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SHOJIRO NAKAHARA ET AL

3,334,318

STRIPLINE CIRCULATOR HAVING MEANS CAUSING ELECTROSTATIC
CAPACITANCE BETWEEN ADJACENT PAIRS OF TERMINALS TO
BE SUBSTANTIALLY EQUAL TO EACH OTHER

Filed Oct. 19, 1965

2 Sheets-Sheet 1

FIG. 1 PRIOR ART

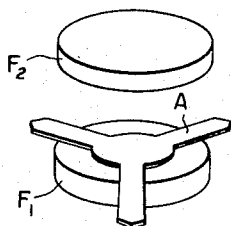


FIG. 2 PRIOR ART

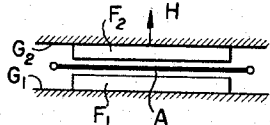


FIG. 3

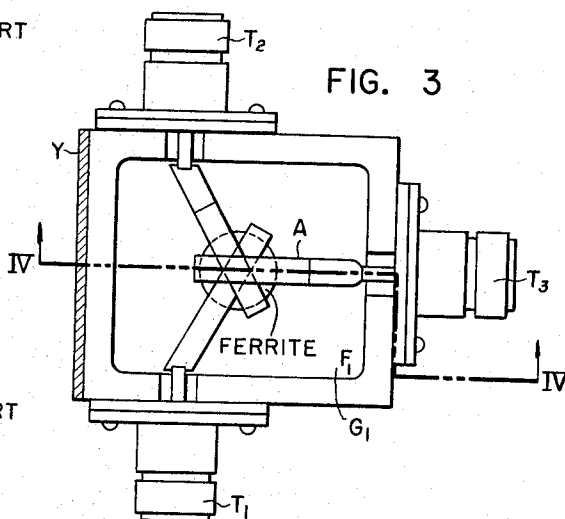


FIG. 5

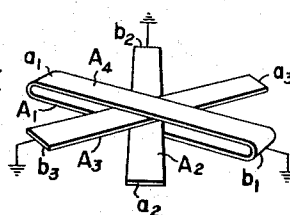


FIG. 4

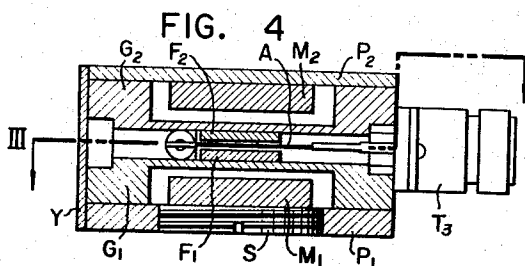


FIG. 6

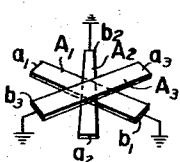


FIG. 7

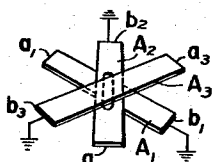
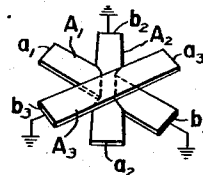


