Signal Path Secrets

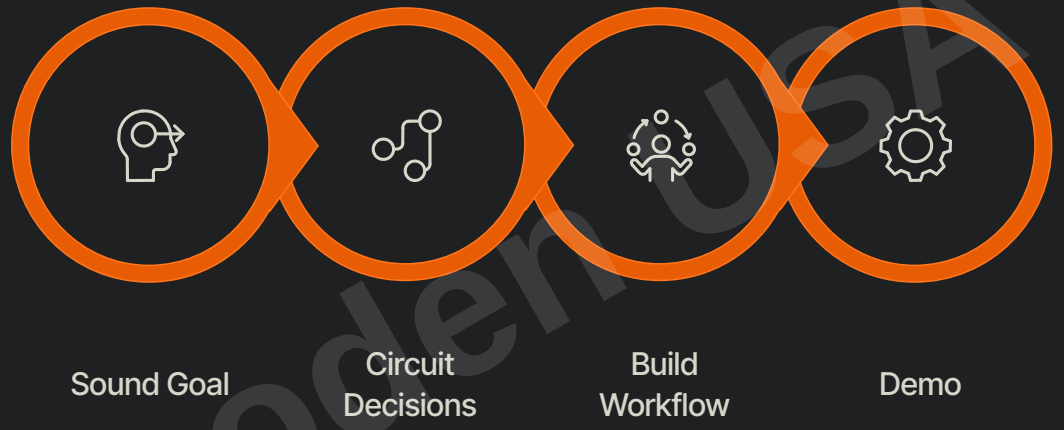
The Engineering Story Behind the Useful Arts Hornet

IEEE Consultants Network of Long Island (LICN)

Presenter: Peter Swann I Useful Arts Audio / Neoden USA

What We'll Cover

A single product. An end-to-end engineering case study. From the original sound goal to a finished product you can hold in your hand.



The Idea

Where the Hornet comes from, the sound I was chasing, the philosophy, and the constraints set before touching a schematic.

The Design

How a microphone preamp actually works, every stage of the Hornet's signal path in detail, and the power supply decisions.

The Build

How the Design becomes a physical product. The decisions I made, why I made them, and the iterations, failures, and breakthroughs along the way..

The Demo

A live manufacturing run on the ND10.

The Self-Taught Path: Learning by Doing

You don't always need a degree. But you do need persistence, resources, and a willingness to grow through failure.

Decades of Hands-On Learning

Buying, modifying, and repairing pro audio gear across every format and era.

Founded Neoden USA (2017)

Providing a solution to manufacturing by bringing in affordable SMT pick-and-place machine.

Founded Useful Arts Audio (2016)

Vintage philosophy with modern execution. No compromise on sound.

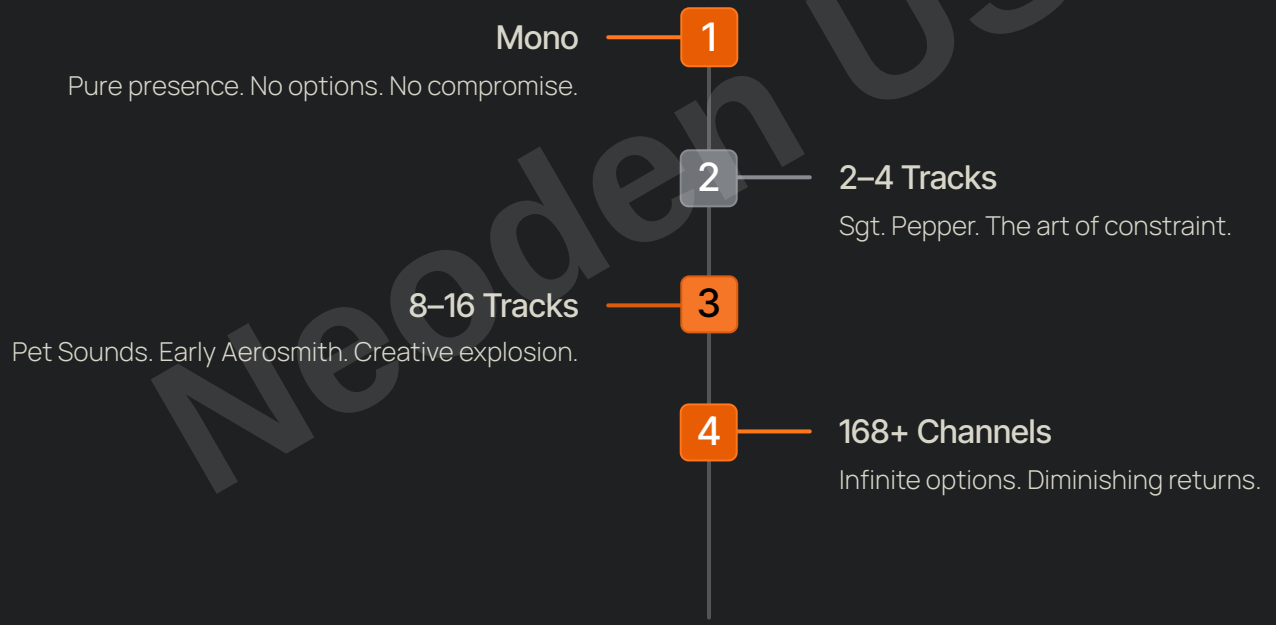
The Hornet

The convergence of both companies. Designed, sourced, and assembled in-house.

