current is given by $I_{LIM}$ = 1.33 (2.75 – DC).

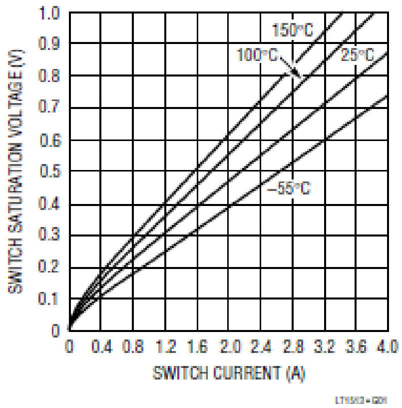
**Note 2:** The $I_{FB}$ pin is servoed to its regulating state with $V_C$ = 0.8V.

**Note 3:** Consult factory for grade selected parts.

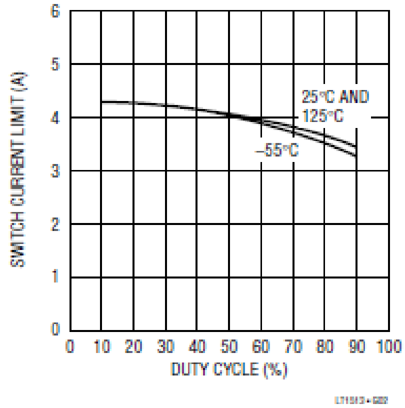
**Note 4:** The $I_{FB}$ pin is sevoed to regulate FB to 1.245V

# TYPICAL PERFORMANCE CHARACTERISTICS

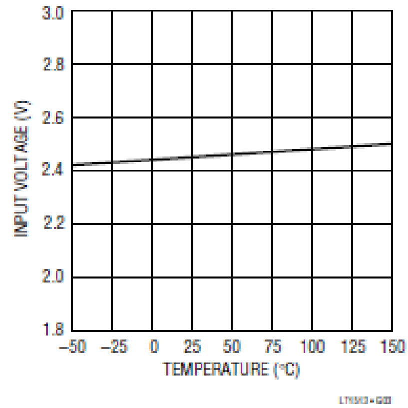
**Switch Saturation Voltage vs Switch Current**



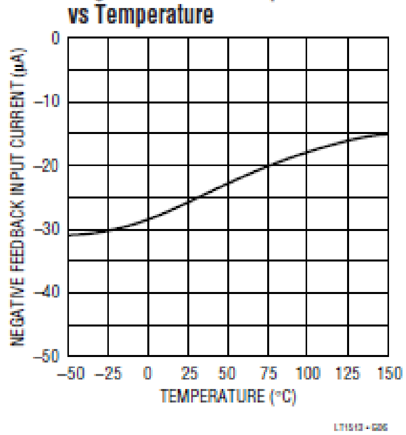

**Switch Current Limit vs Duty Cycle**



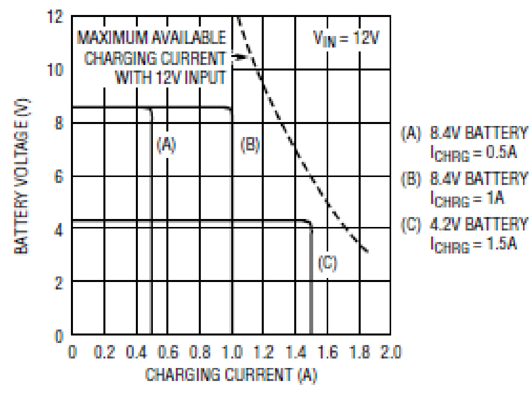

**Minimum Input Voltage vs Temperature**



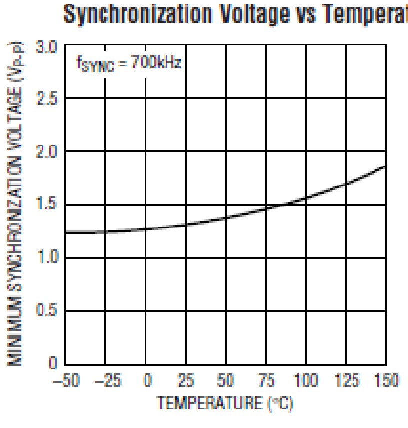

**Negative Feedback Input Current vs Temperature**



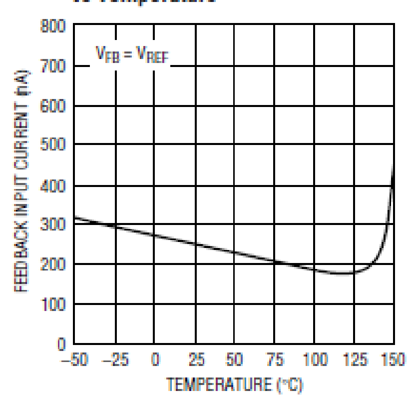

**Output Charging Characteristics Showing Constant-Current and Constant-Voltage Operation**




**Minimum Peak-to-Peak Synchronization Voltage vs Temperature**




**Feedback Input Current vs Temperature**



# PIN FUNCTIONS

**$V_C$ (Pin 1):** The compensation pin is primarily used for frequency compensation, but it can also be used for soft starting and current limiting. It is the output of the error amplifier and the input of the current comparator. Peak switch current increases from 0A to 3.6A as the $V_C$ voltage varies from 1V to 1.9V. Current out of the $V_C$ pin is about 200µA when the pin is externally clamped below the internal 1.9V clamp level. Loop frequency compensation is performed with a capacitor or series RC network from the $V_C$ pin *directly to the ground pin* (avoid ground loops).

**FB (Pin 2):** The feedback pin is used for positive output voltage sensing. The R1/R2 voltage divider connected to FB defines Li-Ion float voltage at full charge, or acts as a voltage limiter for NiCd or NiMH applications. FB is the inverting input to the voltage error amplifier. Input bias current is typically 300nA, so divider current is normally set to 100µA to swamp out any output voltage errors due to bias current. The noninverting input of this amplifier is tied internally to a 1.245V reference. The grounded end of the output voltage divider should be connected directly to the LT1513 ground pin (avoid ground loops).

