Universal, Honeycomb and Lattice Coils In General

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THE sudden wide adoption of the universal winding by radio engineers as standard for inductances, has produced conflict and confusion in the names used in the trade to designate various makes. Technical facts have been ignored in the emphasis laid on "selling points."

There are the following names in use to denote varieties of universally wound coils—"Honeycomb," "unilateral," "duo-lateral," "uni-lattice," "mono-lattice," "bi-lattice," and "multi-lattice." Why all these "names?" Are they necessary? Cannot engineers adopt a "non-partisan" classification of the universally wound coils which are really different in winding layout and electrical properties?

This paper is an attempt to "clear the air." It touches the subject quite fully on the winding and general properties of universal coils. It adopts the terms, "uni-lattice" for "honeycomb" coil, and "bi-lattice" for "duo-lateral" coil. They are both different from "multi-lattice" coils.

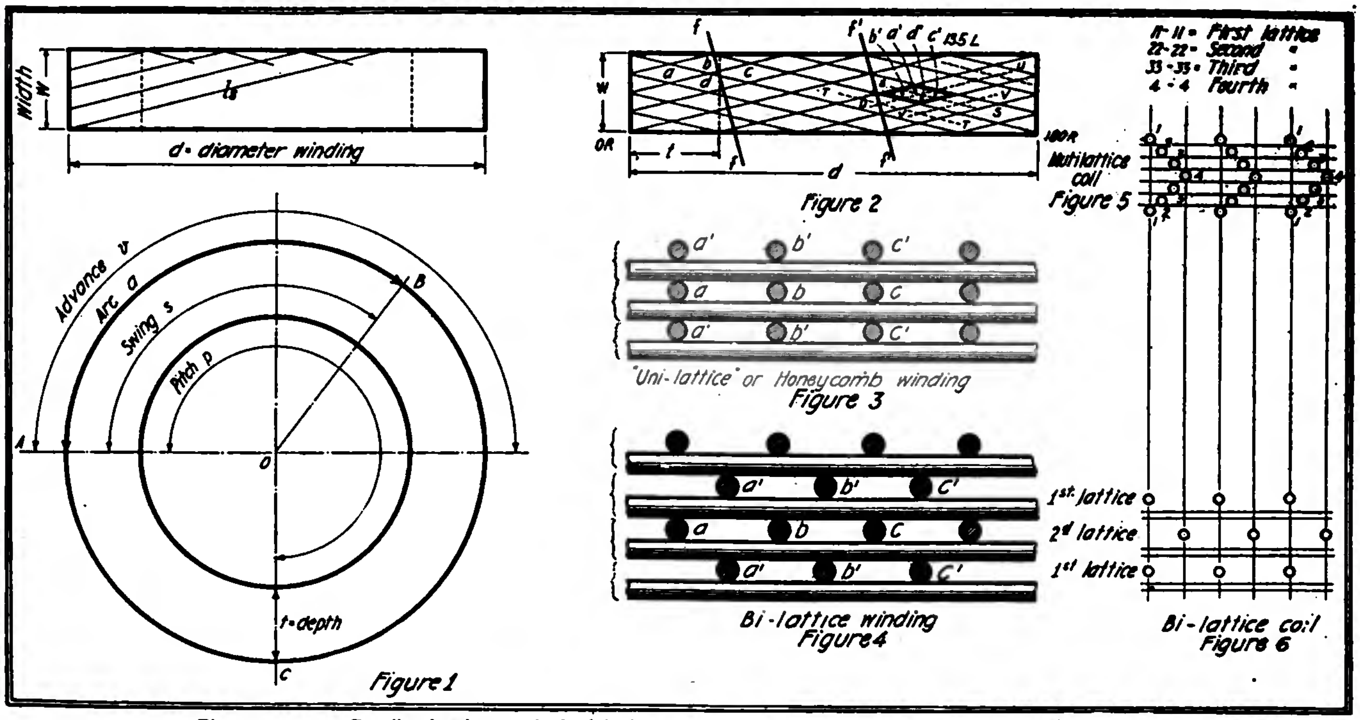
These technical names have an advantage over trade names in that they prevent the physical properties of the different forms from being confused. This has prevented, in several investigations, a great deal of misunderstanding, regarding the differences in their winding schemes.

The following definitions have been tried out by several engineers and have run the gauntlet of general discussion.

All coils wound after the methods used in the machines of the Coto Coil Co. are "universal wound." The average experimenter will not produce a real "honey comb" coil, and still less, a "bi-lattice" coil (these are defined below) by just sticking on a coil frame and winding it up "bobbin-fashion," the way our mothers used to do their sewing machine bobbins. The very thing the experimenter wants—low capacity—will not be obtained to any extent, even at the cost of the extra wire which is needed in all universal windings to obtain a given inductance.

Lattices, with special winding relations, insure a large decrease of distributed capacity. Universal coils, without special winding layouts, do not do this. Bank windings have about the average capacity of the above two classes.

