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ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

MÁSTER EN INGENIERÍA ELECTROMECÁNICA (MII)

AUTONOMOUS CHARGING FRAMEWORK

Autor: Jaime Manuel Cantos Sánchez
Director: Jeremy Hajek

Chicago, IL

Agosto 2018

AUTONOMOUS CHARGING FRAMEWORK

Autor: Cantos Sánchez, Jaime Manuel.
Director: Hajek, Jeremy.
Entidad Colaboradora: Illinois Institute of Technology.

RESUMEN DEL PROYECTO

1.- INTRODUCCIÓN

Este trabajo tiene como objetivo desarrollar un dispositivo capaz de cargar las baterías de los vehículos aéreos no tripulados (UAV por sus siglas en inglés, Unmanned Autonomous Vehicles), de manera autónoma al aterrizar en la plataforma diseñada, reduciendo la necesidad de interacción.

Los avances tecnológicos continuamente cambian la forma en que entendemos los procesos industriales, desde la cadena de suministro hasta la fabricación. Entre estos avances, uno de los más interesantes por su posibilidad de modificar todas las etapas, es el desarrollo de los UAV, también conocidos como drones.

A pesar de su potencial, estos sistemas presentan un grave problema, la dependencia del sistema de alimentación. Los motores que mantienen el sistema necesitan mucha potencia, lo que supone buscar un equilibrio entre el tamaño y peso de la batería, que aumenta el consumo, con la duración que esta confiere. Es un problema bastante complejo, que ha sido atacado desde diferentes ángulos: desarrollar motores con mayor eficiencia energética, aumentar la capacidad de las baterías o buscar sistemas de carga más eficientes, entre otros.

Este proyecto enfoca el desarrollo de un nuevo sistema de carga para las baterías. Para ello, es necesario entender el funcionamiento de las mismas, así como estudiar los sistemas de carga actuales, para poder optimizarlos. Las baterías usadas en los drones están compuestas por varias celdas, generalmente tres, siendo cada una de ellas una batería en si misma.

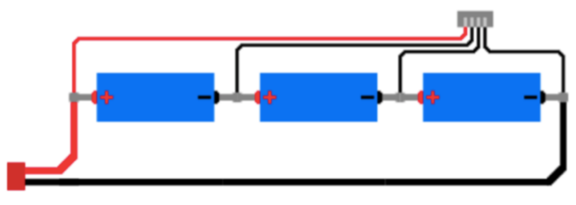

Figura 1. Esquema de la conexión interna de la batería

En la Figura 1 se puede apreciar la configuración de la batería utilizada durante el proyecto con el cableado. Consta de: dos cables gruesos, conectados a un terminal en T por donde se realiza la carga y descarga de la batería; y cuatro cables más finos conectados a los terminales de cada celda, que se utiliza para monitorizar el estado de carga de cada celda independiente. Este es un elemento crítico, pues este tipo de baterías requieren de un cargador inteligente que suministra potencia por los cables gruesos a todas las celdas y, al mismo tiempo, monitoriza el estado de cada celda para asegurar que no haya ninguna cargada completamente. Si se detecta una celda cargada mientras las demás todavía necesitan potencia, detiene el proceso de carga, conecta una resistencia en paralelo a esa celda para descargarla hasta un nivel de seguridad.

Finalizado el proceso de descarga, sigue cargando las tres celdas al mismo tiempo, repitiendo este proceso tantas veces sea necesario hasta alcanzar máxima nivel de carga en las tres.

Este sistema de carga inteligente es la complicación a resolver, pues el elemento que realiza la carga balanceada es demasiado pesado para ser cargado por el dron, pero sin él la batería corre riesgo de daño, pudiendo incluso explotar.

2.- METODOLOGÍA

El sistema se compone de dos elementos fundamentales: la plataforma de aterrizaje, que a su vez actúa como fuente de corriente; y el sistema de acoplamiento a la batería, que actúa como tren de aterrizaje.

2.1 Plataforma de aterrizaje

La plataforma de aterrizaje es un elemento crítico, pues del diseño dependen el resto de los elementos que deberán adaptarse a ella. Dos elementos se consideraron: diseño físico de la plataforma y tecnología para transmitir la potencia al dron.

Se consideraron varios diseños, como el de un sistema cónico en el que el dron al aterrizar tuviese una pata que entrase en la base y a diferentes alturas conectase lo elementos. Sin embargo, a pesar de que una vez conectados el sistema funcionase, fue descartado debido a que los drones se guían por un sistema GPS con un margen de error de ±5 m, por tanto, la posibilidad de cortocircuito es demasiado elevada. Por ello, se decidió diseñar una plataforma plana, con un sistema de estrías con polaridad alternada. Asimismo, se optó por un diseño rectangular que permite crear módulos adaptables a cualquier superficie, en función de las necesidades del consumidor.

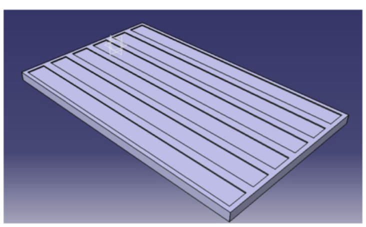

Figura 2. Diseño en CATIA de la plataforma

La plataforma se conecta a corriente a través de un rectificador que transforma la corriente alterna del enchufe en corriente continua a 12V.

Se estudian también diferentes materiales para su fabricación, que dependen de la tecnología que se utilice para ello. Se realiza un modelo para impresión en 3D en plástico, pero debido al tamaño de los módulos, es necesario fabricarlo mediante CNC en madera. Finalmente, para los elementos de contacto se usan láminas de hierro.

2.2 Sistema de acoplamiento a la batería

Una vez diseñada la plataforma de aterrizaje, el siguiente paso es diseñar la conexión entre la plataforma y la batería. Este se diseña en varias fases, dependiendo de las especificaciones que se deben de cumplir.

La primera es un sistema de seguridad, mediante el cual la conexión entre la alimentación y la batería sea siempre con la polaridad correcta y no se produzca ningún cortocircuito. Para ello, el tren de aterrizaje se diseña con una disposición triangular de tamaño tal que se asegure que, sin importar de cómo aterrice el dron, dos de los tres terminales estén siempre en polaridades distintas. Una vez diseñado esto, es necesario añadir un sistema de diodos que tiene una doble función, que la tercera conexión no genere cortocircuito sin importar en qué polaridad haga contacto y que la polaridad que alimente el sistema de carga sea siempre la correcta. El sistema se prueba con un LED, asegurando que la polaridad es correcta y la corriente fluye sin importar el lugar o ángulo con el que aterrice el dron en la plataforma.

La segunda parte es, una vez tenemos la polaridad y corriente correctas, diseñar un sistema de carga balanceada, pues los sistemas comerciales son demasiado pesados para que sea rentable que los cargue el dron. Para ello se precisan dos elementos: TP4056 y NSD15-12S5.

2.2.1 TP4056

El TP4056 es un cargador a corriente y voltaje continuos para baterías de litio de una celda. En nuestro sistema son necesarios tres, cada uno de ellos conectado a una de las celdas de la batería, a través de los cables más finos mencionados previamente. Este elemento introduce numerosas ventajas, permite cargar cada celda independientemente y en paralelo, reduciendo el tiempo de carga necesario. Asimismo, tiene un sistema de detección del nivel de carga de la celda, por lo que cuando está totalmente cargada deja de suministrar potencia, en vez de descargarla y volverla a cargar, alargando la vida útil de la batería. Por último, una ventaja fundamental para poder automatizar estos sistemas, al cargar las celdas por las conexiones finas, permite mantener los sistemas de electrónicos del dron activos, de manera que mientras se está cargando la batería, este no pierde comunicación con el centro de control en ningún momento.

Sin embargo, debido a las conexiones internas, si se conectan directamente a la batería, se crea un cortocircuito entre los terminales de las celdas de la batería, por lo que es necesario añadir un elemento de aislamiento. Además, la tensión de alimentación es de 5V, menor a los 12V que suministra la plataforma.

2.2.2 NSD15-12S5

El NSD15-12S5 es un convertidor CC/CC con tensión de alimentación de hasta 15V y tensión de salida 5V. Este elemento permite suministrar a cada TP4056 los 5V para su correcto funcionamiento, al mismo tiempo que aísla los elementos de la celda, eliminando el riesgo de cortocircuito.

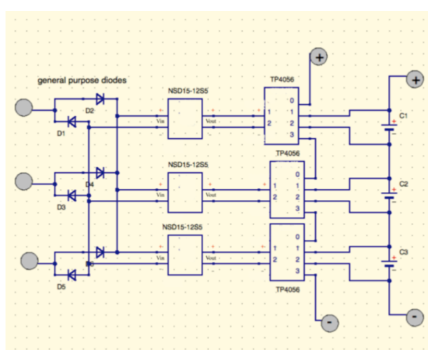

Figura 3. Esquema de conexión de todos los elementos a la batería

3.- RESULTADOS

Una vez diseñados todos los elementos que integran el sistema, se construye un prototipo en madera y con gomaespuma como aislamiento para comprobar el funcionamiento y la viabilidad del proyecto. Se demuestra que funciona como se había previsto, cargando la batería del dron en un tiempo de 2 horas. Manteniendo todos los sistemas de comunicación del dron activos para monitorización remota y automatización.

Se deduce que el tiempo de carga es demasiado largo, comparado con el tiempo de vuelo, para ser comercializado en esta fase, pero se estudian formas de reducirlo, que incluyen elementos más especializados, incluso personalizados, que permitirían reducir el tiempo de carga drásticamente. Asimismo, debido a que todas las conexiones son mediante elementos comunes, la fuente de alimentación puede ser cualquiera, desde un enchufe a energía solar, por lo que, con muy poca adaptación, este sistema se podría instalar en cualquier lugar, por muy alejado que esté de los sistemas de corriente convencionales, aumentando de manera exponencial el uso de los UAVs en zonas remotas o aisladas.

