March 6, 1951 W. F. SANDS 2,543,940

HIGH-FREQUENCY STRAP-WOUND COILS

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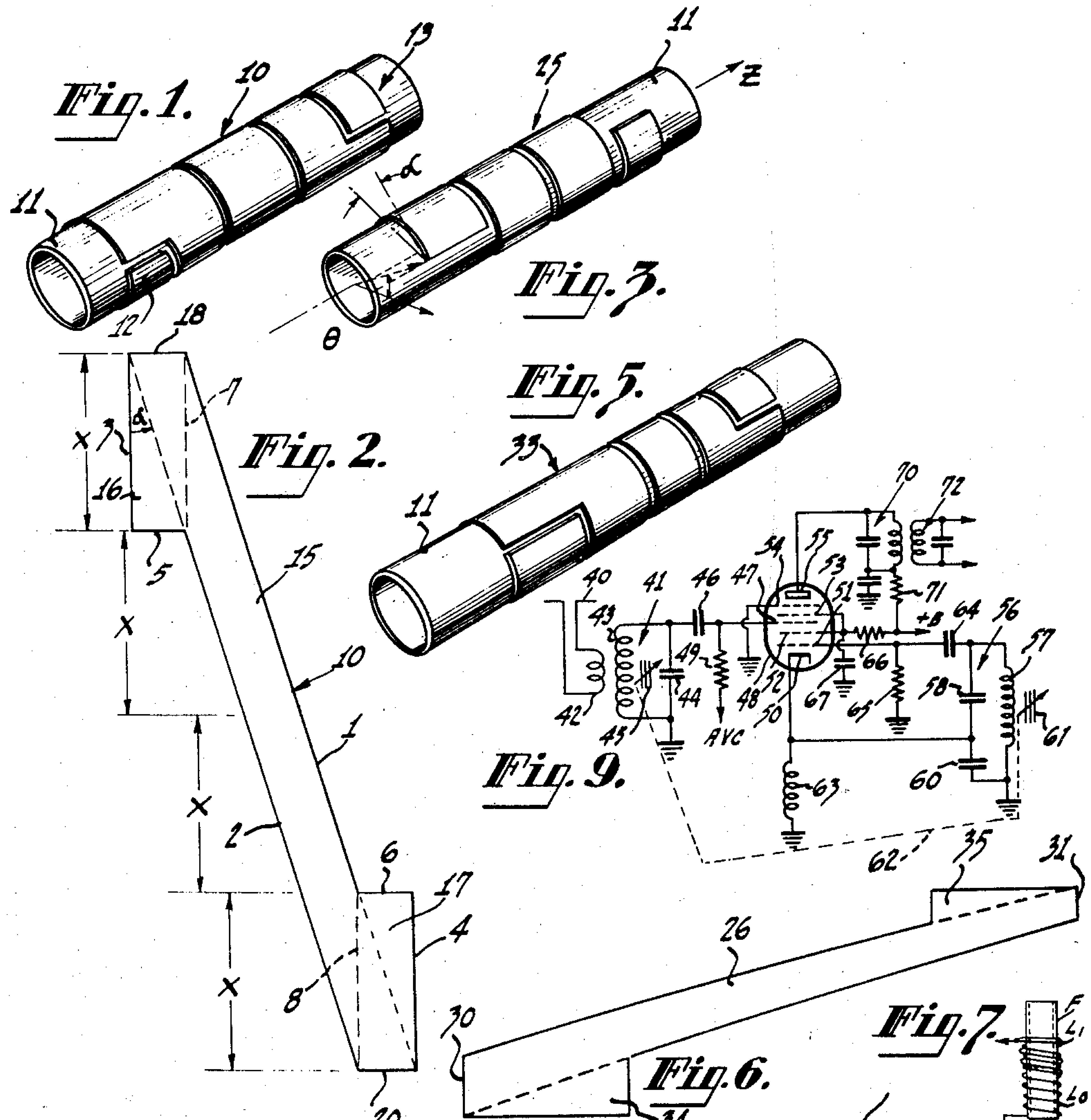

