An Optical Bridge for Conducted RF Noise Isolation

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Introduction

To satisfy the need for higher fidelity audio reproduction, a digital audio upsampler can be used to increase the apparent resolution of the original music. The upsampler accepts standard resolution audio and outputs a much higher resolution stream by applying proprietary algorithms - mapping a curve onto the music data to interpolate intermediate values. An upsampler is typically productized as either software running on a CPU in a standard computer or an appliance device that uses a dedicated FPGA. The CPU approach provides advantages in cost and flexibility while the FPGA approach benefits I/O and utility. Each approach is equally performant and is designed to interface with a DAC (digital-to-analog converter) via USB, I2S, S/PDIF or other digital interfaces.

To achieve the highest level of music fidelity, the upsampler performs many calculations for each input audio sample being processed. In the case of a normal CD quality input file, 44,100 samples per second need to be processed and each interpolated output sample may require many hundreds of thousands of input samples by the upsampling algorithm. To achieve this performance, the upsampler's compute platform typically runs at high frequency - hundreds of MHz for a highly parallel FPGA design and at a high consumption of CPU cycles for a Ghz clocked CPU design. Add to this the need for a commensurately high rate of memory and I/O operations. All this activity generates large amounts of radio-frequency (RF) noise - electrical disturbances that emit from the components and power through printed circuit board (PCB) traces and out through the signal and power connections. Some is even radiated from the upsampler chassis itself via any metallic protrusions that act like antennae.

Product approvals (ie: CE & FCC certification) requires that product meets strict guidelines for emitted radiation so as to not affect the reliable operation of nearby electronics. For an upsampler and all products that operate in the digital domain, any negative effects of RF noise are ostensibly contained by engineering measures to ensure that the bit-processing is always perfect and data is transferred to the DAC without error. There are some conditions that cause digital errors during this data transfer process but they are extremely rare and always caused by pathological conditions - which is not the subject of this paper.

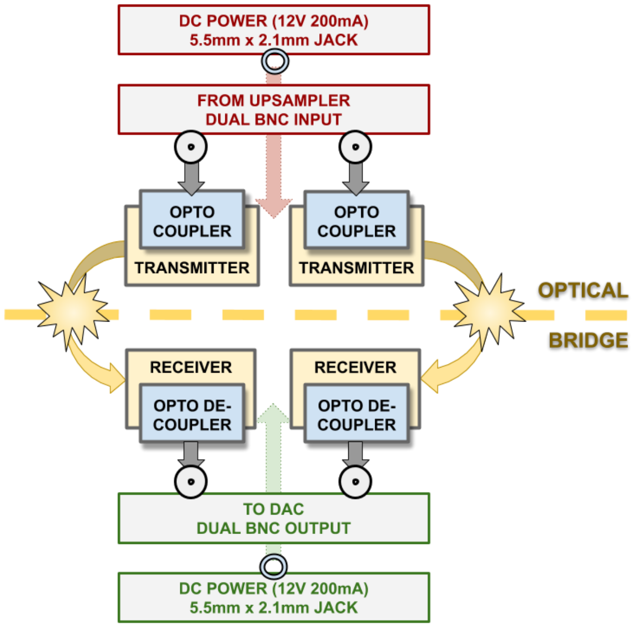
This paper will address the effects of RF noise on the analog domain processing of a DAC and the ways to eliminate it. Even minor variations in the amount of RF noise intruding into a DAC is audible - as evidenced by the changes in transparency one hears as upstream source inputs, power supplies or cables are changed . None of these modifications affects the bitstream; they only alter the character of the conducted and radiated RF noise. How this noise enters the DACs ground plane, upsets the final conversion to analog to manifest into less sound transparency is a complex issue - one only the digital designer may fully understand. However what can be plainly stated is that less RF noise is better: the more isolated is the DAC from all sources of RF noise the more likely you will hear its true potential.

