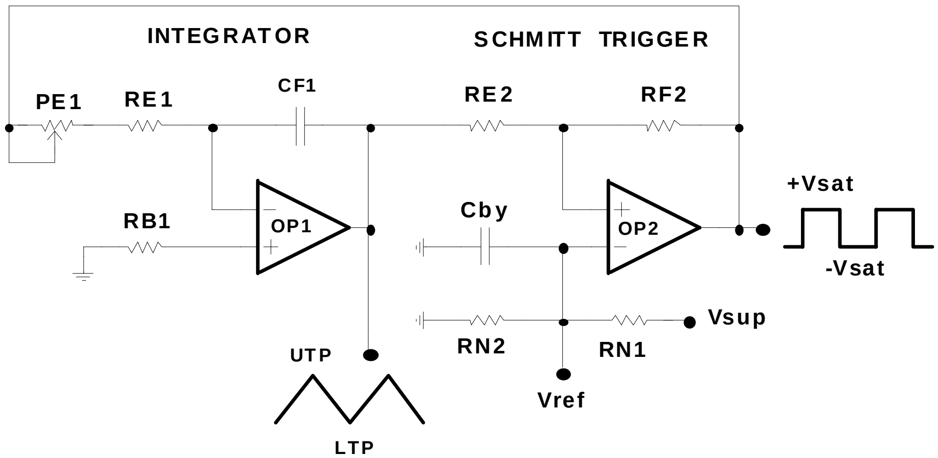
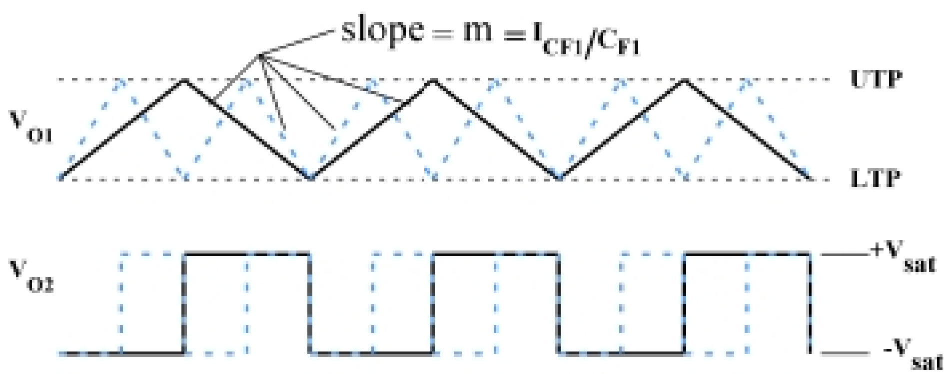
BASIC SQUARE WAVE-TRIANGULAR WAVE OSCILLATOR

1. Circuit description



The above oscillator is basically a switched integrator that outputs a triangular wave whose slopes are controlled by the charging current of C_{F1}, more specifically:

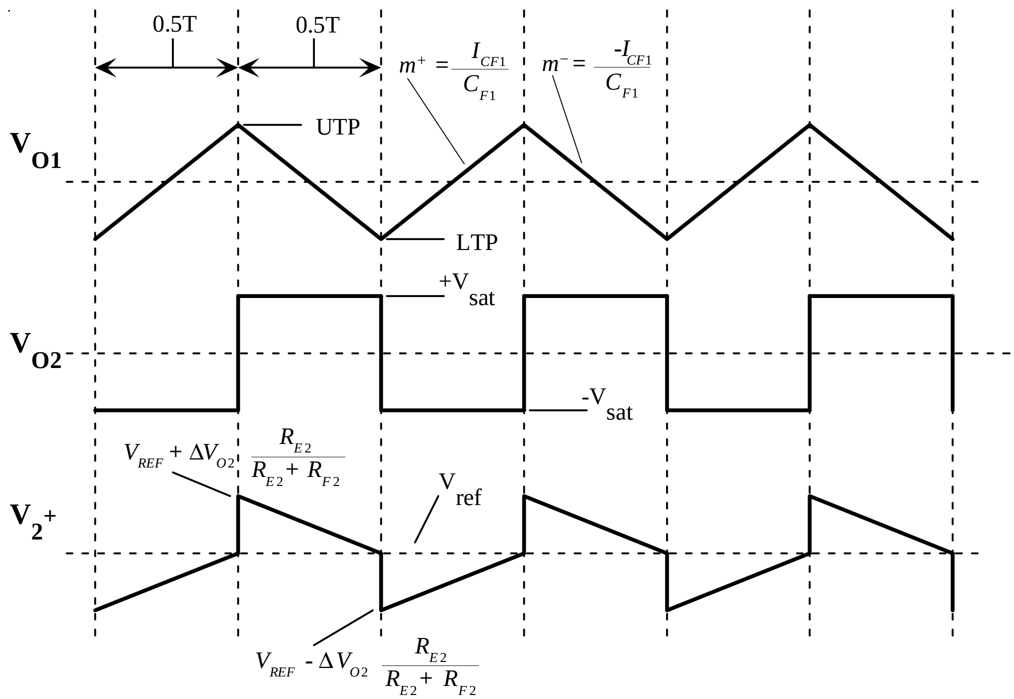
$$\frac{\Delta V_{o1}}{\Delta t} = \frac{I_{CF1}}{C_{F1}} \Rightarrow \frac{UTP - LTP}{0.5 \times T} = \frac{V_{SAT}}{(P_{E1} + R_{E1})C_{F1}} \Rightarrow F = \frac{1}{T} = \frac{V_{SAT}}{2(UTP - LTP)(P_{E1} + R_{E1})C_{F1}}$$