Figure 1 indicates the general method of laying out a lattice winding, and shows the special features which cause a universal coil to have the additional properties of a lattice coil. The general features in figure 1, peculiar to a merely universally wound coil are—first, the "angular swing, S," or simply the "swing" of the wire. This is the angle AOB between the elements of the cylinder, between which the "swing" takes place. Second—the length of the swing or the "linear swing, ls" is the actual length of wire in the swing. Third, the "swing arc" or the "arc," which is the length of the arc denoted by the letter "a." Fourth—the "angular pitch" or the "pitch" which is always twice the swing, e.g. the swing in figure 1 is 135 degrees, and the pitch is therefore 270 degrees. Fifth—the "advance, v," which is the angular distance which some multiple of the pitch first reaches, beyond 360 degrees. The advance in figure 1 is 180 degrees, or the difference between twice 270 degrees and 360 degrees. Sixth—a sparation of wire of h inches. Now the lattice has two additional features, an advance which is an exact submultiple of the pitch and 360 degrees also and a width such that, if m is the above submultiple, the width of the coil w, is $\frac{hm}{2}$ if m is even and $\frac{h(m+1)}{2}$ if m is odd. Hence figure 1 does not represent a lattice coil, strictly speaking.



Figures 1 to 6—Details showing method of laying out winding and views at various stages of the winding

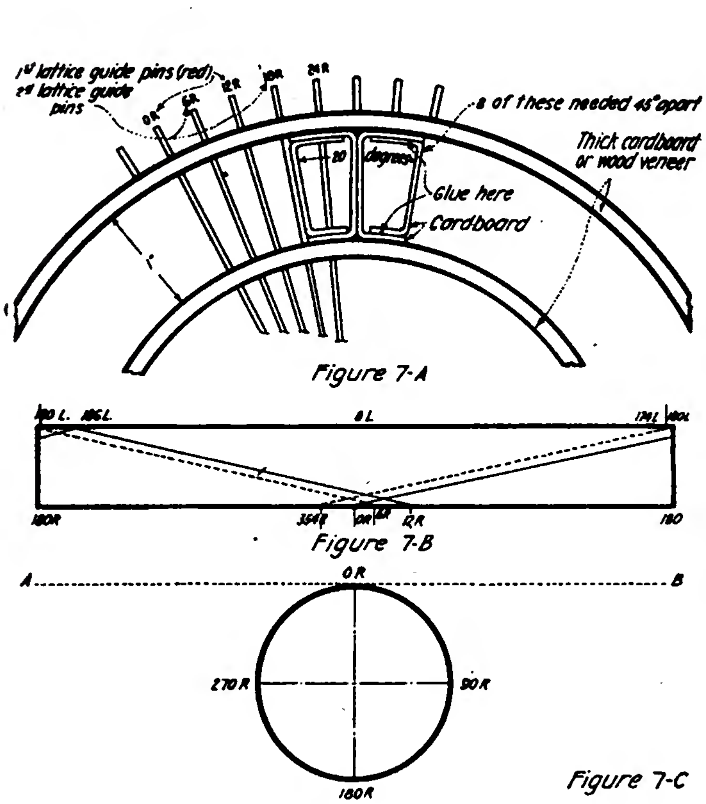
A swing of 82 2/7 degrees, or other odd fraction of a degree is the kind of swing necessary to get a true lattice, in actual computations. A good short rule is this. The advance must divide 360, and the pitch also. If we adopt 1.5 degrees as the advance v = 1.5, we can get along with a pitch of 183 degrees, 186 degrees, etc., since 1.5 goes into 183 degrees, 186 degrees, etc., and 360 degrees exactly.

We now define lattice coils as those universal coils in which the advance is a submultiple of the circumference and the swing. This is limited only by the condition that the advance must be less than one-half the pitch.

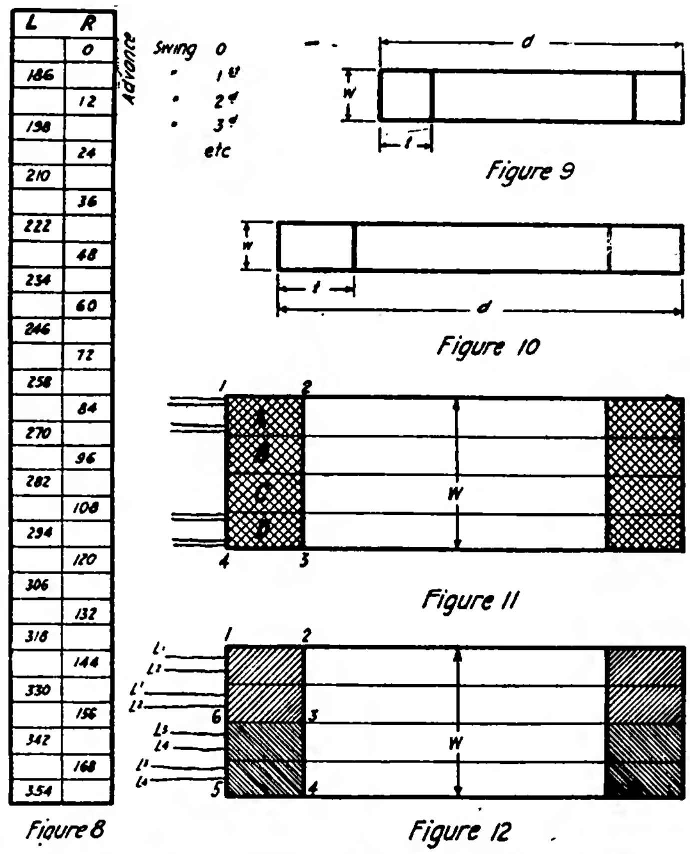
The result of this definition is that all lattice coils end at the same angular point on the circumference at which they start. There is no "creeping" forward of the turns, "stopping up" the radial view through the cells and increasing coil capacity. When the lattice winding has come back to the starting point just once, we have one "layer." This gives us the pattern of a rhombus, or lozenge, which as in the honeycomb coil. Their average self capacity is smaller. In both forms, in fact in all lattice coils, the cells get "flatter" as the coil gets larger, as will be shown later.

