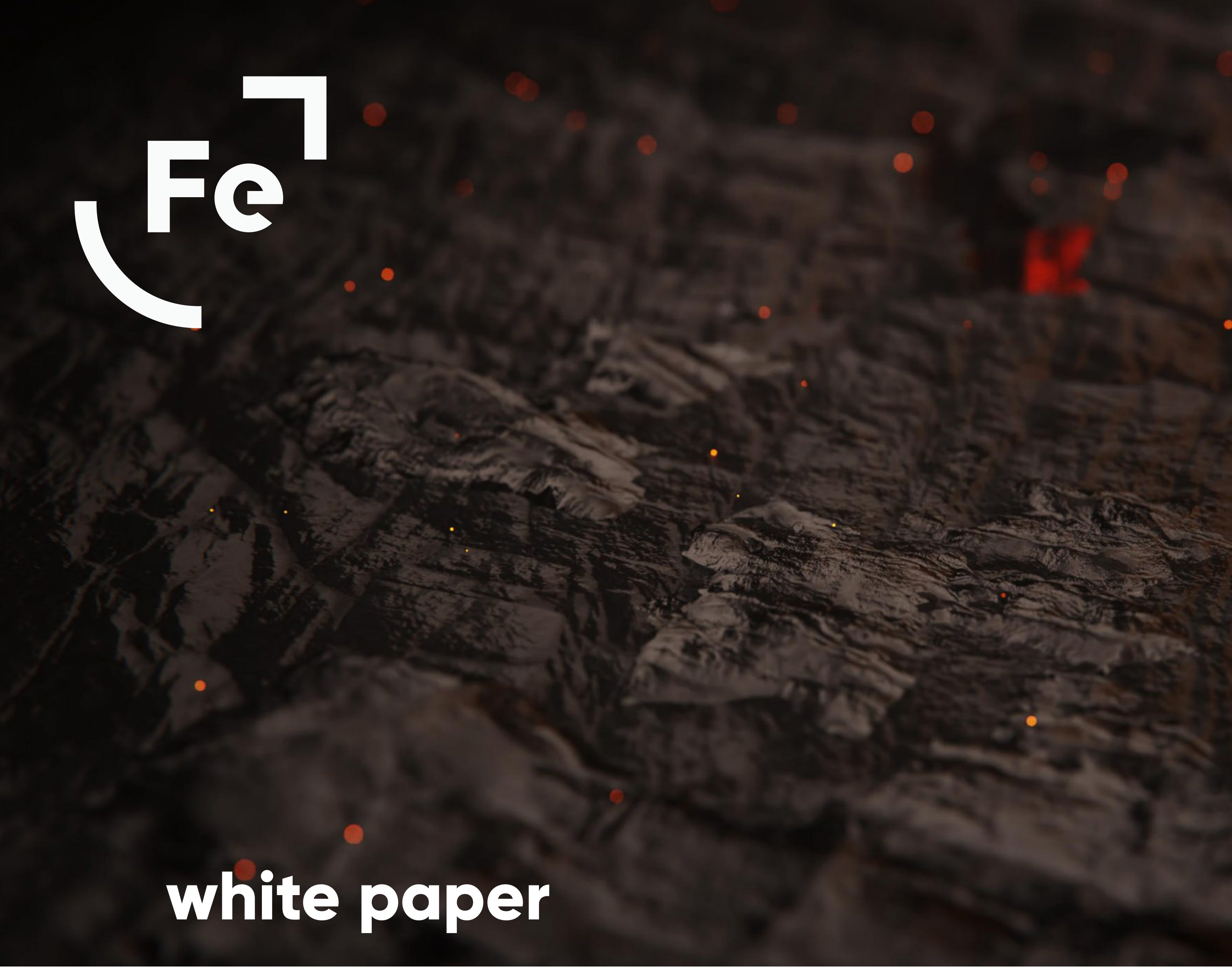

white paper

Ferrum **HYPSOS**

EISA AWARD
Best Product 2021-2022
HI-FI ACCESSORY
Ferrum Hypsos

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Content:

Designing modern audio power supply system
short history of HYPSOS

Sometimes a power supply and its quality is taken for granted in many audio devices. However, it cannot be forgotten, that the power supply is an integral and crucial component of all electronic devices, not only in those dedicated for reproducing sound. No matter, if we are talking about headphone amplifiers, DAC's or even streamers, the power supply of those devices will affect how the final system will sound.