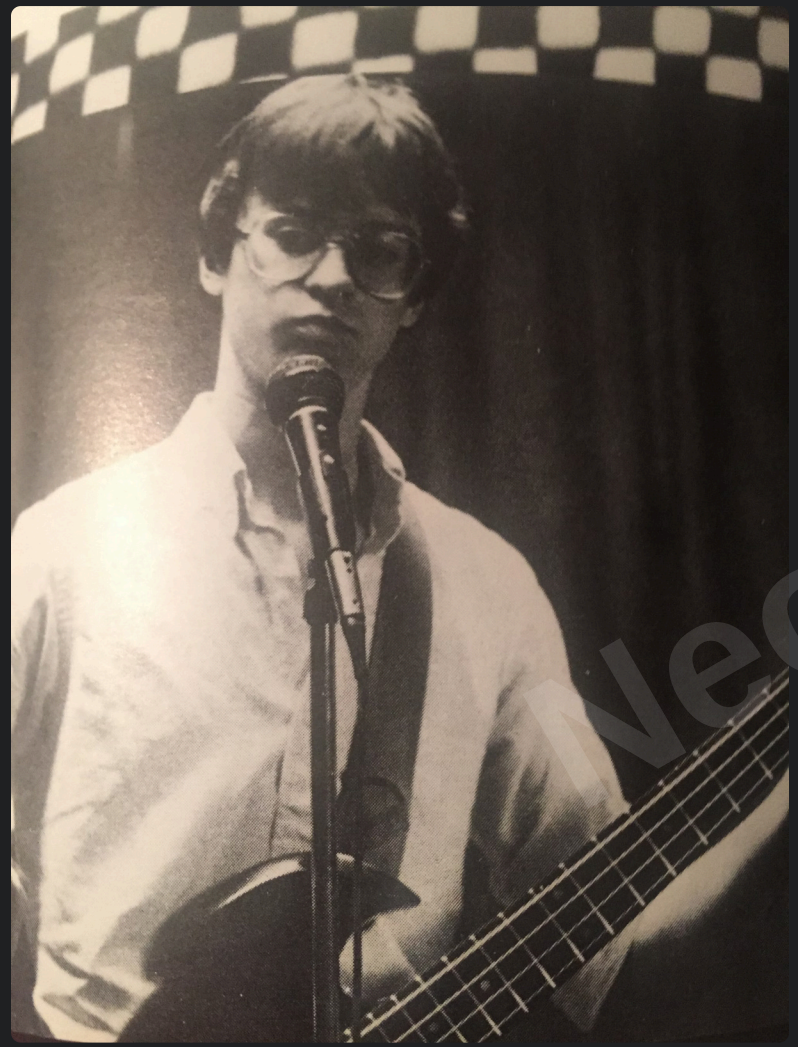
The Obsession That started It All

My earliest memories are at the UCLA film school. Music wasn't something I discovered… it was just always there.

> *"The whole industry was born during my childhood"*



A Teenage Milestone — I recorded in a professional New York studio before most people my age had ever seen one. That experience never left me.



We all Start Somewhere

First audio business: Luddite Electric Amplifiers

The Sound Money Couldn't Buy

As a lawyer and judge, I had access to everything on the market. But the sound I was chasing remained out of reach.

> "I couldn't buy the sound I wanted. So I had to build it."

The Sound

Chet Baker, *My Funny Valentine*, 1954. Present. Intimate. Like he's whispering in your ear.

The Problem

That sound is hard to obtain these days.

The Industry Optimized for the Wrong Things

The disappearance of that 1950's audio presence and intimacy.

The Channel Count Explosion

8 → 24 → 32 → 168+ channels. Tubes couldn't scale. So they disappeared.

The Paradox of Infinite Choice

When you can do anything, you're inspired by nothing.

The Barrier Is Gone

Recording used to cost $2,000/hour (*today's currency). Only the best got through the door. That filter produced extraordinary music.

The Gap

We're still listening to 50-year-old recordings. There's a reason for that.

The Philosophy Behind the Product

The soul of the product: How do we use sonics to translate the intimacy of a human performance?

Useful Arts Audio Products

The Goal: Make a product as good as I can for an affordable price.

1

The Question

If this is all I know, what's the best signal chain I can build? The constraint forces quality.

2

The Problem

Modern gear chases 0.0001% THD. Technically perfect. Sonically flat.

3

The Insight

The brain doesn't hear pitch directly. It hears *harmonics.* Play with harmonics and you play with how alive something sounds. In 1954 it was just guys with soldering irons.

4

The Solution

RCA Radiotron Handbook, military manuals. The complete knowledge base of a 1954 engineer. A control that lets the user choose how much harmonic distortion they want.

Why Even Do This?

