ONE8

FILTER RESEARCH PAPER

From Acoustic Resonance to Morphing Filter Spaces

A client-facing research paper on the audio filter lineage, the shift from static correction to performable tone motion, and the role ONE8 plays as a modern morphing filter instrument.

Covers first principles, historical progression, filter types, collision behavior, Doppler-like sound design, Z-plane morphing, and the reason for 2-, 4-, and 8-filter structures.

Wahida Audio · ONE8 · Research + Application

Abstract

A thesis for why moving filters matter now

Research Position

Filtering is one of the oldest ways humans shape sound. Before audio electronics, resonant cavities in instruments, rooms, and the vocal tract already selected and emphasized partials. In the nineteenth century, Helmholtz resonators made that selectivity deliberate, letting scientists isolate tone components and connect acoustics to perception [1].

Electrical filter design then emerged from communications problems: telephone lines and radio networks needed frequency-selective circuits that could pass one band while rejecting another. By the time studio equalizers and synthesizer voltage-controlled filters became common, filters were no longer only corrective devices; they had become musical gestures.

ONE8 fits the current gap between static equalization and complex modular routing. Its value is not just having many filter models. It is the ability to place filter states into 2-, 4-, or 8-corner morph spaces, route modulation into those spaces, and combine tone, stereo, sidechain, and gain-stage behavior inside one playable system.

Key Terms

Filter — A frequency-selective system that changes gain and phase across the spectrum.

Equalizer — A filter set usually used for stable tonal balance or correction.

Morph — A continuous movement between designed filter states.

Z-plane — The pole-zero map used to describe digital filter behavior.

Collision — The audible result of multiple filters or nonlinear stages interacting.

Paper Map

1. Historical Lineage
From acoustic resonance to electrical filters, studio EQ, voltage control, and DSP.

2. Filter Mechanics
Response type, phase, resonance, nonlinear drive, and what happens when filters collide.

3. ONE8 Context
Why a morphing, matrix-aware, sidechain-aware filter fills a modern production gap.

4. Applied Design
Doppler-like motion, Z-plane use, 4- and 8-filter spaces, stereo analysis, and multi-band ducking.

The Filter Lineage

The same principle appears as cavity, circuit, tone control, synth voice, and software instrument

- **Pre-electronic** — **Natural filtering**: Bodies, rooms, instruments, and vocal tracts select partials.
- **1860s** — **Acoustic analysis**: Helmholtz resonators isolate tone components [1].
- **1910s** — **Wave filters**: Telephone and radio networks need passbands and stopbands [2].
- **1930** — **Response theory**: Butterworth formalizes maximally flat filter response [3].
- **1960s** — **Voltage control**: Filters become performable synthesis modules [4].
- **1990s-now** — **Digital systems**: DSP exposes poles, zeros, modulation, analysis, and recall [5].

Why It Matters

The filter has never been only a frequency curve. It is a way of moving attention. A low-pass filter can imply distance, darkness, enclosure, or a closing object. A resonant band-pass can imply speech, a radio, a pipe, or a moving reflective space.

That is why the historical line bends toward performance. Once filter settings could be voltage-controlled, automated, or modulated, the filter became a time-based instrument. Modern production still needs corrective EQ, but it also needs controlled spectral movement that can be played, triggered, and synchronized.

ONE8 Research Question

What gap remains?
Static EQ is precise but mostly stationary. Single auto-filter effects move, but often along one predictable axis. Modular environments can build complex systems, but setup time rises quickly.

ONE8's answer
Put several filter identities into a small, musical space; let a user morph across them; then let the matrix, trigger system, sidechain, stereo tools, drive stage, and protection system make that movement production-ready.

Before Circuits: Resonance as Selection

The first filters were physical spaces

Every resonant object is a kind of filter. A violin body reinforces some bands and suppresses others. A mouth shape turns a buzzing vocal fold into vowels. A hallway changes the spectrum of a footstep, and a listener understands distance partly through those filtered reflections.

