Vintage Radio

Aerials, coils and how it all works

My column isn't supposed to be about radio theory, but this month we are looking at the theory of antennas, coils and how a tuned circuit works. Although a pretty dry subject, it's at the heart of any radio receiver — old or new — and a good understanding of the concepts is extremely useful when you're troubleshooting.

VINTAGE RADIO enthusiasts, generally speaking, fall into two categories; those who have some sort of training, and those collectors who are trying to find out the theory as best they can. This month's column is aimed fairly and squarely at the latter. However, a grasp of about Year 10 maths, and an understanding of capacitance and inductance will be required.

Back in the days when men were men and boys were boys, wireless sets were tuned with a good old fashioned 'tuning condenser'. Nowdays, they are tuned with anything from a trimpot to a computer! Jokes aside, even with the sophisticated tuning mechanisms of today, in order to receive a signal we generally must have either a variable inductance or a variable capacitance.

In the vintage radio days this was most often achieved by the familiar tuning 'gang', clearly visible atop the chassis.

Aerials vs antennas

FIRST OF ALL, let's clear up the original difference between the terms 'aerial' and 'antenna'. Although these were later used more or less interchangeably, there was once a subtle difference.

Given a traditional 'inverted L' type of arrangement, or similar, the term 'aerial' used to refer to the horizontal portion(s) of the structure. On the other hand 'antenna' referred to the horizontal *and* vertical portions, including the 'lead-in'. The terms became interchangeable once balanced-line or shielded downleads tended to separate the functional part of the antenna from the lead-in...

A radio wave travelling in free space is said to have two components: a magnetic component and a electric component. From a purely vertical transmitting antenna — i.e., a 'vertically polarised' antenna, the electric component radiates parallel to the antenna, and the magnetic component radiates parallel to the surface of the earth. (Tomes have been written upon, and PhD's have been awarded for, the properties of antenna and wave propagation, so this and other explanations appearing elsewhere are greatly simplified.)

The radio wave thus transmitted is said to induce both electric (voltage) and magnetic (current) components into the receiving antenna. A traditional receiving antenna of the inverted L type actually has inductive, resistive and capacitive components of its own impedance. The older texts often referred to a 'standard receiving antenna' as being four metres in height, of 25 ohms resistance, 200pF (0.2nF) capacitance and 20uH inductance. However regardless of the actual figures, the nett result is that there is a measurable voltage appearing across the antenna and earth connections of a receiver.

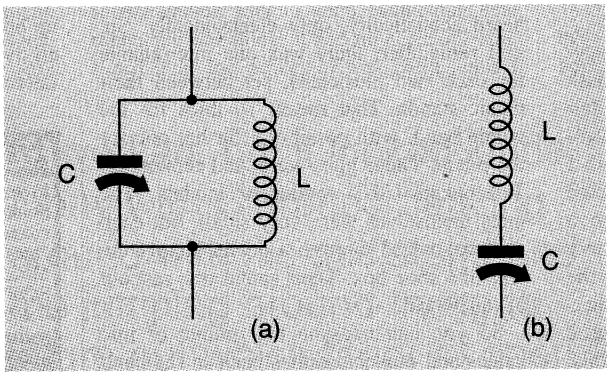

Fig.1: (a) shows a parallel resonant circuit, and (b) a series resonant circuit. The differences are discussed in the text.

Resonance and 'Q'

RESONANCE is a term which applies in physics, not just radio, and is a difficult concept to grasp. What it refers to is as follows.

Most objects have a natural frequency of vibration. If vibrating energy from another source is imparted to the object, at the same natural frequency of vibration, then the object concerned will vibrate of its own accord. The object concerned is said to be *resonating*. The frequency at which this occurs is the resonant frequency. Two good examples of resonance are firstly, air passing through an organ pipe and the pipe sounding its own natural frequency, and secondly, the pendulum of a clock.

