Electron Tube RF Power Amplifier (RFPA) Tank Circuit At Resonance

By Larry E. Gugle K4RFE, RF Design, Manufacture, Test & Service Engineer (Retired)

Note: Fourth and Fifth pages of this document are extracts from the - Radio Engineers Handbook 1943 Edition (By Sc.D. F. E. Terman)

Reactance (X):

At resonance, in a 'ideal parallel LC circuit', having zero resistance, the X_L equals the X_C.

$$[X_L = (2\pi FL)] = [X_C = (1 \div 2\pi FC)]$$

Line Current (I_{LINE}):

At resonance, in a 'ideal parallel LC circuit', when an a-c voltage is applied to a parallel LC circuit having zero resistance, with respect to the line current, the current through the Inductor (I_L) and the current through the Capacitor (I_C) are 180 degrees out of phase. Their vector sum is, therefore, zero, making the Line Current (I_{LINE}) "Zero".

$$I_{LINE} = 0$$

Impedance (Z):

At resonance, in a 'ideal parallel LC circuit', If no line current flows, it has Infinite Impedance (Z) as far as the voltage source is concerned.

$$Z = E_{APP} \div I_{LINE} = E_{APP} \div 0 = \text{Infinity}$$

Note: E_{APP} is the AC Voltage Source.

Circulating Current ($I_{circulating}$):

At resonance, *inside* a 'ideal parallel LC circuit', the current through the Inductor (I_L) and the current through the Capacitor (I_C) are actually one current: called *Circulating Current*. The value is:

$$I_{circulating} = (E \div X_L) \text{ "or" } (E \div X_C) \text{ "or" } (E \div X)$$

Quality (Q):

At resonance, In parallel resonant LC circuits, 'Q' is not determined on the basis of voltage, but rather is determined on the basis of current. The 'Q' (Quality) of a parallel resonant LC circuit is defined as the *ratio* of the *Tank Circulating Current* ($I_{circulating}$) to the *Line Current* (I_{Line}).

$$Q = I_{circulating} \div I_{LINE}$$

Note: Mathematically, this equation can be converted to the following form:

$$Q = (X_L \div R) \text{ "}\underline{or}\text{" } Q = (X_C \div R) \text{ "}\underline{or}\text{" } Q = (X \div R)$$

Note:

1. **Lower the Resistance (R), the Higher the 'Q' of the circuit, and Bandpass is Narrower.**
2. **Higher the resistance (R), the Lower the 'Q' of the circuit, and Bandpass is Wider.**

Bandpass (Bp):

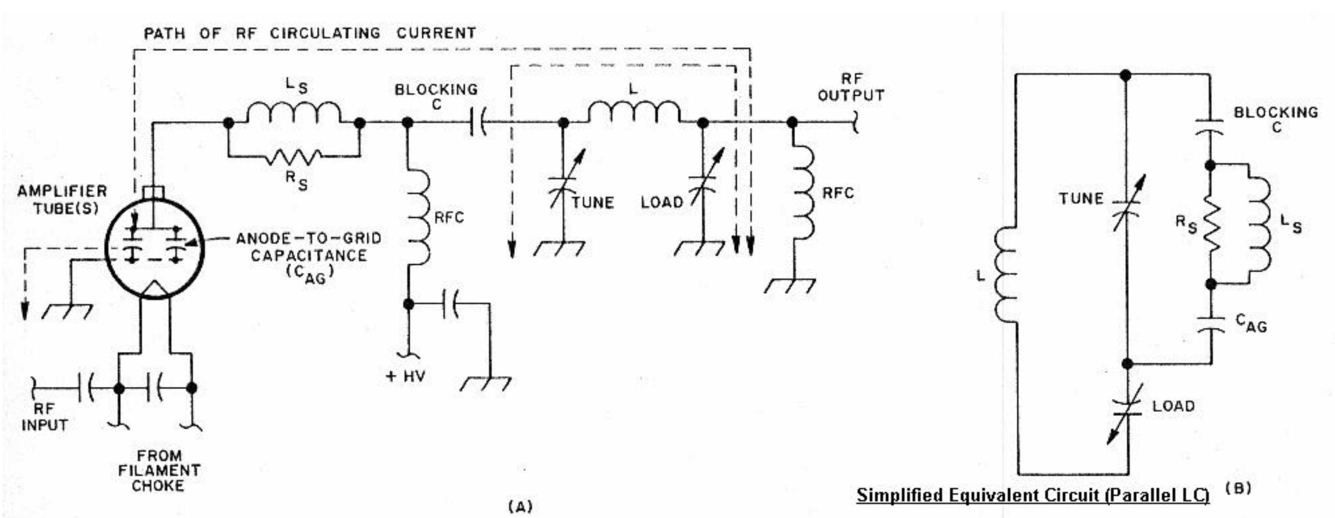
In terms of its 'Q', the Bandpass (Bp) of a parallel resonant LC circuit is.

