MODULAR TUNED CIRCUITS

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This invention relates to electrical apparatus, and more particularly to a modular technique for the construction of electrical networks which allows assembly of a wide variety of configurations from a small number of basic components.

In the development of electronic equipment for use at radio frequencies, such as radio signal receivers, the trend toward miniaturization has resulted in demands for smaller and smaller component parts. This has been true with respect to variable tuned circuits employing inductances and capacitors, because the commonly used parallel-plate, air-dielectric type of capacitor is usually bulky in size, and requires a disproportionate space for installation in proportion to other electronic components in a receiver. When these capacitors are used as tuning elements for radio receivers, two or more units are mechanically ganged together for uncontrol operation, adding even further to the size of the unit.

In the more general application of variable tuned circuits, which, depending upon their function take a multiplicity of different circuit forms, all include inductance and capacitance and may be broadly categorized as series or parallel resonant circuits or combinations thereof. In order to obtain the proper relationship between the values of inductance, mutual inductance, and capacitance it is frequently necessary to use non-standard capacitors and inductors, and it has been common practice to individually adjust the capacitive and inductive elements of such networks to a close approximation of the required values and then to perform a tuning procedure to bring the combined response of the various elements into conformity with the required characteristics. In some cases, even this procedure cannot be employed because of critical interactions among the various components of the network, and in such cases tedious and difficult hand tailoring of the otherwise fixed-value circuit elements must be employed. This practice is obviously time consuming and particularly where the circuit configuration is intended for mass production. In other words, with present practice, series or parallel resonant circuits cannot be readily mass produced from established design parameters, but must, after assembly, be individually aligned even when care is taken in the preparation of the specifications.

It is a general object of the present invention to provide an improved method for manufacturing electrical networks.

It is a further object of this invention to provide a modular technique for the construction of electrical networks, consisting of a small number of basic elements adapted for combination in various ways to provide different types of series or parallel resonant circuits. Another object of the invention is to provide a modular circuit construction wherein a small number of basic elements are essentially isolated and combinable to form a multiplicity of different forms of tuned filter circuits, the electrical parameters of which are reproducible from circuit to circuit and depend only on the mechanical tolerances of the basic elements.

In the attainment of these objects, the invention features the use of circularly printed circuit cards having reactive impedance components, or portions thereof, printed or otherwise applied thereon in lieu of the more conventional component. More specifically, a wide variety of filter circuits are obtainable using only four basic cards. One card is formed with an arcuate conductive sector at its perimeter to provide a stator plate for a variable capacitor, and a second card with a similar conductive sector printed thereon, inwardly from the periphery and having a conductive strip extending to the center of the card for connection to other circuit elements, constitutes a rotor for a variable capacitor. Another card has a conductive path of flat spiral shape printed thereon, starting from the center and terminating in an arcuate conductive area at the periphery of the card to serve as an inductive element, and the fourth card has conductive areas thereon constituting a series-connected inductance and a rotor plate for a variable capacitor. These four basic cards are selectively positioned parallel to and closely adjacent to each other with the several conductive areas separated from each other by the material on which the circuit elements are printed. The cards are supported in a cylindrical housing which is typically, but not necessarily, made of an electrically conductive material. In addition to providing support and proper relative spacing and positioning for the variable element cards, the housing may be used to complete common electrical circuit paths, such as grounds, and/or provide a shield covering for the entire network or parts thereof, as may be required by the particular electrical configuration. Other required electrical interconnections between the elements of the cards are accomplished by means of one or more conductive pins or riblets passing through openings located at the centers of the affected cards. A simple series resonant circuit, for example, requires but two cards, one having a series-connected inductance and capacitor rotor printed thereon and the other having a capacitor stator thereon, the cards being positioned in juxtaposition with the dielectric extending to the center separating the capacitor plate thereon from the capacitor plate on the other card. A pin inserted through the central opening in both cards provides both a terminal for the inductive end of the circuit and a mechanical pivot about which one card may be rotated with respect to the other so that the overlap of the capacitor plates, and hence the capacitance, may be varied.

As another example, a simple parallel tuned circuit, wherein both ends are provided with electrical terminals, may be formed of three element cards: one having an inductance printed thereon, a second having a rotor, and the third having a capacitor stator, the latter two being adjacent each other to form a variable capacitor and the inner end of the inductance being electrically connected to the capacitor rotor element by a conductive pin. The outer terminal of the inductor and the stator element of the capacitor are connected together by the supporting housing.

A parallel resonant circuit may be formed, using only two element cards, which is appropriate for use in such networks wherein energy is to be inserted or extracted by means of mutual inductive coupling. In such case it is not necessary that electrical terminals be provided for both ends of the circuit. This type of parallel resonant structure consists of two cards: one having a series-connected inductance and capacitor rotor printed thereon and the other having a capacitor stator and a conductive strip to its central opening, printed thereon. The circuit is completed by a conductive pin passing through the central opening of both cards which connects one end of the inductor to the capacitor stator.