Helmholtz's resonator work made this intuitive fact measurable. A resonator tuned to a narrow frequency would respond strongly to that partial, making it possible to analyze tone color as a set of components rather than a single mystery quality [1].

In audio terms, this is the birth of the filter idea: not yet a plugin, circuit, or knob, but a designed acoustic object that selects part of a sound. ONE8's morphing spaces are digital, but the musical instinct is the same: a sound changes identity when its resonances move.

From Acoustic Filters to Electric Wave Filters

Telephony turned filtering into engineering

Communications Problem

The first major electrical filter work grew from communication systems. Telephone and radio networks needed to carry useful frequency bands, reject unwanted ones, and divide channels without excessive interference. George Ashley Campbell's work on electric wave filters is a central part of that early lineage [2].

This period established the vocabulary still used in music software: passband, stopband, cutoff, slope, ripple, resonance, bandwidth, and attenuation. The purpose was practical and measurable: separate signals in a network.

Audio production inherited those engineering tools but gave them artistic roles. A passband could become a radio voice. A resonant cutoff could become a build-up. A notch could remove a problem, or become the sweep that makes a loop breathe.

Classic Response Families

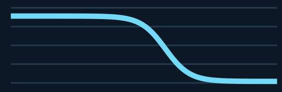
Butterworth
Maximally flat amplitude response; useful when smoothness matters [3].

Chebyshev
Sharper transition for a given order, traded against ripple.

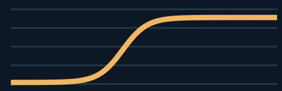
Bessel
Prioritizes phase and transient shape over steep rejection.

Elliptic
Very steep transition, with ripple in passband and stopband.

Audio Translation



Low-pass
A musical control over w
vanishes, and how the e



High-pass
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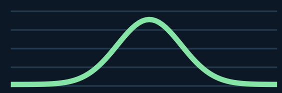
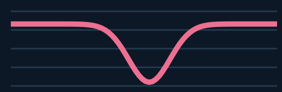
vanishes, and how the e



Band-pass
A musical control over w
vanishes, and how the e



Notch
A musical control over w
vanishes, and how the e

History of Filter Types

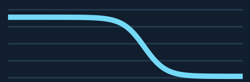
From utility curves to audible identities

EQ, Static Filter, Moving Filter

Equalization usually means a set of filters used to balance or correct a sound. **Static filtering** usually means the curve stays in one place. **Moving filtering** means the curve becomes part of the performance: cutoffs sweep, resonances appear, morph spaces move, or triggers create time-dependent behavior.

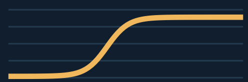
ONE8 belongs to the third category. It can do stable tone shaping, but its design strength is making filter identities move together in ways that remain controllable.

Low-pass



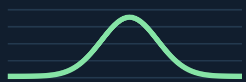
Darkens by allowing lows and reducing highs. Historically useful for noise control, distance cues, synth sweeps, and bass shaping.

High-pass



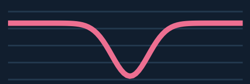
Removes lows while leaving upper content. Useful for cleanup, headroom, bass separation, and small-speaker translation.

Band-pass



Keeps a band and rejects both sides. Useful for radio voices, resonant motion, focused percussion, vowel-like sound, and midrange tunnels.

Notch / band-stop

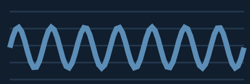


Cuts a focused region. Useful for removing resonances, creating phaser-like holes, or building moving cancellations.

Peak / bell

Boosts or cuts a region. In EQ it is corrective; under modulation it becomes a moving emphasis or accent.

Comb / phaser / all-pass



Uses phase relationships to create repeated peaks and notches. The history runs through physical echoes, delay lines, and all-pass networks.

The Musical Filter: Voltage Control and Gesture

Once cutoff could move under control voltage, filtering became performance

From Tone Control to Instrument

Early tone controls were often set-and-leave devices. The voltage-controlled filter changed the instrument designer's relationship with filtering: cutoff, resonance, and envelope response could be part of the note itself. Robert Moog's voltage-controlled electronic filter patent is a useful historical marker for this shift [4].

