Fundamentals of Radio Servicing

Part III — What Is Induction?

By JOHN T. FRYE

HAVE you sat in a hotel lobby where all was quiet until a cute blonde got up from where she had been sitting unnoticed behind a potted palm and glided across the floor? If you have, you may have noticed—if you were not too busy watching the blonde—that there was something about the girl *in motion* that seemed to exert a magnetic effect on every masculine head in the lobby.

Well, what this blonde has, our friend the little electron has, too; for as soon as an electron starts to move, it is surrounded by a magnetic field. Let me repeat this, for it is one of the most important facts in radio: *an electron in motion is surrounded by a magnetic field.*

The magnetic field surrounding a single hustling electron is too small to be easily measured with crude instruments, but when a few million of them cavort along through a wire carrying a substantial direct current, it is easy to observe the total magnetic field generated. Fig. 1 shows a vertical wire carrying such a current, with four compasses grouped around the wire. Since a magnetic field is the only force that affects a compass needle, and since lines of magnetic force enter the S pole of the compass needle and leave by the N pole, we can see that the magnetic field about the wire consists of circulating concentric lines of force. Reversing the direction of the current causes the needles to reverse their positions, indicating the truth of the left-hand rule for wires:

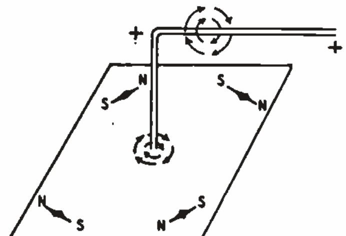


Fig. 1—The field around an electric current.

Grasp the wire with the left hand so that the thumb points in the direction the current is flowing; then the fingers will be pointing in the direction in which the magnetic lines of force encircle the wire.

(Radiomen used to go along with Ben Franklin's original mistake and pretend the current flows from positive to negative—although we know that just the opposite is true. They, of course had to use the right hand.)

Increasing and decreasing the current while moving the compass needles to different distances from the wire will show that the strength of the magnetic field is related to the amount of current flowing. It is easy to see why. More current means that more electrons are moving, and the total magnetic field about the wire is simply the sum of the magnetic fields of the individual electrons that are passing through the wire.

The inductor

Suppose we wind our length of wire into a coil. What happens to the magnetic field about the wire? Fig. 2, showing two adjacent turns of such a coil with an exaggerated separation between the turns, gives the answer. For one thing, we see that as the magnetic lines of force continue their dog-chasing-his-tail routine about the wire of each loop, all of these lines pass through the center of the loop, and as they do so, they are all traveling in the same direction. This is true for all the turns of the coil: when the lines of force are at the "most inside" point of the coil, they are all traveling in the same direction. A half-turn later, when each circling line of force is at its greatest distance from the center of the coil, it is traveling in exactly the opposite direction; and that means that *all* of the lines of force are doing so. Between turns, though, the lines of force of two side-by-side turns are traveling in opposite directions.

When we reflect that these magnetic lines of force are true *forces* and can be added when they are working together, we come to the following conclusions about a coil of wire carrying a direct current:

1. The circulating lines of force about the wire add together inside and outside the coil to produce new and stronger lines of force that issue from one end of the coil, return outside to the opposite end, and then pass through the center of the coil.

2. Between the adjacent turns, the opposite-going lines of force buck each other and so cancel.

3. The new magnetic field is most intense inside the coil where all of the lines of force are crowded together.

4. The coil has a N and a S pole just as does a bar magnet, and reversing the direction of current through the coil causes these poles to exchange places.

5. Since the individual fields of all the turns of wire are added together to produce the field of the coil, it follows that the more turns of wire there are, the stronger will be the magnetic field of the coil. Also, since the strength of the field of each individual turn depends upon the amount of current flowing through it, so does the strength of the field of the coil as a whole depend on the current.