By employing other combinations of the four basic cards, a low pass filter comprising an inductance and two variable capacitors may be fabricated in several forms, the most complex of which requires only five cards, and more complex filter networks, such as multiple tuned band-pass filters, are possible with other combinations of these basic elements.
In the application of this modular concept to the mass production of a particular circuit, the reactance values of the circuit are transformed into their printed circuit equivalents, making it possible to duplicate the circuit components in quantity using available printed circuit techniques. With a supply of each type of element card, the circuit can then be reproduced in quantity by an unskilled technician simply by stacking the cards in the right order in the housing and making necessary electrical connections as directed by insertion of a rivet or two in each assembly. The modular construction also lends itself to applications where it is desirable to transform couple several tuned filter stages in that a spacer ring of specified dimensions may be readily placed between the cards carrying inductors to be coupled, the spacer guaranteeing a constant mutual coupling coefficient which is reproducible from assembly to assembly.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention 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 drawings, in which:

FIGS. 1, 2, 3, and 4 are plan views of an inductance card, a capacitor stator card, a capacitor rotor card, and an inductance-capacitance card, respectively;

FIG. 5 illustrates a variable series-tuned circuit and the schematic equivalent thereof in terms of element cards;

FIG. 5a is an exploded isometric view of the circuit,

FIG. 5 illustrates a variable series-tuned circuit and the invention;

FIG. 6 is a schematic diagram of a parallel tuned circuit and its circuit card equivalent;

FIG. 6a is an exploded isometric view of the circuit of FIG. 6 constructed of circuit cards;

FIG. 6b is a schematic diagram, also indicating circuit card equivalents, of a parallel tuned circuit with inductive coupling;

FIG. 6c is an exploded isometric view of the circuit of FIG. 6b constructed of circuit cards;

FIG. 7 is a schematic diagram of a low pass filter and illustrates the manner in which its various elements are associated with circuit cards;

FIG. 7a is an exploded isometric view of the assembly of the circuit of FIG. 7;

FIG. 8 is a schematic diagram of a stagger tuned filter and its circuit card equivalent;

FIG. 8a is an exploded isometric view of the circuit of FIG. 8 constructed in modular form according to the invention;

FIG. 8b is a fragmentary exploded isometric view of the right end of the structure of FIG. 8a illustrating an alternate output coupling arrangement;

FIG. 9 is a schematic diagram of a two-stage radio frequency amplifier; and

FIG. 9a is an elevation cross-section of the circuit of FIG. 9 constructed in accordance with the modular concept of this invention.

A multiplicity of networks in modular form are obtainable from the four basic card configurations shown in FIGURES 1–4, although in certain networks, physical complexity may be reduced by use of more complex printed circuit cards as typified in the alternate output capacitor arrangement shown in FIG. 8a. The ensuing discussion will employ only the basic card types of FIGURES 1–4, but it is not intended that any other electrical arrangements of the printed circuit cards be excluded from the scope of this invention. The basic cards provide the active circuit elements in the form of printed circuits having essentially circular symmetry. In the fabrication of a particular circuit, the appropriate cards are positioned parallel to and closely adjacent each other and, accordingly, the wafers are all of the same diameter and each is provided with an opening at the center to receive a connecting pin for making electrical connection between selected conductive portions of the various cards and/or providing an axis about which one or more cards may be rotated with respect to the others. More specifically, FIG. 1 illustrates a typical card 10 having an inductive configuration imprinted thereon in the form of a flat spiral 12 originating at the center hole 14 and extending outward and terminating in an arcuate conductive strip 16 which extends out to the periphery of the wafer. At its inner end, the spiral conductor is provided with a conductive circle, in the nature of a grommet 18 or washer encircling the center hole 14 to facilitate connection of the inductor to other elements by a conducting pin or rivet. As will be seen later, the arcuate strip 16, when the wafer is placed in a cylindrical housing, makes electrical contact with the housing and is thereby connected to the housing. To permit tapping of a portion of the inductance afforded by the spiral conductor, additional grommets, such as 20, surrounding a hole or opening 22 in the card, may be conductively joined to the conductor 12 along its spiral contour.

The inductance of the spiral conductor 12 is determined by the physical dimensions of the conductive strip in general accordance with the relationship

$$L = \frac{5.3}{D/2} \text{ microhenry}$$

for short solenoidal coils appearing on page 61 of Terman’s Radio Engineers Handbook, first edition. In this expression, $L$ is the total length of the spiral conductor, $D$ is the distance between centers of adjacent windings (normally designed to be constant), and in this application the term $I$ is a function of the thickness of the conductive strip, the mean radius of the helix and the width of the conductive strip. Thus, with the inductance of a particular circuit specified, it is possible to design the helical contour to achieve the desired inductance.

Referring to FIGS. 2 and 3, the capacitive component for the modular assembly consists of a pair of discs 24 and 26 having flat arcuate conductive areas 28 and 30, printed thereon which functions as the stator and rotor, respectively, of a parallel plate capacitor. The conductive surface 28 of the stator card extends to the periphery of the wafer 24 for electrical connection to a cylindrical housing when assembled therein, and the arcuate conductive area 30 is positioned inwardly from the perimeter of card 26 to clear the housing but is, instead, connected to a grommet 32 surrounding the center hole by a radial conductive member 34. A capacitor is fabricated by positioning the printed side of wafer 26 adjacent to the printed side of wafer 24, with the area 30 overlaying the area 28, whereby the material of wafer 26 serves as the dielectric for the capacitor. The two wafers are maintained in contact with each other by a pin or rivet inserted through the center holes, and the rotor element 30 may be connected to other circuit elements via the rivet or pin.

