Thursday 9/4/25

3) LC based oscillators

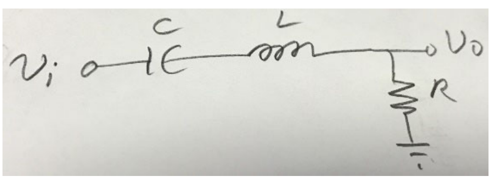
Comparison of RC oscillators with LC oscillators:

(1) An RC pair yields one pole. An LC pair yields two poles.

(2) Passive RC circuits have a maximum Q of 0.5. Passive LC circuits can have much higher Q's.

(3) LC circuits are much better for high frequency oscillators, but inductors are physically large and lossy for low frequency applications.

Consider the RLC circuit below:



$$V_o = V_i \frac{R}{R + \frac{1}{sC} + sL}$$

$$V_o = V_i \frac{sR}{sR + \frac{1}{C} + s^2 L}$$

$$\frac{V_o}{V_i}(j\omega) = \frac{j\omega R}{\frac{1}{C} - \omega^2 L + j\omega R}$$

$$\left|\frac{V_o}{V_i}(j\omega)\right| = \frac{\omega R}{\sqrt{\left(\frac{1}{C} - \omega^2 L\right)^2 + (\omega R)^2}}$$

$$\angle \frac{V_o}{V_i}(j\omega) = \tan^{-1}(\infty) - \tan^{-1}\left(\frac{\omega R}{\frac{1}{C} - \omega^2 L}\right)$$

At $\omega = \frac{1}{\sqrt{LC}}$, $\quad |\frac{V_o}{V_i}(j\omega)| = 1$ and $\quad \angle\frac{V_o}{V_i}(j\omega) = 0^o$

So, this network could be used as β(jω) for a positive feedback oscillator, requiring A(jω) = 1.

Consider the circuit below.

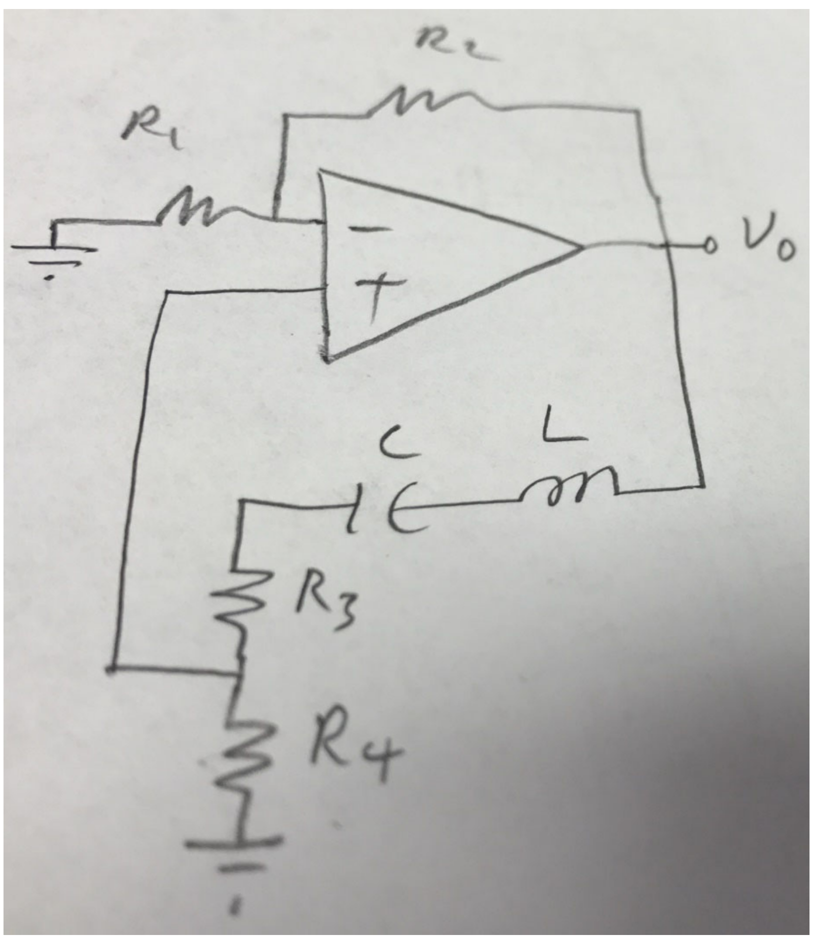
The op amp, R_1 and R_2 form a noninverting amplifier with