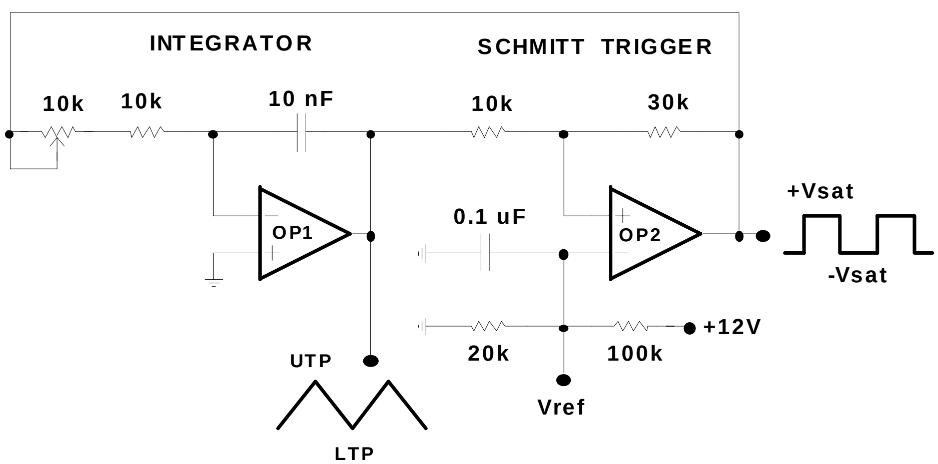
We can see on the above waveforms that if the capacitor charging current is doubled, the frequency of oscillation also doubles because the capacitor is charged twice as fast which results in a slope dV_{o1}/dt twice as large. Note here that the capacitor is charged linearly and not exponentially because the charging current is constant.

If the +ve and –ve saturation voltages are the same, only then are the +ve and –ve charging currents the same which results in a 50% duty cycle square wave.

UTP and LTP are the trigger voltages of the Schmitt trigger.



2. **Analysis example**

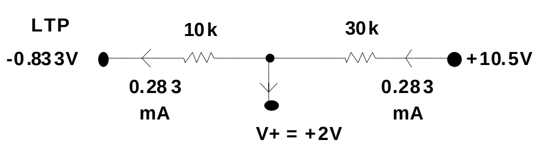


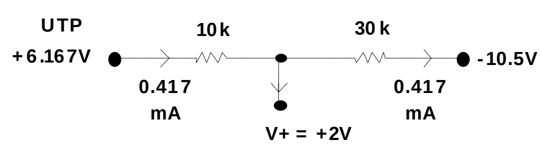
Assuming the op amps are LF347 with the following specs:

