

# FO<sup>2</sup> - Building A Wearable Laser-Feedback DMI with Bela Gem: Performing body-space-technology entanglements

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**Figure 1: 3D printed backpack and controllers. For wearing, straps are attached through the loops of the backpack**

## Abstract

This paper describes the opto-electronic laser-feedback instrument FO<sup>2</sup>, developed in 2025 and created for the composition Fluid Ontologies, developed by Transsonic (Nicola Leonard Hein and Viola Yip). It is a wearable opto-electronic instrument that uses line laser diodes as “opto-loudspeakers” and solar panels as “opto-microphones”. It uses an embedded Bela Gem micro-computer, worn on the performer’s back in a 3D-printed case. Furthermore, it features two 3D-printed handheld controllers that

hold the line laser diodes as well as an array of digital (buttons) and analog (joysticks) control inputs to the Bela. The DSP unit of the instrument is programmed in SuperCollider and enables feedback algorithms as sound sources and live electronic effects to be controlled through handheld controllers. Incorporating the space and its reflective properties into the instrument’s circuit and behavior, FO<sup>2</sup> enables an exploration of the affordances of the performance space unique to this instrument. Furthermore, it engages the performers as bodies in technology and in space and brings about a transmedial listening practice at the core of the musical performance.



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## Keywords

Bela Gem, audiovisual, laser, complexity, feedback musicianship, feedback instruments, SuperCollider, Transsonic, embodied electronics, transmedial listening, cybernetic listening, spatial performance

## 1 Introduction

Transsonic — Nicola Leonard Hein and Viola Yip — is a Berlin-based transmedia performance duo. Since 2018, we have collaborated on new works that bring together instrument building, emerging technologies, and embodied performance practices across sound and light. With our new opto-electronic laser-feedback instrument FO<sup>2</sup>, we created a new piece, Fluid Ontologies, in our line of intermedia works, which foregrounds the translation and interplay of light and sound through laser-feedback instruments. The piece emphasizes new instrument and interface development for musical expression[5], feedback musicianship[6], spatial and musical gesture, and an embodied mode of composition through spatial interaction. Over the course of the performance, we draw on a repertoire of sonic, visual, and spatial gestures that is continuously articulated, recombined, and developed. Fluid Ontologies, therefore, centers on the development and performance of these laser-feedback instruments, projecting movement through space and highlighting embodiment within a multichannel spatialization environment. In this text, we will discuss the technological realization, design approach, and development of our opto-electronic laser-feedback instrument, as well as the emergent forms of performativity in our performances and our investigation into generative modes of spatial interplay.



Figure 2: Impression of performance with FO<sup>2</sup>.

## 2 FO<sup>2</sup> - A LASER FEEDBACK DMI

### 2.1 Basic Concept

The laser-feedback instrument FO<sup>2</sup>, developed in 2025, advances the laser-feedback instrument concept in the composition Fluid Ontologies (2024). FO<sup>2</sup> consists of 2 handheld line laser modules, embedded in 3D-printed handheld control devices, as well as one 3D-printed backpack containing a Bela Gem microcomputer, 2 laser drivers, 2 circuit boards (to connect analog and digital controls to the Bela), and 3 DC step-down converters per performer. The instrument is built around a distinctive mode of audiovisual transduction in which audio signals drive laser modules, encoding sound to light. Using solar panels as microphones,

we transduce light back to the audio domain. This transduction, using it within an audio circuit that generates audio feedback, enables us to explore the mediality of the resulting feedback. By creating an immediate coupling between the sender (line laser) and the receiver (solar panel), the audio circuit produces different feedback dynamics than a circuit using a microphone and a loudspeaker, for example. These dynamics enable us to musically explore and compose with the resulting musical affordances of the instrument, playing the instrument as a kind of string instrument, a percussion instrument, and developing many other characteristics that become accessible due to the dynamics of the feedback and the speed of the closure of the feedback system and its rapid increase in saturation, in coordination with the digital signal processing (DSP) algorithms used for this piece. Using this mechanism, we can develop a close association between the sonic and the visual layers of the performance, since both are generated by the exact mechanism, leading to an audiovisual system that quickly generates material with internal consistency. Lastly, this basic assumption binds body, space, and technology closely, making every bodily movement intended to create sound a spatial gesture, and vice versa, using the reflective properties to influence and shape the sound by reflecting light from surfaces and other objects. Every musical gesture is a spatial gesture, leading to a shift in proprioception on our side as performers, as we connect the spatial and musical layers of gestures in our musical thinking and performance.

