Amplifier Tremolo Technology White Paper

Sometimes to understand who you are, you have to go back to the beginning, back to where it all began. Before smart phones, before computers, before integrated circuits and the transistor—the only effects available to guitarists were tremolo and spring reverb. The guitar players of the day didn't have the rainbow of colors that we have now.

But like a charcoal sketch, there is a stark beauty to the tone without the wash of effects that are now possible. Stripped down to the bare necessities, the contrast of the different tremolos becomes apparent. You feel the beating heart of the photo trem, the rolling waves of the tube trem and the hypnotic swirl of the harmonic tremolo.

Given the storied history of these circuits found within classic amplifiers of the 1960s, there was no doubt that we wanted to develop a studio-class pedal that faithfully delivers three of these iconic and unmistakable tremolo effects. We examined the sonic complexities and tonal interplay, and accounted for every last detail in our hand-crafted algorithms.

The result is the technology found in Flint Tremolo & Reverb. Pete Celi, our Lead DSP Engineer and Sound Designer illustrates the research and sound design process in the White Paper below.

Strymon Amplifier Tremolo Technology White Paper

Amplifier Tremolo Overview

Still incorrectly labeled as 'vibrato' in many cases, the tremolo effect is a cyclical amplitude (volume) modulation of the input signal. Although there are many cool tremolo effects that can be had by using a simple VCA (voltage-controlled amplifier) circuit and applying geometric waveforms (like sine, triangle, square, ramp) to modulate the amplitude, our interest is in exploring the unique, soothing, pulsing, hypnotic effect that comes out of vintage amplifier tremolo circuits.

There were three main variations that came about in the late '50s and '60s. The three types can be referred to as Harmonic Tremolo, Power Tube Tremolo, and Photocell Tremolo. These variations have unique characteristics that result from the very different ways that the effect is achieved

The LFO

One thing that these vintage trem types share in common is the LFO (low frequency oscillator) circuitry, which is generated by a classic positive feedback 'phase-shift' oscillator. A network of resistors and capacitors determine the rate of oscillation, and the resultant LFO signal is a mildly distorted sinusoidal signal.

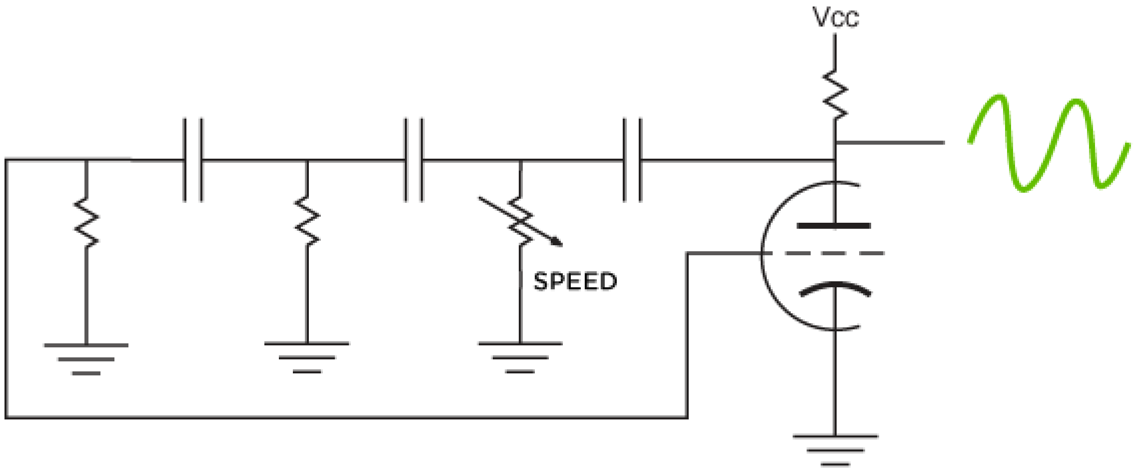

FIG. 1 PHASE-SHIFT OSCILLATOR

As the LFO circuitry is common to all three trem types under investigation, we can see that LFO waveshape is not responsible for the very different sounds that result from the three implementations. Let's look closer at the three types.

Harmonic Tremolo

The Harmonic Trem is actually not a pure tremolo effect. It is really a dual-band filtering effect that alternately emphasizes low and high frequencies. The end-result is a soothing pulse that has shades of a mild phaser effect combined with tremolo due to the nature of the frequency bands that are alternated. This circuit required two tubes to create a two-phase differential LFO that controls the gain of the two frequency bands, and then another tube to sum the two bands together. This implementation had a rather short period of availability perhaps due to the somewhat 'expensive' implementation. The basic idea is shown below:

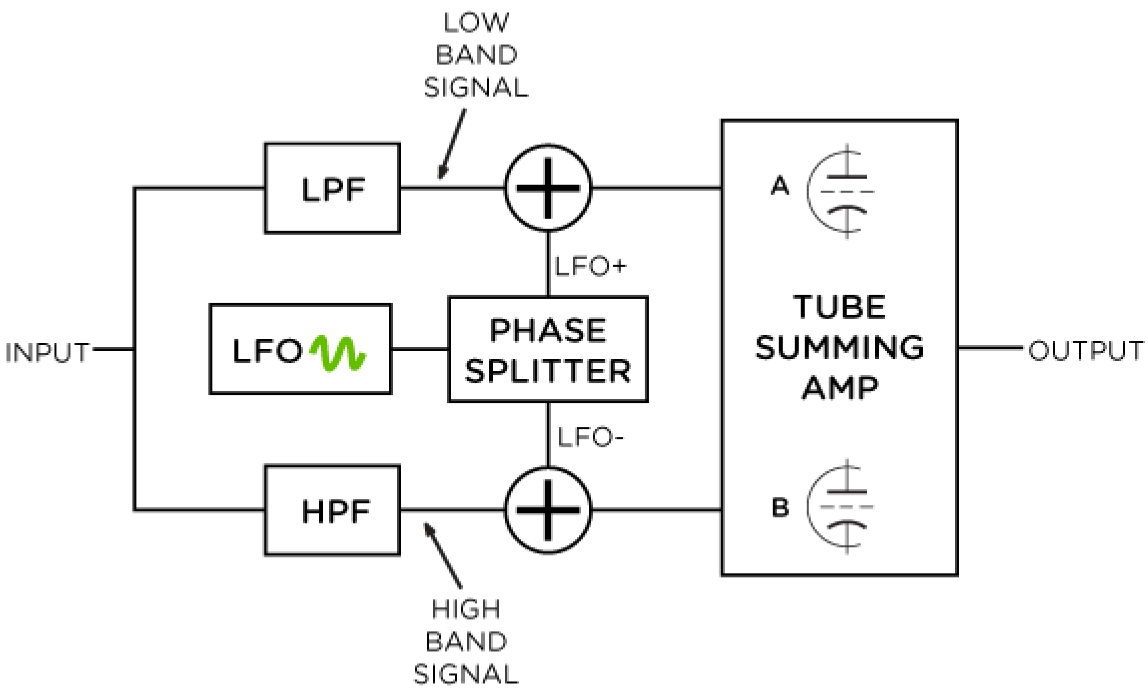

FIG. 2 HARMONIC TREMOLO BLOCK DIAGRAM

One phase of the LFO signal is added directly with the low-band input signal, while the other phase gets added directly to the high-band signal. Essentially, the filtered signal ‘rides’ on top of the LFO signal on its way into the tube summing amplifier. This effectively changes the small-signal operating point of the filtered signal along the tube gain curve. When the LFO signal is at low voltages, the filtered signal will have more gain as the tube operates in its steepest gain region. Conversely, when the LFO is at higher voltages, the tube gain-curve flattens out, and the input signal experiences reduced gain. Since the two bands have opposite phase LFO signals, when one band is experiencing high gain, the other is experiencing low gain. When the two are combined, the opposite phase LFO signals cancel each other out, and the two alternating amplitude-modulated filtered signals comprise the output. This produces the tremolo effect of hearing a loud (bright) signal alternating with a soft (dark) signal.

Also, as a consequence of riding up and down the tube’s gain curve, the filtered signals experience slight changes in harmonic content due to the changing nonlinearities of the gain curve around the signal. This adds further complexity to the trem’s sound.

Power Tube Tremolo

Next in line was a more cost effective circuit that eliminated two tubes from the Harmonic Trem implementation. It used the LFO signal (no longer a two-phase LFO) to directly influence the power tube bias of the push-pull output stage.

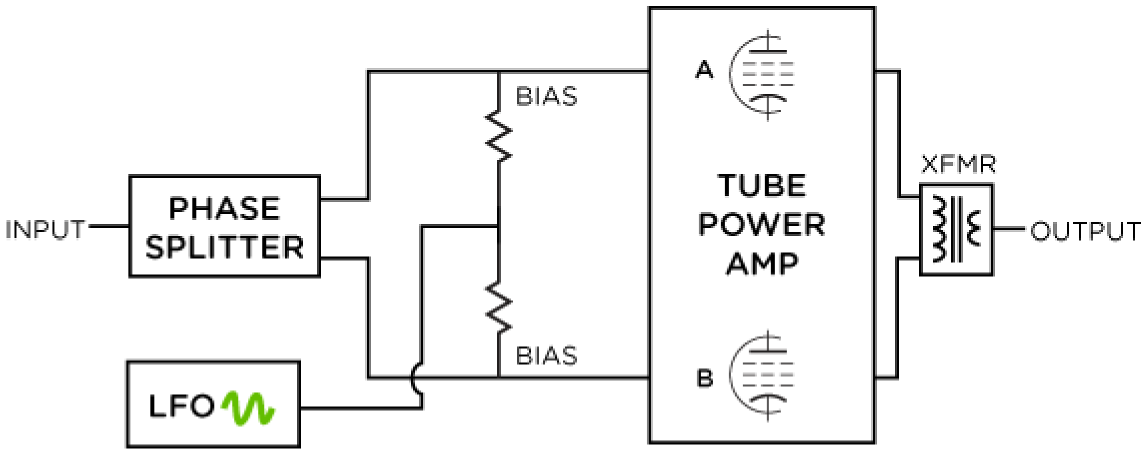

FIG. 3 POWER TUBE TREMOLO BLOCK DIAGRAM

In a push-pull power amplifier, two tubes are employed and biased so that they idle at substantially less than full power. This keeps power dissipation to a minimum when no signal is going through the amp, allowing them to provide power to the speaker more efficiently while increasing tube life. The guitar signal is split into opposite phases so that one tube conducts when the signal is positive, and the other tube conducts when the signal is negative. The two outputs are added together through the output transformer.