**$I_{FB}$ (Pin 3):** The current feedback pin is used to sense charging current. It is the input to a current sense amplifier that controls charging current when the battery voltage is below a programmed limit. During constant-current operation, the LT1513 $I_{FB}$ pin regulates at –100mV. Input resistance of this pin is 5kΩ, so filter resistance (R4, Figure 1) should be less than 50Ω. The 39Ω, 0.22µF filter shown in Figure 1 is used to convert the pulsating current in the sense resistor to a smooth DC current feedback signal. The LT1513-2 $I_{FB}$ pin regulates at 0mV to provide programmable current limit. The current through R5, Figure 5, is balanced by the current through R4, programming the maximum voltage across R3.

**GND (Pin 4):** The ground pin is common to both control circuitry and switch current. $V_C$, FB and S/S signals must be Kelvin and connected as close as possible to this pin. The TAB of the R package should also be connected to the power ground.

**$V_{SW}$ (Pin 5):** The switch pin is the collector of the power switch, carrying up to 3A of current with fast rise and fall times. Keep the traces on this pin as short as possible to minimize radiation and voltage spikes. In particular, the path in Figure 1 which includes SW to C2, D1, C1 and around to the LT1513 ground pin should be as short as possible to minimize voltage spikes at switch turn-off.

**S/S (Pin 6):** This pin can be used for shutdown and/or synchronization. It is logic level compatible, but can be tied to $V_{IN}$ if desired. It defaults to a high ON state when floated. A logic low state will shut down the charger to a micropower state. Driving the S/S pin with a continuous logic signal of 600kHz to 800kHz will synchronize switching frequency to the external signal. Shutdown is avoided in this mode with an internal timer.

**$V_{IN}$ (Pin 7):** The input supply pin should be bypassed with a low ESR capacitor located right next to the IC chip. The grounded end of the capacitor must be connected directly to the ground plane to which the TAB is connected.

**TAB:** The TAB on the surface mount R package is electrically connected to the ground pin, but a low inductance connection must be made to both the TAB and the pin for proper circuit operation. See suggested PC layout in Figure 4.

# BLOCK DIAGRAM

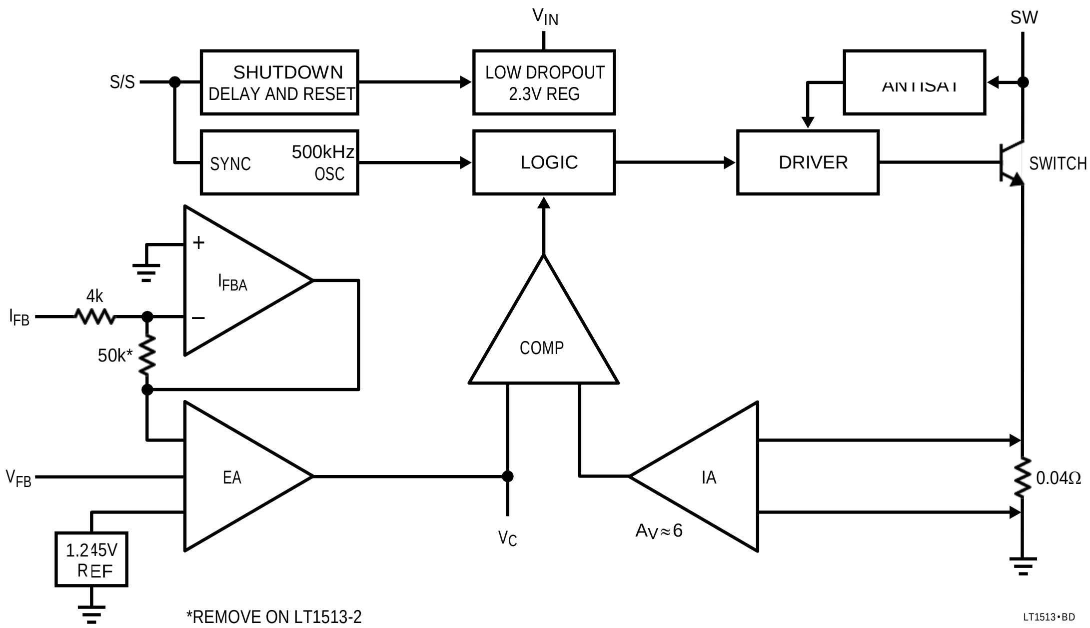



Figure 2

# OPERATION

The LT1513 is a current mode switcher. This means that switch duty cycle is directly controlled by switch current rather than by output voltage or current. Referring to the Block Diagram, the switch is turned "on" at the start of each oscillator cycle. It is turned "off" when switch current reaches a predetermined level. Control of output voltage and current is obtained by using the output of a dual feedback voltage sensing error amplifier to set switch current trip level. This technique has the advantage of simplified loop frequency compensation. A low dropout internal regulator provides a 2.3V supply for all internal circuitry on the LT1513. This low dropout design allows input voltage to vary from 2.7V to 25V. A 500kHz oscillator is the basic clock for all internal timing. It turns "on" the output switch via the logic and driver circuitry. Special adaptive antisat circuitry detects onset of saturation in the power switch and adjusts driver current instantaneously to limit switch saturation. This minimizes driver dissipation and provides very rapid turn-off of the switch.

A unique error amplifier design has two inverting inputs which allow for sensing both output voltage and current. A 1.245V bandgap reference biases the noninverting input. The first inverting input of the error amplifier is brought out for positive output voltage sensing. The second inverting input is driven by a "current" amplifier which is sensing output current via an external current sense resistor. The current amplifier is set to a fixed gain of –12.5 which provides a –100mV current limit sense voltage.

The LT1513-2 option removes the feedback resistors around the $I_{FB}$ amplifier and connects its output to the FB signal. This provides a ground referenced current sense voltage suitable for external current programming and makes amplifier input and output available for external loop compensation.

