Prototyping Begins: Build Sketch and First Component Tests

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1. Build Sketch

A first session marked the start of the prototype phase. Two workstreams ran in parallel: a mechanical sketch of the two devices, and a first round of tests with the electronics already available. The session began with a 3D sketch (in Blender) of the mechanical design. Two structurally identical devices — the loudspeaker and the microphone — each consist of a driver or capsule in an enclosure, fitted with a horn for directionality. Each device is mounted on a two-axis gimbal: a cardan-type suspension with counterweights to balance the load. The gimbal attaches to a standard microphone stand through a 3/8″ thread adapter. The sketch also covers the housings for the electronics, which sit on the stands together with the devices.

The horn is the component that gives the two devices their directionality. A horn acts as an acoustic impedance transformer: it couples the high-pressure, low-velocity vibrations at the driver diaphragm to the low-pressure, high-velocity vibrations of free air (Beranek and Mellow 2019; Kolbrek 2008). This increases the efficiency of the driver and, more importantly for this project, controls the radiation pattern — the sound is focused along the horn's axis instead of spreading omnidirectionally.

The current design uses a tractrix horn with a mouth diameter of 280 mm, driven by a 36 mm, 3 W, 4 Ω miniature loudspeaker. The tractrix contour — the curve traced by a weight dragged along a table, first studied by Huygens in the late 17th century and patented for loudspeaker use by Voigt in 1927 (Voigt, n.d.) — produces a near-spherical wavefront of constant radius. This gives the driver a good acoustic load with comparatively low distortion. Its practical constraint is that the contour has only two degrees of freedom: choosing the throat diameter and either the length or the mouth diameter fixes the entire shape.

To make different horn geometries comparable on the same driver, the horn is attached to the enclosure with a bayonet mount — a twist-lock coupling in which the horn is inserted and rotated into locking lugs. Since the horns are 3D-printed, additional contours can be produced cheaply and exchanged within seconds. A first comparison is planned between four classic contours (Beranek and Mellow 2019; Kolbrek 2008):

- **Exponential horns** expand their cross-sectional area exponentially along the axis. They load the driver well and have a well-defined low-frequency cutoff, but they "beam" at high frequencies: the coverage angle narrows as the frequency rises.
- **Conical horns** have straight walls. They offer the most constant directivity and the lowest distortion, but load the driver poorly at low frequencies; a conical horn would have to be impractically long to achieve good low-frequency output.
- **Hyperbolic horns** (hyperbolic-exponential, or "hypex", horns) form a family with a shape parameter. They reach their load impedance faster than an exponential horn, which improves low-frequency behavior, but low values of the shape parameter also increase distortion.

The sketch also addresses the placement of the devices in the room. A cross-line laser, mounted on a microphone stand, will be used to align the loudspeaker and the microphone so that their aiming axes meet on the wall at a right angle, and to measure the distances involved. The enclosure is designed to sit as close to the driver as possible, to keep sound pressure losses through air gaps low.

2. Component Tests

In parallel to the mechanical sketch, the electronic components already at hand were tested for the first time.

2.1. ESP32 (NodeMCU ESP32S)

Two NodeMCU ESP32S boards will form the control and processing core of the installation. The microcontrollers passed a first "Hello World" test[1], confirming that the boards and the Arduino toolchain are set up correctly. Next, communication between two boards was verified using ESP-NOW, a connectionless protocol built on the Wi-Fi hardware that allows direct communication between devices without a router; the example code provided in the Arduino IDE worked as is. ESP-NOW is well suited to exchanging control data between the two controllers, but it is not designed for streaming audio in its base configuration. The current plan is therefore to transmit the

[1]Using the blinking LED example in the Arduino IDE

audio signal between the two boards over Bluetooth (the A2DP profile) instead; this remains to be verified.

2.2. Analog Input and the ADC

Testing the analog input revealed a first obstacle. The ESP32′s built-in analog-to-digital converter (ADC) is non-linear and noisy, and its characteristics vary from chip to chip. Espressif provides a calibration driver to compensate for offset, gain and nonlinearity, but the calibration code I found online[2] did not work on the first attempt, so this issue is still open. Because the ADC is intended to capture the microphone signal, these limitations matter: for audio-grade sampling, the built-in ADC is at its limit. Adding an external ADC module with an I2S interface is a likely alternative and has been noted as an open task.

2.3. Microphone

The first microphone tested proved unusable for audio purposes: it was not sensitive enough and too noisy for the signal to be useful. This cannot simply be compensated for in software, since the ESP32′s ADC only adds to the problem. A replacement was ordered (see Procurement); if it still proves insufficient, a different solution — most likely a dedicated external ADC — will be needed.

2.4. Servo Motors

The servo motors intended for the gimbals were tested only in their basic function. An instructive mistake came early: powering a servo from the ESP32′s 5 V pin, as many tutorials suggest, drew so much current that the supply voltage sagged; the board's brown-out protection reset it, producing a boot loop. The servo was therefore driven undervolted from the 3.3 V rail, just enough to verify the sweep motion. This is not a test of real performance; the servos will require an external 5 V supply in the final setup. Calibration was deliberately postponed until proper powering is in place.

[2] https://embeddedprep.com/esp32-adc-beginner-friendly-guide/

3. Buy

The tests revealed the parts that were still missing. The following components were ordered:

- a **microphone with a built-in preamplifier**, expected to be significantly more sensitive than the previous one;
- a **miniature loudspeaker** (36 mm, 3 W, 4 Ω) as the driver for the horn;
- a **preamplifier for the loudspeaker** (3–5 W).

4. Next Steps

The immediate next steps are: connecting the new microphone and evaluating whether an external ADC is required, powering the servos from an external supply, building the first enclosure and horn, and closing the first feedback loop between microphone and loudspeaker. Only then can the artistic and empirical questions of the project — how the wall, the horn and the signal processing shape the feedback — be considered.

Bibliography

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