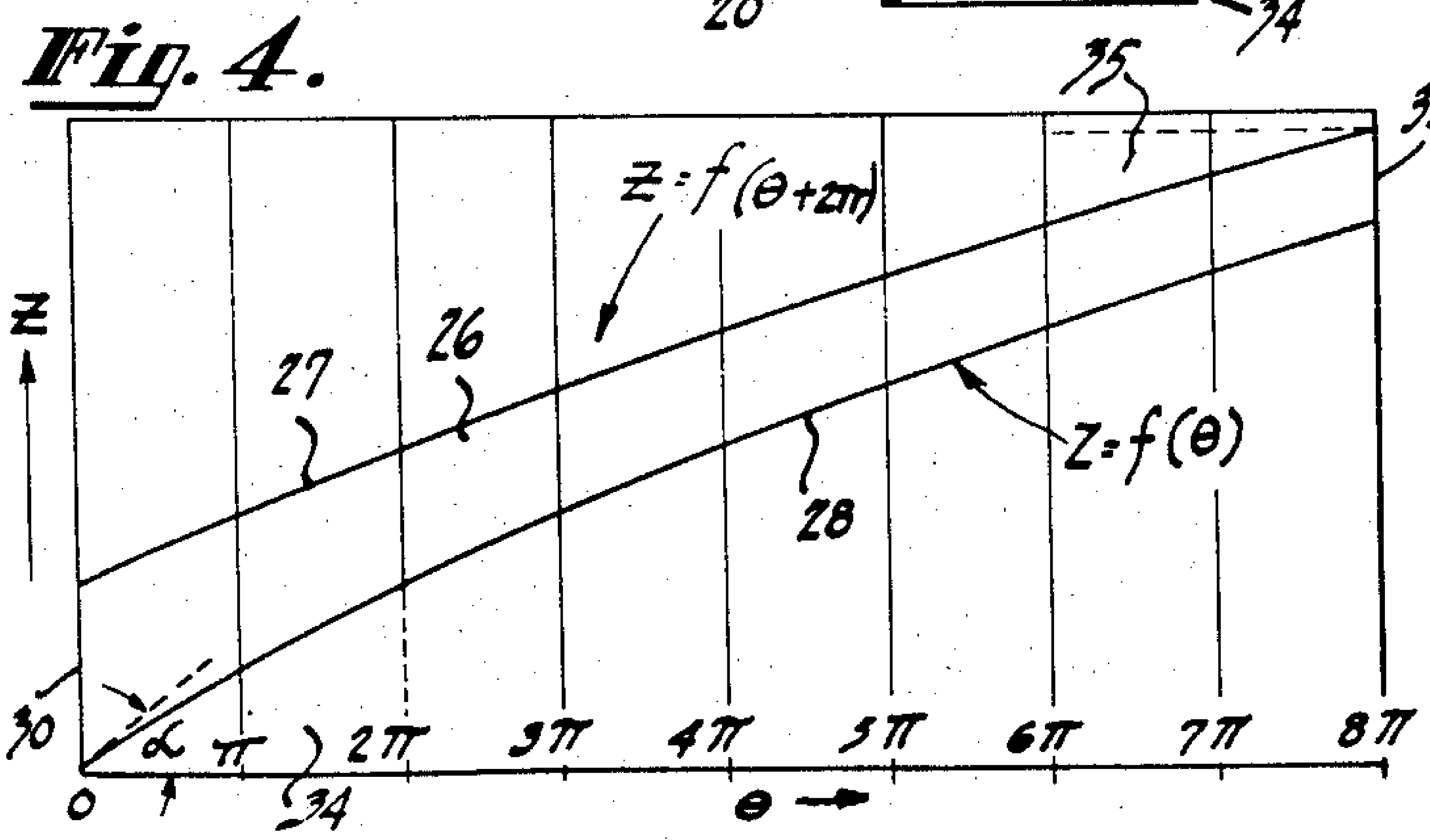

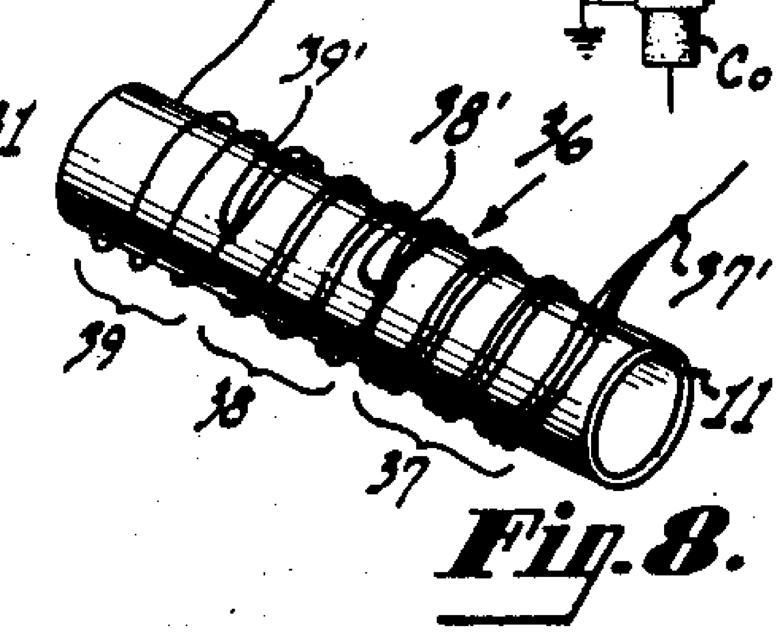

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HIGH-FREQUENCY STRAP-WOUND COILS

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7 Claims. (Cl. 175—359)

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This invention relates to high frequency inductance elements, and particularly to coils wound with a single layer of wire or a flat strap of conducting material which are to be tuned through an extended frequency range by a movable core. This application is related to a portion of my copending application filed on June 28, 1943, Serial No. 492,506, and entitled "Permeability Tuning System," now Patent No. 2,486,986.

An inductance element for use in high frequency resonant circuits must be made with a comparatively small inductance. A high frequency inductance coil accordingly usually consists of a few turns of a conductor such as a wire. It is frequently desired to tune a circuit over a high frequency range by moving a core relatively to the inductance coil of the circuit. In that case, the coil is usually wound with a few turns of wire which are spaced very widely. Accordingly, the intensity of the magnetic field developed when current flows through such a coil is not uniform along the length of the coil. However, in order to vary the inductance of a high frequency coil in a continuous manner by a movable core, a magnetic field is very desirable which is substantially continuous, that is, it does not have appreciable discontinuities.

Inductance elements are known which consist of a strap of conducting material flat-wound in the shape of a helix. Such an inductance element may have a comparatively uniform current sheet. A current sheet is defined by F. W. Grover in his book "Inductance Calculations" published in 1946 by D. Van Nostrand Co., Inc., New York, for example, on pages 15 and 142, as a winding where the current flows around the axis of a cylinder in a very thin layer on the surface of the cylinder. Such previously known strap-wound coils, however, did not have closed end turns, that is, the free end of the coil strap extends for the width of the strap beyond the last turn. It is obvious that only that portion of the coil may be used for tuning it which has a uniform current sheet and that excludes the end portion of the coil. Movement of a core within the end portions of the coil will not vary its inductance as effectively as a corresponding movement of the core in the center of the coil. Consequently, for a given length of coil, the frequency through which it can be tuned is diminished by the existence of a discontinuity of the current sheet. Thus, the previously known strap wound coils can not be tuned by a movable core over the wide tuning range frequency required. In some cases, inductance coils are needed, having a variable pitch

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and being arranged to form a dense current sheet. Such coils were not available heretofore.