Figure 3 shows the cross-section of three wires and three layers of the "uni-lattice" winding taken at f f and figure 4 shows a cross section of three wires and three layers of the "bi-lattice" winding taken at f'f'. The latter is easily seen to possess less distributed capacity than the former—about 15 per cent. less on the average.

It is understood that the second lattice when finished, constitutes a complete separate system of honeycomb cells, whose walls are "staggered" half-way between the cell walls of the first lattice. Since a honeycomb coil is a "uni-lattice" or "mono-lattice" coil, the name "bi-lattice"



Figures 7A, B, C—Constructional details and method of winding bi-lattice coils



Figures 8 to 12—Chart and method of winding multi-lattice coils

resembles a honeycomb cell and suggested the trade name used by many.

All honeycomb coils are lattice coils, but all lattice coils are not honeycomb coils. The bi-lattice coil described below is not a honeycomb coil, but a uni-lattice coil is.

Figure 2 is a lattice coil of external diameter a, and width w. It shows the honeycomb structure at the left and illustrates the "bi-lattice" differences in structure at the right. If we had repeated the first single "layer" of the lattice winding above specified, until a depth t, was reached, we could look down into the four "cells," a, b, c, and d in figure 2, without finding anything to obstruct the vision. The wires forming the walls of the cells are arranged substantially one over the other. They spread slightly as they recede radially from the axis of the coil.

The bi-lattice coil is so wound that every cell of the original four, a, b, c and d, is broken up into four smaller cells a', b', c' and d' by the new wires of the second lattice. These are shown in dotted lines of which four are lettered SS, TT, UU, VV. It is true that we have smaller cells here—honeycomb cells, if you insist—as far as the mere question of looking down through the coil is concerned, but the successive cell wires are not "over" each other, has been given to this other form of winding. Only the alternate layers are started at the same circumferential point.

It was suggested in 1918 to engineers investigating the possibilities of further reducing the self capacity of the honeycomb coil, that by gradually shifting the starting point of the layers forward and then backward, as in figure 5, this self capacity would be reduced. This might be called a "quadri-lattice" coil or "multi-lattice" coil, as the series of lattices is repeated regularly.

However, it is not as good a reducer of capacity for given inductance as the bi-lattice winding, drawn to same scale in figure 6. This has a better selectivity at a given wave length.

Study of Coil Lattices

There are two distinct but related problems to be considered in making a lattice coil:

First, how shall we make the winding repeat every "layer" regularly? The solution of all electrical requirements is based on this purely arithmetical problem, in addition to determining the size and kind of wire and the diameter and width of winding.

Second, what is the best angular pitch to use in a coil of given lattice separation? This is determined by the number of turns and the coil width.

There is no exact analytical or even experimental engineering formula, it may be said, for the inductance of lattice coils. It is safe to recommend Professor Hazeltine's practical coil formula, presented at a meeting of the R. C. A. It is as follows:

This formula, based on Stephan's formula, is accurate to about 3 per cent.

$$L = \frac{.0008\, a^2 N^2}{6a + 9t + 10w} \text{ in milhenries.}$$

where a = mean radius of winding in inches
t = depth of winding in inches
w = width of winding in inches
N = total number of turns

In winding bi-lattice coils, it is not necessary to finish the first layer on one lattice, before starting the first layer of the other. This is especially evident in winding lattice coils by hand.