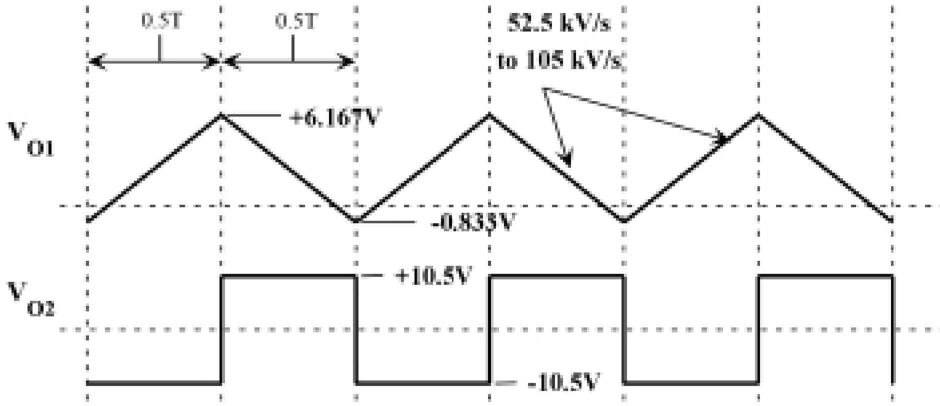
Specs for V_{sup}=±15V	**minimum**	**typical**	**maximum**
O/P Voltage swing, R_L=10K	±12V	±15V	---
I/P voltage range	±11V	+15V, -12V	---

Determine the two O/P waveforms showing voltages and range of PW and SW of square wave. Assume ±12V supply voltages and typical op amp parameters.

Analysis of trigger points of OP2:







$$\frac{I_C}{C_F} = \frac{\Delta V_{O1}}{\Delta t} \quad \Rightarrow \quad \Delta t = \frac{T}{2} = C_F \times \frac{\Delta V_{O1}}{I_C} = 10n \times \frac{6.16\bar{6} - (-0.83\bar{3})}{\frac{10.5}{10k \rightarrow 20k}} = 66.6\bar{6}\ \mu s \rightarrow 133.\bar{3}\ \mu s$$

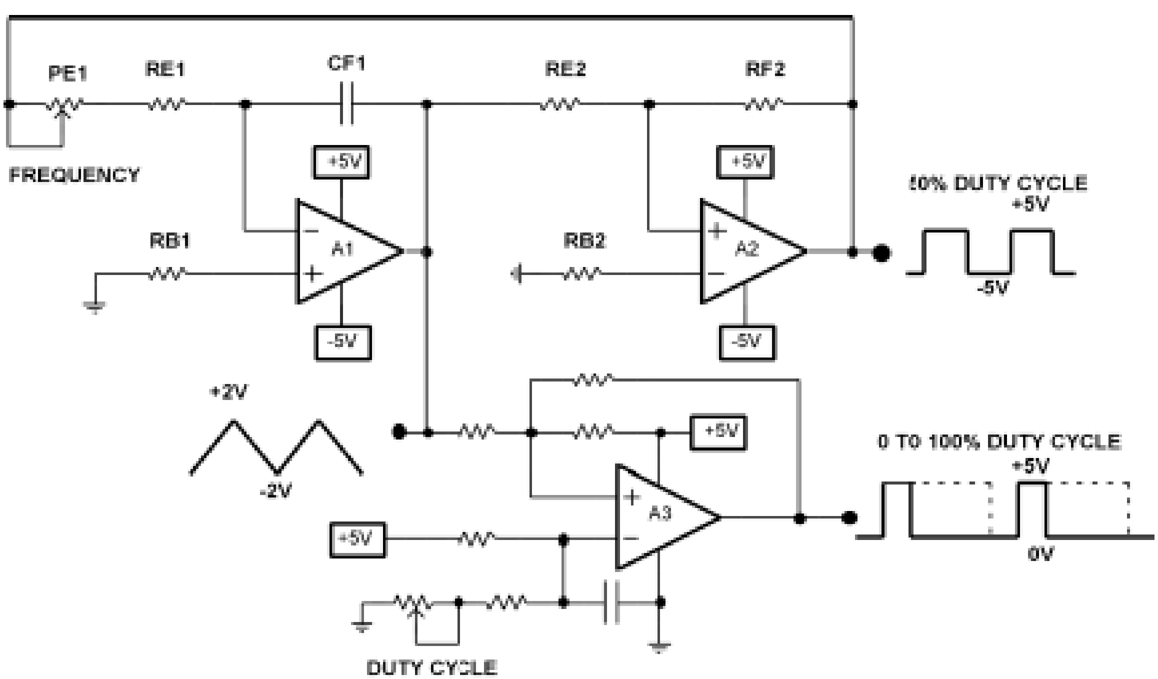
$$T = 133.\bar{3}\ \mu s \rightarrow 266.\bar{6}\ \mu s \qquad F = 3.75\ kHz \rightarrow 7.5\ kHz$$

NOTE: If the +ve and –ve saturation voltages are not exactly equal, then the integrator capacitor charge and discharge currents will be different and the duty cycle will not be exactly 50%. To remedy this, one should use rail-to rail op amps with matching +ve and –ve supply voltages provided by a dual tracking regulator.

