Total DAC Isolation From Radiated RF Noise

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Introduction

The effects of radio frequency electromagnetic interference (RF) on analog audio electronics are well known. Magnetic transducers (loudspeakers) get perturbed to produce hums and rumbles in sympathy with RF frequencies in the audible range. Amplifiers with toroidal transformers dont like any RF energy. Systems with poorly filtered inputs and outputs allow the intrusion of RF to affect the analog signal processing. AC power and ground lines may carry high frequency digital noise to cause all manner of audible effects to connected equipment..

As systems' become more resolving and efficient, they get more sensitive to these effects - which are audible despite electrical insulation, transformer isolation and RF shielding measures. These effects can also manifest across free air between components as connectors and chassis edges act as antennae to encourage reception and transmission of RF. This is why audiophiles keep sources of RF well away from analog electronics - and they even avoid crossing analog signal lines with digital or power cables.

In a digital audio playback system a chain of digital components is followed by analog electronics. Somewhere along this chain there is a delineation between the digital domain and the analog domain - meaning the focus changes from processing digital bits to presenting synchronized and accurate analog voltage levels. Components in the digital domain are the primary sources of RF noise yet they are also designed to work perfectly in the presence of RF. Analog domain components, however, are anathema to RF and this is no more important than in a DAC where the digital and analog domains are in close proximity.

A one-box DAC with integrated upsampling and D/A stage is a more RF problematic design than a two-box DAC system. A one-box design introduces the risk that RF can enter from inputs or is generated internally and conducted (via inductive or capacitive coupling) to the analog. A two-box design separates the inputs and upsampling processing from the final conversion to analog so has a much improved isolation. In both cases, an optical signal input is best however even then, a one-box DAC cannot have the RF rejection performance of an optically isolated two-box design.

The audible effects caused by RF noise are difficult to objectively measure yet are simultaneously subtle and obvious. Suffice it to say that they manifest as a reduction in musical transparency and increased listening fatigue. This paper examines the corollary between RF noise and a DACs sound quality and demonstrably confirm that it is the culprit behind most (if not all) of the issues that plague the audiophile.

RF•STOP, an RF Isolation chamber, used in combination with an optical signal connection and battery based power, is proposed as a total solution for isolating a DAC from the effects of RF noise.

Following the Evidence

In an optically isolated DAC there is no way for RF to be conducted via the Toslink or OPTO•DX signal. In this case the digital domain is RF isolated from the analog domain. This is an objective fact: light is comprised of photons and photons do not conduct electricity. Further, if the components are on batteries there is no other conductive path for RF noise on power either. Such an isolated DAC should be immune to changes in the upstream digital domain - at least those that are incidental to the bitstream. Changes like a power supply, playback source, or USB cable on a digital component should be inconsequential to the DAC and have no audible effect. Yet such changes do, in fact, change the sound and vary the transparency to a degree dependent on the DAC and configuration. Somehow, the effects produced by these changes must be circumventing the optical signal isolation and battery power isolation.

Are these audible changes due to a corruption of the signal? No, the bits are unchanging and perfect. Is it jitter or phase modulated noise? No, while RF noise may alter the S/PDIF timing, modern DACs are immune to source jitter. Is the modulated optical signal itself carrying noise? No, modern DACs have filters on optical inputs and optical modulation itself filters the signal. Is it USB PHY noise getting into the S/PDIF signal? No, there are no spikes of energy noted. Is RF noise somehow riding on the optical cable sheath or jacket? No, optical cable is a totally non conducting construction.

So, what's going on? A well intentioned audiophile public recognizes that RF noise is somehow involved but the cause and effect is proffered as being mysterious. Could radiated RF be the the invisible culprit affecting the DAC at a distance? Audio components are not designed to be antennas but even the best engineering cannot prevent chassis edges and connectors from radiating some amount of RF energy. This is emitted in all directions with an attenuation according to the Free-space path loss formula which is proportional to the square of the distance. Is RF is able to travel the few meters with enough energy to penetrate the chassis and internal circuits of a DAC (let alone affect the sound)?

The author took it upon himself to test this hypothesis and demonstrably confirm or deny radiated RF as being detrimental to a DAC. The tests required a high quality spectrum analyser, antenna and a customized RF isolation chamber. Objective RF noise level measurements combined with subjective listening tests would be performed with a mix of component chain configurations. The intent was to follow the evidence and take inspiration in the words of Sherlock Holmes (Sir Arthur Conan Doyle) *"When you have eliminated the impossible, whatever remains, however improbable, must be the truth."*

This paper confirms that radiated RF is a real phenomenon with energy levels easily measured across meters distance. Also confirmed is that better sound quality is always accompanied by less radiated RF

noise. Moreover, it appears to be a causal effect: RF isolation eliminates dependencies on the DAC's sound quality with changes to the isolated digital chain.

RF•STOP Isolation

An RF•STOP isolation chamber is precision welded aluminum enclosure with RF absorbing liner that prevents the ingress or egress of RF at 90dB attenuation performance. Components placed inside RF•STOP are thus fully isolated from external RF and do not radiate RF to the outside. The only access for signals in or out is through a waveguide port - a shaped metal conduit with openings smaller than the frequency limit wavelength. Through this port only non-galvanic (optical) cables are allowed to pass. A highly filtered AC interface allows component power without undermining the isolation performance. The chamber has a latched lid for equipment access and air vents (also waveguide shaped) for passive or active airflow.

The RF•STOP approach of isolating the digital domain components rather than isolating the DAC's D/A stage and analog domain components are due to practical considerations. Isolation of the analog domain would require a room sized chamber or tent since the listener is connected to the analog domain via galvanic conducting cables to transducers (headphones or loudspeakers). Such a large structure would be mesh-based and would be significantly compromised by weaker RF isolation performance and the need to allow convenient human-size access. Further, the user needs playback control with the digital domain components - a mobile phone or other handheld wifi device. If the user was RF tented, the wifi or cellular signal would be inaccessible by the user. So by isolating only the digital components with RF•STOP, the largest sources of radiated RF noise are fully contained and the user retains their convenient access to wireless networks.

Radiated RF & Sound Quality Testing

The following tests are not laboratory certified. They were performed by the author using best practices with a sample average to ensure validity. No test determines if the RF energy measured actually penetrates the DAC or other analog components. However, the measurements act as a corollary for the observed sound quality. That is the following are validated in the tests below:

1. The subjective sound quality is better with less measured RF energy at the DAC (and visa versa)
2. The subjective sound quality is invariant when RF isolated digital components change
3. The subjective sound quality varies when the same changes are made without RF isolation

All measurements were made inside a larger RF isolation chamber to remove the signal noise caused by ambient microwave/satellite radio communications and household/urban sources. In the case of sound quality listening tests, the larger RF isolation chamber was removed and the DAC selected was tested using both headphones and loudspeakers - in both cases being driven directly from the DAC (no intervening amplifier).

Tests

Ambient Zero	Determine baseline RF in a rural environment and isolation chamber
Distance	Determine the attenuation of RF emissions based on distance.
Power Supply	Determine how power supply changes RF emissions & sound quality
Input Type	Determine how input type changes RF emissions & sound quality
Source Component	Determine how source changes RF emissions & sound quality
Future Tests & Correlates	Component procurement and test setup required to measure RF emissions and sound quality correlates for: ● USB Cable Brand, Quality, Clamp-on Ferrites ● Specialized/Shielded Coax Cable ● NUC OS Settings & Playback Software Configuration ● Windows OS Settings & Playback Software Configuration ● Measure RF emissions from battery sources & SMPS alone ● Determine exactly at what distance the energy from the RF emissions reaches the noise floor of the analyzer ● Double blind listening tests with a variety of subjects/music ● Determine the effects of environmental RF on sound quality These tests will be performed in due course and published in an update to this whitepaper.

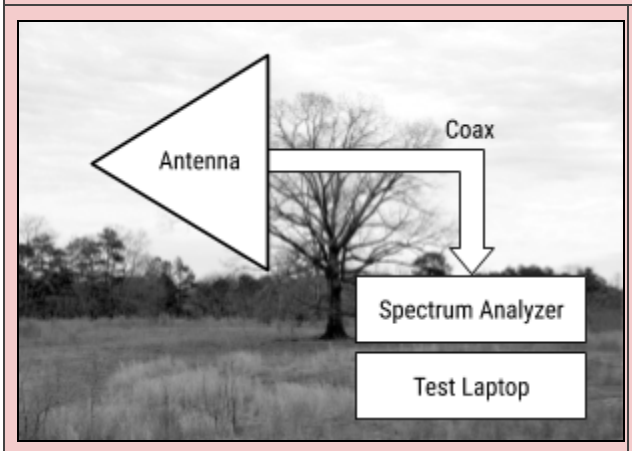
Test Equipment

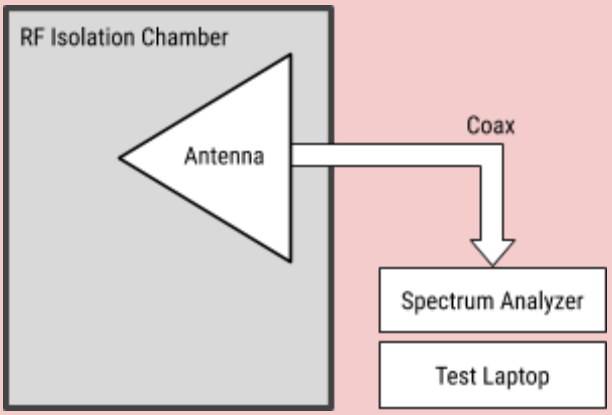
Spectrum Analyzer	Signal Hound SA124A
Antenna	Electro-Metrics EM-6952 (calibrated)
Test Laptop	Lenovo Thinkpad P7, Windows 10, Spike Version 3.3.1
RF Isolation Chamber	Customized AudioWise RF•STOP Isolation Chamber (Larger interior)