The error signal developed at the amplifier output is brought out externally and is used for frequency compensation. During normal regulator operation this pin sits at a voltage between 1V (low output current) and 1.9V (high output current). Switch duty cycle goes to zero if the $V_C$ pin is pulled below the $V_C$ pin threshold, placing the LT1513 in an idle mode.

## APPLICATIONS INFORMATION

The LT1513 is an IC battery charger chip specifically optimized to use the SEPIC converter topology. A complete charger schematic is shown in Figure 1. The SEPIC topology has unique advantages for battery charging. It will operate with input voltages above, equal to or below the battery voltage, has no path for battery discharge when turned off, and eliminates the snubber losses of flyback designs. It also has a current sense point that is ground referred and need not be connected directly to the battery. The two inductors shown are actually just two identical windings on one inductor core, although two separate inductors can be used.

A current sense voltage is generated with respect to ground across R3 in Figure 1. The average current through R3 is always identical to the current delivered to the battery. The LT1513 current limit loop will servo the voltage across R3 to –100mV when the battery voltage is below the voltage limit set by the output divider R1/R2. Constant-current charging is therefore set at 100mV/R3. R4 and C4 filter the current signal to deliver a smooth feedback voltage to the $I_{FB}$ pin. R1 and R2 form a divider for battery voltage sensing and set the battery float voltage. The suggested value for R2 is 12.4k. R1 is calculated from:

$$R1 = \frac{R2(V_{BAT} - 1.245)}{1.245 + R2(0.3\mu A)}$$

$V_{BAT}$ = battery float voltage
0.3µA = typical FB pin bias current

A value of 12.4k for R2 sets divider current at 100µA. This is a constant drain on the battery when power to the charger is off. If this drain is too high, R2 can be increased to 41.2k, reducing divider current to 30µA. This introduces an additional uncorrectable error to the constant voltage float mode of about ±0.5% as calculated by:

$$V_{BAT}\ \text{Error} = \frac{\pm 0.15\mu A(R1)(R2)}{1.245(R1+R2)}$$

±0.15µA = expected variation in FB bias current around the nominal 0.3µA typical value.

With R2 = 41.2k and R1 = 228k, ($V_{BAT}$ = 8.2V), the error due to variations in bias current would be ±0.42%.

A second option is to disconnect the divider when charger power is off. This can be done with a small NFET as shown in Figure 3. D2, C6 and R6 form a peak detector to drive the gate of the FET to about the same as the battery voltage. If power is turned off, the gate will drop to 0V and the only drain on the battery will be the reverse leakage of the catch diode D1. See Diode Selection for a discussion of diode leakage.

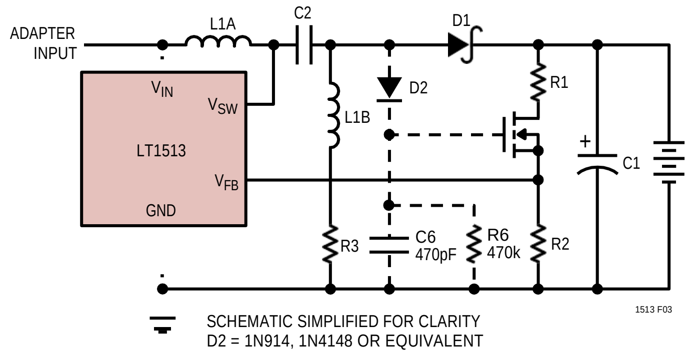



**Figure 3. Eliminating Divider Current**

### Maximum Input Voltage

Maximum input voltage for the LT1513 is partly determined by battery voltage. A SEPIC converter has a maximum switch voltage equal to input voltage plus output voltage. The LT1513 has a maximum input voltage of 30V and a maximum switch voltage of 40V, so this limits maximum input voltage to 30V, or 40V – $V_{BAT}$, whichever is less.

### Shutdown and Synchronization

The dual function S/S pin provides easy shutdown and synchronization. It is logic level compatible and can be pulled high or left floating for normal operation. A logic low on the S/S pin activates shutdown, reducing input supply current to 12µA. To synchronize switching, drive the S/S pin between 600kHz and 800kHz.

### Inductor Selection

L1A and L1B are normally just two identical windings on one core, although two separate inductors can be used. A typical value is 10µH, which gives about 0.5A peak-to-peak inductor current. Lower values will give higher ripple current, which reduces maximum charging current. 5µH can be used if charging currents are at least 20% lower than the values

## APPLICATIONS INFORMATION

shown in the maximum charging current graph. Higher inductance values give slightly higher maximum charging current, but are larger and more expensive. A low loss toroid core such as Kool Mμ®, Molypermalloy or Metglas® is recommended. Series resistance should be less than 0.04Ω for each winding. "Open core" inductors, such as rods or barrels are not recommended because they generate large magnetic fields which may interfere with other electronics close to the charger.

### Input Capacitor

The SEPIC topology has relatively low input ripple current compared to other topologies and higher harmonics are especially low. RMS ripple current in the input capacitor is less than 0.25A with L = 10μH and less than 0.5A with L = 5μH. A low ESR 22μF, 25V solid tantalum capacitor (AVX type TPS or Sprague type 593D) is adequate for most applications with the following caveat. Solid tantalum capacitors can be destroyed with a very high turn-on surge current such as would be generated if a low impedance input source were "hot switched" to the charger input. If this condition can occur, the input capacitor should have the highest possible voltage rating, at least twice the surge input voltage if possible. Consult with the capacitor manufacturer before a final choice is made. A 4.7μF ceramic capacitor such as the one used for the coupling capacitor can also be used. These capacitors do not have a turn-on surge limitation. The input capacitor must be connected directly to the $V_{IN}$ pin and the ground plane close to the LT1513.

### Output Capacitor

It is assumed as a worst case that all the switching output ripple current from the battery charger could flow in the output capacitor. This is a desirable situation if it is necessary to have very low switching ripple current in the battery itself. Ferrite beads or line chokes are often inserted in series with the battery leads to eliminate high frequency currents that could create EMI problems. This forces all the ripple current into the output capacitor. Total RMS current into the capacitor has a maximum value of about 1A, and this is handled with the two paralleled 22μF, 25V capacitors shown in Figure 1. These are AVX type TPS or Sprague type 593D surface mount solid tantalum units intended for switching applications. Do not substitute other types without ensuring that they have adequate ripple current ratings. See Input Capacitor section for details of surge limitation on solid tantalum capacitors if the battery may be "hot switched" to the output of the charger.

