User equipment and terminals
Wii U power and design analysis

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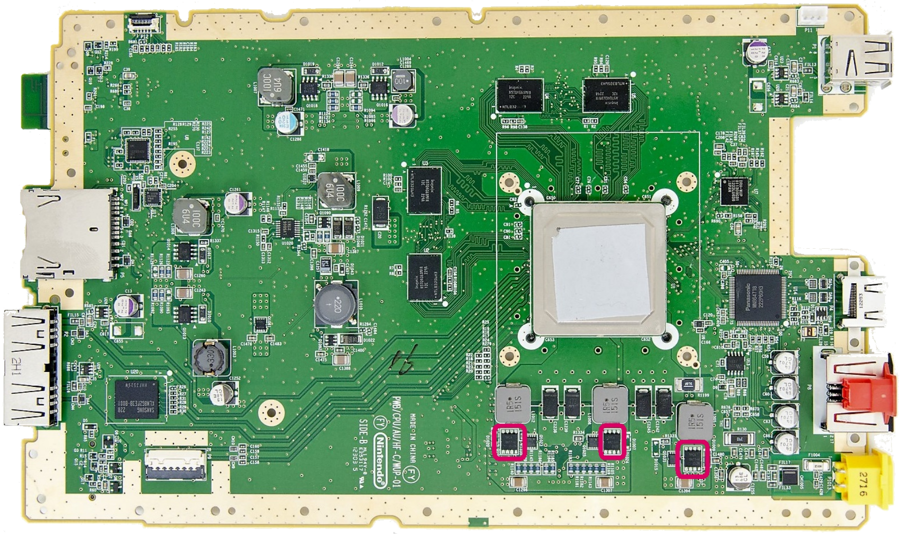

Figure 1: Motherboard front part (power section)

1. Power supply

1.1 Wii U

On the Wii U main console motherboard there is a discrete number of components involved in the power supply section, there are both passive components, discrete semiconductors and Integrated Circuits (ICs) all working together to power the Printed Circuit Board (PCB). In Figure 2 we summarized the main components listed under type and name: it can be seen the huge amount of passive components needed to support the integrated circuits and the discrete amount of transistors and diodes; on the other hand, the number of integrated circuit is restrained [1].

In Figure 1 a photo of the motherboard section regarding the power supply is shown: the red squares represent three N-channel MOSFET, used to minimize losses in power conversion. Since one of their applications like a synchronous rectifier for DC/DC converter, we suppose they are part of the power supply system in the board [2].

1.1.1 Integrated circuits description

The three main integrated components that are worth to be described are:

- **The power management IC**, model TPS65070RSL from *Texas Instruments*;
- **The Regulator DC/DC Converter, Step-Up**, model AIC1634GG from *Analog Integration corp.*;
- **The switching Regulator DC/DC Controller, Step-Down**, model LV5066V from *ON Semiconductors.*

Component type	Name
Integrated circuit	
	Regulator
	Analog IC
	Voltage Detector
	Power Manag. IC
Discrete Semiconductor	
	Diode
	Transistor
Passive comp.	
	Capacitor
	Fuse
	Ferrite Bead
	Inductor
	Resistor

Figure 2: Power supply component list

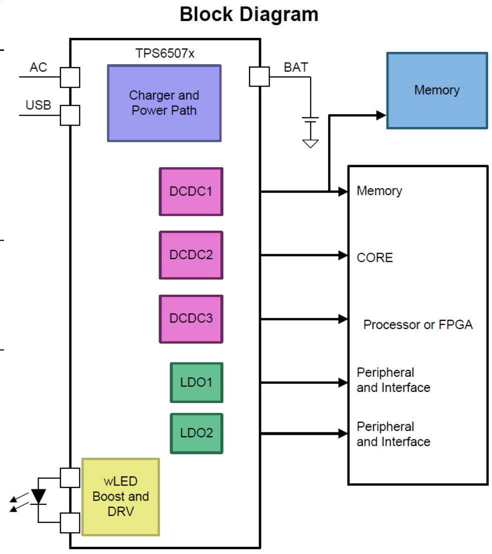

Figure 3: Schematic for TPS65070RSL

Control power IC TPS65070RSL It is a single chip power solution for portable applications, that can be powered through a USB port, or directly by a DC voltage from a wall adapter connected to "AC" pin. The module has the following main characteristics:

- 2A output current on the power path;
- Thermal regulation;
- 3 Step-down converters
  - Fixed-frequency operation at 2.25 MHZ;
  - Up to 1.5 A output current;
  - Adjustable or fixed output Voltage;
  - $2.8V < V_{IN} < 6.3V$
  - $19\mu A$ of quiescent current per converter;
  - 100% Duty cycle for lowest dropout;

A block diagram of the module is represented in Figure 3.