In radio, there are a myriad of radio signals in free space, all simultaneously occurring. How then does a radio reseiver only receive one at a time? It is because the combination of inductance and capacitance in its tuning circuits will resonate at only one given frequency. In other words when a signal of that frequency excites the inductance and capacitance, a larger voltage will be developed across them than is produced by any of the other incoming signals. As we tune the tuning capacitor (or more rarely, the tuning inductor), the combination of inductance and capacitance obviously resonates at a different frequency and selects another of the incoming signals.

The term 'Q' refers to the amount of voltage gain that occurs in the tuned circuit at resonance, and also the 'sharpness' of its resonant peaking.

Parallel vs series resonance

MOST PEOPLE are aware of the two ways of connecting an inductor and capacitor for resonance — in parallel or in series, as shown in Fig.1(a) and (b).

In each circuit, resonance occurs essentially when the capacitive reactance equals the inductive reactance; viz. $X_L = X_C$. This gives rise to the formula for resonant frequency,

$$f_0 = 1/2\pi\sqrt{(L.C)}$$

However, there are differences. In a 'perfect' series tuned circuit, the theoretical impedance at resonance falls to zero. In reality, it amounts to the resistance of the coil. As you move away from resonance in either direction, the impedance of the tuned circuit rises from this value.

In a parallel tuned circuit, although the same formula applies (from a practical point of view) the reverse is the case. Here the theoretical impedance of a 'perfect' parallel tuned circuit at resonance is infinity. But because a practical inductance cannot have zero resistance, the impedance at resonance is never infinity, but very high — perhaps in the order of megohms.

Voltage gain

FIG.2(a) SHOWS just about the universal circuit which couples the antenna to the grid, in a valve-type radio. It's essentially a parallel tuned circuit with the antenna voltage coupling into it via step-up transformer action. However this means that we can redraw it another way, as shown in Fig.2(b). It's now a series tuned circuit in which the EMF from the primary winding acts as a series generator.

Let's assume that the coupled antenna signal, which is now the generator, is say 1mV (0.001 volt) at a frequency of 500kHz. Also that the circuit constants are 405.4uH and 250pF, and the resistance of the inductance is 10 ohms. We'll also use Ec to represent the voltage which appears across the capacitance and therefore between the grid and cathode of the tube.

At resonance, the current in the circuit is I = E/R, or 0.001/10 which equals 0.1mA. By application of the formula for capacitive reactance,

Xc = 1/2πfC,

we find that the reactance of 250pF at 500kHz is 1273.8 ohms.

The voltage across the capacitance is now Ec = IR, or E = 0.0001 x 1274 = 0.1274 volts (127.4mV). The 'Q' of the tuned circuit is the amount of voltage gain, which in this case is 127.4/1 or 127.4. Note that the Q can also be expressed as XL (which is equal and opposite to Xc, at resonance) divided by R, or in this case 1274/10 — which again equals 127.4.

We can see now a classic example of resonance described earlier. A small 'exciting' signal of 1mV produces 127.4mV across the tuned circuit, giving a voltage gain is 127.4 times. In a crystal set, 127mV can be enough to operate the earphones, whereas 1mV is not!

So is there 'amplification' in a tuned circuit or a crystal set? Clearly, there is; up to a point! There can be voltage gain, but no power gain.

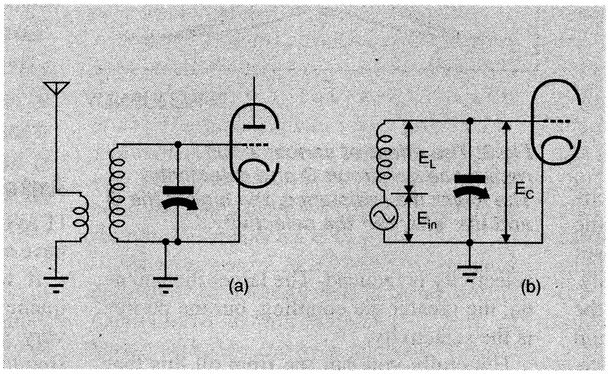

Fig.2: Is the traditional valve radio input circuit in (a) a parallel or series tuned circuit? The resonant grid circuit can be redrawn as in (b), as a series tuned circuit with the voltage induced from the primary as a series voltage generator.