### Coupling Capacitor

C2 in Figure 1 is the coupling capacitor that allows a SEPIC converter topology to work with input voltages either higher or lower than the battery voltage. DC bias on the capacitor is equal to input voltage. RMS ripple current in the coupling capacitor has a maximum value of about 1A at full charging current. A conservative formula to calculate this is:

$$I_{COUP(RMS)} = \frac{I_{CHRG}(V_{IN} + V_{BAT})(1.1)}{2(V_{IN})}$$

(1.1 is a fudge factor to account for inductor ripple current and other losses)

With $I_{CHRG} = 1.2A$, $V_{IN} = 15V$ and $V_{BAT} = 8.2V$, $I_{COUP} = 1.02A$.

The recommended capacitor is a 4.7μF ceramic type from Marcon or Tokin. These capacitors have extremely low ESR and high ripple current ratings in a small package. Solid tantalum units can be substituted if their ripple current rating is adequate, but typical values will increase to 22μF or more to meet the ripple current requirements.

### Diode Selection

The switching diode should be a Schottky type to minimize both forward and reverse recovery losses. Average diode current is the same as output charging current, so this will be under 2A. A 3A diode is recommended for most applications, although smaller devices could be used at reduced charging current. *Maximum diode reverse voltage will be equal to input voltage plus battery voltage.*

Diode reverse leakage current will be of some concern during charger shutdown. This leakage current is a direct drain on the battery when the charger is not powered. High

Kool Mμ is a registered trademark of Magnetics, Inc.
Metglas is a registered trademark of AlliedSignal Inc.

## APPLICATIONS INFORMATION

current Schottky diodes have relatively high leakage currents (5μA to 500μA) even at room temperature. The latest very-low-forward devices have especially high leakage currents. It has been noted that surface mount versions of some Schottky diodes have as much as ten times the leakage of their through-hole counterparts. This may be because a low forward voltage process is used to reduce power dissipation in the surface mount package. In any case, check leakage specifications carefully before making a final choice for the switching diode. Be aware that diode manufacturers want to specify a maximum leakage current that is ten times higher than the typical leakage. It is very difficult to get them to specify a low leakage current in high volume production. This is an on going problem for all battery charger circuits and most customers have to settle for a diode whose typical leakage is adequate, but theoretically has a worst-case condition of higher than desired battery drain.

### Thermal Considerations

Care should be taken to ensure that worst-case conditions do not cause excessive die temperatures. Typical thermal resistance is 30°C/W for the R package but this number will vary depending on the mounting technique (copper area, airflow, etc.).

Average supply current (including driver current) is:

$$I_{IN} = 4mA + \frac{(V_{BAT})(I_{CHRG})(0.024)}{V_{IN}}$$

Switch power dissipation is given by:

$$P_{SW} = \frac{(I_{CHRG})^2 (R_{SW})(V_{BAT} + V_{IN})(V_{BAT})}{(V_{IN})^2}$$

$R_{SW}$ = Output switch ON resistance

Total power dissipation of the die is equal to supply current times supply voltage, plus switch power:

$P_{D(TOTAL)} = (I_{IN})(V_{IN}) + P_{SW}$

For $V_{IN} = 10V$, $V_{BAT} = 8.2V$, $I_{CHRG} = 1.2A$, $R_{SW} = 0.3\Omega$,

$I_{IN} = 4mA + 24mA = 28mA$

$P_{SW} = 0.64W$

$P_D = (10)(0.028) + 0.64 = 0.92W$

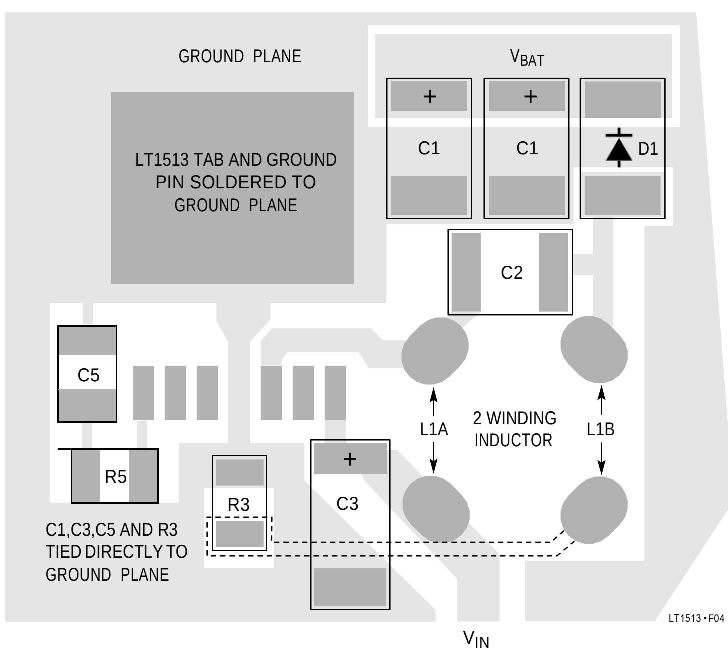



**Figure 4. LT1513 Suggested Partial Layout for Critical Thermal and Electrical Paths**

# APPLICATIONS INFORMATION

## Programmed Charging Current

LT1513-2 charging current can be programmed with a DC voltage source or equivalent PWM signal, as shown in Figure 5. In constant-current mode, $I_{FB}$ acts as a virtual ground. The $I_{SET}$ voltage across R5 is balanced by the voltage across R4 in the ratio R4/R5.

