United States Patent

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[15] **3,680,134**

[45] **July 25, 1972**

[54] LOOP ANTENNA WITH SPACED IMPEDANCE ELEMENTS

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[22] Filed: **July 21, 1971**

[21] Appl. No.: **164,529**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 856,281, Sept. 9, 1969, Pat. No. 3,573,832.

[52] **U.S. Cl.** **343/740**, 343/744

[51] **Int. Cl.** **H01q 11/12**

[58] **Field of Search** 343/739–744, 748

[56] **References Cited**

UNITED STATES PATENTS

3,573,832 9/1969 Callaghan 343/742

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[57] **ABSTRACT**

A directional antenna comprises a pair of semi-circular antenna members arranged to form a loop, each of the antenna members includes arcuate upper and lower wire-like conductive elements which are at a small distance from each other, at the middle of the respective antenna member, and at a relatively large distance from each other at the ends of the antenna member, and interconnecting elements are connected to the upper and lower conductive elements at the ends of each antenna member, and are preferably integral wire-like extensions of the upper and lower elements. Output terminals are connected to one of the antenna members at the narrow portion thereof, and an impedance acting as a dummy load is connected to the narrow portion of the other antenna member. The interconnecting elements at the adjacent ends of the antenna members being held in opposing spaced relation to form impedances therebetween for determining the distribution of current flow in the directional antenna.

11 Claims, 14 Drawing Figures

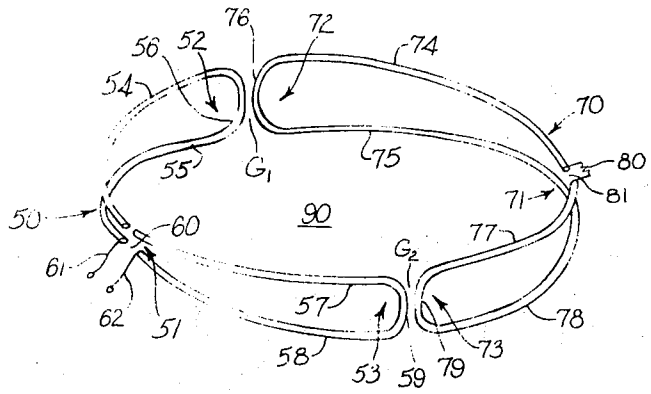


Fig 1

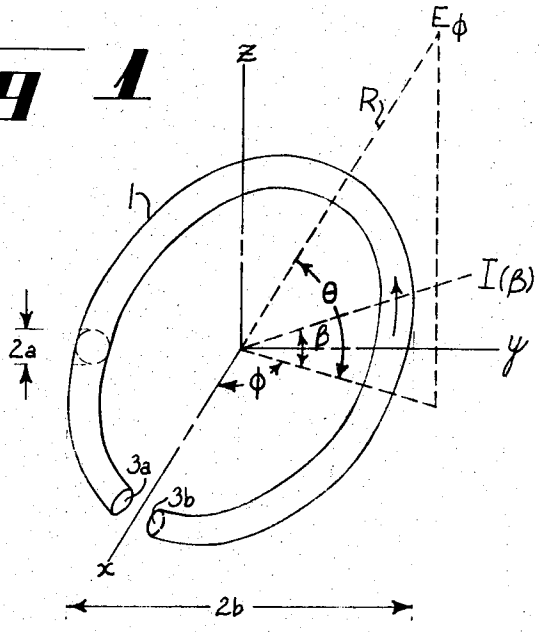
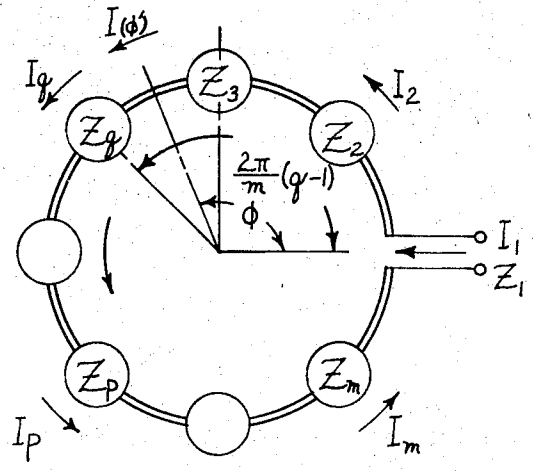
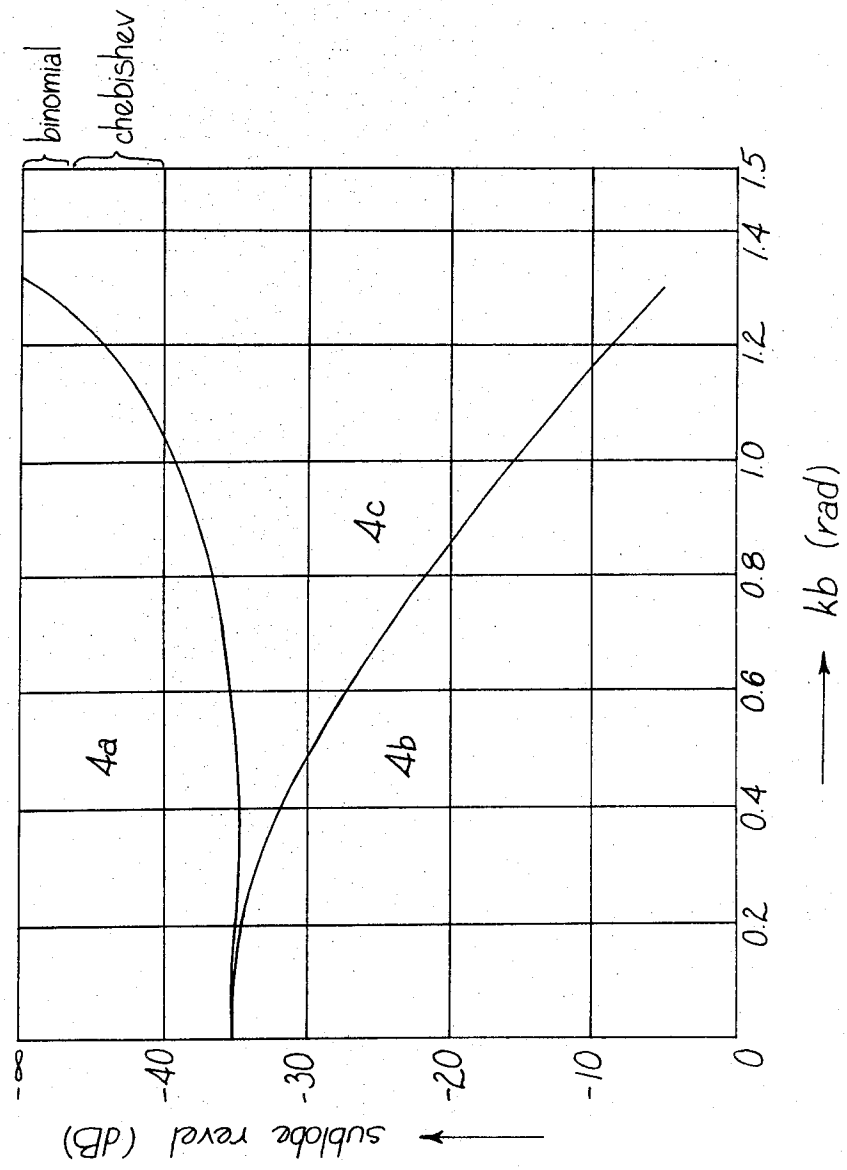