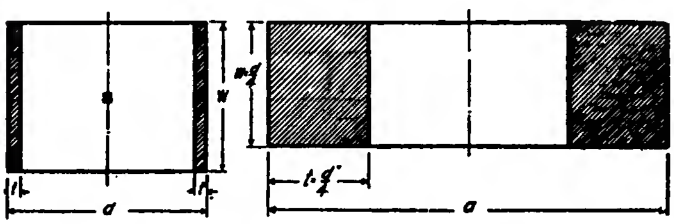


Figure 13 *Figure 14*

Figures 13, 14—Extreme and best ratios

To illustrate, place a double set of, say, red metal pins, No. 50 drill and about 2 inches long—equal in length to twice the coil winding depth—every 12 degrees around the circumference of a cylindrical coil frame, of say, 4 inches diameter and 3½ inches width. Place the holes within ⅛ inch of the faces of the frame. Then arrange another identical set of pins of different surface appearance 6 degrees away circumferentially from the first. Here we have the elements of a bi-lattice coil. We start one coil at OR on red pins only with 186 degrees swing, and another at 6 R, with the other pins only, with 186 degrees swing. Neither of these lattices will conflict, if wound by hand.

The finished coil is a bi-lattice coupler, and in large sizes cannot be surpassed for radio frequency work when used with proper "iron-dust-dielectric" in the lattices of the transformer. Transformers on this principle were tested as early as 1906. Figure 7a gives a sketch of the method. A wooden disk ¼ the width of the coil is used to support the inner cylinder of the winding frame.

In figures 7b and 7c we have a single lattice. In figure 7b it is shown in the form of a single layer, rolled out on the transparent imaginary surface A-OR-B, after being "cut" at 180 in figure 7c. The best way to gain an insight into the law giving the layout of the winding is to examine an actual winding chart to see whether it is practical or not.

Assume a "swing" of 186 degrees; make the "pitch"—which is 372 degrees—always twice the "swing." It happens that this first "pitch" is greater than 360 degrees, and the excess, which is called the "advance" is 12 degrees. The chart shows two things immediately.

First—There is room on this coil for a complete second lattice of the same description starting from the left at OL instead of the right at OR. This can be "hooked up" in series with the previous winding if a coupler is not desired, then we have a regular bi-lattice coil.

Second—The dotted lines in figure 7b are impossible under the above scheme, as winding swings. They cannot be covered by the chart-layout.

The winding chart shown in figure 8 indicates that several separate uni-lattice windings may be wound without in the least interfering with one another. The smaller the wire, the wider the coil and the smaller the "spacing" as shown in figure 4, the greater the number of separate "lattices" which can be wound. It is readily seen how windings started on 2R, 4R, 6R, 8R and 10R will give separate lattices. Thus by using six different double sets of colored pins as winding supports along the "right" and "left" faces of the coil frame, the experimenter may wind a sextuple lattice coil, by winding each lattice only on its own colored pins. The possibilities of various spacings and other winding factors will be treated in the next section.

COIL DIMENSIONS AND WINDING FACTORS

We need to establish general limits within which lattice coil dimensions may be considered to conform to practical experience from mechanical considerations. If a coil form is satisfactory from the above standpoint, it may be left unsupported; as it should be mechanically rigid.

It may keep this rigidity through a large variety of windings, of very different electrical efficiencies, without appreciable mechanical change. In figure 9 we have sketched the kind of coil shown in figure 2 without indicating the lattices formed by the windings. This form gives a ratio

$\frac{d}{w} = 6$ and $\frac{t}{w} = 1$, changing the ratio $\frac{t}{w}$ to 2 and $\frac{d}{w}$ to 10 we obtain figure 10.

Four of these coils, placed close together, coaxially, have a very good time constant if connected in series. We may put this in other words by saying that in this case $\frac{d}{w} = 5$, $\frac{t}{w} = \frac{1}{2}$. Such an equivalent coil is shown in figure 11.

In the light of the "multi-lattice" windings indicated by figure 8, it is interesting to consider the four coils A, B, C and D as wound in a single coil "quadri-lattice" coupler. Every lattice has its pair of separate terminals. By various combinations a range of inductance of 1 to about 36 may be obtained.

A smaller range is obtained by winding the four "coils" of figure 11 as two "bi-lattice" couplers, as shown in figure 12. Each "coupler" with the same area of winding cross-section, 1, 2, 3, 6 or 6, 3, 4, 5 has two sets of terminals, and starts with a lower inductance than figure 11. The first lattice terminals are indicated by L_1L_1, the second lattice by L_2L_2 etc. These changes are really of no effect in determining a change of "swing," "pitch," or "advance," when changing the coil of figure 10 into the multi-lattice coupler coil of figure 11 or the two "bi-lattice" couplers of figure 12. The chart in figure 8 would do for any of them, as the "swing" is independent of the width, within wide limits.

The extreme case is shown in figure 13, where $\frac{d}{w} = 1$.

This is about the limit of $\frac{d}{w}$. The depth of winding is that due to two "layers," and figure 13 could only by courtesy be called a lattice coil.

The best ratios to secure a high time constant are about $\frac{d}{w} = 4$, $\frac{t}{w} = 1$ shown in figure 14.

(To be continued)

Universal, Honeycomb and Lattice Coils

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(*Continued from July* WIRELESS AGE)

It is intended in each instalment to "overlap" slightly in regard to the reiteration of basic lattice winding principles involved in order to save the reader the trouble of referring in detail to the previous instalment where these fundamental laws of lattice winding are introduced. As these laws have hitherto been unpublished it is believed that a good educational purpose will be served.—*Editor.*

RESUMÉ OF FIRST INSTALMENT

Unsystematic practices in vogue in naming various universal wound coils noted.