3. <u>Design example</u>

Design an oscillator that meets the following specifications:

Supply Voltages: ±5V		Op amps:	OP291 DUAL rail-to-rail I/P and O/P
Frequency range: 1 kHz to 5 kHz			
Triangular wave: $\pm 2V_P$		Square wave:	$\pm 5V_P$ with fixed 50% duty cycle and 0V-$5V_P$ with 0% to 100% adjustable duty cycle



Schmitt Trigger Design

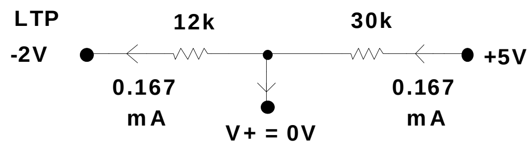
1. No pull-up resistor required

2. $$\frac{R_F}{R_E} = \frac{V_o^+ - V_o^-}{UTP - LTP} = \frac{5-(-5)}{2-(-2)} = 2.5 \quad \Rightarrow \quad R_E = 12K\ std \quad and \quad R_F = 30K\ std$$

3. Calculation of V_{REF}

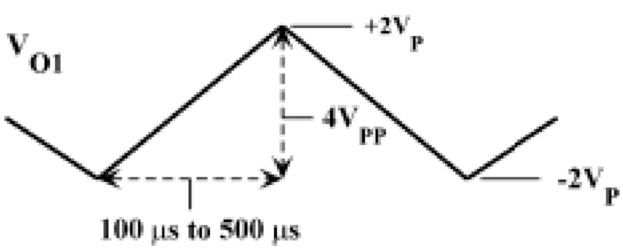
$V_{REF} = V^+ = 0V$ at triggering

Therefore the –ve I/P of A2 has to be grounded.



4. $$R_{B2} = 12k \| 30k = 8.57k \rightarrow 8.2k\ std$$

Integrator Design



$$\frac{I_C}{C_F} = \frac{\Delta V_{O1}}{\Delta t} = \frac{2-(-2)}{100\mu \rightarrow 500\mu}$$

$$\frac{I_C}{C_F} = 40\ kV/s \rightarrow 8\ kV/s$$

$$Let\ I_C \max = 1\ mA,\ therefore$$

$$C_F = \frac{1mA \rightarrow 0.2mA}{40\ kV/s \rightarrow 8\ kV/s} = 25\ nF$$

$$Let \quad C_F = 22\ nF \quad \Rightarrow \quad I_C = C_F \times \frac{\Delta V_{O1}}{\Delta t} = 22n \times (40k \rightarrow 8k) = 0.88\ mA \rightarrow 0.176\ mA$$

$$P_{E1} + R_{E1} = \frac{5V}{0.88\ mA \rightarrow 0.176\ mA} = 5682 \rightarrow 28409 \qquad Let\ R_{E1} = 5.6K\ std$$

$$P_{E1} = 28409 - 5600 = 22.81k \qquad closest\ std\ \ pot\ value\ above\ is\ 50K,\ therefore$$

