Clapp oscillator

John Dunn

Having already examined the Colpitts oscillator, we now look at its first cousin, the Clapp oscillator.

Please consider the following illustration in Figure 1.

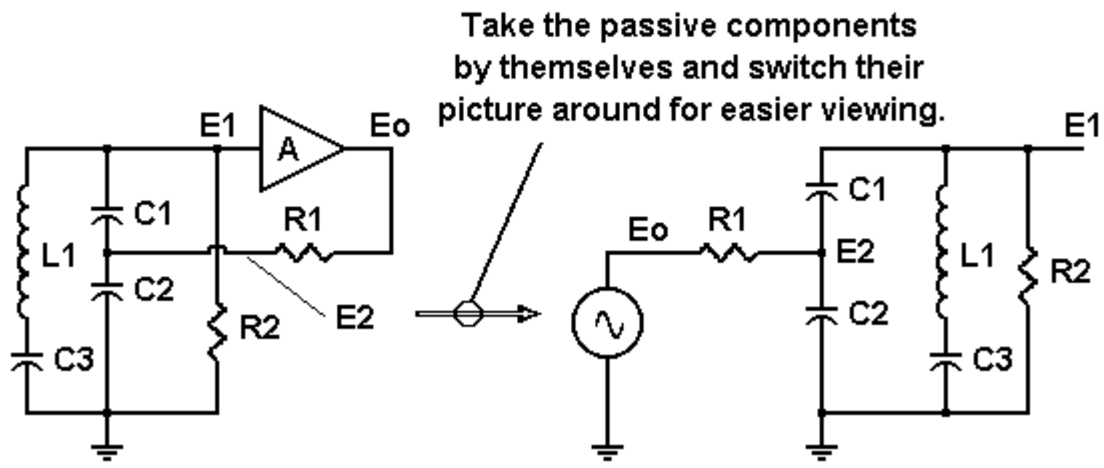

Figure 1 A Clapp oscillator where the passive components are arranged on the right-hand side for easier viewing. Source: John Dunn

There is an R-L-C network of passive components and an active gain block. This circuit differs from the Colpitts by now using a third capacitor (C3) in series with the inductance (L1) and by now needing a DC path: R2, to ground for the gain block. The output impedance of the gain block is zero and the value of its gain (A) is nominally unity or perhaps a little less than unity. The resistance R1 models the output impedance that a real-world gain block might present.

To analyze this circuit, we take the passive components, redraw them as on the right in Figure 1 and where G1 = 1 / R1, G2 = 1 / R2, and the term S = j / (2*π*F), we use node analysis to derive the transfer function E1 / Eo.

The analysis for the Clapp circuit is rather more involved than it was for the Colpitts circuit so for the sake of clarity, I have omitted it here. However, my handwritten notes of that analysis can be seen at the end of this essay. Try not to strain your eyes.

The end result is an expression of the transfer function in a useful form as follows in Figure 2.

$$\frac{E1}{Eo} = \frac{S\,C1\,G1 + S^3\,L1\,C1\,C3\,G1}{\left(\begin{array}{l} S^4\,L1\,C1\,C2\,C3 + S^3\,(\,L1\,C1\,C3\,G1 + L1\,C1\,C3\,G2 + L1\,C2\,C3\,G2\,) \\ \quad + S^2\,(\,C1\,C3 + C2\,C3 + C1\,C2 + L1\,C3\,G1\,G2\,) \\ \qquad + S\,(\,C3\,G1 + C1\,G1 + C1\,G2 + C2\,G2\,) + G1\,G2 \end{array} \right)}$$

Figure 2 Algebraic expression of transfer function for the Clapp oscillator shown in Figure 1. Source: John Dunn

Note that the denominator of this equation is fourth order. It is a fourth order polynomial because there are four independent reactive elements in the circuit, L1, C1, C2 and C3.

Please also note that the order of the polynomial MUST match the number of independent reactive elements in the circuit. If we had come up with an algebraic expression of some other order, we would know we'd made a mistake somewhere.

Graphing the ratio of E1/Eo versus frequency, we see the following in Figure 3.

