The Technology of Auto-Wahs / Envelope-Controlled Filters

The goals: This paper is intended to explain how a particular category of effect works, including the variations in design that are currently in production, or have previously existed. The desired outcomes are that the reader will:

- know how to make any effects they own behave more in the way they want (including injecting a note of surprise or uncertainty)
- have some idea about whether a given commercial effect (including vintage units) will do what they want
- have some idea whether a DIY project can do what they want, and have some intuition about how it will sound
- have some idea about potential mods to existing DIY or commercial units
- have some new concepts in their arsenal to use when thinking about other types of effects

Auto-wahs, more properly called *Envelope-Controlled Filters* (ECF), shape the tone of your instrument (the filtering part) in response to how loud the sound is going into them (the envelope part). They are often called auto-wahs or auto-filters to distinguish them from conventional foot-operated pedals, since they can be used in a set-and-forget manner. Although they can certainly mimic some of what a wah-wah does, they are substantially more flexible in many ways, and have a broader palette of tone shaping capabilities than a wah-wah does. Like anything automatic, however, they don't always respond exactly the way you want them to at any given moment.

Some early history:They were once the darlings of funk and disco music, and seemed to fade away from popularity as disco's start descended (though they never quite disappeared). However, everything old is eventually new again, and the return of disco-like tonalities and timbres with contemporary dance music has brought back filtering with a vengeance, and with it the envelope-controlled filter. The connection with funk and dance music is *not* purely coincidental but is a natural allegiance. Both wah-wah's and ECFs allow the guitarist to accentuate the beat of the song, and in effect, act like an additional percussionist.

If you think of it, some types of percussion are very similar in their action to an ECF, in terms of the relationship between sweep and beat. For example, the first analog drums - the Syndrum being a prime example - and traditional Indian tablas both have the capacity to sweep across a range of emphasized frequencies to accentuate or articulate/complement the beat.

The origins of the ECF lie in the early days of modular analog synthesis. Long before sampling, the most common form of electronic music synthesis was subtractive synthesis. That is, one started out with a standard oscillator-produced waveform (square, ramp, triangle, etc.) that was relatively rich in harmonics, and used filtering to remove harmonics and provide timbres in between the original waveform and a pure sinusoidal waveform. The filters and amplifiers were controlled by envelope-generators that produced a rising and falling control voltage which could make the filters have different cutoff frequencies and the amplifiers modulate the volume. The envelope voltage, in turn, was initiated by each keyboard keypress, such that the cutoff frequency of the filter varied in a predictable manner. By tightly controlling the harmonics of each note, in addition to imposing the same degree of control on the volume of the note, one could attempt to simulate things like plucked or blown notes.

Of course, what impressed the popular mind most was the most blatant and exaggerated filter use, and there can be no better example than the signature 4-pole lowpass filter of the Minimoog; the "bwow" that set the standard. What distinguished this particular tone from what we could already do with wah-wah pedals was the fact that it could be fast and note-specific, and ***very*** resonant, and guitarists wanted it. Some synthesizers started to come with external signal processing capability, which would allow them to apply their filter(s) to something other than the keyboard voltage and on-board VCO's. An envelope follower was part of this.

Keyboards had the advantage that they were hardwired to detect note onset, and could generate a trigger pulse that initiated the envelope generators (which controlled the filters) reliably, consistently, and quickly. How would guitars perform the same function? Unlike electronic keyboards, guitars are used to produce notes that are more likely to go undetected, by virtue of their softness or slurring. Making any circuitry sensitive enough to detect these would also make them sensitive enough to produce false triggering. We didn't want anything as blatant as a Moog-like "bwow" to be triggered by events like string or fingerboard noise.

Enter envelope-controlled filters. Although it might not be possible to reliably initiate a trigger and envelope voltage with each note strummed or plucked on a guitar, the fact was that every note played on a guitar possessed its own envelope. If you could harness that, and convert it into a control voltage, then you could use that to make the filter work in a way that was almost like a synthesizer, with a *bwow* produced as each note was produced and died away.