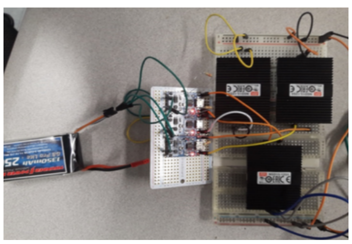

Figura 4. Comprobación del sistema de carga.

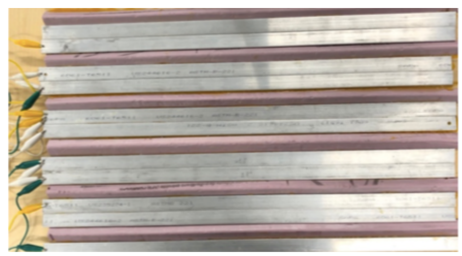

Figura 5. Prototipo de la plataforma

4.- CONCLUSIONES

Una vez finalizados todos las pruebas y experimentos realizados, se determinó que los requisitos propuestos para este proyecto han sido cumplidos. A pesar de esto, el producto no está todavía preparado para la función para la que fue originalmente ideado, la automatización de largas flotas de UAVs. Para ello, hace falta analizar el efecto que tendría la carga de varios elementos al mismo tiempo, las interconexiones entre módulos de plataforma y demás problemas derivados.

A su vez, sería necesario analizar otros elementos que sustituyan a los utilizados para el prototipo para demostrar que es posible reducir el tiempo de carga de manera que haya mayor equilibrio entre el tiempo de vuelo y el necesario para volver a despegar.

Contando todo, se puede considerar que el resultado es un éxito que puede llegar a tener repercusiones directas en todos los niveles de la sociedad, desde la ayuda humanitaria (con flotas de drones llevando paquetes de primeros auxilios o reconocimiento de terreno en zonas inaccesibles tras desastres naturales) hasta usos de negocios (como el caso de Amazon Prime Air), entre otros.

AUTONOMOUS CHARGING FRAMEWORK

Author: Cantos Sánchez, Jaime Manuel.
Director: Hajek, Jeremy.
Collaborating Entity: Illinois Institute of Technology.

ABSTRACT

1.- INTRODUCTION

The present work aims to develop a device capable of charging Unmanned Autonomous Vehicles (UAV) batteries autonomously when landing on the designed platform, reducing the need for interaction.

Technological advances continually change the way we understand industrial processes, from supply chain to manufacturing. Among these advances, one of the most interesting, for its ability to modify all stages, is the development of UAVs, also known as drones.

Despite their potential, these systems present a serious problem, the dependence on the power system. The motors that maintain the system need a lot of power, which means looking for a balance between the size and weight of the battery, which increases consumption, with the duration it gives. It is a rather complex problem, which has been tackled from different angles: developing motors with greater energy efficiency, increasing battery capacity or looking for more efficient charging systems, among others.

This project focuses on the development of a new battery charging system. To do so, it is necessary to understand how batteries work and to study the current charging systems, in order to optimize them. The batteries used in the drones are made up of several cells, usually three, each one being a battery in itself.

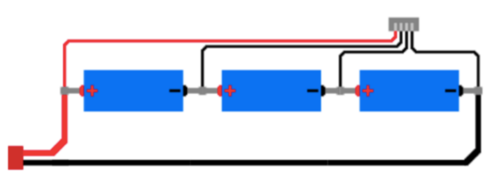

Figure 4. Schematics of the battery

Figure 1 shows the configuration of the battery used during the project with its wiring. It consists of: two thick wires, connected to a T-terminal for charging and discharging the battery; and four thinner wires connected to the terminals in each cell, which are used to monitor the level of charge in each independent cell. This is a critical element, as this type of battery requires an advanced charger that supplies power through the thick cables to all the cells and, at the same time, monitors the status of each cell to ensure that none is fully charged. If one cell is detected to be fully charged while the others still need power, it stops the charging process, connects a resistor in parallel to that cell to discharge until it reaches a safe level. Once the discharging process is finished, it continues charging the battery, repeating this process as many times as necessary, until the maximum level of charge is reached in all three cells.

This intelligent charging system is the complication to solve, because the element that makes the balanced charging is too heavy to be carried by the drone, but without it the battery runs the risk of damage, even explode.

2.- METHODOLOGY

The system consists of two main elements: the landing platform, which also acts as a current source; and the battery coupling system, which acts as the landing gear.

2.1 Landing platform

The landing platform is a critical element, since the rest of the elements must be adapted to it depending on its design. Two elements were considered: physical design of the platform and technology used for transmitting power to the drone.

Several designs were considered, such as a conical system, in which the drone had a leg that entered the base and, at different heights, connected the elements. However, despite the fact that technically the system worked, it was discarded because the drones are guided by a GPS system with a margin of error of 5 m, so the possibility of short circuit is too high. Therefore, it was decided to design a flat platform, with an alternating polarity striation system. In addition, a rectangular design was chosen that allows the creation of modules that can be adapted to any surface, depending on the needs of the consumer.

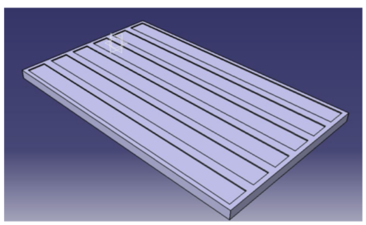

Figure 5. 3D model of the landing pad

The platform is connected to current through a rectifier that transforms the AC current from the socket into 12V DC.

Different materials are also studied for manufacturing, depending on the technology used to build it. A model is made for 3D printing on plastic, but due to the size of the modules, it is necessary to manufacture it by CNC in wood. Finally, iron strips are used for the contact elements.

2.2 Battery coupling system

Once the landing platform is designed, the next step is to design the connection between the platform and the battery. This is designed in several phases, depending on the specifications that must be met.

The first is a safety system, whereby the connection between the power supply and the battery is always correctly polarized and no short circuit occurs. For this purpose, the landing gear is designed with a triangular arrangement of such size that it ensures that, no matter how the drone lands, two of the three terminals are always at different polarities. Once this is designed, it is necessary to add a diode system that has a dual function: firstly, the third connection does not short-circuit no matter what polarity it makes contact with; secondly, the polarity that powers the charging system is always correct. The system is tested with an LED, ensuring that the polarity is correct and the current flows no matter where or at what angle the drone lands on the platform.

The second part is, once we have the correct polarity and current, to design a balanced charging system, because commercial systems are too heavy for the drone to be able to afford to charge them. This requires two elements: TP4056 and NSD15-12S5.

2.2.1 TP4056

The TP4056 is a DC constant-voltage and constant-current charger for single cell lithium batteries. In our system, three are required, each of which is connected to one of the battery cells via the thinner cables mentioned above. This element introduces numerous advantages, allowing each cell to be loaded independently and in parallel, reducing the time required for loading. It also has a system for detecting the load level of the cell, so when it is fully charged it stops supplying power, instead of discharging it and recharging it, extending the life of the battery. Finally, a key advantage in automating these systems is that by charging the cells through the thin connections, the drone's electronics systems are kept active, so that while the battery is being charged, it does not lose communication with the control center.

However, due to the internal connections, if they are connected directly to the battery, a short circuit is created between the terminals of the battery cells, so it is necessary to add an isolating element. In addition, the supply voltage is 5V, lower than the 12V supplied by the platform.

2.2.2 NSD15-12S5

The NSD15-12S5 is a DC/DC converter with a supply voltage of up to 15V and an output voltage of 5V. This element makes it possible to supply each TP4056 with 5V for its correct operation, at the same time as isolating the elements of the circuit, eliminating the risk of short circuit.

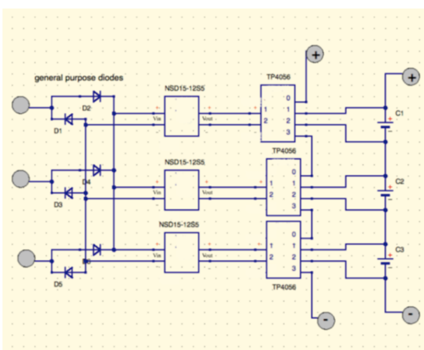

Figure 6. Schematics of the whole charging system

3.- RESULTS

Once all the elements that make up the system have been designed, a prototype is built in wood and with foam rubber as isolation to check the functioning and feasibility of the project. It is proven to work as intended, charging the drone battery in 2 hours, while keeping all drone communication systems active for remote monitoring and automation.

It would appear that the charging time is too long, compared to the flight time, to be marketed at this stage.However, some ways of reducing it are being studied, including more specialised, even customised elements, which would allow the charging time to be reduced drastically. Also, because all connections are through common elements, the power supply can be anything from a solar power plug. So, with very little adaptation, this system could be installed anywhere, no matter how far away from conventional power systems, exponentially increasing the use of UAVs in remote or isolated areas.

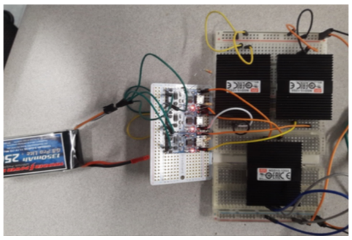

Figure 4. Charging system set up, soldered, and working.

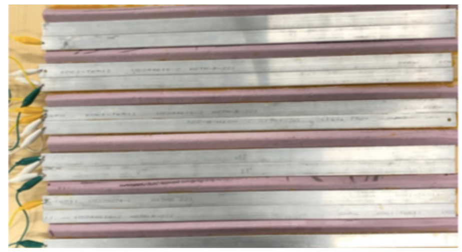

Figure 5. Landing pad's first prototype.

4.- CONCLUSIONS

Once all the tests and experiments carried out had been completed, it was determined that the requirements proposed for this project had been met. Despite this, the product is not yet ready for the function for which it was originally designed, the automation of large UAV fleets. To do this, it is necessary to analyse the effect that the charging of several elements at the same time would have, the interconnections between platform modules and other derived problems.

Other elements to replace those used for this prototype would need to be considered in order to demonstrate that it is possible to reduce the loading time, so as to achieve a better balance between flight time and take-off time.