Classification of universal, and lattice coils.

Methods of hand-winding.

Typical winding chart for a step-lattice coil.

General shape factors indicated.

Multi-lattice coils with one or several wires, and use in wavemeters or direction-finder loops.

Laws of lattice pattern-formation.

General approximate inductance formula.

High frequency lattice transformers with ferro-dust dielectric cores.

SYNOPSIS OF SECOND INSTALMENT

Development of lattice layer on a plane, to show true value of "swing-angle," G.

Simple analysis of relations thus exhibited.

First working formulas shown, giving, K the "cross-step" or simply "step" and swing-angle, G and their general connection with tuning efficiency, P of the coil,

where $P = \frac{1}{R}\sqrt{\frac{L}{C}}$.

Change of swing-angle with diameter illustrated.

Effect of same on properties of lattice "cells."

Distribution of L, C and R as effected at different layers, by this factor.

Suggestions for conditions of tests to secure better average checks on coil constants.

Effect of wire thickness on properties of coil.

Cross-spiral (or simply "spiral") lattices and their general relations to cross-step lattices.

Peculiarities of lattice coils in relation to derivation of design formulas.

Effect of swing-angle G on lattice-coil tuning efficiency, qualitatively considered.

Method of converting single wire uni-lattice into single wire multi-lattice coils.

General method of designing multi-lattice coils approached.

There is a certain angle, the "swing angle," made by the winding "cross-step" with either circumference of the cylinder faces. It directs the winding zig-zag and experience indicates should not be more than 30°. In figure 15 this is discussed in detail.

To the left in figure 15 we have a coil frame, with a wire "swinging" or "stepping" from O at the "right" of the frame to S at the "left." Let the plane XOY be tangent to the cylindrical frame along the element NO. If we draw OY in this plane at right angles to NO, it will be tangent to the circular face OVB. Let the line OR in the plane XOY represent the wire at a "swing angle" equal to G. Then if the wire OR and the plane is allowed to roll on to the cylinder clockwise, with the line OY always touching OVB, the winding OR will lay on the helical line OS, and will have a "swing angle" of G degrees.

To make the matter still clearer, look at it from another point of view. Suppose that the cylinder NOVB were turned with its ends reversed and then rolled clockwise along the line BO^1Y^1 to the right. If we "inked in" the lines on the plane XOY they would all print themselves on the plane $X^1O^1Y^1$, in their exact relations at the left and we would see why the angle G of the "swing" is the same from point O to point S on the winding. Of course X^1O^1 and Y^1O^1 are perpendicular. NS is the "angular" swing, NO is the width W, and O^1S^1 may be called the "cross-step" instead of "linear swing," for accuracy and brevity.

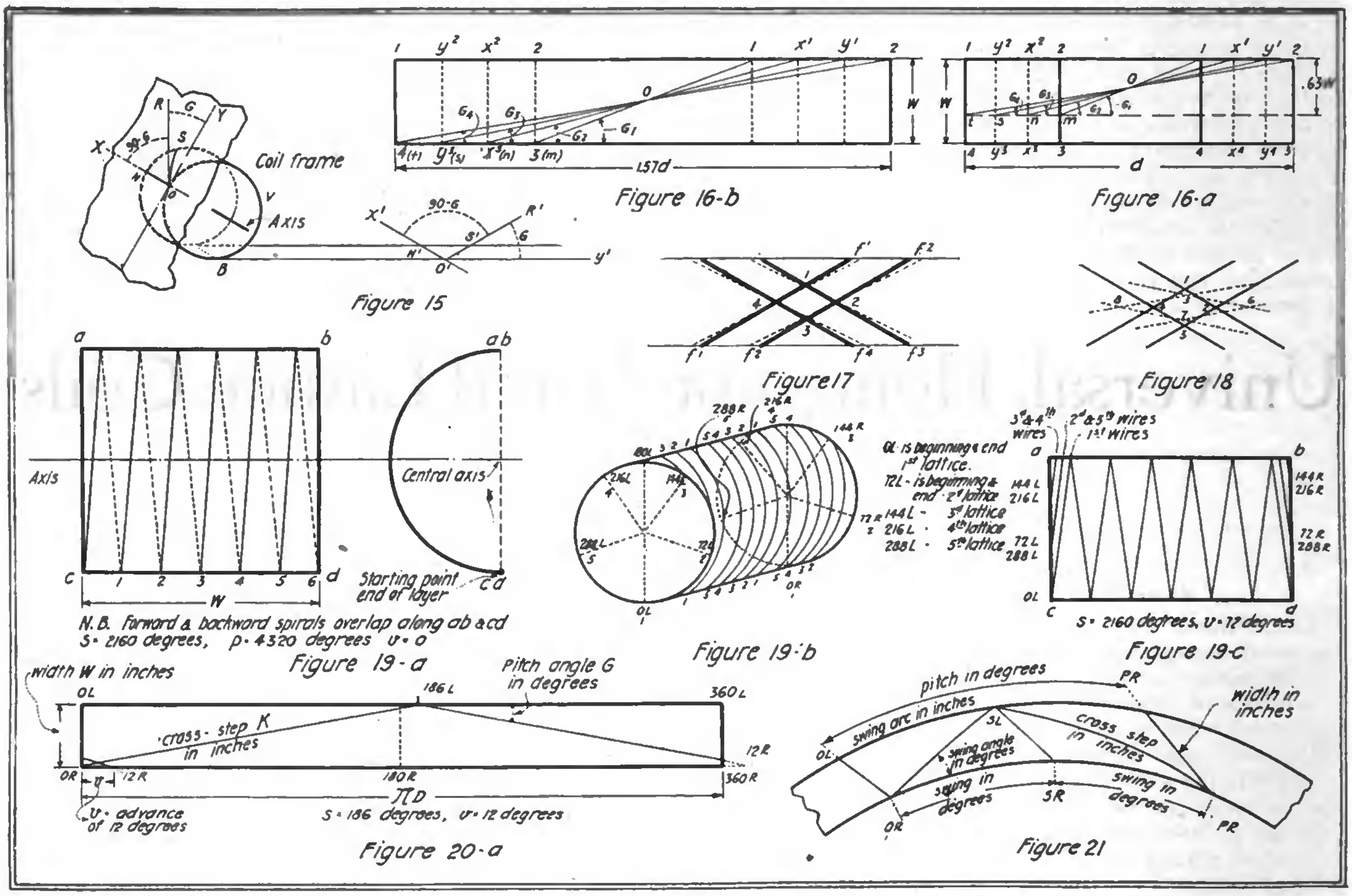
The actual "helical" or "screw" pitch in linear measure is the axial distance along the cylinder traveled during one turn of the winding, like that of any helix, but cannot be greater than W the width of the coil, hence the latter is assumed given and the swing angle calculated from the following two simple relations.