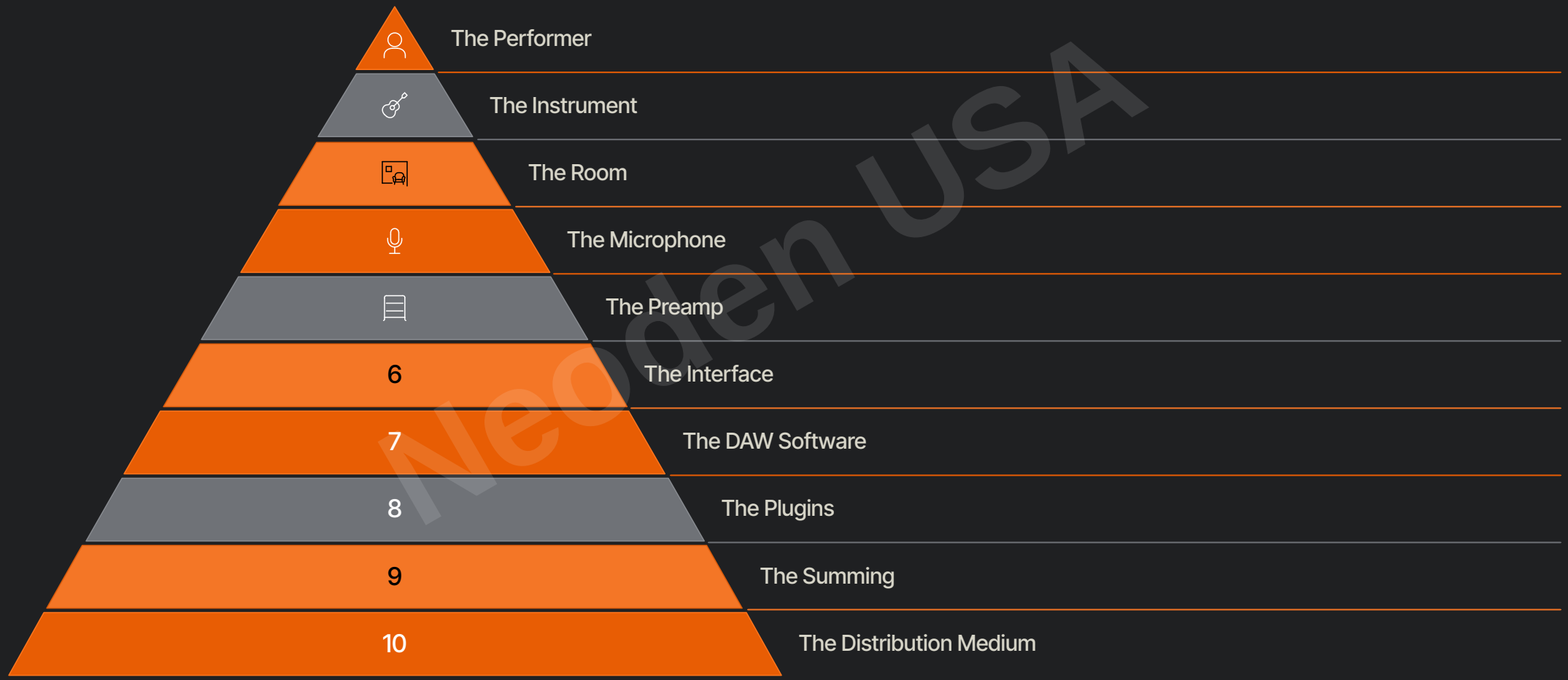
You can amplify a mic signal with a single chip on a board and most mass-marketed products do just that.

Who needs these products?

Why do we care?

The way a recording sounds can either frustrate or inspire the artist and the audience.

In recording, the importance of each element follows the order of the process. Get it wrong early and nothing downstream fixes it. It's always easier to get it right the first time than to fix it later.



Define "Good" Before You Start:

Bridging the gap between subjective performance and traditional measurements.

01

Power Supply

The only thing the audience hears is the power supply and it had better be good.

02

Headroom

How much signal before unpleasant clipping or saturation? .

03

Input Circuitry

Mic and instrument inputs have different requirements.

04

Parts Cost

All of the above. Parts cost below $70. That's the Hornet design challenge. Industry standard for parts cost is ~10-20% of retail. I always go above that.

05

Maximum gain Target

60dB is the standard today.

06

Where to Compromise

Wall warts, knobs, meters, buttons, potentiometers...

What They Got Right That We Forgot

A shared experience through music. When an album came out, everyone listened to the same thing. It defined what it was like to live in that time.

3% THD Was Excellent

By today's standards that's terrible. But what lives between 3% and 0.0001% is where *character* resides.

Simplicity Is the Feature

One mic, one speaker, mono: You get Chet Baker.

The Sweet Spot

0.4–0.6% THD. Not sterile or broken. Musically alive.

3%

1954 Gold Standard

0.5%

The Sweet Spot

0.0001%

Modern "Perfect"

How It Actually Works

Before we go over the Hornet, here's what a mic preamp does and how it works.

What is a Microphone Preamp?

A microphone preamp is the first amplification stage in the recording chain.

Core Idea

A preamp is an audio device that boosts a microphone's weak signal from mic-level up to line level.