Effect of resistance

IN THE PREVIOUS discussion mention was made of the resistance of the coil. If in the example above the resistance of the coil was only five ohms, the current flowing through the circuit is doubled, that is 0.2mA, and therefore the voltage across Ec is also doubled. This means that the gain or 'Q' of the circuit is doubled as well.

In addition to doubling the voltage gain, the circuit becomes more selective as well. This is about the point where higher mathematics takes over from simple illustrations, so the effect of resistance is best illustrated by the curves shown in Fig.3.

How do we reduce the coil resistance? There are two ways. The first is to use thicker wire for the coils. However, the drawback here is the distributed capacitance which occurs. This results from the sum total of the minute capacitances that occur between adjacent turns of the coil. Even though the coil is continuous, a given single turn of the coil forms one plate of a capacitor, and the next turn of the coil is the other plate of a capacitor, and the insulating material forms the dialectric.

Coils in recievers of the 1920's tended to be wound on 3" diameter formers with quite thick wire, of about 26swg. Distributed capacitance was considered less of a problem than a higher resistance winding.

The other method to reduce resistance is to use a powdered ferrite core inside the coil former. The ferrite core (or 'slug' as it became popularly known) increases the permeability of the inductance. What this all means, is that fewer turns are required to produce the same inductance as a simple air cored solenoid. Such coils are easily seen in radios of the post war era.

There are other losses that occur in tuned circuits, and are variously lumped together and referred to AC losses.

The 'L/C' ratio

IN THE EXAMPLE used above, the circuit constants for a tuned circuit resonating at 500kHz were 405.4uH and 250pF. If we halved the capacitance and doubled the inductance, we would still have a circuit tuned to 500 kHz. However it doesn't stop there. Consider the alternative situation of a capacitance of 125pF. The capacitive reactance at the given frequency now becomes doubled. It is now 2547.6 ohms.

So with a current of 0.1mA, the voltage across the capacitance is now doubled. The 'L/C' ratio is said to have doubled.

Hence, it can be seen that for the most efficient and selective tuned circuit we need the smallest practical capacitance with the largest practical inductance.

What is the practical application of this in an ordinary radio? Simply, that as we tune lower in frequency, the capacitance increases, meaning that the L/C ratio decreases, and so does the Q and the selectivity. This is why simple sets, particulaly three stage TRF sets without regeneration, tend to suffer a droop in performance at the lower frequency end of the band.

In a simple regenerative 'Reinartz' circuit, the idea of feedback is to overcome the coil resistance and other circuit losses that occur, in order to improve selectivity. In tuned circuits at radio frequencies, the losses are quite complex indeed and amount to more than simple DC resistance. Feedback can reduce the losses considerably, but too much feedback and the circuit oscillates. Again, tomes have been written on oscillators, and the mathematics can be quite complex.

We have seen how the circuit efficiency decreases with increasing capacitance — i.e., as the L/C ratio decreases. Hence, in a regenerative set more energy needs to be fed back to the tuned circuit the lower you tune in frequency. That is why the reaction capacitor needs to be constantly adjusted in these simple sets as we tune across the band.

Antenna coupling

EARLIER WE SAW that there was once such a thing as a 'standard' antenna. Given the constants as described, this would mean that the antenna was in fact a tuned circuit which theoretically resonates at 2.541MHz. It may well do, but it would indeed be so broad that it might not resonate at all!

However the primary winding of the antenna coil shown in Fig.2(a) is also an inductance, and this would add to the overall antenna inductance and lower the theoretical resonant frequency. The tuning properties of the simple bit of wire hanging out the back of a domestic radio can largely be ignored.

In any RF transformer (i.e., pair of coupled coils), the closer the primary is to the secondary, and the greater the number of turns on the primary, the higher is the induced signal — but at the same time, selectivity is reduced. The larger the antenna, the greater the coupling, but the poorer is the selectivity.