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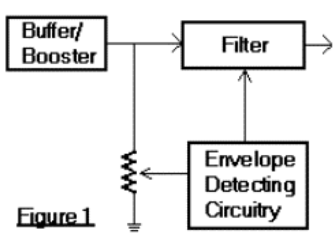

Figure 1

The Basic Characteristics: A block diagram of an ECF is shown in Figure 1. This is not every conceivable ECF ever produced, but does capture most of them. What we see is that there is usually some kind of combination buffer/booster stage at the input. This will bring the signal level up to a point where it is likely to be easily detected by the envelope circuitry, and well above any extraneous signal sources, such as hum. From the buffer/booster stage, it is split and sent to the filter, and to the envelope detection circuitry. Since you never know how big the incoming signal will be, there is usually a sensitivity control between the input stage and the envelope detection circuitry. This will allow you to jack up the sensitivity if you have weak pickups or a less imposing picking style, or turn down the sensitivity if your signal is very hot or if you just want subtle changes despite intense strumming. In some cases (e.g., the Mutron III), the adjustment comes in the form of a gain control for the first stage, rather than a fixed gain followed by an attenuator, as shown here.

The envelope detecting circuitry provides a unipolar signal (i.e., is either all negative or all positive, relative to ground) that is proportional to the amplitude of the incoming signal. Typically, the envelope follower will have some components that shape the envelope signal in some way, either slowing down the attack or onset, or adding some lag so that the envelope does not descend too quickly. Think of the envelope follower as being a bit like the record level meter on your tape deck, or the tachometer on your car dashboard. It responds to the overall average over a moderately brief period, rather than the absolute value at each fraction of a second.

The output of the envelope follower is connected up to some sort of control element. The control element, in turn, is part of a filter, whose bandwidth parameters or center frequency changes as that element changes. In effect, the filter operates like someone twiddling a knob on a note by note basis. In some case, the filter itself may be reconfigured to different types, or it may have control over its resonance or selectiveness. In a few odd cases, the envelope can be combined with other sources of modulation, such as input from a footpedal providing a second control voltage, an LFO, or some master control voltage that several devices are synced to. Most commercial stompbox ECF's are generally confined to the on-board envelope follower, and in a few cases (e.g., the BOSS Dynamic Filter), an external expression pedal.

The Envelope

You might think that the filter is the guts of an ECF, but really the true heart and soul of any ECF is the envelope follower. What gives different ECF's their unique feel is fundamentally determined by the characteristics of the envelope detection circuitry. Why? Well, imagine yourself playing a particular song. If you're planful, and intent on using FX in a tactical way, you may try to get the filter to sweep and emphasize in synchrony with the beat. The time it takes to get from where you are to where you want to be depends on how effectively the

Extracting an envelope is not as easy as you'd think. What kinds of problems are faced in accomplishing this task? First, the output signal of the envelope follower has to be of sufficient amplitude (current OR voltage) and appropriate polarity to drive the control element. Not much problem there. In most cases, this simply means providing appropriate gain within the envelope follower itself, or feeding it with an already boosted (or attenuated) signal. Gain setting can usually be adjusted by a single, easily identified resistor. Polarity is set by either inverting the envelope signal somewhere along the way, or by using diodes to select only signals of a specific polarity, or both.

The envelope has to have appropriate rise and fall characteristics. In a sense, envelope followers almost always lag behind the signal they are detecting because their job is to describe the signal, rather than simply follow it like an amplifier or buffer. There is considerable variation amongst commercial products with respect to attack and decay characteristics, but most will provide an envelope signal that responds with maximum swing over a period of 50msec or less, and drifts back to baseline over a period of 500msec or less. In general, having a faster attack time is desirable, up to a point. For a wide variety of reasons, faster attack times help to define the relationship of the effect to the beat of a song. Faster attack allows for synchrony with the beat, since it is easier for the player to predict where and when maximum sweep will occur in relation to the beat. Besides, slow attack is easy to do with a wah; fast attack isn't. Though there may be some room to stretch with respect to decay, excessive decay tends to ruin the degree of definition of the effect, unless one is into non-rhythmic music.

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All envelope followers do their job best when they output a signal that provides smooth voltage or current changes that are free of what is called ***ripple***. When an AC-to-DC adapter does not provide proper rectification and filtering to turn 60hz AC into steady DC, we hear this as hum superimposed on the audio signal of whatever the adapter is plugged into. Filter the AC better, and the hum is reduced. Envelope followers are essentially operating like AC adapters, converting the AC of the audio signal into something close to a DC voltage. When audio frequency content comes through as part of the envelope signal, we tend to hear this as a distortion-like sound, sometimes almost a hint of a ring-modulator type of sound. We hear it like that because it literally IS modulating the filter. Instead of going "bwow", the filter ends up going "bwaggeta-wiggeta" as the ripple causes momentary fluctuations in the filter center frequency at audio frequency rates.