A filter could now articulate: open quickly on attack, close during decay, scream at resonance, or follow an LFO. It could be controlled by a keyboard, envelope, pedal, sequencer, or oscillator.

Modern plugin users expect the same movement, but inside DAW workflows. That means recall, modulation routing, tempo sync, sidechain awareness, stereo monitoring, and output safety all matter.

ONE8 Performance Vocabulary

ONE8 keeps the performable-filter idea but expands the destination. Instead of one cutoff controlled by one envelope, the sound can move through a filter space while a second or third source changes resonance, drive, width, or sidechain response.

This is why the product fits between a traditional EQ and a modular environment. The player gets motion depth without building the whole rig from scratch.

Digital Filters and the Z-plane

A digital filter can be understood as poles and zeros on a complex plane

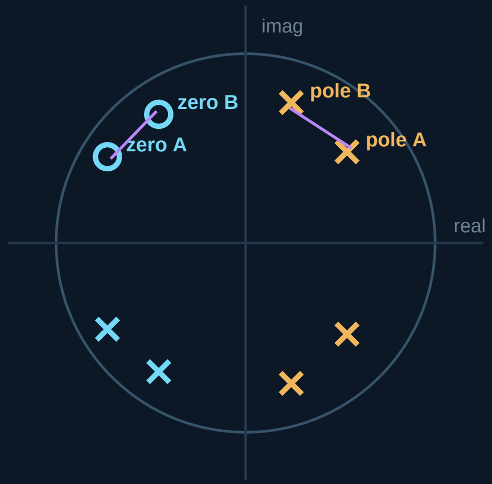
What the Z-plane Represents

In digital signal processing, many filters can be represented by a transfer function. Its zeros tend to cancel or reduce energy at parts of the spectrum; its poles tend to emphasize, resonate, or extend decay. Their positions on the Z-plane describe how the filter behaves [5].

A stable filter keeps poles inside the unit circle. As poles move closer to the circle, resonance and ringing increase. As zeros move, cancellations and spectral notches change.

This is not just math decoration. A Z-plane view explains why two filter states can sound smoother when their internal pole-zero structures are interpolated carefully instead of simply crossfading two output signals.

Pole-zero Map



Real-life Analogy

Walking down a street is a natural morphing filter system. A passing car, a shop doorway, parked vehicles, walls, and your own head position all change the balance of direct sound, reflected sound, absorption, and resonance.

Nothing jumps from one EQ preset to another. The world continuously shifts the apparent source, brightness, reflections, stereo width, and low-frequency buildup.

Z-plane and morphing methods are different digital attempts to give a plugin that same sense of continuous spectral identity change.

Where Audio Filtering Is Now

Modern production has precision, but precision alone does not create movement

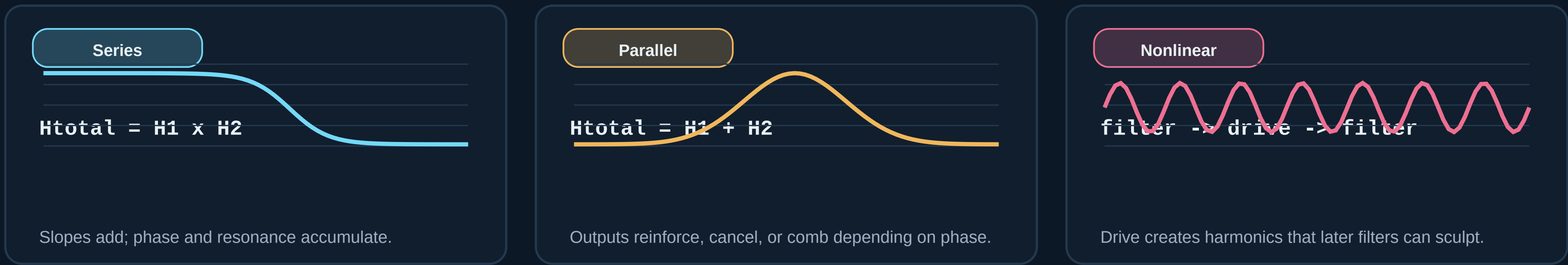
Static EQ	**Typical use:** Precise correction, tonal balancing, cleanup, mastering moves.	**Creative edge:** Excellent for repeatable decisions; limited as a performance gesture.
Dynamic EQ	**Typical use:** Band gain changes in response to input level.	**Creative edge:** Great for resonances and masking; usually still band-by-band and utility-led.
Auto-filter	**Typical use:** A cutoff or band sweeps under LFO/envelope/automation.	**Creative edge:** Fast musical movement; often one-dimensional.
Modular patch	**Typical use:** Anything can feed anything, with deep control.	**Creative edge:** Very powerful; setup and recall can become the creative bottleneck.