$$Bp = Fr \div Q$$

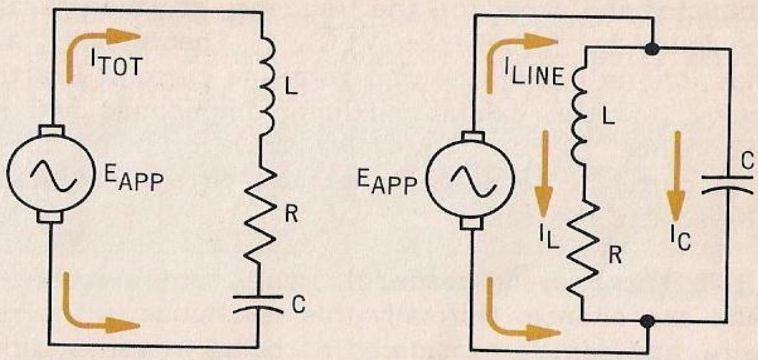
Voltage (E):

$$E = \sqrt{P \cdot X \cdot Q}$$

Notes:
P = Power to Tank Circuit [Tube(s) Plate dissipation in watts]
X = Reactance of the Tank Circuit
Q = Quality of Tank Circuit



AC Series and Parallel RLC Circuit Comparisons



PROPERTIES AT RESONANCE

	Series Resonant Circuit	Parallel Resonant Circuit
Resonant Frequency (f_R)	$\frac{1}{2\pi\sqrt{LC}}$	$\frac{1}{2\pi\sqrt{LC}}$
Reactances	$X_L = X_C$	$X_L = X_C$
Impedance	Minimum; $Z = R$	Maximum; $Z = QX_L$
Current (I_{TOT} or I_{LINE})	Maximum; I_{TOT}	Minimum; I_{LINE}
Q, Quality	$E_L/E_{APP} = X_L/R$	$I_{TANK}/I_{LINE} = X_L/R$
Bandwidth	f_R/Q	f_R/Q

PROPERTIES OFF RESONANCE

	Series Resonant Circuit		Parallel Resonant Circuit	
	Above f_R	Below f_R	Above f_R	Below f_R
Reactances	$X_L > X_C$	$X_C > X_L$	$X_L > X_C$	$X_C > X_L$
Impedance	Increases	Increases	Decreases	Decreases
Phase Angle Between E_{APP} and I_{TOT} or I_{LINE}	I lags E	I leads E	I leads E	I lags E
Inductive or Capacitive Circuit	Inductive	Capacitive	Capacitive	Inductive

Tank-circuit Design.—The tuned circuit connected between the cathode and plate of the Class C amplifier, commonly called the *tank circuit*, must supply the proper impedance and must not consume an undue proportion of the power output of the amplifier.