Ripple is most likely to be heard during the decay phase of the filter sweep. Partly because the attack is too fast for ripple to be heard, and partly because the decay portion won't occur unless you stop playing, so your attention is easily focussed on the modulation.

Let's go back to attack and decay characteristics for a moment. If an envelope follower is set for an attack time of 10msec, then it will be unable to rise fast enough to respond to track any envelope fluctuations faster than 100hz (1000/10 = 100). So any ripple in the envelope signal above 100hz simply won't impact on the filter.

Audible effects of ripple are also most likely to occur if the control element is of the type that can respond very fast. Photocell-based ECF's are relatively immune from audible ripple, simply because photocells don't return from their MAX/ON to MIN/OFF value very fast, and impose a longer decay period without additional circuitry. The same envelope follower circuit used with a transistor as the control element may well result in considerable audible ripple unless the decay period is deliberately smoothed out with additional circuitry or larger value capacitors. The pros and cons of control elements are described in more detail in a section below.

The most common way is to use diodes to select half of the audio signal by use of half-wave rectification.

The side-chain approach: "Side chains" are circuits that provide an output which, in a sense, *describe* an input signal. If the input signal is like *this*, then the side chain signal will be like *that*. An envelope extractor or detector is a side chain that describes (i.e., is proportional to) the amplitude of the input signal. Normally, the ECF derives its envelope signal from the instrument you are playing, but there is often no reason why that has to be the case. A perfect analogy is the use of an external input with a noise gate. Normally, in noise gates, there is an electronic switch or fader, which is governed by the envelope of the instrument being fed into it; when the signal exceeds a predetermined level, the gate opens up. However, the gate (and many provide for this option) can be "keyed" by other signals. For example, in the classic David Bowie tune "Let's Dance", producer Nile Rodgers mixed down the entire horn section and ran it through a gate, using his guitar to control the gate. The result had an interesting feel; not quite horns, not quite guitar.

In many (though not all) instances, modifying the ECF to accept external signals is quite feasible. This would permit the filter to be swept by a wide variety of sources other than your instrument. You could control the filter with your voice, a drum machine, a radio, the rest of the band, or what the hell....a wireless mic hidden in the washroom of the bar you're playing in.

Just in case you get some wild ideas, this is NOT the same thing as a vocorder. Vocorders use the *frequency* content of the side chain signal to determine the frequency content of the input signal. An externally keyed ECF would vary the frequency content based on the *amplitude* of the input. In fact we can construct a little 2 x 2 matrix here that shows the relationship between several different kinds of devices:

	Modify input amplitude	Modify input frequencies
Use side chain amplitude	noise gate, ducker	keyed ECF
Use side chain frequencies	de-esser	vocorder

Here is a practical example with an old favourite: the Electro-Harmonix Dr. Q. The DQ consists of a bandpass filter, an envelope follower, and a transistor linking the two. Unlike Figure 1, there is no buffer stage. The Sensitivity control takes its signal directly from the input shared with the filter, but there is no reason why it has to. Connect the input of the pot to a jack and feed it an external signal as in **Figure X,** and the external signal will trigger the sweep of the filter. You may want to put a cap ahead of the pot to filter out any possible DC coming from the external source (although most of the time there won't be any, but it's still good practice). Depending on the amplitude of what you feed in, you may also find that the gain in the envelope follower is insufficient. If that's the case, you can up the value of the feedback resistor from 2.2meg to 2.7 meg or even 3.3meg, using the trimpot to make fine adjustments.

Jack Orman's improved version of the DQ, called the Dr. Quack, leaves the filter essentially untouched, but adds a FET buffer ahead of the filter and envelope follower, in addition to fixing up a few other things. The Sensitivity control connects up to the output of the buffer, but is still able to be disconnected from there and driven directly from an external input. The same general logic can be applied to virtually any ECF with a Sensitivity pot between the input and envelope follower. The only qualifications would be that: a) if the normal input stage provides some gain, that gain will have to be made up somewhere else when disconnecting the Sensitivity pot, perhaps requiring a small op-amp or single transistor stage, and b) attention will need to be paid to any possible DC entering the envelope follower. A good example would be the Mutron III, which uses an adjustable gain stage at the input for the filter and envelope follower, rather than a fixed gain stage and Sensitivity pot.