The elements of the capacitor are designed in accordance with the basic formula for parallel plate condensers,

$$C = \frac{2244K}{d^2} \text{ microfarads}$$

where $K$ is the dielectric constant of the rotor wafer 26, $A$ is the effective area of the mutually opposed areas 28 and 30, and $d$ is the thickness of the wafer 26. The capacitance may be adjusted by varying the effective area of overlap of areas 28 and 30, and to this end, wafer 24 is provided with a tab 36 for rotating the rotor element about its central axis relative to the stator card. The latter typically has a somewhat wider tab 38 on its periphery, which, in cooperation with a slot in the cylindrical housing (to be described), maintains the stator element in fixed position.
Because of the frequent necessity in tuned circuits to connect one terminal of an inductor to one plate of a capacitor, it is convenient to provide a fourth card as shown in FIG. 4 having thereon an inductive element and a conductive area constituting a rotor plate of a capacitor. The wafer 46 is formed of dielectric material and has a tab 42 on its unprinted side for rotational movement which can be used to adjust the degree of overlap of the conductive area 44 with the conductive area 28 on a cooperating stator card. The inductive element 46 has a grommet 48 surrounding the center hole in the wafer to permit electrical connection thereof to other cards, and the other terminal is conductively joined to the printed area 28. The spiral inductor 45 is designed in accordance with the principles outlined in connection with FIG. 1, and the rotor plate 44 is designed according to the basic formula for parallel plate condensers to which earlier reference has been made. It will be noted that the outer periphery of conductive area 44 does not extend to the edge of the wafer so as to avoid contact with the housing in which the wafers are assembled. It will be appreciated that the card of FIG. 4 constitutes an inductor in series with one side of a capacitor, which when juxtaposed with a stator card of FIG. 2, provides a simple series resonant circuit.

In an actual embodiment of the invention which has been sufficiently disposed in the second frequency range, cards having a diameter of 2½ inches have been found suitable. This dimension is, of course, illustrative only, inasmuch as the dimensions of the cards may be changed in accordance with changing requirements of inductance and capacitance. It is important to note, however, that once the conductive configurations for the four cards is established to give the proper tuning range in a particular tuned circuit, the circuit can be mass-produced with assurance of having identical electrical characteristics by controlling the thickness of the dielectric wafers, which is readily achievable, and reproducing the conductive areas on the cards. This is work which is also readily attainable with known printed circuit techniques.

Apart from the advantage of reproducibility, the construction of the four basic cards of FIGS. 1-4 permits the selective combination of these cards to form a multi-plicity of different circuits in a compact modular form, and having a minimum of connections to be made by the assembler. Consider first the elementary series-tuned circuit of FIG. 5 having terminals a and b and an inductor L in series with a variable capacitor C. In terms of the reactive components on the cards of FIGS. 1-4, this circuit can be divided into two structural parts represented by the dotted enclosures appearing at the right in FIG. 5, the inductor and the rotor plate of the capacitor being afforded by card 40, and the stator of the capacitor by a stator card 24. In FIG. 5, and in subsequent figures to be described, the dotted enclosures are labeled with primed numbers corresponding to the reactive components on the cards needed in the construction of the circuit.

The physical embodiment of the circuit of FIG. 5, illustrated in the exploded view of FIG. 5a, comprises two wafer cards, one the inductance-capacitance card 40 of FIG. 4 and the other the stator card 24 of FIG. 2, positioned adjacent each other, with the unprinted side of card 40 in juxtaposition with the printed side of card 24. The cards are assembled within a cylindrical conductive housing 50 having an inner diameter equal to the outer diameter of the wafers, whereby the outer periphery of the wafer makes electrical contact with the housing. The tabs 38 and 42 on the respective cards project through a longitudinal slot 52 in the wall of the housing, the slot having a width corresponding to that of tab 38 so as to firmly position card 24 in the housing while allowing limited rotational movement of card 40 by reason of the narrower tab 42 thereon. The cards are positioned with conductive area 44 overlaying conductive area 25, the base material of wafer 40 constituting the dielectric between the capacitor plates thus formed, and the relative rotation between cards 40 and 24 allowing adjustment of the degree of overlap of the two capacitor plates. To maintain the wafers in juxtaposition, and to provide a terminal for the construction of the tuned circuit, the cards are secured together by a conductive pin or rivet 54, the head of which engages the grommet 48 at the inner end of the helical contour 46. It will be noted with reference to FIG. 5, that the head of rivet 54 constitutes terminal a of the series resonant circuit and the conductive housing 50, by virtue of the connection of conductive area 28 thereto, constitutes terminal b of the series resonant circuit. Tuning is afforded by rotation of card 40; the value of the inductance of helical conductor 46 is not affected by the rotation of card 40 relative to card 24. Although the housing has been illustrated as having considerable length, it will be understood that if the module is to consist only of a single series resonant circuit, the housing need be only slightly longer than the combined thicknesses of the wafers 40 and 24.

