One-VCA Precision 4Q Multiplier
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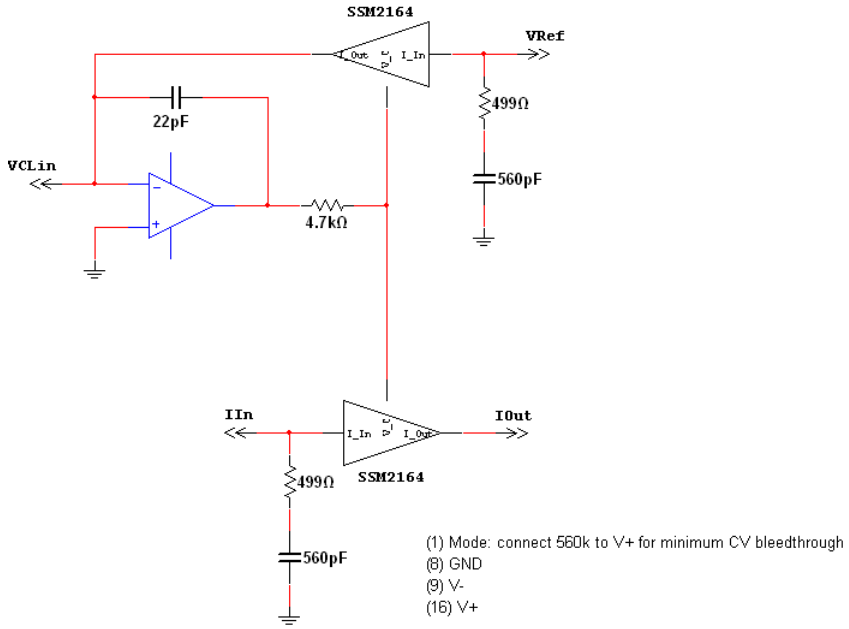
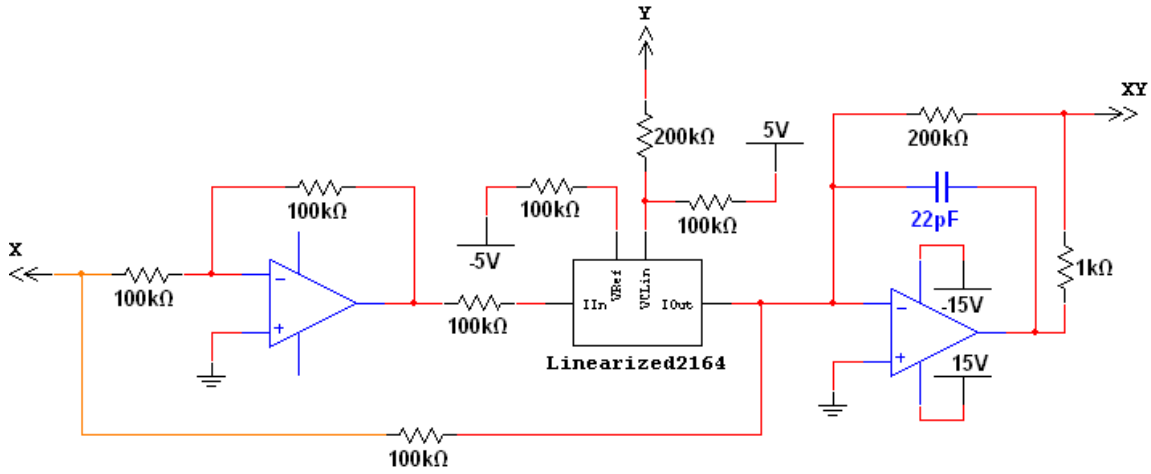
This is a balanced modulator circuit which was designed specifically as part of a Bode-style frequency shifter. As long as the resistors are all 1% tolerance or better, it provides very accurate four-quadrant multiplication.

It is based on a linearized 2164 VCA. Since this requires two 2164 VCAs, and there are four VCAs in a 2164 IC, this means that the design is ideally suited to building a dual multiplier. This is, of course, ideal for Bode frequency shifters, which require two multipliers.

Linearized 2164 VCA schematic:



Multiplier schematic:



Note: the 22pF stability caps could be a bit larger. Also, the 4.7k resistor in the VCA could be replaced with 0 ohms.

Explanation of circuit operation:

The linearized 2164 VCA is set up to be at unity gain at a control voltage of 5V. The fixed 5V input through the 100k resistor into VCLin will, in the absence of a Y signal, lock the VCA at unity gain.

