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# Coils—Why Some Are Better Than Others

## *It is the Lines of Magnetic Force Which are Important*

By HORACE V. S. TAYLOR

WHEN you build a wireless set, wire is one of the most important things. Of course, it is the wire used to wind the coils and not a conductor strung through the street like a telegraph line, which is important in radio. When you open the cover of a radio set, you always find one or more coils, no matter whether the set is a single circuit crystal or a nine-tube superheterodyne.

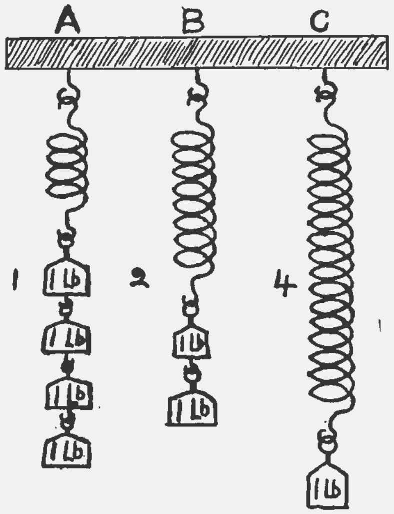

Fig. 1. Coil is Like Weight

There are a great many wrong ideas about the action of a coil, and why some are better than others. For instance, in some places you see a statement that the inductance varies as the square of the number of turns. This would mean that by doubling the turns we should get four times the inductance. Other authorities state that the inductance varies directly as the turns, which would only give twice the inductance in the above example. Which one is right?

### What Kind of a Coil?

As a matter of fact both answers are right, depending on what kind of coil we have. This will be explained in a few minutes. To begin with, the reason why a coil is used is because it furnishes electrical weight to the system and this allows it to vibrate. It is exactly like a weight attached to a spring in mechanical vibration. A heavy weight makes a slow speed and a heavy coil has the same effect.

Referring to Fig. 1, we see that a short spring with a heavy weight corresponds in time of oscillation to a long spring with a light weight. The rule is that the product obtained by multiplying the value of the spring by the value of the weight gives the tuning factor. So in Fig. 1 a spring 1-inch long with 4 pounds on it will bob up and down at exactly the same speed as a spring 2 inches long with 2 pounds on it. Again the same vibration will happen with a 4 inch spring and 1 pound weight.

If this is understood in Fig. 1, then it will be easy to follow the electrical case as shown in Fig. 2. Here the spring is represented by a condenser of one micafarad and the weight by the coil, with an inductance of four millihenries. This will give the same wave length as a circuit with a 2 mfd. condenser and a 2 mh. inductance or a 4 mfd. capacity and a 1 mh. coil.

### Coil is a Weight

From this you will see that it is the weight of the coil measured electrically which counts. The resistance plays practically no part in determining what wave length the coil will have. Of course, it is an advantage to have the resistance as low as possible because all the current is wanted to operate the set and to force current through a high resistance uses a lot of energy. That is why coils are wound with fairly good sized wire. If the same number of turns had been wound into the same space using much finer wire, the tuning of the coil would have been practically unchanged, that is, it would have sent out the same wave length. It would have had this disadvantage, however, that the music coming through it would not have been nearly so loud, as considerable of the energy received would have been used up in the unusually high resistance.

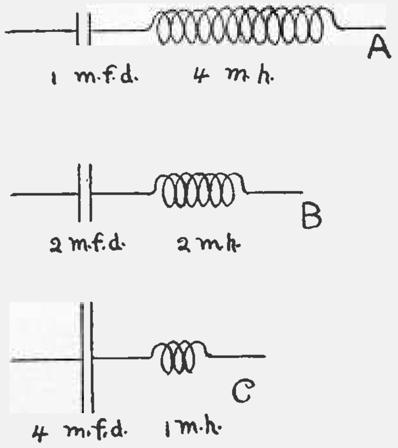

Fig. 2. Coil and Condenser for Tuning

The question that naturally comes to mind at this point is, what causes the weight of the coil? We have already said that it is not the resistance. That has no part at all. To understand this it is necessary to know something about the magnetism of a coil or solenoid, as a long coil is called. When a solenoid is connected into a battery circuit so that a current flows through the winding, it makes a magnet of the coil and this magnet is powerful enough to turn the needle of a compass or pick up small iron articles. It does this because of the so-called "magnetic field," which exists all around the coil. This field is merely a name for the magnetic effect, but it is convenient to show it by means of lines drawn around the coil as shown in Fig. 3.