Control Elements

A big part of what goes into the design of an ECF is the choice of a control element; the components that are made to vary with envelope amplitude. As the table below shows, there are a variety of types of control elements to choose from. These include:

- *field effect transistors* used as variable resistors either directly or optically coupled to LED's,
- *photoresistors* driven by incandescent bulbs or LED's or by individual LED's,
- *operational transconductance amplifiers* such as the CA3080, CA3094, and LM13700,
- *switched capacitors* driven by clocked analog switches such as the CMOS 4066
- *bipolar transistors* such as the 2N3904 or 2N5088.

Table 1 - Comparison of Control Elements

Element	Cost	Speed	Noise	Current	Matching	Availability	Distortion	Flexibility	Space
FET	++	++	-	++	+	++	--	+	++
LED/FET	--	++	-	++	++	-	--	+	+
Lamp/photocel	+	--	++	--	--	+	++	++	-
LED/photocell	-	-	++	-	++	-	++	++	+
OTA	--	++	+	++	++	-	-	+	-
Switched Capacitor	++	++	+	++	++	++	++	+	+
Transistor	++	++	-	++	++	++	-	--	++

++ = Very good; + =Good; - = So-so; -- = Problematic

I've provided a very rough rating scheme for each control element along a number of dimensions. These aren't everything, but they include most of the things that a design and product would be sensitive to:

cost: typical street price

speed at which they can respond to rapid signal changes, both in terms of initial attack time and recovery or decay time (Note: fast speed means susceptibility to ripple distortion, see below.)

- *cost*: typical street price
- · *speed* at which they can respond to rapid signal changes, both in terms of initial attack time, and recovery or decay time (NOTE: fast speed also means susceptibility to ripple distortion; see below)
- · *noise* and hiss
- · *current* consumption
- · *matching*: the ability to easily find two or more units that are matched for characteristics
- · *availability*: how easy it is to find them (i.e., will most walk-in retailers carry them?)
- · *distortion*: how easily they handle large signals
- · *flexibility*: how easy it is to incorporate them into different filter configurations or place them anywhere in a filter design (e.g., if they can only be used as control elements tied to ground)
- *space*: the overall space occupied by the element and awkwardness of placement of components (e.g., multiple photocells coupled to a single lamp)

An excellent more technical discussion of the various types of control elements used in voltage-controlled filters and how they work from an electronic design perspective can be found at http://www.octavo.demon.co.uk/japan-vcf.htm#0B. The page also includes a list of what elements are used in what commercial analog products so you can figure out what elements and filter configurations sound which way.

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The other thing to consider about the control element is that these represent the major distinction from, and advantage over, wah-wah's. In a typical wah-wah, the user sweeps a single control element (usually a pot) with their foot. Having only one controllable element limits one considerably with respect to filter design, which is why so many wah-wahs tend to sound similar in their functioning. Many types of filters require simultaneous control of two elements, which can be problematic in some instances, though not exceedingly so. For example, the state-variable filter in the Mutron III requires two elements to be changed simultaneously. In the Mutron, this is done with photocells, however it can also be done with a dual-ganged pot. In fact, if you've ever seen Craig Anderton's *Electronic Projects for Musicians* book (which often gets referred to as *EPFM* by those who cite it regularly), his "Super Tone Control" project is exactly that. Mount it in a footpedal with a dual-ganged pot controllable by the foot mechanism and you have a helluva wah. That digression aside, in many instances, it is possible to construct more complex filters using envelope control of control elements. If the designer is willing to use AC power, rather than relying on batteries alone, the possibilities become wide open.

The Role of Signal Level and Dynamics<>:

Level: A wah-wah will wah, and an EQ will equalize, regardless of signal level, as long as you twiddle the controls. The signal to noise ratio and the distortion characteristics may not be the greatest if the level is too low or too high, but it will work as intended. Not so with an ECF. The envelope follower is designed to assume a particular signal level and detect variations within that range. If the signal you feed it is hotter than it expects, you may find that only the lowest 10% of the sensitivity pot's rotation is useful, and anything over that will send the filter right to the limits of its sweep and keep it there a long time. If the signal is much weaker than it expects, you may find that the filter fails to react unless the sensitivity is up full tilt. Both types of situations are likely to be interpreted by users as a busted or nonfunctional effect. Meanwhile the effect is just waiting for its preferred type of signal to show what it can do.