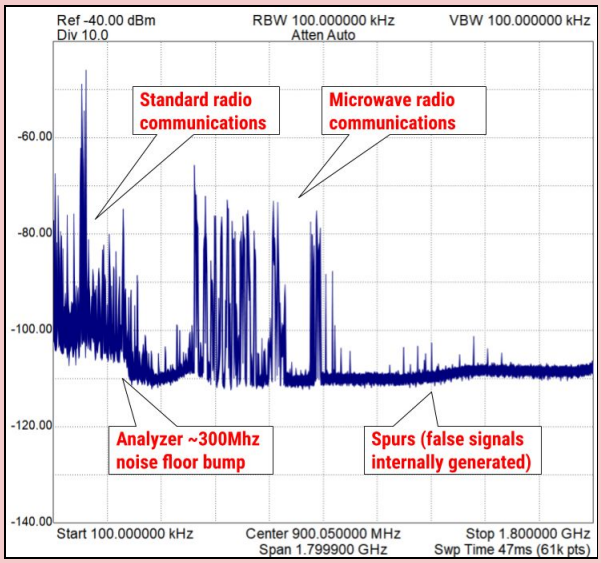
Upsampler	Chord Electronics Hugo M Scaler
DAC	Chord Electronics Hugo TT2, Hugo2
Music Laptop	Lenovo Yoga Pro 3 / Windows10 / JRiver MC24
PowerAdd	PowerAdd PilotPro2 Battery 23000mAh (9v-20v)@4.5amps
LT3045 Power	MPAudio DLS-HPULN PS
Goal Zero	Goal Zero Lithium 400 or Lithium 1000 Battery
Intel NUC	NUC7CJYH Celeron Processor, AudioLinux/Squeezelite/Logitech Media Server
CD Player	Panasonic BMP-BD35
USB-SPDIF Converter	Breeze Audio XMOS U8
Fibre Ethernet	Trendnet TFC-1000MSC w/10meter SC fibre cable
OPTO•DX	AudioWise Inc. OPTO•DX with 1.5m patch cable
RF•STOP	Standard AudioWise RF•STOP Isolation Chamber
Loudspeakers	DIY Voxativ AF-2.6, REL S/5 SHO Subwoofer, Analysis Plus Silver Oval 2 Cables
Headphones	Audioquest Nighthawk - factory cables

Ambient Zero

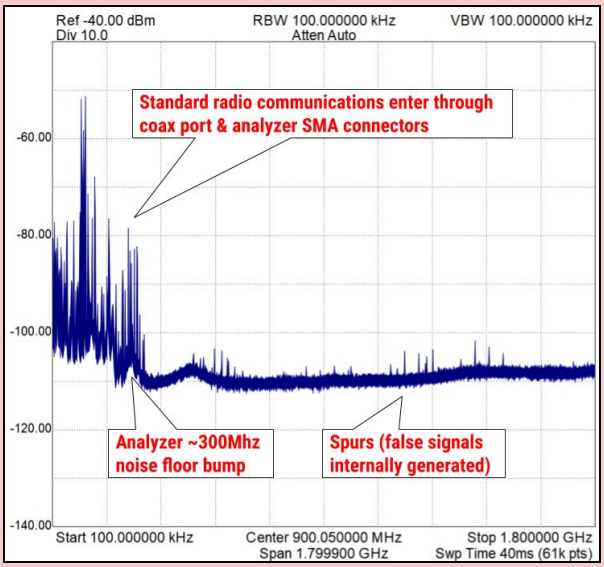
The spectrum analyzer was able to measure up to 13Ghz but in a rural environment only signal energy up to 1.8Ghz was noted - with only analyzer noise floor beyond this frequency. This was also determined to be the range of RF emissions from digital components so was established as the preset range setting for all subsequent measurements. Note that the spectrum analyzer is a software controlled radio design and uses different circuits to tune into different frequency ranges. The transition between circuits is indicated by a step change in sensitivity and noise floor - which is the case at ~300Mhz in these measurements.







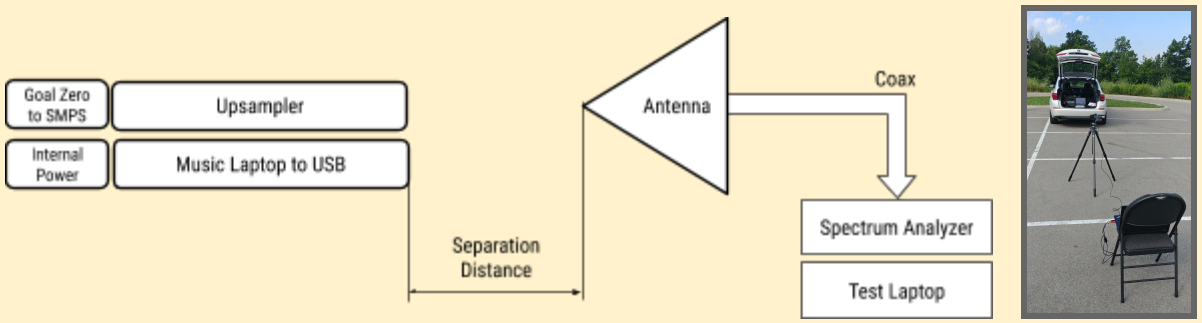
Rural Isolation Ambient Zero Baseline

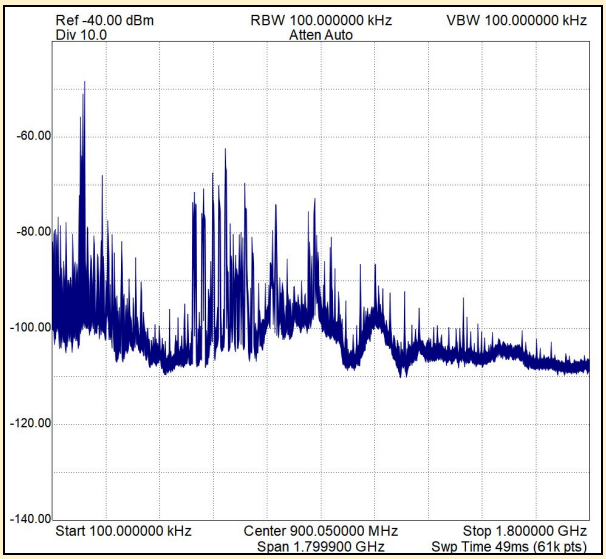


RF Isolation Chamber

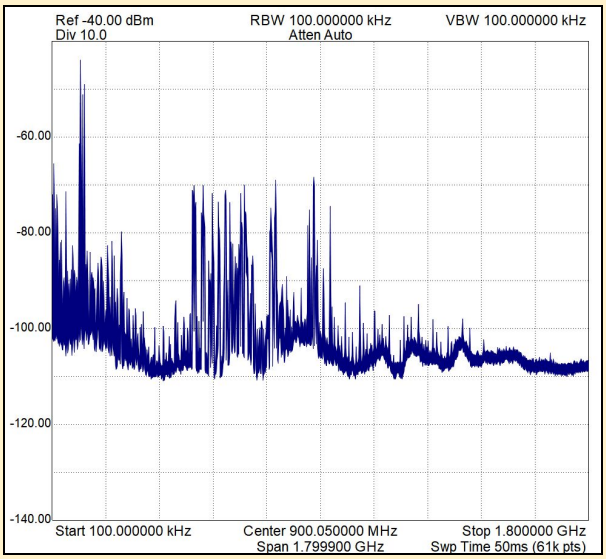
Distance

Testing was carried out in a rural environment using the Upsampler as the device under test (DUT). Significant RF energy in the range 200MHz to 1.5GHz was noted. At 5.0m separation distance, the RF energy is visually noted to be nearly the same as the ambient baseline. Further analysis is warranted to determine if the orientation of the DUT to the antenna changes the attenuation.