The two inputs to the power path (AC and USB) support the same voltage rating but normally have different current limits (Ac is at the higher limit). If voltage is applied at both inputs and both are enabled AC will be preferred over USB and the device will only be powered from AC. The current at the input is shared between charging the battery and powering the system load; anyway priority is given to the system load. The current is always monitored, so that the charging current is reduced automatically if the sum of the charging and system load currents exceeds the present maximum input current [3].

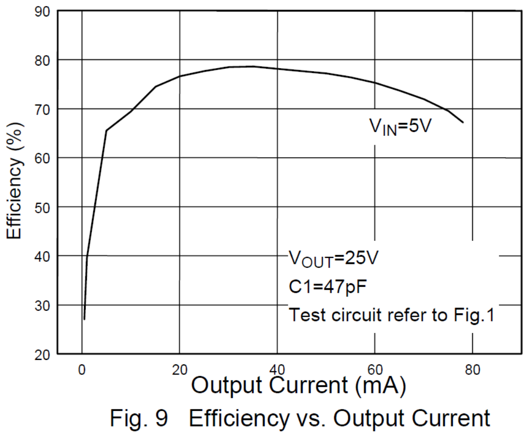

Figure 4

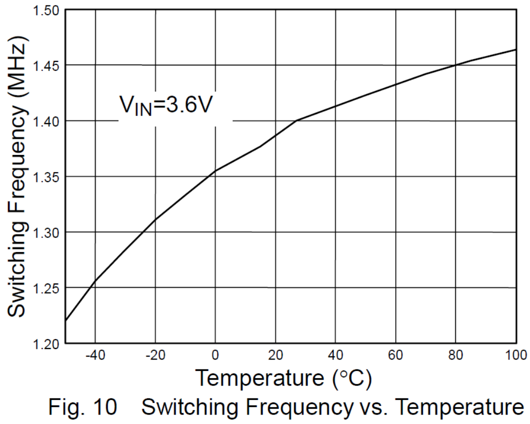

Figure 5

The Regulator DC/DC Converter AIC1634GG The module is a current-mode pulse-width modulation (PWM), step-up DC/DC Converter which, through the N-channel MOSFET, allows for step-up applications with up to 30V output voltage. The high switching frequency (1.4MHz) allows the use of small external components.

There are several characteristics that can be compared in the module, here we list just two comparisons as examples. The first chart (Figure 4), shows how the efficiency of the module varies with the evolution of the output current: it can be seen that its value rapidly saturates for low current values and starts decreasing beyond the 40 mA threshold. The second chart (Figure 5) describes the evolution of the switching frequency over the temperature: differently from the efficiency, the frequency continues to constantly grow with the temperature increase [4].

Figure 6 shows the block diagram for the module.

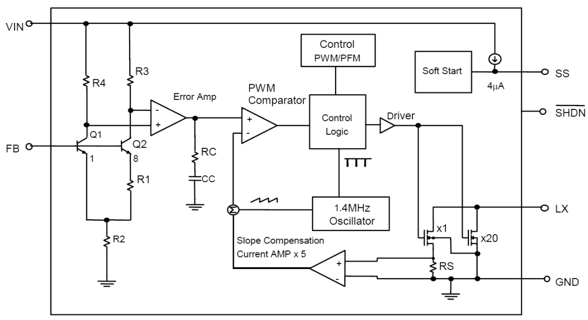

Figure 6: AIC1634GG block diagram

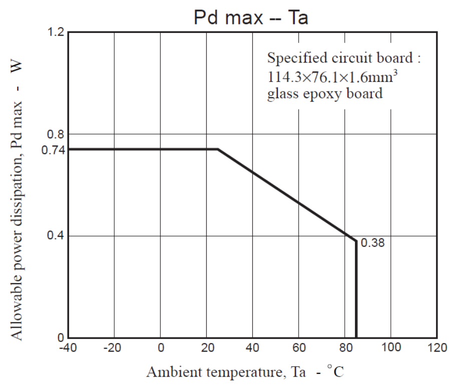

Figure 7: Power constraint over the ambient temperature

The switching Regulator DC/DC Controller LV5066V The last element of this analysis is a step-down switching regulator controller: it has one channel with an operation current of $80\mu A$ and low power consumption. Also, from Figure 7 it can be observed the evolution of the allowable power dissipation depending on the ambient temperature: it can be seen how there is a clear power constraint, with a linear decrement of the latter during the interval representing the normal temperature range of a room.

