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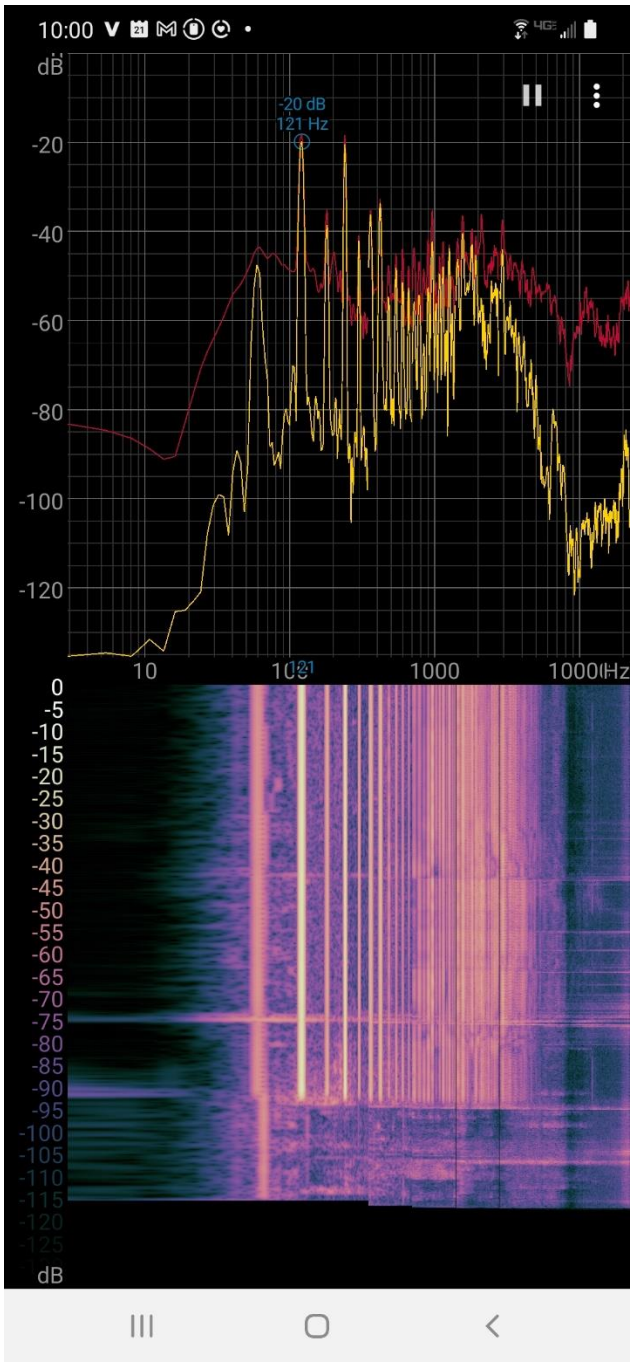
The Physics of Faraday Shielding and Star Grounding in a Semi-Hollow Guitar (ES-335)

Noise Spectrum – Note the spectral spike around 120 Hertz (AC rectified ripple)



Introduction

Electric guitars like the ES-335 are extremely sensitive electrical systems. Pickups are designed to detect tiny changes in magnetic fields from vibrating strings—but they also unintentionally pick up unwanted electrical noise from the environment which dramatically affects tone. This document addresses proper wiring harness design to minimize noise and hum as well as a suggested pedal order for better tone and noise suppression. At the end of this document is a wiring schematic diagram that implements the concepts for tone and noise reduction explained in this document.

How Noise Affects Tone

Tone vs Noise: What's Really Happening

Your guitar signal is **tiny**.
Your amp and pedals make it big.

The problem:

- They don't just amplify your tone
- They amplify **everything riding along with it**

Simple Model: Music + Garbage in the Same Pipe

Think of your signal like **clean water with a flavor (your tone)**.

Noise and hum are like:

- Dirt
- Sand
- Tiny air bubbles

All mixed into that same stream.