First: $K = \frac{Rds}{360}$

Where K = length of swing—O^1S^1 in figure 15—and therefore equals the "cross-step" or "step" "K."

s = angular swing, in degrees.

d = diameter of winding at a given layer. (N.B. We do not say "diameter of frame.")



Figures 15 to 21—Diagrammatic details of coils showing dimensions, method of winding, angle of pitch and general design principles

Second: $G = \sin^{-1} \frac{W}{K}$ which means that "G in the angle whose sine is $\frac{W}{K}$" and any book of trigonometric tables gives us G as soon as we know W and K. G must be less than 30 degrees. You ask—"why?"

First—It saves wire.

Second—It raises the selective power or tuning efficiency P of the coil, thus cutting down the damping; since

$$P = \frac{1}{R} \sqrt{\frac{L}{C}}$$

From purely manufacturing considerations it is not common practice to build a "step-lattice" coil with the "swing" much greater than 180 degrees.

The sine of $60° = \frac{1}{2}$, hence $\frac{W}{K}$ must be generally less than $\frac{1}{2}$ or W is less than $\frac{K}{2}$. In the best lattice coils its average value is less than $\frac{K}{6}$. This is shown in figure 16a, where cross-steps K, of constant angle (S) but varying length, are laid out.

Figure 16a is a plane section of a lattice coil. The diameters of four "layers" are indicated by pairs of lines, at left and right. The exact properties of lattice "layers" will be given later. The four lines at the left are 2-3, X_2-X_3, Y_2-Y_3 and 1-4. The winding cross-section at right and left is 1234. If we take .63—the ratio of the diameter of any layer to its semi-circumference—of the width W, and lay out the swing-angles G_1, G_2, G_3 and G_4 by joining m, n, s and t at the left to 1, X_1, Y_1 and 2 at the right, we will find these angles are accurate. Figure 16b proves this; as it is nothing more than figure 16a with the various layers rolled out or "developed" on a plane. The lettering is kept similar to that of figure 16a. The "similar" angles G_1, G_2, etc., in both sketches are exactly equal.

These two figures show that the cell walls of lattice coils slowly change direction as the coil grows in diameter, somewhat like the pitch of a propeller blade. This means that there is a slight mechanical loss of rigidity in lattice "cells" whose linear dimensions are large and flattened as in figure 17a, especially when used with a small diameter of wire.

The wire f_1f_1 is called the "cross-step," and the swing angle G which it makes with the face of the coil, changes as shown in figures 16a and 16b, so that the cell-walls do not receive the support of the "steps" except at a fraction of their length. The dotted lines show the next outer set of "steps." This is shown, greatly exaggerated, in figure 18, where 1, 2, 3, 4 is a cell in one layer and 5, 6, 7, 8 is a cell on the next outer layer. Here is the real "secret" of the lattice coil. The greater the difference between the swing angles of successive layers, the smaller the distributed capacity of the coil, and the more economical it is of wire; since when G is small the time-constant is good. This change is slower near the outer layers, where, however, the effective radial capacity per unit length of coil is also smaller, for electrical reasons.