### 2.2 Using Lasers as Opto-Loudspeakers and Solar Panels as Opto-Microphones

To transduce sound to the line lasers used in FO<sup>2</sup>, the DC power supply of the laser modules is modulated via its pulse-width modulation input. The PWM modulation input signal is provided by a Bela Gem microcomputer. The Bela Gem microcomputer's audio output provides audible sound for us performers and the audience, as well as the driver signal for PWM modulation of the laser drivers (via its 5V analog output). This allows the lasers to transduce or encode sound signals into light, effectively operating as an oscillator and projecting sonic information into the room, inaudible yet materially present within the performance space. We intentionally use laser modules with 110° line optics to cast laser light as extended lines. These lines carve through the performance space, suggesting new architectures and reframing existing spaces. Working with lines (rather than laser dots) lets us engage directly with the particular geometry and the idiosyncratic formation of the performance space. Alongside the laser modules—which function like “opto-loudspeakers,” projecting audio encoded in light into the room—FO<sup>2</sup> uses solar panels in the performance space to convert that light back into sound. The 5V solar panels work as photoelectric transducers excited by illumination rather than air pressure, functioning as “opto-microphones”. When struck by the laser lines, they generate an electrical current that, when routed into an audio circuit and reproduced through loudspeakers, becomes audible. In this way, the light impulses produced by the laser modules are sonified. Altering the spatial and functional relationship between the solar panels and the laser modules produces different sounds—different readings of the light. By working with indirect illumination, reflections, and materials with varying refractive indices, Fluid Ontologies opens up a wide range of compositional options. Shifts in light intensity, reflection patterns, and panel response allow us to activate different feedback nodes, changing the

behavior of the laser-feedback instruments in real time. Through the mediality of light—varying distance, angle, and the degree of reflection between lasers and panels—the feedback accentuates different overtone structures and dynamic profiles, moving between states of relative stability and instability. In combination with our DSP processes, changes in the angle of incidence become especially consequential, shaping the aesthetic character of the feedback dynamics. The immediacy of this optical feedback differs markedly from microphone–loudspeaker systems in the audio domain. When the beam hits the panel, the feedback can reach maximum intensity within a few milliseconds. The electrical signals from the solar panels are routed to two instrument units—one per performer—where they are processed using DSP algorithms.

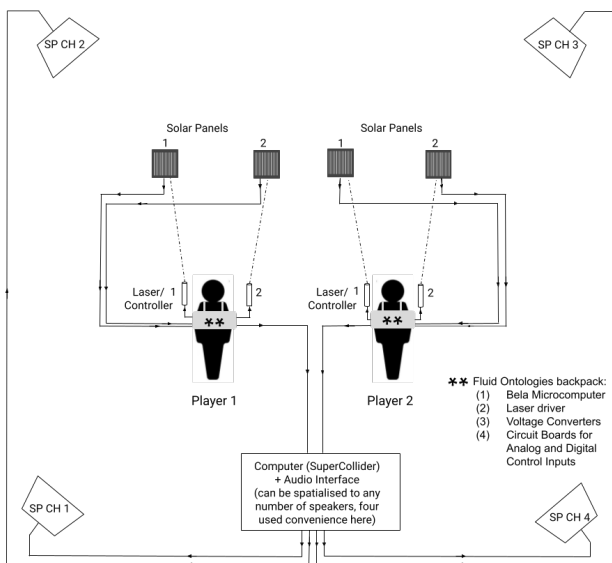


Figure 3: Signal flow chart of performance with FO<sup>2</sup>.

### 2.3 Bela Gem and SuperCollider

FO<sup>2</sup> uses a Bela Gem microcomputer as its DSP unit. The Bela microcomputer [7], with its integration of several programming languages into a low-latency platform, provides analog and digital I/O and the flexibility needed for this project. FO<sup>2</sup> is programmed in SuperCollider [14]. It leverages its flexibility between *sclang* and *scsynth* to maximize performance gains, running only the synthesizer and audio effect algorithms needed at a given moment on *scsynth*, while keeping the other algorithms available. The SuperCollider patch used for FO<sup>2</sup> currently uses seven different stereo feedback algorithms as sound sources for the instrument. Each laser “opto-loudspeaker” is linked to one solar panel “opto-microphone” and runs in parallel, with parallel controls for synthesis parameters. These have been composed to allow for clearly defined musical topoi in the composition of Fluid Ontologies. All these algorithms define a specific kind of musical space and invite unique spatial interaction, as they react differently to input from the solar panels and lasers. Each synthesis algorithm exposes two parameters per channel, which can be controlled via the hall-sensor joysticks (x and y dimensions) on the handheld controllers (left and right hands independently). Every algorithm uses an added pink noise (or other noise) source that is modulated