It is the principal object of the present invention, therefore, to provide novel strap-wound inductance elements suitable particularly for use in high frequency tunable resonant circuits, and straps of conducting material for such elements.

Another object of the invention is to provide novel, high frequency coils wound with a strap or with a single layer of wire forming part of a resonant circuit, and which may be tuned by a movable core through a larger frequency range than was possible heretofore.

A further object of the invention is to provide strap-wound coils with uniform or non-uniform pitch which may be used in a superheterodyne radio receiver for the purpose of providing a constant frequency difference between the continuously variable resonant frequencies of two resonant circuits, the circuits being tuned by moving a core relatively to an associated strap-wound coil.

Still another object of the invention is to provide, in a superheterodyne radio receiver, an improved variable tuning system having movable cores for causing the oscillator and signal input circuits to track accurately one with the other at a multiplicity of points throughout a predetermined frequency range.

In accordance with the present invention, there is provided a high frequency inductance element consisting of a strap of conducting material arranged in helical shape and having closed end turns extending between two spaced planes arranged at right angles to the longitudinal axis of the element. In this manner it is possible to form a uniform dense current sheet extending between the two planes. The inductance element or coil may be wound as a helix having a uniform pitch, or having a non-uniform pitch, such as a helix with a uniformly varying pitch. Thus, the coil may consist of a winding of uniform thickness and variable width.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The operation itself, however, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawing, in which:

Fig. 1 is a view in perspective of an inductance element wound in the shape of a helix with uniform pitch and embodying the present invention;

Fig. 2 is a developed view of the strap of which the inductance element of Fig. 1 is formed;

Fig. 3 is a view in perspective of a modified inductance coil in accordance with the invention, having a uniformly varying pitch;

Fig. 4 is a graph illustrating the manner in which the strap of which the coil of Fig. 3 consists may be designed;

Fig. 5 is a view in perspective of another embodiment of the invention, consisting of a helically wound coil with uniformly varying pitch and closed end turns;

Fig. 6 is a developed view of the strap of the coil of Fig. 5;

Fig. 7 illustrates a modified inductance coil in accordance with the present invention;

Fig. 8 is a view in perspective of an inductance coil consisting of a trifilar, a bifilar and a single wire section to provide windings of varying width; and

Fig. 9 is a circuit diagram of a portion of a superheterodyne receiver including a pre-tuner and frequency converter wherein the inductance elements of Figs. 1 and 5 may be used.

Referring now to the drawing, and particularly to Figs. 1 and 2, there is illustrated a strap-wound coil 10, which may be wound on a coil form 11 of suitable insulating material such as Bakelite. Coil form 11 preferably is in the shape of a cylinder, as illustrated. Coil 10 may of course be made self-supporting in which case coil form 11 may be omitted.

Coil 10 consists of a strap or sheet of conducting material such as copper or silver, and is wound in helical shape and provided with two right cylindrical end turns illustrated at 12 and 13. Coil form 11 need not necessarily be of circular cross-section, but may have instead a square or rectangular cross-section. In that case a helical coil 10 is obtained having a non-circular cross-section. Coil 10 is wound with a uniform pitch, and a suitable gap is provided between adjacent turns so as not to short-circuit the windings of the coil. Alternatively, the conducting strap obtained may be suitably insulated, for example, by covering the strap with lacquer, and in that case the strap may be wound without a gap.