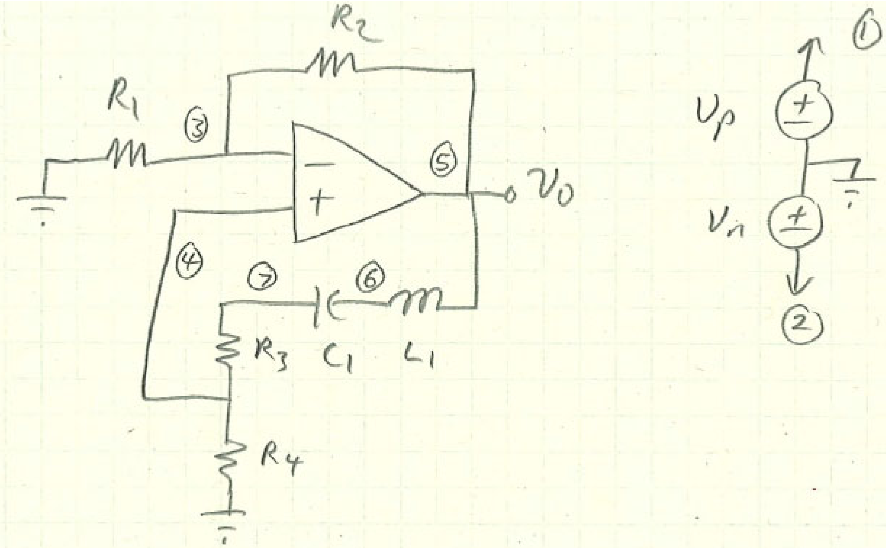
$$Gain = 1 + \frac{R_2}{R_1}$$

R_3, R_4, C and L form the RLC β(jω) network

R_3 and R_4 form a voltage divider, allowing the loop gain to be increased to 1 at the oscillation frequency.

Note: R_3 could represent some or all of the inductor's series resistance.





