VCO Ramp Circuit

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Abstract

Many AMO experiments involve quickly sweeping a laser's frequency over a range of a few MHz. The frequency of the beam is often controlled with an AOM driven by some odscillator with a variable radio frequency output. The RF generators we had previously been using to drive our AOMs were too slow; the sweeps took tens of milliseconds. To overcome this limitation, we incorporated a voltage controlled oscillator (VCO) driven by a sawtooth wave input. With this setup, we are able to sweep our AOM frequency by many megahertz in as little as 60 microseconds.

1 Introduction

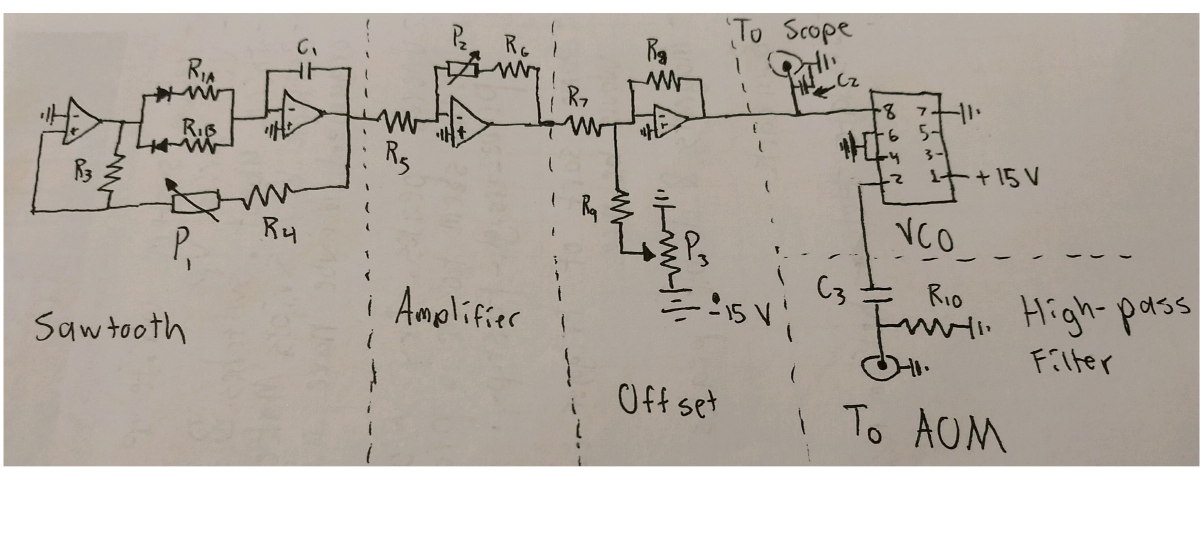
The VCO sawtooth circuit was designed with several constraints in mind. The first set of these constraints are the specs of the VCO itself. The tuning input of the VCO has a 3 dB bandwidth of 100 kHz, so the ramp should be designed to operate below this value. The voltage of the tuning input must be between 1 and 18 volts.

We want a linear ramp. Various effects from the electronics can distort the signal from linearity. These include capacitive effects and op-amp slew rate. To avoid capacitive effects, all timescales involved in the circuit should be engineered to be much less than the RC time constant. To avoid slew rate effects, op-amps with sufficiently fast slew rates must be chosen. In addition to slew rates, the op-amps can add complications if too much current is drawn from them. The resistors used in the circuit should be large enough to avoid this.

Another set of constraints is that the circuit should have adjustable parameters. These parameters include frequency, amplitude, and offset. Adjustability can be achieved using potentiometers. The range over which these parameters can be adjusted should be within the constraints discussed above.

The last constraint is that the whole system, ramp and VCO, should be included on the same circuit board. Previous iterations of this idea have involved several separate boxes which made it somewhat clunky to use.