All in all, the results can be considered a success, one that can have a direct impact on all levels of society, from humanitarian aid (with fleets of drones carrying first aid kits or terrain recognition after natural disasters) to business uses (such as Amazon Prime Air), among others.

AUTONOMOUS CHARGING FRAMEWORK

BY

JAIME MANUEL CANTOS

INDUSTRIAL TECHNOLOGY AND OPERATIONS

Submitted in partial fulfillment of the
requirements for the degree of
Master in Industrial Technology and Operations
in Industrial Technology and Management department
in the Graduate College of the
Illinois Institute of Technology

Supervised by Prof. Jeremy Hajek
Adviser

Chicago, Illinois
08 2018

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Especial mention to my family of Chicago, Westies, with whom I have had the pleasure of sharing this incredible experience.

TABLE OF CONTENTS

CONTENT NAME PAGE

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

LIST OF SYMBOLS / ACRONYMS

Symbol	Definition
m	Meter
cm	Centimeter
mm	Millimeter
ft	Feet
gr	Gram
Kg	Kilogram
A	Ampere
Ah	Ampere hour
mAh	Miliampere hour
W	Watt
Wh	Watt hour
kWh	Kilowatt hour
V	Volt
kV	Kilovolt
Hz	Hertz
mHz	Milihertz
ºC	Celsius degree
Ω	Ohm
mΩ	Milliohm
C	Coulombs

ABSTRACT

New technologies are changing the way we understand transportation, discovering ways to automate it, reducing or suppressing the need for human interaction on site. Through this advancements, the appearance of Unmanned Aerial Vehicles (UAVs) was possible, and their uses keep evolving.

They are now being used for business purposes, such as Amazon's proposal of having delivery drones, or terrain recognition for construction companies; humanitarian, with drones delivering first aid kits in natural disaster cases, or locating people in places with limited access; amongst others.

Nevertheless, like every technology, it has its limitations. In this case, the battery life. Batteries have evolved greatly over the last years; however, they have not yet reached the potential to fulfill the requirements for the new applications of UAVs, for this reason, the use of drones has been stuck. For many of the ideas, a large fleet of drones would be necessary, and there is still no technology developed through which numerous drones can be charged at the same time autonomously.

The aim of this project is to present a solution for the battery charging issue, while other projects focus on improving batteries, we will focus on improving the charging mechanism for current batteries, finding a way to make UAVs really autonomous. For doing so, a research on the history of UAVs and their batteries has been done, multiple solutions were analyzed, weighing the benefits and disadvantages, and a working prototype was built. Furthermore, we will also analyze the repercussions it will introduce.

CHAPTER 1

INTRODUCTION

The uses for UAVs are growing exponentially, and they don't really have a limit. The more we investigate, the more ways to revolutionize industries come up. It started revolutionizing the military, but this technology is now present in virtually every industry possible, from transportation (Dubai's drone taxi service project), to services (with drones being used for aerial photography for construction, real state or security) and even logistics (Amazon's project to use drones to deliver packages around the major cities).

The project is derived from the Autonomous Movement Framework, a project which had as main goal to design and develop a framework to control and manage drone fleets from a far distance being used in some situations like search, rescue or natural disasters. This project presents very exciting possibilities for the evolution of this technology. However, even if we call them "unmanned or autonomous" vehicles there is still a major issue that limits the progress, the battery.

Batteries for drones tend to last a very limited period of time, and the technologies now available to charge the batteries usually either need human interaction to take the battery from the vehicle and plugging it to the balanced charger, or are extremely expensive systems based on robotic arms and sensors. The aim is to develop a system that would allow the charge of a scaled fleet of drones simultaneously.

This project is born as an alternative to conventional charging methods, seeking for UAVs to reach their full potential in shaping the future of our society. For this, first a brief research on UAVs has been done, analyzing their history, their batteries and the possibilities available in the market. Secondly, the electronics behind the project will be introduced and tested, to ensure maximum functionality.

After that, a prototype will be built, as a proof of concept, to make sure the product is feasible and it responds to a necessity. Finally, once the operating prototype is built and tested, a set of them will be manufactured to test its capacity to adapt to a fleet of drones.

CHAPTER 2

STATE OF THE ART

For better comprehending the repercussions of this project, and the impact it may have in the industry, research was conducted. First, a brief history of how UAVs have evolved, and how they are changing the way we understand transportation; secondly, the drones used in this project will be introduced, and their specs; lastly, the technologies available for autonomous charging of batteries, how they work, and the advantages and disadvantages they present.

2.1 HISTORY OF UAVS

Like many of the advances done in technology, Unmanned Aerial Vehicles (UAVs), commonly known as drones, were developed centuries ago for military purposes. The earliest recorded use of a UAV was on 1849, when Austrians used unmanned balloons loaded with explosives to attack Venice. Shortly after, in 1915, British military used aerial photography to their advantage in the Battle of Neuve Chapelle.

After this, the United States developed the first pilotless aircraft in 1916, during First World War, and continued experimenting with radio-controlled aircrafts. In 1937 they created the Curtis N2C-2 drone, the first of the successful prototypes.

Figure 1. A Curtis N2C-2 at the National Museum of Naval Aviation (Naval Aviation Museum)

During World War II Reginald Denny created the first remote-controlled aircraft, called the Radioplane OQ-2, which became the first mass-produced UAV product in the world.

Continuous improvement and research have been done since then, and in 1990 miniature and micro UAVs were introduced.

Once UAVs started being mass produced, their prices dropped. They went from being an expensive military weapon to an affordable technology able to revolutionize virtually every industry, present even in the common household.

2.2 THE IRIS+ DRONE

This is the drone used in the project, developed by 3D Robotics. This was chosen because of their modular build, being easy to manipulate and modify, key to this project as free access to the circuitry was needed. According to 3D Robotics, the flight time of the IRIS+ is between 16 and 22 minutes with the battery fully loaded, depending on external factors, such as wind, load, elevation, temperature, etc. However, the real flying time was 15 minutes, empirically proved.

The drone is controlled by the Pixhawk processor, which is an autopilot-on-module for robotic platform focused on the movement, such as helicopters, cars, and boats. The processor is highly optimized to improve control when the drone is flying and provides many services to the drone, including GPS and a backup system for in-flight recovery.

Figure 2. The IRIS+ drone (APMCopter)

Table 1. IRIS+ drone specifications (APM Copter)

	IRIS+
Battery	3D Robotics, 5100 mAh 3S 8C lithium polymer
Motors	AC 2830, 950 kV
Propellers	IRIS+ Propeller Set (10.5 x 4.7 inches)
GPS	uBlox GPS with integrated magnetometer
Telemetry	3DR Radio 915mHz

2.3 AUTONOMOUS CHARGING IN THE MARKET

The concept of "autonomous charging" is quickly being implemented in today's society, specially through systems aimed to charge portable devices, such as cell phones, or small appliances like electric toothbrushes. The technology used is called inductive charging, commonly known as Qi charging, and it is based on electromagnetic principles.

The way it works is as follows, the transmitter is fed from a power source, and the current is forced to flow through a coil, producing a magnetic field. When the receiver is placed above the transmitter, the magnetic field generates a current in the receiver coil, from which the battery is powered. The schematics of this system can be appreciated in Figure 3.

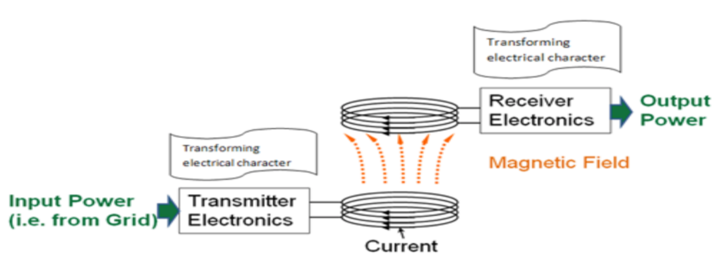

Figure 3. Inductive charging schematics

As previously stated, this technology is revolutionizing the way small electronics are being charged in many households as it introduces many advantages over conventional charging.

- Simplicity: Qi charging works by just placing your receiver on top of the transmitter, no need to plug it or have cables everywhere. Furthermore, this technology is being implemented in many public spaces, such as airports, stadiums, and restaurants. Allowing you to power your electronics everywhere.
- Longevity: because of the lack of movable parts and cables, it is a much robust system, without dealing without the risk of busting cables or parts inside.
- Maintenance: connected to longevity, the maintenance of this system is much lower, being isolated from the elements and dust, it is much safer.
- Applicability: it can be installed in virtually any surface. It is already been implemented in furniture, cars, etc.

However, it also introduces certain disadvantages, specifically for the intent of this project:

- Accuracy: in order for Qi to work, the coil in the transmitter and the one in the receiver must be as close as possible, if not the magnetic field won't generate the current flow. As it will be later introduced, this is the main drawback, because most UAVs work through GPS and it has a big accuracy error.
- Efficiency: in Qi its much lower than direct contact because current has to be transformed into a magnetic field, and then reconverted to a voltage difference. In both transformations there is a heat loss, reducing the efficiency. This is acceptable in small power appliances, but the power needed to charge big batteries is too high and the percentage lost is big enough to not use this technology yet.
- Speed: related to efficiency, inductive chargers are slower than wired systems.
- Cost: even if long-term the maintenance cost is much lower, setting up an inductive charger presents a bigger initial investment, which might be another drawback.

After weighing the advantages and disadvantages, it is decided not to focused on inductive charging, but a system based on direct contact between the charging system and the drone, especially considering the balanced charging necessary for this battery, which will be introduced in Chapter 3: The battery.

CHAPTER 3

THE BATTERY

3.1 BATTERY CONFIGURATION

Figure 4. 3D Robotics Lithium Polymer battery (Notus)

The battery aimed to charge in this project is a lithium polymer battery (LiPo) with XT60 connector and JST-XH charging connector manufactured by 3D Robotics, can be seen in Figure 4. The specifications of the battery are shown in Table 2. However, during the tests another battery was used, to make sure the system worked correctly without damaging the bigger, more expensive ones, as it will be seen in some of the following figures.

