Colpitts Oscillator
Design Considerations

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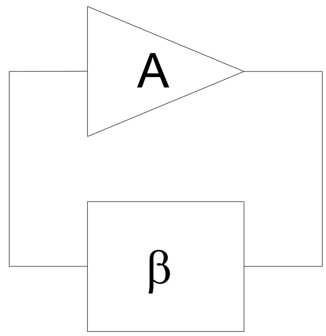
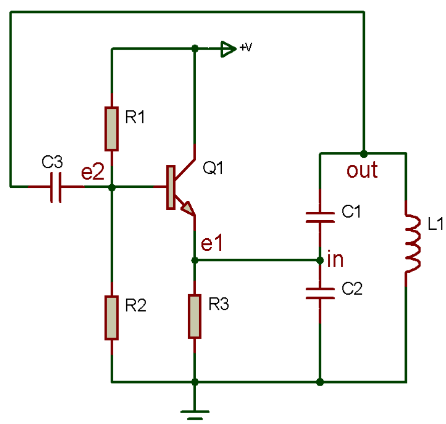


Gain A x $\beta \geq 1$
Phase A + $\beta = 0$

This article will go through the process of designing a common collector Colpitts Oscillator. An oscillator is an amplifier with positive feedback.



The emitter follower has a high current gain and has a voltage gain of < 1. The phase through the emitter follower will be 0^{θ} so the circuit should not oscillate. The gain takes place in the feedback network.

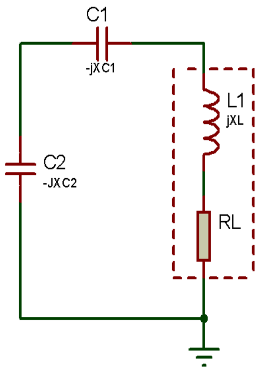
A = e1/e2 = < 1

$\beta =$ e2/e1 = > 1

A x β = > 1 for the circuit to oscillate.

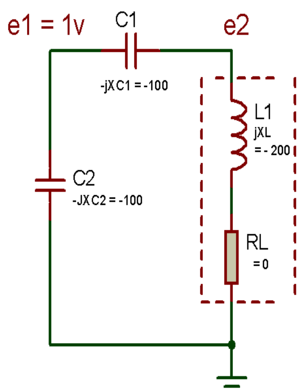
There is no power gain in the feedback network but it can convert power into voltage gain. The emitter follower provides current gain therefore the circuit does provide some power gain.

Lets examine the feedback network.



XL could be a reactance of an inductor or motion inductance of a crystal.

RL = The inductor loss or series resistance.



We can find i by applying ohms law

Z = -jXC1 + jXL + RL
= -100 + 200 + 0
= 100R

Therefore

i = e1/Z = 1/100 = 0.01A

Now we can calculate e2

e2 = i x jXl
= 0.01 x 200
= 2v

So the feedback network gives a voltage gain of 2.

β = e2/e1 = 2/1 = 2

So the condition has been met for the circuit to oscillate.

Definitions

e1 = i x (RL + jXL – jXC1) volts
e2 = i x (RL+jXL)

e1 could also be defined as the voltage across C2

e1 = i x jXc2

Note the magnitude of jXC2 is used because the capacitor is in shunt therefore -jXC2 becomes positive.

$$\beta=\frac{e2}{e1}=\frac{i(RL+jXL)}{i(RL+jXL-jXC1)}$$

$$\frac{e2}{e1}=\frac{RL+jXL}{RL+jXL-jXC}$$

$$\frac{e2}{e1}=\frac{RL+jX1+jX2}{RL+jX1+jX2-jX1}$$ Substituting jX1+jX2 for jXL

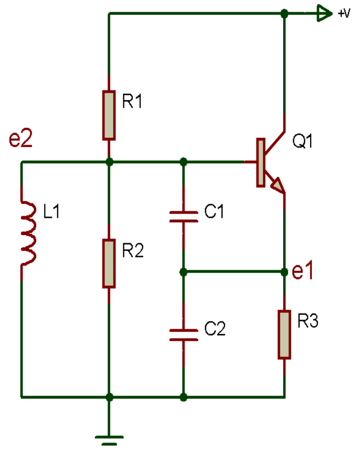
$$\frac{e2}{e1}=\frac{RL+jX1+jX2}{RL+jX2}$$

$$\frac{e2}{e1}=\frac{RL+X1+X2}{RL+X2}$$

$$\frac{e2}{e1}=\frac{X1+X2}{X1}$$ Letting RL = 0 as its normally very small

Therefore the gain becomes

$$\frac{e2}{e1}=\frac{X1+X2}{X1}$$



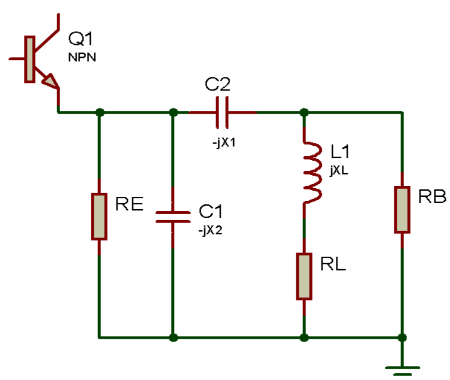
$$e1 = e2\frac{X2}{X1+X2}v$$

$$\beta = \frac{e2}{e1} = \frac{X1+X2}{X2}$$

Rearranging the voltage divider equation gives the gain equation as above. The overall gain of the circuit should be A$\beta \geq 1$.