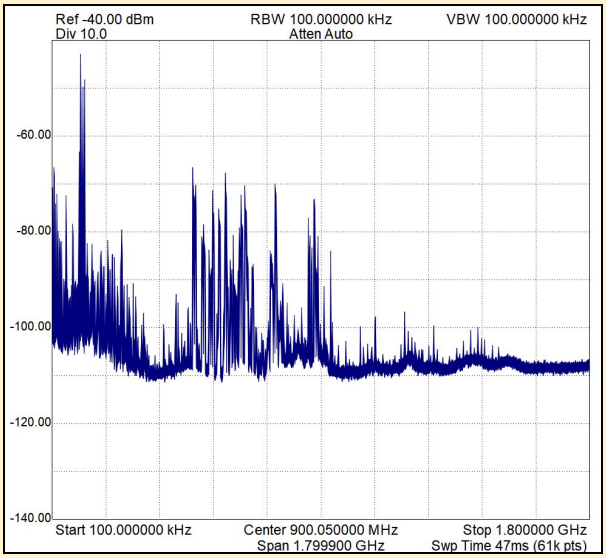




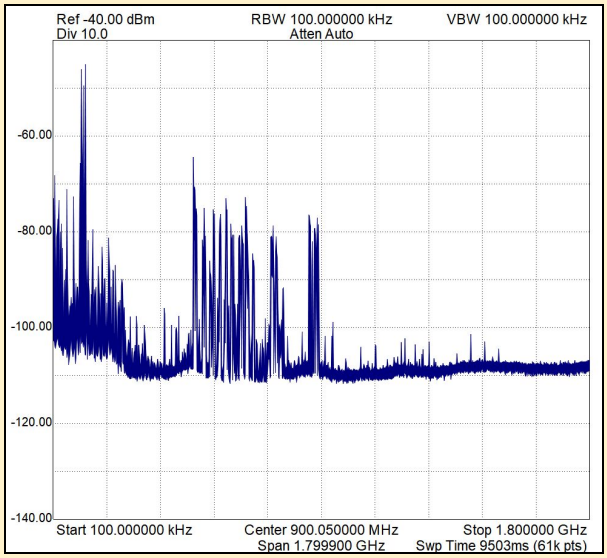
0.3m Separation Distance



1.0m Separation Distance



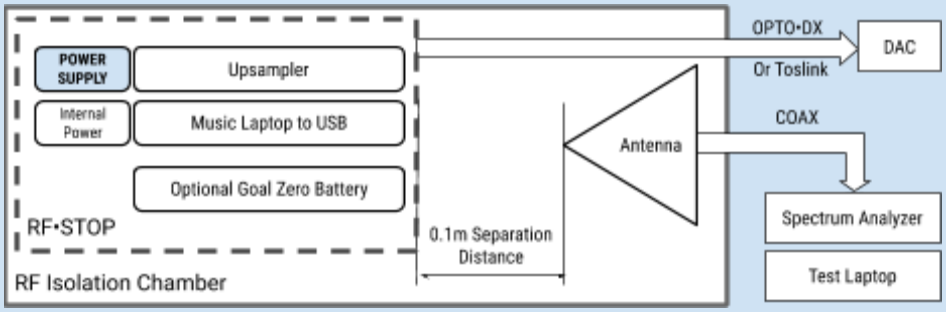
2.0m Separation Distance

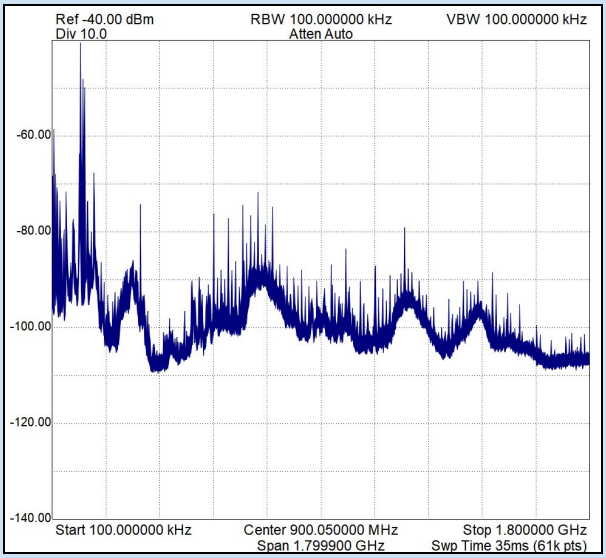


5.0m Separation Distance

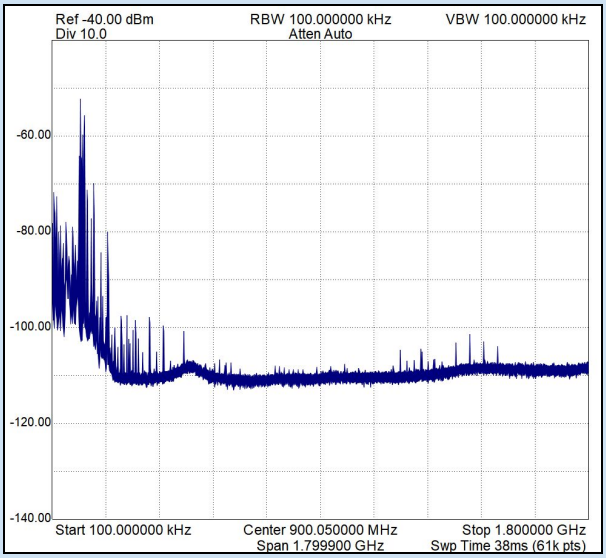
Power Supply

Varying the power supply does alter the spectrum of the radiated RF noise and these change the sound (non-isolated). The subjective perception of transparency when non-isolated is that battery supplies sound better than SMPS however this is not apparent by the measured spectrum plots. All RF•STOP isolated tests sounded better (equally best).

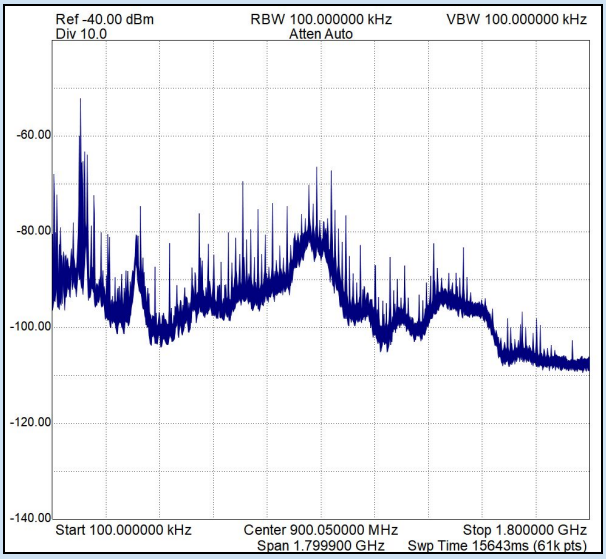




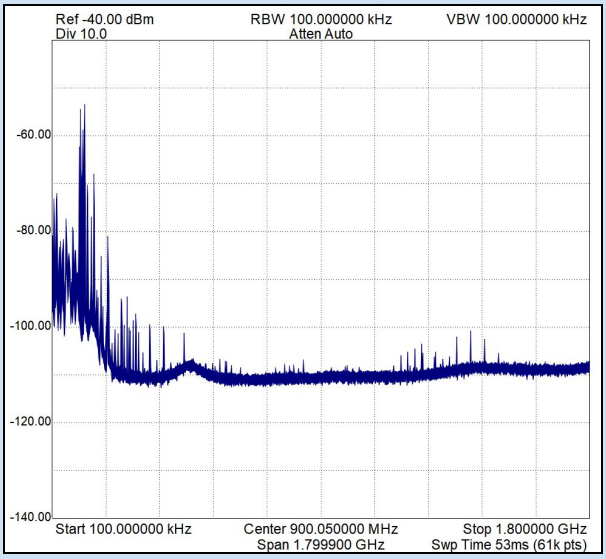
Factory SMPS @ 15V + GoalZero DC/AC



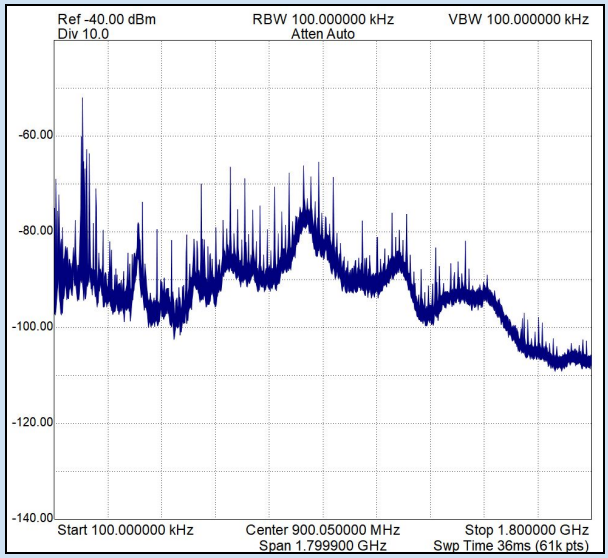
RF•STOP Isolated (SOUNDS BETTER)



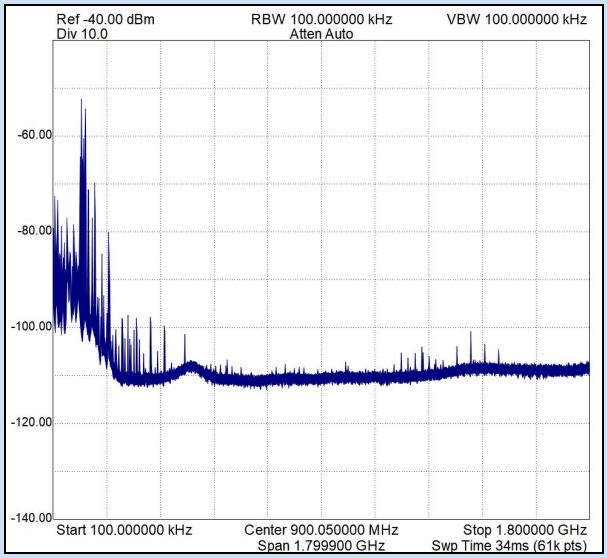
PowerAdd @ 12V



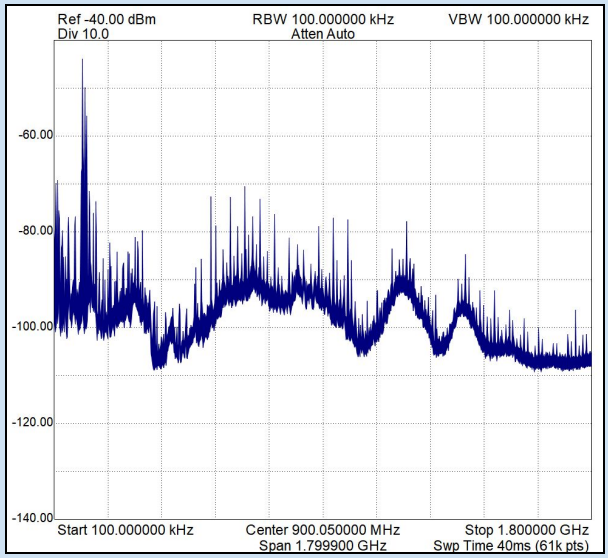
RF•STOP Isolated (SOUNDS BETTER)