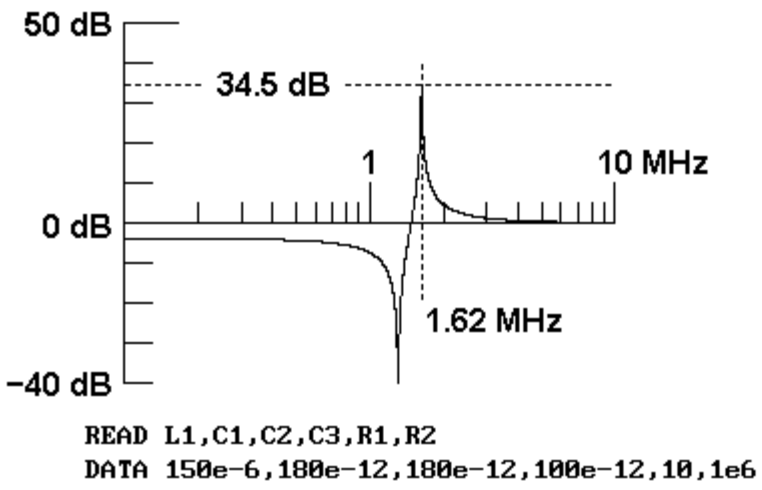

Figure 3 E1/Eo versus frequency from algebraic analysis. Source: John Dunn

The transfer function of the passive R-L-C network has a pronounced peak at a frequency of 1.62 MHz and a null at a slightly lower frequency. When we run a spice simulation of that transfer function, we find very nearly the same result (Figure 4). I blame the differences on software numerical accuracy issues.