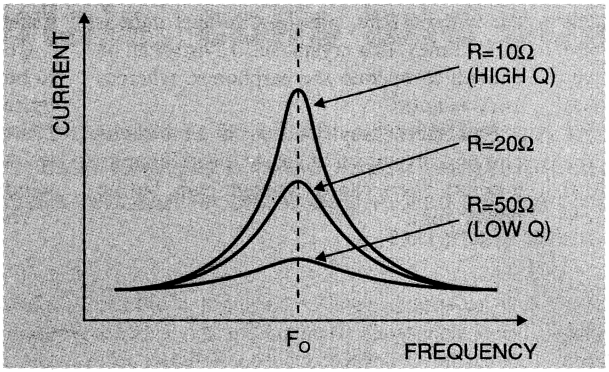

Fig.3: The effect of series circuit resistance on circuit Q and selectivity. The lower the resistance, the higher the Q and the 'sharper' the selectivity.

Hopefully you can see from all this that much of the workings of antenna, coil coupling and L/C ratio on the performance of a tuned circuit and its ability to be selective, is all a huge compromise. Too much of one factor means a reduction in another, and so on. One of the joys of early radio enthusiasts was experimenting with their coils for the best results. It still is!

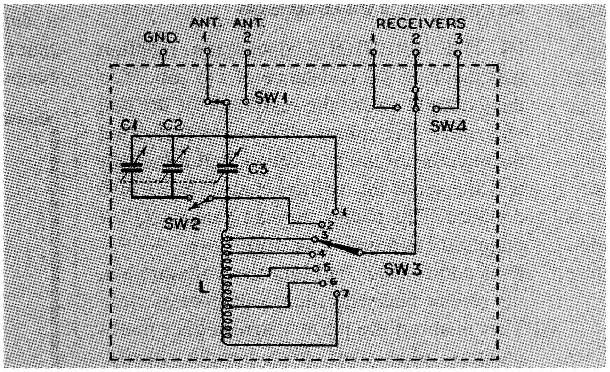

Fig.4: The antenna tuner described in Radio News for February 1934.

In the late 1930's, coil designers produced coils of quite sound design that overcame many of the problems. They had a very large inductance primary, which tended to have a resonant peak at about 500kHz. This was to overcome the inevitable L/C ratio losses. They were also wound with Litz wire, to overcome the so-called 'AC losses', and were slug tuned to allow for greater Q. AWA in particular made very very good coils, and the results 'spoke for themselves' (pun intended).

Scanning through the old *Official Australian Radio Service Manuals* shows various ways coil designers have modified their coils over the years to give the intended results. Sometimes they loaded the primaries with a resistor of about 10k, to broaden the tuning. At other times, small capacitors of 4 to 10pF were connected from the hot end of the primary to the hot end of the secondary. This was done to improve performance at the high frequency end of the band. Philips in particular incorporated this design.

Antenna tuners

IT WOULDN'T DO for this column not to have at least one circuit, so we'll do so.

If we wanted to receive only one frequency, we could design an antenna to be very efficient at that frequency and that frequency alone. This what happens in an antenna designed for a transmitter, and many radio amateurs have specifically selective receiving antennas for the given amateur frequencies. However domestic receiving antennas must be more versatile.

One method was to incorporate an antenna tuner, and such a device was published in *Radio News* for February 1934. Its circuit is shown in Fig.4.

This tuner is placed in series with the antenna and the receiver(s), and an improvement of 17dB at 600kHz to 5.1dB at 1500kHz was claimed, with best results using maximum capacitance for the minimum inductance on the coil.

Does this fly in the face of the foregoing text? It doesn't, because this circuit is tuning the antenna, not the incoming signal. It is adjusting the constants of the antenna for maximum compatability with the aerial coil primary of the receiver. Bear in mind that this device was in the days of simple solenoid coils, and not the better coils of the late 1930s as described above.

For those who are interested, the capacitor is a traditional three-gang type, and the coil is 150 turns of say 22swg enamel wound on a 3" diameter coil tapped at 5, 20, 50 and 100 turns. The former needs to be about 5" in length. It needs to be built in a shielded box, and separately earthed from the receiver. ❖