2. Power Management

2.1 Wii U

The Wii U transformer has a maximum output voltage of 15V and a maximum output current of 5A, so this console consumes $15 \cdot 5 = 75W$ under full load. Actually, even when a resource-demanding game is running, the power consumed by Wii U is a bit more than an half of the maximum power consumption.

Figure 8: Wii U without external case

Figure 9: Wii U Multi Chip Module

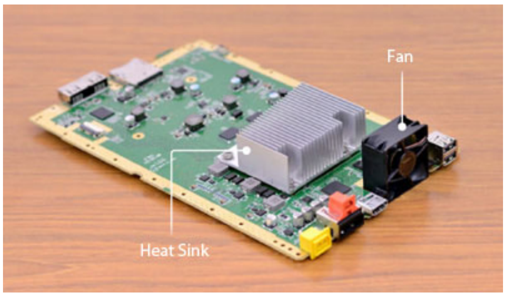

Figure 10: Fan and heat sink position

Figure 11: Wii U air flow demonstration

In Figure 8 the console without its external case is shown: the first thing we notice is that the bigger components inside the Wii U are the optical drive, a single heat sink used to cool down the entire console and two fans to allow the air to pass through the console.

Analysing the position of the fans and of the heat sink, we note that the heat sink is positioned on the main source of heat (CPU and GPU), it is close to the fan and rotated in such a way that the air can pass through it, as shown in Figure 11.

Removing the heat sink we see another thermal component that covers both CPU and GPU. These two are put close to each other to reduce the latency and the power consumption.

2.2 GamePad

The GamePad transformer has a maximum output voltage of 4.75V and a maximum output current of 1.6A, so it consumes $4.75 \cdot 1.6 = 7.6W$ under full load.