Fig 2



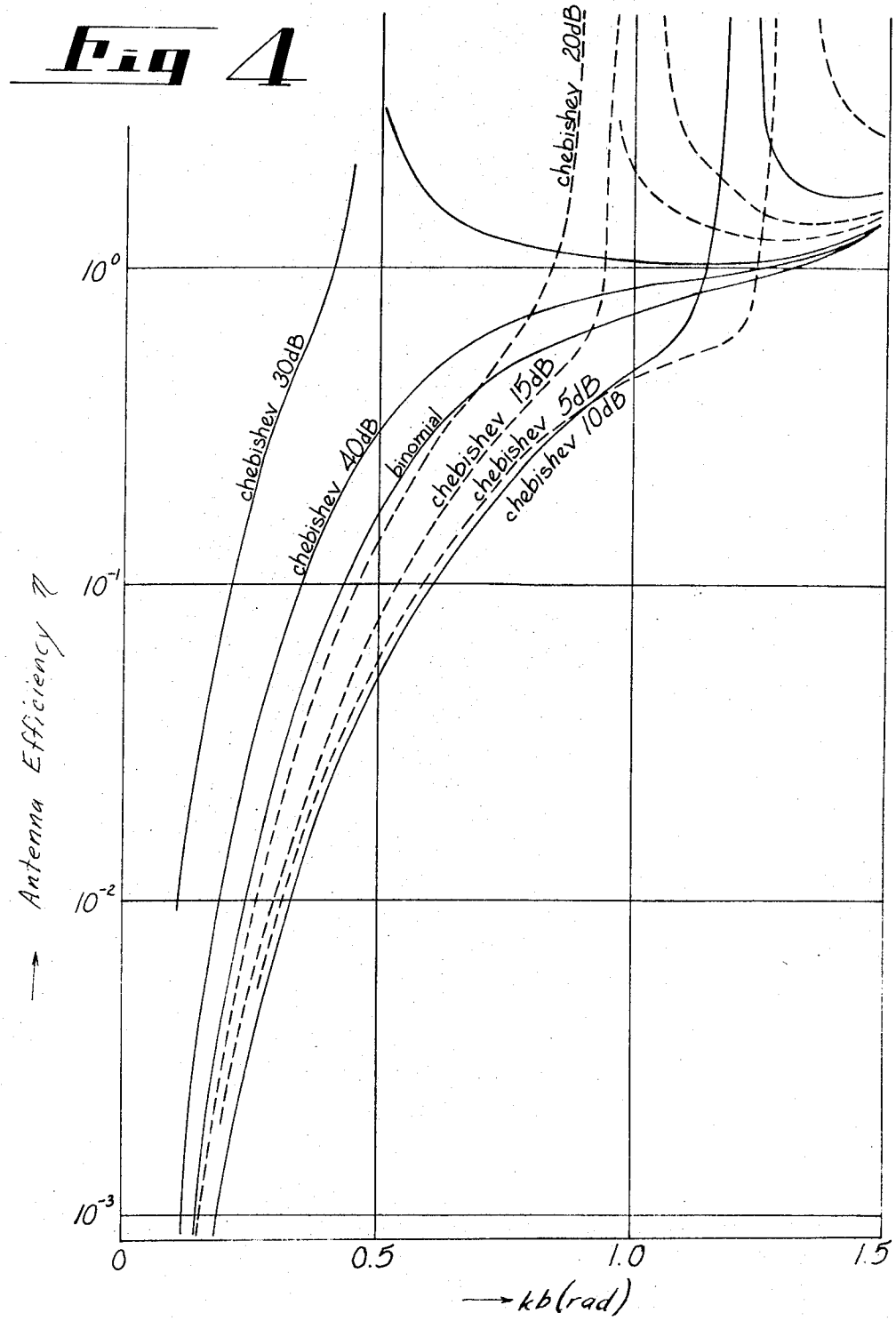
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Fig. 1



