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Purpose

A second proposed variation of the above research would include creating a digital 'delay' in the audio feedback for the limbs. The delay is estimated to be between 200-500 milliseconds.

As an example, the New Breed "Regular" version described above would be played with a musical accompaniment in 5/8, 6/8, 7/8 and 12/8. The combined sound of drums and accompaniment would be heard through headphones. An audible delay would be generated for either Hand or for the Right Foot or Left foot channel. Of interest is to observe:

1. how quickly the brain can adapt to this audio delay, possibly by ignoring the delay, and
2. what differences in fNIRS data can be observed between data captured without delay, as described in the exercises above, and data captured with audible delays.

Prior research

Speech and delayed auditory feedback (DAF) using fNIRS

- **Ishida et al. (2019)** used fNIRS to study *speech fluency under delayed auditory feedback*. Participants reading aloud experienced delays of several hundred milliseconds via headphones. The study found significant increases in oxygenated hemoglobin (HbO) in bilateral superior temporal gyrus—especially on the right—when speech became disfluent with DAF. The level of brain activation correlated with the frequency of disfluencies.
    - **Relevance**: While it's speech rather than drumming, it's a clear demonstration of cortical adaptation to auditory delay using fNIRS.

Sensorimotor temporal recalibration and motor-auditory delay adaptation

- **Delayed feedback in tapping tasks**: Participants tapped alternately with left and right index fingers; auditory feedback on one hand was delayed (e.g. 200 ms). The authors reported that participants **anticipatorily adjusted their tapping timing** to compensate for the delay—consistent with a *sensorygoals- model* (i.e. aiming to produce a steady auditory rhythm rather than purely motor timing) (Drewing, 2013)
- **Motorsensory- temporal recalibration**: Sugano, Keetels & Vroomen (2016) and others have shown that when exposed to a fixed delay between action and auditory (or visual) feedback, the brain gradually shifts its internal representation to compensate—so that sync feels restored, even though objectively there's still a lag.
    - **Relevance**: These classic experiments establish the behavioral shift you want to measure—anticipatory adjustment in response to feedback delay.

fNIRS mapping of motor timing tasks

- **Timing and tapping with fNIRS**: A validation study showed that fNIRS can map activation in motor cortex (M1), premotor cortex, supplementary motor area, and superior temporal gyrus during synchronization vs. syncopation tapping tasks. Complex timing (e.g. syncopated continuation) recruits broader cortical network and leads to measurable changes in HbO/HbR in SMA, frontal regions, auditory areas (Sugano, Keetels & Vroomen, 2016).
    - **Relevance**: Confirms the viability of using fNIRS to study motorauditory synchronization effects in rhythmic tasks similar to- drumming.

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fNIRS in delayed feedback for teleoperation (non-musical)

- **Zhou et al. (2023/2024)** studied **delayed feedback** in a robotteleoperation context using fNIRS-. They manipulated feedback delays and measured cortical blood responses in motor and timing-related areas, showing that delays influenced neural activation—and that adaptation improved performance over trials.
  - **Relevance**: Though the task isn't musical, it closely parallels your idea: intentionally delayed sensory feedback, with fNIRS tracking cortical adaptation.

Synthesis & How This Informs The Experiment

- **Behaviorally**, previous tapping/timing studies show that people can **anticipate and adjust** their motor output within a few taps when hearing delayed feedback from one limb—and compensation scales with delay magnitude (e.g. 200–500 ms) (Drewing, 2013).
- **Neurally**, fNIRS reliably tracks timing- and auditory-related cortical activity, including responses in SMA, auditory cortex (STG), and premotor areas—even during complex synchronization tasks (Rahimpour et al, 2020).
- **Time course**: Although fNIRS suffers from the intrinsic **slow hemodynamic response** (onset 2–5 s, peak around ~6 s after neural activation), these studies show it can nonetheless track adaptation across repeated trials or blocks with a temporal resolution appropriate for multi-second changes.