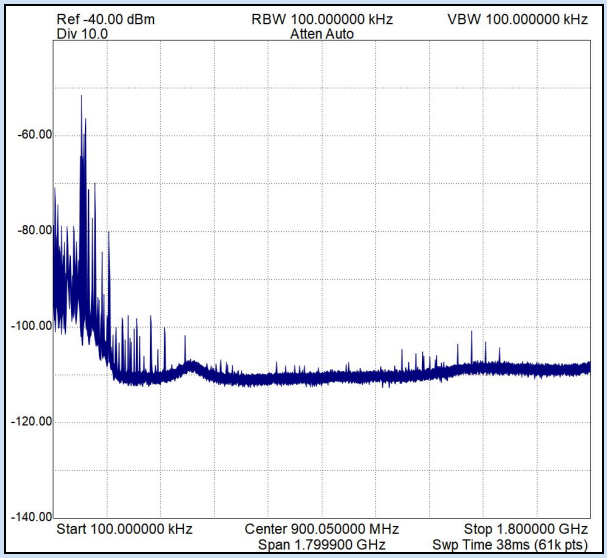
PowerAdd @ 16V



RF•STOP Isolated (SOUNDS BETTER)



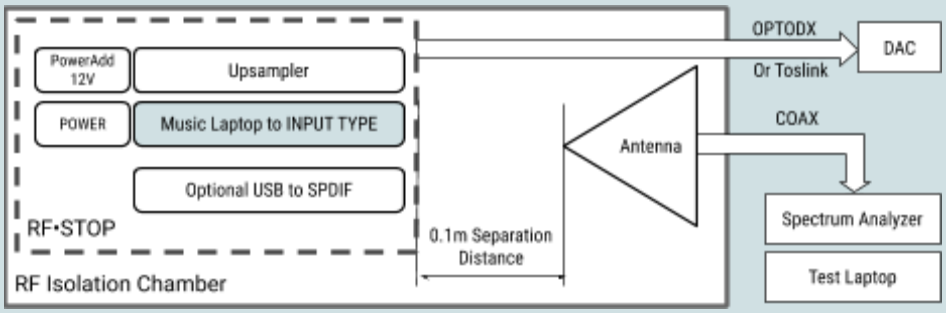
LT3045 Power @ 12V + GoalZero DC

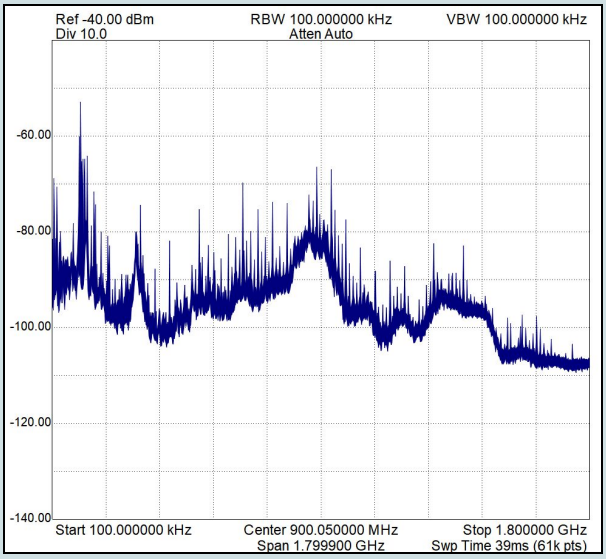


RF•STOP Isolated (SOUNDS BETTER)

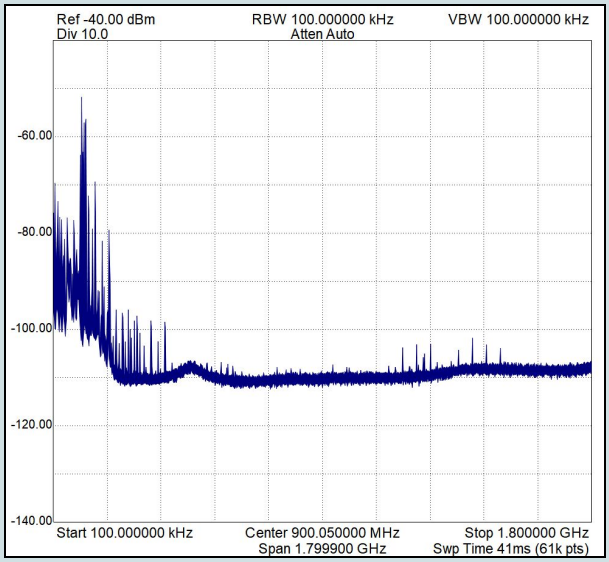
Input Type

Three different inputs were selected: USB, Toslink and SPDIF (Coax) using an optional SPDIF converter. All inputs produced different RF spectrums and sounded different non-isolated. All RF•STOP RF spectrums were identical and all sounded identical.

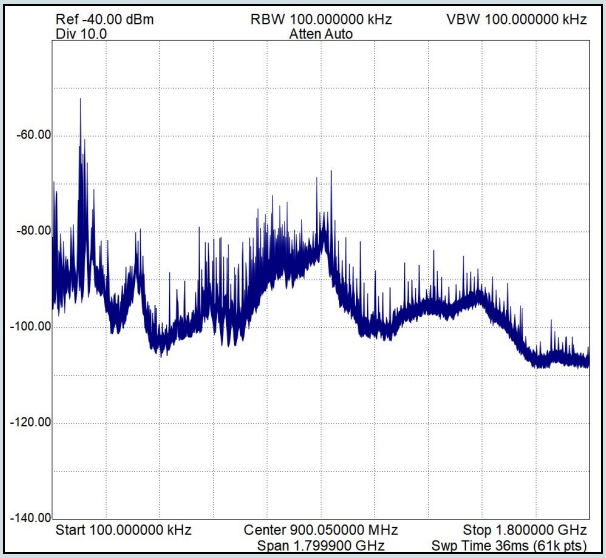




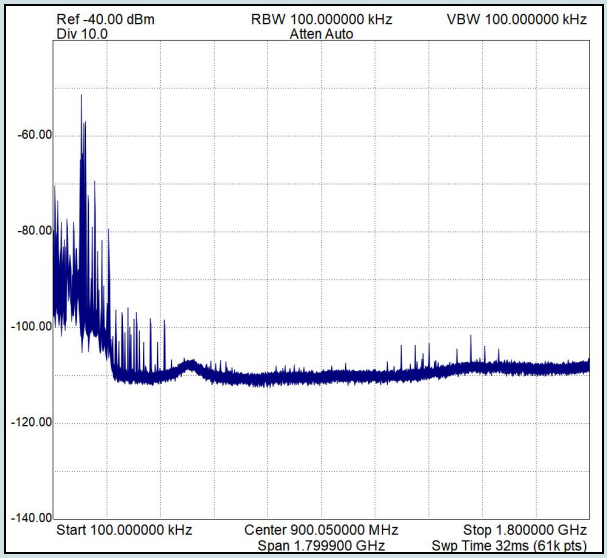
USB Input



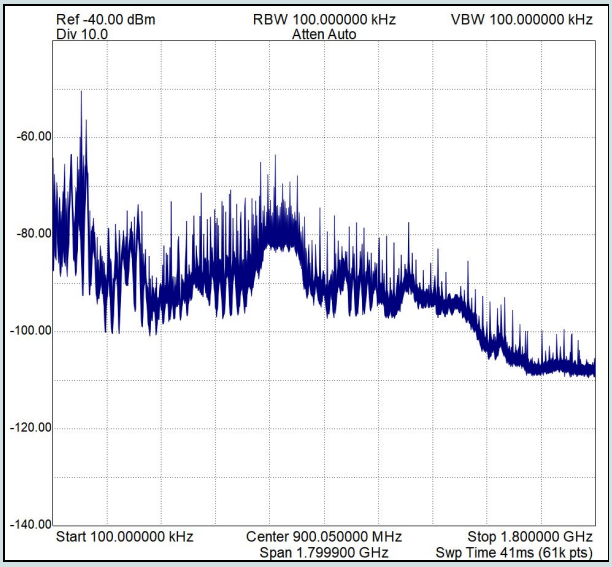
RF•STOP Isolated (SOUNDS BETTER)



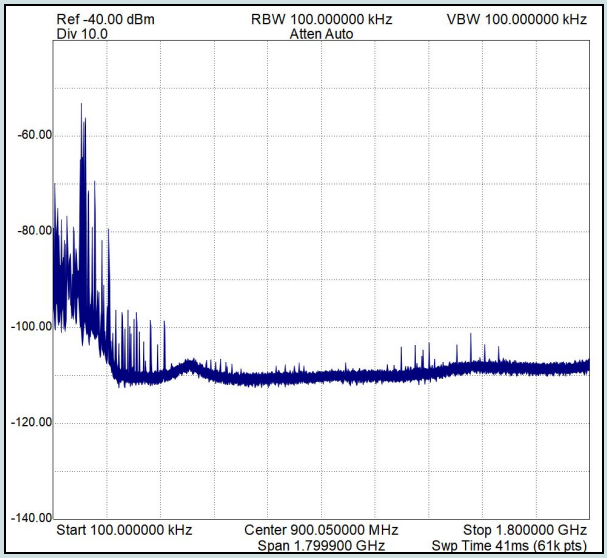
Toslink Input



RF•STOP Isolated (SOUNDS BETTER)



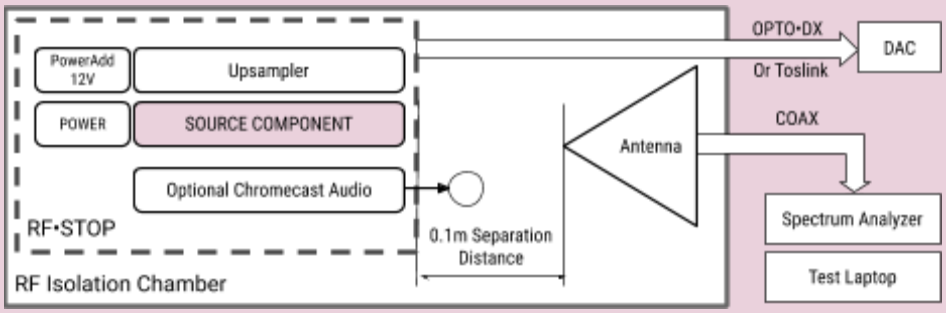
S/PDIF (Coax) Input

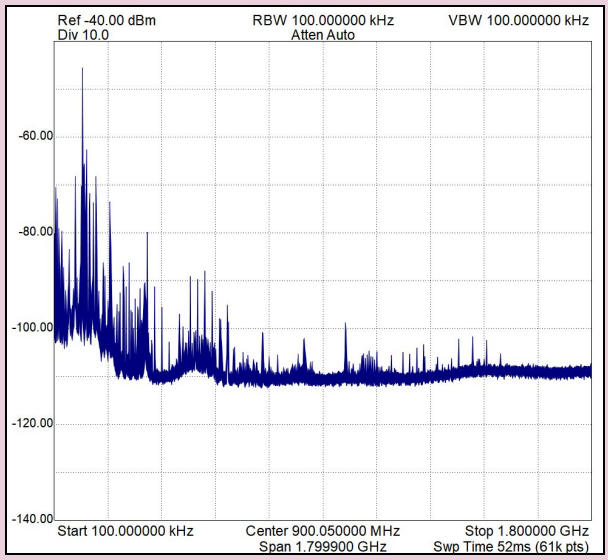


RF•STOP Isolated (SOUNDS BETTER)