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Fig 4



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Fig 5

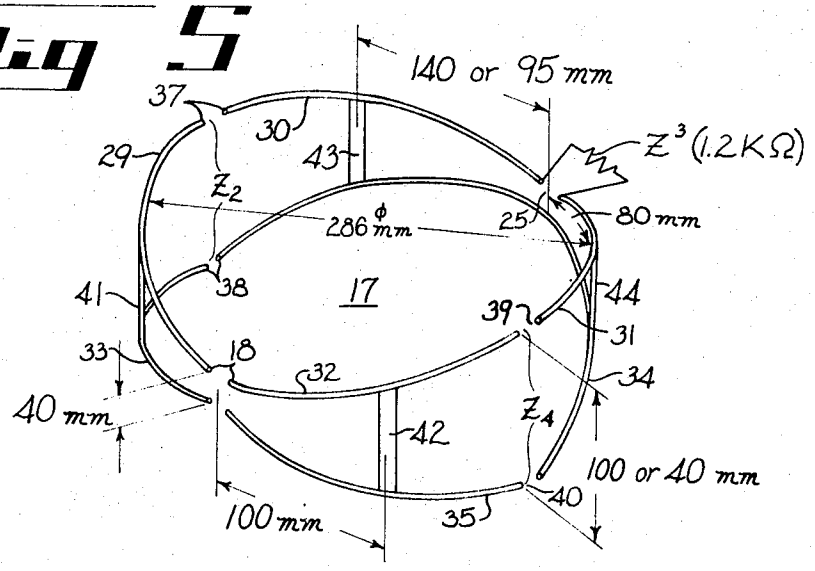


Fig 6

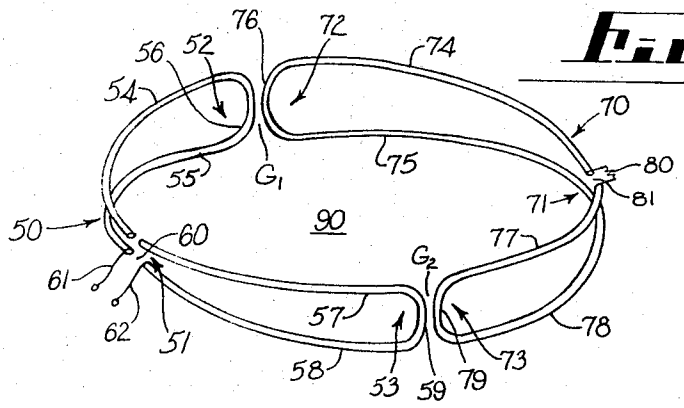
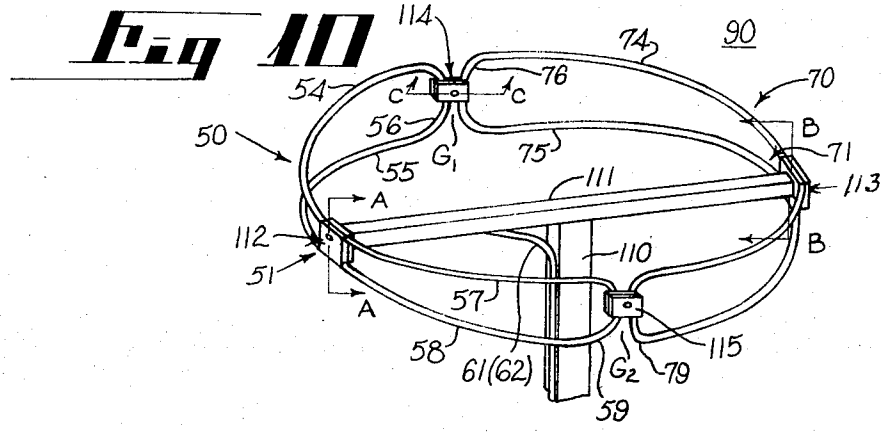