The X signal is being inverted into the VCA, and a non-inverted version bypasses the VCA. These two signals are then summed at the final current-to-voltage (I2V) converter opamp. Hence, when the VCA is at unity gain (when Y = 0V), these inverted and non-inverted versions of X cancel each other out, and XY is 0. In actual fact, there may be a slight amount of signal leaking through under this condition, but this can be minimized by hand-selecting the four 100k resistors processing the X signal. Non-hand-selected 1% tolerance resistors should be close enough for reasonable accuracy.

The 200k input resistor for Y effectively applies a gain of 0.5 to this signal, and this is summed with the 5V at unity gain. Hence, a 10Vpp sine wave fed at Y will give the equivalent of a sine wave from 2.5V to 7.5V, which will vary the VCA gain from 0.5 to 1.5.

At a gain of 0.5, the non-inverted X signal is summed with 1/2 of the inverted X signal, giving half the non-inverted signal. This is then multiplied by a gain of -2 by the 200k resistor on the final I2V converter, thus giving the inverted signal at unity gain.

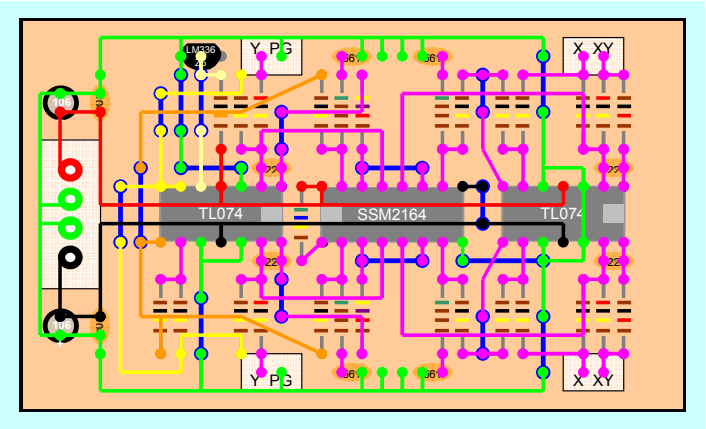
At a gain of 1.5, the non-inverted X signal is summed with 3/2 of the inverted signal, giving 1/2 the inverted signal. This is then processed through the I2V converter at a gain of -2 to give the non-inverted X signal at unity gain.

The reason for doing it this way is to avoid the effective VCLin voltage ever reaching 0V and giving zero gain at the VCA, which would create distortion in the multiplication. The way this circuit is arranged, one could feed up to a 20Vpp signal into Y and still have accurate 4Q multiplication. However, a 10Vpp Y signal is ideal.

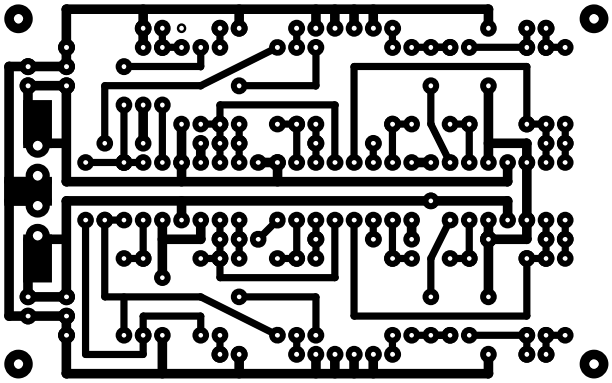
Although it may be obvious, it is worth noting that the key to accurate multiplication in this circuit for frequency shifting purposes is to provide effective AC coupling on all of the signals entering the multipliers. Passing the signals through 47uF electrolytic caps is sufficient for this purpose.

Here is my layout for this circuit on a one-sided PCB, along with the transfer image for making a PCB (set to 3.3" x 2.1" for printing the transfer).

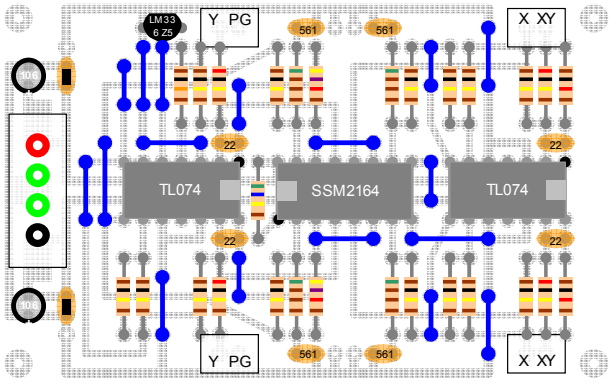
Layout image:



Transfer image:



Build guide image:



(Note: 5% resistors are shown in the layout and guide images, for ease of readability. Please use 1% resistors.)