set $R_1 = R_2 = R_3 = R_4 = 10\,K\Omega$

set $C_1 = 1\,\mu F$ and $L_1 = 1\,mH$

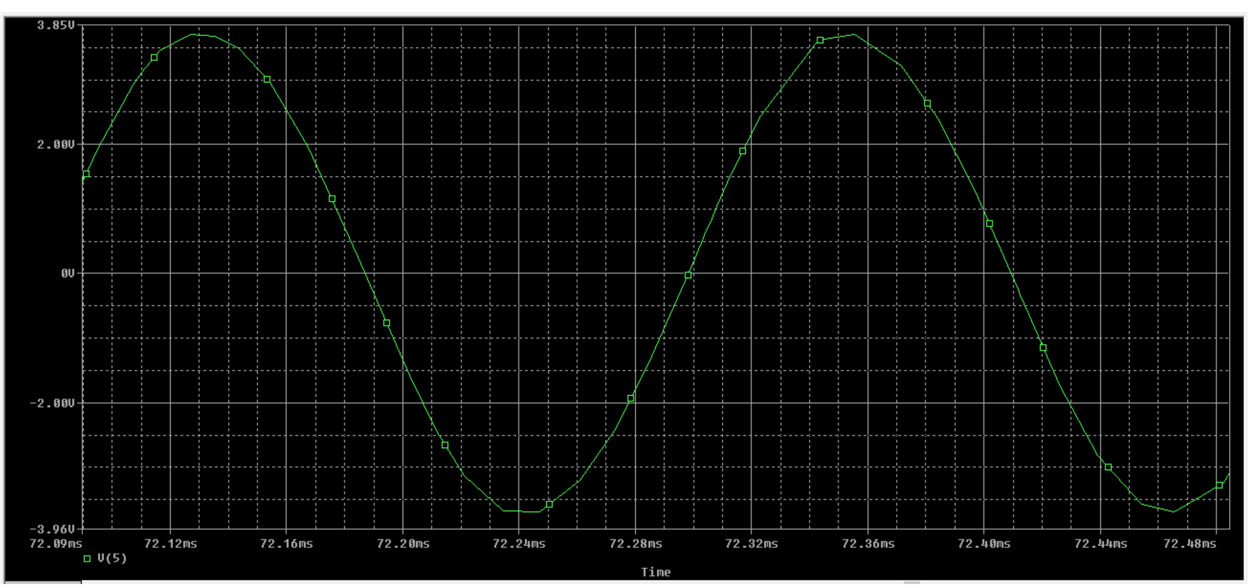
$$f = \frac{1}{2\pi\sqrt{LC}} = 5032.93\ Hz$$

Result: no oscillation

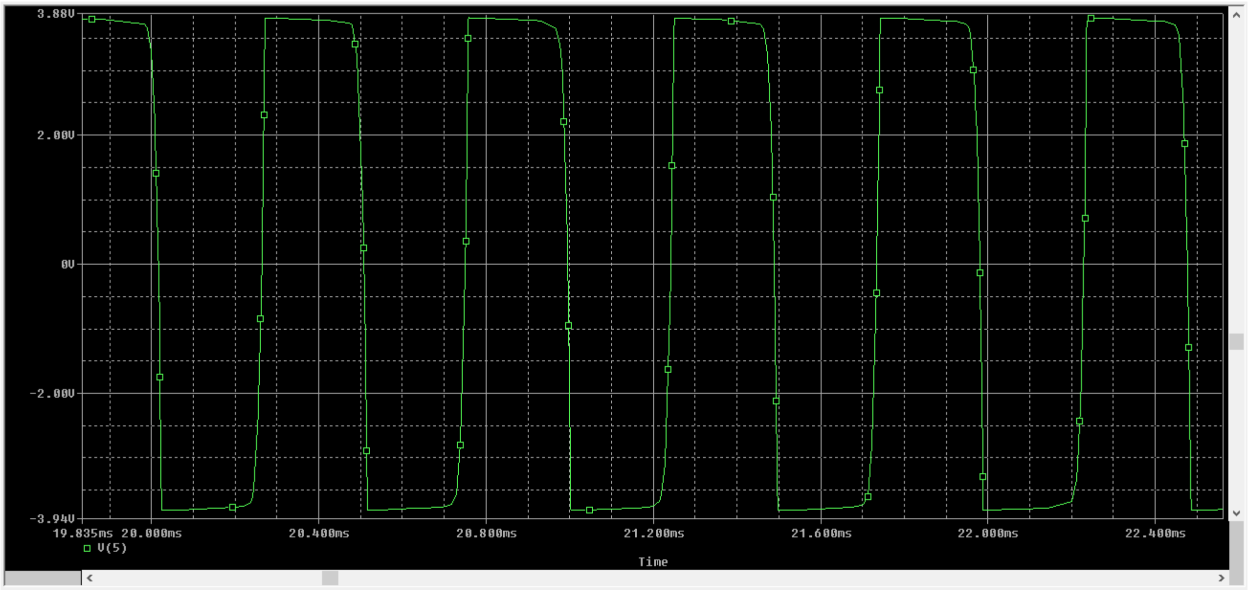
$\therefore$ R_2 increased to $10.001\,K\Omega$