Fig 10



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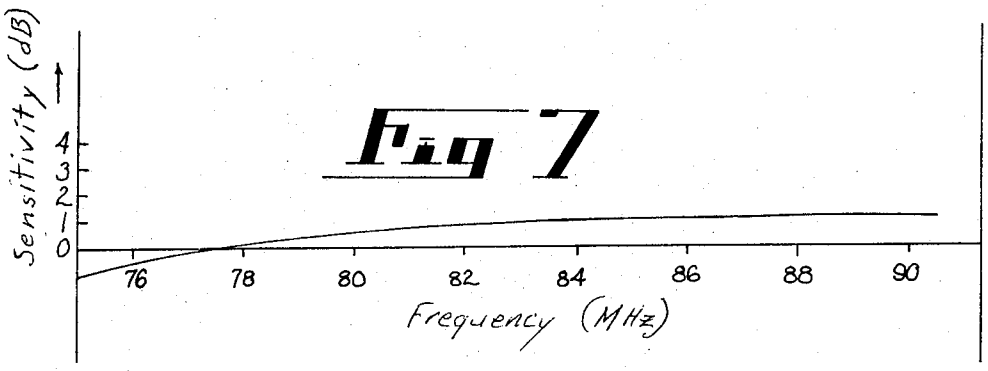
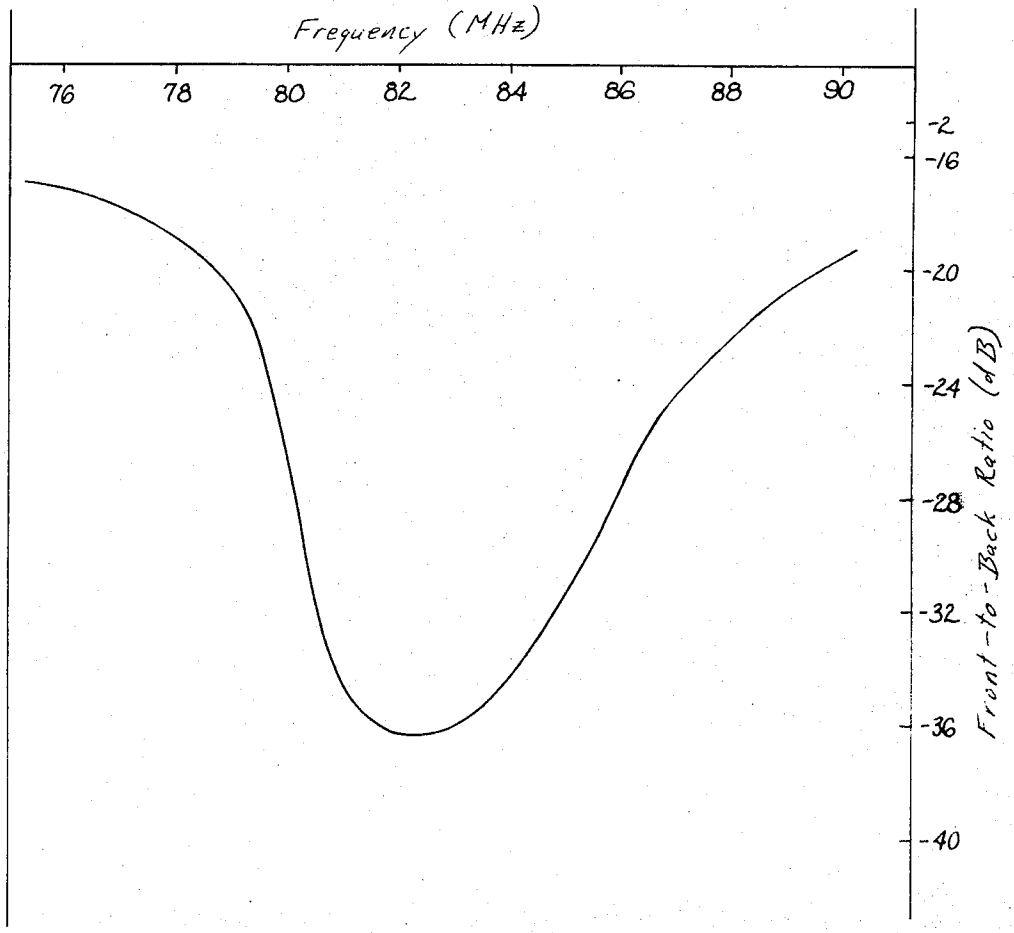