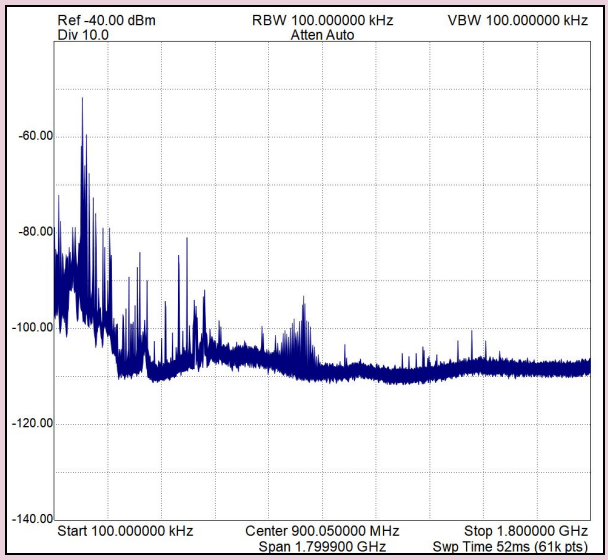
Source Components

Components at idle and playing a track were measured. Connection to the upsampler and signal chain to the DAC was tested with and without RF•STOP isolation. In all cases, the RF•STOP test sounded better - and equally so with all sources.

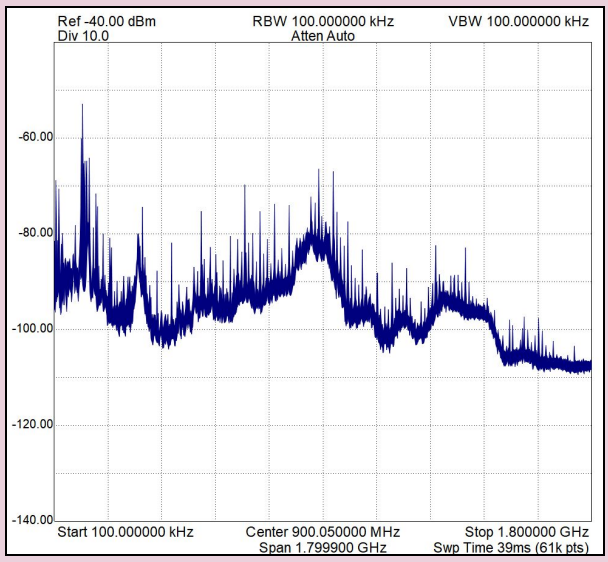




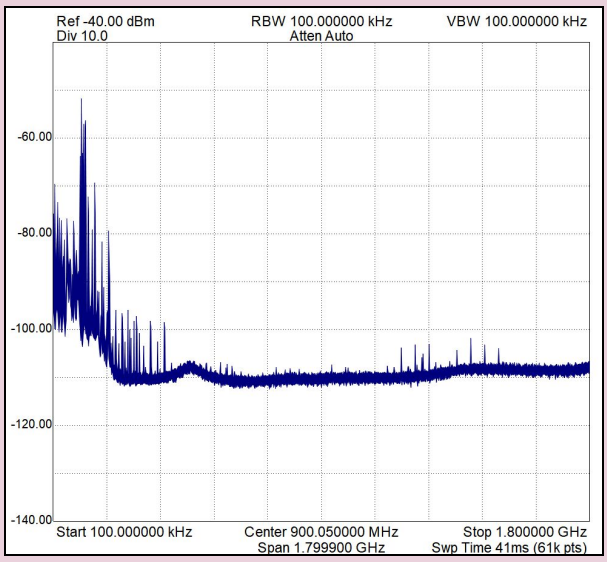
Music Laptop Only (Idle)



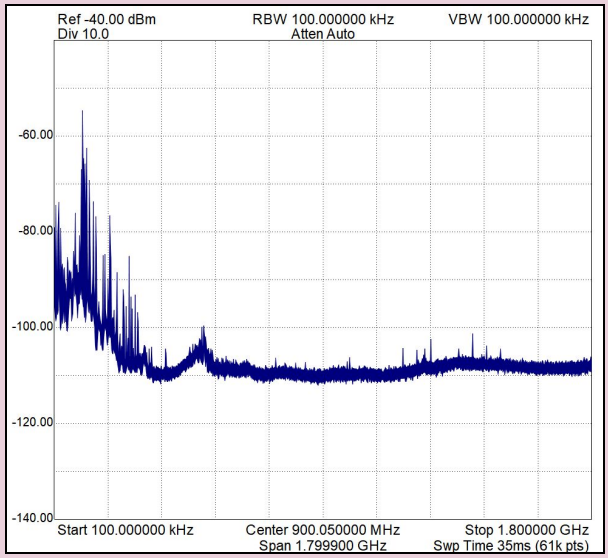
Music Laptop Only (Playing Music)



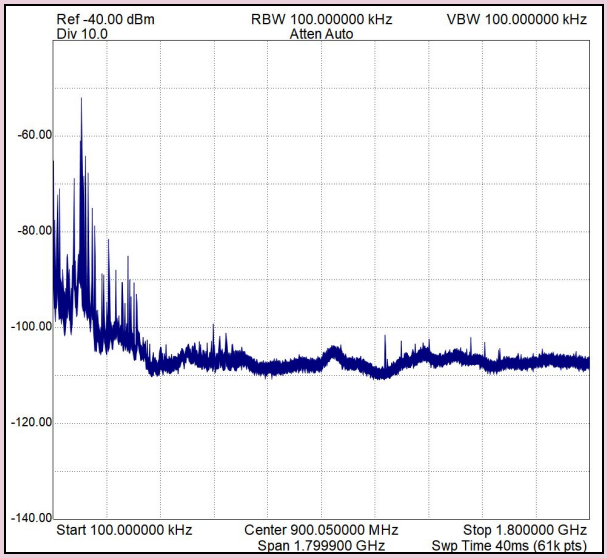
Music Laptop with Upsampler



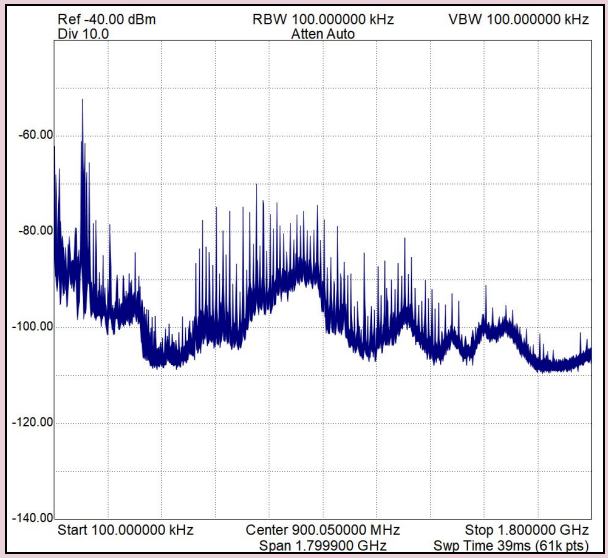
RF•STOP Isolated (SOUNDS BETTER)



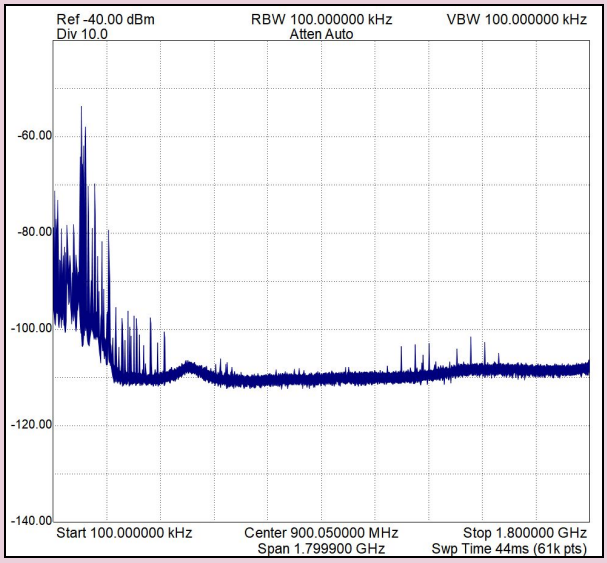
Intel NUC Only (Idle)



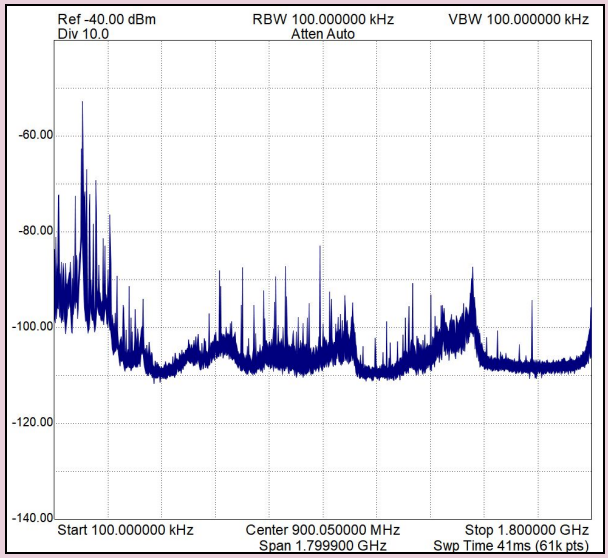
Intel NUC Only (Playing Music)