Signal Isolation

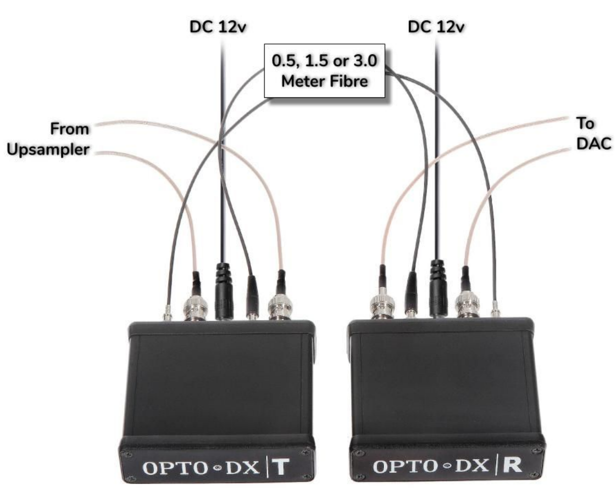
In a two-box system, the physical separation of the upsampler from the DAC is already a great step toward an ideal system configuration. Two boxes isolate the RF noisy intensive digital processing from the (relatively) less intensive processing required for final conversion to analog. The isolation of the connecting signal path, however, is consequent on the galvanic (electrical conduction) isolation between the two boxes. So while a upsampler + DAC system using the S/PDIF interface allows the use of existing, proven technology and inexpensive coax cabling, it is not the ideal. The coax cable may be shielded against external RF noise, however its conductive metal structure still allows the galvanic flow of RF noise through the interior. This can be attenuated with the addition of clamp-on ferrites to target selected frequencies, however, the benefits are limited because of the coax's shielded construction and the wideband nature of RF noise.

A wireless connection (like bluetooth, wifi or cellular) may seem like the best candidate solution but for various practical, technical and product integration reasons a direct connection is still preferred. Hence, for systems already supporting a S/PDIF wired interface, an optical bridge is both the most practical and objectively superior solution. Light involves photons, not electrons, so with optical, there is no mechanism for the transference of electrical current or conducted RF noise.

This whitepaper describes OPTO•DX, a product that implements such an optical bridge to provide complete optical galvanic isolation for the single or dual-coax S/PDIF interface. OPTO•DX modulates the coax signal to optical and back to coax over a short length of optical fibre. It does this without any digital re-sampling or re-clocking - fully preserving the S/PDIF signal integrity and timing (See Note1). OPTO•DX uses high performance RC-LED photonic devices with enough bandwidth to modulate the S/PDIF signal directly. Each coax signal is optocoupled through a transmitter, sent over a tuned length of optical fibre, received and decoupled by a receiver back to coax - a process that adds no additional delay.



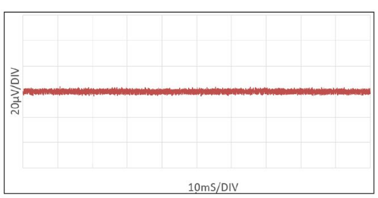
The OPTO•DX transmitter ('T') and receiver ('R') are separated into two boxes to maximize RF isolation. High frequency systems are subject to unpredictable behaviours that fall outside the ideal. A one-box solution may be the preferred packaging but would have introduced the possibility of RF noise coupling (capacitive, induced or radiated) - not the best design compromise to support customers for an end-game. Hence, the two OPTO•DX chassis are physically separable. Further, each chassis is an aluminum Faraday cage and the PCB itself incorporates additional metal shields around all high frequency circuits.



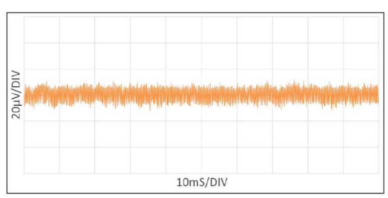
Power Isolation

The insidious nature of RF noise means it follows all conductive paths in the audio chain - including the power path. RF noise generated by digital devices upstream of OPTO•DX may traverse out through their respective power supplies to the wall outlet where it can affect downstream AC powered system components. For this reason, each side of the OPTO•DX optical bridge has separate 12VDC power inputs. This ensures that the S/PDIF input (RF noisy transmitter side) is isolated from the S/PDIF output (ultra low noise receiver (DAC) side). To maintain this isolation, batteries (or highly regulated/isolated power supplies) are an OPTO•DX system's preferred power choice. Batteries provide total power isolation for the optical bridge and a guarantee of total isolation from all AC noise. Although larger audio components like amplifiers, powered speakers or subwoofers have high current needs that may require specialty batteries or DC/AC inverters, the majority of digital devices can be powered by a wide range of inexpensive portable battery packs.