When you turn up your amp:

- You're not just making the flavor stronger
- You're also making the **contamination stronger**

Two Main Types of Noise You Had

1. Random Buzz / Hash (Electric Field Noise)

This is:

- Lights
- Power supplies
- Electronics in the room

What it does to tone:

- Adds a **grainy, fuzzy layer** on top of your sound
- Kills clarity

Water analogy:

Like **static or grit** in the water—you lose smoothness

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2. Hum (60 Hz / 120 Hz)

This is:

- A steady low-frequency tone underneath everything

What it does to tone:

- Masks low-end detail
- Makes everything sound **muddy and less defined**

Water analogy:

Like a **constant vibration in the pipe** that shakes everything

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Why Noise Hurts Tone (Even If You "Don't Notice It")

This is the part most players miss:

Noise doesn't just sit quietly—it competes with your signal

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1. It Reduces Dynamic Range

Dynamic range = difference between quiet and loud notes

With noise:

- Quiet notes get buried

- Loud notes feel less impactful

Analogy:

Trying to hear a whisper in a noisy room

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2. It Blurs Detail

Your tone has:

- Attack (pick hit)
- Harmonics (richness)
- Sustain (decay)

Noise fills in the gaps and smears those details.

Analogy:

Like looking through **foggy glass instead of clear glass**

---

3. It Interferes with Harmonics

Your pickups capture very complex overtones.

Noise:

- Adds unrelated frequencies
- Interferes with those harmonics

Result:

- Less “3D” sound
- Less warmth and sparkle

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4. Distortion Makes It Worse

When you use:

- Overdrive
- Fuzz
- Compression

You're increasing gain.

That means:

- Noise gets amplified **just like your tone**

Analogy:

Putting both your music and your garbage through a **magnifying glass**

What Your Shielding Did for Tone

Your Faraday shielding:

- Blocked external electric noise before it entered your signal

Result:

- **Cleaner high end** (less fizz)
- **More clarity in chords**
- **Better note separation**

Water analogy:

You stopped dirt from entering the pipe at all

What Your Star Ground Did for Tone

Your star ground:

- Eliminated ground loops
- Stopped circulating currents (internal hum)

Result:

- **Tighter low end**
- **Less muddy bass**
- **More stable, focused sound**

Water analogy:

You fixed the plumbing so water flows straight instead of swirling

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The Combined Effect on Tone

This is the big payoff:

Before:

- Signal + noise mixed together
- Blurry, smeared tone
- Hidden detail

After:

- Mostly pure signal
- Clear, defined tone
- More responsive to playing

What You Probably Noticed (Even If You Didn't Realize Why)

After your mods, your guitar likely feels:

- More **touch sensitive**
- More **articulate**
- Less "fizzy"
- More "hi-fi" or "open"

That's not placebo—that's physics.

Why Cleaner Signal = Better Feel

Tone isn't just what you hear—it's how it responds.

With less noise:

- Your picking dynamics come through
- Subtle differences matter more
- Sustain sounds smoother

Analogy:

Like driving on a smooth road vs a bumpy one

Final Simple Model

Think of your tone like **a voice**:

- Noise = crowd talking over you
- Shielding = soundproofing the room
- Star grounding = fixing the mic wiring

Now:

- Your voice is clear
- Every word is heard
- No background chaos

Bottom Line

Noise doesn't just make your rig louder—it makes your tone worse by:

- Reducing clarity
- Masking detail
- Killing dynamics

Your shielding + star grounding didn't just remove hum—they:

→ Unlocked the true tone your guitar already had

Shielding and Grounding

Two of the most effective ways to reduce that noise are:

- **Faraday shielding**
- **Star grounding**

To understand why these work, we need to look at two invisible forces in the air around us:

- **Electric fields (E-fields)**
- **Magnetic fields (B-fields)**

Electric Fields (E-fields): Like Water Pressure in the Air

An electric field is created by voltage—like the voltage in your house wiring, lights, wall warts, etc.

Simple analogy:

Think of an electric field like **water pressure pushing in all directions**.

- If your guitar wiring is exposed, it's like **open pipes sitting in a rainstorm**
- That "rain" is electrical noise constantly hitting your circuits

Your guitar wiring acts like an antenna and "collects" that noise.

Faraday Shielding: Building a Metal Roof

When you line your guitar cavities with conductive material (copper foil, conductive paint, etc.), you create a **Faraday cage**.

What it does:

- It gives all that "electrical rain" somewhere else to go
- Instead of hitting your signal wires, the noise hits the shield

Water analogy:

Imagine:

- Your wiring = a dry floor you want to protect
- Noise (E-fields) = rain
- Shielding = a metal roof with gutters

The rain hits the roof, flows along it, and drains away—never touching the floor.

Physics version:

- Electric fields push electrons around on the shield surface
- Those electrons move to cancel the field inside
- Result: **inside the shield = electrically quiet zone**

Why Shielding Must Be Grounded

If you don't connect the shield to ground, it's like:

- Building a roof with **no drain**

Water (noise) hits it… but has nowhere to go.