FIG. 8



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FIG. 9

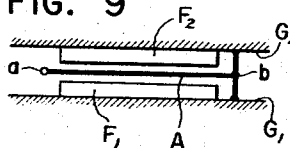


FIG. 11

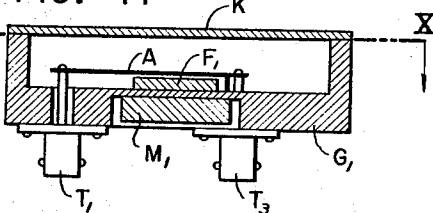


FIG. 10

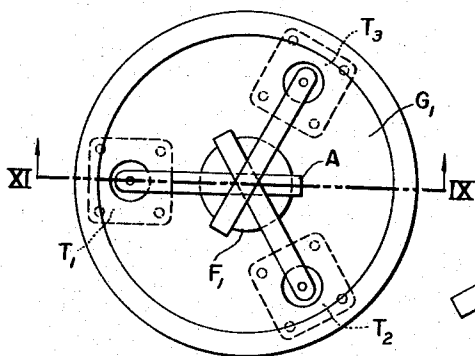


FIG. 12b

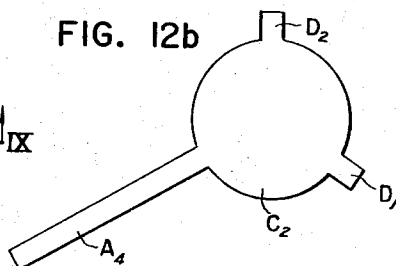


FIG. 12a

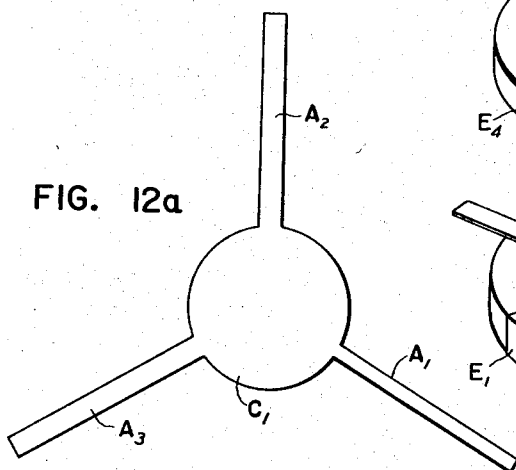
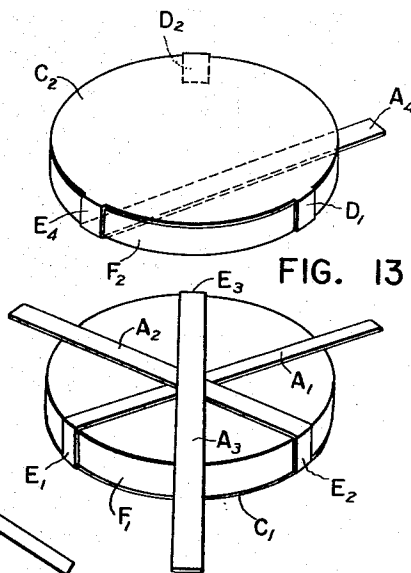


FIG. 13



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STRIPLINE CIRCULATOR HAVING MEANS CAUSING ELECTROSTATIC CAPACITANCE BETWEEN ADJACENT PAIRS OF TERMINALS TO BE SUBSTANTIALLY EQUAL TO EACH OTHER

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4 Claims. (Cl. 333—1.1)

ABSTRACT OF THE DISCLOSURE

Electric circulators having at least three strip lines in the form of thin strips successively stacked on one another at angles of 120 degrees with a thin insulating sheet interposed between each pair of adjacent strips at their junction to electrically insulate the strips from each other. Each strip line has one end connected to a common ground plate and the other end connected to an individual terminal. The circulators are characterized by means balancing stray capacitances between the terminal pairs. To this end, four strip lines are used such that a pair of aligned and spaced strip lines are connected at both ends together to provide a single strip line and the two remaining strip lines are interposed between the end strip lines such that all the four strip lines are stacked on one another at angles of 120 degrees. Alternatively when three strip lines are used, the intermediate strip line may have a suitably selected shape and dimension to cross the other strip lines with an area smaller than an area with which the remaining strip lines cross the intermediate strip. The circular is of a microstrip structure and a simple and effective method of producing a circulator including the above-mentioned four strip lines is taught.

This invention relates to improvements in an electronic circulator.