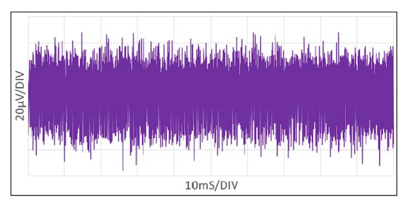
The OPTO•DX transmitter has only moderate need for an ultra low noise power supply. The benefit of lower noise for the transmitter is to ensure a precise optical modulation of the S/PDIF waveform. This is of particular importance for older compatible DACs which may have legacy dual-coax synchronization circuits. Conversely, the OPTO•DX receiver benefits greatly from ultra low noise power because the demodulated S/PDIF coax signal is galvanically connected to the DAC. Its at the DAC that RF noise from any input gets manifested into a reduction in transparency - so lower noise here is always better. Further, as per the diagram below, a LT3045 (or similar) regulated supply provides an even lower noise profile than a Li-Ion battery ...and certainly lower noise than a typical SMPS.



LT3045 Regulated Supply



Li-Ion Battery

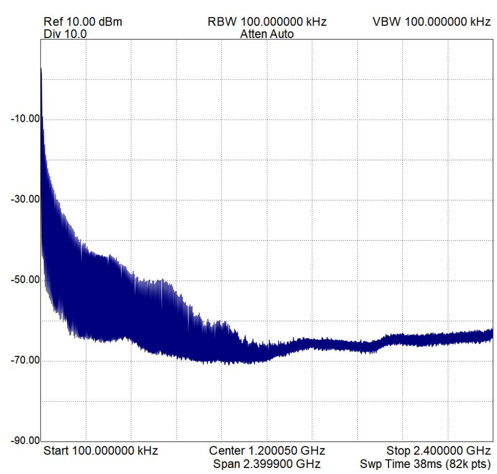


Typical Regulated SMPS

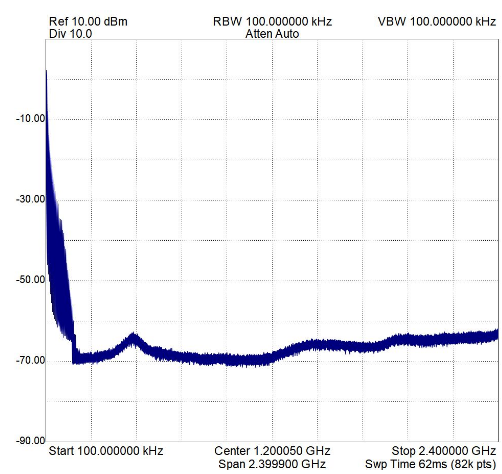
Optical Bridge Noise Reduction

A S/PDIF waveform is train of pulses modulated by the data signal - plus there are irregularities (secondary modulations) affecting the signal amplitude and phase. The latter, phase modulation, is jitter in the timing of the edges of the waveform caused by variations in the clock or signal path of the upsampler. This results in sample timing that skews over time and also creates a modulation of the phase energy at the S/PDIF receiver due to varying pulse widths. Modern DACs are designed to be immune to bit errors caused by jitter and they also show no measured change in distortion during jitter stress tests. However, the reports of a causal, collateral or coincidental audible effect with changes in DAC input source or the upstream signal chain are being investigated and the results will be published. What is certain is that OPTO•DX's waveform modulation is all-analog and does not compound the signal jitter with any re-clocking - hence it cannot correct phase modulation originating with the source signal.

The secondary effect of amplitude modulation on the S/PDIF waveform results in spikes, ringing and ripples. Such modulation is due to RF noise that is internally generated or introduced from signal and power inputs. Also the very character of a digital square wave with abrupt transitions introduces high frequency noise. A 384kHz S/PDIF stream has a bitrate of about 50Mbits/sec meaning an equivalent nyquist bandwidth of 100MHz is required by any modulation or signal path. OPTO•DX takes advantage of this bandwidth limit and the inherent dual-frequency nature of S/PDIF (being multiples of 44.1khz or 48khz) to fine tune the optical modulation so it only passes the intended digital data frequencies and filters all else. This removes the noise induced secondary modulation and the noise caused by the square waveform. OPTO•DX is an optical bridge that passes the S/PDIF data signal and nothing more.