onto the laser but not audible through the loudspeakers, to produce light and act as a trigger to excite the feedback. FO<sup>2</sup> uses 10 live electronic effects, controlled via 10 keys on the two handheld controllers. These are composed in pairs, divided between the performers’ hands; each finger of the left and right hand (and palms) forms a pair of related algorithms. The pairs of related algorithms are: 1. Stutter Freeze/Freeze, 2. Comb Delay/Reverb, 3. Fuzz/Generative Feedback Reverb, 4. Forward Looper/Backwards Looper, 5. Waveset Distortion/FFT Amplitude Modulation. Furthermore, the index finger key on each hand serves as a gate for the laser and audio output of that hand, enabling the performer to control which sound is visible and audible. .

### 2.4 3D-printed Backpack with Bela Gem

FO<sup>2</sup> utilizes a 3D-printed backpack carried on the performers’ backs to embed the Bela Gem microcomputer (DSP), the laser drivers (with PWM input), circuit boards for connecting the handheld control output (digital and analog) to the Bela inputs, and three DC step-down converters. The backpack enables us to be mobile during performance and move around the performance space.

### 2.5 3D-printed Handheld Controllers

The piece Fluid Ontologies and the instrument FO<sup>2</sup> use two 3D-printed handheld controllers, each with 6 keyboard keys as digital switches, a hall-sensor joystick (with integrated button), and a line laser module per hand. Every performer has two handheld controllers connected to their 3D-printed backpack.



Figure 4: One 3D-printed handheld controller.

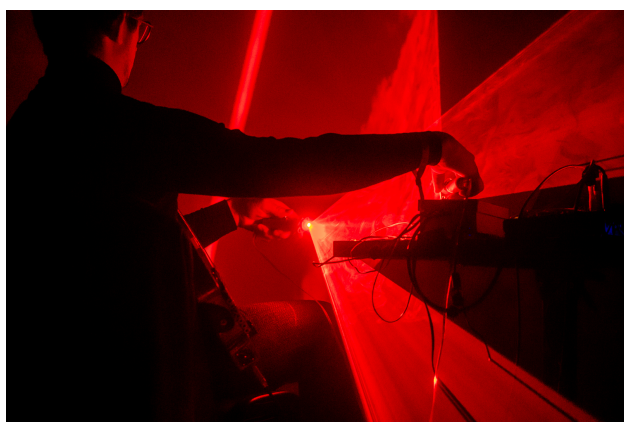
## 3 AFFORDANCES OF AN OPTICAL FEEDBACK TECHNOLOGY IN MUSICAL PERFORMANCE

The piece Fluid Ontologies, along with the instrument FO<sup>2</sup>, produces a unique form of musical composition and performance through opto-electronic feedback instruments. They bring forth an emergent choreography, as every musical impulse and development is also bodily and spatial, letting new relationships emerge from the constellation of the “performance ecosystem” [13]. As a performer, using laser light as a musical medium offers alternative insights into how music could be mediated and perceived in a particular environment/system. In Fluid Ontologies, as discussed, laser light is used as a musical medium to carry an audio signal. It affords a different kind of performativity in music

and offers alternative insights on how music could be mediated and perceived in a particular environment/system. It furthermore explores the agency of different materialities involved in the performance.

### 3.1 The Materiality of Laser Light

Laser light is highly focused; it can be pointed precisely and quickly in and out of the solar panel to create the feedback loop. Furthermore, laser light, like other forms of light, can be reflected from any reflective surface. When the laser light is pointed at the wall, it reflects off the wall. When reflected light reaches the solar panels, feedback also emerges. Depending on the distance and the reflective surface's light absorbance, the laser light will carry the audio at different intensities, and hence the feedback will change.