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Example Framework for this study

Component	Example design features based on prior studies
Delay range	200–500 ms auditory delay (similar to speech or tapping DAF studies)
Task	Drumming one pad delayed; others normal; repeated strokes/blocks
Measurements	Behavioral: shift in stroke timing on delayed pad over trials; Neural: HbO/HbR changes in STG, SMA/PFC, sensorimotor cortex via fNIRS
Timing	Each block lasting tens of seconds to allow hemodynamic response; compare early vs late trials
Hypotheses	1. Behavioral compensation (stroke advance) scales with delay magnitude; 2. fNIRS shows increased activation during early exposure, which then normalizes as adaptation happens

Summary

- Behavioral tapping studies confirm **anticipatory temporal adaptation** to delayed auditory feedback—even in the 200 ms range.
- fNIRS has been used successfully to **capture cortical adaptations and activation patterns** in sensorimotor timing tasks, including auditorymotor- tasks.
- Research in teleoperation delays further supports **measurement of adaptation to feedback delays** with fNIRS.

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Experimental design

Timing Paradigm Design

The experiment uses a block design optimized for fNIRS hemodynamic sensitivity. Each cycle includes four phases:
- Baseline (15 sec): All limbs play synchronized rhythm; no delay.
- DAF Block (30 sec): One limb (e.g., left hand) receives 200-500 ms auditory delay through headphones.
- Post-DAF Block (30 sec): Delay removed; observe aftereffects.
- Rest (15 sec): Silence for hemodynamic recovery.

Repeat 6–8 cycles for averaging.
Task: Perform a 4-limb rhythm (e.g., samba, salsa, rock pattern, jazz pattern).

fNIRS Channel Placement

Optodes will be placed over SMA, M1, STG, DLPFC, and IPL to target motor, auditory, and integrative functions:
- SMA: Timing and sequencing (FCz)
- M1: Motor execution (C3/C4)
- STG: Auditory feedback (T3/T4)
- DLPFC: Cognitive control (F3/F4)
- IPL: Multisensory integration (P3/P4)

A 16–24 channel montage with 3 cm spacing is recommended.

Statistical Analysis of Hemodynamic Adjustment

- Use General Linear Model (GLM) to model task conditions.
- Compare DAF vs. Baseline and track change over blocks.
- Use ROI-based analysis for SMA, STG, etc.
- Include behavioural timing errors as covariates.
- Expected adaptation: HbO signal reduces across blocks in auditory/motor areas.

Wiring Diagram of Single-Channel Delayed Audio Feedback (DAF) Unit

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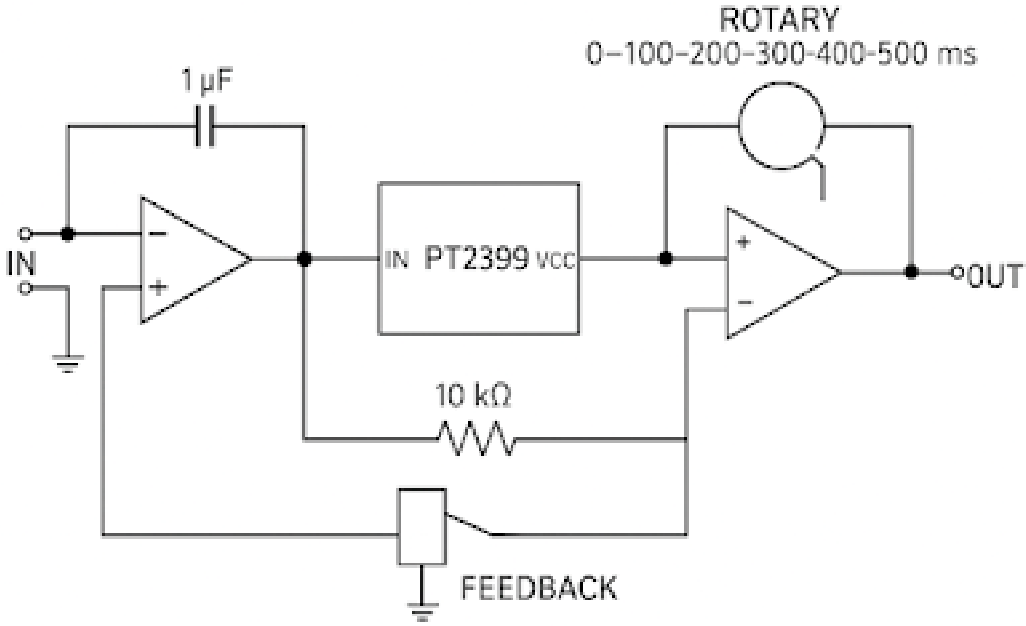