When grounded:

- The noise current flows **into ground**
- Like water draining into a pipe

So grounding the shield is essential—it completes the system.

Magnetic Fields (B-fields): A Different Problem

Magnetic fields come from current (like transformers, power supplies, amps).

Key point:

- **Faraday shielding does NOT stop low-frequency magnetic fields well**

Water analogy:

If E-fields are rain…

- B-fields are more like **slow-moving waves passing through walls**

They don't care much about your "roof."

That's why:

- You still get **60 Hz hum** even with perfect shielding
- Humbuckers help because they cancel magnetic interference internally

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Star Grounding: One Drain Instead of Many

Grounding is where many guitar builds go wrong.

If you connect grounds randomly, you create **loops**.

What is a ground loop?

A loop is when current has **multiple paths** to return to ground.

Water analogy:

Imagine your house plumbing:

- Instead of one drain, you have **multiple interconnected pipes**
- Water starts circulating in circles → turbulence, noise, chaos

That circulating current = **hum**

Star Grounding: The Single Drain System

Star grounding means:

- Every ground connection goes to **one single point**
- Usually the **output jack sleeve**

Water analogy:

- All pipes go directly to **one main drain**
- No loops
- No circulation
- Smooth, quiet flow

Why Star Grounding Reduces Noise

In real physics terms:

- Any wire has resistance
- When current flows through ground wires, small voltage differences develop
- These differences create unwanted signals (noise)

With loops:

- Those tiny voltages get amplified
- They circulate → hum

With star grounding:

- No loops = no circulating current
- Everything references the same exact ground point

How Shielding and Star Grounding Work Together

Think of the full system:

Shielding:

- Catches the “rain” (electric field noise)

Grounding:

- Provides the “drain” for that noise

Star grounding:

- Ensures the drain system is clean and non-turbulent

If you only do one:

- Shielding without good grounding → noise builds up
- Grounding without shielding → noise still gets in

Together:
→ You get **maximum noise reduction**

Why Your ES-335 Benefited So Much

Semi-hollow guitars are especially prone to noise because:

- Large internal air volume = more space for fields to couple
- Long wire runs = more antenna effect
- F-holes allow external fields in

By adding:

- Full shielding (Faraday cage)
- A clean star ground
- Tailpiece grounding tied properly

You effectively:

- Blocked incoming electric noise
- Eliminated ground loops
- Gave noise a clean path to exit

What Noise Still Remains (and Why)

Even with a perfect setup, you may still hear:

1. 60 Hz hum

- Caused by magnetic fields
- Not fully stopped by shielding

2. Pedal noise

- Comes from power supplies and internal circuits
- Needs isolation and filtering (which you've already worked on)

Final Mental Model (Simple Summary)

Think of your guitar like a house:

- **Electric noise = rain**
- **Shielding = roof**
- **Ground = drain**
- **Star grounding = single clean plumbing system**

If everything is done right:

- Rain hits the roof
- Flows into the gutter
- Drains cleanly away
- Your house (signal) stays dry and quiet

Conclusion

Faraday shielding and star grounding aren't magic—they're just smart control of how electrical energy moves.

- Shielding **blocks and redirects noise**
- Grounding **removes it**
- Star grounding **keeps it from circulating**

What you achieved with your ES-335 is essentially turning a noisy antenna into a **controlled, quiet electrical system**—which is exactly what high-end studio gear tries to do.

Why You Hear ~120 Hz Instead of 60 Hz

In the U.S., wall power is **60 Hz**. So naturally you'd expect hum at 60 Hz.

But you're mostly hearing **120 Hz**. That's not random—it comes from **rectification inside power supplies**.

Step 1: AC Power = A Back-and-Forth Wave

Your wall power is like water sloshing back and forth:

- 60 times per second → 60 Hz
- Voltage goes **positive → negative → positive → negative**

Water analogy:

Think of it like a wave rocking left and right in a pipe.

Step 2: Rectifier Diodes Flip the Negative Side

Inside:

- Pedals
- Amps
- Wall wart power supplies

There are **rectifier diodes** that convert AC → DC.

A full-wave rectifier takes the negative half of the wave and **flips it upward**.

This is the key relationship:

$$f_{ripple} = 2f_{AC}$$

So:

- 60 Hz AC → **120 Hz ripple**

Step 3: Imperfect Filtering = Ripple (Your Noise)

After rectification, capacitors try to smooth the signal.