Charging current is given by:

$$I_{CHARGE} = \frac{(V_{ISET})(R4/R5) - I_{FBVOS}}{R3}$$

$I_{FB}$ input current is small and can normally be ignored, but $I_{FB}$ offset voltage must be considered if operating over a wide range of program currents. The voltage across R3 at maximum charge current can be increased to reduce offset errors at lower charge currents. In Figure 5, $I_{SET}$ from 0V to 5V corresponds to an $I_{CHARGE}$ of 0A to 1A +37/–62mA. C4 and R4 smooth the switch current waveform. During constant-current operation, the voltage feedback network loads the FB pin, which is held at $V_{REF}$ by the $I_{FB}$ amplifier. It is recommended that this load does not exceed 60μA to maintain a sharp constant voltage to constant current crossover characteristic. $I_{CHARGE}$ can also be controlled by a PWM input. Assuming the signal is a CMOS rail-to-rail output with a source impedance of less than a few hundred ohms, effective $I_{SET}$ is $V_{CC}$ multiplied by the PWM ratio. $I_{CHARGE}$ has good linearity over the entire 0% to 100% range.

## Voltage Mode Loop Stability

The LT1513 operates in constant-voltage mode during the final phase of charging lithium-ion and lead-acid batteries. This feedback loop is stabilized with a series resistor and capacitor on the $V_C$ pin of the chip. Figure 6 shows the simplified model for the voltage loop. The error amplifier is modeled as a transconductance stage with $g_m$ = 1500μmho

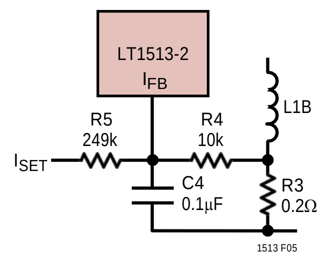
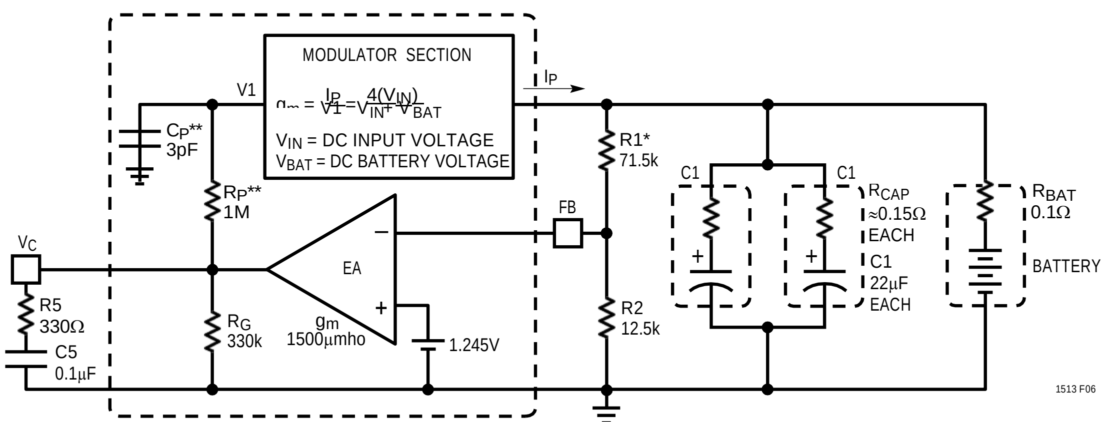



Figure 5




* FOR 8.4V BATTERY. ADJUST VALUE OF R1 FOR ACTUAL BATTERY VOLTAGE

** $R_P$ AND $C_P$ MODEL PHASE DELAY IN THE MODULATOR

THIS IS A SIMPLIFIED AC MODEL FOR THE LT1513 IN CONSTANT-VOLTAGE MODE. RESISTOR AND CAPACITOR NUMBERS CORRESPOND TO THOSE USED IN FIGURE 1. $R_P$ AND $C_P$ MODEL THE PHASE DELAY IN THE MODULATOR. C3 IS 3pF FOR A 10μH INDUCTOR. IT SHOULD BE SCALED PROPORTIONALLY FOR OTHER INDUCTOR VALUES (6pF FOR 20μH). THE MODULATOR IS A TRANSCONDUCTANCE WHOSE GAIN IS A FUNCTION OF INPUT AND BATTERY VOLTAGE AS SHOWN.

AS SHOWN, THIS LOOP HAS A UNITY-GAIN FREQUENCY OF ABOUT 250Hz. UNITY-GAIN WILL MOVE OUT TO SEVERAL KILOHERTZ IF BATTERY RESISTANCE INCREASES TO SEVERAL OHMS. R5 IS NOT USED IN ALL APPLICATIONS, BUT IT GIVES BETTER PHASE MARGIN IN CONSTANT-VOLTAGE MODE WITH HIGH BATTERY RESISTANCE.

**Figure 6. Constant-Voltage Small-Signal Model**

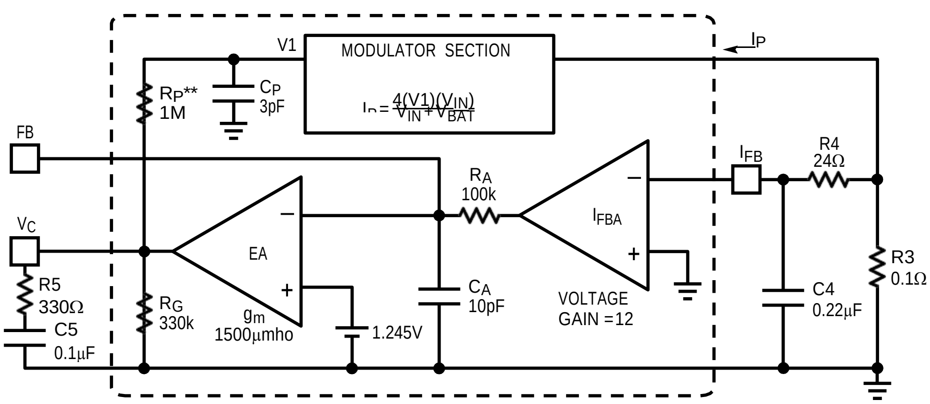
## APPLICATIONS INFORMATION

(from the Electrical Characteristics). Amplifier output resistance is modeled with a 330k resistor. The power stage (modulator section) of the LT1513 is modeled as a transconductance whose value is $4(V_{IN})/(V_{IN} + V_{BAT})$. This is a very simplified model of the actual power stage, but it is sufficient when the unity-gain frequency of the loop is low compared to the switching frequency. The output filter capacitor model includes its ESR ($R_{CAP}$). A series resistance ($R_{BAT}$) is also assigned to the battery model.

