UpTone Audio — USB REGEN explanation.   August 2, 2015

To explain how the UpTone Audio USB REGEN works and why it is so effective with such a wide range of USB input DACs, we first need to define some technical terms and some problems inherent in USB audio interfaces—hopefully in not-too-technical language:

PHY: PHY is an abbreviation for the electronics that interface to the physical bus. PHYs exist in most every type of data interface (Ethernet, FireWire, optical, etc.) A USB PHY serves two primary functions: to convert the analog voltages used on the Data-plus and Data-minus wires into a digital format normal logic can understand, and convert the high speed one-bit-at-a-time serial data stream into a slower parallel set of wires to be sent to the USB protocol engine (XMOS processor, FPGA with USB core, etc.). The lowly PHY chip is actually a tremendously noisy and complicated device containing several PLLs and clocking at various phases—and there is no such thing as an optimized-for-audio PHY. The PHY part of a DAC’s USB is highly susceptible to the condition of the USB signal, its "Signal Integrity" (SI).

SIGNAL INTEGRITY: A high-speed USB signal runs at 480 mega bits per second, which is fairly high. SI is comprised of the rise/fall times of the signal edges, amplitude of the signal, noise sitting on top of the signal and jitter of the edges. Variations in any or all of these can decrease the SI. The computer determines this initially, and then it can get significantly degraded by running through cables and connectors.

The decrease in SI can be so large that it becomes difficult for the PHY to determine the actual bits. Thus the PHY contains several methods used to pre-process the analog signals in order to make it easier to determine the bits. When the SI is very good, the PHY can turn off the pre-processing steps and easily determine the bits. As the SI degrades the PHY turns on different parts of the pre-processing as needed. Each of these steps takes a fair amount of power to operate, thus creating noise on the power and ground planes. The more processing the PHY needs to use to determine the bits, the more noise is generated. Thus part of the packet noise is directly related to the signal integrity of the incoming signal. The higher the SI, the lower the noise.

PACKET NOISE: In a DAC the data packets coming in on the USB bus are not continuous—there is significant time in-between each packet. Thus the processing of these packets produces noise on the power supply and ground plane that come in bursts, and we refer to this as "packet noise". Since the rate of USB packets is 8KHz there are strong components of this noise in the audio band. This noise can cause jitter in clock oscillators, re-clocking flops, and DAC chips. It can also go directly into noise on the output of DAC chips.
Part of this noise is determined by the USB protocol engine (chip after the PHY) and is going to be constant for a particular DAC.

POWER DELIVERY NETWORK (PDN): In order for a power supply to properly respond to instantaneous load variations, it needs to have a low impedance over a very broad range of frequencies. For digital audio this is from low Hz to hundreds of Mhz range. The entire supply flow from mains AC to board layout and capacitors on the board play a role in getting this right. The process of frequency optimizing the PDN is something that is done in expensive high-speed network equipment, but is almost never done in consumer products, especially audio equipment. (And our experience with the REGEN points to this being quite important for digital audio.)

Okay, now that some definitions and issues have been set forth, let's look at how the UpTone Audio USB REGEN addresses them.

To recap the issue:
The lower the signal integrity (SI), the harder the PHY has to work, which produces greater packet noise. If the SI is very good, the packet noise from the PHY is less than that from the protocol engine. As the SI degrades the packet noise from the PHY can dominate.
Again, the packet noise consists of two parts: noise from the USB protocol engine and from the USB PHY. The protocol engine noise does not depend on the input signal quality, just the data, so its impact is always going to be the same no matter what is done with the input. The PHY is the part that actually connects to the electrical signals on the bus, ITS contribution to packet noise IS dependent on the quality of the input signal.

It is very important to keep in mind that all this is what happens INSIDE the DAC by its own operation, it is NOT noise on the USB bus that is somehow getting into the DAC as is commonly thought.
At this point there aren't any DACs that have been specifically optimizing their USB inputs for SI and impedance match, it's too new as a specific concept to design to. But the best DACs do optimize this to some degree, whether by trial and listening or as a by-product of optimizing for something else.

So tell us how the darn thing works already!:

The REGEN is at its core a single-port USB 2.0 hub. All hubs actually contain two USB interfaces and a full-blown USB protocol engine. It is not just working at the analog level, it is actually receiving the data from the computer, putting it in a buffer and retransmitting (and the other way for the packets from the DAC).
It uses a selected USB hub chip to create a new USB stream to deliver a very high signal integrity to the DAC's USB PHY, thus decreasing the PHY's contribution to packet noise. It is called "REGEN" since it completely REGENerates the data signals that cables are messing up—it's not just a re-clocking. Because it uses clean power and a low jitter clock, the output of the hub has low noise and low jitter. To be most effective, and to maintain best signal integrity and ideal impedance matching it is best positioned right at the input to the DAC, thus its small size, low weight, and included male>male USB 'A'>'B' adaptor.
The result is that the PHY in the DAC doesn't have to use any of its pre-processing circuit arsenal so the packet noise is as low as it is going to get.

Does the REGEN eliminate the need for a good USB cable and other computer optimizations?:
No. The hub chip inside the REGEN has its own PHYs and protocol engine, which themselves generate packet noise on ITS power and ground planes. So the REGEN itself is also sensitive to the SI of the signal fed to it, which is why good USB cables and specialty USB host boards feeding it still make a difference—maybe just not as much. A lot of time was spent on the design and board layout to minimize this packet noise but it is still there. The impedance of the "Power Delivery Network" (PDN) over a broad range of frequencies determines the amplitude of the packet noise produced by the hub chip. The REGEN's frequency optimized PDN is what makes it such a good sounding source.

The ideal solution would be to figure out how to prevent all this noise from crossing out of the USB input system and getting into the DAC chip and clock. Unfortunately this is really tough and nobody has completely figured out yet how to do so. Thus every DAC ever built will have some level of susceptibility to external influences, some more some less.

The question everybody asks then is:
Well what about DACs that have full galvanic isolation after the USB system and re-clocking on the DAC side? Unfortunately USB input noise of all sorts still makes it through to some extent and reaches the DAC master clock. Exactly how this works is complicated, John Swenson has written in-depth about this elsewhere The upshot is that neither galvanic isolation nor re-clocking completely get rid of it. They help attenuate it some, but don't get rid of it.

The REGEN's secondary function is to ignore the 5V USB bus power coming down the cable from the computer (or other host) and to provide—to DACs that require it—a very clean and isolated 5V supply. The REGEN has a separate ultra-low-noise regulator for this. (For DACs that don't use the 5V wire, that regulator in the REGEN is not used for anything.)

Lastly (unlike another hub-chip based device out there), the UpTone REGEN uses a 4-layer board, primarily to allow a proper impedance match. With a standard thickness 2-layer board it is impossible to attain a proper impedance match to the hub chip. The pins on the chip are small and close together, this necessitates very thin board traces. With a two layer board the distance between ground plane and these traces (this is called a differential micro-strip configuration) produce an impedance that is much greater than the spec. With a 4-layer board the ground plane can be much closer to the top layer, and that allows for appropriate impedance with the very narrow traces. The REGEN also uses surface-mount USB jacks that allow for appropriate trace width and spacing to continue the impedance matching through to the USB jacks. The result of this is that there will be very minimal reflections at the REGEN side. Even if the DAC does not have good impedance matching—which is pretty common and which WILL cause a reflection at the DAC end—it will be absorbed at the REGEN because of the proper impedance matching.