The efficiency of the tank circuit is the fraction of the total power delivered to this circuit by the tube that is transferred to the load, and is

$$\left.\begin{matrix}\text{Tank-circuit}\\ \text{efficiency}\end{matrix}\right\} = \frac{Q_1 - Q_2}{Q_1}\,100 \text{ per cent} \qquad (88)$$

where Q_1 is the Q of the tank resonant circuit with no load coupled, and Q_2 is the effective Q of the tank circuit when the load is coupled to it. From the point of view of efficiency, it is desirable that the effective Q of the tank circuit, when the load is taken into account, be as low as possible, with the actual Q of the circuit in the absence of load as high as is practicable. A low effective Q tank circuit also reduces the reactive energy that must be stored, and so permits the use of inductances and capacities with smaller volt-ampere ratings, an important item in large amplifiers. At the same time, a low tank-circuit Q results in an appreciable impedance being offered to harmonic components of the plate-current pulse.[1]

The effective Q of the tank circuit is usually made at least 8 or 10, although in the case of some very large push-pull Class C amplifiers, values of effective Q as low as 2 or 3 are employed. With such very low values of Q it is necessary to use a tuning procedure such that the tank circuit is adjusted to offer a resistance impedance to the tube, even though the magnitude of the resulting impedance may not necessarily be maximum for this condition (see Par. 2, Sec. 3).

When the desired Q of the tank circuit has been decided upon, the inductive reactance ωL can then be determined in terms of the required load impedance. In the case of direct coupling with a tank circuit Q not too low, one has

$$\omega L = \frac{\text{required load impedance}}{\text{effective } Q} \qquad (89)$$

When ωL is known, the tank-circuit inductance and capacity for a given frequency are then calculated by obvious methods.

A useful relation in the design of tank circuits is the connection that exists between the voltage across the tank circuit, the effective Q, and the power delivered to the circuit. This relation is

$$\left.\begin{matrix}\text{Effective voltage}\\ \text{across tank circuit}\end{matrix}\right\} = \sqrt{P\omega L Q_{\text{eff}}} \qquad (90)$$

where P = power, watts, delivered to tank circuit.
ωL = reactance of inductive branch of tank circuit.
Q_{eff} = effective Q of tank circuit, when the effect of the coupled load resistance is taken into account.

Equation (90) applies to all types of tank circuits, including arrangements such as in Figs. 75*b*, 75*c*, and 75*d*, where the plate-cathode connection is made across only a portion of the tank circuit.

[1] The relationship between the harmonic and fundamental frequency voltages developed across the tank circuit and the effective Q for the case where the harmonic voltage is small is approximately

$$\left.\begin{matrix}\text{Per cent second}\\ \text{harmonic}\end{matrix}\right\} = \frac{67}{Q}\,\frac{\left(\frac{I_2}{I_m}\right)}{\frac{I_1}{I_m}} \qquad (88a)$$

where I_1/I_m and I_2/I_m are coefficients obtained from Fig. 86 for the angle θ_p of plate-current flow involved. See E. H. Schulz, R-f Power Amplifier Chart, *Electronics*, Vol. 12, p. 33, December, 1939.

Circulating Tank Current at Resonance

The Q of a circuit has a definite bearing on the circulating tank current at resonance. This tank current is very nearly the value of the line current multiplied by the effective circuit Q. For example: an r-f line current of 0.050 amperes, with a circuit Q of 100, will give a circulating tank current of approximately 5 amperes. From this it can be seen that both the inductor and the connecting wires in a circuit with a high Q must be of very low resistance, particularly in the case of high power transmitters, if heat losses are to be held to a minimum.

Because the voltage across the tank at resonance is determined by the Q, it is possible to develop very high peak voltages across a high Q tank with but little line current.

Plate Efficiency Formula:

$$\eta_p = \frac{\text{a-c power output to the load}}{\text{d-c power input to the plate circuit}} \times 100\%$$

Formula Example: A single 3-500Z Power Triode running in Class AB_2 with 3500VDC Plate Input Voltage will have a maximum **AC Power Output to a load of 890 Watts** (***note: date taken from Eimac datasheet)*** and two 3-500Z Power Triodes in Parallel configuration, would have **1780 Watts** With a **DC Power Input to the Plate circuit of 3500 VDC** the **Plate Efficiency would be 50.85%**

(Plate Efficiency = 1780 Watts / 3500 VDC x 100%)