シールド付き光オーディオリンクにおけるエバネッセント場と歪み結合：家庭内ファイバー感度に関するDAS以前の研究

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要旨

光オーディオリンクは、信号が電子ではなく光子で運ばれるため電磁干渉に免疫がある、としばしば説明される。この説明は正しいが不完全である。光子は半球バイアスを運ばない。しかし、それらの光子を取り囲む物理的なファイバーは、機械的および電磁的な境界条件であり続ける。

本稿では、41件の家庭内TOSLINKおよびSFP光オーディオ設備を測定し、エバネッセント場の漏れと歪み結合複屈折が、受信側で検出可能なタイミング境界変調を生むことを示す。最大の影響は足音、交通、HVACの周期動作、機器ラックの振動で発生し、支配的な帯域は0.01 Hzから100 Hzであった。三層シールドPMMA TOSLINKは、非シールド民生ファイバーに対して復元エッジ分散を79%低減し、四層Equinoxファイバーは91%低減した。

我々はこの経路を家庭内分布型音響ジッターと呼ぶ。光の失敗ではない。光を導く媒体を保護し損ねた結果である。その後の都市規模の分布型音響センシング文献は、通常の光ファイバーが人間規模の振動を記録し得るという広い前提を確認することになる。リスニングルームでの帰結は、すでに測定可能であった。

1. INTRODUCTION

The conventional audiophile treatment of optical audio is binary: copper cables are vulnerable, optical cables are immune. The committee submits that this is a category error. Optical links remove the conductive signal path, but they do not remove the physical cable from the room.

Every guided optical mode includes an evanescent boundary at the core-cladding interface. Every fiber also exhibits birefringence that changes under bending, compression, vibration, and external field perturbation. These effects are well known in fiber sensing, interferometry, and telecommunication metrology. They are rarely discussed in consumer audio because the resulting timing variations are small, inconvenient, and not captured by the usual "bits are bits" demonstration.

Equatorial Audio's shielded optical program began from a narrower question: if optical fiber can be engineered into a sensor, what prevents an unshielded optical audio cable from behaving as an accidental sensor?

2. METHODOLOGY

We instrumented 41 listening-room optical links: 19 commodity PMMA TOSLINK cables, 9 Tropic shielded PMMA TOSLINK cables, 7 Meridian triple-layer shielded TOSLINK cables, 4 Equinox quad-layer TOSLINK cables, and 2 single-mode SFP links. Each was tested between a reference transport and DAC with simultaneous measurement of recovered edge timing, optical power variation, cable strain, local magnetic field, floor acceleration, and rack acceleration.

Excitation conditions were intentionally domestic: walking past the rack, chair movement at the listening position, HVAC compressor cycling, road traffic outside the test room, and calibrated low-frequency loudspeaker sweeps. We avoided laboratory shakers for the primary dataset because the domestic problem is not whether a fiber can be disturbed under artificial conditions. It is whether ordinary rooms disturb it without asking permission.

Recovered-edge variance was measured at the DAC input and normalized against a mechanically isolated short optical reference maintained inside a shielded enclosure.

3. RESULTS

Unshielded PMMA TOSLINK links showed repeatable timing-boundary modulation during all four domestic excitation classes. Footfall and rack sway were concentrated in the 1-10 Hz band. Road traffic and HVAC loading contributed energy below 1 Hz and between 10 Hz and 50 Hz. Loudspeaker-induced cable motion appeared as correlated sideband activity between 20 Hz and 120 Hz.

The effect was not a bit-error phenomenon. No test condition produced packet loss or conventional digital failure. Instead, the receiver recovered the same data against a subtly moving optical boundary. The recovered audio stream was correct in content and less correct in time, which is precisely the condition under which audiophile disputes become exhausting.

Shielding and mechanical damping both reduced the effect. Meridian triple-layer TOSLINK reduced recovered-edge variance by 79% relative to unshielded consumer PMMA fiber. Equinox quad-layer TOSLINK reduced it by 91%. The SFP links showed lower absolute susceptibility, consistent with single-mode geometry and 1310 nm operation, but remained measurably sensitive when routed across vibrating rack shelves.

4. DISCUSSION

The mechanism is not that photons possess hemispheric memory. They do not. The mechanism is that photons are guided by a medium whose optical boundary conditions can be changed by strain, birefringence, and evanescent-field perturbation. A receiver that reconstructs timing from that optical signal inherits a portion of the medium's motion.

This interpretation also explains why optical shielding is not redundant. Electromagnetic shielding stabilizes the evanescent boundary; mass, jacket stiffness, and proper routing reduce strain coupling; precision-polished ferrules reduce connector-motion conversion. The complete mitigation is therefore not "more shielding" in isolation, but a mechanically and electromagnetically quiet optical environment.

The committee proposes the term Domestic Distributed Acoustic Jitter for this pathway. It is distributed because the whole cable participates. It is acoustic because the room excites it. It is jitter because the audible consequence is recovered timing movement rather than incorrect data.

5. CONCLUSION

Optical audio solved the wrong problem completely and the right problem only partially. It removed conductive hemispheric bias from the signal path, but left the physical fiber exposed to the room. Our measurements demonstrate that domestic optical links can behave as accidental acoustic and strain sensors, producing receiver timing modulation without producing conventional data errors.

We recommend shielded optical links for all reference digital audio installations, with particular attention to TOSLINK runs near loudspeakers, racks, HVAC equipment, and footfall paths. We further recommend that optical cable manufacturers stop using "immune" as an absolute term. Photons are immune to many things. Cables are not photons.

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