Purpose

Microphones output a very weak signal, which is too quiet to send directly into most recording gear. The preamp raises the signal from ~1 milivolt to 1 volt - enough for converters, recorders, and other studio gear to use cleanly.

Why it Matters

- Provides a strong enough signal of ~1 volt.
- What you're hearing is the power supply for the amplifier, so you need to focus on the power first.
- If ADCs had to work without a preamp, they would be measuring microvolt differences directly, which is not feasable with electronics known today.

Key points:

- Microphone output = very low-level signal
- Line level = stronger, standardized signal used by interfaces and processors
- The preamp makes the signal usable for recording and further processing

The Analog to Digital Transition

Typical Signal Path

The preamp sits between the microphone and the audio interface, preparing the signal before digitization.

Bottom Line

A microphone preamp is the bridge between a weak analog source and the rest of the recording chain. And ultimately, almost all sources begin as analog.

The Product

What I was trying to build and why.

I Was a Tube Snob

Every product I'd ever built was tubes. Then Jerry Barnes said something that changed that.

> "Kids today aren't going to buy a $3,000 rack-mount tube preamp. They want a studio in a backpack."

The Tube World

Hot, heavy, expensive, high voltage. Extraordinary sound. Totally impractical for a portable product.

The Challenge

Same philosophy. Same sonic goals. Solid state execution. $300 price point. Could it be done?

A Studio in a Backpack

The Modern Rig

MacBook, cheap interface, plugins. Capable and affordable, but missing something real.

The One-Box Solution

Add one box to the chain and everything sounds like it went through a real console.

Why Not Tubes?

Hot, heavy, expensive, high voltage. A backpack tube product is physically impossible, except as a marketing gimmick. Digital plugins can do amazing things, but they work best with good data to start with.

Meet the Hornet

An affordable, portable preamp/DI that goes toe to toe with $8,000+ preamps on the market.

Ultra Low-Noise Front End

Creamy thickness, bite, and power — even at 60 dB of gain.

Color Control

Adds personality without compression or EQ.

Tiny Form Factor

Studio-grade performance in a backpack-friendly enclosure.

~60dB
Max Gain

$300
Retail Price

$8K+
What It Competes With

Discrete gain cell. Custom Cinemag transformer. JFET DI. One PCB.

"The BlackBird Sessions"

Compares a million dollar neve consul to the Swarm (same as hornet)

YouTube

Useful Arts -- The Blackbird Sessions

This past summer, after the NAMM show in Nashville, we had the honor of booking some time at the legendary Blackbird Studios in town. There, we unveiled the...

Marrying Old Philosophy with Modern Technology

The Hornet is a **70s inspired audio product with the best available modern components.**

Signal Path

Making decisions around sound quality and affordability

Parts

PSU, metering, controls, and SMT assembly is fully modern throughout.

The Exception

Tubes and transformers. The originals are still hard to beat, so I kept them.

SMT as Enabler

Surface mount isn't a compromise. It makes better components accessible at dramatically lower cost.

Where to Compromise

Every decision was deliberate. The question was always: **will the customer feel this?**

Making the Engineering Work With the Economics

Cost constraints vs design decisions.

$300 Retail

After distributor margin, retailer margin, parts, and overhead: ~$50 build cost ceiling.

~$4 Enclosure

Guitar pedal box, molded in China, painted and ready. The box does its job and nothing more.

One PCB

One pass through the pick-and-place machine.

$20 Transformer

The most expensive component in the box. The one I absolutely refused to cut.

What I Cheaped Out On and Why

The Meter — LM3916

A 1980s chip. No longer manufactured. Sourced from eBay. All it does is show something's happening.

The Switches

No relays in the signal path. Basic mechanical switches.

Coupling Capacitors

$6 polypropylene film in the tube units. Inexpensive SMT ceramics and electrolitics in the Hornet.

Magnetism

A transformerless circuit is cheaper, simpler, and technically adequate. I use transformers anyway.

Transformerless

Lower cost. Fewer components. Perfectly functional. Used by virtually every preamp at this price point.

With Transformers

More expensive, but you get more isolation, impedance interaction, and character. Adds butter to the sound.

> "One of my philosophical choices in life that keeps costing me money: I don't worry so much about profit margin. I make it as good as I can make it."

Analog oscilloscope

$6 vs. 8 Cents

Same job. Very different components. This is what principled cost tradeoffs look like in practice.

Tube Units — $6 Film Cap

Polypropylene film. 600V rated. Size of a D-cell battery. Audibly different in a high-voltage tube circuit.

Hornet — 8¢ SMT Ceramic

Surface mount. Tiny. Distortion characteristics consistent with the sonic goal of the unit. Same function, 75x price difference.

Knowing when each is appropriate can have a big impact.

9 Cents vs. $30

The BC846C costs about 9 cents. A tube costs $30 and needs 200+ volts to operate. Both amplify a signal. Only one fits in a backpack.

Vacuum Tube

Extraordinary character. Expensive. Hot. High voltage. Requires custom enclosures and serious safety considerations.