The Open Space

The modern problem is not a lack of filters. It is the distance between technical precision and playable complexity. ONE8 narrows that distance by making the filter structure itself a performable space, then exposing movement through macros, LFOs, envelopes, processors, triggers, sidechain sources, and stereo tools.

What Happens When Filters Collide?

Multiple filters interact through amplitude, phase, resonance, and nonlinear stages



Audible Results

Steeper edges: In series, two low-pass filters can make the cutoff feel more decisive because their attenuation accumulates.

Hollowing: High-pass plus low-pass can form a band-pass. Notch plus peak can create nasal, vocal, or telephone shapes.

Motion complexity: If two moving notches cross, a static curve becomes a changing field of cancellations and reinforcements.

Headroom pressure: Resonance and drive can raise peaks, so output trim, clipping, loudness match, and SAFE behavior matter.

Why Collision Is Useful

Collision is not always a problem. In creative filtering, collisions are often the point. A comb filter colliding with a formant model can make a sound feel like it is inside a resonating object. A ladder-like low-pass colliding with a moving peak can make an otherwise flat sweep speak.

The production challenge is to keep those interactions legible. ONE8's morph space, matrix range limits, slew controls, drive types, stereo meters, and safety tools exist to make collisions playable rather than random.

Collision Case Studies

Useful collisions are designed around order, phase, and gain

Case 1 — **Low-pass + resonance + soft drive**

Mechanism: A resonant edge feeds a rounded transfer curve. The drive adds harmonics near the cutoff, so a small resonance change becomes more audible.

Use: Use for bass movement, growl, and build-up energy.

Case 2 — **Notch + phaser / all-pass**

Mechanism: Both create phase-sensitive cancellations. When their centers move differently, the ear hears an animated hollow space rather than a simple sweep.

Use: Use for pads, transitions, filtered percussion, and movement behind a lead.

Case 3 — **Band-pass + formant**

Mechanism: A band-pass frames the voice-like resonances. The result can suggest mouth shape, small speakers, or a resonant tube.

Use: Use for vocal chops, synth speech, and call-and-response effects.

Case 4 — **Sidechain duck + filter morph**

Mechanism: A sidechain event changes level while the filter space moves away from a masking zone. The listener hears clarity without the whole signal disappearing.

Use: Use for bass/kick separation, vocal-under-synth clarity, and groove-aware motion.

How Z-plane Morphing Works

It is a structural interpolation rather than a simple volume crossfade

Concept

A normal crossfade blends the outputs of two filters. That can be useful, but the listener may hear two filter identities fading against each other.

A Z-plane morph treats the filter as a structure. For compatible filter types, the poles and zeros of one state are paired with the poles and zeros of another, then interpolated. The result is a single filter whose internal behavior moves.

In ONE8, the Z-plane path is used for the two-filter morph case when both source filters are supported by the morphing biquad path. Low-pass, high-pass, band-pass, notch, peak, low shelf, and high shelf shapes are compatible; complex creative models such as comb, phaser, formant, hybrid, and custom filters fall back to weighted output blending.

Stability

The practical concern is stability. Poles outside the stable region can cause runaway output. A robust implementation keeps the interpolated poles inside safe bounds and sanitizes extreme values before later stages.

That safety work is what lets a musical morph feel smooth rather than fragile.