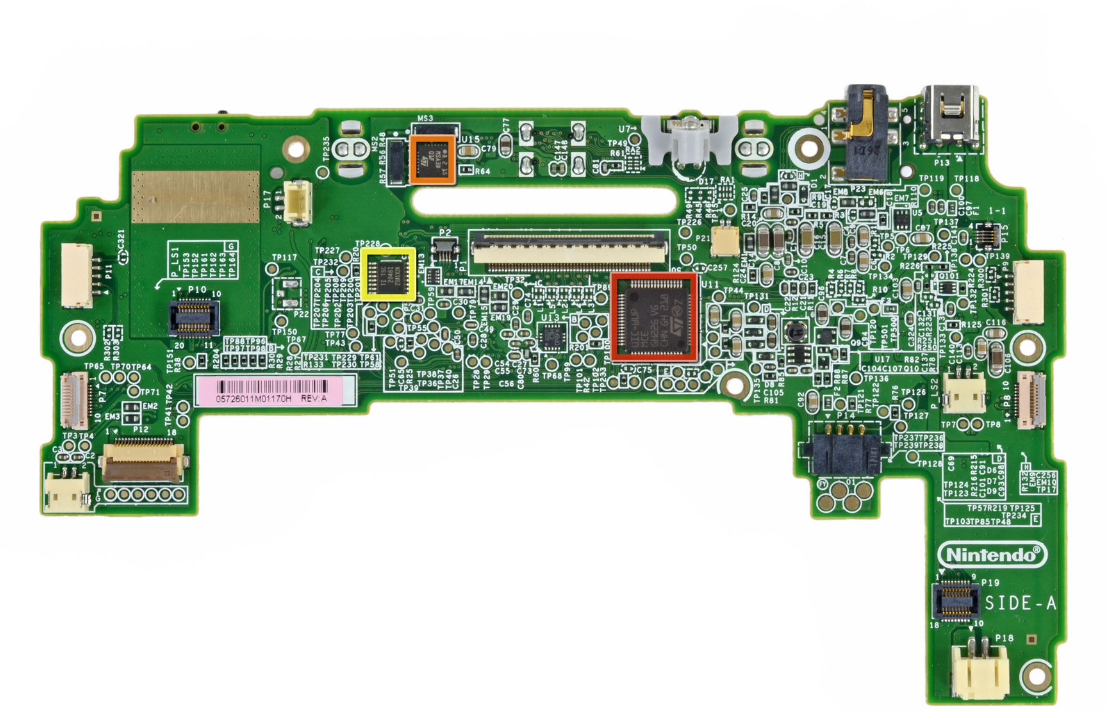

Figure 12: GamePad's motherboard

2.2.1 Touch Screen Controller

TSC2046I is the touch screen controller used in the Wii U's GamePad. TSC2046I is a chip integrated in the GamePad's motherboard, to be specific, it is the chip in the yellow square in Figure 12.

Checking the datasheet [5] we can get some interesting information:

- The controller has an on-chip $2.5V$ voltage reference that can be used for the auxiliary input, battery monitor, and temperature measurement modes. This can be powered down when not used to conserve power.
- The power consumption is less than $0.75mW$ at $2.7V$.

In Table 1 we see summarized the parameters relative to the chip thermal management. In Figure 13 and Figure 14 it is shown how the previously mentioned on-chip reference voltage is actually not fixed at $2.5V$ but is floating around this value and depends on the Temperature and on the input voltage V_{CC}. In Figure 15 and Figure 16 it is shown how the Sample Rate of the Touch Screen Controller varies with the input voltage and how the latter varies with the temperature.

In general we can deduct that if V_{CC} is too low (more or less lower than $3V$), both the sample rate and the reference voltage V_{REF} will decrease.

Parameter	Value
Power Dissipation	250mW
Maximum Junction Temperature	$+150°C$
Operating Temperature Range	$-40°C$ to $+85°C$
Storage Temperature Range	$-65°C$ to $+150°C$
Lead Temperature	$+300°C$

Table 1: Thermal management in TSC2046I

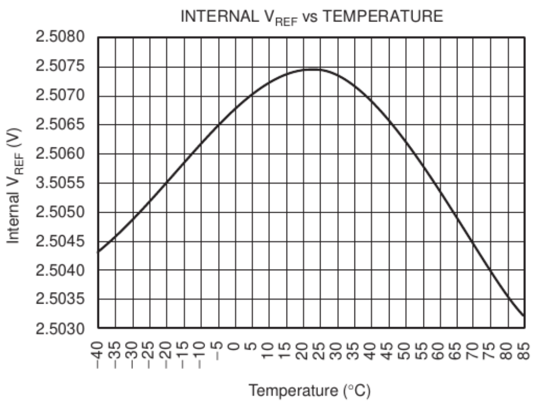

Figure 13: Variation of V_{REF} with Temperature

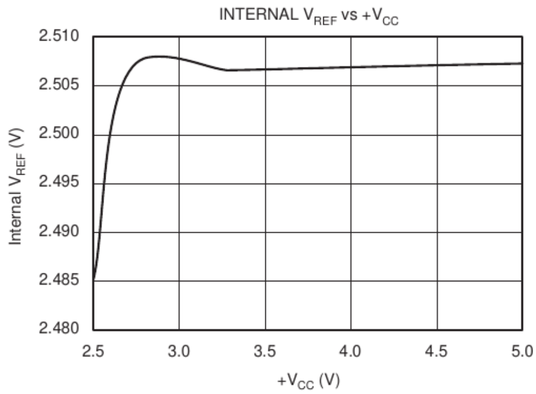

Figure 14: Variation of V_{REF} with V_{CC}

Finally, the temperature inside the chip is measured through a diode in the following way: the diode voltage V_{BE} has a well-defined characteristic that depends on temperature, so the ambient temperature can be predicted in applications by knowing the +25°C value of the V_{BE} voltage and then monitoring the delta of that voltage as the temperature changes.