The wiring diagram provided is a **conceptual synthesis** based on standard analog audio signal flow principles commonly used in:
Audio electronics and **signal processing** (see: Horowitz & Hill, *"The Art of Electronics,* (2015)")
Delay line implementations in music and neuroscience setups, such as in:

- **Real-time auditory feedback experiments** in music cognition (e.g., Pfordresher, 2005)
- **Musical timing and feedback control** research (e.g., Repp, 2005)

It is not taken from a single specific published source, but reflects typical signal path configurations involving:

- **Op-amp buffering**
- **Adjustable gain (variable resistor)**
- **Delay line module** (analog bucket brigade or digital DSP chip)
- **Feedback routing**

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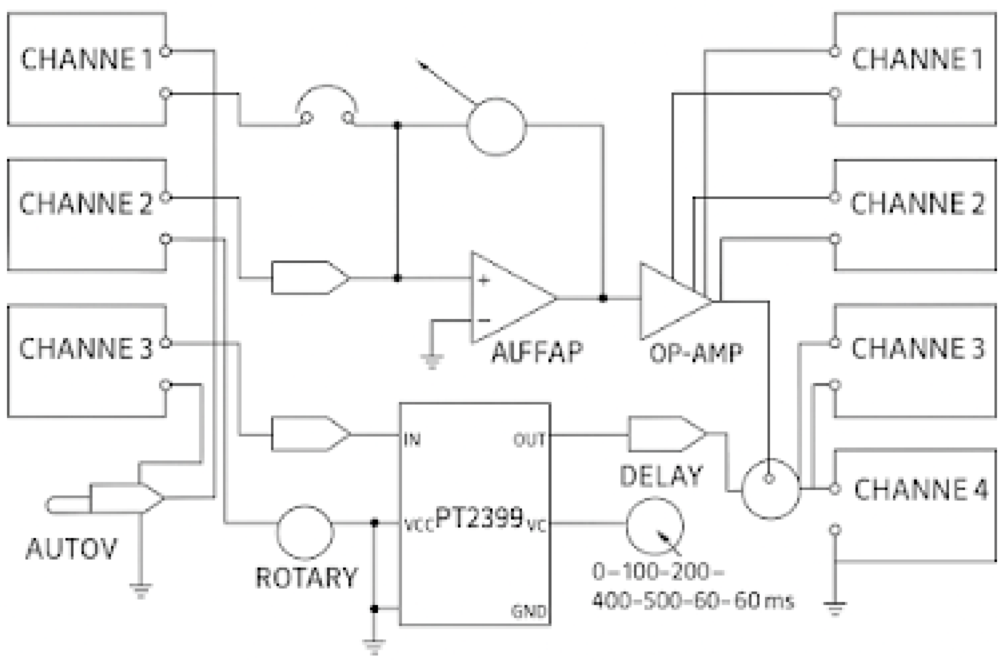
To implement a working version, you'd select a delay module (e.g., PT2399 for digital delay) and match impedance and gain staging for your application.

This is a wiring diagram with four inputs/outputs, similar to the above



A **step-by-step builder's guide** to accompany the schematic of the **4-channel selectable audio delay circuit** with adjustable delay time (0–600 ms):

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Build Guide: 4-Channel Audio Delay Unit with Selectable Delay Time

🔧 Overview

This circuit uses:

- A **PT2399 digital delay IC** to introduce audio delay
- A **rotary switch** to select between 4 input channels (Channel 1–4)
- A **second rotary switch** or stepped potentiometer to control delay time in discrete steps: 0 ms, 100 ms, ..., 600 ms
- Corresponding outputs per channel

🔌 Inputs & Outputs

- **Inputs (Channels 1–4):** Can be TRS jacks, triggered by piezo sensors or audio signals from an electronic drum pad.
- **Selector Switch (S1):** A 4-position rotary switch selects the active input channel routed to the delay line.
- **Outputs (Channels 1–4):** The delayed signal is routed to the corresponding output, matching the input.