What It Sounds Like

Output crossfade
Often sounds like two filters trading level.

Parameter interpolation
Can be smooth when filters share a structure, but may be unstable or misleading across different types.

Z-plane interpolation
Moves the filter's internal identity. It is most convincing when the start and end filters are structurally compatible.

Weighted multi-filter morph
Best for larger creative spaces where filter types may be intentionally different.

Different Approaches to Filter Morphing

Each method solves a different musical and technical problem

Output blend	**How:** Runs multiple filters and blends their audio outputs.	**Trade-off:** Reliable across unlike filter types; may sound like layered filters rather than one changing object.
Parameter interpolation	**How:** Moves cutoff, resonance, gain, and other parameters between states.	**Trade-off:** Efficient and intuitive; can become awkward when the two filters do not share the same design.
Pole-zero interpolation	**How:** Moves the digital filter roots in the Z-plane.	**Trade-off:** Can sound like one coherent filter morph; requires compatible structures and stability checks.
Spectral-frame morph	**How:** Analyzes and reshapes short-time spectral data.	**Trade-off:** Can be very fluid or surreal; usually heavier and less knob-like.

ONE8 Uses More Than One Approach

The two-filter Z-plane path is a structural morph when the two filters are compatible. The 4- and 8-filter spaces are weighted morph spaces designed for bigger identity shifts: low-pass into formant, notch into peak, comb into phaser, or utility filter into character model.

Why ONE8 Fits a Gap

A filter plugin that behaves like a designed modulation instrument

The Gap

Static EQ: precise, essential, but mostly stationary.

Single motion effect: quick movement, but commonly one main sweep.

Full modular patch: unlimited, but slower to build and easier to overcomplicate.

ONE8: a dedicated morphing filter space with matrix routing, trigger logic, macro performance, sidechain awareness, stereo tools, drive, and safety.

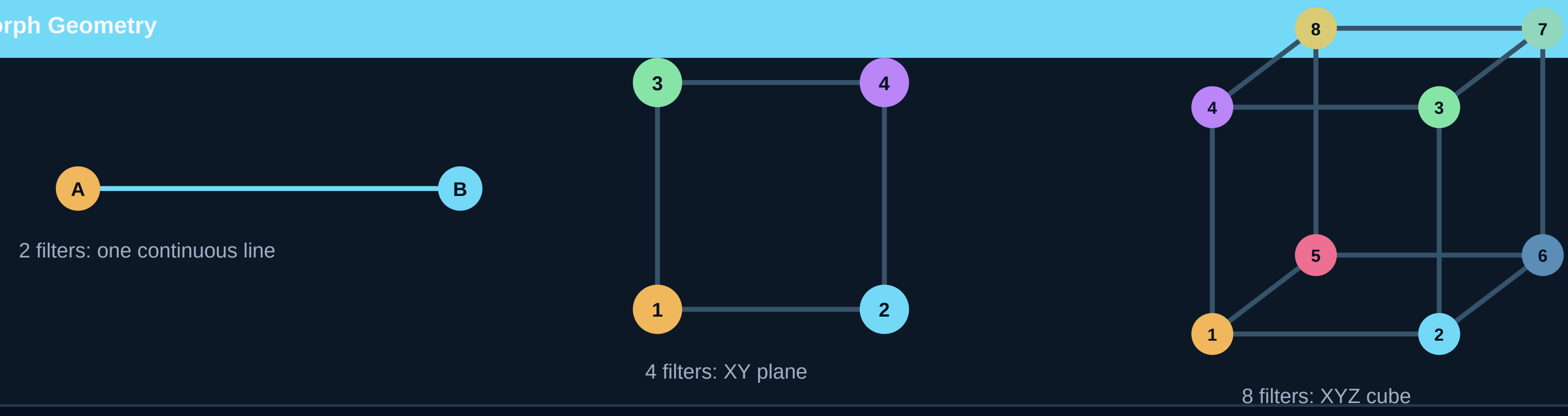
Product Rationale

The current implementation accepts 2, 4, or 8 filter states as the core morph structure. It includes a Z-plane path for compatible two-filter morphs, and weighted XY/XYZ blending for larger spaces. That matters because the user can design a compact sound world rather than automate dozens of separate filter parameters.