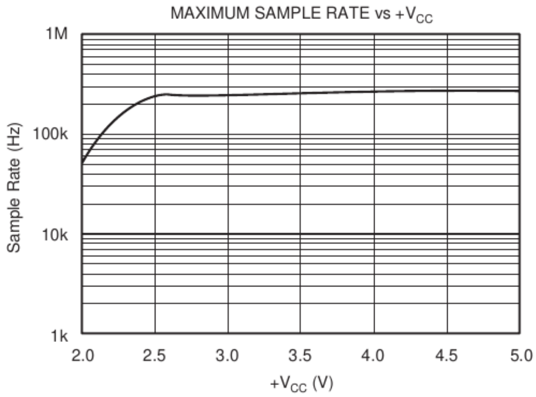

Figure 15: Variation of the Sample Rate with V_{CC}

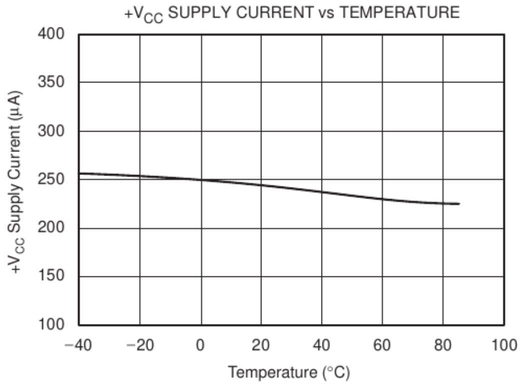

Figure 16: Variation of V_{CC} with the temperature

2.2.2 Dual Antenna Wireless Module

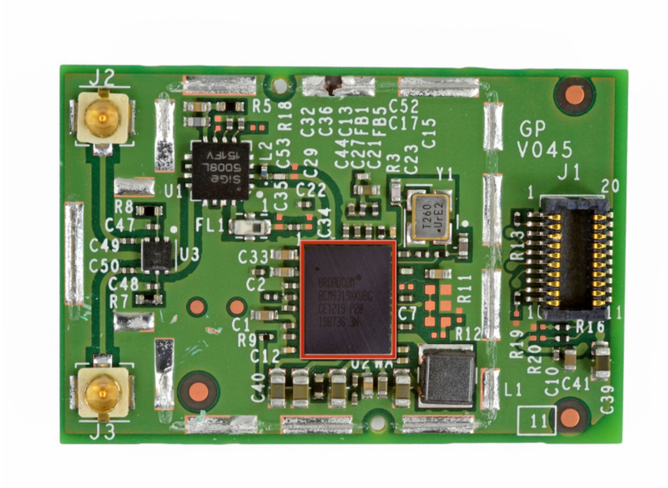

Figure 17: GamePad's wireless module

Another module that can be extracted from the motherboard is the Dual Antenna Wireless Module, i.e. the module that allows to stream video and data between Wii U console and the GamePad. The module is shown in Figure 17 and was mounted in place of the blue square in Figure 12.

This module is powered by a Broadcom BCM4319XKUBG (red square in Figure 17) and its functioning is explained in [6].

Its Power Management Unit (PMU) provides significant power savings by putting the BCM4319XKUBG into various power management states, which are appropriate for the current environment and activities that are being performed. The PMU enables and disables internal regulators, switches, and other blocks based on a computation of the required resources and the relationship between resources and the time needed to enable and disable them.

Also the clock speed can be dynamically changed depending on the current requirements. Obviously, slower clock speeds are used wherever possible.

Free different power states are defined:

Active Mode All BCM4319XKUBG cores are powered up and fully functional, all required regulators are enabled and put in the most efficient mode. Clocks' speed is dynamically adjusted by the PMU.

Sleep Mode All main clocks are shut down, only one clock is active and is used from the PMU to wake up the chip. In Sleep mode, the primary power consumed is due to leakage current.

Power-down mode The BCM4319XKUBG is effectively powered off by shutting down all internal regulators. The chip is brought out of this mode by external logic re-enabling the internal regulators.

3. Electromagnetic compatibility

The console has also been designed in order to manage the electromagnetic compatibility of all its components. In particular, by observing the structure of the PCB, we can notice several precautions regarding different aspects, like:

- Grounding;
- Shielding;
- Signal timing;

3.1 Wii U motherboard PCB

3.1.1 Grounding

The Wii U motherboard is a very complex entity, so in this work we will focus only on some examples of Electromagnetic compatibility (EMC). In Figure 18 and Figure 19 there are two zoomed images of the power connector and its relative components: from Figure 18 it can be seen the power and the ground connections as the two pins coming out from the connector and going to several capacitors. The lower pin represents the ground voltage reference, which is brought to the bottom side of the PCB through the coupling capacitor ndeg C1428. On the other hand, the fuse numbered as F1004, testifies that the upper pin is the power reference and it is coupled to the ground voltage through the capacitor ndeg C1429. On the other figure (Figure 19) we see the bottom side of the motherboard, where it is clear the connection of the top side voltage reference to the ground plane through the track framed in orange.