BC846C Transistor

9 cents. High voltage for a transistor. High hfe. Great sound. Drop one on the floor and grab another from the reel

What I Never Compromised

Three areas where cutting cost would directly degrade the output. **No cuts made.**

Gold-Plated XLR Connectors

Anything plugged and unplugged constantly must not fail. Connector quality is felt on day one and day one thousand.

The Full Signal Path

Transformer in. Discrete gain cell. Color control. Transformer out. No shortcuts, no substitutions.

Internal Voltage

Spent more on the op amp to maintain 38.6V throughout. The headroom is what makes the output stage sound the way it does.

Why This Architecture Is Unusual at $300

Most preamps at this price point skip the important parts. I didn't.

No Input Transformer

What virtually every $300 preamp does. Works fine. No character.

No Discrete Gain Stage

Most use a monolithic IC. Cheaper, simpler, and far less control over the sound.

The Hornet

Custom Cinemag transformer in. Discrete gain cell. Color control. Transformer out. Closer to a $2,000 preamp than a $300 one.

Into the Signal Path

Every stage. Every decision. Every reason why.

The Signal Journey

Discrete gain cell. Custom Cinemag transformer. JFET DI. One PCB. One pass through the machine.

Stage by Stage

Here's what actually happens to the signal as it moves through the Hornet.

01

48V Wall Wart

External supply. All switching stays outside the box.

02

Linear Regulator and Capacitor Multipliers

Cleans up the power. Distributes stable rails to every stage.

03

Input Transformer

First thing the mic signal sees. Isolation, impedance interaction, and character.

04

Input Switching

Routes signal from mic/line or DI input into the main signal path.

05

Discrete Gain Cells

Amplification. One cell includes the Color Control.

06

OPA 454 + Output Transformer

Current drive and balanced XLR output.

Two Ways to Amplify a Signal

Not all amplification is the same. Understanding the difference explains several key decisions in the Hornet's architecture.

Voltage Gain

Increases the voltage of the signal. What most people think of when they think "amplifier." Used in the discrete gain cell stage.

Current Gain

Increases the current driving capability. Critical for driving the output transformer. Why the OPA 454 op amp exists in this circuit.

The discrete gain cells primarily handles voltage gain. The op amp typically handles current gain.

Two Inputs. One Signal Path.

The Hornet handles two very different input types. Input switching is how they meet.

Mic/Line Input

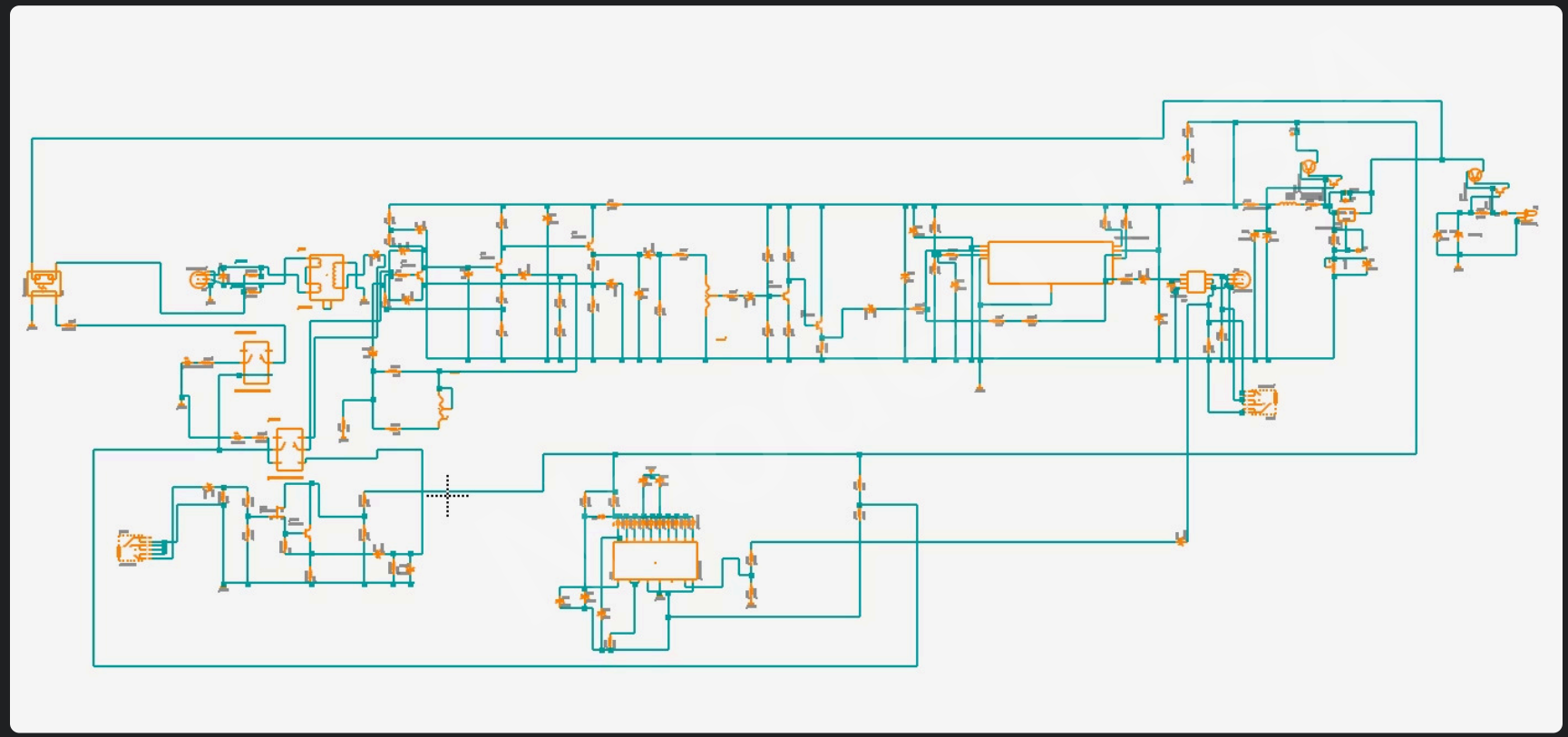
Low impedance. Small signal. Comes in through the input transformer first before entering the main signal path.