📦 Component List

Component	Description	Qty
PT2399	Digital delay IC	1
Rotary switch (4-position)	Channel selector	1
Rotary switch / Potentiometer (7-position)	Delay selector (0–600 ms)	1
3.5mm / 6.3mm Audio jacks	For input/output	8
Resistors (10k, 47k, etc.)	Delay tuning and input buffer	~6
Capacitors (0.1µF to 10µF)	Filtering and delay setting	~6
LM386 or op-amp (optional)	Output buffer/amplification	1
Diodes (e.g., 1N4148)	Signal protection (optional)	2

Component	Description	Qty
Voltage Regulator (e.g., 7805)	To power the PT2399 with 5V	1
Power supply (9V DC)	Wall wart or battery	1
PCB or perfboard	Assembly surface	1
Enclosure	Case with knob cutouts	1

⚙️ How It Works

1. **Input Selection:**
   - A 4-position rotary switch selects one of the 4 input channels.
   - Only the selected input is passed to the delay processing stage.
2. **Delay Processing:**
   - The PT2399 receives the signal and delays it.
   - The delay time is determined by a set of resistors switched by a rotary selector (or a stepped potentiometer), producing delays in increments from 0 to 600 ms.
3. **Output Routing:**
   - The output of the delay line is routed to the matching output channel (based on the selected input).
   - This allows real-time redirection of the delay to any of the four limbs (e.g., in a drumming setup).

Delay Time Control

Selector Position	Resistance (approx.)	Delay Time
1	0 Ω	~0 ms
2	2.7 kΩ	~100 ms
3	5.6 kΩ	~200 ms
4	8.2 kΩ	~300 ms
5	12 kΩ	~400 ms
6	15 kΩ	~500 ms
7	18 kΩ	~600 ms

Use metal film resistors for accuracy. You may swap in a 6-way rotary switch and one fixed resistor if you prefer fixed steps.

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Assembly Tips

- Use **shielded cables** for input/output to reduce noise.
- Mount **delay selector** and **channel selector** firmly to your case with knobs.
- Place the PT2399 socket on a socket base for easy replacement.
- **Test each input/output** individually before closing the case.
- Add **bypass capacitors** (0.1 µF) near power pins for stability.

Troubleshooting

Problem	Possible Cause
No audio output	Incorrect wiring, unpowered PT2399
Signal distorted	Overdriving input, missing capacitor
No delay	Wrong resistor on delay selector
Cross-channel noise	Ground loop or poor shielding

📐 Enclosure Layout Suggestion

- Top panel with two rotary knobs (channel select, delay time)
- Four input and four output jacks
- LED indicator (optional)