Because both terminals of the inductor L and of the capacitor C of the parallel-resonant circuit of FIG. 6 are connected to the external terminals a and b, three wafers are appropriately disposed and the other cards connected are required for the fabrication of this circuit. More specifically, the inductance L is provided by the conductive helix 12 of the card 10 of FIG. 1, and the capacitance C is provided with two cards, a fixed stator card 24 and a rotor card 26 which is rotatable. The tabs 36 and 38 of the wafer cards project from a slot 52 in the housing 50, the narrower tab 36 permitting rotational movement of card 26 relative to card 24 to vary the degree of overlap of conductive areas 28 and 38. One terminal of the inductance is electrically connected to the housing 50 by the peripheral conductive area 16, and its other terminal is connected to the capacitor rotor by a conductive rivet 54 inserted through the center holes of all of the cards and engaging the grommets 18 and 32 on cards 10 and 26, respectively. The conductive area 25 on stator card 24 is likewise electrically connected to the housing 50. Thus, it will be seen that the head of rivet 54 constitutes terminal a of the circuit of FIG. 6 and the housing 50 is terminal b. Alternatively, the simple parallel tuned circuit may be constructed from but two cards for those applications where energy is inserted or extracted by means of mutual coupling. This case is schematically illustrated in FIG. 6a wherein energy is inductively coupled to or from the inductance L. The physical embodiment, shown in FIG. 6c, comprises a card 40 having series-connected inductance and capacitor rotor elements, and a second card 26a which differs from that shown in FIG. 5 only in that the arcuate conductive surface is extended to the edge of the card so as to contact the cylinder 50. The inner terminal of the inductance is connected to the stator of the capacitor by pin 54.

The three-terminal low pass filter of FIG. 7 is also readily fabricated from the basic cards of FIGS. 1-4, requiring two pairs of rotor and stator cards, a slightly modified inductance card 10a and spacer rings or wafers to physically separate certain of these cards. More specifically, with reference to the right hand portion of FIG. 7 and to FIG. 7a, the capacitor C1 is provided by the rotor and stator cards at the left end of the structure of FIG. 6a, and the capacitor C2 is afforded by a pair of like cards assembled at the right end of the structure of FIG. 7a. It is to be noted that the conductive area 28 on both of the stator cards are electrically connected to the cylindrical housing 50 whereby the housing constitutes terminal b of the circuit of FIG. 7. The inductance L is provided by the wafer 10a having a spiral contour 12a originating at a conductive grommet at the center hole and terminating short of the periphery of the wafer in a grommet 20.
FIG. 1 since the outer terminal must be connected to the rotor of capacitor C2—not to the housing, as would occur with the standard card of FIG. 1. The rotor of capacitor C2 is electrically connected to the inner terminal of helical contour 12a by a rivet 56 inserted through the center hole of the two capacitor cards and the induc
tance card 10a, with an insulating spacer ring 58, or an insulating wafer 60, formed of low dielectric constant material. The physical separation by the ring 58, or the insertion of the dielectric wafer 60, minimizes stray capacity which might otherwise exist between the adjacent cards.

Electrical connection between the outer terminal of inductance 12a and the rotor of capacitor C2 is afforded by an insulating wafer 62 having a radially disposed conductor 64 printed thereon terminating at its inner end in a conductive grommet 65 surrounding a center hole and at the outer end in a grommet 68, also surrounding a hole in the card 10a. The conductive grommet 65 is inserted through 70 the tip of the conductive grommet 66 surrounding the center hole and is electrically connected to the two cards 48 and U5 by means of a rivet 78 inserted through 70 the center hole of the two insulators 62 and 66 and electrically engaging grommets 70 and 68 to minimize shunt capacitance introduced by the proximity of the rotor of capacitor C2 and inductance 12a, and for another reason to be explained shortly, cards 10a and 62 are also pref
cisely separated by a spacer ring 58. It may be noted at this juncture that the two spacer rings, and cards 10a and 62 are fixed relative to the housing 50. The rotor of capacitor C2 is connected to grommet 66 and wafer 62 with a rivet 78 inserted through the center hole in the two capacitor cards and wafer 62. The spacer ring 58 insures that the inner end of rivet 72 does not contact the inner end of rivet 56 and short out the inductor when all of the cards are assembled in close proximity with each other. Except for this latter problem, the spacer ring 58 might be eliminated by printing the conductor 64 on the opposite surface of wafer 62 from that illustrated and care taken that the length of rivet 70 is just short of the combined thickness of wafers 62, 26, and 24.

As in the previously described configurations, the stator card of FIG. 1 consists of two capacitors having a thin sheet of mylar, the two capacitor cards are fixed in position with respect to the housing 50 by the two conductive grommets 56 and 65. The edges of a longitudinal slot 52, both capacitors being variable, independently of each other, by rotation of the rotor cards. From what has been said, it will be seen that rivets 56 and 72 constitute terminals a and c, respec
tively, of the circuit of FIG. 7, and the housing 50 is the terminal b.