Since G becomes smaller as the coil diameter increases the inner layers are relatively inefficient in producing a good time-constant. Therefore it is not a fair test to use the whole coil to get the selectivity or tuning power P, which is measured by $\frac{1}{Ro}\sqrt{\frac{Lo}{Co}}$ where Ro, Co and Lo are the radio frequency resistance, capacity and inductances respectively. The whole coil shows up too well!

If the winding were stopped at half the total "layers" to be wound, or else a "tap" taken there, a test for Lo, Co and Ro to represent the uncompleted coil would give a more just average result. The former method is preferable on account of capacity dead-end effects present in the latter method.

It is important to remember that, the thicker the wire, the greater the change of swing-angle with a given change in number of circuits of winding and the less the distributed capacity always provided the spacing between "cell-walls" centers is kept equal to a constant multiple, say 3, of the diameter of wire. Otherwise, these wires of increased diameter in themselves have greater capacity and will neutralize a large part of the above advantage.

SPIRAL LATTICES

It has been stated that for mechanical reasons "swings" or "steps" of more than 186° as given in figure 8 are usually avoided, except when the coil has a ratio of $\frac{d}{W}$ like figure 13 or else is small in diameter.

In these circumstances we may save wire and utilize the rapid change swing-angle G for small diameters—figures 17 and 18—by making the swing angle so small that many turns will be completed before the winding makes one swing. In this case we have a "cross-spiral"—instead of a "cross-step"—when the winding returns with 720° pitch, i.e. two turns or more to the starting point, or just beyond it, making a uni-lattice pattern if the pitch is exactly two turns, i.e. the winding starts a second layer at the original starting point. See figure 19a.

Now if the advance is an exact submultiple of 360° we have, a bi-lattice spiral for an advance of 180°, a tri-lattice spiral for 120° advance and an N-fold lattice spiral if the advance is $\frac{360}{N}$.

A penta-lattice spiral is shown in figure 19b with advance v equal to 72°. We could wind this as a five-wire uni-lattice spiral by starting separate wires at 0°, 72°, 144°, 216° and 288°. By choosing the turns in each lattice we can design an excellent unit for replacing five separate wavemeter coils.

In figure 19b we have the conditions in figure 19a modified to show five separate windings, giving as many lattices, each lattice formed from a cross-spiral. Colloquially we abbreviate "cross-step" and "cross-spiral" into "step" and "spiral" respectively. This spiral lattice or rather "five-spiral lattice" is shown in the forward swing of its first "layer," but for simplicity it is drawn in isometric projection and as though its wires each has only two instead of six complete turns or 2160° to a swing. The left face, nearest the reader, is lettered OL-72L etc., to show the starting points of the first to the fifth wires, as indicated on the top and bottom cylindrical elements 180L-180R,-OL,OR, by the series of numbers 321,54321,54, and 1543215432 respectively.

In figure 19c we get a side view of figure 19b showing, however, the twelve turns made by the first wire on the pitch of 4320°, the forward and backward spirals crossing at the starting element and 180° away. A five-wire spiral-lattice with 10 terminals is the result, although only the beginning and ending of the second, third, fourth and fifth spirals are here indicated.

We have to note, in figure 19a, that $\frac{d}{W} = 1.00$ and the angle G is too small here, to exhibit much change as the new layers are added. The layout of figure 19a is satisfactory, provided the "axial" or "helical" pitch 1-2, 2-3 etc., is at least thrice the diameter of the wire used.

The winding starts at OL—calling OL, OR the zero or starting element—and ends on OR. It immediately returns on the back swing of six turns (not shown) with a total "angular pitch" of 4320°, or twelve turns, to its starting point OL, and therefore, has no spiral "advance," or "step-advance," as shown in figure 1 or in winding-chart figure 8. The layers simply repeat from OL; as no "advance" of any kind is necessary for such a coil, which is therefore of the uni-lattice spiral type.

There is nothing to prevent efficient multiple-wound spiral lattices being used for couplers or wavemeters, etc.

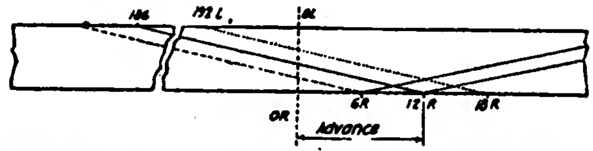


Figure 20b—A uni-lattice coil with swing 186° and advance 12°

There is a positive advantage in it, up to four separate lattices, as the change in G for separate layers of the same lattice is greater, making the cell shape more efficient. These corresponding "layers" for any particular lattice would really be four layers apart radially, and would have their distributed capacity correspondingly reduced, without reducing the inductance too much.