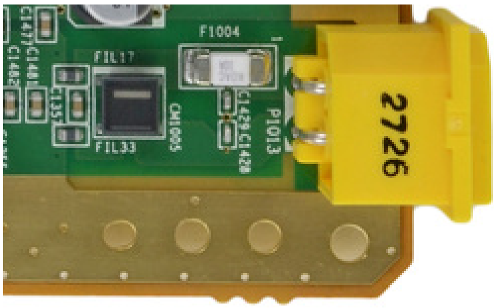

Figure 18: Power connector top side

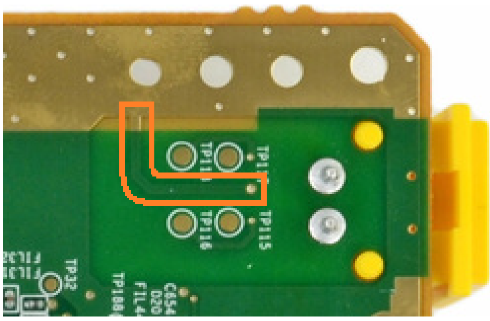

Figure 19: Power connector bottom side

Another example of grounding is represented in Figure 20 and Figure 21, where there is a voltage regulator and its schematic. From the schematic we can see, for example, that some pins are part of the power structure of the IC and are coupled with the ground level through some capacitors. In particular, pins V_{IN} and V_{DD} are connected to ground by two capacitors; moreover pins $VLIN5$, V_{DD}, $CBOOT1$ and $CBOOT2$ appear to be connected in a parallel way to ground. Finally, we can also see that pins $ILIM1$ and $ILIM2$ are connected to the same ground through the connection segment in green, whose function is supposed to be avoiding quiet ground terminals and ground loops [7].

3.1.2 Shielding

The motherboard is entirely enclosed in a metallic case in order to be well shielded, the case is shown in Figure 24. Moreover, the aspect of shielding is present also in parts autonomous from the board, like cables going to the speakers or to the buttons (Figure 22 and Figure 23): in this case we see the classic twisted cable useful to eliminate the constant component due to noise.

3.1.3 General shrewdnesses

Other classical aspects characterize the design of this board:

- as always, all the components and the tracks are surrounded by a ground plane useful to reduce coupling and radiation;
- from Figure 1 and Figure 25 it can be observed the great amount of ground traces in between the layers;
- the connectors of the board have several balancing resistances at the beginning/end of their transmission lines;
- of course, all the components are Surface Mounted Device (SMD) type in order to minimize the space and optimize the surface occupation of the pins, so as to reduce as much as possible the impedance of the pitches;