Why 2, 4, and 8 Filters?

The numbers are musical geometry: line, plane, cube

Morph Geometry



2 filters

A/B morphing. Best for a single identity transition, and the place where ONE8 can use its compatible Z-plane morph path.

4 filters

An XY plane. One axis can be dark/bright while the other is clean/character, narrow/wide, or static/moving.

8 filters

An XYZ cube. Three independent dimensions can define a complex sound world: tone, shape, intensity, distance, depth, or mix role.

Implementation note: unsupported morph counts are not treated as musical modes; the product keeps the usable structures to 2, 4, and 8.

Filter Model Families Inside ONE8

A compact map of the current filter catalog

Family	Includes	Use
Core / EQ	**Includes:** Low-pass, high-pass, band-pass, notch, peak, shelves, tilt, all-pass.	**Use:** Correction, cleanup, balance, and controlled sweeps.
Analog character	**Includes:** State-variable blends, ladder-style low-pass, diode-style ladder, OTA/SEM-style, Sallen-Key-style, bite models.	**Use:** Weight, personality, resonance, and nonlinear color.
Creative modulation	**Includes:** Comb, feedback comb, formant vowel, all-pass chain, LP-BP motion, twin peak, resonator bank, wah BP.	**Use:** Movement, voice-like tone, metallicity, phasing, flutter, and spatial illusion.
Dynamic / utility	**Includes:** Moving tone blend, punch sweep, presence trim, cleanup shelves, de-ess notch, bass/lead/pad-focused macros.	**Use:** Fast production-specific tone shaping and morphable utility states.
Custom drawn	**Includes:** A user-shaped curve feeding custom band behavior.	**Use:** Design a personal filter response and include it in the morph space.

Modulation and Triggered Filtering

Movement becomes musical when it can react to the signal

Modulation Sources

ONE8's routing language includes envelopes, LFOs, step sequencer, automation, macros, buses, processors, MIDI sources, sidechain followers, stereo analysis values, and trigger lanes.

The important idea is not just more sources. It is source combination: an LFO can move a morph axis, an envelope can add resonance, a sidechain follower can push the filter away from masking frequencies, and a macro can scale the whole behavior.

Trigger Logic

Trigger watch conditions include Above, Below, Crosses Up, Crosses Down, Inside Range, and Outside Range. Outputs include Gate, Pulse, Envelope, Toggle, and Sample & Hold.

Example: watch LFO1. When it Crosses Up through a threshold near the top of its cycle, send a Pulse to drive or resonance. Example: watch Stereo Width. When the signal moves Outside Range, trigger a brief narrowing or drive accent.

Why Triggers Matter

Watch
LFO peak, stereo width, sidechain energy, macro position

Condition
Crosses Up, Outside Range, Above threshold

Output
Pulse, envelope, gate, toggle, sample-hold

Route
Drive, resonance, morph, cutoff, width, mix

Result
Events instead of constant movement

Stereo Analysis, Sidechain, and Multi-band Ducking

Filtering is also a spatial and masking decision

Stereo Analyzer

The stereo tools show width, correlation, and vector/scope behavior. Use them to verify whether movement is widening, collapsing, leaning left/right, or creating phase risk.

For moving filters, this matters because resonant or all-pass-heavy effects can make a sound feel wider while also reducing mono reliability.

Sidechain Use

Sidechain lets another signal influence tone movement. A kick can duck bass energy, a vocal can push synth midrange out of the way, or a drum loop can make a pad pulse without muting the entire pad.

The detector can be shaped with high-pass and low-pass limits so the response follows the part of the sidechain that matters.

Why Multi-band Ducking

Full-band ducking makes space by lowering everything. Multi-band ducking makes space where the conflict exists. That keeps low-end weight, vocal presence, or high-frequency air from disappearing unnecessarily.

In ONE8, target bands and detector bands make ducking part of sound design rather than only a mix utility.