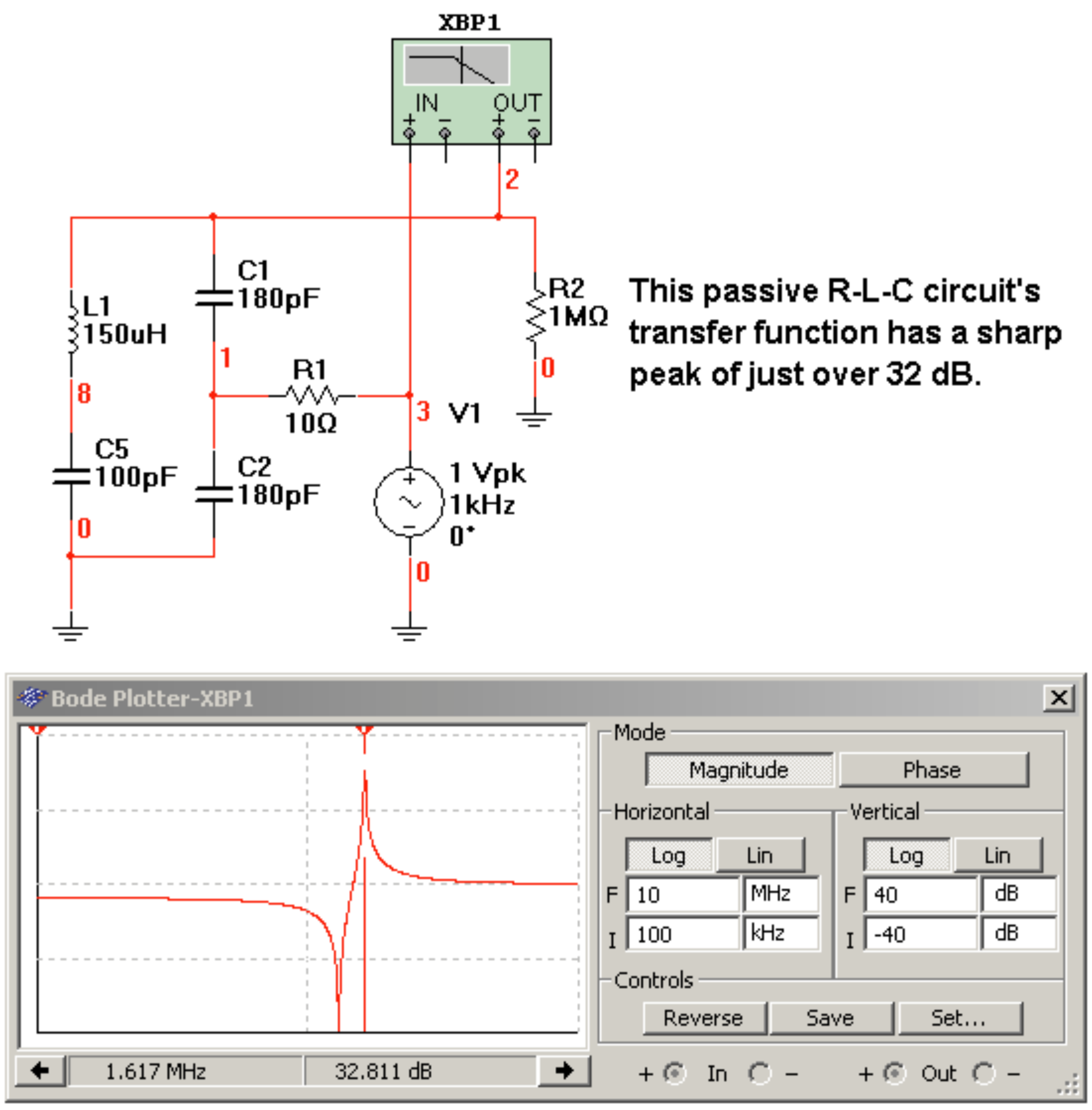

Figure 4 E1/Eo versus frequency from SPICE Analysis. Source: John Dunn

When we let our gain block be a voltage follower—a JFET source follower in the following example—we see oscillation at the frequency of that transfer function peak as shown in Figure 5.