Fig 7

Fig 8



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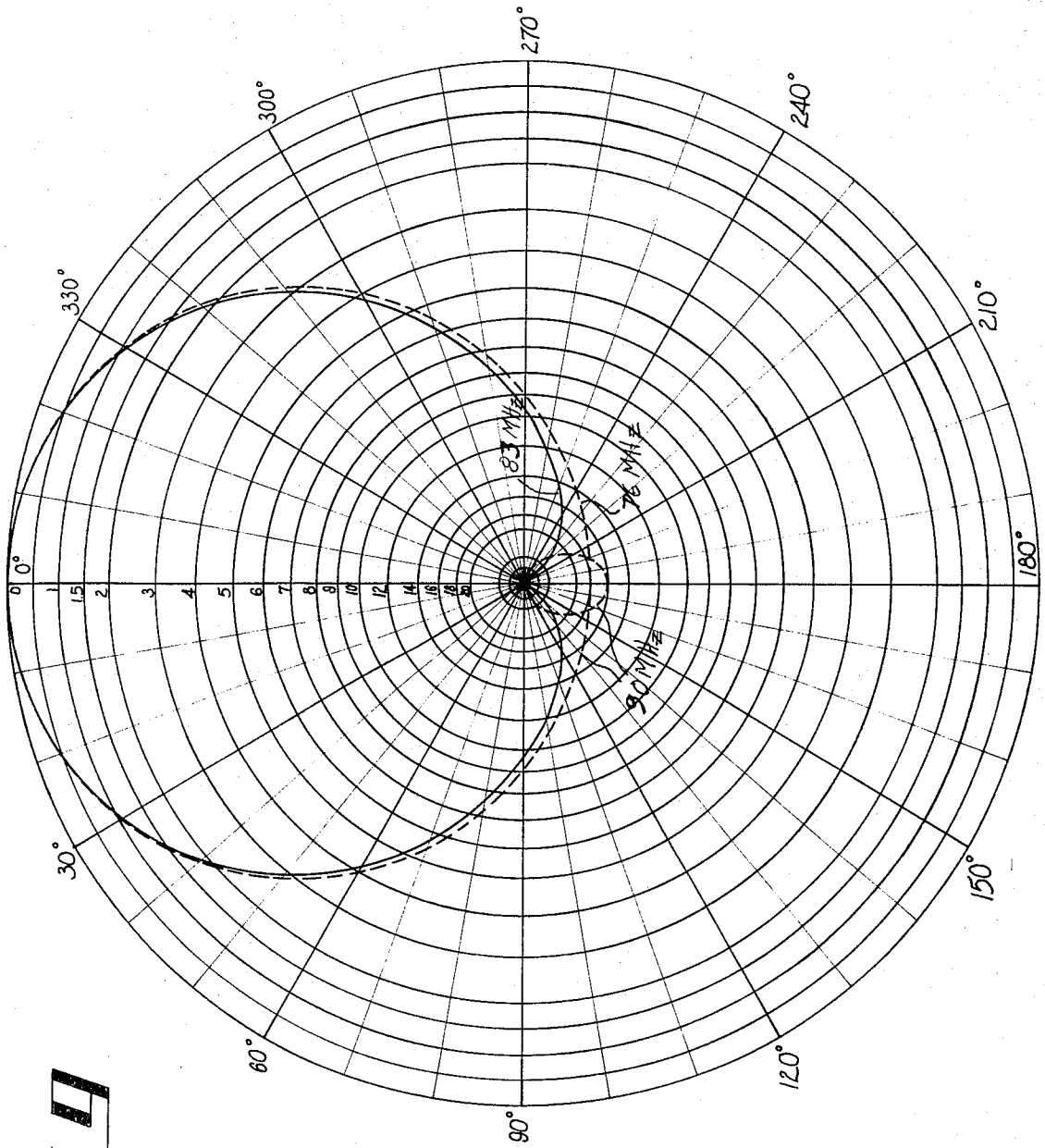