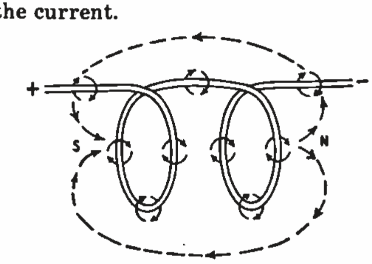


Fig. 2—The fields help or hinder each other.

If a bar of iron is thrust through the center of our coil, the magnetic field is greatly increased. The reason is that a magnetic line of force feels about iron the way a cat feels about catnip. It just loves to wriggle through that soft iron, and it will endure a great deal of crowding to be permitted to do so. In fact, a coil with an iron core will accommodate several hundred times as many lines of force as will the same coil carrying the same current with only air in its center. The more lines of force there are, the stronger is the magnetic field.

Magnetism creates current

One of the nicest things about the study of electricity is that it is such a *vice versa* business: There are so many statements in this subject to which you can add, "And so is the opposite true." An example is our statement about the moving electron creating a magnetic field. *If a conductor is cut by the lines of force of a magnetic field, an e.m.f. is set up in the conductor which causes electrons to move, or current to flow.*

When we speak of the conductor being "cut by lines of force," we mean that either the conductor or the lines of force must be moving. A wire moved between the poles of a horseshoe magnet, a bar magnet thrust into a coil, or a wire placed so as to intercept the expanding and contracting lines of force that surround another wire through which a current of varying intensity is flowing all fulfill this requirement. Remember, though, that either the field or the conductor has to hold still while the other moves through it—or else one has to be zigging when the other is zagging.

The intensity of the e.m.f. "induced" by this action depends upon how many lines of force are cut in how short a time. This means that a strong magnetic field with many lines of force and a very rapid movement of either those lines of force or the conductor will produce a high voltage.

Self-induction

And now we are ready to meet *self-induction*, which is just about as bull-headed and conservative a quality as you will find anywhere, inside electricity or out! It simply cannot bear a change. Take the case of Fig. 3. Here we have a battery connected across an iron-core coil of many turns. A lamp that barely lights on the battery voltage is across the coil, and a switch and an ammeter are in series with it and the battery.

When we close the switch, the light glows dimly; but the hand of the current-indicating meter rises quite slowly to a maximum reading. Why so slowly? We know that electrons move with the speed of light. Why are the little cusses apparently dragging their feet just because there is a coil in the circuit? Well, when the current started to flow through the coil, a magnetic field started to build up around that coil. As the lines of force of this expanding field cut the turns of the coil, an e.m.f. was induced in those windings that had a polarity opposite to the voltage applied by the battery. This "bucking" voltage was very nearly equal to the battery voltage.

However, as the induced bucking voltage or back-e.m.f. approached the battery voltage, it slowed down the increasing current from the battery. This in turn slowed down the expansion of the magnetic field that was producing the bucking voltage.

As you can see, this gives the battery voltage the whip-hand: if the induced e.m.f. could rise to the value of the battery voltage, it would stop the current flow; and this would spell its own doom. The net result is that the battery steadily wins the tug of war, but it takes time. Eventually the current rises to the maximum amount the battery can push through the resistance of the coil wire, and then the magnetic field ceases to expand. It just hovers out there in the vicinity of the coil without either increasing or decreasing. Since the lines of force are no longer moving and cutting the turns of the coil, there is no more back-e.m.f.

Now let us quickly open the switch. Instantly the ammeter falls to zero, but a split-second later the lamp flashes very brightly and then goes out. Where did this lamp-flashing voltage—obviously higher than our battery voltage—come from? How could current continue to flow through the lamp *after* the battery had been cut off? Gremlins?

No, the answer lies in what happened to that hovering magnetic field when we opened the switch. Since this cut off the sustaining current, we simply knocked the props from under that field, and it did the only thing it could do: collapsed. As the field contracted, the lines of force whizzed through the coil turns faster than a small boy going through his yard gate at curfew time; and the speed with which these lines of force intercepted the wires accounts for the fact that high e.m.f.—higher than the battery voltage—was set up in the coil.