Considering a further application of the modular circuit construction technique of the invention, the triple tuned filter network of FIG. 8 which has five inductors and five capacitors and a requirement for mutual coupling between each pair of the inductors, is readily and easily constructed in a compact package using only eight of the circuit cards, of the three types represented by FIGS. 2, 3, and 4. The low number of cards is in part attributable to the fact that a single capacitor stator card can be placed between two capacitor rotor cards to provide a variable capacitor which is independently adjustable.

More specifically, starting at the left end of the assembly of FIG. 8a, the stator of capacitor C2 of the circuit of FIG. 8 consists of a stator card 24, and the inductance L1 and the rotor of capacitor C2 is afforded by a combi
nation of inductance-capacitance card 40. The inner end of the spiral conductor 46 is connected by a rivet 74 extending through the two cards to the inner conductor of connector terminal 76 affixed to the end of the housing to comprise terminal a of the circuit of FIG. 8.

The serially connected inductors L1 and L3 are provided by the spiral conductors on two cards 49 of the type shown in FIG. 4, the inner terminals of which are connected together by a rivet 78 inserted through their center holes. The two cards 49 are positioned on opposite sides of a common stator card 24, the dielectric material of the left hand card 40 serving as the dielectric for capacitor C2, and the dielectric of card 24 disposed between the conductive grommet of the center hole and the conductive grommet of the right hand card 40 serving as the dielectric capacitor C3.

The mutual coupling M1 between L1 and L3 is main
tained (and faithfully reproduced from assembly to assembly) by spacer ring 36 having such length as required to give the desired mutual coupling. It will be noted that the spacer ring 36 also prevents rivet 78 from contacting the head of rivet 74. Similarly, the mutual coupling M2 between inductors L1 and L4 is maintained by a spacer ring 82 of similar construction.

The final stage of the circuit including C1, L1, L4 and C3 is likewise formed of three cards arranged the same as the center section, with the inner terminals of the two inductor conductors connected together by a rivet 84. With each of the stator cards 24 electrically connected to the housing 50, the latter constitutes terminal b of the circuit of FIG. 8, and the output coupling condenser C4 from the junction of L3 and C3 in FIG. 8, is a lumped inductor capacitor combination complete by virtue of the spiral card 40 with the capacitor plate on the final card 40 and the center conductor of a coaxial output terminal 88, which constitutes terminal c of the circuit of FIG. 8. Although the final card 40 may be rotated through a narrow arc to afford tuning of the final capacitor C4, a flexible connec
tion between capacitor 86 and the card does not interfere with this movement. As an alternative to the lumped capacitor 86, the output coupling capacitor C4 may be provided by printed cards as shown in FIG. 8b. The final inductor, a stator capacitor, and another card 43 having a conductive ring 45 and variable capacitors of the type shown on the other side of the capacitor, the base material of card 49 serving as the dielectric. The junction of the spiral 46 and area 44 is electrically connected to the ring 41 on the other side of the card by a short pin, or by plating through a hole, and external connection is made to ring 45 as by soldering. Thus, the module of FIG. 8 can conveniently accommodate, when necessary, lumped pa
terparameter components as an integral mechanical part with the circuit cards. This assembly also illustrates the con
cvenience with which external connection of the cards, and connection of the module to other conventional cir
cuity and/or similarly constructed modular circuitry, can be made. Further, this structure can be expanded to ac
commodate n-tuned circuits merely by adding the requisite number of sets of cards and spacer rings.

As a final example of the versatility of application of this invention in the fabrication of specific circuits, refer
cence is made to FIGS. 9 and 9a where are respectively a schematic diagram and a cross-sectional view of a two
tage radio frequency preamplifier packaged in modular form. Considering the schematic diagram only briefly, the radio frequency signal to be amplified is applied through an input jack 100 and L1-coupled to the cathode of a planar electrode tube, for example, a type 6299, the grid of which is grounded. The output from the stage is taken from the anode and is coupled to the cathode of the next stage by double-tuned transformer coupling.

The grid of the second stage 104 is also grounded, and the output signal is transformer coupled to the grid of the double
tuned circuit, to an output jack 106. The shape of the planar electrode triode makes it particularly useful in this type of modular construction and is readily connect
able to associated tuned circuitry associated therewith when the latter is provided on circuit cards of the type shown in FIGS. 1-4. Not all of the components of the schematic of FIG. 9 are reduced to circuit wafers; it is convenient to use conventional lumped type components where reproducibility is not critical, such as radio fre
quency choke for power supply filtering. The card tech-
ique is used on those elements of the tuned circuits where reproducibility from assembly to assembly is essential, these being shown in the dotted line enclosures, the non-critical components being of conventional form and method of assembly and secured by a combination of inductance-capacitance card 49 positioned adjacent thereto. Referring now to FIG. 9a, the modular assembly of the circuit of FIG. 9 is in the form of a cylindrical circular member comprised of a number of cup shaped enclosures 108, 109, 110, 112, 114, 116, and 118, each supporting some of the components of the circuit and stacked together to form the complete assembly. The cup shaped enclosures 108 has a circular flanged member 120 secured thereto on which is supported a coaxial input jack 160, the inner conductor 162 of which extends inside the housing. An inductance card 19 of the form shown in FIG. 1 is secured across the open end of the cup-shaped member by a flanged ring 122, the peripheral conductive area 16 of the card accordingly being in electrical contact with the cup-shaped shell. This constitutes the grounded terminal of the input inductance of tube 102 of the circuit of FIG. 9. The input capacitor is of the conventional variety and is shown at 124 connected between the inner conductor of the input jack and the conductive grommet 20 on the inductance card 19 to tap a portion of the inductance of the helical conductor.