By applying the LFO to the bias, the power tubes are being biased into lower and higher idle currents. At low idle currents, the tubes are shutting off and signal gain (volume) is reduced. At higher currents, the tubes are running hot and higher gain results. This alternating gain produces the tremolo effect.

But there is more going on than just a change in volume. Secondary effects coming into play are crossover distortion as the tremolo volume heads towards zero and the tubes are shutting off. At the other end, increased power tube harmonic distortion occurs as the tremolo nears its maximum volume. The effects of power-supply sag also contributes to some of the dynamic response when playing through this kind of tremolo circuit, as it influences the relative bias point of the power tubes. All these things add up to contribute to the ‘magic’ of this trem circuit.

Photocell Tremolo

The Photocell tremolo uses a light-dependent resistor (LDR) to attenuate the input signal. The LDR is coupled with a miniature light bulb that is connected to the LFO. As the LFO oscillates, the bulb gets brighter and dimmer which in turn varies the resistance of the LDR. The varying resistance works with other circuit impedances to change the signal level.

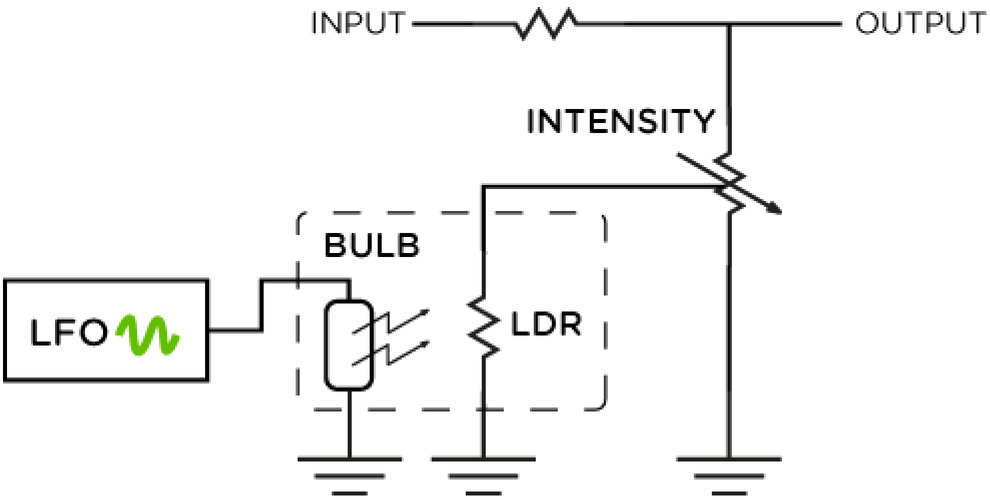

FIG. 4 PHOTOCELL TREMOLO BLOCK DIAGRAM

The light element used in the classic photo-trem circuits in the 60s was a neon bulb which has a very fast response time, meaning it turns on and off very quickly and spends very little time in between. This produces a characteristic ‘hard’ sounding tremolo that is moving between two levels, almost like a square wave. The duty cycle (symmetry) of the tremolo depends on the characteristics of the bulb relative to the LFO voltages, but the classic Photo-trem circuits were tuned to spend most of their time at the higher output level (duty cycle >>50%, bulb is ‘off’), switching to the lower level only briefly during the cycle. At maximum intensity, a choppy trem results.

Also, as the photocell trem circuit is not buffered, the tremolo creates a varying load resistance in the signal path as the bulb changes the resistance of the LDR. This in turn has secondary effects on the signal’s frequency response that contribute subtle characteristics as well.

Capturing the Magic

We can see from the discussions above that the end result of these vintage tremolo circuits is much more than a simple cyclical volume fluctuation. The depth, warmth and overall vibe of each one of these tremolo types can only be created by giving consideration to the entire circuitry used in the process. For the harmonic tremolo, the interaction of the LFO with the input signal in relation to the preamp tube’s operating characteristics must be accounted for. The Power-tube tremolo must recreate the vintage push-pull power tube section including the phase-splitter, tube characteristics, and power supply considerations. The photocell trem must involve the proper bulb-LDR characteristics in relation to the LFO signal, along with secondary consideration of variable loading in the signal path. When these things are all properly accounted for, the difference from a simple VCA tremolo is apparent. The complex and subtle nuances come to life, producing the mojo of their vintage amp brethren.