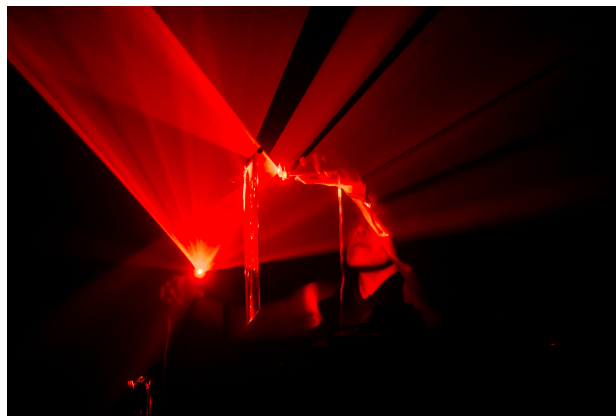
**Figure 5: Performer combines two laser beams to form two overlapping planes..**

### 3.2 The Materiality of the Space

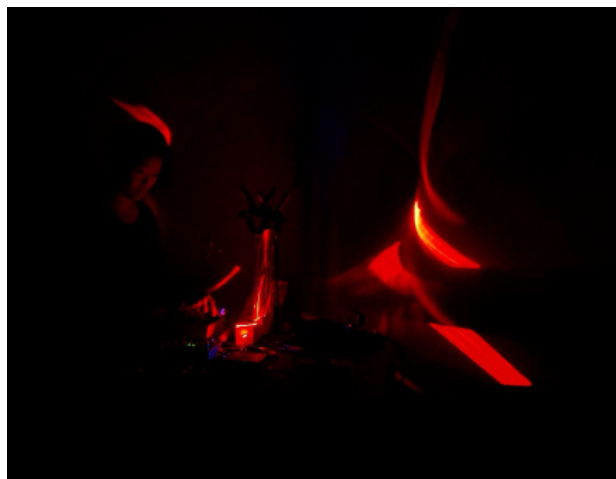
When the distance and the light-absorbing quality of a wall matter in a laser feedback instrument, it is not difficult to imagine that the materiality of the performing space also contributes to the laser feedback performance. Its size, shape, architectural features such as the height of the ceiling, pillars, or wall texture, and the level of darkness/light in the space, etc., offer their musical agency to the performance-making, due to the laser's reflexivity and the reflected light's reception by solar panels. These mediating elements do not exist independently; they are different aspects of the same performing space. When laser light is projected into space, it is mediated and multiplexed by the combination of various materialities.

### 3.3 The Materiality of Fresnel Lenses

Furthermore, Fresnel lenses are incorporated to bend the light further. Each lens allows further reflection and refraction. With the laser projected from the handheld device, the movements of performers' bodies and the distance between the handheld laser and the lens form a tight relationship for determining the sizes and shapes of the refracted and reflected lights. These relationships thus shape the sonorities of the feedback and, by extension, the sound of Fluid Ontologies.



**Figure 6: The performers move their laser instruments, allowing the laser to fill the space and create architectural features.**



**Figure 7: The performer bends the laser beam by pointing it through the Fresnel lens.**

### 3.4 Laser as an Audiovisual Medium

The laser feedback instrument FO<sup>2</sup> has expanded the audiovisuality of a musical instrument. When an audio signal is modulated onto the laser light, the relationship between the audio and the visual is both dependent and independent at the same time. On the one hand, the audio signal depends on the laser light, since the laser carries it. The transmission of the audio signal also depends on the quality of the laser transmission: whether it reaches the solar panel directly over a short distance or is reflected off a metal rod on a high ceiling, where the laser is diffused before it reaches the solar panel. On the other hand, although the audio signal is embedded in the laser beam, they are experienced quite independently on the perceptual level. When the laser beam from the handheld device reaches the solar panel, light and audio feedback occur. Yet the laser beam can come from different sides of the solar panel to produce the same audio feedback. By combining the laser direction with observations of the reflections and refractions it creates, while achieving the same audio feedback, we reveal the complexity and versatility of this laser feedback setup. This expands the audiovisual contrapuntal possibilities in the performance, which heavily relies on the performing bodies, the

network of materialities in the performance space, and dynamic relationships between the two.