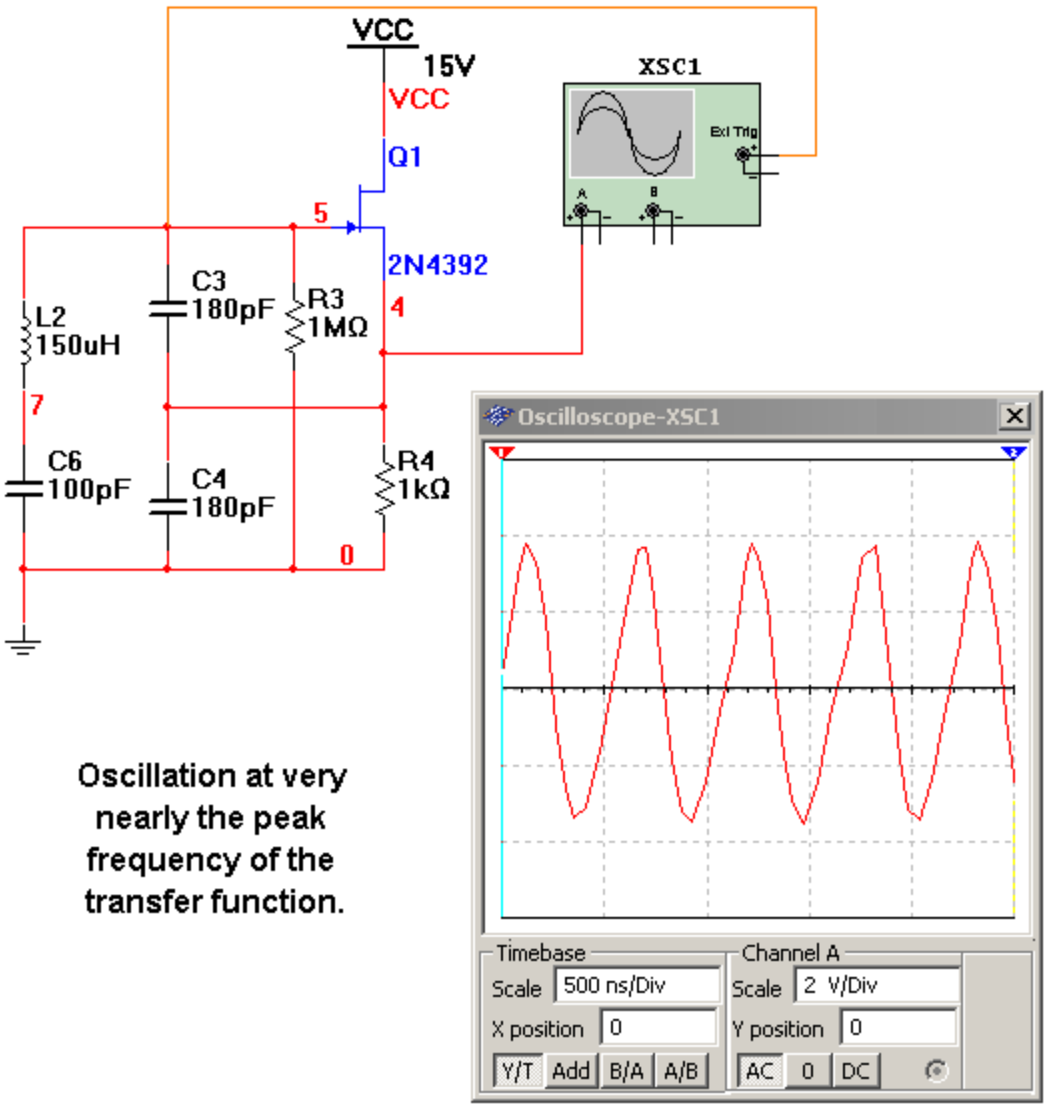

Figure 5 Clapp Oscillator simulation after letting our gain block be a voltage follower. Source: John Dunn

The algebraic derivation of the Clapp oscillator transfer function is shown in handwriting in Figure 6.

Please forgive the handwriting. I just didn't have the patience to turn this into a printout.

$$E_2\left(sC_1 + sC_2 + G_1\right) - E_1 sC_1 - E_0 G_1 = 0$$

$$E_1\left(sC_1 + \frac{1}{sL_1 + \frac{1}{sC_3}} + G_2\right) - E_2 sC_1 = 0$$

$$E_2 = \frac{E_1\left(sC_1 + \frac{sC_3}{1+s^2L_1C_3} + G_2\right)}{sC_1}$$

$$E_1\left[\frac{\left(sC_1 + \frac{sC_3}{1+s^2L_1C_3} + G_2\right)\left(sC_1 + sC_2 + G_1\right)}{sC_1} - sC_1\right] - E_0 G_1 = 0$$

$$E_1\left[\left(sC_1 + \frac{sC_3}{1+s^2L_1C_3} + G_2\right)\left(sC_1 + sC_2 + G_1\right) - s^2C_1^2\right] = E_0 G_1 sC_1$$

$$\frac{E_1}{E_0} = \frac{G_1 sC_1}{\left(sC_1 + \frac{sC_3}{1+s^2L_1C_3} + G_2\right)\left(sC_1 + sC_2 + G_1\right) - s^2C_1^2}$$

$$\frac{E_1}{E_0} = \frac{sC_1 G_1 \left(1 + s^2L_1C_3\right)}{\left[sC_3 + \left(sC_1 + G_2\right)\left(1 + s^2L_1C_3\right)\right]\left(sC_1 + sC_2 + G_1\right) - s^2C_1^2\left(1 + s^2L_1C_3\right)}$$

$$\frac{E_1}{E_0} = \frac{sC_1G_1 + s^3L_1C_1C_3G_1}{\left[sC_3 + sC_1 + G_2 + s^3L_1C_1C_3 + s^2L_1C_3G_2\right]\left(sC_1 + sC_2 + G_1\right) - s^2C_1^2 - s^4L_1C_3C_1^2}$$

$$\frac{E_1}{E_0} = \frac{sC_1G_1 + s^3L_1C_1C_3G_1}{\left[\begin{array}{l} s^2C_3C_1 + s^2C_3C_2 + sC_3G_1 \\ + \cancel{s^2C_1^2} + s^2C_1C_2 + sC_1G_1 \\ + G_2sC_1 + G_2sC_2 + G_1G_2 \\ + \cancel{s^4L_1C_1^2C_3} + s^4L_1C_1C_3C_2 + s^3L_1C_1C_3G_1 \\ + s^3L_1C_3G_2C_1 + s^3L_1C_3G_2C_2 + s^2L_1C_3G_2G_1 \\ - \cancel{s^2C_1^2} - \cancel{s^4L_1C_3C_1^2} \end{array}\right]}$$

$$\frac{E_1}{E_0} = \frac{sC_1G_1 + s^3L_1C_1C_3G_1}{\left[\begin{array}{l} s^4L_1C_1C_2C_3 \\ + s^3\left(L_1C_1C_3G_1 + L_1C_1C_3G_2 + L_1C_2C_3G_2\right) \\ + s^2\left(C_1C_3 + C_2C_3 + C_1C_2 + L_1C_3G_1G_2\right) \\ + s\left(C_3G_1 + C_1G_1 + C_1G_2 + C_2G_2\right) \\ + G_1G_2 \end{array}\right]}$$

Figure 6 John Dunn's transfer function derivation. Source: John Dunn

John Dunn is an electronics consultant, and a graduate of The Polytechnic Institute of Brooklyn (BSEE) and of New York University (MSEE).

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