Drive as a Filter Companion

Nonlinear stages change what the following filters have to sculpt

Drive Types in ONE8

Type	Character
Soft Clip	rounded limiting
Tanh	smooth saturation
Hard Clip	firm ceiling
Tube	asymmetric warmth
Console	punchy restrained knee
Hybrid	body plus edge
Tape	rounded magnetic-style compression
Diode	asymmetric sharper knee
Transformer	thick odd-harmonic weight

Collision Order

Filter before drive: resonance and cutoff decide what excites the nonlinear stage.

Drive before filter: saturation creates harmonics first, then filters carve the result.

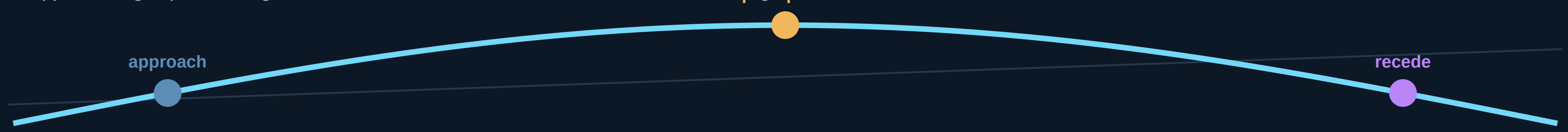
Drive inside a morphing system: the harmonic material changes as the filter space moves, so small matrix changes can feel larger than their numerical amount.

Can ONE8 Create Doppler-like Effects?

It can create convincing flyby cues, but not a physically exact pitch-shift Doppler

Physical Doppler vs Musical Approximation

True Doppler changes pitch through relative motion. ONE8 creates the related mix cues: brightness, resonance, level, width, drive, and reflections.



Physical Definition

The Doppler effect is a frequency shift caused by relative motion between a wave source and an observer [6]. A siren approaching rises in perceived pitch; after it passes, the pitch drops.

A true Doppler processor normally needs time-varying delay or pitch shifting. ONE8 is not presented as that type of processor.

ONE8 Flyby Approximation

ONE8 can build the surrounding cues: approaching brightness, center-point resonance, level lift, drive accent, stereo rotation or width change, and darker receding tone. These are often enough for a mix effect, especially when the source does not need literal pitch movement.

The useful result is not physics accuracy; it is a controllable spectral story.

Complex Effect Recipe: Filter Flyby

A step-by-step design that uses morphing, trigger logic, stereo, and drive

1. **Build the space**
Use 4 filters for an XY plane: far/dark, near/bright, near/resonant, far/thin. For a deeper version, use 8 filters and dedicate Z to reflection/comb/formant intensity.

2. **Move through it**
Route Automation, Movement, or LFO1 to Morph X. Use an S-Curve for natural acceleration and Morph Time/Slew to prevent abrupt jumps.

3. **Add pass-point event**
Set a trigger to watch Morph X or LFO1. When it Crosses Up near the middle, output a short Envelope or Pulse to resonance, drive, or mix.

4. **Place it in stereo**
Modulate Stereo Image Rotation or Width subtly during the sweep. Watch the analyzer so the effect stays stable in mono.

Finish safely

Suggested Matrix Shape

LFO1 or Movement -> Morph X | Trigger 1 (Crosses Up) -> Drive or Resonance | Macro 1 -> overall flyby amount | Sidechain Follower -> optional duck or cutoff recovery.

Why a Morphing Filter Space Is Different

It changes the design task from parameter automation to sound-space design

Traditional Workflow

A static workflow asks: What frequency should I cut or boost?

An automation workflow asks: Which parameter should move over time?

A morph-space workflow asks: What worlds should exist at the corners, and how should the listener travel between them?

ONE8 Workflow

The user designs states first: clean, dark, bright, hollow, resonant, wide, gritty, vocal, thin, or heavy. Then the user decides what controls the journey: macro, LFO, envelope, sequencer, trigger, sidechain, MIDI, or stereo analysis.