There are several fixes to the problem of poorly matched signal level:

- <>Make sure your guitar volume is up full (or down), although this may conflict with your plans for how you want to use your guitar volume to drive other things, or how you planned out volume levels over the course of a song/piece.
- <>Use some kind of outboard/stompbox pre-amp with an adjustable output level. If you can't find a suitable one, most stompbox compressors with adjustable output level are able to sub for this (see below), as can EQ boxes.

Stick a distortion/overdrive device ahead of the ECF (although this has some other effects; see below).

Keeping the optimal signal level in mind, it is unwise to stick any device ahead of an ECF that is likely to alter the volume in a way that alters the envelope of each note or strum. For the ECF to sweep in sync with your picking, the initial attack of the note must be the strongest part of the signal. Any alteration of that, and the ECF will start to behave in unusual ways. This may be what you want, but then again it might not. Examples of this would include any effect that sweeps back and forth automatically such as a stompbox tremolo, a phase shifter, a flanger, and a univibe. Although the tremolo is the only one that explicitly alters the volume, the notches introduced into the signal by these other devices may well result in a volume drop for some notes at some points, and cause the ECF to behave erratically.

Dynamics: ECF's are dynamic devices. They depend not only on signal **level** but on **variations** in signal to work. If the signal doesn't vary, then the effect won't sweep. So, while you don't want the overall signal level to be too high or too low, you do want it to vary a lot.

Effects that can reduce dynamics include limiters and compressors set to clamp the volume at a very steady level, and fuzzes that clip very heavily, or simply result in a more compressed sound. If the signal level fed to the ECF is not that strong to begin with, and the dynamics are compressed in some manner, then you can crank up the sensitivity all you want, and pick as hard as you want and may not hear any effect whatsoever. Conversely, if the sensitivity is turned up, and the signal lacks dynamics, you won't hear much sweep because it will hang-up at the extreme point of the sweep.

On the other hand, you can use this to your advantage if you want the sweep to be subtle, or if you want to be able pick very hard without getting pronounced sweeps. One of my favourite sounds involves use of a compressor ahead of an ECF. Especially if it's a bad compressor. A bad one? Yes. Compressors and limiters have their own envelope followers, that are used to adjust the gain or level of the signal instantaneously. Bad ones will often exhibit a phenomenon called "breathing", that involves a clumsy recovery from the initial attack, sometimes resulting in a slight gain over the life of a note. Although it makes vocals sound unnatural, it can add an other - worldy sound to things sometimes (I especially like it on the rear pickup of a Tele, but that's another thing). In our case, it can add a gentle openning-up of a note or chord after you've picked/strummed it, by getting the ECF to sweep very slowly and very subtly.

The bottom line here is that getting an ECF to do interesting things, and especially do them the way you want, depends on keeping one eye on the overall dynamics of your signal chain.

Common Controls: These are the most commonly observed controls on commercial ECF's. Those controls labelled with an asterisk are part of the envelope detection circuitry.

- *Sensitivity, Gain, or Depth**<>: Adjusts input signal going to the envelope detection circuitry, and determines how much the filter responds to your playing. Less sensitivity means less sweep for the same strum. Important for matching responsiveness of effect to differing input levels (e.g., post fuzz).
- *Q or Peak*: Adjusts filter emphasis or resonance at the turnover frequency.
- *Initial or Start Frequency**<>: Point at which the filter starts its sweep.
- *Drive, or Direction**<>: Selects whether the filter starts its sweep going down from a starting point or going up.
- *Range*: Usually selects between two or more sets of capacitors that determine the overall range of sweep
- *Filter Type*: Selects between basic types of filters. Usual configurations are bandpass/lowpass, with highpass and notch thrown in sometimes. In some cases (e.g., Dr. Q) the switch may select between two versions of the same basic filter category.
- Less common controls might include:

- *Attack**: The time taken for the filter to sweep from its resting frequency to the point of maximum sweep (wherever that happens to be).
- *Decay**: The time taken for the filter to settle back to its resting level.
- *Sweep**: Pans between inverted and non-inverted versions of the envelope signal. Since the centre position usually mixes inverted and non-inverted envelope signal and results in cancellation, this type of control effectively becomes a combined sweep width and direction control.