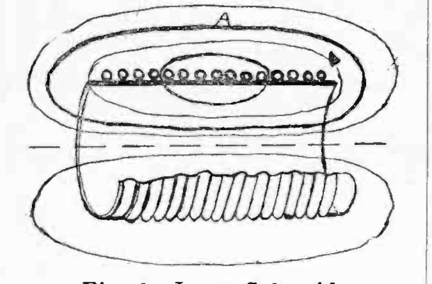

Fig. 3. Long Solenoid

### What "Average Line" Means

The solenoid shown in Fig. 3 consists of a single layer of insulated wire, wound on a cardboard or fibre tube. This in the drawing is shown cut open so that at the top we see the coarse section of the tube and wires, while in the lower part of the drawing the outside view appears as we naturally see it. The various lines running around the wires and through the center of the tube represent the lines of force, as explained in the preceding paragraph. Notice that one of these lines is rather heavier than the rest, and is labelled "A." This represents the average line. It is spaced at such a distance that the magnetism outside of it is just the same in amount as that inside. Of course, it is rather hard to locate this experimentally, but the position shown in the figure would be about right.

All the lines of force are closed on themselves, that is, they have no beginning or ending. Naturally they all run through the center of the tube. Most of them surround all the wires, as for instance, the line A, but a few are crowded into such a small distance that they do not take in the entire number of turns of wire. This can be seen represented in the center of the winding space.

### Measuring the Coil

There are two things of special interest in a coil. One is the amount of magnetism it can make, and the other is its electrical weight, as we have just been discussing. The amount of magnetism of the coil is found by running a current of exactly one ampere through the turns and then determining by the pull of the solenoid, or in any other convenient way just how much magnetism is produced. This may be expressed in various ways, but a convenient one is to leave the answer as so many lines. Of course, if we double the current to two amperes, there will be twice as many lines—that is the number is proportional to the current. That is why we must have a unit current of one ampere flowing when the measure is made, or else the result would not mean anything.

The electrical weight of the coil depends not only on the turns, but also on the lines of magnetism. As a matter of fact, the weight is proportional to the product of the magnetic lines multiplied by the number of turns. From this it can easily be seen that to get an effective coil (one which is quite heavy) we must have either a large number of turns, or a large number of lines, or both. Of two coils with the same number of turns, the one that has most magnetism will be the better.

### What Makes the Lines?

The quantity of magnetism which exists or flows is determined in just the same way as the quantity of water flowing in a pipe is effected. We all know the the higher the pressure, the more water we get. That is why a fire engine, pumping at high pressure, will squirt a lot more water into the flames than if we just had the city pressure on the fire hose. But, besides the pressure, the other important thing is the size, or we might say, the resistance of the pipe. A large pipe with a low resistance will naturally pass a great deal more fluid than a small one. In other words, the smaller the resistance of the pipe, the more current we get, even with the same pressure. The same thing holds true in the magnetic case.

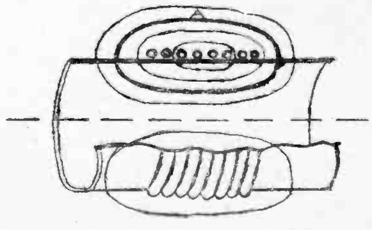

Fig. 4. Short Wound Coil

The resistance of the magnetic circuit is called "reluctance." It means exactly the same thing as the resistance of the pipe. If there is a big area to conduct the magnetism, then the reluctance is low and lots of lines will flow. On the other hand, if the area is small, it will be like a small pipe, and the magnetic current, if we may call it that, will be reduced proportionately. But there is another thing besides cross section of the pipe which influences its current, and that is its length. You probably know that if you have an ordinary water pipe connected to the street main fifty feet away, you will get plenty of water, but if you use the same size of pipe, and run it several hundred feet, it will take you quite a while to fill up a bucket because the flow will be so small through its great length. The same thing applies in the case we are discussing. If the length of the magnetic circuit is a long one, then with the same current flowing in the solenoid the number of lines will be small, but if the circuit is a short one we shall get proportionately more magnetic effect.

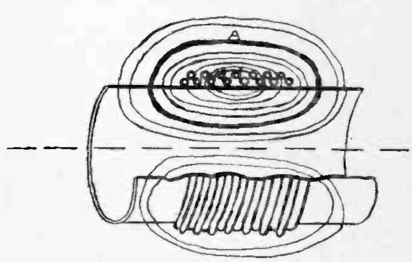

Fig. 5. Two Layer is Efficient

### What the Average Line Does

The "length" of the magnetic circuit may not seem to mean very much since some of the lines are very short, as shown in our picture, and others send out far beyond the limit of the drawing. What is meant by this length? In such a case, it is found by experiment that the average line is a measure of the magnetic circuit. If this line A is a long one, then the amount of magnetic flux will be small, but if it is short, the flux will be so much greater. Expressing it another way, if we have two coils with the same number of turns wound on the same tube and having the same current, then the amount of magnetism will be inversely proportional to the length of the average line A. The proportion is inverse because a long line means a small amount of magnetism, and a short line a large amount.