Table 2. 3D Robotics battery specifications (Manufacturer)

	3D Robotics Li-Po battery
Dimension	5.3 x 1.6 x 1” / 13.5 x 4 x 2.5 cm
Weight	11.3 oz / 320 gr
Discharge Rate	8 C
Number of cells	3
Voltage	11.1 VDC
Battery capacity	5100 mAh
Connector	Output: XT60 Charging: JST-XH

These batteries are built by connecting 3 smaller batteries, called cells (3.7 V each), in series. When the cells are connected in series the effect each has is added, therefore the total voltage of the battery is 11.1 V. The schematics that rule the connections inside the battery can be seen in Figure 5. Different wires are shown: two thick ones ending in a T-connector, used for both charging and discharging the battery; and 4 thinner ones, connected to both poles on each cell, used for the balanced charging.

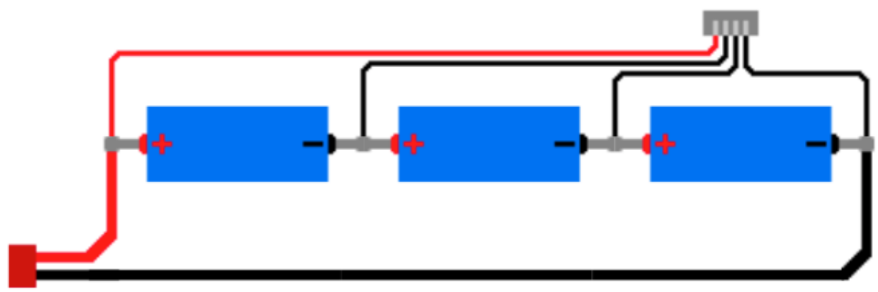

Figure 5. Schematics of the battery, showing the three cells (Amazon)

This cell configuration allows for the battery to be much smaller than a conventional 11.1 V battery should be. Furthermore, it also makes the battery much lighter. Considering the fact that the flight time is directly related to the weight the drone has to carry, it is imperative the battery is as small and light as possible, so as to not sacrifice the utility of the UAV. There is, however, a major downfall to this configuration, the need for a balanced charger.

3.2 BALANCED CHARGING

As previously stated, the charging of the battery is done through the thick cables ending on the T-connector, thus transmitting power to all three cells at the same time, charging the battery faster.

Usually, individual cells inside a battery have different capacities, charging and discharging at different rates. Therefore, it is impossible to guarantee that all three cells will be at the same state of charge (SOC), and this must be accounted for when charging the battery. The balanced charger is an electronic device that continuously monitors the SOC of each cell independently, when one of the cells is fully charged while the rest of them are not, stops the power flowing to the battery and connects that individual cell to a resistor, discharging it partially. Once the level of charge of that cell has been reduced, it disconnects the resistor and continues charging all of the cells. It does this process until all cells are fully charged.

If it were not for this, while charging the battery the cell with the smallest capacity would almost surely overcharge, damaging the battery and even catching fire, posing a very serious hazard. Commercial balanced chargers are sold, and the one used during our project was the SkyRC E4 3A Lipo/Life AC Balancing Charger.

Figure 6. SkyRC E4 3A Lipo/Life AC Balancing Charger (Amazon)

Table 3. SkyRC E4 3A Lipo/Life AC Balancing Charger specifications (Amazon)

	AC Input	**Bat. Type**	**Cell count**	**Current**	**Power**	**Weight**
SkyRC	100-240V	LiPo/LiFe	2-4	1/2/3 A	20 W	176 g

CHAPTER 4

ELECTRONICS

As stated on Chapter 2: State of the Art, this project aims to develop an autonomous charging mechanism through direct contact. The main concern is the safety of the battery, needing the function of the balanced charger to make sure the battery is not damaged. Previous ideas involved attaching the charger to the drone, and make it land on a platform powered with 100-240 VAC. These ideas were discarded because of two main reasons:

- Safety: having a landing pad that anyone could step on powered at that voltage could represent a serious hazard for people interacting with it.
- Drone flying time: adding more weight to the drone equals sacrificing its flying time, even if the balanced charger is not heavy enough so that the drone can't carry it, it still represents an extra weight that should be reduced from the load the drone would be able to transport.

Once they were discarded, and after analyzing how the balanced charging works, it was decided to design and build a customized balanced charger. By doing this, we solve the issues aforementioned: the pad would not be powered at high tension, but at 12VDC, that is obtained by most commercial rectifiers seen in electronics in any household; and the total weight of the elements needed is not even a quarter of the commercial balanced charger.

In order to build a customized balanced charging two elements are needed: TP4056 and NSD15-12S5.

4.1 TP4056

The TP4056 is a complete constant-current/constant-voltage linear charger for single cell lithium batteries. This element is to be connected directly to each of the cells in the battery, charging them in parallel which can be much quicker than the series charging of the commercial balanced charger. Thanks to the safety systems embedded in it, it will detect and stop charging as soon as the cell is fully charged, avoiding the overcharge problem, reducing the risk of battery damage or it catching fire. It detects the cell is fully charged when the battery current drops to 1/10th of the programmed value.

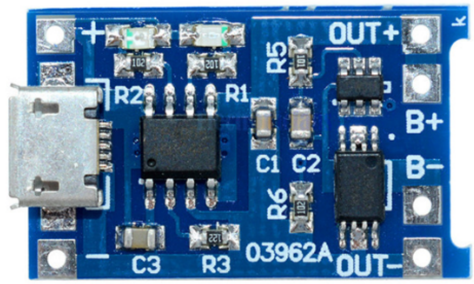

Figure 7. TP4056 (Mouser)

It can be powered through a micro-USB or the terminals + & – located at the left side in Figure 7. The terminals B+ & B– will connect to each of the poles in a cell. The current flowing to the battery can be controlled by R_3 (see Table 4), controlling the speed at which cells are charged. It has two LED indicators: the red one indicates that the cell is charging, and the blue one indicates that it is powered and the cell is fully charged.

Table 4. Relation between R3 and IBat (TP4056 Datasheet)

R_3 (kΩ)	10	5	4	3	2	1.66	1.5	1.33	1.2
I_{Bat} (mA)	130	250	300	400	580	690	780	900	1000

The issue this element present is that the terminals B+ is connected to OUT+ and – to OUT– therefore, when all three to the battery cells are connected, a short-circuit is created between the terminals of the battery, damaging it, which is why there is need to add an isolator.

4.2 NSD15-12S5

The NSD15-12S5 is an isolated DC/DC converter. It was implemented because of its isolating properties, avoiding the aforementioned short-circuit problem. There are, however, other advantages to be considered.

- The landing pad is powered through a basic rectifier circuit that provides 12VDC, through the use of the NSD15, it provides 5V independently to each of the TP4056 not compromising the speed of charging the cells.
- Because of the electronics it is based in, it won't activate until the drone has fully landed on the pad, avoiding peaks and unpredictable power to the charging system, protecting the battery.

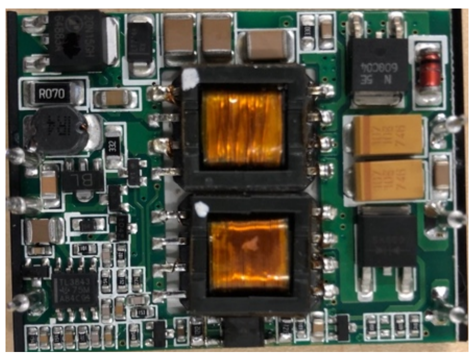

Figure 8. NSD15-12S5 (Mouser)

4.3 CONNECTION OF ELECTRONIC ELEMENTS TO BATTERY CELLS

The connection of the electronic elements to the battery is as shown in Figure 9.

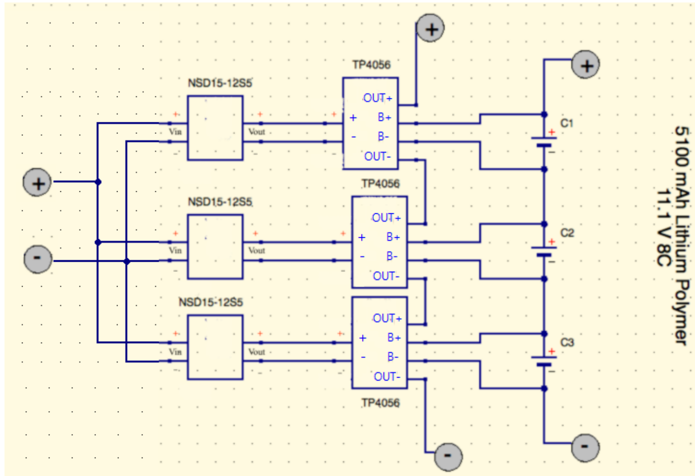

Figure 9. Schematics for the balanced charging

The result once all these elements were soldered into a base plaque is shown in Figure 10. The red LEDs show that the TP4056 are powered and charging the battery cells, thus proving the system is able to recognize uncharged batteries and to actually charge them individually and in parallel.

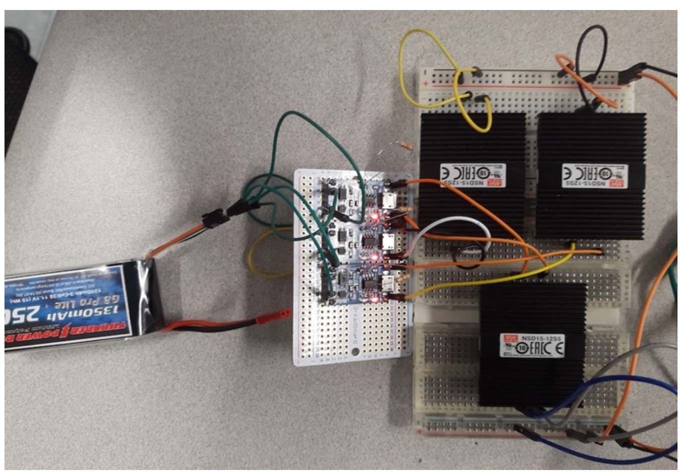

Figure 10. Charging system set up, soldered, and charging the test battery

CHAPTER 5

LANDING PAD: PROTOTYPE

One of the hardest goals this project presented was the design of the landing pad. The desire to make it flat, while delivering the polarity needed, and the need for it to be modular, so it could be made custom according to the necessities of the use it was going to be given where some of the concerns that had to be overcame.