In general, electronic circulators of the type which the invention concerns utilize the phenomena that when a body of ferromagnetic material such as a ferrite is disposed in a high-frequency rotating magnetic field the effective permeability thereof varies in magnitude. Therefore the electronic circulators should be, of course, of such a construction that at least a high-frequency rotating magnetic field is established in the ferromagnetic material involved. For example, one type of conventional electronic circulators includes a sheet of electrically conductive material in the form of a trifurcation or Y-shape sandwiched between a pair of circular disks of any suitable ferromagnetic material such as a ferrite or garnet having a static magnetic field applied thereto in the common axial direction of both disks with the assembly of conductive sheets and ferromagnetic disks being sandwiched between a pair of ground plane conductor plates.

In the devices of the type just described, the trifurcated conductive member acts as a distributed parameter circuit. This known type of device has a disadvantage in that the device is large in dimension provided that the same is to be operated within a range of relatively low frequencies, for example, in the VHF (very high frequency) or UHF (ultra high frequency) band. In order to avoid that disadvantage, another type of the electronic circulators has been previously constructed on the basis of the lumped parameter principle. For example, a hybrid set is associated with a circular disk of any suitable ferro-

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magnetic material and serves as three input and output conductors. This measure does not provide a small dimension and good characteristics of the devices.

In order to minimize a dimension of an electronic circulator, it is very desirable to dispose a member of ferromagnetic material involved in a stronger high-frequency rotating magnetic field and to exert that magnetic field upon the ferromagnetic member over its area as great as possible.

A principal object of the invention is to provide a new and improved electronic circulator substantially reduced or minimized in dimension.

Another object of the invention is to provide a new and improved electronic circulator using microstrips and having a miniature dimension and excellent characteristics.

With the above cited objects in view, the invention resides in an electronic circulator comprising a ground plane conductor member, a plate of ferromagnetic material disposed upon the grounded conductive member, at least three strips of electrically conductive material disposed upon the plate of ferromagnetic material so as to be electrically insulated from each other and from the latter and crossing each other at angles of substantially 120 degrees. Each of the three strips of electrically conductive material including one end electrically connected to the ground plane conductor member and the other and providing an input and output terminal, and means are provided for applying to the ferromagnetic plate a direct current magnetic field traversing the ferromagnetic material plate and those portions of the conductive strips crossing each other.

In a preferred embodiment of the invention, the conductor group consists of four electrically conductive members in the form as above described and disposed in the manner as above described, and a pair of the outermost conductive strips are equal in width to each other, and disposed in aligned relationship with those two strips connected together at both ends.

Advantageously, the conductor group consists of three electrically conductive members identical to those as above described and disposed in the manner as above described and the intermediate conductive strip crosses either of the remaining strips with an area smaller than an area with which either of the remaining strips cross the intermediate strip.

The invention also provides a method of producing an electronic circulator as outlined above, comprising the steps of preparing a pair of conductor members of foil copper with a suitable dimension and a pair of ferromagnetic plates of circular shape in predetermined dimensions, forming a first star-shaped, electrically conductive element of foil copper including a central portion corresponding in both shape and dimension to said ferromagnetic plate, and three long relatively wide arms radially extending at angles of substantially 120 degrees therefrom, and a second star-shaped foil copper element having a central portion corresponding in both shape and dimension to the ferromagnetic plate and two shorter arms and one longer arm radially extending at angles of substantially 120 degrees therefrom, disposing one of said ferromagnetic plates concentrically on the central portion of said first star-shaped element and then successively folding said three long arms along the side surface of said first ferromagnetic plate and over the opposite face of the latter while electrically insulating sheets are inserted between the adjacent arms to insulate the crossed portions of the arms from each other disposing the second ferromagnetic plate concentrically on said central portion of said second star-shaped conductive element and then folding two shorter arms and the longer arm along

the side surface of said second ferromagnetic plate along the side surface and over the opposite surface of said second ferromagnetic plate assembling those two ferromagnetic plates with respective conductive elements so as to align that folded arm portion of said first element nearest to the associated ferromagnetic plate with the folded longer arm portion of said second element, connecting the folded shorter arms from said second element to the arms from said first element corresponding in position to the shorter arms at those portions of the arms from the first plate disposed on the side surface of the latter, and operatively associating the assembly of ferromagnetic plate and conducting elements with the pair of ground plane conductor members and previously prepared magnet means of known construction in the known manner.

The invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is an exploded perspective view of an electronic Y circulator constructed in accordance with the teachings of prior art;

FIG. 2 is a diagrammatic view of the circulator shown in FIG. 1 and illustrates the position of the electrically conductive portion relative to the remaining parts after the device has been assembled;

FIG. 3 is a plan view, partly in section of an electronic circulator constructed in accordance with the teachings of the invention with the section taken along the line III—III of FIG. 4;

FIG. 4 is an elevation section view of the circulator illustrated in FIG. 3 with the section taken along the line IV—IV of FIG. 3;

FIG. 5 is a perspective view in enlarged scale of a group of electrically conductive strips illustrated in FIGS. 3 and 4;

FIGS. 6 through 8 are views of several modifications of the group of electrically conductive strips illustrated in FIG. 5;

FIG. 9 is a view similar to FIG. 2 but illustrating the group of conductive strips shown in any one of FIGS. 5 through 8;

FIG. 10 is a section view of another embodiment of the invention taken along the line X—X of FIG. 11;

FIG. 11 is a section view of the embodiment of FIG. 10 taken along the line XI—XI of FIG. 10;

FIGS. 12a and b are plan views of electrically conductive elements constructed in accordance with the teachings of the invention; and

FIG. 13 is an exploded perspective view illustrating an electronic circulator being assembled in accordance with the teachings of the invention.

Throughout the figures the like reference characters designate similar components.

Referring now to FIGS. 1 and 2, there is illustrated an electronic circulator of the prior art type. As shown, a pair of circular plates F_1 and F_2 made of any suitable ferromagnetic material such as ferrite or garnet has sandwiched therebetween a strip A of electrically conductive material in the form of a trifurcation. Then the ferromagnetic plates F_1 and F_2 and the conductive strip A sandwiched therebetween are sandwiched between a pair of ground plane conductors G_1 and G_2 as diagrammatically shown in FIG. 2. The device thus prepared is arranged to have a magnetic field H applied thereto in the direction of the arrow illustrated in FIG. 2. The operation of the device just described is familiar to those skilled in the art and need not be described.

As previously described, however, the electronic circulator such as shown in FIGS. 1 and 2 is disadvantageous in that if the same is to be operated in a VHF (very high frequency) or a UHF (ultra high frequency) band it becomes inevitably large in dimension because the conductive strip functions as a distributed parameter element. Further its characteristics are generally bad. The inven-

tion contemplates eliminating the abovementioned disadvantages.

Referring now to FIGS. 3 and 4, there is illustrated an electronic circulator constructed in accordance with the teachings of the invention. An arrangement illustrated comprises a pair of ground plane conductor members G_1 and G_2 of U-shaped section disposed in spaced parallel relationship with the recessed surfaces thereof facing externally. The conductor member may be preferably of a rectangular shape. Rigidly secured on the opposed surfaces of the ground plane conductor members G_1 and G_2 are a pair of circular plates F_1 and F_2 of any suitable ferromagnetic material such as a ferrite or garnet with a space formed therebetween having a predetermined width. Positioned within the abovementioned space is an electrical conductor group generally designated by the reference character A and including three strips of any suitable electrically conductive material crossing each other at angles of substantially 120 degrees. Each of the conductive strips has one end portion projecting beyond the periphery of each ferromagnetic plate F_1 or F_2 and electrically connected to different one of terminals T_1 , T_2 and T_3 electrically insulated from and attached on three side surfaces of the rectangular ground plane conductor members G_1 and G_2 by any conventional means such as screws. As will be readily understood by those skilled in the art, these terminals T_1 , T_2 and T_3 can act as either input or output terminals as the case may be.

