A Quick Guide to Tank Circuits

Introduction

The tank circuit, a common building block in electronic systems, is a parallel resonant circuit comprised of an inductor, a capacitor, and an optional resistor. Since the capacitor and the inductor both store energy, this type of circuit is referred to as a tank circuit. By taking advantage of its bandpass response characteristic, tank circuits are typically used to limit bandwidth. This is of particular interest in filtering an IF signal which is to be amplified by a very large gain. By limiting the bandwidth, one is able to limit the noise power of the unfiltered signal, which could easily saturate the amplifier.

Terminology

The tank circuit has three main specifications: Bandwidth, Quality Factor, and Insertion Loss. These parameters define the passband, shape, and loss of the tank circuit response.

The half-power bandwidth, *BW*, is defined as the difference between the upper (f_2) and lower (f_1) half-power frequencies.

There are two types of quality factor. The first is component *Q*. Component *Q* is defined as the ratio of the magnitude of the component's series reactance to its series resistance at a particular frequency. A perfect, lossless component would have infinite *Q*. Component *Q* will have an effect on the overall circuit *Q*.

The second is circuit *Q* which is used to denote the relative selectivity of a circuit. It is defined as

$$Q = 2\pi \times \frac{\text{Maximum Instantaneous Energy Stored in the Circuit}}{\text{Energy Dissipated per Cycle}}$$

The half-power bandwidth and the circuit Q are related by the equation

$$Q = \frac{f_c}{BW}$$

where f_c is the center frequency. As can be seen by the above relationship, an increase in Q will result in narrower bandwidth and higher selectivity.

The insertion loss, *IL*, of the tank is the measure of how much the applied signal is absorbed by the tank circuit components. Ideally, they would not absorb any of the signal, but since the components are not ideal, they will attenuate the signal by some finite amount. If viewed with a spectrum analyzer, the insertion loss will shift the entire bandpass characteristic down by some number of decibels.

The source resistance and load resistance are not really tank circuit parameters, however they have a direct relationship on the tank's performance. The source and load resistance, from a calculation viewpoint, are connected in parallel with the inductor and resistor. So, if the source or load resistance is a relatively low value, then it will load the circuit and reduce the circuit *Q*.

Circuit Topology

As mentioned before, the tank circuit is comprised of a capacitor, an inductor, and optionally a resistor connected in parallel as shown in the following figure.

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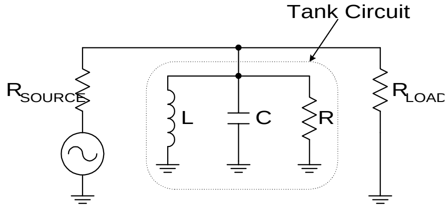

Sample Calculations

The following calculations will demonstrate typical calculations used to determine the proper tank circuit component values. By reworking the equations presented, the designer could also start with known components and calculate the resultant bandwidth. The first set of calculations will assume ideal, lossless components. The second set of calculations will assume practical components. In each case we will assume a center frequency of 50MHz, a bandwidth of 2MHz, and source and load impedances of 1500Ω.

The calculations begin with the designer knowing the center frequency and the desired bandwidth. From these parameters, the circuit *Q* is calculated.

$$Q = \frac{f_c}{f_2 - f_1} = \frac{50}{2} = 25$$

Next, the source and load resistance are combined to determine the total parallel resistance of the circuit.

$$R_P = \frac{1500 \cdot 1500}{1500 + 1500} = 750\Omega$$

Now that the circuit *Q* and the parallel resistance is known, the parallel reactance is determined.

$$X_P = \frac{R_P}{Q} = \frac{750}{25} = 30\Omega$$

Finally, the parallel reactance value is used to calculate the inductor and capacitor values.

$$L = \frac{X_P}{\omega} = \frac{30}{2 \cdot \pi \cdot 50 \cdot 10^6} = 95.5nH$$

$$C = \frac{1}{\omega \cdot X_P} = \frac{1}{2 \cdot \pi \cdot 50 \cdot 10^6 \cdot 30} = 106.1pF$$

If standard values are used, such as a 100nH inductor and a 100pF capacitor, the bandwidth will be 2.1MHz.

The calculations below are a little more complicated but, like those above, are straightforward.

For these calculations it is assumed that the inductor has a component *Q* of 30. This is a typical value for a high quality inductor at this frequency. Again, the center frequency is 50MHz, the desired bandwidth is 2MHz and the source and load impedances are 1500Ω.

As before, the circuit *Q* is determined by the ratio of the center frequency to the bandwidth. Therefore, the circuit *Q* is 25.

In the case of lossless components, just the source and load impedance appeared across the tank. In the case of the lossy components, the inductor will also present an effective resistance across the tank. The total parallel resistance across the tank will then be due to the source and load impedance plus the inductor effective resistance. The inductor resistance will lower the circuit parallel resistance, with the overall effect of reducing the *Q* of the circuit. So, to keep the same bandwidth, different component values will be used.

The circuit *Q* is still given by the ratio of resistance to reactance, but in this case the resistance has the additional term due to the inductor.

$$Q = \frac{\dfrac{R_P \cdot R_S \parallel R_L}{R_P + R_S \parallel R_L}}{X_P} = 25$$

Additionally, we know the relation for the component *Q*

$$R_P = Q_P \cdot X_P$$

By substituting the second relation into the first, X_P can be determined.

$$X_P = \frac{\dfrac{Q_P \cdot R_S \parallel R_L}{Q} - R_S \parallel R_L}{Q_P} = \frac{\dfrac{50 \cdot 750}{25} - 750}{50} = 15\Omega$$

Now that X_P has been determined, the values of the inductor and the capacitor can be found.

$$L = \frac{X_P}{\omega} = \frac{15}{2 \cdot \pi \cdot 50 \cdot 10^6} = 47.75nH$$

$$C = \frac{1}{\omega \cdot X_P} = \frac{1}{2 \cdot \pi \cdot 50 \cdot 10^6 \cdot 15} = 212.21pF$$

Additionally, the value of R_P can be determined by substituting the value of XP into the equation above

$$R_P = Q_P \cdot X_P = 50 \cdot 15 = 750\Omega$$

As can be seen, this value of R_P will load the tank circuit and hence reduce the bandwidth. Therefore, the values required for the inductor and the capacitor had to change considerably to retain the desired bandwidth.

Earlier it was mentioned that the tank circuit could also have an optional resistor. This resistor can be accounted for in the above calculations by combining it in the parallel combination of the source and load resistance. From the above calculations, it can be seen that the optional resistor lowers the value of the parallel combination, lowers the circuit *Q* and thereby increases the bandwidth.

One additional note is that in the above calculations the capacitor *Q* was assumed to be infinite (i.e., the capacitor is lossless). This assumption, although not theoretically correct, is valid in a practical sense, as capacitor *Q* is usually quite high. For example, a high quality ceramic low-loss capacitor has a *Q* ranging from 1,000 to 20,000 at 50MHz, depending on the capacitance value. The error induced in the actual circuit usually will not be large enough to warrant the more complicated calculations. At higher frequencies, though, this may not be the case. The designer should consult the manufacturer's data to know exactly what the component properties are.

Conclusions

Tank circuits are a common building block that, when designed properly, will provide a desired bandwidth around a center frequency. However, in order to achieve the desired response, both the circuit and component quality factors must be taken into account. The examples provided show that lossy components will reduce the circuit quality factor, and the bandwidth will therefore be larger than if lossless components are assumed.

References

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