

# The Technician Explains

## Inductance Coil Design

(By "Cathode")

### Second Instalment.



In case any readers should not have noticed the correction inserted in the issue of September 6, it is desired to point out that in the design charts printed in the issue of August 23, and giving the number of turns necessary to attain certain specified inductances with different dimensions of coil, curve A refers to a coil diameter of 3 inches and not 2 inches, as stated, while curve C relates to a coil diameter of 2 inches.

The subject to be dealt with in this paper is that of the most efficient, or, as it is termed, the "optimum" diameter of wire for any particular coil.

The fact that for any particular coil there exists one diameter of wire which will be productive of higher efficiency than can be obtained from any other diameter of wire is fairly well known, thanks to the publicity with which the introduction of the original Browning-Drake coils was attended. The statement then made, that the most efficient design entailed having the wire spaced by half its diameter is, of course, nonsense, as Glenn Browning would doubtless be first to admit in the light of fuller knowledge; the error was one that is very common—that of too readily propounding a general rule from a particular instance; however, Browning did succeed in focussing attention on the problem of increasing coil efficiency, and for this he is deserving of every credit.

To appreciate just why the diameter of the wire employed should affect the efficiency of the coil in this manner it is necessary that the reader should have some understanding of what is meant by high-frequency resistance. It will be remembered that in the writer's last paper in this series, it was mentioned that the amplification obtain-

able from a high-frequency stage depends, other things being equal, on the magnitude of a factor  $L/CR$ , where  $L$  is the inductance of the tuning coil,  $C$  the associated capacity, and  $R$  the coil's high-frequency resistance in ohms. It was pointed out that some advantage could be gained by increasing  $L$  and decreasing  $C$ , but at the cost of some slight loss of selectivity; what it is desired to stress now is that a very considerable advantage can be gained by reducing  $R$ , not only an advantage in the direction of increased amplification, but also in the direction of enhanced selectivity.

If it were desired to reduce the direct-current resistance of a tuning coil, the obvious thing would be to use as heavy a wire as could be accommodated. Studying Fig. 1, it is apparent that increasing the diameter of the wire steadily reduces the d.c. resistance of the coil. A glance at the curve labelled r.f. resistance (radio-frequency or high-frequency resistance) however, shows that there is a point beyond which any increase in wire diameter is productive of an actual decrease in efficiency (i.e., an increase in high-frequency resistance). Obviously, then, the point at which the high-frequency resistance is at a minimum represents the best or "optimum" wire diameter.

The reason for the increase in resistance which accompanies an increase in wire diameter beyond the optimum will perhaps not be clear without explanation. One factor contributing to this result is what is known as "skin-effect." When a wire (over a

certain very small diameter) is carrying a current alternating at a very high frequency, the current is not evenly distributed throughout the wire, but is carried on the outside or "skin" of the wire; moreover, if this wire is wound into a coil, the current will not

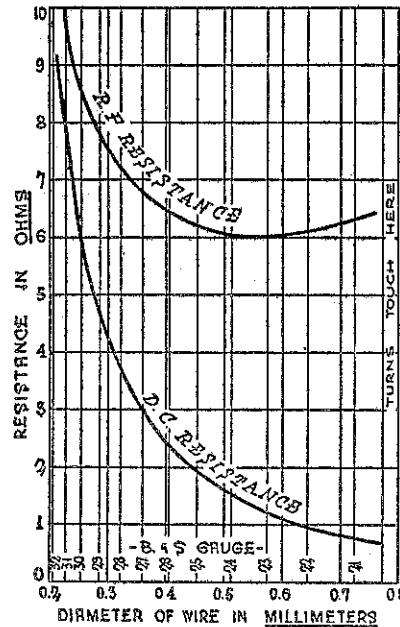


Fig. 1.—Comparison of D.C. and R.F. Resistance.

even be evenly distributed over the surface, but will crowd to the inner surface (i.e., the surface nearest the centre of the coil) of the wire; thus an increase in the diameter or area of the wire is not productive of anything like the expected effect in reducing the high-frequency resistance.