But they're never perfect.

What's left:

- A small up-and-down ripple at **120 Hz**

Water analogy:

- Rectifier = turning waves into pulses all going one direction
- Capacitor = a reservoir smoothing the flow
- Bad filtering = you still see **ripples in the water**

That ripple leaks into your audio path → **you hear it as hum**

Why Your Guitar Fix Didn't Remove It

Your shielding + star grounding mainly attack:

- **Electric field noise (E-fields)**
- **Ground loop noise**

But 120 Hz ripple is:

- Already **inside your power system**
- Not coming from the air

So your guitar can't fully stop it—it's downstream of that.

Where Your 120 Hz Is Actually Coming From

Based on your setup, the likely culprits are:

1. Pedal power supply

Even "isolated" supplies can still leak ripple.

Especially:

- Cheaper switch-mode supplies
- Shared internal grounding

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2. Noisy pedals (you already identified them)

You mentioned:

- Behringer compressor
- Tube overdrive

These are classic offenders.

Why?

- Cheap filtering caps
- High gain stages amplify ripple
- Poor internal grounding

Water analogy:

These pedals aren't just letting ripple pass…
They're **amplifying the waves like a pump**

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3. Gain stacking

When you chain:

- Compressor → Overdrive

You're boosting:

- Signal ✓
- Noise ✓✓✓

Why It Sounds Like a "Clean" Hum Now

Because you fixed:

- Random buzz
- RF noise
- Ground loops

What's left is:

- A **pure, steady 120 Hz tone**

That's actually a sign your system is now **well-controlled**.

How to Reduce 120 Hz Further

Now we're in "fine tuning" territory.

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1. Improve Power Filtering

Think: bigger, better reservoir

- Higher quality isolated supply (truly isolated transformer outputs)
- Or add extra filtering (like you started experimenting with)

You already noticed:

Adding capacitors helped

That's exactly right.

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2. Upgrade or Isolate Noisy Pedals

Your biggest gains will come from:

- Replacing the noisiest pedals
- Or powering them separately

Even one bad pedal can contaminate everything.

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3. Gain Staging (Huge Impact)

Try:

- Lower compressor sustain
- Lower overdrive gain
- Raise amp volume instead

Principle:

Don't amplify noise early—amplify signal late.

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4. Physical Separation

Keep:

- Power supplies away from pedals

- Cables away from transformers

Magnetic coupling can still sneak in.

Final Simple Model

Let's combine everything:

Before your fixes:

- Rain (E-field noise) getting in everywhere
- Plumbing loops (ground loops) causing chaos
- Plus ripple waves

→ Messy, noisy system

After your fixes:

- Roof installed (shielding) ✓
- Clean drain system (star ground) ✓
- Only remaining issue: **waves inside the water supply**

→ That's your 120 Hz ripple

Bottom Line

- **60 Hz noise** = environmental magnetic hum
- **120 Hz noise** = power supply ripple

You've already eliminated the harder, messier problems.