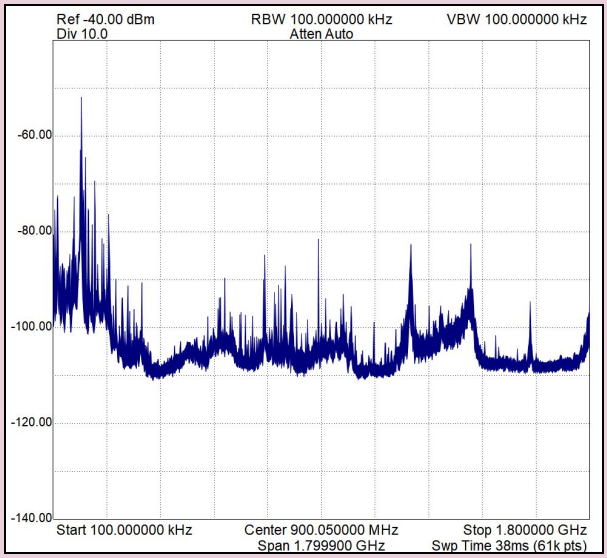
Intel NUC with Upsampler (USB)



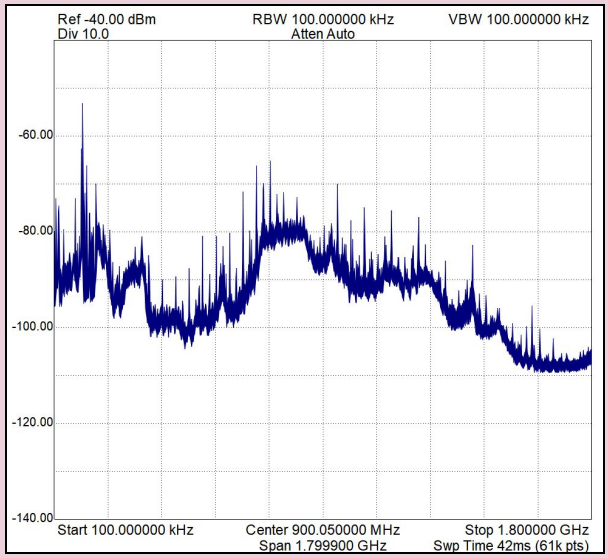
RF•STOP Isolated (SOUNDS BETTER)



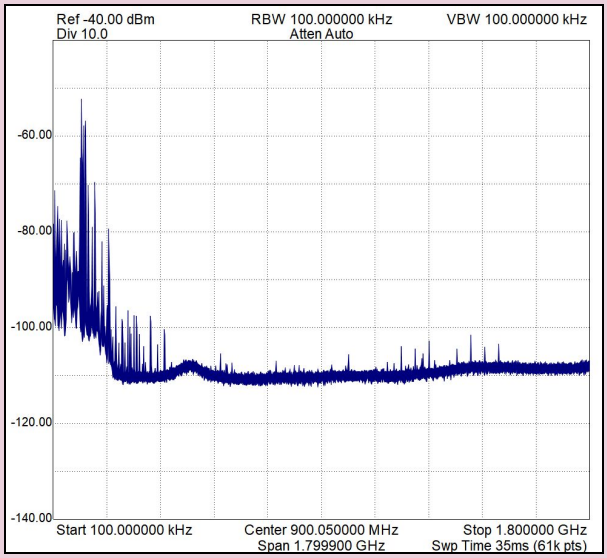
CD Player Only (Idle)



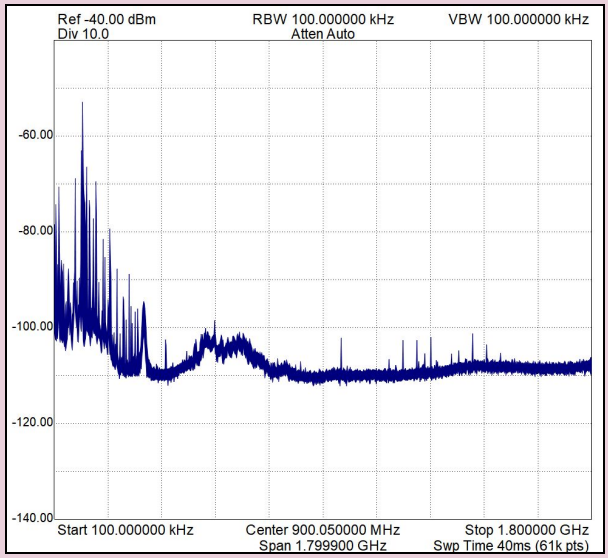
CD Player Only (Playing Music)



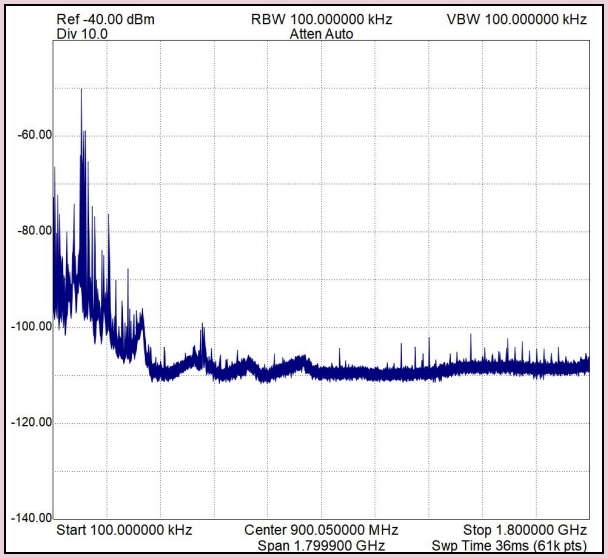
CD Player with Upsampler (Toslink)



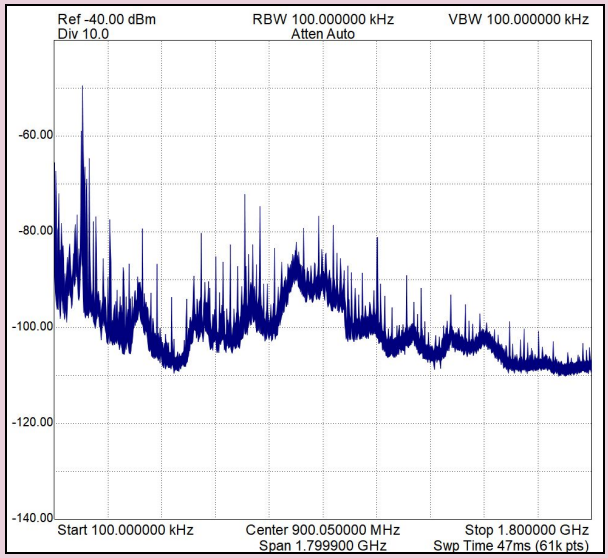
RF•STOP Isolated (SOUNDS BETTER)



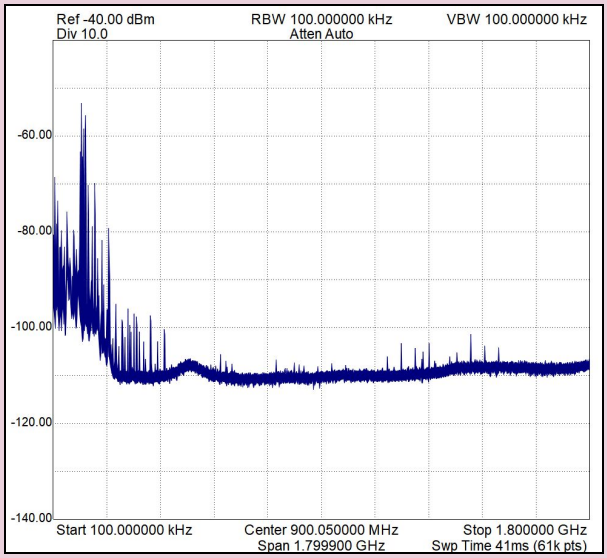
Chromecast Audio Only (Idle)



Chromecast Audio Only (Playing Music)



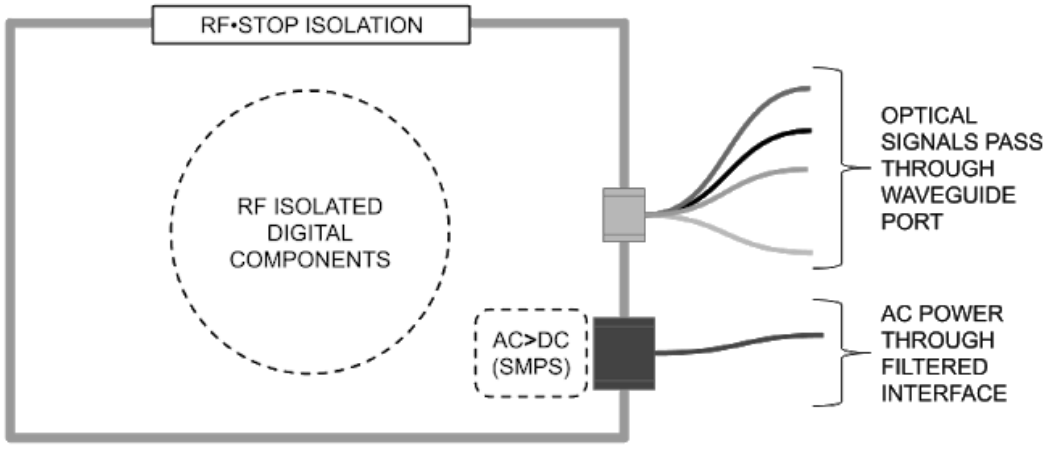
Chromecast Audio with Upsampler (Toslink)