96/24 S/PDIF from Upsampler direct coax signal. Note the energy up to ~1Ghz.



96/24 S/PDIF from OPTO•DX optical bridge. Note only noise floor beyond ~100Mhz

See Note 2.

How well the S/PDIF receiver circuits reject RF noise is DAC dependent however the subjective improvement of a DAC isolated from such RF noise using an optical bridge is readily apparent. When the presentation is DAC-direct to headphones or efficient loudspeakers (without external amplification or extraneous downstream components) the most minute details are laid bare; the music sounds astonishingly real and, in the opinion of the author, the presentation becomes much easier to listen to at louder volumes and for longer periods.

Can the benefit of an optical bridge be directly measured at the analog outputs of a DAC? In other words, is there a measurement such as Total Harmonic Distortion(THD) or Frequency Response that demonstrably shows the audible benefits obtained? In short, the answer is no. Or perhaps not yet. (See Note3). The benefit of RF isolation is audibly real yet the analog output of a DAC that is RF isolated measures very similarly to one that is not. If this is due to the limits of the measuring device, the parameters of available tests or due to the minute nature of the differences is unknown. As some of the most accomplished DAC designers have stated, the ear/brain is an amazing tool that discerns variations in timing so small that they cannot be measured. However to move our understanding forward, the development of such a measurement is imperative and is under investigation by the author.

Conclusion

The need for isolation of DACs from RF noise has been given less emphasis as the desire for access to content has increased the preponderance of streamers, wireless sources, upsamplers and other devices in the digital chain. This has provided the music lover with choice, convenience and control but there has been a lost appreciation of the importance of the analog domain in a digital world. Not all aspects related to sound quality are with regard to the bits. In the pursuit of end-game transparency, it's the conversion of bits to volts within a DACs final analog stage that matters most - and here is where RF noise manifests itself.

Audiophiles understand all this. RF noise compromises the ultimate sound quality possible and is the invisible culprit that must be addressed. Partial fixes are aplenty to provide a mix of RF noise attenuation or alteration - but they only hint at the ultimate sound quality possible with an optical isolation solution. For users with a two-box system of upsampler and DAC connected using S/PDIF, the OPTO•DX optical bridge offers such a solution. Total optical galvanic isolation guarantees an RF noise-free direct signal to the DAC so that the audiophile can enjoy the sonic benefits of a modern digital chain without compromise.

Note1: *It's important to not confuse RF noise issues with signal processing on the bitstream. Digital manipulations such as volume, sample rate conversion or equalization performed prior to upsampling* <u>*do*</u> *alter the bitstream and will cause degradation to the sound by reducing the dynamic range and introducing round-off errors. This is not remedied by OPTO•DX and must be resolved by correcting the settings for music playback at the source. The upsampler should only process the original recorded music data and any digital manipulations should be carried out at the highest audio resolution possible - either at the output of the upsampler or within the DAC itself.*

Note2: *Signal measurements were performed using a Signal Hound SA124 Spectrum Analyzer using Spike V3.3.1 software. Upsampler tested was the Chord Electronics Hugo M Scaler. Signal input to the SA124 was 75ohm terminated factory standard coax cables direct from the upsampler or through the OPTO•DX bridge over a 0.5m optical patch cable. All measurements were averaged 32-times. Upsampler was powered with the factory SMPS; OPTO•DX was powered with dual PowerAdd Pilot Pro 2 battery packs.*

Note3: *Tests were performed using an Audio Precision APx525 Signal Analyzer using V4.5 Software. Upsampler tested was the Chord Electronics Hugo M Scaler. DACs tested were the Chord Electronics Hugo 2 and Hugo TT2. Signal input to the APx525 was 75ohm terminated factory standard coax cable. OPTO•DX was at factory configuration and powered with dual PowerAdd Pilot Pro 2 battery packs.*