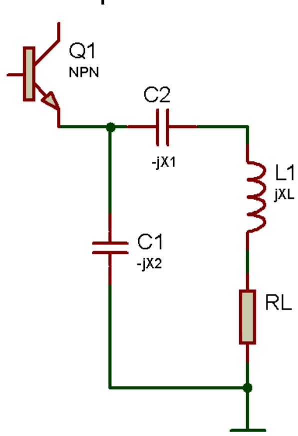
So for the circuit to oscillate $A\left(\frac{X1+X2}{X2}\right) \geqslant 1$

The voltage gain of the emitter follower is defined as $A = \frac{gm*Zl}{1+gm*ZL}$



Because RE & RB are normally high they can be ignored.

Now to add the parallel impedance's



$$Z_L = \frac{Product}{Sum.}$$

$$Z_L = \frac{-jX2(RL + jXL - jX1)}{RL + jXL - jX1 - jX2}\Omega$$

Substitute X1 and X2 for XL at resonance

$$Z_L = \frac{-jX2(RL + jX1 + jX2 - jX1)}{RL + jX1 + jX2 - jX1 - jX2}\Omega$$

$$Z_L = \frac{-jX2(RL + jX2)}{RL}\Omega$$

$$Z_L = \frac{-jX2*RL - j^2 X2^2}{RL}\Omega \quad j^2 = -1$$

So

$$Z_L = \frac{-X2*RL + X2^2}{RL}\Omega$$

If RL is very small compared to X2 then RL can be put to 0. Then ZL will become :-

$$Z_L = \frac{X2^2}{RL}\Omega$$

The load is purely resistive and is only valid for frequency of oscillation.

So the final loop gain formula for the Colpitts Oscillator becomes :-

$$\left(\frac{gm\frac{X2^2}{RL}}{1 + gm\frac{X2^2}{RL}}\right) x \left(\frac{X1 + X2}{X2}\right) \geq 1$$ which simplifies to $gmX1X2 \geq RL$

This equation shows you need to have gain in the loop to over come losses in the circuit.

Considerations

1. Transistor Biasing
2. Loaded Q (Crystal)
3. Load Capacitance (Crystal)
4. Stray Parasitic's
5. Power Output
6. Loop Gain

Design

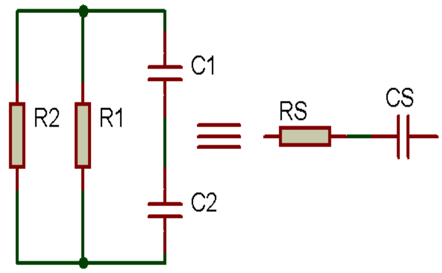
1. Select the bias point for the transistor the ideal bias point will be mid rail
2. Determine the bias current
3. Calculate the transconductance gm. $gm=\frac{I(mA)}{26}$
4. Select the bias resistors the higher the less effect on the loaded Q but will induce noise. The noise introduced would be $v_n=\sqrt{4k_B TBR}$

where k_B = Boltzmann constant
T = Resistors Absolute Temperature (k)
B = Bandwidth (Hz)
R = Resistor Value (ohms)

Selecting the bias resistors to be not more the ~ 10 x RE should be enough to compensate for variations in transistor β.

Selecting C1 to be large enough to swamp C_e of the transistor. Making C1 ~ 10 times greater than C_e is a good starting point.

Check to see if the load across the resonator does not load its Q too much. This can be done by converting the base bias resistors and the feedback caps into a series equivalent circuit and making sure R_s is << RL or series resistance of a crystal.



$$R_s=\frac{R_p}{Q^2+1}\Omega \qquad Q=\frac{R_p}{X_p}$$

$$X_s=\frac{X_p \cdot Q^2}{Q^2+1}\Omega$$

If using a crystal Cs needs to be the parallel load capacitance required for the crystal to be on frequency.

If using a crystal check the power dissipation in the crystal using :-

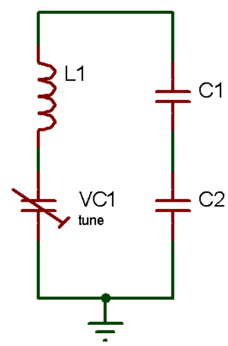
$$P=\left(\frac{Vrms}{Xco+XL}\right)^2 RL \quad \text{W}$$

Vrms = Voltage across the crystal

Xco = C1C2 // Crystal

XL = Crystal motion inductance

Its very easy to modify these design equations to use with a Clapp Oscillator. All you need to do is to add the series tuning capacitor to the inductor value so XL would become XL – Xc_{tune}



Conclusion

It has been shown an oscillator can be realized for an amplifier with positive feedback when loop gain of $\geq$ 1. In the case of the case of the common collector colpitts oscillator the amplifier has a voltage gain of < 1 the voltage gain takes place in the feedback network. It was also shown there is some power gain due the current gain of the amplifier and the voltage gain of the feedback network. It is common practice to follow the oscillator with a buffer to minimize loading effects on the oscillator.

References

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Youtube Video
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