#### 4 Body and Technology Entangled in Space

Transsonic’s approach pushes embodiment beyond conventional musical practice by placing the performer’s body within an immediate feedback ecology in which movement, light, and sound continually form and reshape one another. Rather than separating body, instrument, and technology, Fluid Ontologies treats them as interdependent agents within a dynamically shifting multimodal architecture. By foregrounding physical presence, shared space, immediacy, and feedback, the work proposes alternative ways of understanding the performer’s role and the performative capacity of the environment itself. At the same time, Fluid Ontologies articulates an embodied relationship to technology—specifically, an embodied practice of laser performance. In contrast to many “standard” show-laser contexts, which tend to remain comparatively disembodied, Transsonic’s hand-held laser-feedback instruments generate a distinctive choreography and performative language. The lasers become playable, bodily negotiated instruments, enabling forms of movement and expression that would not be achievable through conventional laser setups. Crucially, the work is not only about performing with technology; it also concerns how bodies are situated within technological systems, and how technology itself becomes embodied. Don Ihde [4] describes three ways of being bodies in technology: (1) the technomorphism of human movement, whereby working with tools and systems generates new bodily habits and “laws” of motion; (2) the anthropomorphic orientation of technology, through which technical systems are configured around the human body and its capacities; and (3) we not only employ technologies but are also shaped by them—engaging in reciprocal “dances of agency” [11] where human and technical agencies co-emerge; All three modes of embodiment are central to Transsonic’s performance practice and decisively inform the operation of Fluid Ontologies.

#### 5 Conclusions

Fluid Ontologies seeks to investigate and articulate new notions of light’s instrumentality as a medium for sound. By folding the visual into an expanded sonic field, it foregrounds performative relations between bodies and the site’s architecture, as well as the ongoing negotiation between human and machine agency, also enabling new avenues for musical improvisation [1] and exploration. Ultimately, the work concerns bodies in performance and embodied spatial practice—realized through laser-feedback instruments. The title Fluid Ontologies proposes that the “objecthood” of instruments is not fixed but dynamic. It also points to the permeability of bodies, instruments, and spaces: light turns into sound, bodily movement becomes compositional material. In this line of thought, embodiment entails a loosening of rigid divisions—the body is no longer simply a “human performer,” the laser is no longer merely a “beam of light,” or a technical object, and the environment is no longer an inert “container.” Instead, each element remains porous, defined through ongoing exchange. On the one hand, our bodies themselves become technologically augmented—indeed, technological musical instruments, as Tanaka and Donnarumma [12] argue. The distinctions of the body are continually in flux, shaped by embodied practices arising from sonic, visual, corporeal, material, and conceptual feedback loops. Our bodies, via FO<sup>2</sup>, gain the ability to project our movements sonically and visually into space, and in fact to

perceptually define it by creating new light architectures. On the other hand, the technology we use is augmented by our bodies, growing agential capacities in dances of agency [11], becoming entangled and embodied. Following Karen Barad, we can say that these relations of performance do not pre-exist their relations but co-constitute one another through intra-actions [2]. Our bodies, FO<sup>2</sup>, and the performance space become body-space-technology entanglements. The listening practice we cultivate in this piece should be understood as embodied listening—a mode of attention that involves not only the ears but also the eyes, skin, proprioception [13], and other sensory modalities in a body-space-technology entanglement. Pauline Oliveros uses the term deep listening to name precisely these situated and embodied dimensions of listening. She writes, “Deep Listening comes from noticing my listening or listening to my listening and discerning the effects on my bodymind continuum, from listening to others, to art and to life” [8]. This concept supports our position: deep listening is not an abstract or purely analytical activity, but one grounded in lived, sensory experience. Oliveros invokes the “bodymind continuum” [9, 10] to describe the embodied nature of the mind, and to express “the continuum of the living matrix, that there is no separation between mind and body” [8]. Pushing the emphasis on mediality in listening in our transmedial practice even further, we propose understanding this as transmedial listening or also cybernetic listening [3]. Transmedial listening is “situated within an assemblage of human and machine bodies, media, and space, intra-acting with the imaginations and senses of performers and listeners. This listening practice is articulated through multiple registers and highlights the emerging agency between ‘things’ in the act of listening. All in all, it suggests a holistic listening practice that involves integrating sense and media, acknowledges the symbiotic relationships between human, machines and space, as well as the intra-actions [2] that emerge from the system of materials and bodies” [15].

#### 6 Ethical Standards

The research for this work was carried out with support of Initiative Neue Musik Berlin. Furthermore, it was supported by the Goethe Institute for international presentation. No possible conflict of interest between this work and the hosting institution of NIME 2026 is known to the authors. The human researchers, as the performers of their own work, consented to the research conducted to realize the work.

#### Acknowledgments

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## A Online Resources

A demonstration video showing the operation of an early version of the laser feedback instrument and a trailer of the piece are available on YouTube: <https://www.youtube.com/watch?v=woXAJJIVOIM>, <https://www.youtube.com/watch?v=6lAPmeeqWJ0>. The SuperCollider code for FO<sup>2</sup> can be found on Github: <https://github.com/NicolaLHein/FO2/>.