Fig. 4

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Fig 11

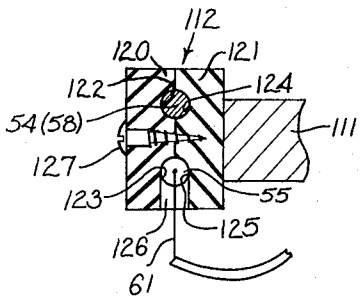


Fig 12

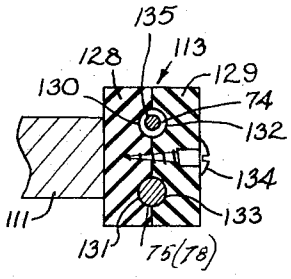


Fig 13

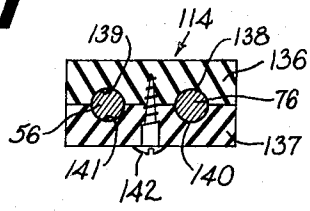
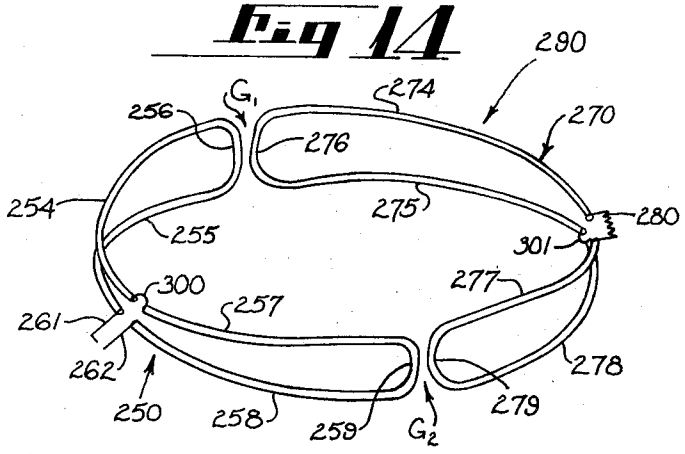


Fig 14



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LOOP ANTENNA WITH SPACED IMPEDANCE ELEMENTS

This application is a continuation-in-part of application Ser. No. 856,281, filed Sept. 9, 1969, now U.S. Pat. No. 3,573,832.

This invention relates to directional antennas, and more particularly to antennas specifically suited for use with FM radio and television receivers.

With the development of transistors, semiconductor integrated circuits and the like, electronic communication instruments have been increasingly miniaturized, and a demand has arisen for a miniaturized antenna for use with such instruments. The directivity of an antenna suitable for such use has to be sharp so as to provide excellent communication unaffected by the interference of multiple reflected waves, noise and so on in cities and mountain districts. Further, communication instruments, such as FM radio and television receivers, require antennas of sharp directivity over a wide frequency band. To comply with this requirement, the broad band Yagi antenna has been proposed, but this type of antenna is inherently bulky and hence is not suitable for use with portable television receivers.

Accordingly, an object of this invention is to provide an antenna of sharp directivity.

Another object is to provide an antenna which is small in size and of sharp directivity.

Still another object is to provide a small antenna having sharp directivity over a broad frequency band.

A further object of this invention is to provide an antenna which is suitable for use with FM radio and television receivers.

In accordance with an aspect of this invention, a directional antenna comprises a pair of semi-circular antenna members arranged to form a loop, each of the antenna members including arcuate upper and lower wire-like conductive elements having a relative small distance therebetween at the middle of the respective antenna member and a relatively large distance between the conductive elements at each of the ends of the antenna member, and interconnecting elements, preferably in the form of integral extensions of the wire-like conductive members, extending between, and connected to the latter at the ends of the respective antenna member. Output terminals are connected to one of the antenna members at a location where the upper and lower conductive elements are at the small distance from each other, and an impedance acting as a dummy load is connected at a similar location to the other antenna member. The interconnecting elements at adjacent ends of the antenna members are held in opposing, spaced relation to form impedances determining the distribution of current flow in the antenna.

The above, and other objects, features and advantages of this invention will be apparent in the following detailed description of illustrative embodiments which is to be read in connection with the accompanying drawings, wherein:

FIG. **1** is a perspective view of a loop antenna to which reference will be made in explaining the present invention;

FIG. **2** is a schematic plan view of a loop antenna to which reference will be made in explaining this invention;

FIG. **3** is a graph showing the relation of the sub-lobe level characteristic to the diameter of a loop;

FIG. **4** is a graph showing the relation of antenna efficiency characteristic to respective approximations;

FIG. **5** is a perspective view showing an antenna adapted to provide desired directivity over a wide frequency band-width, and to which reference will be made in explaining this invention;

FIG. **6** is a schematic perspective view similar to FIG. **5**, but showing an antenna in accordance with an embodiment of this invention;

FIG. **7** is a graph showing the frequency-sensitivity characteristic of the antenna depicted in FIG. **6**;

FIG. **8** is a graph showing the relationship of frequency to the front-to-back ratio for the antenna of FIG. **6**;

FIG. **9** is a graph showing the directional patterns of the antenna depicted in FIG. **6**;

FIG. **10** is a perspective view showing a practical embodiment of the antenna of FIG. **6**;

FIG. **11** is a sectional view taken along the line A—A on FIG. **10**;

FIG. **12** is a sectional view taken along the line B—B on FIG. **10**;

FIG. **13** is a sectional view taken along the line C—C on FIG. **10**; and

FIG. **14** is a schematic perspective view similar to FIG. **6**, but showing another embodiment of this invention.