Cup shaped member 110 supports the tube 102 and connectors for making electrical connection thereto, and is positioned with its rim engaged by the flange 122 such that the cathode 162c of the tube faces the card 19. The tube is surrounded by an insulating member 126 supported on the bottom of cup 110, the tube being placed in a cylindrical bore 126a therein. A disc 128 having a central hole therein is positioned across the outer end of the bore 126a. A cylindrical conductive structure, 130, electrically secured to plate 128, extends longitudinally of the bore 126a to engage the circumferential cathode ring 162c of the tube. The grid 162g of the tube is grounded to the housing by a cylindrical spring clip 152, and the coaxial pin heater connection is electrically connected to a heater contact terminal 134 secured to member 126. Heater current from an external source is coupled to the tube through a feed-through capacitor 136 mounted in the wall of cup 110 and a radio frequency choke 138 connected to the heater contact terminal 134. The heater and cathode of the tube are internally connected, as shown in the circuit diagram of FIG. 9, the common point thereof being connected to ground through the inductance on card 19 by a conducting pin 140 inserted through the center hole of the card and engaging the inner terminal of the helical contour thereon and at the other end engaging the plate 125 which makes contact with the cathode of the tube. Operating voltage for the anode 102p of the tube is supplied from an external source, represented by terminal 142, and is coupled to the anode via a feed-through capacitor 144 mounted in the wall of cup 112 and a radio frequency choke 146. The choke coil 146 is electrically connected to a conductive stud 148 which at one end engages the anode cap 102p of the tube and at the other end is secured through the center hole of a pair of circuit cards, to be described.

To summarize, the first stage of the circuit of FIG. 9 is physically contained in the two cup-shaped housings 108 and 110, with the anode stud of the tube projecting through the bottom of cup 118 to permit its connection to the next stage. Replacement of the tube is readily accomplished by separating the cup 110 from the balance of the assembly. In the first stage only one printed circuit card is employed, the balance of the components being of the lumped constant variety. As shown in FIG. 9, the anode of tube 102 is transformer coupled to tube 104 with circuit alignment provided by three variable capacitors Cb, Cc and Cf. Reproducibility of the mutual coupling M1 between the inductances L1 and L2, and of the variable capacitors, is achieved with five printed cards of the type described in FIGS. 1-4. The grounded stator of capacitor Cb is provided by a stator card 24, the conductive area of which is electrically connected to the rim of cup 112, and the inductance L1 and the rotor of capacitor Cc are afforded by a combination of inductance-capacitance card 49 positioned adjacent thereto. The central grommet 48 of the card 40 is electrically connected to the anode of tube 102 by the pin 148, and the capacitance may be varied by rotation of card 40 relative to card 24 by its tab 42 projecting through a slot (not shown) in the outer cylindrical member. A second card 40 of the type shown in FIG. 4 provides inductance L2 and the rotor of capacitor Cf, the degree of coupling M2 between the inductances being determined by the spacing between the cards, which is insured by a spacer element 150. A single stator card 24 serves as the stator for both of capacitors Cc and Cf, and the circuit is completed by an additional rotor card 26. Adjustment of capacitors Cc and Cf is afforded by tabs 42 and 36, also projecting through the longitudinal slot in the outer wall of the housing.

Tube 104 is mounted in the same manner as tube 102 and will not be again described except to say that the inner inductance 48 of the inductance on card 40, and the grommet 32 on the rotor card 26 are connected by pin 152 to the cathode terminal 128c of the second tube. Heater voltage for the tube is applied from an external source through feed-through capacitor 136, a radio frequency choke 138 and through heater contact terminal 134. Ground for the heater heating current is provided by radio frequency choke 154 connected between the heater terminal contact and the grounded cup shaped member 114.

The output coupling stage is identical to the interstage coupling circuit, including a radio frequency choke 146 through which B+ is supplied to the anode of tube 104, and five printed circuit cards, two stator cards, a rotor card, and two combination inductance-capacitance cards disposed in the same manner as in the interstage coupling circuit. The proper mutual coupling is maintained by a spacing element 150' between the two combination cards 40. The output signal is coupled from the circuit by a conductive pin 156, conductively secured at one end to the inner terminal of the final inductor L2', and to the rotor of the final capacitor Cc', and at the other end to a sleeve 158 connected to the inner conductor of the output coupling 166. As illustrated, the output coupling 166 is centrally mounted on a closure plate 160, which, in turn, is secured to the bottom of cup 118. As shown, the cup shaped members are assembled in pairs, with retaining rings 122, 122' and 122" surrounding them at their confronting rims, each pair having a heavier plate of slightly larger diameter at the ends thereof. The subassemblies are rigidly held together in a columnar configuration by retaining bolts extending through holes near the periphery of the extending plates, one of which is shown at 162. Thus, the entire circuit of FIG. 9 is contained within a cylindrical module of small dimensions. This assembly has been constructed and satisfactorily operated, and is approximately 2 ½ inches in diameter and 6 inches long. The circuit is completely shielded by the metallic shell, and is readily connectable to other circuitry through the coaxial connectors 100 and 106.