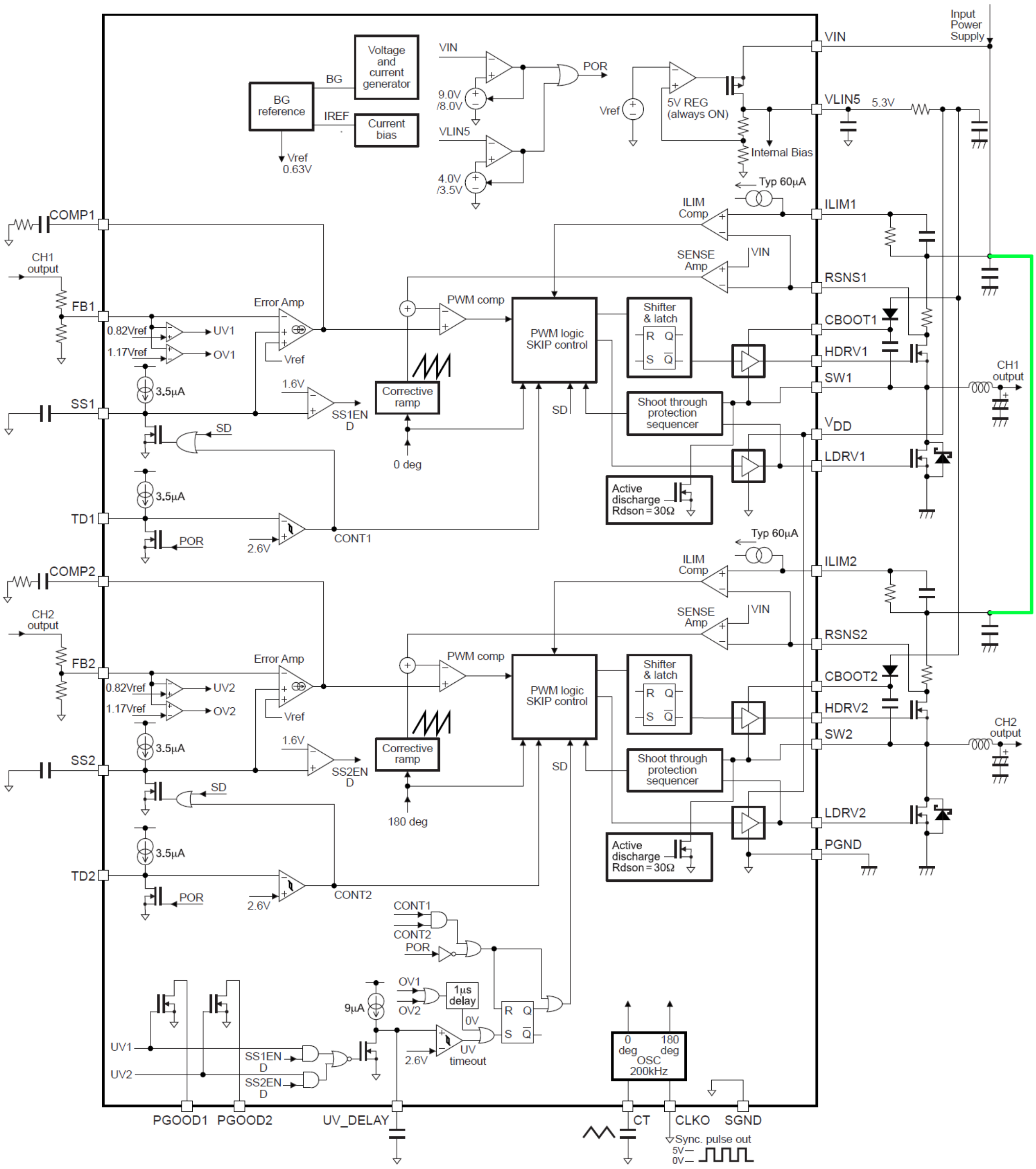

Figure 20: LV065 Voltage controller block diagram

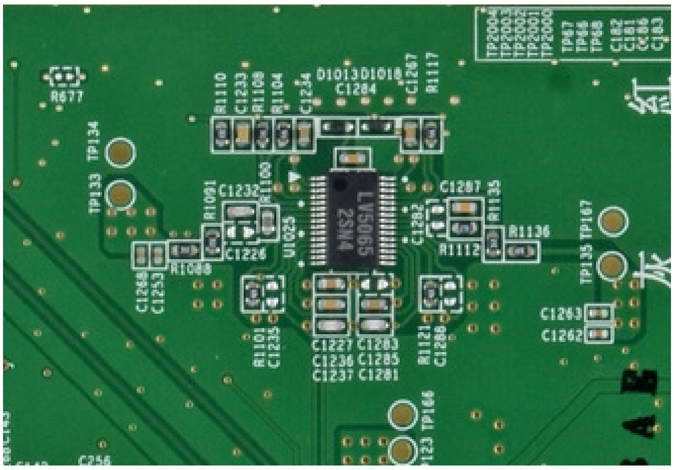

Figure 21: LV065 Voltage controller

- all the tracks have a width which is proportionate to the amount of current they have to bear, moreover there are no right angles on them;

4. Human Computer Interaction

4.1 Wii U

Wii U has 4 USB ports (two more than its predecessor *Wii*), and each of them can also be used to recharge the GamePad. This allows the user to connect more devices such as External Hard Disks or USB pens containing photos, games or music.

A failure in the Wii U design is that 2 GamePads are supported, but this feature has been never used since no games have been developed including the possibility of using 2 GamePads.

4.2 GamePad

The first thing that the GamePad displays when you try to connect it to your TV, is a brief questionnaire about your TV model. Indeed, with a dedicated button on the Wii U's GamePad, the user can control his TV, change the channel and the volume, or view the program guide like a normal Universal Remote. This interesting function makes sense in terms of efficiency since usually the user plays with the Wii U on the same device where he normally watches TV. Since it is common for a player to switch between games and television, having a single device to control everything makes this action simpler.