The strap of which inductance coil 10 is formed is shaped as illustrated in Fig. 2 and consists of a main portion 15 and two end portions 16 and 17. The main portion 15 has two flared parallel edges 1 and 2 forming an angle α with the vertical edge 3 of end portion 16, where α is the pitch angle of the coil. End portions 16 and 17 are of triangular shape having their apices adjacent to straight horizontal edges 18 and 20 of the strap. End portions 16, 17 have vertical edges 3, 4 and horizontal edges 5, 6. The length of vertical edge 3 or 4 is determined by the circumference of coil form 11, which is the circumference of the coil. The width of straight edges 18 and 20, which is the width of main portion 15, is determined by the distance between the centers of two adjacent windings or turns of coil 10. The total distance between straight edges 18 and 20 is given by the desired number of turns of the coil and the coil diameter. The strap illustrated in Fig. 2 may be wound into a coil having four complete turns, for example, so that the distance between edges 18 and 20 does not exceed $4x$, as illustrated.

The strap of Fig. 2 may also be considered as consisting of a main portion bounded by straight edges 1, 2 and by vertical edges 7 and 8 shown in dotted lines. In that case, end portions 16 and 17 consist of rectangles which are bounded by straight edges 18, 3, 5 and 7 and by edges 6, 8, 20 and 4, respectively.

When coil 10 is wound with an insulating gap between the individual windings as illustrated in Fig. 1, it will be necessary to remove a small strip from the strap of Fig. 2 along edges 18, 1 and 6. Alternatively, a small strip may be removed along edges 5, 2 and 20. The portion removed from the strap should correspond to the desired width of the insulating gap of coil 10.

Strap-wound coil 10 accordingly permits the formation of a uniform dense current sheet between the two planes between which the coil extends. This means that the current flowing through coil 10 is of substantially uniform density between the two planes and thereby produces a uniform magnetic field. In view of its closed end turns, inductance coil 10 may be tuned by a movable core over a larger frequency range in a manner to be presently explained. The coil preferably is used in the high frequency range between approximately 30 and 300 megacycles.

Inductance coil 10 may with its inherent distributed capacitance, or a connected shunt condenser form a resonant circuit which may be tuned in various ways. Thus, it is feasible to move a paramagnetic core within coil form 11 to effect permeability tuning of the coil. A paramagnetic material is defined as a material having a magnetic permeability greater than that of a vacuum, which is unity. The magnetic permeability of a paramagnetic material may be independent of the magnetizing force or it may vary with the magnetizing force, in which case the material is usually called ferromagnetic.

It is furthermore feasible to tune the resonant circuit including inductance coil 10 by moving within coil form 11 a core which may consist of a high conductivity non-magnetic metal such as copper, brass, aluminum or silver. In this manner eddy current tuning of the coil 10 may be effected. Finally, it is feasible to move within coil form 11 a core which consists of a material having a high dielectric constant. Certain ceramic materials are suitable for this purpose, such as barium, strontium or calcium titanates having a dielectric constant larger than 1000. In this manner the capacitance existing between the core and the windings of coil 10 may be varied, thereby to provide dielectric tuning of the coil. These three types of tuning may generically be termed "core tuning."

It is to be understood that coil 10 need not be wound from the strap illustrated in Fig. 2, but the conductor may be applied to coil form 11 by electrolytically depositing a conducting material on the coil form or by spraying or printing the conducting material, or other well known methods, to obtain coil 10. A method of obtaining a printed inductance has been disclosed by Ryder in Patent No. 1,837,678. By following the teachings of Schoop, 1,256,589, an inductor may be obtained by spraying metal on a coil form.

Referring now to Fig. 3, there is illustrated an inductance coil 25 consisting of a specially shaped strap of considerable tapered width and having flared end turns. The strap may therefore be wound in helical form with a uniformly varying pitch. Coil 25 may be wound on a cylindrical coil form 11. For some purposes it is desirable to have an inductance coil with a non-uniform pitch. A coil of this type may be used with advantage for obtaining tracking in a superheterodyne receiver. If the coil is wound from a strap of non-insulated conducting material, it is, of course, important that the strap be formed in such a manner that there is an insulating gap between successive windings or turns thereof.