DI Input

High impedance. Instrument level. JFET stage optimized for direct instrument use. Feeds into input switching downstream.

Why JFET? Instruments like guitars have a very different electrical output than microphones. A JFET input stage presents the right impedance and handles the signal correctly before it joins the main signal path.

Schematics



Gain Structure: How 60 dB is Distributed

- Passive voltage gain from transformer rejected in this design: 1:1 transformer
- No more than 15 dB gain per stage
- NFB rarely used and very intentional
- All single-ended design

Running an Op Amp on a Single Supply

Most op amps (and many discreet stages) are designed to run on a split supply: positive and negative rails. The Hornet runs the OPA 454 on a single supply. Here's what that means and why it matters.

Split Supply

Positive and negative rails. The op amp's reference point sits naturally at zero. Standard approach for most designs.

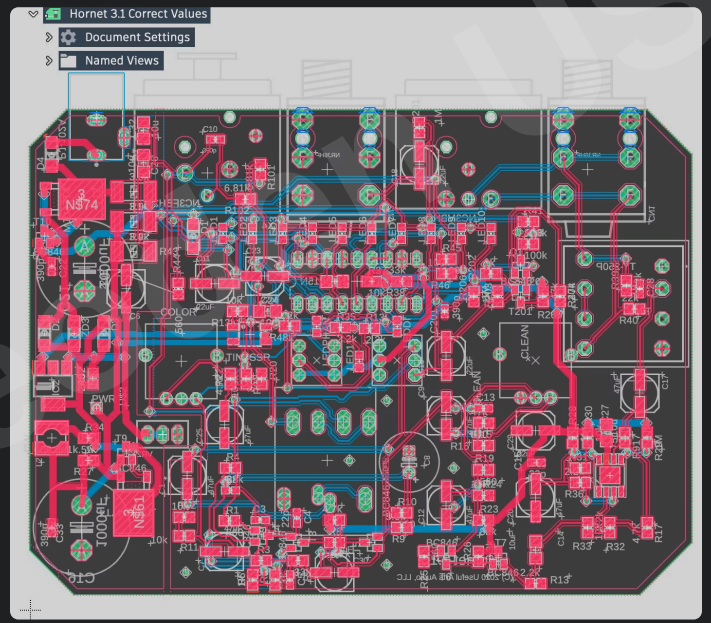
Single Supply

One positive rail. The reference point is created artificially, typically at half the supply voltage.