Referring to the drawings in detail, and initially to FIG. **1**, it will be seen that the loop antenna **1** is there shown to have a diameter **2***b* and to be formed of an arcuate conductive member of circular cross-section having a diameter **2***a*. A current is supplied to loop **1** at terminals **3***a* and **3***b*. When the loop **1** is arranged so that its plane lies in the plane defined by the x and y axes of rectangular coordinates x, y and z with the center of the loop **1** at the origin O and a certain current distribution $I(\beta)$ exists on the loop **1**, a radiation electric field $E\phi$ (R, θ, ϕ) based upon the current distribution is expressed by the following equation:

$$E_\phi(R,\theta,\phi)=\frac{1}{4\pi J\omega\epsilon}\int_{-\chi}^{\chi} I(\beta)k^2b\cos(\phi-\beta)4\pi G(R,\theta,\phi,b,\beta)d\beta \tag{1}$$

where $k=2\pi/\lambda$.

$$G(R,\theta,\phi)=\frac{e^{-Jk R'}}{4\pi R}\left\{Jo(kb\sin\theta)+2\sum_{m=1}^{\infty} e^{J\frac{m\pi}{2}}\cos m(\phi-\beta)Jn(kb\sin\theta)\right\} \tag{2}$$

When the current distribution $I(\beta)$ and the directional pattern of the loop antenna are respectively developed into Fourier series of cos $m\phi$, the following relation is established between coefficients im and Am of their terms:

$$im=\frac{8J}{kbS}\cdot\frac{Am}{e^{J\left|\frac{m-1}{2}\right|\pi}J_{|m-1|}(kb\sin\theta)+e^{J\frac{m+1}{2}\pi}J_{m+1}(kb\sin\theta)} \tag{3}$$

where $\rho=\sqrt{\mu o/\epsilon_o}$.

Since the terms of both Fourier series are the same in number, the directional pattern $D(\theta, \phi)$ and the current distribution $I(\phi)$ can be expressed as follows:

$$D(\theta,\phi)=\sum_{n=1}^{\nu} An\cos n\phi \tag{4}$$

$$I(\phi)=\sum_{n=0}^{\nu} i_n\cos n\phi \tag{5}$$

Further, if a power source connected to the terminals **3***a* and **3***b* is expressed in the form of a δ function and the loop **1** is a perfect conductive member, a current $I_0(\phi)$ in the loop **1** is as follows:

$$I_0(\phi)=\frac{V_1}{J\pi\rho}\sum_{n=-\infty}^{\infty}\frac{e^{Jn\phi}}{\alpha_n} \tag{6}$$

where

$$\alpha_n=\frac{1}{2\pi}\int_{-\pi}^{\pi}\frac{e^{-JkbR(\phi)}}{R(\phi)}\left[\frac{\pi b}{\lambda}\left\{e^{-J(n+1)\phi}+e^{-J(n-1)\phi}\right\}\frac{\lambda n^2e^{-Jn\phi}}{2\pi b}\right]d\phi \tag{7}$$

If the loop antenna has impedance elements Z_2, Z_3,... Z_q,...Z_m of a number $(m-1)$ connected thereto so that the impedance elements and the terminals **3***a* and **3***b* are arranged at substantially equal intervals, as shown on FIG. **2**, then the electromotive forces at the impedance elements Z_2, Z_3,...Z_q, ...Z_m are as follows:

$$\begin{bmatrix} Z_1 \\ \vdots \\ Z_{\nu+1} \end{bmatrix} = j\pi\rho \begin{bmatrix} I_1 & & \\ & I_2 & 0 \\ & \ddots & \\ 0 & & I_{P+1} \end{bmatrix}^{-1} \begin{bmatrix} 1 & 2 & 2 & 2 & & 1 \\ 1 & 2\cos\frac{\pi}{\nu} & \cdots & 2\cos\frac{\nu-1}{\nu}\pi & & -1 \\ 1 & 2\cos\frac{2\pi}{\nu} & \cdots & 2\cos\frac{2(\gamma-1)}{\nu}\pi & & 1 \\ \vdots & \vdots & & \vdots & & \vdots \\ 1 & \cos\pi & \cdots & 2\cos(\gamma-1)\pi & & (-1)^{\gamma} \end{bmatrix} \begin{bmatrix} \alpha_0 & i_0 \\ \alpha_1 & i_{1/2} \\ \vdots & \vdots \\ \alpha_\gamma & i_{\nu 1/2} \end{bmatrix} \tag{13}$$

$$V_q = -Z_q I_q,\ I_q = I\left(2\pi\frac{q-1}{m}\right) \tag{8}$$

where $q = 1 - m$. Accordingly, it follows that

$$I'(\phi) = -\sum_{q=1}^{m} y_m(\phi, q) I_q Z_q \tag{9}$$

$$I_p = -\sum_{q=1}^{m} y_m(P, q) I_q Z_q \tag{10}$$

where

$$y_m(\phi, q) = \frac{1}{J\pi\rho} \sum_{n=-\infty}^{\infty} \frac{e^{J n\left(\phi - \frac{2\pi}{m}(q-1)\right)}}{\alpha_n}$$

$$y_m(P, q) = \frac{1}{J\pi S} \sum_{n=-\infty}^{\infty} \frac{e^{J\frac{2\pi n}{m}(P-q)}}{\alpha_n} \tag{11}$$

A desired current distribution, and consequently a desired directional pattern, can be obtained by selecting the impedance values of the impedance elements $Z_2, Z_3, \ldots Z_q, \ldots Z_m$ so that the current distribution of the antenna of FIG. 2 obtainable from the above equations (9) and (10) agrees with that of the equation (5). However, this requires an infinite number of impedance elements because equation (11) is an infinite series. Accordingly, suitable approximation is required in practice. If the sampling theorem is used, sampling is achieved at 2γ points between $0 \leqq \phi \leqq 2\pi$ of the distribution of the equation (5) and currents of impedance elements at the sampling points and those of the impedance elements $Z_2, Z_3, \ldots Z_m$ are made to be equal to one another. In this case the required number of the impedance elements is 2γ.