Reaching full potential

In hi-fi audio, a proper power supply system is necessary for unleashing the full potential of the device. For example, when an output stage of a headphone amplifier is driving its output to some voltage, the power supply must be able to deliver sufficient current and to reach desired voltage on the output. This current drawn by the headphone amplifier will cause some disturbances in voltage of the supply rail. Those disturbances can get on the output of the amplifier and distort the output signal. Care must be taken to lower these changes caused by the current drawn from the power supply to the lowest possible level.

Minimising disturbances

At first glance a power supply for audio devices seems to be easy to design, because the current change drawn from the supply is limited in bandwidth for something around 200kHz (even for Hi-Res audio). However, modern music is stored mainly in digital form, so we need devices, which convert the data from its digital form to the analogue counterpart. Those devices have their digital sections, which draw transient current from the supply, which are far beyond 200kHz in bandwidth. Analog and digital sections in such devices have separate power supplies, but those separate supplies are supplied by one main supply. In such case the voltage ripple caused by the digital section may appear on the input of the analog section of the power supply and propagate further on the supply rail of the analog section. Therefore, we need the power supply to be able to respond quickly to these transient currents, and to minimise the voltage disturbances caused by this current.

Proper cabling

When we were designing HYPSOS, we wanted it to be able to respond really well to this 'digital' current. However, in an external power supply, you need a cable to deliver power to the load. This introduces another problem. The cable is not ideal, it has its own parasitic resistance, inductance, and capacitance, which forms resonance circuit. Some of you may know, that those parasitic elements of cable are quite low, so it may seem that this will not be problematic. However, in many devices on the power supply input, there is huge bank of capacitors. This enormous capacitance is driven by some resistance and inductance of the cable and unfortunately this forms a low pass filter. Bigger capacitance means filter with lower cut off frequency, but on that topic I will focus later. First, I will discuss the effect only of the resistance of the cable.

4T Remote Sensing

If we want our power supply to maintain its output voltage over wide range of currents, we need some sort of negative feedback. This feedback measures voltage on the output of the power supply and adjusts the voltage which is steering the output section to keep the voltage on the output steady. Now comes the main problem. Most of the power supplies measure the voltage directly on its output, so it's able to precisely set the voltage on its output before the cable, not on the other side of it! If the cable has its own resistance, the voltage on the other side of the cable will not be regulated precisely. Let's assume, that our cable has 50mOhms of resistance and current flowing through it is changing from 0.5A to 1A. This scenario is quite possible in most DAC's. The voltage on the one wire of the cable changes from 25mV to 50mV, but it is only voltage drop on the one wire. The full path consists of two wires, because we need to give a way for returning current. Therefore, the full voltage drop on the cable changes from 50mV to 100mV. This is a significant difference, and this disturbance will appear on the supplied load. For this reason, in HYPSOS we are using remote sensing, which is basically a Kelvin connection. This incorporates four wires, two for delivering current to the load and another two for measuring voltage directly on the load. This gives us an opportunity to get away with cable resistance, because now we are measuring voltage directly on the load, so the power supply stabilises the voltage on the load and compensates for the drop on the cable resistance.

Now the voltage difference on the load depends mainly on the gain of the error amplifier of the power supply. If it has enough gain, the voltage drop difference between 0.5A and 1A current drawn form the supply can be lower than 10mV.

Disastrous effects of parasitic elements of the cable

Now we can get back to the other parameters of the cable. Its capacitance in most cases can be neglected because the capacitance on the power supply output and on the input of the load is much higher, so capacitance of the cable does not have much influence. However, this cannot be said about the inductance of the cable. Inductor is an element, which resist the changes in current that is flowing through it. The higher the inductance, the more the inductor will resist to change its current. This causes huge problems when the load tries to draw surge current. Even though we have remote sensing, this is not solving the problem, because the error amplifier has limited bandwidth and it will not be able to compensate for the lag in current, which introduces the inductance of the cable. You may ask "what if the error amplifier was fast enough and it would be able to compensate for this lag?" Unfortunately, here comes the low pass filter, which is created by the inductance of the cable and the capacitance on the input of the load, which may be quite high in some devices. This low pass filter introduces some phase shift in the feedback network of the error amplifier, and this can cause oscillations on the output of the power supply. If those oscillations appear in the audio band this will have disastrous effects on the supplied device or can even destroy both the device and the power supply (this one is regardless of the frequency of the oscillation). Therefore, now it might seem, that this enormous capacitance is just limiting the supply performance, but it is not so simple. Everyone, who had designed some voltage regulator, knows that giving more capacitance on the output of the regulator will improve its transient response. (Of course, the parasitic series resistance of the capacitor must be considered, otherwise it may end in the oscillation of the regulator, however this is really complicated topic and we will leave this in this article). This capacitance slows down the regulator itself, but when the surge current occurs it starts to supply current for the load, so the voltage drop on the output is reduced. This capacitance on the input of the load may help, because when the inductance of the cable is blocking power supply from delivering surge current, the capacitance near the load starts to supply the current, when the power supply cannot.