Analysis of this loop normally shows an extremely stable system for all conditions, even with 0Ω for R5. The one condition which can cause reduced phase margin is with a very large battery resistance (>5Ω), or with the battery replaced with a resistive load. The addition of R5 gives good phase margin even under these unusual conditions. R5 should not be increased above 330Ω without checking for two possible problems. The first is instability in the constant current region (see Constant-Current Mode Loop Stability), and the second is subharmonic switching where switch duty cycle varies from cycle to cycle. This duty cycle instability is caused by excess switching frequency ripple voltage on the $V_C$ pin. Normally this ripple is very low because of the filtering effect of C5, but large values of R5 can allow high ripple on the $V_C$ pin. Normal loop analysis does not show this problem, and indeed small signal loop stability can be excellent even in the presence of subharmonic switching. The primary issue with subharmonics is the presence of EMI at frequencies below 500kHz.

### Constant-Current Mode Loop Stability

The LT1513 is normally very stable when operating in constant-current mode (see Figure 7), but there are certain conditions which may create instabilities. The combination of higher value current sense resistors (low programmed charging current), higher input voltages, and the addition of a loop compensation resistor (R5) on the $V_C$ pin may create an unstable current mode loop. (A resistor is sometimes added in series with C5 to improve loop phase margin when the loop is operating in voltage mode.) Instability results because loop gain is too high in the 50kHz to 150kHz region where excess phase occurs in the current sensing amplifier and the modulator. The $I_{FBA}$ amplifier (gain of –12.5) has a pole at approximately 150kHz. The modulator section consisting of the current comparator, the power switch and the magnetics, has a pole at approximately 50kHz when the coupled inductor value is 10μH. Higher inductance will reduce the pole frequency proportionally. The design procedure presented here is to roll off the loop to unity-gain at a frequency of 25kHz or lower to avoid these excess phase regions.




THIS IS A SIMPLIFIED AC MODEL FOR THE LT1513 IN CONSTANT-CURRENT MODE. RESISTOR AND CAPACITOR NUMBERS CORRESPOND TO THOSE USED IN FIGURE 1. $R_P$ AND $C_P$ MODEL THE PHASE DELAY IN THE PowerPath. C3 IS 3pF FOR A 10μH INDUCTOR. IT SHOULD BE SCALED PROPORTIONALLY FOR OTHER INDUCTOR VALUES (6pF FOR 20μH). THE PowerPath IS A TRANSCONDUCTANCE WHOSE GAIN IS A FUNCTION OF INPUT AND BATTERY VOLTAGE AS SHOWN.

THE CURRENT AMPLIFIER HAS A FIXED VOLTAGE GAIN OF 12. ITS PHASE DELAY IS MODELED WITH $R_A$ AND $C_A$.

THE ERROR AMPLIFIER HAS A TRANSCONDUCTANCE OF 1500μmho AND AN INTERNAL OUTPUT SHUNT RESISTANCE OF 330k.

AS SHOWN, THIS LOOP HAS A UNITY-GAIN FREQUENCY OF ABOUT 27kHz. R5 IS NOT USED IN ALL APPLICATIONS, BUT IT GIVES BETTER PHASE MARGIN IN CONSTANT VOLTAGE MODE.

1513 F07

**Figure 7. Constant-Current Small-Signal Model**

## APPLICATIONS INFORMATION

The suggested way to control unity loop frequency is to increase the filter time constant on the $I_{FB}$ pin (R4/C4 in Figures 1 and 7). The filter resistor cannot be arbitrarily increased because high values will affect charging current accuracy. Charging current will increase by 1% for each 40Ω increase in R4. There is no inherent limitation on the value of C4, but if this capacitor is ceramic, it should be an X7R type to maintain its value over temperature. X7R dielectric requires a larger footprint.

The formula for calculating the minimum value for the filter capacitor C4 is:

$$C4 = \frac{(R3)(4)(V_{IN})(12)(1500\mu)(R5)}{2\pi(f)(R4)(V_{IN} + V_{BAT})}$$

$V_{IN}$ = Highest input voltage
1500μ = Transconductance of error amplifier (EA)
f = Desired unity-gain frequency
$V_{BAT}$ = Battery voltage

For example, assume $V_{IN(MAX)}$ = 15V, R3 = 0.4Ω (charging current set to 0.25A), R4 = 24Ω, R5 = 330Ω and $V_{BAT}$ = 8V,

$$C4 = \frac{0.4(4)(15)(12)(0.0015)(330)}{6.3(25000)(39)(15 + 8)} = 1\mu F$$

The value for C4 could be reduced to a more manageable size by increasing R4 to 75Ω and reducing R5 to 300Ω, yielding 0.47μF for C4. The 2% increase in charging current can be ignored or factored into the value for R3.

### More Help

Linear Technology Field Application Engineers have a CAD spreadsheet program for detailed calculations of circuit operating conditions. In addition, our Applications Department is always ready to lend a helping hand. The LT1371 data sheet may also be helpful. The LT1513 is identical except for the current amplifier circuitry.