Added to this "skin-effect," however, is another factor which we may term the "proximity effect." Each turn of wire, when passing high-frequency current, has its own magnetic field, and the effect of these fields in introducing eddy current losses and current flow distortion in neighbouring turns is such as to still further increase the high-frequency resistance over the direct-current resistance. Furthermore, it will be clear that the nearer the turns approach each other (or what is the same thing, the greater the diameter of the wire) the more serious this effect will become. It is, in fact, this "proximity factor" which is the root cause of the increase in high-frequency resistance when the wire diameter is increased beyond the point we have christened the "optimum diameter."

The formula for the calculation of high-frequency resistance of solenoids takes into consideration both the effects we have just discussed, and was originally formulated by S. Butterworth, of the Admiralty Research Laboratory. It may be stated as follows:—

$$R_{HF} = R \left( 1 + F + G \left( \frac{R_{HF}}{2D} \right)^2 \right)$$

Where  $R_{HF}$  is the high-frequency resistance in ohms at the particular frequency involved;  $R$  is the direct current resistance of the winding in ohms,  $n$  is the number of turns;  $d$  is the diameter of the wire in millimetres;  $D$  is the coil diameter in millimetres. To ascertain the values of the factors  $F$  and  $G$ , it is necessary first to solve the subsidiary equation

$$Z = d \frac{\sqrt{f}}{92.8}$$

where  $f$  is the frequency in cycles per second, and  $d$ , as before, the diameter of the wire in millimetres. Having figured out the value of  $Z$ , the values of  $F$  and  $G$  may then simply be read off from the charts reproduced in Figs. 2 and 3.  $K$ , the only remaining factor, is a shape factor depending on the ratio of the length of the winding to its diameter, and may be read directly from Fig. 4.

In case the method of working this formula is not immediately apparent, it is proposed to work out the resistance at 300 metres (or one million cycles per second) of a coil having 74 turns of 3-inch diameter and a winding length of 24-inch (actually the coil used for preparing Fig. 1). We will assume the wire diameter to be 0.565 millimetres, which reference to Fig. 1 indicates to be the optimum diameter.

The direct current resistance of 0.565 m.m. (24 S.W.G.) copper wire may be ascertained from a wire table to be approximately .02145 ohms per ft.; the d.c. resistance of 74 turns 3 inches in diameter will be  $.25 \times 3.1416 \times 74 = 58.1$  feet at .02145 ohms per ft. = 1.24 ohms. So  $R$  is 1.24 ohms. Before finding  $F$  and  $G$  we must know  $Z$ , and this found to be

$$Z = 0.565 \frac{\sqrt{1,000,000}}{92.8} = 6.09$$

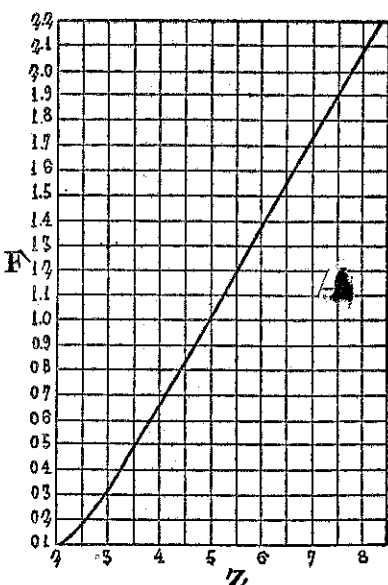


Fig. 2.—Values of "F" corresponding to "Z."

Then from Fig. 2 we find the value of  $F$  corresponding to this value of  $Z$  to be 1.43, from Fig. 3 the value of  $G$  corresponding to a figure of 6.09, for  $Z$  is .948. So  $F$  is 1.43 and  $G$  is .948.

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