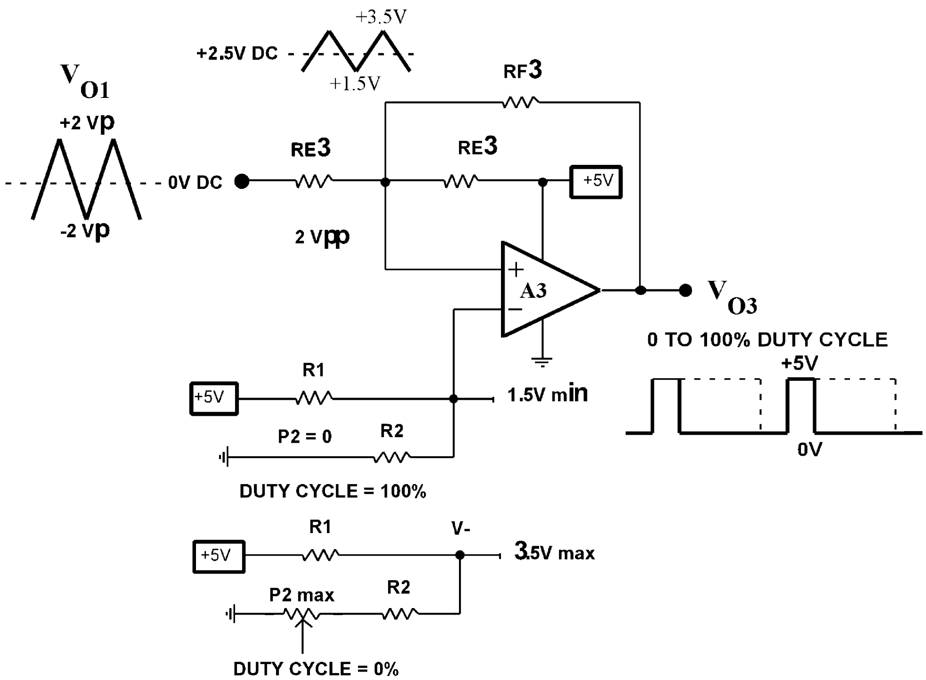
$$\frac{1}{50k} + \frac{1}{R_{par}} = \frac{1}{22.81k} \rightarrow R_{par} = 41.94k \rightarrow 43k\ std$$

$$P_{E1} + R_{E1} = 5.6k \rightarrow 28.72k \quad (P_{E1} + R_{E1})_{ave} = R_{\mathbf{B}1} = 17.16k \rightarrow 18k\ std$$

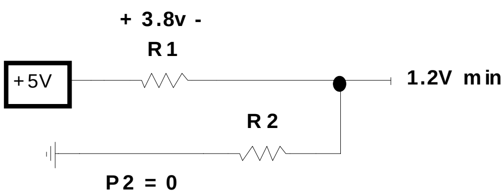
Standard pots available: 1k, 2k, 5k, 10k, 20k, 50k, 100k, 200k, 500k

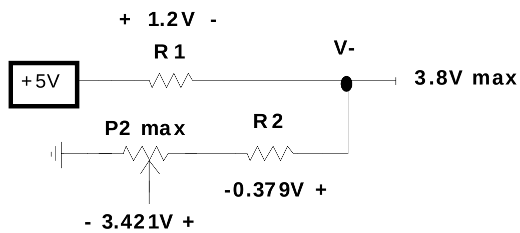
Level Detector Design

A3 is powered with +5V only to obtain 0V and +5V levels at the O/P, therefore we cannot apply the triangular wave directly to the I/P of A3. The two R_{E3} resistors will attenuate the triang. wave by 50% and will also pull it up to +2.5V average. R_{F3} provides a little DC hysteresis to prevent O/P chattering of A3. Let the hysteresis be 20 mV.



To be safe and ensure that 0% to 100% range is covered, let V_3^- range from 1.2V to 3.8V.





$$\frac{P_2}{R_1} = \frac{3.8}{1.2} = 3.16\overline{6} \qquad\qquad \frac{P_2}{R_1} = \frac{3.421}{1.2} = 2.85$$

P_2	R_1=P_2/2.85	R_1 std	R_2=R_1/3.166	R_2 std	V^-_{min}	V^-_{max}
10000	3509	3600	1137	1100	1.170	3.776
10000	3509	3600	1137	1200	1.250	3.784
10000	**3509**	**3300**	**1042**	**1000**	**1.163**	**3.846**
10000	3509	3300	1042	1100	1.250	3.854