It is perfectly practicable to have these "intermediate" wire layers—in this case, 3 layers—replaced by an insulating lattice of moisture-proof hard cord. Such insulating lattices have been used in the past for different purposes. In regard to the mechanics of the thing, it is a fact that in one case, a coil of about four feet diameter was successfully wound out of small diameter rope. Furthermore, the use of large multi-lattice coils of bare and insulated wire for direction-finder loops is today being looked into, as a promising variation both mechanically and electrically.

WINDING PECULIARITIES OF LATTICES, IN RELATION TO DERIVATION OF FORMULAS

There are several unobtrusive points about lattice coils which must be constantly kept in mind.

First: There is no "bedding" of wires at one level in the hollow or trough formed by the two adjacent wires underneath on the lower level. This is shown in the first diagram of this article.

Second: The question "what is a lattice winding level?" is answerable only by accepting a convention. The position of the wires in a "level" is only the same at certain repeated elements of the cylinder constituting the winding. The positions of wires in each level in a "layer" alternate from side to side and the levels themselves have their wires transposed radially in a peculiar way as one mentally passes a plane through the axis and rotates it while examining the winding.

Third: There are small or large projecting bands to be allowed for in calculations of length. These do not occur noticeably in form-wound coils, but lattice coils are not only form-wound, but when constructed of coarse wire with large diameter and few turns, they may be with advantage wound by hand and may purposely have as much as 2.5 per cent of wire added to aid in "tapping" the coil at the wire "bends"—say at a two-inch length of arc projecting from the face of the coil.

Fourth: The length of the wire in a lattice coil is based on the turns per "double level" or "layer," which is the design-unit. It is not convenient to use the "turns per level." This will be shown as being due to the alternate changing of upper to lower levels and vice versa which is illustrated graphically further on in this article.

Turning back to figure 20a we have the elements of the above peculiarities simplified. The perfectly practical winding-plan of figure 8 is given in sketch form. The symbols of figure 1 are applied, with a swing (s) of 186 degrees and an advance (v) of 12 degrees. The development shown in principle in figure 15 is used in figure 20a and the length, say, OL-360L represents the length of the circumference. The swing angle (G) depends, of course, with given cross-step K, on the width of the coil in a "step lattice" winding. In a spiral lattice winding it also depends on the axial width, or rather in this case, the axial length of the coil frame, provided the "cross-spiral" is constant in length. The term "cross-step" or simply "step" for ordinary use, is so much more convenient than the descriptive term "linear swing" (ls) that no excuse is needed for dropping the latter, except as a purely descriptive term. The length of a series of steps is that of a helix of the same angular development. This is obvious if we imagine all the odd or even steps, turned symmetrically to themselves and fitted to the other set, arranged as parts of a broken helix on the coil cylinder considered as extended. The result is a perfect helix, which we treat under the popular generic name of "spiral."

Since the advance v, travels forward by its own length during a certain number of applications of the pitch to the circumference, it must itself be contained in the pitch an exact number of times. Therefore, when the pitch is traveled over once by the advance we have a pattern or a complete lattice "layer." By "slipping" back the starting point when the "pitch" has gone beyond 360° as shown in figure 20b, we form a bi-lattice.

A uni-lattice coil with swing 186° (therefore pitch 372°) and advance 12 degrees, is shown in figure 20b in the full lines. If the swing 186L-12R is "slipped" back to 6R, losing 6 degrees or half the advance, it will come around again, arriving at, say, the swing, 192L-18R, if continued, giving the beginning of a bi-lattice pattern. To continue this bi-lattice, however, this again is slipped back 6 degrees to 12R and the next "circuit," which is defined as a revolution of the winding around the coil frame, starts at 12R, as it would have done originally, with a uni-lattice winding. Here we have the single wire bi-lattice winding. If we started a separate duplicate uni-lattice winding at 6R, and kept it separate, we would have a double or two-wire bi-lattice coil.

In figure 21 we have a value of s of about 30°. We are purposely showing the coil as wide enough to give a swing angle of 35°—an excessive amount. About 10° is good practice for coils about five inches external diameter. This figure also shows the winding surface more in detail than does figure 1.

Synopsis of Third Instalment—September

1 Laws governing width of coils in terms of "pitch" and "advance," Charts for layout of two types, "odd" and "even" lattices. 2—General relations involving "levels" and "layers" in lattice coils. 3—General properties of lattices in regards to shifting and transposition of wires. 4—Studies in "radial" and "axial" transposition with resultant "banking" of wires and "levels." 5—Detailed graphical analysis of above. 6—Handwinding and tapping of lattices with allowances for same. 7—Changes of swing-angle as related to diameter of wire. 8—Classification of results in preparation for examination of design-factors and formulas. 9—Tabulation of symbols, design-factors and formulas. 10—Selection of 12 coil-problems for mechanical design and comparison of windings. 11—Discussion of same. 12—Solutions of problems. 13—Lines of design development indicated for cross-step lattice coils. 14—Comparison of "cross-step" and "cross-spiral" design factors in lattice coils. 15—Conclusion of analysis and illustration of flexibility of lattice coil nomenclature suggested in this article. 16—Concluding remarks on etymology of nomenclature vs. practical utility in description and specification.