While the cylindrical housing 50 has been described as being formed of conductive material, it may be more convenient and economical in some cases to form the housing of non-conductive material and imbed in the wall thereof, or plate on the inner surface, conductive strips or areas only to the extent necessary to interconnect the elements extending to the edge of a card. This alternative might be used where shielding is not required and where weight and cost reduction are necessary. It is accordingly the intention, in the appended claims, that the term "conductive cylinder" include a cylinder which is conductive at least on those portions of its surface.
where connection is to be made to circuit elements extending to the edge of a card.

From the foregoing description it is seen that applicant has provided a method for the fabrication of electrical networks of many configurations which lends itself to mass production while insuring reproducibility of the frequency-determining portions of the tuned circuit, thus eliminating the time-consuming problem of hand tailoring. It has been shown that with four basic element cards a wide variety of circuits can be fabricated and interconnected simply made. The use of thin wafer cards permits compact modularization of the electronic circuitry, to which connection to other modules or conventional circuitry is readily made. The mutual inductance between inductive elements can be held to tolerances determined by the mechanical tolerances of spacer rings, and because of the circular symmetry of the spiral inductors, inductively coupled circuits can be tuned while holding the mutual inductance invariant.

Although a few representative tuned circuits employing the invention have been described by way of example, it will now be possible for ones skilled in the art to adapt the invention to other circuit configurations. It will be apparent, also, to those skilled in the art that the invention is capable of considerable variation in physical form with some variation in the electrical characteristics. It is to be understood, therefore, that the description of specific apparatus is by way of illustration only and not as a limitation to the scope of the invention as set forth in the objects thereof and in the appended claims.

What is claimed is:

1. A modular circuit comprising a cylindrical housing having conductive areas on the inner surface thereof, at least first, second, and third flat circular cards of dielectric material having central openings therein and having an outer diameter corresponding to the inner diameter of said housing, said cards being positioned within said housing normal to the longitudinal axis thereof, said first card including on one surface thereof a flat arcuate conductive area extending to the perimeter of the card for electrical connection with said housing and constituting a stator member, said second and third cards including on the corresponding surface thereof a flat arcuate conductive area positioned inwardly from the periphery of the card and a flat spiral conductor connected to said arcuate area and terminating in a conductive area surrounding the central openings in the cards, said first and second cards being in contact with the dielectric material of said first card interposed between the arcuate conductive areas on said first and second cards, a spacer ring and third second and third cards being of conductive material with the mutual inductance between the spiral conductors on said second and third cards, said spiral conductors having circular symmetry whereby the extent of overlap of the arcuate conductive areas on said first and second cards may be varied without changing said mutual inductance, a conductive pin inserted through the central openings in said first and second cards maintaining said cards in contact and electrically connected to the conductive area surrounding the opening in said second card, and means for rotating said second card relative to said first and third cards about the axis of said pin.

2. Modular structure for circuitry including inductance-capacitive networks comprising, in combination, a hollow cylindrical conductive housing, at least two circular insulating cards having diameters equal to the inner diameter of said housing assembled adjacent each other with said housing normal to the longitudinal axis thereof and engaging the inner surface thereof, each of said cards having a central opening therein, a flat conductive pattern on one surface of a first of said cards consisting of an arcuate sector located inwardly from the periphery of the card and connected to a conductive area surrounding the central opening by a conductor in the form of a spiral circularly symmetrical with respect to the central opening, a flat conductive pattern on the corresponding surface of a second of said cards consisting of an arcuate sector extending to the periphery of the card and engaging the inner surface of said cylinder, and a conductive pin inserted through the central openings in said two cards and electrically connecting said components and the order in which said conductive pin is inserted through the central openings in said first cards, one end of said pin constituting one terminal of said network and said housing constituting another terminal of said network, said first card being rotatable on said pin relative to said second card to vary the extent of overlap and hence the capacitance of the arcuate conductive areas on said first and second cards.

3. The modular structure according to claim 2 additionally including third, fourth and fifth circular cards assembled closely adjacent each other within said housing, means within said cylinder for spacing said third card a fixed distance from said first card, said third and fifth cards having conductive patterns on corresponding surfaces thereof identical with the conductive pattern on said first card, and said fourth card having a conductive pattern on its corresponding surface identical with the conductive pattern on said second card, a second conductive pin inserted through the central openings in said third, fourth and fifth cards and electrically connected to the conductive area surrounding the central opening in said third and fifth cards, said third and fifth cards being individually rotatable on said second pin relative to said fourth card to vary the extent of overlap and hence the capacitance between the arcuate conductive areas on said third and fifth cards and the arcuate conductive area on said fourth card, the circular symmetry of the spiral conductors on said first and third cards insuring substantially constant mutual inductance between them regardless of relative rotation of either of said first and third cards with respect to said second and fourth cards, respectively.