5.1 THE FLAT PAD

The main issue when designing the pad was the fact that a positive and a ground terminals were needed in a single flat surface, plus the fact that it is impossible that all drones land in the exact same relative position to make sure that there was no possibility of short-circuit between terminals.

Regarding the design of the pad we opted for a stripe system, shown in Figure 11. This first prototype was built using a wood board with metal stripes and Styrofoam as isolator between them. The connections are not shown, but they are alternatively positive terminal and ground.

Figure 11. First prototype of the landing pad

This stripe design has the advantage of it being very easy to interconnect between different pad modules, which allows the customization of the pad to any surface, based on whatever the need.

5.2 SECURITY SYSTEM

Once the problem of having both terminals in a flat surface was solved, the next step was to design a security system that would make sure that no matter where in the pad, or what angle the drone landed, the polarity seen by the charging system was always the correct one. Furthermore, making sure that even in the more than probable case that two contactors fell in the same stripe there was no risk of short-circuit.

The problem was tackled from two angles that, working together, were able to solve all issues. First of them, a mechanical designed system, in which the contactors on the drone were designed with a triangular shape with the right dimensions, to ensure that at least two of them would always touch stripes with different polarity.

Once this was built, the next angle was that other contactor, depending on the angle the drone lands can be in touch with either polarity. For this a simple diode security system was enough, shown in Figure 12. It assures that no matter what stripe the contactors touch, the top one will always be positive, while the lower one will always be ground.

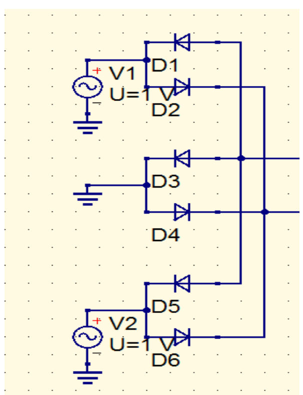

Figure 12. Diode security system for simulation

Once these systems were designed, simulated and set up the next step was to prove they worked. In order to do so, a simple electronic system with a red LED attached to it was built. The premise behind this is that it would only light up in case the polarity is the correct one no matter how the drone lands. All sort of positions and locations on the pad were tried and in all of them the LED light up, proving the sturdiness of the system designed. The test can be seen Figure 13.

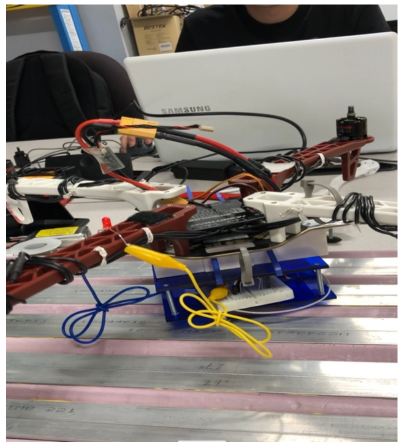

Figure 13. Test with LED to check correct polarity

Once all of the systems were designed, set up and successfully tried independently, the next step was to integrate them in one circuit. The schematics for it is shown in Figure 14.

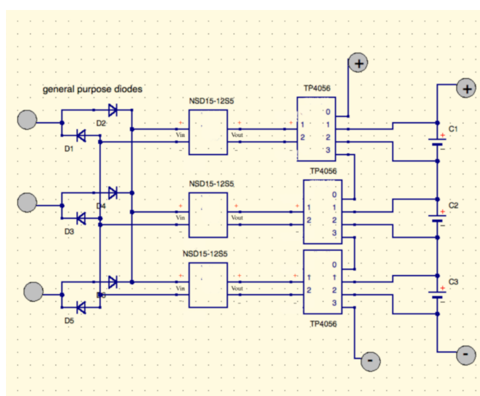

Figure 14. Schematics of the whole charging system

The final circuit, with all of the elements soldered, can be seen in Figure 15.

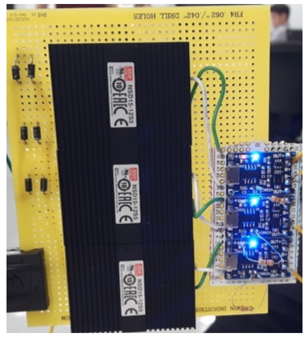

Figure 15. Final circuit soldered

Once all the tests were conducted and having the proof of concept that the prototype works, charges the battery in the expected and desired way, the next step was to start manufacture of the final design of the working framework.

CHAPTER 6

LANDING PAD: FINAL DESIGN

6.1 TECHNOLOGIES AVAILABLE FOR MANUFACTURING

For the manufacturing of the landing pad, two technologies were considered: 3D printing and Computer-Numerically-Controlled (CNC) Router.

3D printing is a type of additive manufacturing technique that is able to create digital models by adding material layer by layer. The materials that can be used for this technology are varied, from plastic filaments to metal through laser cutting. This is a very promising technology that is revolutionizing the manufacturing industry. However, it is not appropriate for this project.

- Advantages: the material this machine uses are resins, which are more resistant to environmental factors, allowing to deploy this charging system outside. Furthermore, it is capable of complex designs, easily introducing changes.
- Disadvantages: although the investment on fixed costs tends to be low, when the volume of manufacturing increases, it becomes very expensive. Also, considering it builds a piece by adding layers, they tend to have a limited strength and endurance, breaking easily. Lastly, and the reason this technology is not used, is because of the size of the 3D printers accessible, they were too small for the design of the pad.

The 3D printer used for small pieces, although ultimately rejected, in this project was the Object30 Prime manufactured by Stratasys. The specs are shown in Table 5.

Table 5. Object30 Prime printer specifications (Stratasys)

Working Dimension	Material	Layer thickness	Accuracy	Build Resolution
294x192x148.6 mm	Rigid and flexible resin	16microns (0.016mm)	0.1 mm	X-axis/Y-axis: 600 dpi Z-axis: 1600 dpi

The ShopBot Router is a CNC router capable of performing precision, large-format, cutting, drilling and shaping of wood sheets. It works by moving a drill-looking cutter spun by a motor called a router or spindle. Although it looks like a drill, it is designed to cut through the sides as well as the tip, allowing to make 3D shapes. It is a tool capable of creating virtually every shape or pattern on wood. This technique has both advantages and disadvantages compared to 3D printing:

- Advantages: the main one is the ability to shape larger pieces, which is the main one in the particular case of this project. Also, although the fixed price is lower in 3D printing, for producing large amounts this is the most economical option of the two. Finally, the time to cut in the wood is much lower than to build layer by layer.
- Disadvantages: the ShopBot accessible in this project was only able to cut in wood, limiting the available materials for manufacturing. Requires the use of a more complex software to control the cutter and precision is lower.

Besides this disadvantages, and mainly because of the size of the landing pad designed the landing pad will be manufactured in wood through the CNC.

Figure 16. ShopBot's CNC router (ShopBot)

6.2 3D DESIGNS FOR MANUFACTURING

For the manufacturing of the landing pad, first it is necessary to do a 3D model on CAD. The software used throughout the project is CATIA, as it allows both the layering for the 3D printing and the export as vectors for the use of the CNC software, VCarve.

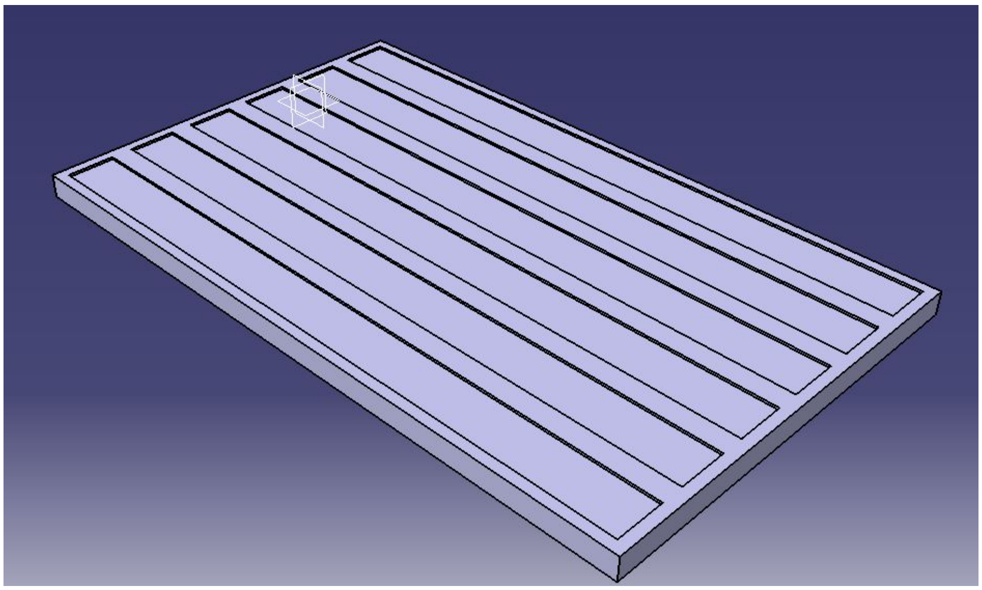

Figure 17. 3D model of the landing pad, with the strips.

For better comprehension of the dimensions of the pad, the following views are shown: top, front, side and a transversal cut, showing the wood interior and the metal strips on top.