Referring now to Fig. 4, a curve is illustrated which may be employed in determining the shape of strap 26 which may then be utilized for winding coil 25. The outline of the edges of strap 26 may be determined by the formula $Z=f(\theta)$, where $f(\theta)$ is determined by the desired variation of the pitch angle. As shown in Fig. 4, Z is the ordinate and θ the abscissa which equals the angle from the beginning of the winding of coil 25 to a given point on strap 26 as illustrated in Fig. 3.

Let it be assumed that it is desired to wind coil 25 with a uniformly varying pitch, where the second derivative of $f(\theta)$ becomes a constant. Accordingly, let

$$Z=a\theta^2+b\theta+c$$

which is the formula of a parabola. For

$$\theta=0$$

$$Z=Z_0$$

and, accordingly,

$$Z_0=c$$

In Fig. 4, c has been made equal to 0.

The value of the constants a and b may be determined in the following way:

$$\frac{dZ}{d\theta}=2a\theta+b$$

and

$$\frac{dZ_0}{d\theta}=b$$

Therefore, $b=\tan \alpha$, where α is the pitch angle at the point Z_0 as shown in Figs. 3 and 4. Finally, by differentiating Z again, we obtain

$$\frac{d^2Z}{d\theta^2}=2a$$

where a is the acceleration of the pitch which, of course, must be constant for all values of Z for a parabola.

The upper edge 27 of strap 26 is obtained by the formula

$$Z=f(\theta+2\pi)$$

while the lower edge 28 of strap 26 is obtained by the formula

$$Z=f(\theta)$$

Thus, the upper edge 27 has the same curvature as the lower edge 28, but is displaced by 2π, or a full winding, from that of the lower edge 28. Strap 26 is terminated by two straight edges 30 and 31 which extend parallel to the $Z=0$ axis, edge 30 coinciding with the $Z=0$ axis while edge 31 is spaced from edge 30 a distance corresponding to the desired number of turns of coil 25, which equals four in Fig. 4. The length of edges 30 and 31 is determined by the width of the first and last turns, respectively, of coil 25. The abscissa distance 2π corresponds to the circumference of the helix, that is, of coil 25.

It will be understood that strap 15 may also be developed according to the formula $Z=f(\theta)$. In that case, $Z=b\theta+c$, which is the equation of a straight line, where b and c have the values given hereinbefore. Thus, b again equals tan α and, because the pitch is uniform, the angle α is the same for the entire strap.

It will be observed that coil 25 does not have closed end turns. It has already been pointed out that it is very desirable to provide a strap-wound coil having closed end turns so as to permit the formation of a uniform dense current sheet. Such a coil is illustrated in Figs. 5 and 6. Coil 33 may again be wound on a cylindrical coil form 11 and the developed strap, shown in Fig. 6, may have a main portion 26 corresponding to the strap of Fig. 4. In order to provide the closed end turns, strap 26 is provided with two substantially triangular end portions 34 and 35, each having an edge parallel to edges 30 and 31 and another edge extending at right angles thereto. The length of each triangle 34 and 35 is determined by the circumference of coil form 11, while the height or width of each triangular portion 34, 35 is determined by the width of the windings at the beginning or end of coil 33. Since coil 33 has a non-uniform pitch, that is, a uniformly varying pitch, the height of triangular portions 34 and 35 is not equal. As shown in dotted lines in Fig. 4, triangular portions 34 and 35 may be added to strap 26. These portions have horizontal edges which are parallel to the $\theta=0$ axis and a vertical edge which determines the height of triangular portions 34, 35 arranged parallel to the $Z=0$ axis.

It is to be understood that it is also feasible to wind a coil from a strap designed according to another function of θ, depending upon the desired change of the pitch angle.

In Fig. 7 another possible coil structure is shown in which an auxiliary inductance L_1 is wound on coil form F over a portion of a tuning inductance L_0. Indeed, it may be possible to wind the auxiliary coil L_1 between the turns of the tapped portion of coil L_0, thus forming a bifilar portion on coil L_0. Coils L_0 and L_1 may be tuned by movable core C_0.