In order to establish a magnetic field in the material for the circular ferromagnetic plates F_1 and F_2 , magnets M_1 and M_2 are disposed in a recess formed on the external surface of each of the ground plane conductor members G_1 and G_2 and rigidly secured to a magnetic pole plate P_1 or P_2 of any suitable magnetic material attached on the external surface of the associated conductor member G_1 or G_2 . One of the magnets, in this case, the lower magnet M_1 is preferably attached to a screw member S of the same material as the pole plate adjustably screwed into a threaded central opening formed on the lower pole plate P_1 . It will be appreciated that screwing of the screw member S into and out the threaded opening on the lower pole plate P_1 causes movement of the magnet M_1 attached thereto, toward and away from the associated ground plane conductor member G_1 respectively thereby to control the strength of the magnetic field in the material for the ferromagnetic plates F_1 and F_2 . Therefore the screw member S serves to control the strength of the magnetic field. A plate Y of any suitable magnetic material is provided to magnetically interconnect the pair of pole plates P_1 and P_2 as shown in FIGS. 3 and 4.

According to the teachings of the invention, the conductor group A as above described may be preferably of a construction as illustrated in FIG. 5. More specifically, the conductor group A includes three strips A_1 , A_2 and A_3 of any suitable electrically conductive material having a common width and laying one upon another in electrically insulating relationship while crossing one another at angles of substantially 120 degrees, and an auxiliary strip A_4 identical in material and shape to the strips A_1 , A_2 and A_3 . The auxiliary strip A_4 is disposed substantially parallel to the lowermost strip A_1 and above the uppermost strip A_3 with the strips A_4 and A_1 connected together at both ends. Each of the conductive strips A_1 , A_2 and A_3 has one end a_1 , a_2 or a_3 connected to the individual terminal T_1 , T_2 or T_3 and the other end b_1 , b_2 or b_3 connected to the ground plane conductor members G_1 and G_2 .

With the arrangement illustrated in FIG. 5, the conductive strips A_1 , A_2 and A_3 act as lumped parameter elements with respect to the ferromagnetic plates F_1 and F_2 . This leads to an advantage that the conductive group A can become small-sized even in the case of the low operating frequencies.

However, if only three conductive strips A_1 , A_2 and A_3 having a common width constitute the conductive group A then a capacitance between any pair of three strips will not be equal to that between another pair of the strips and therefore the degree of isolation as viewed from the respective terminals is not balanced. On the other hand, the degree of isolation between a certain pair of terminals will be higher while the decoupling degree of isolation between another pair of terminals will be lower.

In contrast, the provision of the auxiliary strip A_4 according to the teachings of the invention permits the conductive strips A_1 , A_2 and A_3 connected respectively to the terminals T_1 , T_2 and T_3 to have the equal number of the strips disposed adjacent the same. In the arrangement illustrated each strip has two strips disposed adjacent the same. Therefore the capacitance between each pair of the strips will be equal to that between other pair of the strips and the degrees of isolation between pairs of strips will become higher and uniform.

The conductor group A may be preferably constructed through the steps as illustrated in FIG. 13. First prepared from a foil of any suitable conductive material such as copper are a first conductive element including a central portion C_1 corresponding in shape to the associated ferromagnetic plate and three long arms A_1 , A_2 and A_3 radially extending at angles of substantially 120 degrees therefrom (see FIG. 12a) and a second conductive element including a central portion C_2 identical in shape to the central portion C_1 of the first element and two shorter arms D_1 and D_2 and one longer arm A_4 radially extending also at angles of 120 degrees therefrom (see FIG. 12b). In this case, since it is assumed that the ferromagnetic plates F_1 and F_2 are circular as in the arrangement of FIGS. 3 and 4, the central portions C_1 and C_2 are of a circle having the same radius as the ferromagnetic plates.