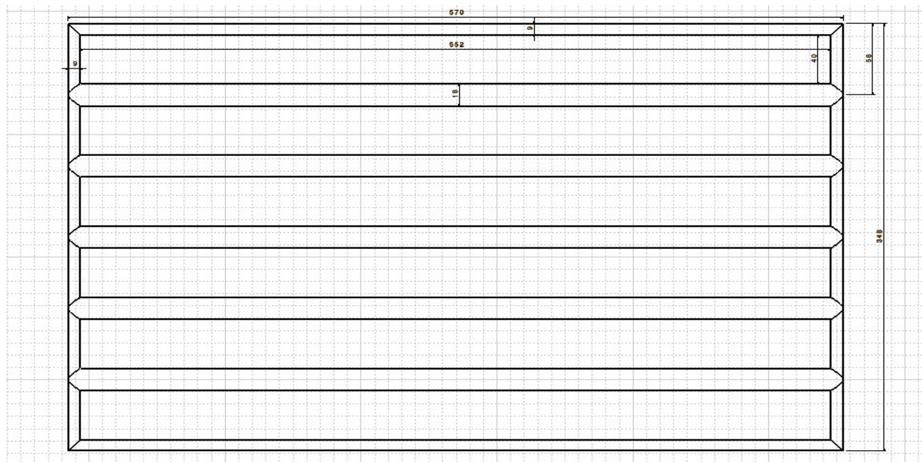

Figure 18. Top view of the landing pad design with measures in mm

Figure 19. Front view of the landing pad with measures in mm

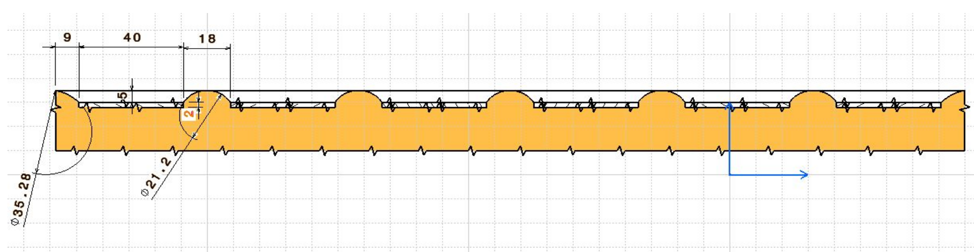

Figure 20. Front view of a transversal cut showing details of the composition of the pad with measures in mm

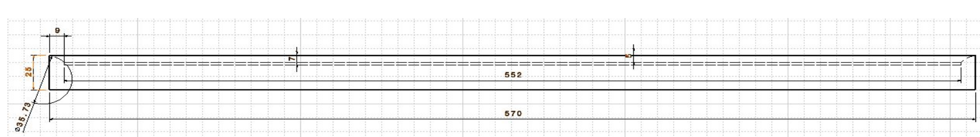

Figure 21. Side view of the landing pad with measures in mm

6.3 INTERCONNECTION OF VARIOUS PAD MODULES, BUILDING A BIGGER PAD

One of the main goals of this project was to be able to make this a system as customizable as possible; because of this a symmetrical square design with rounded borders was chosen as the final design. This introduces to main advantages.

The first one is the fact that no matter how we locate the modules next to the other, when the drone lands on it, will always be the same. Also, in case the drone's contacts landed between two strips of the pad, the round shape will ensure it will drop until in touch with the powered strips, omitting issues with the GPS, or other communication protocols, and their accuracy.

There are two solutions for interconnecting the modules in order to create a big landing surface: installing multiple outlets and connect each module to one of them, and connecting the modules amongst themselves. Both have advantages and disadvantages worth considering:

- Each module connected independently: this system would need no change on the original design, just varying the size of the modules any surface could be covered with the basic and cost-efficient shape shown above; furthermore, because of the size of the modules, each would have a maximum of two drones landing on each, having a lower current flowing through the system, not needing any extra security measure. However, as drawbacks, it would require a higher investment cost, as a bigger and personalized electrical installation would be required; plus, once the outlets are installed they will determine the location of the modules, reducing the adaptability in case of moving or remodeling.
- Connecting the modules: if all the modules are connected together, with only one power outlet a big extension could be covered, reducing investment costs and having a much more adaptable and transportable system. As drawbacks, a new design where the modules not only need to be next to each other, but somehow contact, would be necessary, as if they were pieces of a puzzle, considering security to ensure no misconnection happens; also a deeper study on materials would be needed, as the current flowing through the system would raise proportionally to the amount of drones charging, incurring in risk of fire, amongst others.

Because of the limitations on time and budget, for this project the first option will be tested, each module connected to a different outlet, although the second one would be ideally preferable.

6.4 FUTURE DEVELOPMENTS FOR THE LANDING PAD

Besides having tested the proof of concept using multiple outlets, this is not the optimal approach to the solution aimed for this project. Nor are the materials to which there was access, as they are not deployable on the outdoors. There is, then, some developments still needing to be done.

- Change the design to facilitate interconnection between modules. Finding solution to the main issue, how to ensure that the user will not connect it incorrectly. These present several solutions, both geometrical and electrical that, nevertheless, escape the scope of this research due to a lack of time.
- Further research on the materials for the landing station. If the interconnection of modules were possible, as mentioned, the amount of current will drastically rise, this presents a series of hazards that require using specialized materials capable of handling big amounts of current without overheating or catching fire. Furthermore, not only the conductor would need to be upgraded, but the materials for the base as well, many of the uses for UAVs are outdoors, and wood is easily damaged by these conditions, therefore the current system is only applicable indoors.

CHAPTER 7

FUTURE DEVELOPMENTS

Although all of the goals proposed where covered throughout the project, the more this technology advances, new and exciting possibilities open up for future developments, which scape the scope of this project. The most important ones are:

- Reducing the charging time. As technology advances, electronics is always evolving, obtaining new elements with better capacity, and able to handle more power. After designing the charging system, the charging time was, empirically obtained, around 2 hours. Although it's a breakthrough to be able to charge the drone's battery autonomously, this is a little to high to be commercial yet. Further studies on this subject should be able to find ways to short this waiting time in approximately half.
- Finding alternative sources of power. As stated numerous occasions, the main goal is to have fleets of drones being able to fly autonomously and freely. This is something rather easy in a big city, as there is an accessible power outlet in virtually every corner; however, in certain areas, usually the ones suffering from natural disasters can't trust the system to fully work continuously.

  It may be very interesting to study the possibility of using power sources locally available everywhere, such as sun and wind. Once this barrier is destroyed, this system could truly be deployed everywhere, without needing human interaction at all, not even for the installation.
- One of the issues that this project tried to solve was how to keep the drone's systems active during the charging period, although some ideas were thrown (using a relays system, for example), no steps were actually taken to test the plausibility of such theory. This is a milestone, as the fact that drones don't lose contact with the control center is an imperative. In order to automate the system, the control center must have continuous access to the charging level of every battery in the network of UAVs.

CHAPTER 8

APPLICATIONS

The applications of such technology are as varied as the ones for the UAVs in today's society. Furthermore, they are not limited by what is being done nowadays, but reach out to amazing new opportunities that keep appearing every day. The main utility of the system developed in this program is the potential to automate large fleet of drones, which has not been successfully done yet. This is very important because in a world that is more connected and automated, most of the new applications require the use of large autonomous fleets of drones, which is the goal this project was born from. Nevertheless, the three most important applications will be exposed here.

8.1 HUMANITARIAN CRISIS

This was the main idea fueling the Autonomous Movement Framework, developing a system that would have a positive impact on human life.

According to data presented in the year 2017 by the United Nations Office for Coordination of Humanitarian Affairs (OCHA), 324 natural disasters occurred in 2016, affecting a total of 105 countries and 204 million people. Of those, the countries most afflicted where: United States (85.1 million), China (72.1 million), Haiti (57.8 million), Philippines (55.3 million), and South Sudan (3.8 million).

Focusing on the United States, almost 90% of the natural disasters that occurred where floods and storms. These types of disasters usually leave complete areas out of communication, power and access, and taking the rescue teams too much time to reach the victims (OCHA).

Through the automation of the charging system for drone fleets we would be able to help areas struck by these natural disasters. It is better explained through example. If we knew a tornado is going to strike somewhere in Texas, we would be able to deploy before a dormant fleet of drones. Once the disaster has passed, when people need it the most, drones carrying first-aid kits, vision and other technologies would start recognizing the terrain. This would greatly benefit the rescue and support units, having UAVs access areas with difficult reachability and being able to help a bigger number of people. Another example of use would be to deliver needed supplies to dangerous areas, without risking human lives. The applications can be limitless.

Figure 22. Drones being used for disaster relief, carrying first aid kit (left) and terrain recognition (right)

Two of the uses of UAVs in emergency situations can be seen in Figure 22. Note how there is only one drone on each image, a fleet of automated drones would be extremely beneficial for the victims and would greatly impact on the chances of surviving the disaster.

8.2 BUSINESS APPLICATIONS

Drones are changing the way we understand logistics, supply chain and transportation. Some examples include:

Amazon's proposed plan to implement UAVs to deliver packages across major cities in the world (Amazon Prime Air) (Amazon). Through this system they could have an entire floor covered in the pads (custom made) and UAVs could autonomously fly in and out of the distribution centers, carrying the packages anywhere. Also, many buildings could have charging spots, where if the delivery distance is too long for a single battery life to complete, a network of charging stations can be deployed, so there is always enough power to deliver the goods.

Figure 23. Amazon Prime Air prototype (Amazon)

Construction companies almost always need to do terrain recognition in their projects. It would be possible to deploy a pod with numerous drones that could autonomously do that task and, once done, send the information to the companies. This would save time and reduce the costs for construction companies, not needing to send people to do the task.

Agriculture: this is an industry where the use of UAVs is expected to have a great impact. It can help farmers save a lot of money, not only would it allow to detect and monitor the health of the crops, it can alert the farmer which plants are failing, and even carry pesticides and water to take care of certain damages before they spread. Furthermore, if there are animals, it will allow to keep track on them, their health, and population.

Security companies: if there were a network of charging stations throughout major cities, it would be possible to have UAVs monitoring the city continuously, alerting the authorities in case of any emergency. This could also benefit through new connectivity technologies, such as IoT and similar. For example if drones not only had vision system but gunshot detection elements, authorities could be instantaneously alerted.