4. In a modular circuit including inductive-capacitive networks, the combination comprising, a hollow cylindrical housing having a conductive inner surface, a plurality of components each supported on a circular insulating card having a central opening therein, said cards having an outer diameter equal to the inner diameter of said housing and stacked adjacent each other within said housing normal to the longitudinal axis thereof and engaging said inner surface in a conductive area around the central openings in the cards, they are being assembled selected, according to the nature of the network, from a group of cards having flat conductive patterns on one surface thereof respectively defining: (1) an inductance in the form of a spiral extending from a conductive area surrounding the central opening to a conductive area at the periphery of the card, said spiral being concentric with said opening; (2) a capacitor stator plate in the form of an arcuate sector at the periphery of the plate; (3) a capacitor rotor plate in the form of an arcuate sector located inwardly from the periphery of the card connected to a conductive area surrounding the central opening; and (4) an inductance in series with a capacitor rotor plate in the form of an arcuate sector located inwardly from the periphery of the card connected to a conductive area surrounding the central opening in the card by a conductor in the form of a spiral which is concentric with said central opening; those of said components having a conductive area surrounding the central opening in its respective card being electrically interconnected by means coaxial with said housing extending through the central openings of the assembled cards for functional use; a longitudinal axis of said spiral allowing rotation of selected cards relative to others about the longitudinal axis of said housing, and those of said components having a conductive area at the periphery of its respective card being electrically interconnected by the conductive inner surface of said housing.

5. In a modular structure for electronic circuitry which includes inductive-capacitive networks, the combination
comprising, a hollow conductive cylinder constituting a housing for said circuitry and serving as a common terminal for said inductive-capacitive networks, and means within said cylinder constructed and arranged to form desired inductive-capacitive networks for said circuitry, said last-mentioned means comprising assemblies of circular insulating cards, all having a diameter equal to the inner diameter of said cylinder and a central opening therein, selected from a group of cards having flat conductive patterns on one surface thereof respectively defining: (1) an inductance in the form of a spiral extending from a conductive area surrounding the central opening to a conductive area at the periphery of the card, said spiral being concentric with said opening; (2) a capacitor stator plate in the form of an arcuate sector at the periphery of the plate adapted to electrically engage the inner surface of said cylinder; (3) a capacitor rotor plate in the form of an arcuate sector located inwardly from the periphery of the card connected to a conductive area surrounding the central opening; and (4) an inductance in series with a capacitor rotor plate in the form of an arcuate sector located inwardly from the periphery of the card connected to a conductive area surrounding the central opening in the card by a conductor in the form of a spiral which is concentric with said central opening; the cards in respective ones of said assemblies being positioned normal to the longitudinal axis of said cylinder whereby those conductive patterns extending to the periphery of its card electrically engage said cylinder, and conductive pins extending through the aligned central openings in the cards of each of said assemblies for electrically interconnecting the conductive areas surrounding the central openings of those cards in the assembly having conductive areas surrounding its central opening, said pins each being of a length substantially equal to the combined thickness of the cards in a respective assembly and arranged to maintain the cards in each assembly closely adjacent each other and to permit relative rotation of selected cards relative to others about the longitudinal axis of said cylinder, said pins further constituting other terminals of said networks.

6. Apparatus in accordance with claim 5 including spacers between said assemblies for maintaining substantially constant the spacing between said assemblies.

7. For the fabrication of a variety of complex inductive-capacitive networks in modular form, the form factor of which is substantially the same regardless of the complexity of the network, a hollow cylindrical housing having a conductive inner surface adapted to serve as one terminal of said networks, a plurality of circular circuit cards having four different types of flat conductive patterns thereon from which selection may be made to fabricate a desired network, each of said cards being formed of flat dielectric material and having a diameter equal to the inner diameter of said cylindrical housing whereby said cards may be assembled transversely within said cylindrical housing, each of said cards further being formed with an opening at the center thereof so as to be coaxial with said housing when the cards are assembled therein, said four conductive patterns including: (1) a spiral extending from an area surrounding the central opening in the card to a conductive area at the periphery of the card adapted to engage the inner surface of said cylinder and constituting an inductive component, (2) an arcuate sector extending to the periphery of the card adapted to engage the inner surface of said cylinder and constituting a stator plate for a variable capacitor, (3) an arcuate sector located inwardly from the periphery of the card and connected to a conductive area surrounding the central opening in the card and constituting a rotor plate for a variable capacitor, and (4) an arcuate sector located inwardly from the periphery of the card and connected to a conductive area surrounding the central opening in the card by a conductor in the form of a spiral and constituting a rotor plate for a variable capacitor in series with an inductance, the spiral conductors on cards of types (1) and (4) being circularly symmetrical whereby adjacent assembled cards of these types may be rotated with respect to each other without altering the mutual inductance therebetween; and conductive pins adapted to be inserted through the central openings in a plurality of assembled cards for conductively engaging the conductive area surrounding the central openings in selected ones of the cards of types (1), (3), and (4) to electrically interconnect the circuit components on such cards while permitting relative rotation of said cards about the longitudinal axis of said cylinder, one or more of said conductive pins constituting other terminals of said network.

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