Result: oscillation at 4464.3 Hz

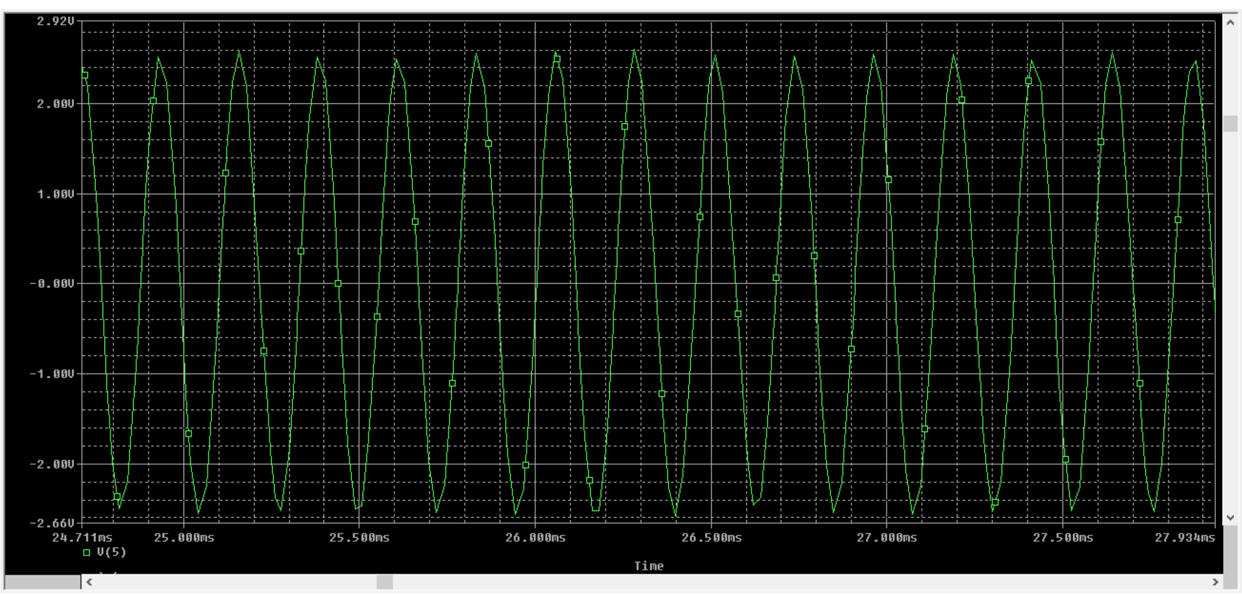
Higher gain → increased distortion to a square wave



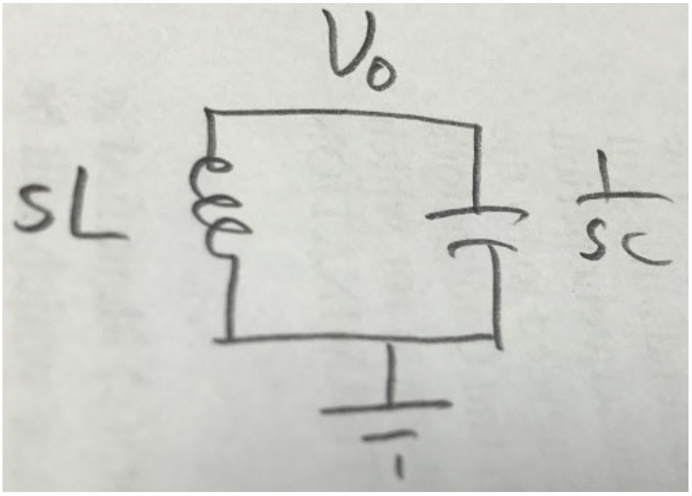
Increasing R_2 from 10.001 kΩ to 10.101 kΩ increased the loop gain, resulting in this square wave:



An AGC was added by replacing R_2 with a pot and adding two Schottky diodes between the wiper and node 5. Results shows that it basically works, with some distortion and variation in the amplitude:



The LC tank circuit:



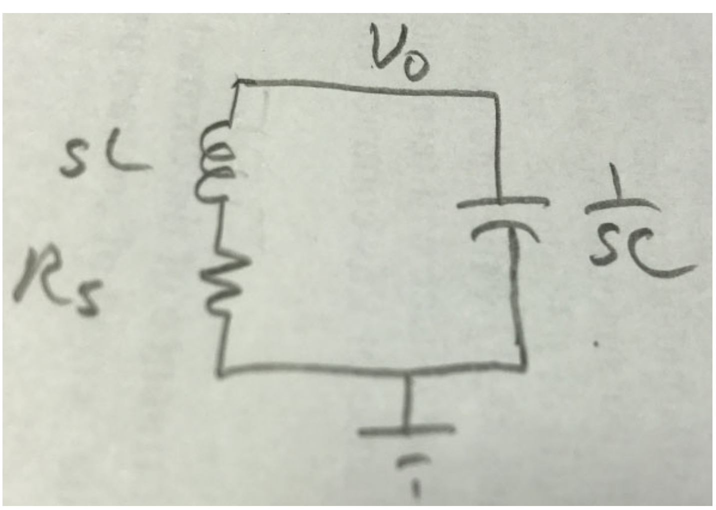
$$V_o\left(s^2 + \frac{1}{LC}\right) = 0$$

An initial condition on the inductor, or on the capacitor, or on both, will result in sustained oscillation with

$$\omega_o = \frac{1}{\sqrt{LC}}$$

The impedance looking into an ideal tank circuit is a short at DC and at infinite frequency, and is infinite (an open) at ω_o.

This LC tank is lossless. All real LC tanks with have losses (energy dissipating mechanisms). Consider the LC tank below:



$$V_o\left(\frac{1}{sL+R_s}+sC\right)=0$$

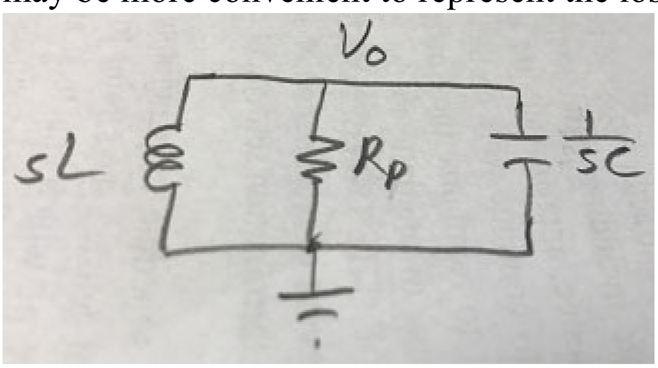
$$V_o(1+s^2LC+sR_sC)=0$$

$$V_o\left(s^2+s\frac{R_s}{L}+\frac{1}{LC}\right)=0$$

$\omega_o=\frac{1}{\sqrt{LC}}$ and $Q=\frac{1}{R_s}\sqrt{\frac{L}{C}}$

The impedance looking into this "real" tank circuit is a R_s at DC, a short at infinite frequency, and has a maximum value at ω_r.

R_s represents the line losses in the inductor and the traces. Sometimes, however, it may be more convenient to represent the losses like this:



$$V_o\left(\frac{1}{sL}+\frac{1}{R_p}+sC\right)=0$$

$$V_o\left(\frac{1}{LC}+s\frac{1}{CR_p}+s^2\right)=0$$

$\omega_o=\frac{1}{\sqrt{LC}}$ and $Q=R_p\sqrt{\frac{C}{L}}$

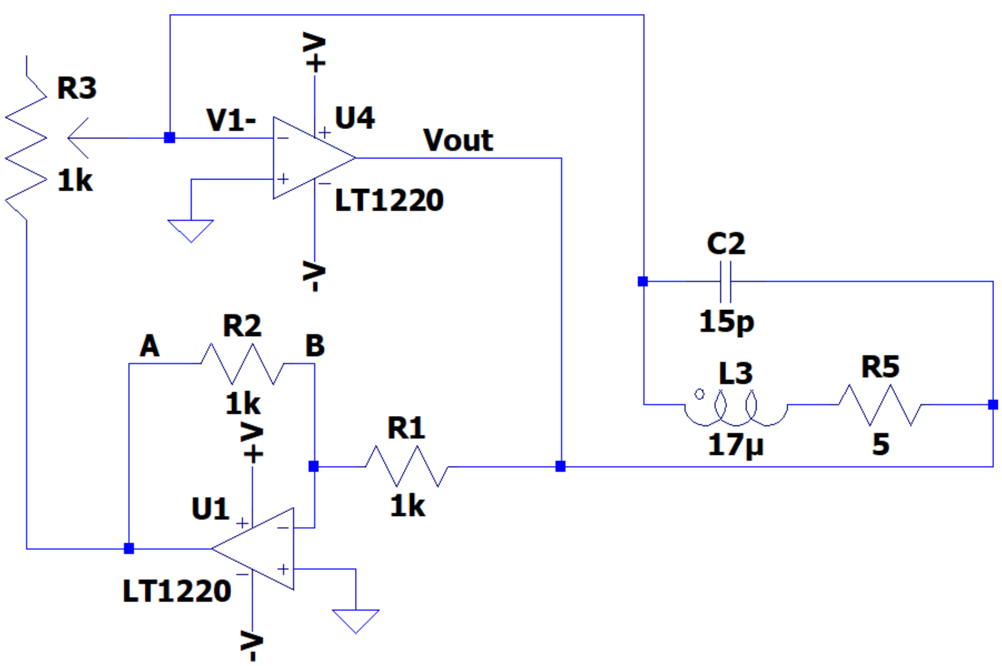
Therefore $R_pR_s=\frac{L}{C}$ and $R_p=\frac{L}{R_sC}$

R_p can represent the line losses in the inductor and the traces. It can also represent dielectric losses in the capacitor, and any load the tank circuit is driving. Observe that for a lossless system $R_s \rightarrow 0\ \Omega$ and $R_p \rightarrow \infty\ \Omega$.

4) LC Oscillator for LC Sensor tags

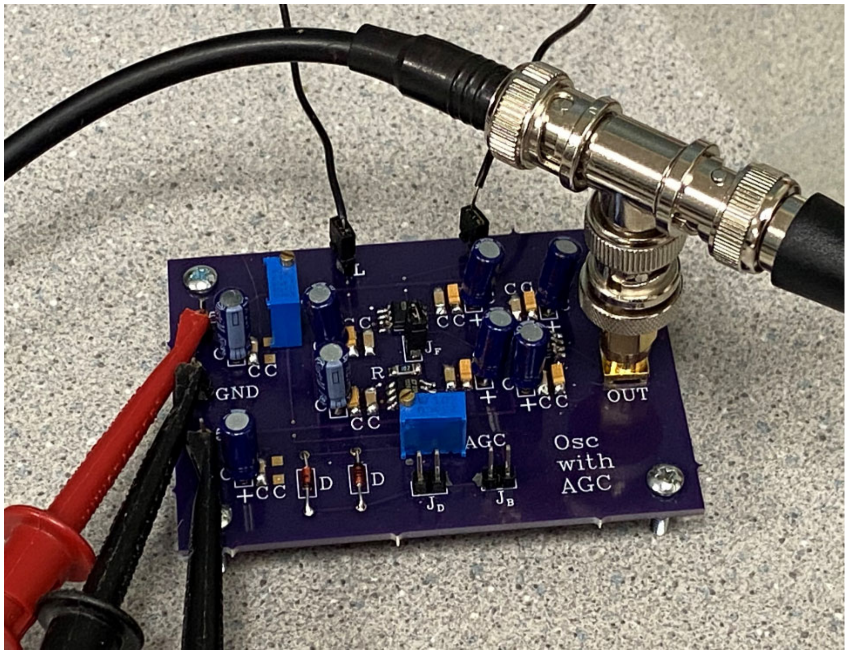
LC tank sensor tags usually use a capacitive sensor, and a planar inductor for inductively coupling to a base station planar inductor, realizing a coupled lossy LC coupled tank circuit.