This are but a few of business applications that would greatly benefit from this project.

CHAPTER 9

ECONOMIC STUDY

In order to study the viability of the project, an economic study is performed, both for the prototype and the final design of the charging framework.

9.1 ELECTRONICS

Table 6. Electronics economic study

Item	Price per unit	Number per drone	Total cost
TP4056	$0.80	3	$2.4
NSD15-12S5	$14.12	3	$42.75
Diode	$0.12	6	$0.72
Subtotal			$45.87
O&R		8%	$3.67
Taxes		6%	$2.75
Total electronics cost per drone			**$52.29**

9.2 LANDING PAD

9.2.1 Prototype

Table 7. Landings pad's prototype economic study

Item	Unitary Price	Quantity needed	Total Cost
Wood	$0.00296/cm^3	4959 cm^3	$14.67
Stripes	$3.478/m	3.312 m	$11.52
Total prototype cost per module			**$26.19**

9.2.2 Final Design

Table 8. Landing pad's final design economic study

Item	Unitary Price	Quantity needed	Total Cost
Wood	$0.00362/cm^3$	4959 cm^3	$17.95
Stripes	$5.215/m	3.312 m	$17.27
Sub-total			$35.224
O&R		8%	$2.81
Taxes		6%	$2.11
Total prototype cost per module			**$40.15**

9.3 TOTAL COSTS

Table 9. Total cost of the design

Element	Price
Electronics	$52.29
Landing Pad	$40.15
Total Price per module	**$92.44**

CHAPTER 10

CONCLUSION

The aim of this research project was to develop a solution for the autonomous charging of the drones, working alongside the Autonomous Movement Framework, in order to be able to allow large drones of fleets to work without human interaction.

This presented serious complications, mostly regarding the battery of the drones, the three cells system, and the trouble that derives from the need of a dual polarity in order to allow power to flow to the battery to charge it, while using a flat surface and avoiding the risk of short-circuit. This problem was tackled in different steps, to assure the success of it.

First, a “home-made” balanced charger was built, to reduce weight carried by the UAV, optimizing battery life, and tested. Once demonstrated it was possible to charge a smaller battery, the next step was to try it with the original one. It was demonstrated it worked, because of the limitations of the elements, the current had to be limited, slowing the charging process, but charging nonetheless.

Secondly, the next issue to solve was the dual polarity on a flat surface. In order to solve it, a combination of security systems was used: an electronic one, with a series of diodes positioned in a way that ensures that no short-circuit was ever produced, and that the power transmitted to the balanced charger had the same polarity no matter where the contactors on the drone landed; and a mechanical/design one, where the contactors on the drone where shaped as a triangle, making sure that out of the three, two of them would touch different polarities. This idea was designed, simulated and then built on a prototype to confirm it was possible.

Once the previous steps were finalized, the next step was the design of the definitive landing pad, for this, the prototype system was used as model. The pad was designed in 3D using a

CAD software called CATIA. Once the design was satisfactory, the manufacturing with the ShopBot CNC could start, making the first definite designs. This step was also a success.

Although all the goals initially proposed were met, there is still research that needs to be done; in order to improve the systems exposed in this paper, and allow this technology to meet it's full potential. The applications are numerous, and they keep on growing every passing day, touching every industry, and each use more exciting and useful than the previous.

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APPENDIX A

TP4056 DATASHEET

TP4056 1A Standalone Linear Li-Ion Battery Charger with Thermal Regulation in SOP-8

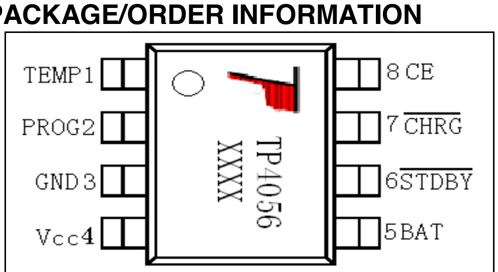
DESCRIPTION

The TP4056 is a complete constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Its SOP package and low external component count make the TP4056 ideally suited for portable applications. Furthermore, the TP4056 can work within USB and wall adapter.
No blocking diode is required due to the internal PMOSFET architecture and have prevent to negative Charge Current Circuit. Thermal feedback regulates the charge current to limit the die temperature during high power operation or high ambient temperature. The charge voltage is fixed at 4.2V, and the charge current can be programmed externally with a single resistor. The TP4056 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.
TP4056 Other features include current monitor, under voltage lockout, automatic recharge and two status pin to indicate charge termination and the presence of an input voltage.

FEATURES

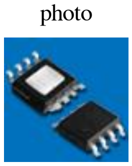
- Programmable Charge Current Up to 1000mA
- No MOSFET, Sense Resistor or Blocking Diode Required
- Complete Linear Charger in SOP-8 Package for Single Cell Lithium-Ion Batteries
- Constant-Current/Constant-Voltage
- Charges Single Cell Li-Ion Batteries Directly from USB Port
- Preset 4.2V Charge Voltage with 1.5% Accuracy
- Automatic Recharge
- two Charge Status Output Pins
- C/10 Charge Termination
- 2.9V Trickle Charge Threshold (TP4056)
- Soft-Start Limits Inrush Current
- Available Radiator in 8-Lead SOP Package, the Radiator need connect GND or impending

PACKAGE/ORDER INFORMATION



SOP－8

photo



ORDER PART NUMBER TP4056-42-SOP8-PP

PART MARKING TP4056

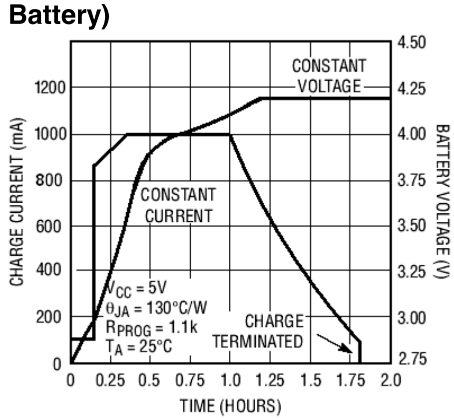
ABSOLUTE MAXIMUM RATINGS

- Input Supply Voltage(V_{CC})：-0.3V～8V
- TEMP：**-0.3V**～10V
- CE：**-0.3V**～10V
- BAT Short-Circuit Duration：Continuous
- BAT Pin Current：1200mA
- PROG Pin Current：1200uA
- Maximum Junction Temperature：145℃
- Operating Ambient Temperature Range：-40℃～85℃
- Lead Temp.(Soldering, 10sec)：260℃

APPLICATIONS

- Cellular Telephones, PDAs, GPS
- Charging Docks and Cradles
- Digital Still Cameras, Portable Devices
- USB Bus-Powered Chargers,Chargers

Complete Charge Cycle (1000mAh Battery)



TEMP(Pin 1) :Temperature Sense Input Connecting TEMP pin to NTC thermistor's output in Lithium ion battery pack. If TEMP pin's voltage is below 45% or above 80% of supply voltage V_{IN} for more than 0.15S, this means that battery's temperature is too high or too low, charging is suspended. The temperature sense function can be disabled by grounding the TEMP pin.

PROG(Pin 2): Constant Charge Current Setting and Charge Current Monitor Pin charge current is set by connecting a resistor R_{ISET} from this pin to GND. When in precharge mode, the ISET pin's voltage is regulated to 0.2V. When in constant charge current mode, the ISET pin's voltage is regulated to 2V.In all modes during charging, the voltage on ISET pin can be used to measure the charge current as follows: $I_{BAT} = \frac{V_{PROG}}{R_{PROG}} \times 1200$ (V_{PROG}=1V)

GND(Pin3): Ground Terminal

Vcc(Pin 4): Positive Input Supply Voltage V_{IN} is the power supply to the internal circuit. When V_{IN} drops to within 30mv of the BAT pin voltage, TP4056 enters low power sleep mode, dropping BAT pin's current to less than 2uA.

BAT(Pin5): Battery Connection Pin. Connect the positive terminal of the battery to BAT pin. BAT pin draws less than 2uA current in chip disable mode or in sleep mode. BAT pin provides charge current to the battery and provides regulation voltage of 4.2V.

$\overline{\text{STDBY}}$(Pin6): Open Drain Charge Status Output When the battery Charge Termination, the $\overline{\text{STDBY}}$ pin is pulled low by an internal switch, otherwise $\overline{\text{STDBY}}$ pin is in high impedance state.

$\overline{\text{CHRG}}$ (Pin7): Open Drain Charge Status Output When the battery is being charged, the $\overline{\text{CHRG}}$ pin is pulled low by an internal switch, otherwise $\overline{\text{CHRG}}$ pin is in high impedance state.

CE(Pin8): Chip Enable Input. A high input will put the device in the normal operating mode. Pulling the CE pin to low level will put the YP4056 into disable mode. The CE pin can be driven by TTL or CMOS logic level.

ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at **T_A=25℃，V_{CC}=5V**，unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{CC}	Input Supply Voltage		●	4.0	5	8.0	V
I_{CC}	Input Supply Current	Charge Mode, R_{PROG} = 1.2k StandbyMode(Charge Terminated) Shutdown Mode (R_{PROG} Not Connected, V_{CC} < V_{BAT}, or V_{CC} < V_{UV})	● ● ●		150 55 55	500 100 100	µA µA µA
V_{FLOAL}	Regulated Output (Float) Voltage	0℃≤T_A≤85℃，I_{BAT}=40mA		4.137	4.2	4.263	V
I_{BAT}	BAT Pin Current Text condition:VBAT=4.0V	R_{PROG} = 2.4k, Current Mode R_{PROG} = 1.2k, Current Mode Standby Mode, V_{BAT} = 4.2V	● ● ●	450 950 0	500 1000 −2.5	550 1050 −6	mA mA µA
I_{TRIKL}	Trickle Charge Current	V_{BAT}<V_{TRIKL}, R_{PROG}=1.2K	●	120	130	140	mA
V_{TRIKL}	Trickle Charge Threshold Voltage	R_{PROG}=1.2K, V_{BAT} Rising		2.8	2.9	3.0	V
V_{TRHYS}	Trickle Charge Hysteresis Voltage	R_{PROG}=1.2K		60	80	100	mV
T_{LIM}	Junction Temperature in Constant Temperature Mode				145		℃

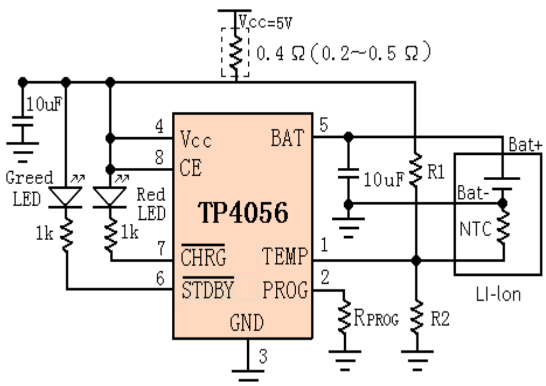
indicator light state

Charge state	Red LED $\overline{\text{CHRG}}$	Greed LED $\overline{\text{STDBY}}$
charging	bright	extinguish
Charge Termination	extinguish	bright
Vin too low; Temperature of battery too low or too high; no battery	extinguish	extinguish
BAT PIN Connect 10u Capacitance; No battery	Greed LED bright，Red LED Coruscate T=1-4 S	

Rprog Current Setting

R_{PROG} (k)	I_{BAT} (mA)
10	130
5	250
4	300
3	400
2	580
1.66	690
1.5	780
1.33	900
1.2	1000

TYPICAL APPLICATIONS



APPENDIX B

NSD15-12S5 DATASHEET

MEAN WELL

15W DC-DC Regulated Single Output

NSD15-S series

■ Features :

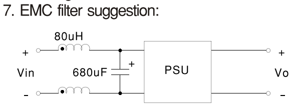
- Wide 4:1 DC input range
- Protections: Short circuit / Overload / Over voltage
- 1500VDC I/O isolation
- Built-in EMI filter
- Cooling by free air convection
- Output voltage trimming function
- Built-in remote ON-OFF control
- 100% full load burn-in test
- Low cost
- High reliability
- 2 years warranty

SPECIFICATION

MODEL		NSD15-12S3	NSD15-12S5	NSD15-12S12	NSD15-12S15	NSD15-48S3	NSD15-48S5	NSD15-48S12	NSD15-48S15
OUTPUT	DC VOLTAGE	3.3V	5V	12V	15V	3.3V	5V	12V	15V
	RATED CURRENT	3.75A	3A	1.25A	1A	3.75A	3A	1.25A	1A
	CURRENT RANGE	0.18 ~ 3.75A	0.15 ~ 3A	0.06 ~ 1.25A	0.05 ~ 1A	0.18 ~ 3.75A	0.15 ~ 3A	0.06 ~ 1.25A	0.05 ~ 1A
	RATED POWER	12.375W	15W	15W	15W	12.375W	15W	15W	15W
	CAPACITIVE LOAD (max.)	3300uF							
	RIPPLE & NOISE (max.) Note.2	100mVp-p(25% ~ 100% load) for 3.3V only 75mVp-p(25% ~ 100% load)							
	VOLTAGE TOLERANCE Note.3	±2.0%							
	LINE REGULATION	±1.0% at 10% ~ 100% load							
	LOAD REGULATION	±1.0% at 10% ~ 100% load							
	TRIM OUTPUT (Typ.)	+10%	±5.0%	±5.0%	±3.0%	+10%	±5.0%	±5.0%	±3.0%
INPUT	RATED DC INPUT	12VDC				48VDC			
	VOLTAGE RANGE	9.4 ~ 36VDC				18 ~ 72VDC			
	EFFICIENCY (Typ.)	73%	77%	81%	81%	77%	81%	84%	85%
	DC CURRENT	1.8A/12VDC				0.4A/48VDC			
	SHUTDOWN IDLE CURRENT	20mA							
PROTECTION	OVERLOAD	Above 105% rated output power							
		Protection type : Over power limiting, recovers automatically after fault condition is removed							
	OVER VOLTAGE(CLAMP)	5.8 ~ 6.93V	5.8 ~ 7.5V	13.8 ~ 18V	17.25 ~ 22.5V	5.61 ~ 6.93V	5.5 ~ 7.5V	13.8 ~ 18V	17.25 ~ 22.5V
	SHORT CIRCUIT Note.4	Recovers automatically after fault condition is removed							
FUNCTION	ON/OFF CONTROL	Logic "1" or open circuit : ON Logic "0" or short to PIN2 : OFF							
ENVIRONMENT	WORKING TEMP.	-25 ~ +70℃							
	WORKING HUMIDITY	0% ~ 95% RH max.							
	STORAGE TEMP., HUMIDITY	-40 ~ +85℃, 0 ~ 95% RH							
	TEMP. COEFFICIENT	±0.03%/℃ (0~50℃)							
SAFETY & EMC (Note 5)	SAFETY STANDARDS	UL60950-1 approved, Design refer to TUV EN60950-1							
	ISOLATION VOLTAGE	I/P-O/P:1.5KVDC							
	ISOLATION RESISTANCE	I/P-O/P:100M Ohms / 500VDC / 25℃/ 70% RH							
	EMC EMISSION	Compliance to EN55022 (CISPR22) Class B							
	EMC IMMUNITY	Compliance to EN61000-4-2,3,4,6,8; EN55024, light industry level, criteria A							
OTHERS	MTBF	1734K hrs min. MIL-HDBK-217F (25℃)							
	DIMENSION	50.8*38.1*9.82mm (2"*1.5"*0.387") (L*W*H)							
	PACKING	0.03Kg; 180pcs/6.4Kg/0.97CUFT							

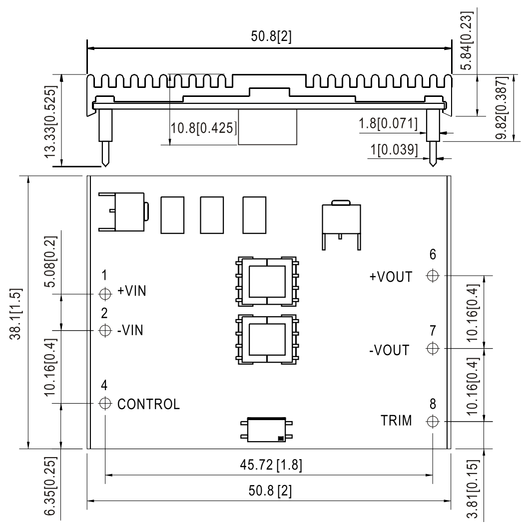
NOTE

1. All parameters NOT specially mentioned are measured at 12, 48VDC input, rated load and 25℃ of ambient temperature.
2. Ripple & noise are measured at 20MHz of bandwidth by using a 12" twisted pair-wire terminated with a 0.1uf & 47uf parallel capacitor.
3. Tolerance : includes set up tolerance, line regulation and load regulation.
4. Short circuit no more than 60 seconds.
5. The power supply is considered a component which will be installed into a final equipment. The final equipment must be re-confirmed that it still meets EMC directives. For guidance on how to perform these EMC tests, please refer to "EMI testing of component power supplies." (as available on http://www.meanwell.com)
6. Derating to 80% load is needed for NSD15-48S series at 18Vdc input voltage. Full output wattage can be acquired when the input voltage is higher than 20Vdc.
7. EMC filter suggestion:



Mechanical Specification

Unit:mm[inch]

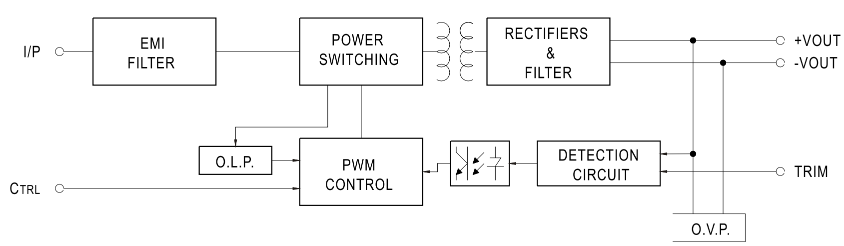


Pin No. Assignment

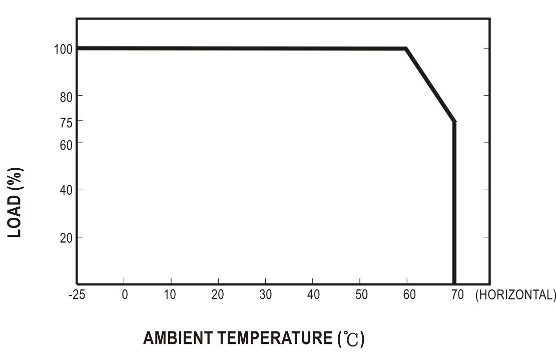
Pin No.	Assignment	Pin No.	Assignment
1	+VIN	6	+VOUT
2	-VIN	7	-VOUT
3,5	No Pin	8	TRIM
4	CONTROL		

Block Diagram

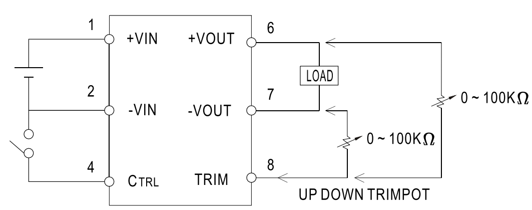
fosc : 400KHz



Derating Curve



ON/OFF Control & Output Trim



CONTROL INPUT....................................PIN4

CONTROL COMMON................................PIN2

LOGIC COMPATIBILITY......CMOS OR OPEN COLLECTOR TTL

CONTROL VOLTAGE

ON............+5.5VDC min OR OPEN CIRCUIT

OFF......+2.5VDC max. OR SHORT TO PIN2