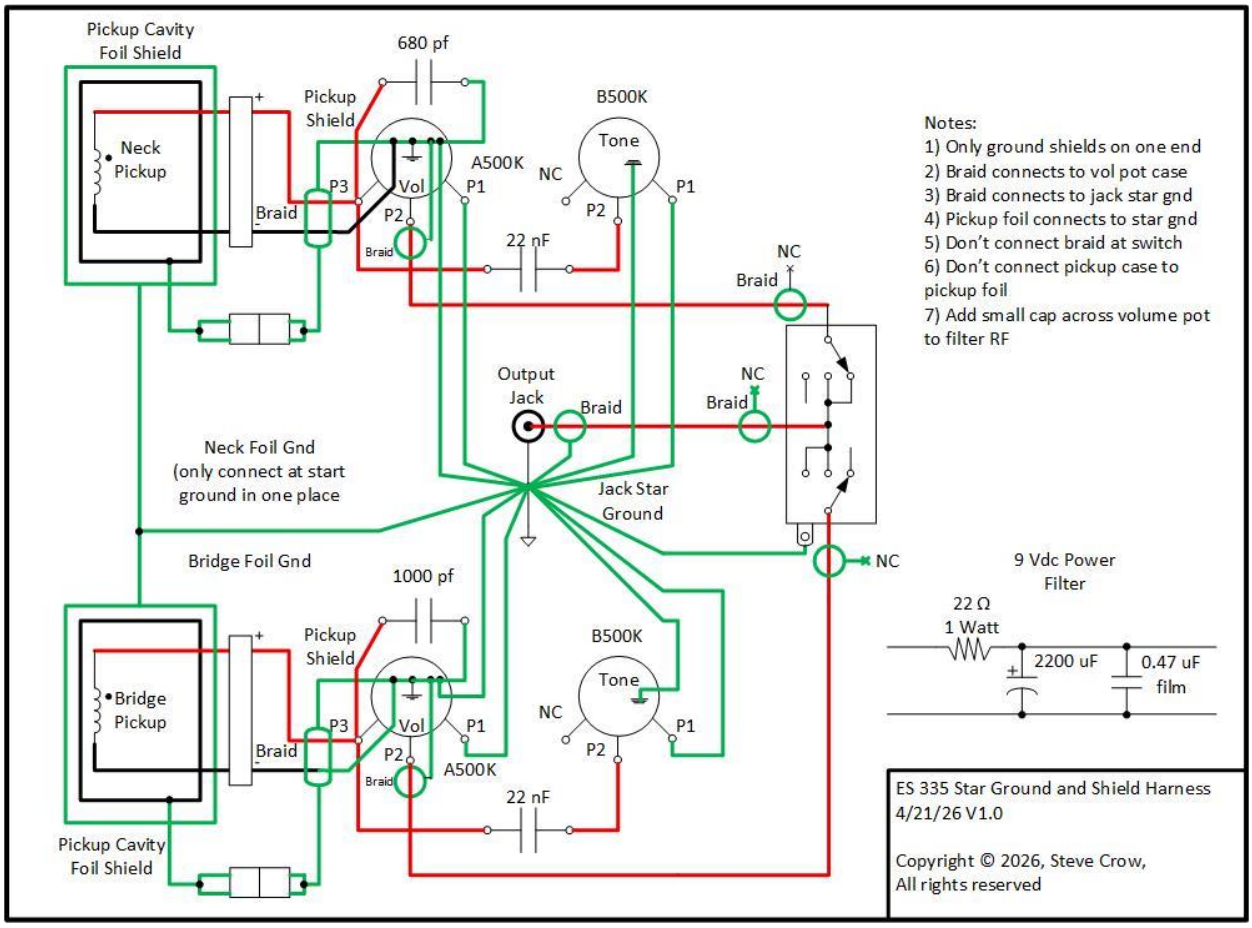
What you're hearing now is:

The "last 10%" — and it lives in power filtering and pedal quality

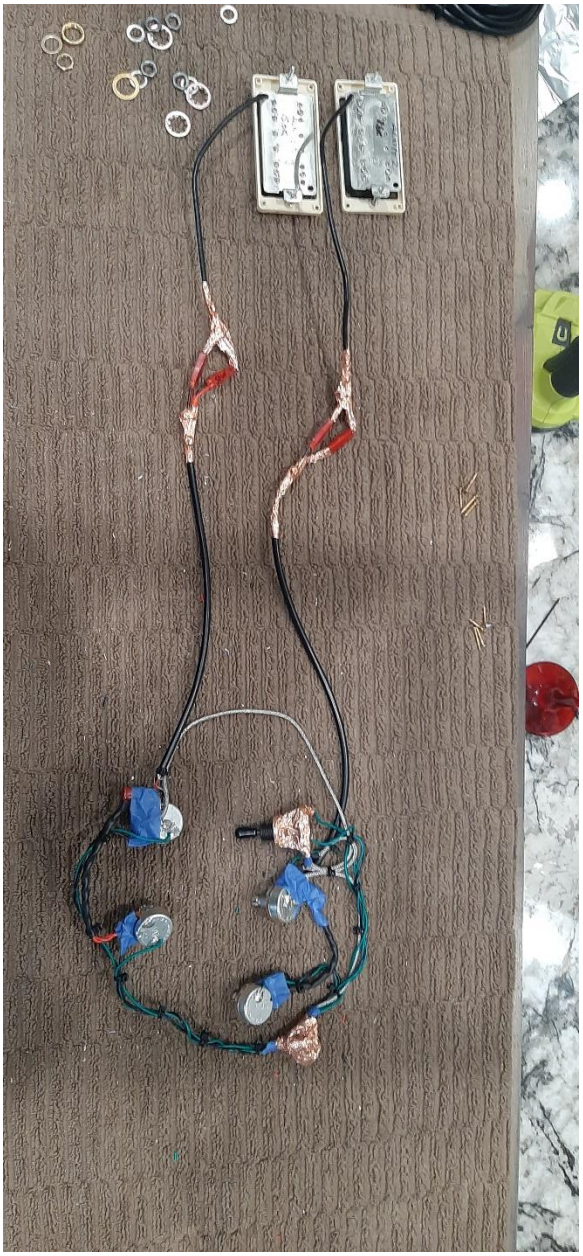
ES 335 Wiring Harness Foil Shield and Star Ground System