With these facts in mind, we can analyze the effect of different forms or kinds of windings. Fig. 3 shows a coil composed of a single layer of 16 turns. This gives a certain number of lines, which in our drawing we have represented as 4 on each side. (Some of the lines in the lower half are omitted to avoid confusion.) The average length of line A is about 4½ inches. Now look at Fig. 4. This has half as many turns, that is, 8. It is wound on the same tube and has the same current—one ampere—flowing through it. The average turn is now 2¼ inches long, or half that shown in Fig. 3, since the length of winding is only half as great. In this case the number of turns causing the magnetism is one half, and the reluctance holding back the magnetism is half, which will give the same number of lines—4. This will be seen from our water pipe analogy. If we have 2 pipe lines and the second has half the pressure forcing the water through, and half the area allowing water to flow, then the current in the two will be just alike. Compare Fig. 3 and 4. Once more we shall see that the magnetism in either case is the same.

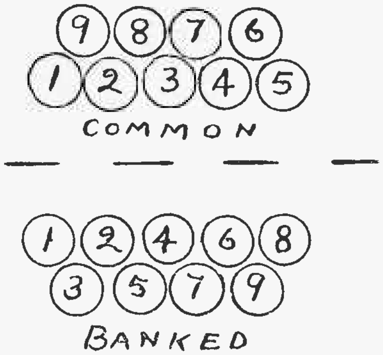

Fig. 6. Two Styles of Coils

### How the Weight Varies

Now what shall we say about the inductance or weight of these two coils. You will remember that the rule was just given that the inductance (weight) equals the product of the number of turns multiplied by the number of lines. In Fig. 3 the weight is 16x4=64, while in Fig. 4, the weight works out as 8x4=32. From this we see that the inductance of the first coil is twice that of the second.

Now let us see what happens when we wind the coil in two layers. Fig. 5 shows a tube of the same size as before, and 16 turns wound in two layers of 8 each. This one ampere current flowing through this solenoid gives the same magnetic force as that of Fig. 3, which also had 16 turns. But notice that the length of the average line will be the same as the 8 turn coil in Fig. 4. This is because the same amount of tube length is used in both cases. Since the same pressure is used, but only half the resistance, we shall get twice the magnetism or 8 lines instead of 4. Again compare the water pipe. Instead of having half the pressure on our large pipe that we do on the small one, we apply the same to both. Naturally twice as much water will flow through the big diameter pipe.

### A Very Efficient Coil

From this it will be seen that the short coil in Fig. 5, although having the same number of turns as the long one of Fig. 3 will, nevertheless, give us twice the amount of magnetism. This, as explained, is owing to the fact that the reluctance of the short path is only half as great. The inductance of this coil will be 16x8=128, as compared with 64 for coil 3 and 32 for coil 4.

Now let us return to the first part of this article. There it was stated that in some cases the inductance varied directly as the first power of the number of turns. This is seen to be true by comparing Fig 3 and 4. The eight turn coil has an inductance of 32, while the 16 turn inductance coil was 64. This you will see is exactly a two to one ratio for each and so the proportionality holds. Again it was stated that in some cases the inductance varied as the *square* of the number of turns. This is seen by comparing Figs. 4 and 5. The 16 turn coil in Fig. 5 has twice the turns, but four times the inductance of Fig. 4, and so the variation is as the square of the turns. If we had used three times as many turns, we should have got 9 times the inductance (3x3=9).

### How to Tell Which is Which

The rule which applies to all cases, may be expressed in this way. In single turn coils, where the length of winding along the tube varies as the number of turns, then the inductance varies directly as the turns. But if the length of winding is kept the same, and additional turns are put on in layers on top of the first, then the inductance varies as the square of the number of turns. This rule will hold in all cases.

Noticing again that with the same amount of wire Fig. 5 is four times as effective as Fig. 3, it naturally follows that the two layer coils are much more efficient than the single layer. This is indeed correct. Why then, are most radio coils wound in a single layer? The answer is to be found in the fact that a two layer coil as usually wound has a great deal of leakage capacity, and so will not give good tuning.