This turns complex filtering into a repeatable instrument-like patch instead of a pile of disconnected automation lanes.

When to Use - and When Not To

Use it when a sound needs movement, identity shifts, musical masking control, stereo-aware filtering, triggered accents, or macro performance.

Use a simpler static EQ when the job is a single corrective move with no musical motion, no sidechain relationship, and no need for morphing.

This is the clearest way to position ONE8: not as a replacement for every EQ, but as a specialist for animated filtering and production-ready spectral performance.

Method, Limits, and Claims

A research paper should separate historical fact, technical principle, and product behavior

Method

Historical claims in this paper are drawn from established references on acoustic resonance, early electric wave filters, classic filter response theory, voltage-controlled filter development, digital filters, and the Doppler effect [1-6].

ONE8-specific behavior is described from the product's current implementation: filter model categories, drive type names and behavior, morph count structure, two-filter Z-plane path, weighted 4-/8-filter morphing, matrix sources and destinations, triggers, stereo parameters, sidechain compressor and multi-band ducking controls, and gain-stage protection [7].

The paper intentionally avoids presenting parked compatibility parameters as user-facing features.

Limits

Doppler: ONE8 can create Doppler-like filtering, level, width, and reflection cues. It is not a physically exact Doppler pitch-shifter.

Z-plane: Z-plane morphing is most appropriate for compatible filter structures. Larger creative spaces use weighted morphing because unlike filter types cannot always share a stable pole-zero interpolation.

Filter collisions: Collisions can be desirable or destructive. Resonance, phase, and drive interactions should be monitored with output trim, stereo analysis, and safety tools.

4 and 8 filters: The choice is not about excess. It is about useful geometry: two axes for an XY plane, three axes for an XYZ cube.

Conclusion

ONE8 belongs to the lineage of filters becoming instruments

Research Finding

The history of filtering moves from acoustic selection, to electrical communication, to studio correction, to synthesis performance, to digital structures that can be automated, analyzed, and morphed. Each stage adds control over the same core idea: sound identity changes when frequency, phase, resonance, and level are shaped over time.

ONE8 fits a current gap because it is neither only a corrective EQ nor only a simple sweep effect. It turns multiple filter states into a playable surface and gives that surface a production context: modulation routing, trigger logic, sidechain behavior, stereo analysis, drive character, and gain-stage safety.

Why It Matters for Users

A user can design motion that sounds intentional: not just a cutoff sweep, but a journey through several tonal identities. That is useful for bass movement, vocal shaping, transition design, mix-space carving, stereo animation, and responsive sidechain effects.

Why It Matters for Product Position

The product's strongest claim is not the number of knobs or filters. It is the way those filters become a controllable sound space. The 4-filter plane and 8-filter cube make complex motion understandable; the two-filter Z-plane path preserves a more structural morph when the filter types allow it.

References

Cited Sources

[1] Hermann von Helmholtz, On the Sensations of Tone as a Physiological Basis for the Theory of Music, first German edition 1863; English translation 1875.

[2] National Inventors Hall of Fame, George Ashley Campbell biography and electric wave filter work.

[3] Stephen Butterworth, 'On the Theory of Filter Amplifiers,' Wireless Engineer, 1930.

[4] Robert A. Moog, Voltage Controlled Electronic Filter, US Patent 3,475,623, 1969.

[5] Julius O. Smith III, Introduction to Digital Filters with Audio Applications, CCRMA / Stanford.

[6] Encyclopaedia Britannica, Doppler effect.

[7] Wahida Audio ONE8 current implementation, 2026: MorphFilter, FilterModels, Saturation, PluginProcessor parameter set.

Reference Links

Helmholtz: https://archive.org/details/onsensationsofto00helmrich
Butterworth: https://bibbase.org/network/publication/butterworth-onthetheoryoffilteramplifiers-1930
Campbell: https://www.invent.org/inductees/george-ashley-campbell
Moog patent: https://patents.google.com/patent/US3475623A/en
Digital filters: https://www.dsprelated.com/freebooks/filters/
Doppler: https://www.britannica.com/science/Doppler-effect