Some months after the Wii U's release date, Nintendo released a service called *TVii*, a platform that allows to use the GamePad as a Remote Controller for a cable TV (as the stock one yet explained) and for streaming platforms like *Netflix*, *Amazon Prime Video*, and so on. The aim of the service is to widely foster the use of the device (Cri

Figure 22: One of the console speakers

Figure 23: The connection to the console buttons

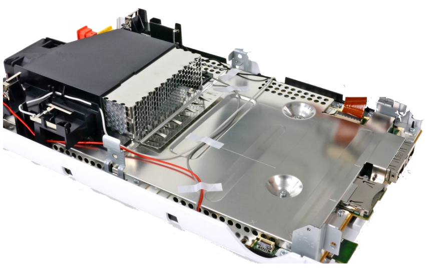

Figure 24: The metallic case shielding the PCB

says: prova a vedere se così va bene), but actually in the User Interface (the virtual one) 27 buttons are displayed at the same time, plus 18 hard buttons are distributed throughout the GamePad (in the front and in the back), making the usability of the service very difficult (the problem is shown in Figure 26).

The GamePad offers four different input types:

- Hard buttons
- Touchscreen controller
- Stylus Pen
- Motion Control

This wide choice can be viewed as an innovative approach to this type of devices or, more probably, a confusing and not so comfortable feature.

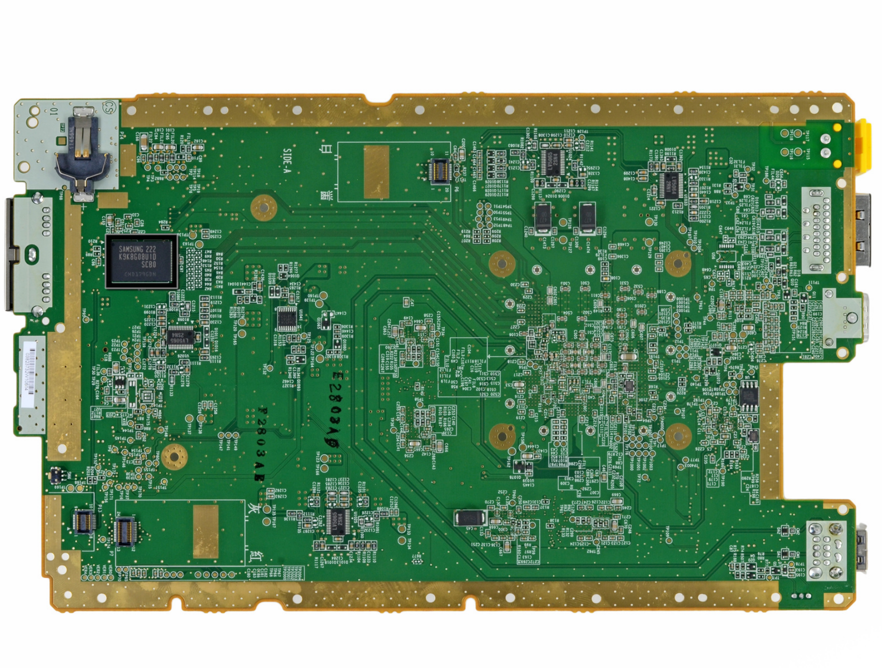

Figure 25: The bottom side of the motherboard PCB

Figure 26: TVii user interface

Figure 27: The TV screen mirrored in the GamePad makes the gameplay very confused

The possibility to have different type of inputs makes the videogames' design more complex, with the result that some games are developed to use most of Wii U's features, while the others use only a little part of them. Moreover, some games (even of the same *Nintendo*), use the TV as a mirror for the GamePad, making the gameplay very confused.

Another critical part in the Human Computer Interaction analysis is the battery life of the device. The device has an autonomy of (on average) 4 hours and considering that the GamePad can be used both as Universal Remote or to play games, 4 hours are definitely not enough.

5. Conclusions

The Wii U console is a very complex device with several subsystems and components. Its power and thermal management system is detailed and well structured, even though the battery performance could be improved. The Electromagnetic compatibility is standard but well functioning, and attention has been payed also on the timing aspects (from Figure 1 it can be seen how some tracks form serpentines in order to be lengthened and allow an on-time signal passage). Finally, the Human computer interaction is not one of the best that Nintendo designed, but the concepts and ideas on which it was based had some potential.

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