Low inductance cables

The problem is in the cable itself because the inductance of the cable separates the supply from the load in case of transient. In this situation the only solution is to reduce the inductance of the cable because this allows the amplifier to be faster and regardless of the capacitance on the input of load, to be stable and able to respond for surges in current faster. For this reason, we use wide Canare cables, which have low inductance.

Linear supply vs switching supply

Next thing we wanted in HYPSOS was the universal output. What I mean is the wide range of voltages, which HYPSOS will be able to support. Most of audio devices have DC supply voltage in the 5V to 30V range, so this was basically our goal. We wanted our supply to have the lowest noise possible. Of course, the easiest way to do this is the linear regulator. However, with such wide output voltage range, when supplying low voltages, we need way more current to supply the same amount of power to the input. This introduces huge amount of voltage on the regulator and makes almost all the power to be dissipated in the regulator. This is unacceptable, because the heatsink would be comparable in size to the moon and still it would be extremely hard to not overheat the device. Therefore, we needed another solution. To lower the heat dissipation, the only solution was the switching mode power supply. However, in this case keeping the noise down is much harder task to do. Nevertheless, this is not impossible, it just requires much more attention to pick the correct topology of switching power supply and is highly susceptible for bad layout of components. Again, the parasitic inductance is the cause of almost all problems. In fast switching current paths inductance will cause the conducted and emitted noise rise. Just as with the cable on the output of power supply, minimising the trace inductance between most crucial paths in switching power supply is critical.

“Quiet” switching controller

Therefore, we are using controllers, which have internal switches and its own ground plane. This gives the shortest possible path for switching current. Furthermore, this chip has integrated input capacitors, which supplies the current for the fastest part of the surging current and reducing the EMI. To reduce the ripple on the output we are using the stepdown converter, which has much lower output ripple, compared to other topologies. This is because the step-down converter has an inductor on its output in contrary to other converters, which have a diode. Diode on output has highly unlinear current, which needs to be filtered by output capacitors, while inductor resist to change its current quickly, so the output capacitors have much easier work to do, to keep the output voltage ripple low. We are using input and output EMI filters, to localise the switching current only around the switching power supply. Apart from that, we are using double EMI filters in the IEC inlet for further reduction of noise, which could be induced into our device from outside. However, we should go back to output voltage. Our switching power supply is working at 1MHz frequency. This keeps the switching noise far from audible range, however this does not mean, that it should not be suppressed. This noise can be modulated by amplifiers again in to audible range, so it must be kept as low as possible. Output EMI filter is not actually working on this frequency, so we are using another LC filter after it, to suppress the noise in megahertz region. However, this LC filter is not only affecting the ripple on the output of the supply, it introduces some phase shift also. This switching power supply has its error amplifier with limited bandwidth. If we just measure the voltage after the LC filter it may end up in oscillation. If we measure the voltage before the LC filter, the circuit will be stable, but it will not be able to respond quickly for transients (because the inductor will separate it from the supply) and the output resistance will be higher, because of the parasitic resistance of the inductor. This will cause a voltage drop with changing current.

Hybrid joining advantages from both topologies

Our final topology to solve this problem is the reason, why our supply is called HYPSOS, because this is a hybrid power supply system. This solution is quite known, and this incorporates the switching power supply followed by linear regulator. We have designed our own low dropout regulator, based on NMOS transistor. It has dropout low as 300mV with 6A output current, so we were able to set the voltage of the switching power supply below 1V over the voltage on the output of the LDO, to keep the heat dissipation in LDO to minimum. This gave us opportunity to have the low noise, stable switching power supply with additional LC filter, at the same time maintaining fantastic load regulation, because this is maintained by the LDO, which has its own differential error amplifier, which serves as remote sensing part. Furthermore, because we have two regulating stages, the ripple coming from bridge after transformer is almost completely attenuated.