2 The Circuit



Element	**Value**
R_{1A}	1 kΩ
R_{1B}	
R_3	120 kΩ
R_4	
R_5	
R_6	2 kΩ
R_7	10 kΩ
R_8	10 kΩ
R_9	10 kΩ
R_10	

Element	**Value**
P_1	20 kΩ
P_2	150 kΩ
P_3	300 kΩ
C_1	
C_2	
C_3	

All op-amps are LF411 and all diodes are 1N5817.

3 The Sawtooth Generator

Noone I talked to about this section of the circuit was familiar with this method of generating a sawtooth wave. For that reason, I think it is worth while to explain it.

There are two op-amps in the sawtooth generator. The one on the left I will call op-amp 1, and the one on the right I will call op-amp 2. Op-amp 1 is hooked up in positive feedback mode and will therefore be outputting ± V_{cc} (±15 V). Since this op-amp is saturated, we cannot assume ideal op-amp performance. Specifically, we cannot assume that the inputs are at the same voltage (the current output from the op-amp is limited).

Op-amp 2, however, will not be saturated. It will therefore act as expected, like an integrator. But, this is no ordinary integrator. A typical op-amp integrator has a single input resistor. Here that resistor is replaced by the two antiparallel diode-resistor pairs. This is where the magic happens and is what causes the circuit to produce a sawtooth (asymmetric triangle) wave. Since the two input resistors are not the same and since the diodes are antiparallel, the charging and discharging of the capacitor will have unequal time constants. This is what causes the asymmetry of the wave.

Because its input voltage is a constant, the output voltage of the integrator will be proportional to the input voltage.

$$V_{out} = \begin{cases} \frac{V_{in}}{R_{1A}C_1}\Delta t, & V_{in} > 0 \\ \frac{V_{in}}{R_{1B}C_1}\Delta t, & V_{in} < 0 \end{cases}. \tag{1}$$

The condition for op-amp 1 to switch between high and low output is controlled by resistors R_3 and R_4. The switch happens when the voltage drop across R_3 is equal to the output voltage of op-amp 1, which will bring its non-inverting input to ground.

The voltage drop across R_3 follows Ohm's law since it is just a standard resistor. The current across R_3 can be determined from the voltage difference between the outputs of op-amp's 1 and 2 (the non-inverting input of op-amp 1 still draws no current dispite non-ideal performance), V_{cc} and V_{out} respectively. The current is given by

$$I = \frac{V_{cc} - V_{out}}{R_3 + R_4 + P_1}. \tag{2}$$

The threshold on V_{out} to switch the sign of V_{cc} is then

$$V_{R_3} = V_{cc} = \frac{R_3}{R_3 + R_4 + P_1}(V_{cc} - V_{out})$$

or

$$V_{out} = \frac{R_4 + P_1}{R_3} V_{cc}. \tag{3}$$

The timescales for the switches are then given by

$$\Delta t_{switch} = \begin{cases} \frac{R_4+P_1}{R_3} R_{1A} C_1, & V_{cc} > 0 \\ \frac{R_4+P_1}{R_3} R_{1B} C_1, & V_{cc} < 0 \end{cases}. \tag{4}$$

4 Other Considerations

There are a few other aspects of the circuit that we have not discussed yet. These concern noise and are as follows:

- Each op-amp has a 1μF decoupling capacitor across its power inputs.
- The BNC output of the ramp has a small capacitor across it (C_2). This acts as a low-pass filter to eliminate high frequency coupling noise from the VCO on the ramp signal.
- The BNC output of the VCO has a high-pass filter before it. The raw signal from the VCO has amplitude and offset variations that follow the ramp signal. This filter eliminates those so that a fairly constant amplitude and offset signal goes to the AOM.
- For some reason, when a coax cable is attached to the VCO output, it acts as a fairly strong antenna causing a large amount of coupling with the SRS box output. The specs on the VCO output state the output power is 9.5 dBm. In contrast, the amplified signal from the RF generators going to the AOMs which are about 35 dBm hardly couple at all. I do not understand why. To fix this issue, I put 6 dB of attenuation on the output of the VCO along with a shielded coax cable. I also put an 11 MHz low pass filter on the output of the SRS box.
- There are still some ripples after each sharp transition in the ramp wave.