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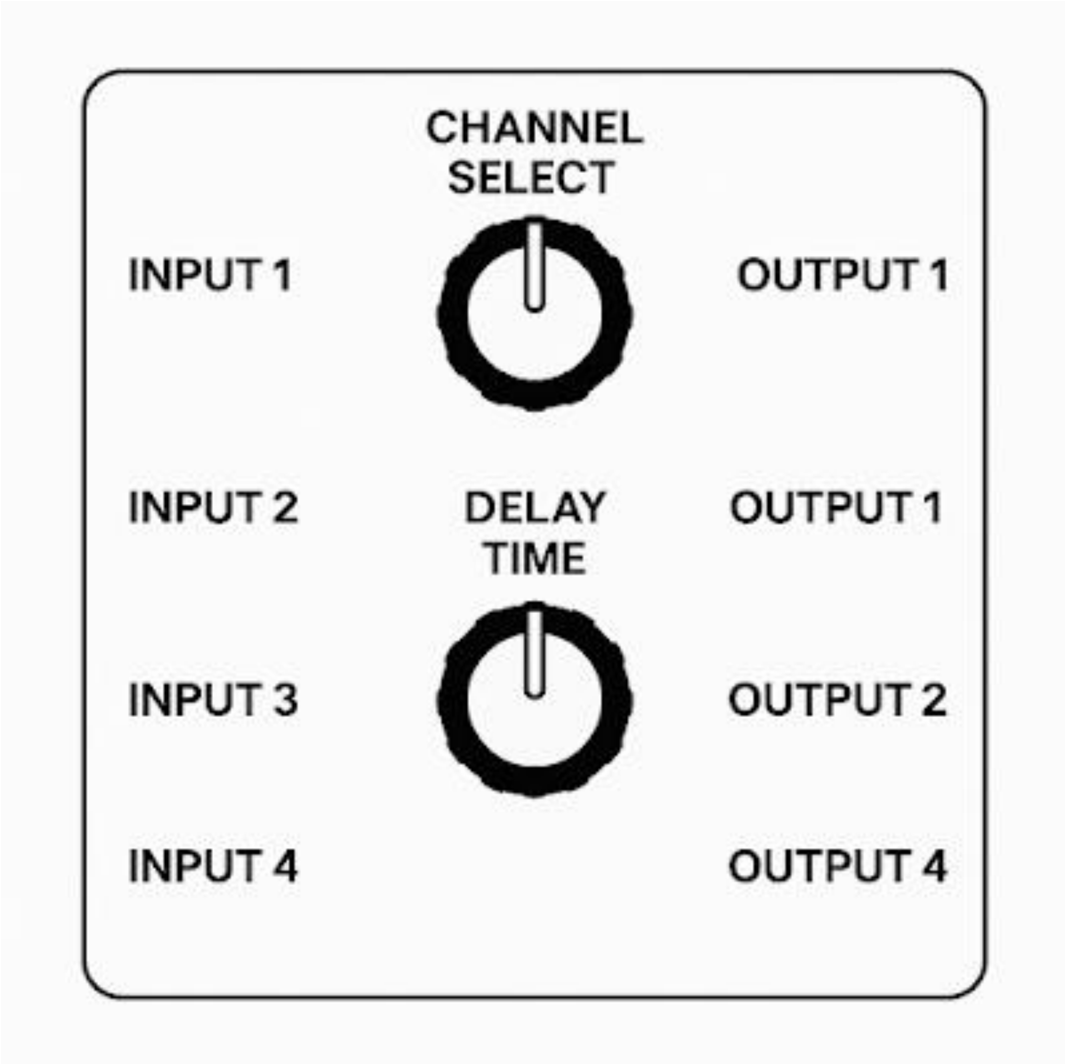

Note: Output labels on left side have been mislabeled. Should match Inputs on right side.

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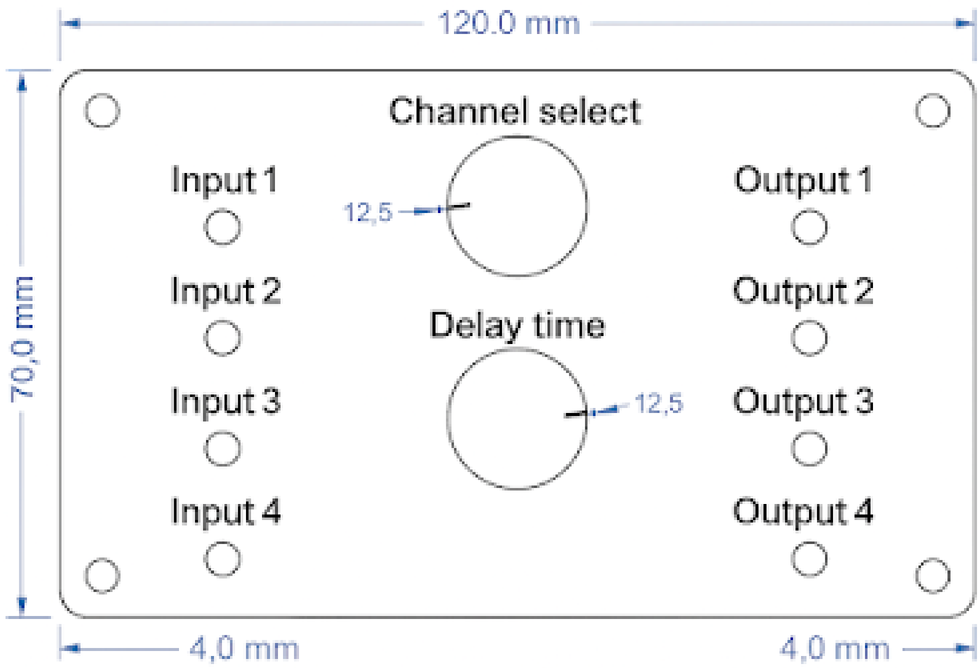

Note: Actual Inputs and Outputs will be placed on the left and right sides of the box.

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