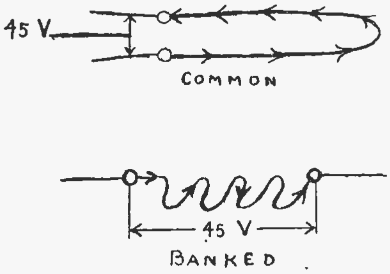

Fig. 7. High and Low Capacity

### What Makes the Leakage

You will remember that a condenser may be defined as any two conductors separated by an insulator. Here we have the upper layer a conductor separated from the lower layer by the insulation wrapped around each wire. To be sure the two layers are connected at the other end of the coil, but this does not prevent a large amount of leakage capacity between the two ends of the winding, which are at the same end of the coil. In the single layer of coil, the two ends of the winding are separated by the full length of the solenoid, and so the capacity action is very small, but in the two layer coil, the end lies directly on top of the beginning, and so the capacity is large.

How can we arrange so that the beginning of the winding shall lie at the opposite part of the tube from the ending? There is only one way— that is by winding a "banked" coil. This means that instead of winding a complete layer and then another one on top of it, you wind the two layers at the same time. Fig. 6 illustrates this. These circles shown

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represent a cross section of the wires themselves, magnified quite large. The numbers in the circle show the order in which the turns are put on. Thus it will be seen the first turn goes at the left, the second turn right side of it, then the third, etc., until the end of the winding is reached at 5. The sixth lies on top of 5, the seventh on 4, etc., until the end turn lies right over the beginning This is the natural way to wind the coil and it gives four times as efficient a solenoid as the single layer in point of inductance. The trouble is, as just explained, the distributed or leakage capacity is so high as to prevent sharp tuning in radio.

### How to Bank the Winding

The lower half of Fig. 6 shows the order of winding a banked coil. Two turns are put on side by side. Then the third is wound on top of 2. 4 goes side of 2 and 5 on top of it. 6 is side of 4 and 7 on top of it. This scheme of winding is continued until the end of the solenoid is reached. Such a winding gives exactly the same inductance as an ordinary two layer coil, but the leakage capacity is reduced to a small fraction of what it would otherwise be. The only reason that most coils do not use this winding, comes from the fact that it is rather difficult to make the wire stay in place. When you attempt to wind wire 3 on top of 1 and 2, it is apt to spread 1 and 2 apart and crowd in between them. To make a neat looking job requires a great deal of practice.

### Doubling Back on Itself

Fig. 7 shows the effect of the common winding in doubling the current path back on itself. Suppose we put 45 volts across the terminals of the solenoid. With the common form of two layer coil the electricity will run along the lower layer to the right (of course, spinning around the tube from turn to turn) until it gets to the end, and then will loop back through the upper turns, coming out about where it started. This puts full pressure of 45 volts between the lower end turn and the upper one. It is this closeness which gives the high capacity. With the bank winding, on the other hand, the current goes through a lower layer turn and then an upper layer one, back to the lower, then to the upper, continuing this action, as shown, just like the teeth of a saw. The end is spaced the full length of the coil away from the beginning, so no two turns have very much voltage between them. The result is the low capacity and sharp tuning of the bank winding.

It may be asked how various type of coil compare—ordinary solenoid, honeycomb and spider web coils. The honeycomb coil consists of a great many layers, and so it is very efficient from the point of view of inductance. The wires cross each other at an angle and so the distributed capacity is not nearly as great as it would be if the wires were parallel. The first and last turns are separated only by the number of layers in the coil, and being much closer than in a single layer, so will cause more capacity than in such a coil with the same number of turns. However, it must be pointed out that it is not fair to compare with a coil of the same turns. It is the inductance which you want. Comparing with a coil of the same inductance we find its distributing capacity is low. On both points then the honey-comb is very satisfactory. The chief reason it cannot be used in a variocoupler for instance is because it is quite difficult to arrange to take off taps at intermediate points in the winding.

Comparing a spider web coil with the others, we find that while not quite as efficient as the honey comb, it excels the solenoid, both in inductance and lack of leakage capacity. That is one reason why this form of winding is proving very popular.

In conclusion we may state that, for an ordinary variocoupler, the single layer winding with taps is the most practical form. If considerable more inductance is needed to tune to the high wave lengths used in code, then this solenoid should be banked in two or perhaps three layers. If a coil with large inductance and no taps is needed, then a honey-comb best fills the bill. For miscellaneous coils, which do not need a rotor turning inside (like a variocoupler) the spider web is very efficient and easy to wind.