Harness Wiring Diagram

Due to the fact there is no cavity access in a typical ES 335 to apply copper foil shielding inside the cavity and around the electronic components, the foil shield is wrapped around individual components. The foil is connected only at one end for each component to the Jack star ground. This provides Faraday shielding around the components. The pickup cavities can be lined with copper foil and then grounded to a single point at the Jack star ground. Do not connect the pickup body/case to the copper foil shield. You can use a two conductor with shield to connect the pickup to the volume pot (signal +, signal -, shield). If using connectors for the pickups to accommodate easier pickup swap use a three pin connector or two, two pin connectors. If using two pin connectors run a separate connection of the pickup's cable shield. The schematic below depicts this methodology of Faraday shielding and star ground system. This minimizes ground loops and antenna action picking up erroneous signals as described above (electromagnetic interference – EMI). The star ground system is the interference "drainage" system.



ES 335 Harness



Best Pedal Order (Low Noise + Good Tone) and Why

Guitar → Compressor → Overdrive → Fuzz → Reverb → Amp

Why This Order Works

1. Compressor First

Guitar → Compressor

What it does:

- Evens out your signal (boosts quiet parts, tames loud ones)

Water analogy:

Your guitar signal is like water coming out in bursts:

- Some strong
- Some weak

The compressor turns that into a **steady flow**

Why it goes first:

- It works best on your **clean, natural signal**
- If you compress later, you'll also compress **noise and distortion**, which makes things worse

---

2. Overdrive Next

→ Overdrive

What it does:

- Adds mild distortion and warmth
- Boosts mids

Water analogy:

This is like adding **controlled turbulence** to your smooth flow

Why before fuzz:

- Overdrive is **more subtle and controlled**

- It shapes the tone before the “wild” fuzz hits

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3. Fuzz After Overdrive

→ Fuzz

What it does:

- Heavy, raw, aggressive distortion

Water analogy:

This is like turning your flow into a **chaotic, crashing river**

Why it goes here:

- Fuzz reacts strongly to what comes before it
- Putting it after overdrive gives you:
    - More control
    - Less harsh randomness

⚠ Note:
Some vintage fuzzes prefer being first—but modern rigs (especially yours, focused on low noise) usually sound cleaner and more controlled this way.

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4. Reverb Last

→ Reverb → Amp

What it does:

- Simulates space (room, hall, etc.)

Water analogy:

This is like taking your finished signal and putting it into a **big echoing canyon**

Why reverb MUST go last:

If you put reverb earlier:

- Distortion pedals will **distort the echoes**
- That creates **muddy, noisy mess**

If it's last:

- Your tone is already shaped
- Reverb just adds space around it

Noise Perspective (Important for Your Setup)

You've already done great noise reduction, so order matters even more now.

This layout minimizes noise because:

- Compressor early → doesn't amplify pedal noise
- Gain stages (OD + fuzz) are grouped → predictable behavior
- Reverb last → doesn't feed noise back into distortion

What Happens If You Change the Order

Fuzz before overdrive

- More chaotic
- Less controlled
- Can get noisy fast

Compressor after distortion

- Boosts hiss and hum (bad with your 120 Hz issue)

Reverb before distortion

- Turns clean echoes into distorted noise clouds

Final Simple Model

Think of your signal like water going through stages:

1. **Compressor** → smooths the flow
2. **Overdrive** → adds light turbulence
3. **Fuzz** → creates heavy chaos
4. **Reverb** → puts everything into a big space

If you mix the order, it's like:

- Trying to smooth water after it's already crashing
- Or echoing noise before shaping it

One Small Adjustment You Can Experiment With

If your fuzz feels weird or gated:

Try:
Guitar → Fuzz → Compressor → Overdrive → Reverb

But only if needed—your original order is the best starting point for:

- Low noise
- Clean control
- Predictable tone