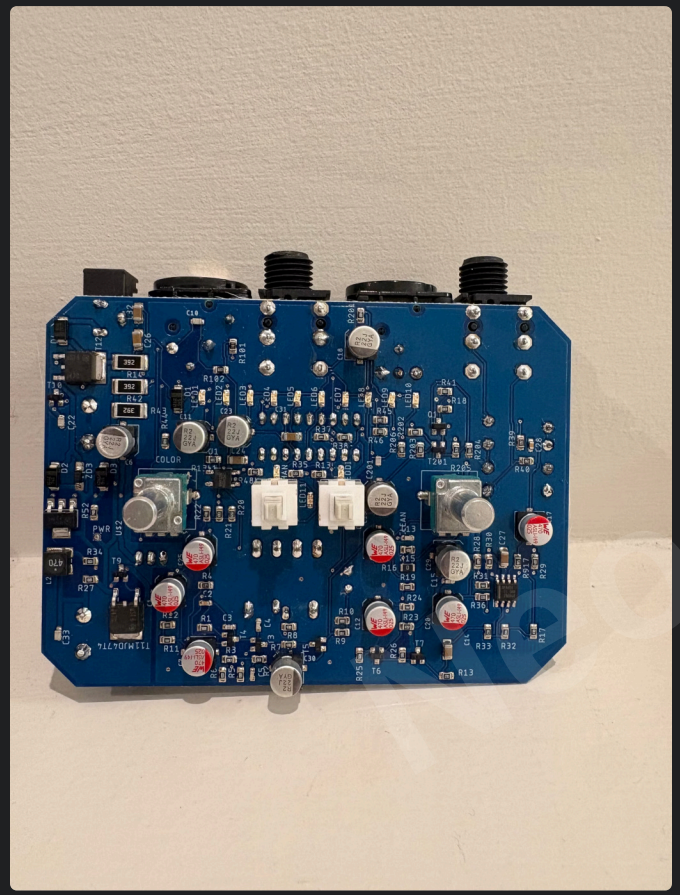
Why It Matters Here

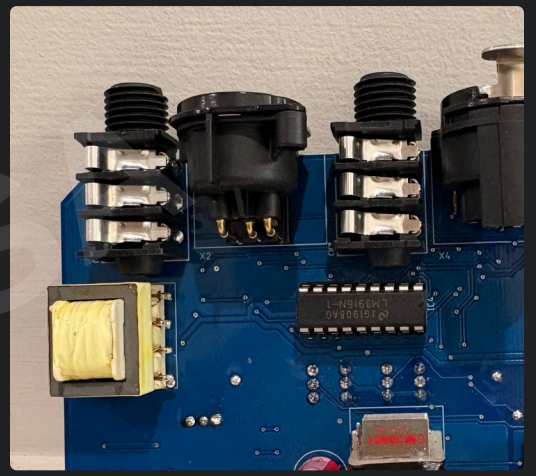
Single supply operation at 38.6V gives the output stage the headroom it needs while keeping the design simple and manufacturable.

PCB Design



PCB Layout





- the entire amplifier is just a small section on the right
- power supply on the left
- LEDs for meter at top
- Significant board space just for the power supply

- input transformer
- output transformer
- 80s cheap chip that does the metering
- the entire amplifier is just a small section on the right

Why Discrete Transistors?

There's lore in audio that ICs are bad and discrete transistors are good. The gain cell in the Hornet is discrete. Here's why that actually matters.

Complete Control

Every operating point is mine to set. Impossible with a fixed IC solution.

Headroom & Character

The discrete topology produces the saturation behavior my 1954 philosophy demands.

The BC846C

High voltage. High hfe. Great sound. But limited current output — which creates a downstream problem the OPA 454 solves.

Thermal Stability

Discrete designs require careful attention to stability under varying load and temperature. Not optional.

The Discrete Gain Cell: Operating Points

Each discrete gain cell is

Each gain cell only has to do part of the work

Power Supply Voltage - 38.6V

Running the transistor at high voltage gives the stage headroom before it saturates. Higher voltage = more headroom.

Removes the problem areas

Here's How I Do It

Distortion = any difference between input and output

Harmonic distortion — the good kind — even-order Odd harmonics can be interpreted as clarity and bite. Higher order harmonics are almost always bad for sound.

The brain hears A440 by detecting its 880 Hz second harmonic — play with that and you play with perceived warmth

> "I give you the knob to decide what your ear likes."

Bad Distortion: Clipping, IM, crossover

The Color Control: What's Actually Happening

The Color control doesn't add distortion the way a guitar pedal does. It changes the configuration of the gain stage, which changes the inherent distortion that the active device creates.

Low Color Setting

- The gain stage operates in a more linear region. Even-order harmonic content is minimized. The output is cleaner, closer to what a modern transparent preamp produces

High Color Setting

- The operating point shifts toward a region where the transistors become nonlinear more readily. Second and third harmonic content increases. The brain interprets this as warmth, thickness, presence. This is the "1950s" end of the dial.

- **Why Transistors, Not Tubes** — Tubes are more likely to produce even-order harmonics. Transistors are more likely to produce a mixture of even and odd harmonics.
    - I use transistors because I can get a good sound for a much lower price.

Layout Is Where Theory Meets Reality

Input Transformer

I intentionally had the input transformer custom designed as a humbucker to eliminate hum and buzz from the outside world.

PSU Ripple as Noise

Poorly filtered supply rails modulate the audio. PSU design is signal path design.

Why a Second Transformer?

Not the cheapest way to create a balanced output. But it's the best-sounding way — so that's what I use.

What It Does

Converts the single-ended signal to a balanced output.

The Current Problem

Driving an output transformer requires significant current. The BC846C can't do it alone — this is why the OPA 454 exists in this circuit.

The OPA 454

Selected specifically to handle 38.6V single supply operation and deliver the current the output transformer demands. $5 vs. a 10-cent alternative. Worth every penny.

> "The higher the internal voltage, the better it sounds." I can't prove it mathematically. But every engineer in this room will agree when they hear it.

The Humbucking Transformer

A standard transformer winding picks up electromagnetic interference from the environment — 60-cycle hum from power lines, nearby equipment, anything radiating a field. The solution is borrowed directly from guitar pickups.

The Problem	The Solution
A single winding acts like an antenna. Any electromagnetic field induces a voltage in the winding — and that voltage appears in your signal. At mic-level gain, even tiny interference is audible.	Two identical windings wound in opposite directions and wired out of phase. The desired signal adds — it sees both windings in series. The interference cancels — it induces equal and opposite voltages in both windings. Net interference: zero.

01

Winding 1

signal + interference

02

Winding 2

signal + oposite interference

03

Combine Output

signal only

The same principle is why a guitar humbucker has two coils. Two single-coil pickups wired out of phase cancel the hum while preserving the guitar signal. Peter applied it to the input transformer for the same reason.