SST - Sweet Spot Tuning

As wrong as it sounds, changing the supply voltage may alter the final sound signature of the device. For an instance raising the voltage on the input of the switching power supply lowers down the current, which is drawn by it, so modulated current which is drawn is smaller in the amplitude, so this can lower down the noise on the supply line. Raising the voltage on the input of the linear regulator gives it more voltage reserve and many of those linear regulators better reject the noise from the input in such circumstances. Knowing that different voltage level on the power supply input may change how the device will behave, we wanted to give everyone opportunity to tweak how their devices will sound. Therefore, we have added SST. It lets you to change the voltage in the region specified by the manufacturer of the device in 0.1V steps. If the permissible voltage region isn't specified by the manufacturer (or you are in the manual configuration of output), you are allowed to change voltage in +-5% range from the nominal voltage. This is protection from setting the wrong voltage, which might destroy your device.

ATVA - Automatic Transfomer Voltage Adjust

In our EU/US version of HYPSOS we use automatic changing of the Transformer setting, to adjust the voltage on the output of the transformer regardless from the input mains voltage. When HYPSOS is being turned on the transformer is always set for EU mains. The voltage on the output of the transformer is measured and if it is too low (which means US mains) the transformer is switched to US setting. This procedure is done in every startup. This design rejects the typical mains switch problems, which was connecting the device in US setting to EU mains, which blows the fuse.

EOVPS - Electronic Output Voltage Polarity Switch

There are some devices, which have flipped polarity on the output of the supplying cable. They have hot wire connected to the outer barrel and ground connected to the inside barrel. In HYPSOS you don't need to buy special cables or polarity converters to switch polarity. In manual configuration you can just select needed output voltage polarity. However, beware, if you choose wrong polarity and your device is not protected from such event, you may damage your device.

SSM - Spread Spectrum Mode

Switching mode power supply, which we are using have spread spectrum mode. When this mode is activated, the switching frequency of the converter is modulated to 20% of its nominal frequency. This technique lowers down even more the EMI, because the spectrum of the generated noise by the switching nature of the regulator is spread in spectrum and the harmonics of the switching frequency are lower in magnitude. In some sensitive devices it may completely change the behaviour of the device.

Overcurrent protection

We have incorporated quite sophisticated overcurrent protection in HYPSOS. First of all we have two maximum permissible values of output current. First from them is the current in pulse, which is 9A. Therefore, with the 30V output in pulse we can deliver even 270W of power. Next one is the maximum continuous current. This one is a little bit trickier to explain because it is more complicated. First of all, information about the output current and voltage is sent to the microprocessor. The microprocessor monitors the output current and voltage and even calculates the power delivered to load. All those parameters let us protect HYPSOS well. However, let's get back to how it works. Maximum continuous output power is 80W, so this means that lowering the output voltage raises the maximum output current, because current related to voltage and power is: $I = P/V$. However, there is absolute boundary of output current, so there is voltage below which we aren't able to deliver more current. This absolute boundary is 6A and this is maximum continuous current with voltage below 13.3V. Therefore, the maximum output power lowers down with the voltage below 13.3V in this manner: $P_{out}[W] = V_{out}[V] * 6[A]$. Microprocessor checks how long the current above 6A is applied and if this time exceeds 3 seconds it shuts down the output. However above 13.3V the limit treshold changes to $I_{out}[A] = 80[W] / V_{out}[V]$.

Overvoltage protection

Apart from measuring the output current, we are measuring the output voltage on the load. However, in the case of cable faults (or the power supply itself) we need to react properly. For example, when the two wires measuring output voltage are shorted (without shorting the supplying wires) the LDO gets the information, that the voltage on the output is zero, even though it is not true. However, this is information for LDO, that it should raise its output voltage and it will do it until there is no voltage for driving the output transistor. Such event may end up in exceeding the maximum supply voltage of the connected device and permanent damage of it. Therefore, we are checking if there is some substantial current and the measured voltage is near 0. When such event occurs, the output is disconnected to prevent connected device from overvoltage.