<>*External triggering*<>: Allows something other than what the user is playing to drive and control the filter circuitry. This might be processed as if it were an instrument (i.e., it goes through the envelope follower circuitry) or or treated as if it were the output of the envelope follower circuitry (i.e., it directly drives the filter)

Mysteries of Envelope Detection<>: For the most part, envelope detection is the heart and soul of an ECF, and a large part of what makes one commercial product different from another. Although most commercial ECF's use very traditional design ideas (read "cookbook") to extract the envelope of the input signal, they will vary in terms of how many available features of that basic envelope extractor design they use, and the preset component values decided upon when something that could be varied is left at one value. For example, a particular type of envelope detection circuit might easily permit different attack times if one were to replace a fixed resistor with a variable one, but the manufacturer may have decided to select a one-attack-time-fits-all value just to save on chassis space for another control, in additional to the cost of the pot, knob, labour, and chassis.

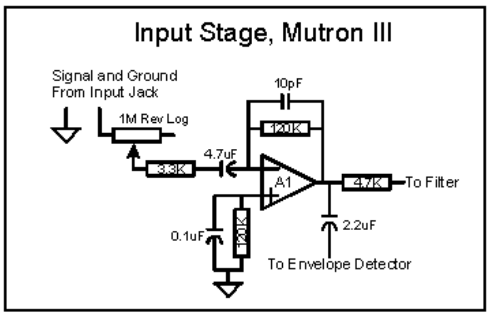
Why should this matter to you, and why would I label envelope extraction the heart and soul of an ECF?

earn their name by changing their filtering characteristics depending on the amplitude envelope of the incoming signal. The amplitude envelope

An Example: Circuit analysis of the Mutron III

There were many others in the 70's, but the Musitronics Mutron III established many of the more common features to be found on many commercial, and probably homebrew, ECF's of the time, and since then. Figure X shows a schematic of the Mutron II. Let's take it apart.

Input Stage

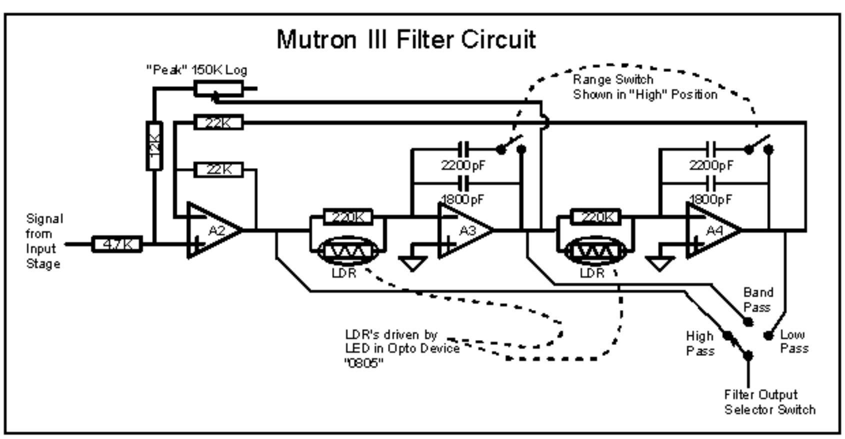


The op-amp labeled A1 is the inverting input buffer and gain stage. The 120k resistor in the feedback loop sets the gain of this stage, in conjunction with the 1meg pot labeled "Gain". The gain can be set from an attenuation of about 90% (i.e., 10% of the input level, for very hot signals) to a gain of about 40. Pretty versatile, with respect to the range of input signals it can handle, although bear in mind that the gain is applied to both the signal going to the filter and the signal going to the envelope follower. Any attempt to increase the input signal to improve the S/N ratio automatically results in a stronger envelope signal, and any attempt to keep signal clipping at bay in the filter will reduce the envelope signal.