RF•STOP Isolated (SOUNDS BETTER)

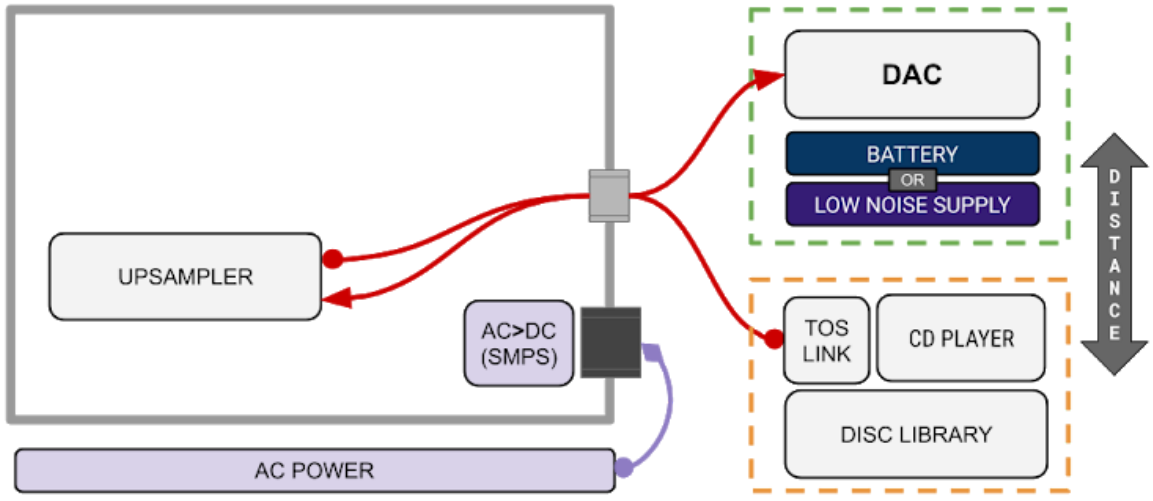
RF•STOP Example Configurations

The examples below show use of RF•STOP isolation for a variety of system configurations. Optical signals (up to six) pass through a waveguide port. DC power cables pass through a filtered interface.



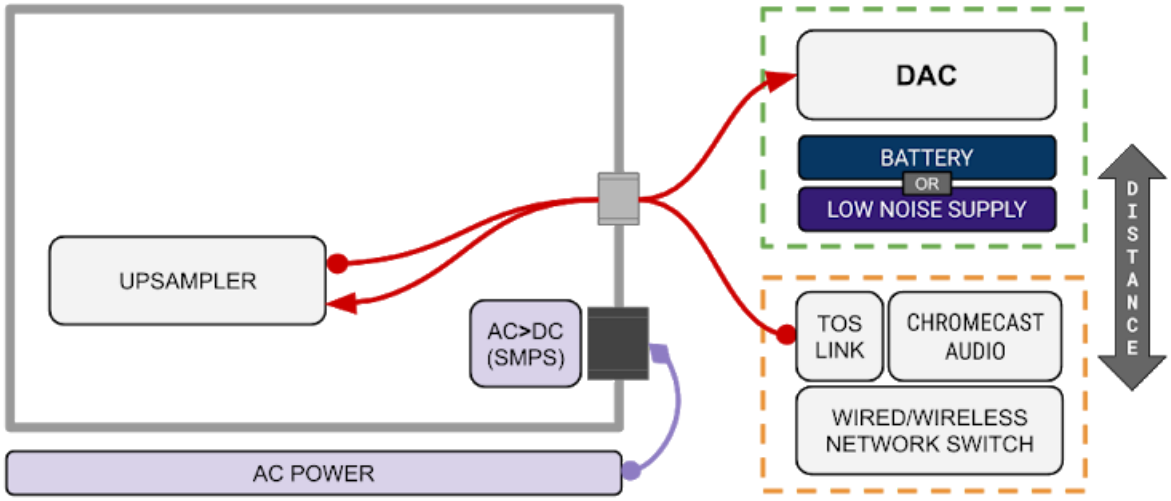
Disc Player

The most basic configuration is to isolate the RF noisy upsampler from a relatively RF noise-free disc player and use Toslink as the signal connection. In this case, the data bandwidth from the CD player is 44.1kHz @ 16bits and from upsampler to the DAC is a maximum of 192kHz @ 24bits. The addition of OPTO•DX to this chain (see below) allows full resolution upsampling from the disc player to the DAC. Note that the upsampler reclocks the input (Toslink) to the output (Toslink) from its own stable clock.



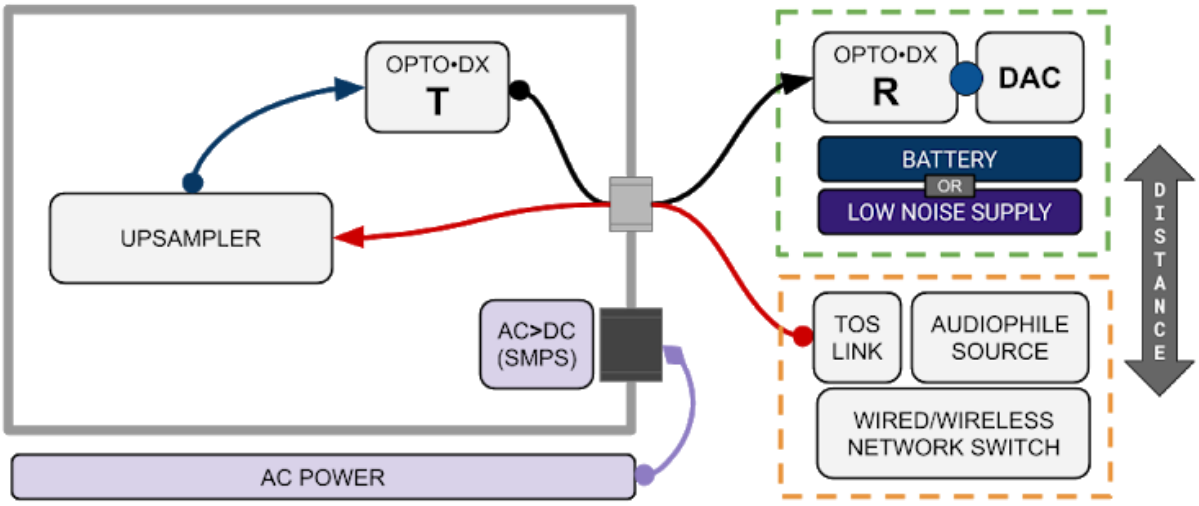
External Toslink Source

With a simple digital source like Google Chromecast Audio the upsampler is isolated and Toslink is used as the signal interface. Again, in this case, the music data bandwidth is limited by the Toslink maximum of 192kHz @ 24bits. Adding OPTO•DX to this chain allows full resolution upsampling. Also, in this case, the DAC is still subject to radiated RF from Chromecast Audio and networking hardware. Note that the upsampler reclocks the input (Toslink) to the output (Toslink) from its own stable clock.



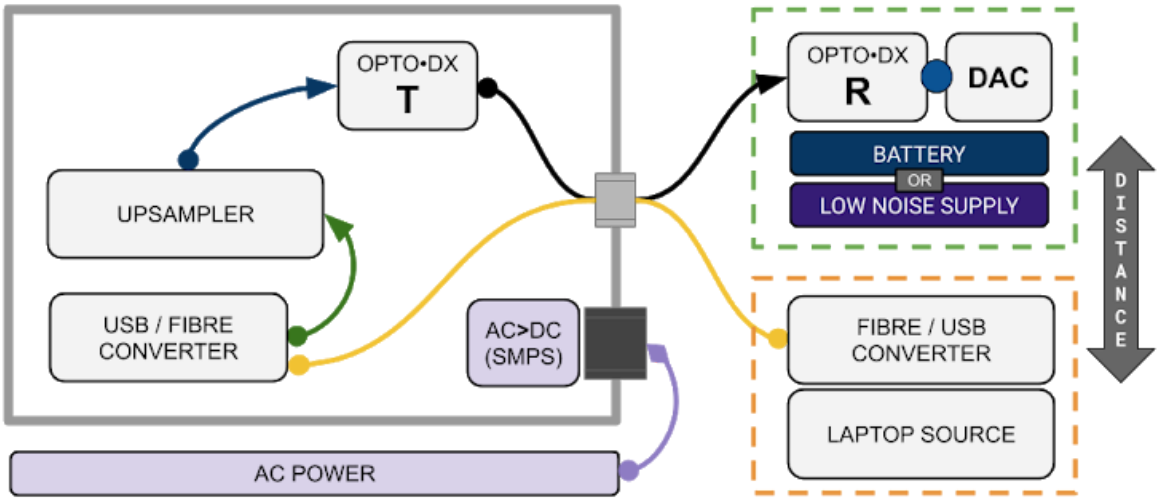
External Toslink Source with OPTO•DX

In the next example, OPTO•DX is used to increase the upsampler-to-DAC maximum bandwidth to 768kHz @ 24bits - or to support a coaxial DAC input. The source below has been changed to audiophile grade - which means it is engineered to produce low jitter and low RF noise. The lower radiated RF noise helps since the source, being non-isolated and proximate, may still radiate RF to affect the DAC. Note that the upsampler reclocks the input (Toslink) to the output (dual-coax) from its own stable clock.