# TYPICAL APPLICATIONS

**Lithium-Ion Battery Charger with Switchable Charge Current**

Many battery chemistries require several constant-current settings during the charging cycle. The circuit shown in Figure 8 uses the LT1513-2 to provide switchable 1.35A and 0.13A constant-current modes. The circuit is based on a standard SEPIC battery charger circuit set to a single lithium-ion cell charge voltage of 4.1V. The LT1513-2 has $I_{FB}$ referenced to ground allowing a simple resistor network to set the charging current values. In constant-current mode, the $I_{FB}$ error amplifier drives the FB pin, increasing charging current, until $I_{R4}$ is balanced by $I_{R5}$.

$$I_{CHARGE} = \frac{(I_{R5})(R4) - I_{FBVOS}}{R3}$$

There are several ways to control $I_{R5}$ including DAC, PWM or resistor network as shown here. If the lithium cell requires precharging, Q1 is turned on, setting a constant current of 0.13A. When charge voltage is reached, Q1 is turned off, programming the full charge current of 1.35A. As the cell voltage approaches 4.1V, the voltage sensing network (R1, R2) starts driving the $V_{FB}$ pin, changing the LT1513-2 to constant-voltage mode. As charging current falls, the output remains in constant-voltage mode for the remainder of the charging cycle. When charging is complete, the LT1513-2 can be shut down with the S/S pin.

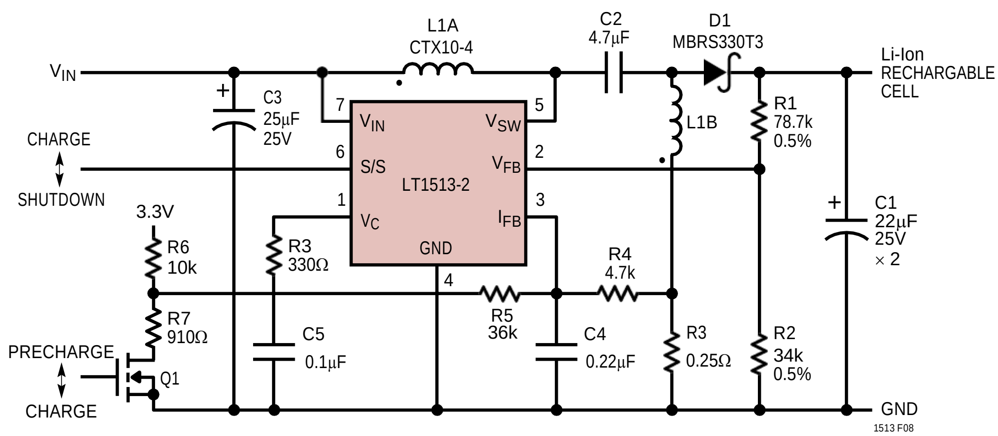
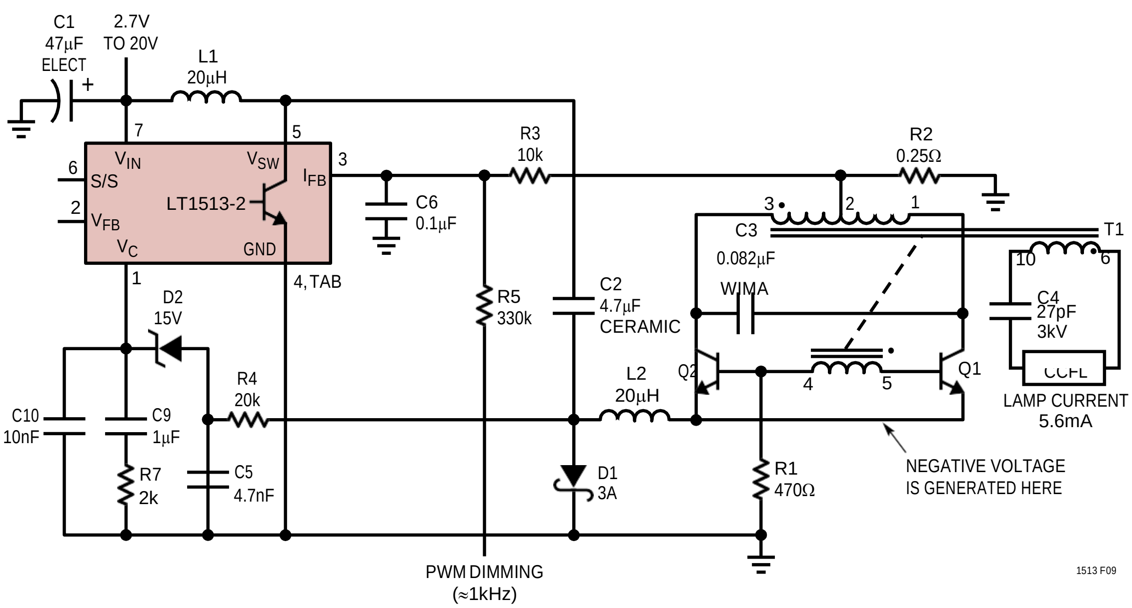



**Figure 8. Lithium-Ion Battery Charger**

## TYPICAL APPLICATIONS

This Cold Cathode Fluorescent Lamp driver uses a Royer class self-oscillating sine wave converter to driver a high voltage lamp with an AC waveform. CCFL Royer converters have significantly degraded efficiency if they must operate at low input voltages, and this circuit was designed to handle input voltages as low as 2.7V. Therefore, the LT1513 is connected to generate a negative current through L2 that allows the Royer to operate as if it were connected to a constant higher voltage input.

The Royer output winding and the bulb are allowed to float in this circuit. This can yield significantly higher efficiency in situations where the stray bulb capacitance to surrounding enclosure is high. To regulate bulb current in Figure 9, Royer *input* current is sensed with R2 and filtered with R3 and C6. This negative feedback signal is applied to the $I_{FB}$ pin of the LT1513. For more information on this circuit contact the LTC Applications Department and see Design Note 133. Considerable written application literature on Royer CCFL circuits is also available from other LTC Application and Design Notes.