The coil structure of Fig. 7 may be considered as consisting of a single layer winding of uniform thickness where successive turns are of different effective widths. In other words, the bifilar portion of coils L_1 and L_0 has the same effect as a strap of conducting material of the same width as the parallel wires, because adjacent points of the bifilar winding are equipotential.

It is also feasible to wind an inductance element consisting of a plurality of sections the conductor in each section having a different effective width with respect to the conductor of the other sections. Such a coil 36 is illustrated in Fig. 8 and consists of three sections 37, 38 and 39 which are wound upon coil form 11. Section 37 consists of a trifilar winding, the three parallel wire conductors being connected together as illustrated at 37'. Section 38 consists of a bifilar winding with the two parallel wires connected together at the beginning and end of the bifilar winding, as shown at 38' and 38'. Finally, section 39 consists of a single wire. Accordingly, the effective width of the conductor forming coil 36 varies from section to section. It is to be understood that coil 36 may be wound with a uniform pitch as illustrated, or it may have a non-uniform pitch.

Inductance coils 10 and 33 may be used with advantage in a superheterodyne receiver of the type illustrated in Fig. 9. The circuit includes a dipole antenna 40 for intercepting a high frequency-modulated carrier wave which is impressed on a tuned input circuit 41. Dipole antenna 40 is connected across coil 42 which is inductively coupled to coil 43 across which is connected a condenser 44. Coil 43 may, for example, be identical with coil 10 of Fig. 1 and may be tuned by a core illustrated at 45. As previously explained, core 45 may consist of a paramagnetic material, of a dielectric material or of a non-magnetic high conductivity metal.

The radio-frequency input signal is impressed through coupling condenser 46 on signal control grid 47 of pentagrid converter tube 48. Converter tube 48 comprises cathode 50, oscillator control grid 51, two screen grids 52 and 53 between which signal control grid 47 is provided, suppressor grid 54 which is grounded as shown, and anode 55. An automatic volume control voltage (AVC) may be impressed through resistor 49 on signal control grid 47.

The oscillator section is coupled between cathode 50 and oscillator control grid 51 and comprises a tuned tank circuit 56. Tank circuit 56 includes coil 57, bypassed by two series condensers 58 and 60. Coil 57 may be identical with coil 33 of Fig. 5 and may have a uniformly varying pitch to secure tracking of tuned circuits 41 and 56. The junction point of coil 57 and condenser 60 is grounded as shown. The circuit may be tuned by core 61, which may be moved in unison with core 45 as indicated at 62 and which may consist of the same material as core 45. The junction point of condensers 58 and 60 is connected to cathode 50, which is grounded through choke coil 63. The high potential terminal of tank circuit 56 is coupled to oscillator control grid 51 through coupling condenser 64. Grid 51 may be grounded through grid leak resistor 65.

The oscillator section is arranged as a Colpitss oscillator and operates in a conventional manner. The screen grids 52, 53 are connected together to a suitable source of positive voltage, indicated at +B, through dropping resistor 66. Screen grids 52, 53 are bypassed for radio-frequency currents by grounded condenser 67. The intermediate frequency may be obtained from anode circuit 70, connected through resistor 71 between +B and anode 55, and the intermediate-frequency signal may be derived from output circuit 72, magnetically coupled to anode circuit 70.

The operation of the circuit of Fig. 7 is conventional and no further explanation is needed here. For the purpose of obtaining tracking, a strap-wound coil with uniform pitch, such as coil 10, may be used in the radio-frequency input circuit 41, while a strap-wound coil with uniformly varying pitch, such as coil 33 or coil 36 having a variable winding width, may be used in oscillator tank circuit 56.