Consider the LC oscillator circuit below:

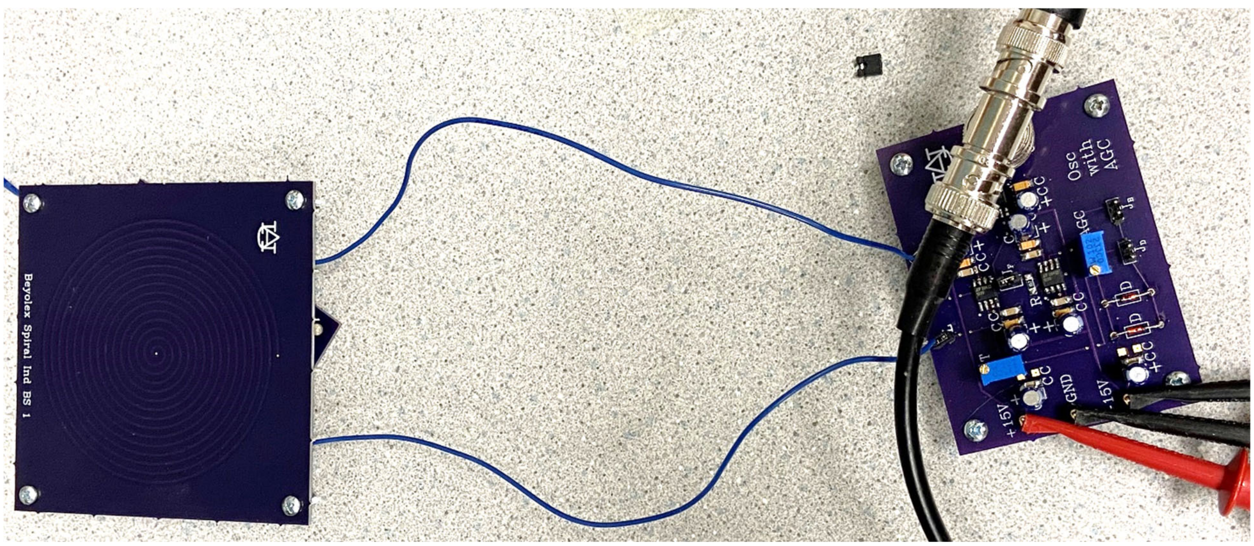


The LT1220 is a ±15 V 45 MHz GBW product op amp. The circuit uses two inverting amplifiers in a loop, where the gain of the upper one is controlled by the impedance of lossy coupled tank circuit. The R3 pot adjusts the loop gain. L3, R5, and C2 represent the coupled LC tank circuit. At some ω_r that is adjusted by the sensor tag's sensor capacitance:

$$A(j\omega)\beta(j\omega) = 1\underline{|360^\circ}$$



A photograph of the PCB base station oscillator PCB.



A photograph of the PCB base station oscillator connected with a base station planar inductor.

Example oscillator's output waveform on the oscilloscope (left) and the frequency counter displaying the output frequency in MHz (right).

The output signal is very distorted, which was not a problem for this application.

Possible reasons for the observed excessive distortion:

a. Too high of an oscillation frequency for this op amp.

b. Higher order effect in the circuit not accounted for in the simple model.

c. Nonlinear effects as the voltage level approaches the op amp limits.

d. Slew rate limitations of the op amps.