Then the ferromagnetic plate F_1 is disposed on the central portion C_1 of the first conductive element and three arms A_1 , A_2 and A_3 are successively folded along the edge surface of the ferromagnetic plate F_1 and over the opposite face of the latter as shown on the lower portion of FIG. 13. Similarly the ferromagnetic plate F_2 is disposed on the central portion C_2 of the second conductive element and the shorter arms D_1 and D_2 and the longer arm A_4 are folded along the edge surface of the ferromagnetic plate. The longer arm A_4 is further folded over the opposite face of the ferromagnetic plate F_2 as shown on the upper portion of FIG. 13. In this case it is to be noted that those portions of the arms A_1 , A_2 and A_3 folded over the opposite surface of the ferromagnetic plate F_1 should be suitably electrically insulated from the latter and each other while that portion of the longer arm A_4 folded over the opposite surface of the ferromagnetic plate F_2 should be suitably electrically insulated from the latter. Also it is to be noted that in order to allow the arms A_1 , A_2 , A_3 and A_4 to project beyond the periphery of the associated ferromagnetic plates F_1 and F_2 in folded state, they should have a length greater than the sum of the thickness and diameter of the plates and that the shorter arms D_1 and D_2 should have a length slightly greater than the thickness of the ferromagnetic plate.

The ferromagnetic plate F_2 having the second conductive element folded thereon is put upon the ferromagnetic plate F_1 having the first conductive element folded thereon in such a manner that the folded along arms are sandwiched between the two plates while the folded arm A_1 located nearest the plate F_1 aligns with the folded arm A_4 on the plate F_2 with the arm A_4 suitably insulated from the outermost folded arm A_3 . When both plates F_1 and F_2 are associated in the manner just described it will be seen that the folded shorter arms D_1 and D_2 align with the portions E_2 and E_3 respectively of the folded arms A_2 and A_3 positioned on the edge surface of the plate F_1 . The conductive group A associated with both ferro-

magnetic plates F_1 and F_2 is completed by soldering the arms A_1 and A_4 together at both ends and also soldering the extremities of the shorter arms D_1 and D_2 to those portions E_2 and E_3 of the arms A_2 and A_3 disposed on the edge surface of the plate F_1 .

Thus the conductive group A operatively coupled to the ferromagnetic plates F_1 and F_2 can now be operatively associated with the ground plane conductive members G_1 and G_2 including the magnets M_1 and M_2 so as to bring the central portions C_1 and C_2 of the conductive elements into electrical contact with the ground plane conductor members G_1 and G_2 respectively followed by the electrical connection of the free ends of the arms A_1 , A_2 and A_3 to the respective terminals T_1 , T_2 and T_3 .

The steps of assembling the conductive group as above described in conjunction with FIGS. 12 and 13 is particularly advantageous in that the angles at which the conductive strips A_1 , A_2 and A_3 cross each other can be precisely controlled for the reason that such crossing angles are determined by the shape of the conductive elements as previously described and in that the device can be very simply constructed only through the folding and soldering operations.

The conductive group A may be variously changed in construction as shown in FIGS. 6 through 8.

An arrangement shown in FIG. 6 is similar to that illustrated in FIG. 5 excepting that the intermediate strip A_2 is smaller in width than the upper and lower strips A_1 and A_3 with the auxiliary strip A_4 omitted. The width of the intermediate strip A_2 is selected such that a capacitance between each pair of the terminals is substantially equal to that between other pair of the terminals. In order to equal substantially the capacitances between the pairs of terminals to each other, the intermediate strip A_2 may be provided with a slot on that portion thereof crossing the remaining strips as shown in FIG. 7. Alternatively only that portion of the intermediate strip A_2 crossing the remaining strips may be reduced in width as shown in FIG. 8.

FIG. 9 shows diagrammatically a circulator including the conductor group A illustrated in any of FIGS. 5 through 8.

Referring now to FIGS. 10 and 11, there is illustrated a modification of the invention applied to a microstrip line structure including a single ground plate. The main difference between the arrangements illustrated in FIGS. 10 and 11 and FIGS. 3 and 4 is that in FIGS. 10 and 11, a cover plate K substitutes the upper ground plane conductor member G_2 and ferromagnetic plate F_2 shown in FIGS. 3 and 4. The other components are substantially the same as those illustrated in FIGS. 3 and 4.