Power Supply

Why I use a 48V Wall Wart

Why 48 Volts?

Phantom power requires 48V. By using a 48V supply I step voltage *down* internally.

All Switching Stays Outside

The wall wart handles high-speed switching. Nothing like that happens inside the Hornet. Clean separation from the start.

Linear Regulation Inside

Messy DC comes in. Clean, stable, high-voltage rails go out to every stage of the circuit.

38.6V Internal Rails

Enough headroom to make the output stage sound the way I want it to. This number was not accidental.

From Design to Manufacturable Product

What it actually takes to bring an idea to life

Design for Manufacturability

Every layout decision affects how the board gets built.

Component Spacing

Tight spacing enables a smaller board but creates stencil aperture challenges and hand-rework nightmares.

Component Orientation

Uniform orientation throughout. Faster machine programming. Fewer pick-and-place errors. Measurable time savings at volume.

SMT Wherever Possible

Better components, faster assembly, smaller footprint. Some through-hole remains unavoidable — connectors and transformers.

One PCB

Cost, simplicity, and assembly speed. One pass through the machine is one opportunity for error.

Sourcing Is an Engineering Decision

01

Primary Strategy

Established distributors for commodity parts. Price, availability, and reliability all weighted equally.

02

The LM3916 Story

Discontinued. Sourced from eBay. Finite stock. A known supply risk, accepted as a deliberate cost-vs-quality tradeoff.

03

Lead Times and Minimums

Small-volume producers face MOQs that distort economics. Plan for it or get surprised by it.

04

Plan for Obsolescence

Any part that could disappear needs a known replacement or a redesign strategy. Reactive procurement stops production.

Build It. Listen. Iterate.

Simulation tools tell you about voltages and frequencies. They don't tell you what something *sounds like.*

The Hum Problem

The original transformer design picked up 60-cycle hum from the environment. Not caught in simulation. Caught by building and listening.

The Fix

Two windings wired out of phase. Borrowed from guitar pickup design. Custom specification back to Cinemag. Problem solved permanently.

> "You can simulate all day. But you have to build it and listen to know if it's right."

NEODEN USA

useful arts
HAND-BUILT IN THE USA

Let's Build Something

Why Neoden USA Exists

The Hornet is possible at $300 partially because I can build it myself with in-house manufacturing.

The Bigger Point

If you have a product idea that requires SMT assembly, you no longer need a factory. You need a machine and a process.

The Neoden 10 Pick and Place Machine

The machine that makes it all possible

Specs

- 8 nozzle placement head
- Flying vision alignment system
- 18,000 CPH
- ±0.01mm Placement Accuracy
- 66 × 8 mm feeder capacity
- Min Component Size: 0201
- Max Component Size: 40 × 40 mm

Why It Matters

- Contract manufacturing. Minimum orders. Long lead times. Expensive setup. Out of reach for small-volume producers.
- In-house production: same accuracy, fraction of the cost.
- Prototype a new design, test it, and build it all in the same day

Stencil → Pick-and-Place → Reflow → Done

How SMT flows

1

Paste Application

Solder paste applied through a stencil printer.

2

Pick-and-Place

Neoden ND10 places each SMT component with repeatable accuracy.

3

Reflow Oven

Controlled temperature profile. Solder melts and solidifies. Components self-align under surface tension.

4

Through-Hole

Connectors, transformers, selected components.

Live on the Neoden ND10

1

Stencil + Paste

Watch the paste go down. Aperture-matched stainless stencil. Clean, consistent deposit on every pad.

2

Pick-and-Place

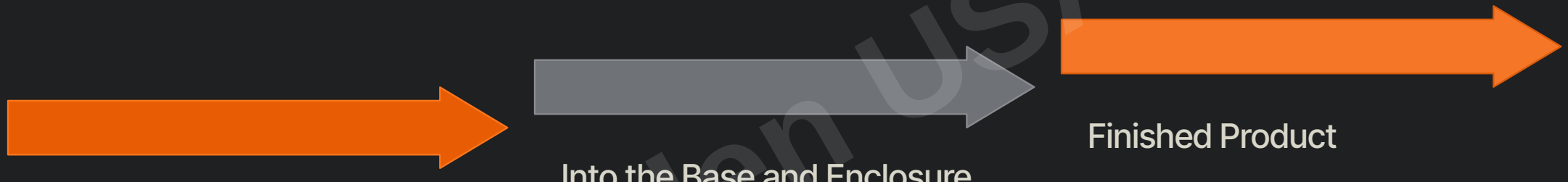
Watch the machine populate the board. Component by component. Repeatable. Reliable.

3

The Result

A populated PCB ready for reflow. This is what small-volume in-house SMT manufacturing looks like.

From PCB to Finished Product



Bare PCB

The whole product. Runs without the box. Input transformer, discrete gain cell, color control, output transformer .

Into the Base and Enclosure

PCB seated, connections made. The $4 box does its job.

Finished Product

This is what ships.

Thank You

Peter Swann | Useful Arts | Neoden USA

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