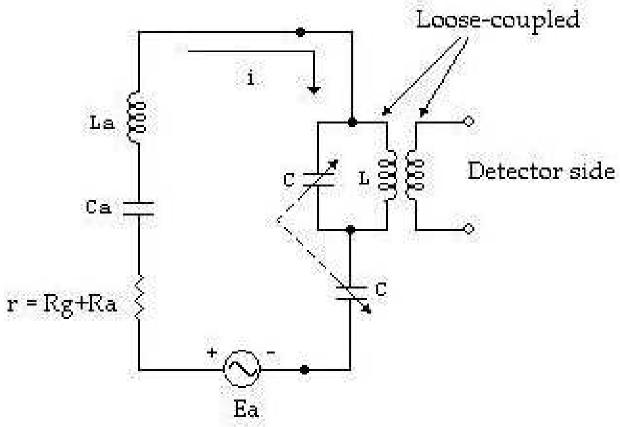
# Analysis of the Tuggle Front End

This article analyzes the Tuggle tuner, of common use in high-performance DX crystal sets. An equivalent circuit for the antenna-ground system with the tuner connected is shown in Fig. 1 below. It must be recognized that there is some stray capacitance of the rotor and frame of the two-gang variable capacitor to ground. This should be shown as a fixed capacitor across the bottom variable capacitor. Its presence will reduce the maximum frequency to which the circuit will tune. However, in the present analysis this stray capacitance is neglected.




-Ea is the voltage induced in the antenna by the radio wave.
-La is the equivalent series inductance of the antenna.
-Ca is the equivalent series capacitance of the antenna.
-r accounts for the antenna radiation resistance Ra and ground losses Rg.

Fig. 1 The Tuggle front end connected to an antenna-ground system

The mesh current is described by:

$$I = \frac{Ea}{r + j\left(\omega La - \frac{1}{\omega Ca}\right) + \overline{Z} - \frac{j}{\omega C}} \qquad \ldots(1)$$

$$\overline{Z} = \frac{1}{\overline{Y}}$$

where:

$$\overline{Y} = \frac{1}{j\omega L} + j\omega C$$

$$= j\left(\omega C - \frac{1}{\omega L}\right)$$

$$= j\left(\frac{\omega^2 LC - 1}{\omega L}\right)$$

$$\therefore \qquad \overline{Z} = \frac{1}{j}\left(\frac{\omega L}{\omega^2 LC - 1}\right)$$

or:

$$\overline{Z} = j\left(\frac{\omega L}{1-\omega^2 LC}\right)$$

Then, $I = I_{MAX}$ when:

$$\left(\omega La - \frac{1}{\omega Ca}\right) + \left(\frac{\omega L}{1-\omega^2 LC}\right) - \frac{1}{\omega C} = 0$$

This is, when:

$$\omega\left(La + \frac{L}{1-\omega^2 LC}\right) - \frac{1}{\omega\left(\frac{CaC}{Ca+C}\right)} = 0 \qquad \ldots(2)$$

which is satisfied at certain radian frequency $\omega_r$.
At this frequency, the L-C tank circuit behaves as an equivalent inductance

$$\frac{L}{1-\omega_r^2 LC}$$

Usually, L is much greater than $L_a$ for antennas used in crystal set work. Then,

$$La << \frac{L}{1-\omega_r^2 LC}$$

Equation (2) can be written as:

$$\frac{\omega_r L}{1-\omega_r^2 LC} - \frac{1}{\omega_r\left(\frac{CaC}{Ca+C}\right)} = 0$$

We can then write:

$$\frac{\omega_r L}{1-\omega_r^2 LC} = \frac{Ca+C}{\omega_r CaC}$$

After some algebraic manipulation we obtain:

$$\omega_r^2 LC\left(\frac{2Ca+C}{Ca+C}\right) = 1 \qquad \ldots(3)$$

The equivalent capacitance resonating with L is:

$$C_{eq} = C\left(\frac{2Ca + C}{Ca + C}\right)$$

Clearly, $C_{eq}>C$.

Following is a numerical example illustrating the use of the above results.
Let C be a variable capacitance with $C_{MIN}$ = 20 pF and $C_{MAX}$ = 475 pF. Let also $C_a$ be 200 pF. Then, $C_{eq}$ varies between $C_{eqMIN}$ = 38.18 pF and $C_{eqMAX}$ = 615.74 pF.

If we wish to tune the MW broadcast band starting at 530 kHz, then the required inductance L will be:

$$L = \frac{1}{\omega_{rMIN}{}^2 C_{eqMAX}}$$

$$= 146.45uH$$

The circuit will tune up to:

$$f_{MAX} = f_{MIN}\left(\frac{C_{eqMAX}}{C_{eqMIN}}\right)^{\frac{1}{2}}$$

$$= 2.128MHz$$

If we use for C a variable capacitance with $C_{MIN}$ = 20 pF and $C_{MAX}$ = 365 pF, then $C_{eqMIN}$ = 38.18 pF and $C_{eqMAX}$ = 494.20 pF, giving for the required inductance L a value of 182.46 uH. The circuit will tune up to $f_{MAX}$ = 1.906 MHz.

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Ramon Vargas Patron
rvargas@inictel.gob.pe
Lima-Peru, South America
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