You remember that the e.m.f. generated by the expanding magnetic field was of such polarity as to resist the voltage of the battery. As might be suspected, the voltage induced by the collapsing field is of opposite polarity and tries to keep the current flowing after the battery has been cut off. After doing all it could to prevent the current from starting to flow in the first place, now the self-inductance does all it can to prevent that current from stopping!

This property of a coil or wire that tends to *prevent any change* in the current passing through it—that always tries to preserve the *status quo*—is called *inductance*. The unit of measurement of how much of this property a circuit element has is the *henry*. When a current change of 1 ampere per second in a circuit produces an induced e.m.f. of 1 volt, the circuit is said to have an inductance of 1 henry. If 2 volts are produced, the inductance is 2 henries, etc. Smaller units are the *millihenry* (one thousandth of a henry) and the *microhenry* (one millionth of a henry).

Inductors are often used in radio work, but they are usually called by some other name. For example, we have filter and audio chokes which consist of many turns of wire on iron cores and may have inductances from 1 to 100 henries. R.f. chokes have fewer turns of wire with an air core, and they vary from a few microhenries to 100 millihenries.

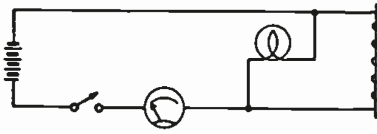
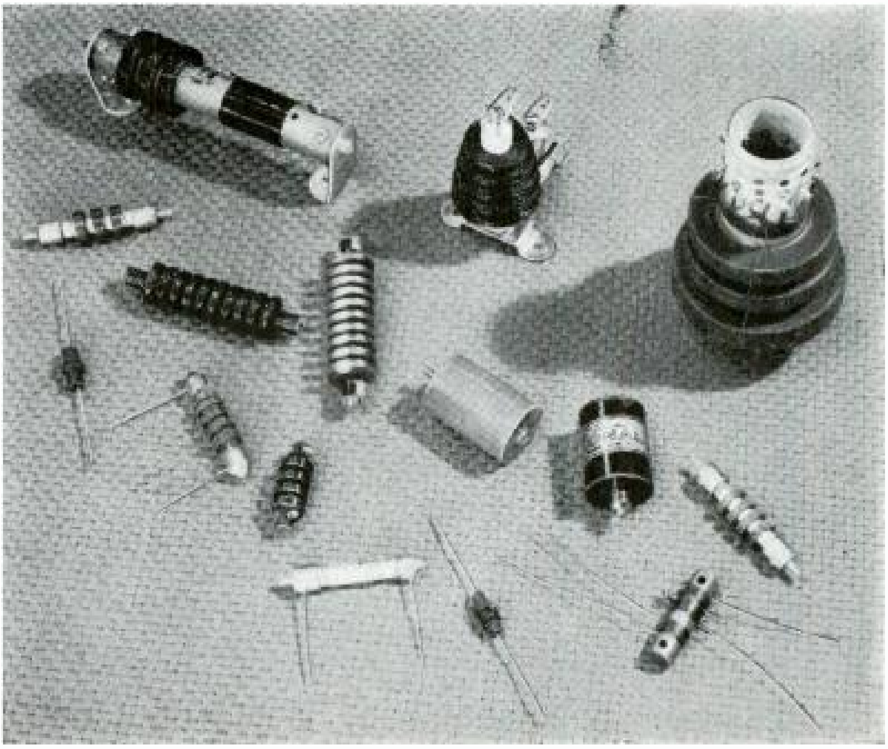


Fig. 3—Setup to demonstrate self-induction.

Inductance is chiefly concerned with coils, and anything having to do with coils is of major importance in radio. This business of magnetic induction is the key to understanding what goes on in many of the parts you find in any radio receiver. Do not, therefore, dismiss it as not being of practical value. A knowledge of magnetic induction is as practical in understanding radio as the knowledge of the alphabet is in learning to read.



This group of high-frequency (r.f.) inductors includes both transformers and chokes.