Filter Stage

The filter is what is referred to as a state-variable filter, made up of op-amps A2-A4. This is a very standard filter that shows up in many applications beyond the Mutron. Craig Anderton used the state-variable configuration for his Super Tone Control project in the two *Electronic Projects for Musicians* books. The state variable filter can produce any of 4 different types of functions that can be tapped at different outputs:

- lowpass (LP) - only frequencies below a certain value pass unimpeded
- highpass (HP) - only frequencies above a certain value pass unimpeded
- bandpass (BP) - only frequencies between a certain minimum and maximum value pass unimpeded

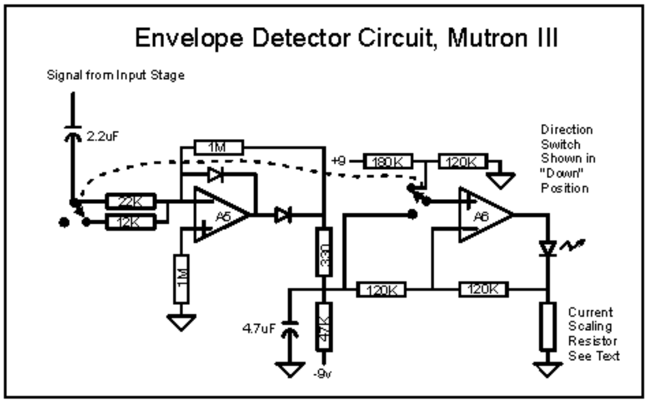


If you combine the highpass and lowpass outputs, you also get a notch filter output, which provides a dip in frequency response in the range where the highest part of the lowpass filter, and lowest part of the highpass filter, meet. You can select which of the first three types of outputs you want via the "mode switch" seen on the extreme right. If HP and LP are selected at the same time, the output is a notch-type filter. This is done on the upgraded version of the Mutron that Electro-Harmonix markets as the Q-Tron and Q-Tron+. If you own, or have made, an ECF that has a similar kind of mode switch with LP, BP, and HP settings, chances are that it is a state variable filter, and you can add the notch function by providing some sort of switching arrangement that lets you select both HP and LP at once.

The frequency at which all of this happens is set by the value of the capacitors in the feedback loop of A3 and A4, the resistor between A2 and A3, and the resistor between A3 and A4. The capacitors need to be matched, and so do the resistors. You can tune the corner frequency of the filter by varying either the resistors OR the capacitors simultaneously. The Mutron sets a maximum resistance via the two 220k resistors labeled R10 and R12. In parallel with each of these two resistors are photocells, whose resistance varies depending on the light that falls on them. They are contained in the mystery component labeled 0805 in the drawing. As the light shining on the photocells varies, so will the combined resistance of the fixed resistors and photocells, and the corner frequency of the filter's output will change for all of the various types of outputs it provides.

The overall *range* of filter frequency sweep can be changed by simply changing the capacitor values. The Mutron does this by adding in a second pair of caps in parallel with C5 and C7, to lower the range set by C5 and C7. Since the Mutron has no real way of setting the "start" or initial frequency of filter sweep, the range switch is pretty handy. What some folks do is use a switch with more than 2 positions, such as a 2P6T rotary switch. In a rather cumbersome way, this simulates being able to manually tune where the filter starts sweeping from. Some ECF's, such as the PaiA *Motion Filter*, allow one to tune the start frequency via a pot.

The Envelope follower and Inverter



The Mutron uses what is referred to as a precision half-wave rectifier. That is, it provides an AC voltage that is unipolar - varying between ground (0 volts) and some positive value. The signal from the input stage is routed into the precision rectifier amplifier A5 with one of two gains set by one pole of the "Direction" Switch. A5 has two diodes associated with it; one allows the positive half cycles of signal to cause current to leave the amplifier, going into the 330 ohm resistor and the 4.7uF capacitor to ground. This half of the signal is reproduced at high gain due to the 1M feedback resistor from the cathode of the output diode to the non-inverting input.

When the signal attempts to go negative, it forward biases the diode from the non-inverting input to the output of A5, and reverse biases the diode from the output of A5 to the 330 ohm resistor. Only the half of the signal that causes current to flow into the 330 ohm resistor and 4.7uF capacitor go into making up the envelope.

The voltage on that 4.7uF capacitor is what is taken to be the envelope of the input signal. We see that even for very fast "attacking" signals, the speed that the capacitor can charge is limited by the 330 ohm resistor. The capacitor discharges primarily through the 47K resistor to -9V. The "attack time" is then controlled by the 330 ohm resistor and the "decay time" or "release time" is (primarily) controlled by the 47K resistor to -9V.

The inverter circuit A6 determines whether the detected envelope causes the filter to sweep higher in frequency on louder notes or lower with louder notes - the difference between a "wah" and an "ow" sound.