There has thus been described a high frequency strap-wound coil of uniform pitch arranged in such a manner as to permit the formation of a uniform dense current sheet throughout the length of the coil. Furthermore, a strap-wound coil has been disclosed which may have a non-uniform pitch, such as a uniformly varying pitch. This coil may take the form of a coil consisting of wire conductors of varying effective width. The strap-wound coil of non-uniform pitch may also be arranged in a manner to provide closed end turns. Two strap-wound coils, one having a uniform pitch and the other having a uniformly varying pitch may be used, for example, for securing tracking in a superheterodyne receiver.

What is claimed is:

1. A high frequency inductance element consisting of a strap of conducting material of considerable width along the entire length of the strap and arranged in a flat helix with end turns of substantially right cylindrical shape adjacent respectively to two spaced planes at right angles to the longitudinal axis of said element, thereby to permit the formation of a uniform dense current sheet between said planes.

2. A high frequency inductance element consisting of conducting material having considerable width and flared end pieces, said element being arranged helically with a uniform pitch in the shape of a cylinder having right cylindrical sections adjacent to two spaced planes arranged at right angles to the longitudinal axis of said element, thereby to permit the formation of a uniform dense current sheet between said planes.

3. A high frequency inductance element consisting of a strap of conducting material of considerable tapered width along the entire length of the strap and having flared end pieces, said strap being arranged with uniformly varying pitch and in the shape of a helix having end turns of substantially right cylindrical shape adjacent respectively to two spaced planes arranged at right angles to the longitudinal axis of said element, thereby to permit the formation of a uniform dense current sheet between said planes.

4. A preformed strap wound into a high frequency inductance coil having a helical winding, said strap consisting of a continuous sheet of conducting material having the shape of one edge determined by $Z=f(\theta)$ and having the shape of the other edge determined by $Z=f(\theta+2\pi)$, where Z is the ordinate and θ the abscissa which equals the angle from the beginning of the winding to a given point on said strap, and where $f(\theta)$ is determined by the desired variation in pitch of said coil, said strap further having two straight edges arranged parallel to the $\theta=0$ axis, the length of said strap between said straight edges being determined by the desired number of turns in said winding and the diameter of said helical winding.

5. A preformed strap wound into a high frequency inductance coil having a helical winding with substantially right cylindrical end turns, said strap consisting of a continuous sheet of conducting material having one edge determined by $Z=f(\theta)$ and having the other edge determined by $Z=f(\theta+2\pi)$, where Z is the ordinate and θ the abscissa which equals the angle from the beginning of the winding to a given point on said strap, and where $f(\theta)$ is determined by the desired variation in pitch of said coil, said strap having two straight edges parallel to the $\theta=0$ axis, the length of said strap between said straight edges being determined by the desired number of turns in said winding and the diameter of said helical winding, said strap further including two substantially triangular end portions having their apices on said straight edge, each of said triangular end portions extending parallel to the $Z=0$ axis for one turn of said coil and having an edge parallel to the $\theta=0$ axis.

6. A preformed strap wound helically into a high frequency inductance coil having the shape of a right cylinder, said strap consisting of a continuous sheet of conducting material having two identical rectangular end portions, having a length equal to an integral number times the circumference of said cylinder and a width determined by the distance between the center of two adjacent turns of said coil, and having a main strap portion with parallel edges forming acute triangular end sections, said parallel edges each being integrally connected to one edge of a corresponding one of said rectangular end portions,

said acute triangular end sections having the acute angle determined by the desired pitch angle of said coil.

7. A preformed strap helically wound into a tapered high frequency inductance coil having a right cylindrical shape, said strap comprising a continuous sheet of conducting material having a main portion of substantial width bounded by two parabolae and terminated by two straight edges spaced apart a distance determined by the desired number of windings of said coil, said strap further comprising two flared end portions each having one edge parallel to said straight edges and a further edge extending at right angles thereto and positioned so as to provide right cylindrical end turns of said coil.

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