The arrangement illustrated in FIGS. 10 and 11 may include a conductive group shown in any one of FIGS. 5 through 8.

While the invention has been described as including a conductive group having only the construction illustrated in any of FIGS. 5 through 8 it is to be understood that the conductive group may have such a construction as one portion thereof with the satisfactory results. For example, it is assumed that six insulated conductive strips cross one another in the manner as previously described and that a first and a fourth strip are connected to a first terminal, a second and a fifth strip connected to a second terminal and a third and a sixth strip are connected to a third terminal. Then a seventh or auxiliary strip may lie upon the sixth strip in parallel to the first strip and is connected to the first strip.

The invention has several advantages. For example, since widening of the conductive strip operating on the associated ferromagnetic disk does not lead to unbalance among the capacitances as viewed from the respective terminals the effect of high-frequency magnetic field upon the ferromagnetic disk can increase. Thus the invention provides improved electronic circulators small in dimension and excellent in characteristics.

While the invention has been shown and described in conjunction with certain preferred embodiments thereof it is to be understood that various changes and modifications may be made without departing from the spirit and scope of the invention.

What we claim is:

1. An electric circulator comprising a group of electrical conductors comprising at least three electrically conductive wide strip members disposed crossing one another at angles of substantially 120 degrees and insulated each from the other, a plate of ferromagnetic material disposed in contact with one side of one of said strip members of said group of electrical conductors, a ground conductor disposed on a side of said ferromagnetic plate opposed to said one strip of said group of electrical conductors, magnet means for applying across said ferromagnetic plate and across overlying portions of said electrically conductive strip members crossing one another a direct current magnetic field in a direction transverse to said ferromagnetic plate and to said crossed portions of said electrically conductive strip members, each of said electrically conductive strip members having one end connected to said ground conductor and for each other end of said strip members an individual terminal connected thereto, and means causing electrostatic capacitance between adjacent pairs of said terminals to be substantially equal to each other.

2. An electric circulator according to claim 1, in which said group of electrical conductors consists of four electrically conductive strip members each crossing an adjacent one of said strips at angles of substantially 120 degrees in insulated relationship, and wherein a pair of outermost conductive strip members are equal in width to each other and are disposed aligned in parallel relationship and connected together at both ends thereof.

3. An electric circulator according to claim 1, in which said group of electrical conductors consists of only three electrically conductive strip members crossing one another at angles of substantially 120 degrees and in which an intermediate one of said conductive strip members comprises one of said crossed portions having an area

smaller than areas of the crossed portions of each of the remaining strip members.

4. An electronic circulator comprising, a first ferromagnetic plate, a first thin, flat, conductive member on said first plate and insulated therefrom and having a central portion corresponding in shape and dimension to said first ferromagnetic plate and the strip arms extending from said central portion at angles of 120 degrees from each other, said three arms being disposed folded over the edge of said first plate and disposed overlying each other on a side of said first plate opposite to a side on which said central portion is disposed and extending across said first plate side opposite to the side on which said central portion is disposed, a second ferromagnetic plate, a second, thin, flat, conductive member on said second plate and insulated therefrom and having a central portion corresponding in shape and dimension to said second plate and having one long strip arm and two shorter strip arms extending from said central portion at 120 degrees from each other folded over the edge of said second plate with only said one long arm disposed extending across a side of said second plate opposite to a side on which said central portion of said second conductive member is disposed, said first plate and said second plate being disposed with said one long arm overlying an arm on said first plate with the central portions disposed on outermost sides of said plates, magnetic means applying across said plates and overlying portions of said strip arms a direct current magnetic field in a direction transverse to said plates and to said strip arms, means connecting said arms in a configuration effective to cause said plates and said conductive members to function in operation as an electronic circulator.

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P. L. GENSLER, *Assistant Examiner*.