Interesting Things You Can Do With an ECF<>: There is a whole lot more to the universe of ECF's than playing "Disco Duck" or "What I Am is What I Am". For starters, much like a foot-operated wah-wah, ECF's have a different impact when placed before a distortion device, than when placed after one. I like to think of fuzzes as a kind of additive synthesis, where what you feed in determines the type and proportion of harmonics added at the output. Placed ahead of a fuzz, an ECF further alters the kind of harmonics that come out by emphasizing certain frequencies, and clipping them more than others. Since the harmonics generated extend beyond the passband of the ECF, you'll hear this as a kind of animation to an otherwise broadband sound, rather than any sort of obvious wah. Placed after a fuzz, the same device now eliminates harmonics outside of the passband, providing a more obvious "wah" or "ow" (depending on how you set drive/sweep direction).

I sent the guitar to a compressor. Again, used to constrain dynamics, and provide another source of envelope follower recovery time. From the compressor, it went to a 6-band EQ, set for bass cut and mid-boost, and from there to an ECF; in this case an MXR Envelope Filter set for a slow attack time, and moderate sensitivity. The MXR-EF sweeps up, and has a fairly meaty, rather than thin, sound. With attack set for slow, it would take a few tenths of a second for the filter to reach the midrange and treble. With the EQ set the way it is, there wouldn't be enough signal to really push the envelope follower hard, so you shouldn't expect a wide sweep. The compressor works by boosting the signal, and using an envelope follower to drive a gain-reduction control element. If the control element in the compressor has a slow recovery time, then what will happen is that the signal will appear to retreat and gain output slightly shortly after you pluck or strum hard.

ECF hall of fame: While there are lots of one and two-knob wonders, there are also some absolutely stunning and functionally complete units out there. Some historical brightlights would include:

- The Musitronics Mutron III, and its descendants, the Electro-Harmonix Q-Tron and Q-Tron+. There have been a number of workalikes of the Mutron over the years, which I suppose attests to its attractive set of features. The Ibanez Auto-Wah and the Univox Funky Filter both have the exact same set of features as the original Mutron. I used to own a Funky Filter, and it was a Mutron every inch of the way. In recent years, Mike Biegel updated the Mutron design for Electro-Harmonix, eventually incorporating a send/return loop so that dynamics could be preserved by extracting the envelope signal prior to any additional effects processing. Very handy.

- The Biegel Sound Labs Envelope Controlled Filter. This is kind of the holy grail of ECF's, with very few actually built and sold. This was a rack mount unit that everything the Mutron had (no small coincidence, given the designer), plus much better fine control over the envelope.

- The Electro-Harmonix Microsynth for Guitar or Bass. The EH-MS provides for an automatic swept filter sound of the straight guitar and several other derived tones (fuzz, octave). The begin and end points of the filter sweep can be used to set both the direction of sweep and the width of sweep. Although the guitar's natural envelope is not used to drive the filter, it is used to drive the VCA and provide some degree of dynamics. Not a dedicated ECF, strictly speaking, but the absence of of a number of other features made the swept filter the most prominent feature of the MS, and one of the major reasons for using it.

The resurgence of interest in ECF's has also produced some very classy and thoughtful products:

- Moogerfooger Lowpass Filter: This is a stompbox version of the very filter that got people hungry for a guitar version of what a synth could do in the first place. Bob Moog has put a 4-pole lowpass filter in a classy footbox with top notch external control capabilities and Moog tone.
- Lovetone Meatball: A twiddler's wet-dream. This British baby has more knobs than you can shake a stick at, including excellent control over envelope characteristics, and an external loop (like the Q-Tron+) for using the pre-loop dynamics to control an additionally processed signal.

- Frostwave Funk-A-Duck and Chunk Systems Agent 00Funk: A pair of Australian gems. Not quite as tweakable as the Lovetone but both have solid thick classic tones, with good envelope control, and a high resonance filter for getting those Korg MS-20 sounds that have populated dance music as of late. The Duck has pretty much all the controls of the Mutron, plus a little more. The 00Funk has control voltage input and output for driving, and being driven by, other devices.

- Z-Vex Seek-Wah: An intriguing combination of sequencer and triggered wah, this baby doesn't neatly fit into any category. In a loose sense, it corresponds to, and is sort of synched to one's playing, but doesn't correspond directly to the signal envelope. Rather, the signal that drives the filter section can be shaped by 8 trimpots.