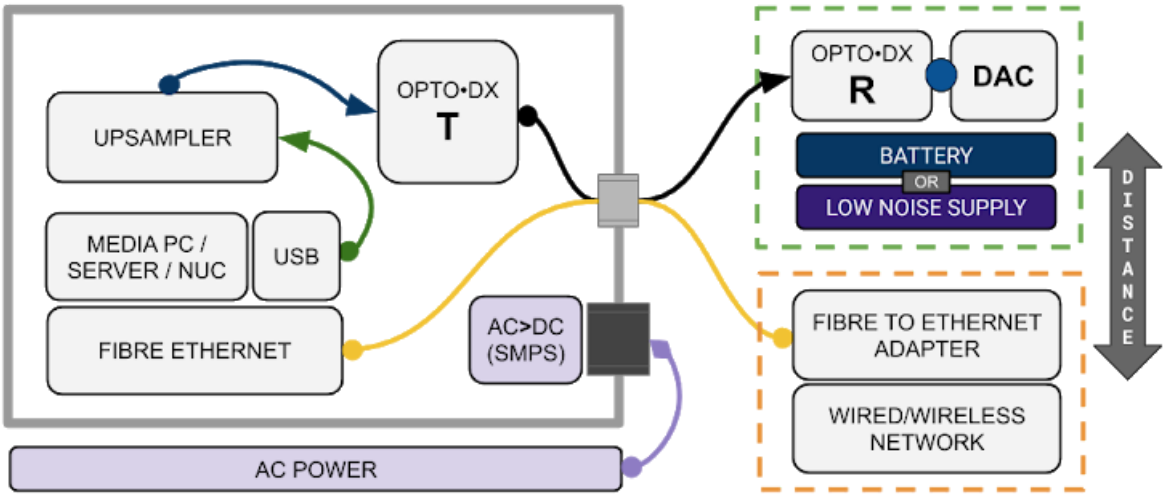
External USB Source with OPTO•DX

In this case, the source is a laptop transparently connected to the upsampler with a USB/Fibre connection. This allow full resolution DSD and PCM content to the played across the fibre link. The radiated RF noise from the laptop may still affect the DAC. Note that the upsampler reclocks the input (USB) to the output (dual-coax) from its own stable clock.

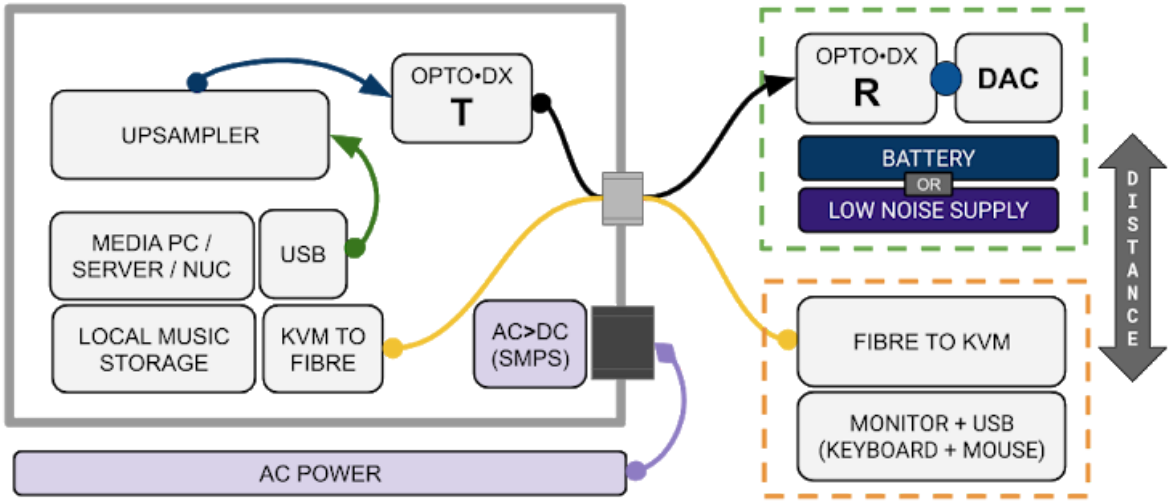


Fully Isolated Source with Network Control

Here most all of the major RF culprits are fully isolated. In this case, the choice of source hardware, software OS, media storage or USB cable is immaterial to sound quality as data delivery to the upsampler is always bit-perfect and no RF noise affects the DAC. Connection to a network is with commodity fibre ethernet media converters. Long lengths of fibre will allow distancing of the network endpoint away from the DAC for maximum isolation. Note that the upsampler reclocks the input (USB) to the output (dual-coax) from its own stable clock.



Fully Isolated Source with Storage & Local Control
For those wishing to listen to music off-the-grid and away from wireless networks, this example adds a large local storage and a direct connection to the source via a fibre KVM extender. This configuration can also be used for watching videos at the clent monitor with fully isolated audio. Note that the upsampler reclocks the input (USB) to the output (dual-coax) from its own stable clock.



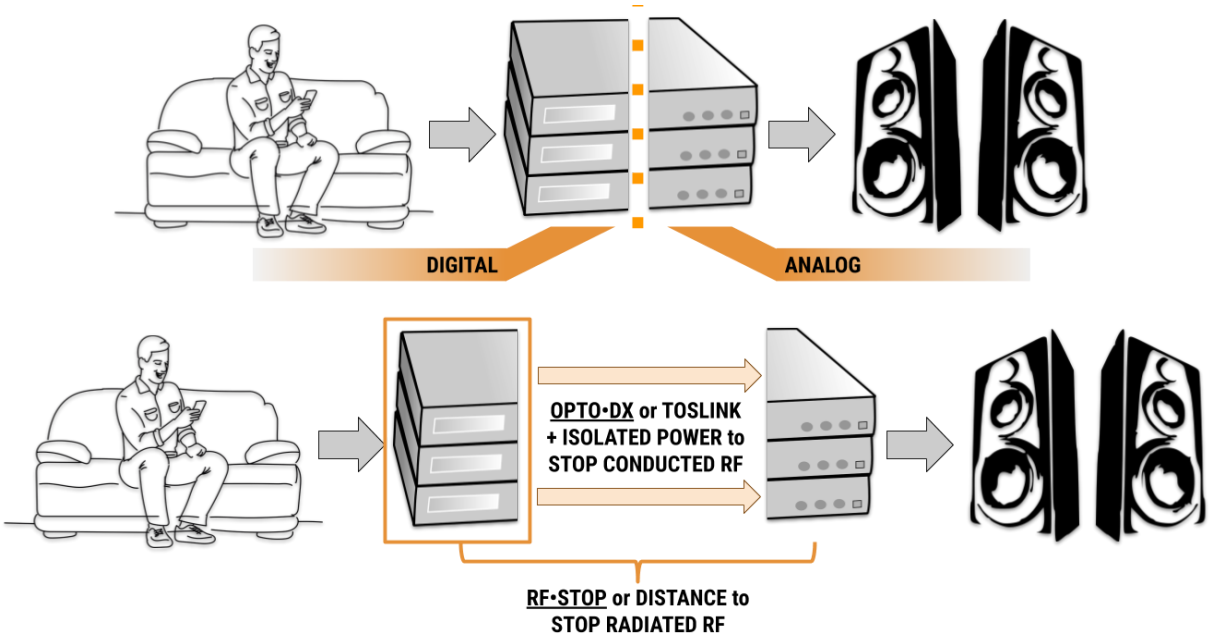
In all the examples shown above, the DAC (D/A stage) is assumed to be in a low noise island: DC powered and directly connected to headphones or high efficiency speakers. In the case where a DAC is AC powered or there is a galvanic connection to downstream AC powered electronics (amplifiers, pre-amplifiers or sub-woofers), an RF noisy AC source will affect sound quality.

RF•STOP isolated digital electronics only required functional power for operation. So the recommendation for a 'Low Radiated Noise Supply' is principally to avoid switching power supplies. For the DAC island and downstream components, batteries are not always practical nor desirable but they do provide assurance against AC noise.

Total RF Isolation is Revelatory

To attain forensic levels of audio transparency from a DAC, here are the two key takeaways from this paper:

1. **STOP CONDUCTED RF NOISE**
2. **STOP RADIATED RF NOISE**



The first point is readily attained by using only optical signal connections and battery power. For a one-box or two-box DAC this means using only Toslink for the source input and running the digital or analog side (or both) on battery. Additionally, a two-box DAC system linked with S/PDIF allows the use of OPTO•DX or a similar optical modulation for higher bandwidth.

To achieve the second point, separate the noisiest digital components from your DAC by a distance of at least 5m (16.5ft) to attenuate the RF emissions close to the level of the ambient zero environment. Alternatively, use an RF•STOP isolation chamber for complete elimination of all RF emissions regardless of distance. Components used outside RF isolation should be low noise (audiophile grade) or kept away from the DAC. Environmental RF (wi-fi, wireless communications, etc.) is a part of the urban listening environment and is what it is. A follow-on paper will measure the effects of environmental RF on sound quality and ways to mitigate its effects on sound quality without undue burden on user friendliness.

In all cases follow best practices to incorporate battery based power for the digital domain and, as much as is practical, for the analog domain. Any galvanic conduction via the power path (even using transformers) will void the RF isolation. And since the analog domain is highly sensitive to clean power (particularly the crystal oscillator clocking the final output D/A samples) use ultra-low noise power here.

With these measures implemented the mysterious audible effects from digital changes go away and your DAC has never sounded better. This is a remarkable and astonishing conclusion - but one that is backed up by measurements and subjective listening. A specific energy or frequency of RF does not appear to determine how a DAC is affected. Even configurations with low levels of RF noise are audibly worse sounding than a fully RF isolated configuration. Of course, this paper is not the final word but strongly suggests that a DACs sensitivity to RF noise cannot be overstated. Continuing work is underway to uncover more information and also to find more room for improvement:

- The effects of environmental RF noise (a work in progress)
- The effects of mechanical noise & vibration (SQ definitely improves with mechanical isolation of a DAC)
- The effects of RF noise on analog transducers (speakers and headphones)
- The effects of RF noise on analog cables: interconnects, speaker wire

For more information, visit www.audiowise.ca. To dialog with the author, email dan@audiowise.ca.