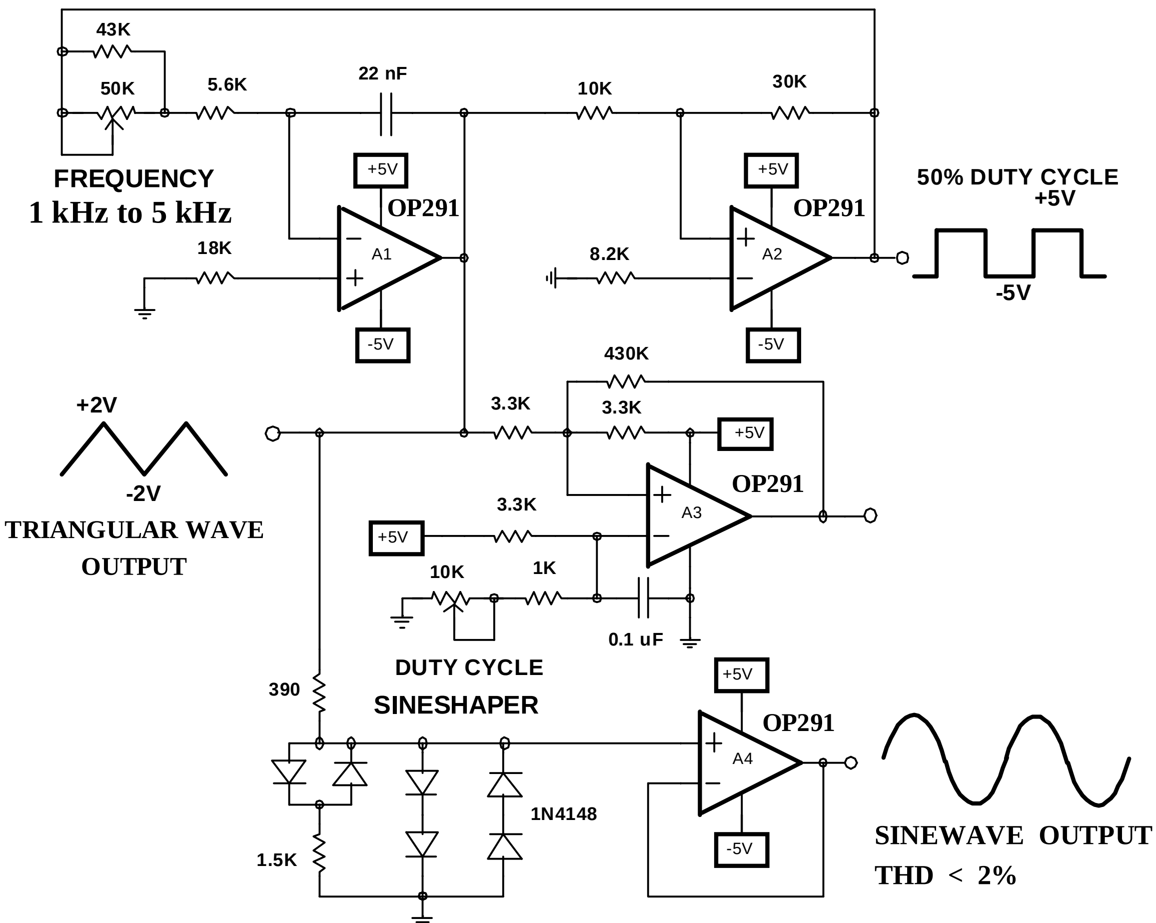
Assuming mid-range setting of pot for balancing I/P resistance of A3 (for min O/P offset voltage), we have

$$R_N = 3.3K \| (1000 + 0 \to 10K) = 767 \to 2538 \qquad R_N ave = 1653$$

$$R_P = R_{E3} \| R_{E3} \| R_{F3} \approx R_{E3} \| R_{E3} = 0.5\, R_{E3} = 1653 \to R_{E3} = 3306\ (3.3K\ std)$$

$$\frac{R_{F3}}{R_{E3} \| R_{E3}} = \frac{V_{O3}^+ - V_{O3}^+}{UTP - LTP} = \frac{5-0}{20m} = 250 \quad \Rightarrow \quad R_{F3} = 250 \times \frac{3.3k}{2} = 412.5k\ (430k\ std)$$

Final Circuit



The sineshaper uses the diodes' non-linearity to distort the triangular wave into a crude sinewave that usually has less than 2% THD (total harmonic distortion) which is typical for a general purpose lab function generator but not good enough for testing audio equipment where < 0.01% THD would be required for the sinewave test signal.

To adjust the amplitude of the output waveforms, we could have a SP4T (single pole, quadruple throw) switch that selects one of the four O/P waveforms and then use a potentiometer to control the final amplitude of the selected waveform.