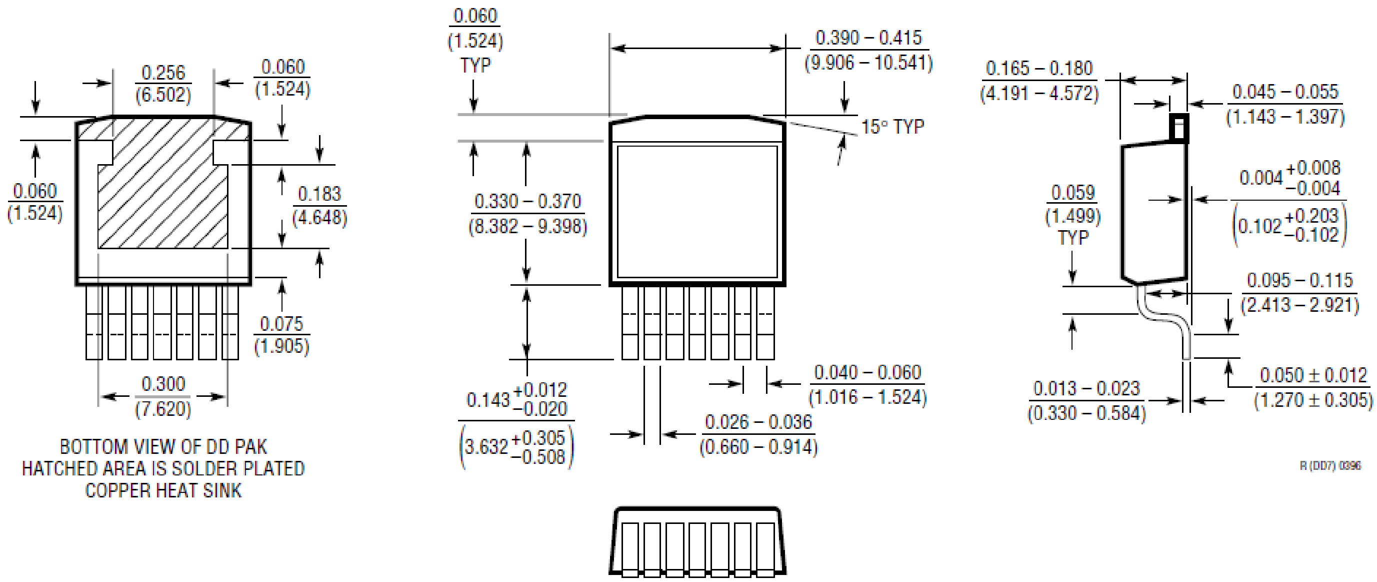

C2: TOKIN MULTILAYER CERAMIC
C3: MUST BE A LOW LOSS CAPACITOR, WIMA MKP-20 OR EQUIVALENT
L1, L2: COILTRONICS CTX20-4 (MUST BE SEPARATE INDUCTORS)
Q1, Q2: ZETEX ZTX849 OR FZT849
T1: COILTRONICS CTX110605 (67:1)

**Figure 9. CCFL Power Supply for Floaing Lamp Configuration Operates on 2.7V**

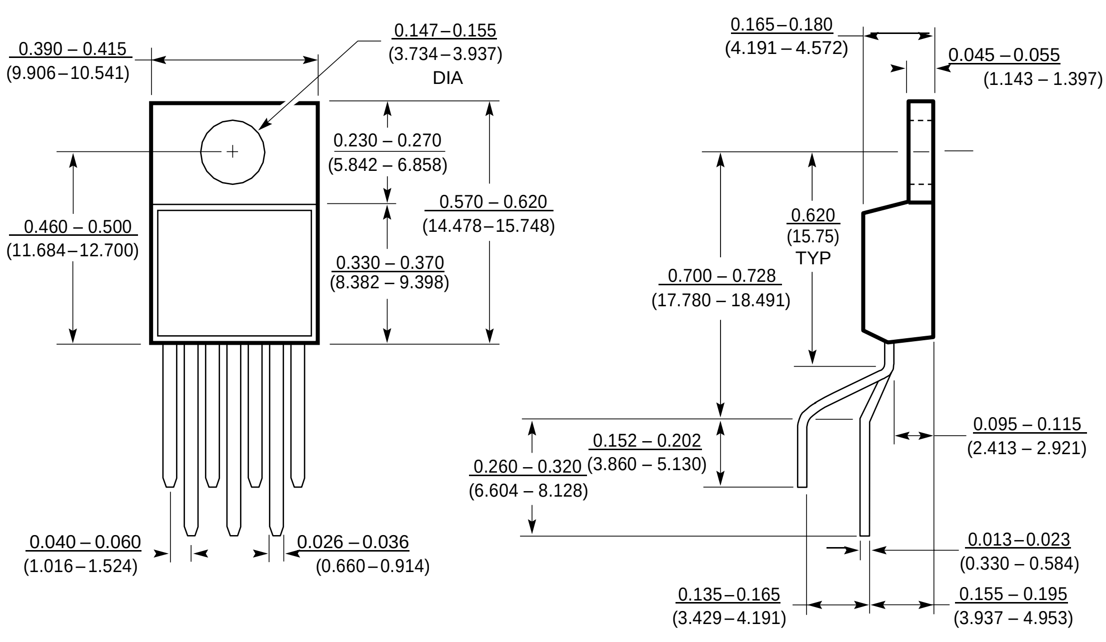
## PACKAGE DESCRIPTION

**Dimensions in inches (millimeters) unless otherwise noted.**

**R Package**
**7-Lead Plastic DD Pak**
(LTC DWG # 05-08-1462)




**T7 Package**
**7-Lead Plastic TO-220 (Standard)**
(LTC DWG # 05-08-1422)



## RELATED PARTS

| PART NUMBER | DESCRIPTION | COMMENTS |
|---|---|---|
| LT1239 | Backup Battery Management System | Charges Backup Battery and Regulates Backup Battery Output when Main Battery Removed |
| LTC®1325 | Microprocessor Controlled Battery Management System | Can Charge, Discharge and Gas Gauge NiCd, NiMH and Pb-Acid Batteries with Software Charging Profiles |
| LT1510 | 1.5A Constant-Current/Constant-Voltage Battery Charger | Step-Down Charger for Li-Ion, NiCd and NiMH |
| LT1511 | 3.0A Constant-Current/Constant-Voltage Battery Charger with Input Current Limiting | Step-Down Charger that Allows Charging During Computer Operation and Prevents Wall-Adapter Overload |
| LT1512 | SEPIC Constant-Current/Constant-Voltage Battery Charger | Step-Up/Step-Down Charger for Up to 1A Current |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