As a result of this, currents I_1 to I_m at the 2γ sampling points are specified and if $m = 2\gamma$, the current distribution given by the equations (9) and (10) can be rewritten as given below. In the case of a directional pattern symmetrical with respect to the terminals 3*a* and 3*b*,

$I_P = I_{m-P+2}$, $Z_P = Z_{m-P+2}$, $(2 \leqq p \leqq m/2)$

and $\alpha_n = \alpha_{-n}$, so that

$$\sum_{q=1}^{m} I_q Z_q \sin\frac{2P(q-1)\pi}{m} = 0$$

$$\cos\frac{2P(q-1)\pi}{m} = \cos\frac{2P(m-P+1)\pi}{m}$$

Accordingly, it follows from the equation (9) that

$$I'(\phi) = -\frac{I_1 Z_1 + 2\sum_{q=2}^{\gamma} I_q Z_q + I_{\gamma+1} Z_{\gamma+1}}{j\pi\rho d_0} - \frac{2}{j\pi\rho} \sum_{n=1}^{\infty} I_1 Z_1 + 2\sum_{q=2}^{\gamma} I_q Z_q \cos\frac{n(q-1)}{\gamma}\pi + (-1)^n I_{\gamma+1} Z_{\gamma+1}) \cdot \frac{\cos n\phi}{\alpha_n} \sum_{n=0}^{\infty} i_n' \cos n\phi \tag{12}$$

There are the following two methods for determining the impedance values of an input impedance Z_1 and the impedance elements Z_2 to Z_m from the equations (12) and (5). The one method is to put

$i_0 = i'_0, i_1 = i'_1, \ldots i_\nu = i'_\nu$

and solve the following equation:

The other method is to put

$$I_{(0)} = I'_{(0)},\ I\left(\frac{2\pi}{m}\right) = I_\mu\left(\frac{2\pi}{m}\right), \ldots I\left(\frac{2\pi}{m}(m-1)\right) = I'\left(\frac{2\pi}{m}(m-1)\right)$$

and solve the following equation:

$$\begin{bmatrix} Z_1 \\ \\ Z_m \end{bmatrix} = -\begin{bmatrix} I_1 & & \\ & I_2 & 0 \\ & & I_m \end{bmatrix}^{-1} \begin{bmatrix} y_m(l,l) & \cdots & y_m(l,m) \\ & & \\ y_m(m,l) & \cdots & y_m(m,m) \end{bmatrix}^{-1} \begin{bmatrix} I_1 \\ I_2 \\ I_m \end{bmatrix} \tag{14}$$

Then, the value of each impedance means is calculated from the equation (14). Expressing the horizontal level pattern in the form of a linear polynominal of cos ϕ, the directivity, the current distribution and the relation between their coefficients are given from the equations (3), (4) and (5) as follows:

$$D(\phi) = A_0 + A_1 \cos\phi \tag{15}$$

$$I(\phi) = i_0 + i_1 \cos\phi \tag{16}$$

$$i_0 = \frac{8}{kb\rho} \cdot \frac{A_0}{2J_1(kb)} \tag{17}$$

$$i_1 = \frac{8}{kb\rho} \cdot \frac{A_1}{J_0(kb) - J_2(kb)} \tag{18}$$

If admittances are defined as follows:

$$y_b = \frac{2}{J\pi\rho} \sum_{n=-\infty}^{\infty} \frac{1}{\alpha 2n} \tag{19}$$

$$y_u = \frac{2}{J\pi\rho} \sum_{n=-\infty}^{\infty} \frac{1}{\alpha 2n-1} \tag{20}$$

it follows that

$$y_2(1, 1) = \frac{y_b + y_u}{2},\ y_2(1, 2) = y(2, 1) = \frac{y_b - y_u}{2} \tag{21}$$

Accordingly, if one impedance means Z_2 is connected to the loop 1 at a point symmetrical with the terminals 3*a* and 3*b*, its value is given from the equation (14) as follows:

$$Z_2 = \frac{y_b + y_u}{2y_b y_u} + \frac{y_b - y_u}{2y_b y_u} \frac{I_1}{I_2} \tag{22}$$

Approximating similarly the horizontal level directivity in the form of a quadratic polynominal of cos ϕ, it follows that

$$D(\phi) = A_0 + A_1 \cos\phi + A_2 \cos 2\phi \tag{23}$$

and

$$I(\phi) = i_0 + i_1 \cos\phi + i_2 \cos 2\phi \tag{24}$$

Defining

$$y_a = \frac{2}{J\pi\rho}\left[\frac{1}{\alpha_0} + \sum_{n=1}^{\infty}\left(\frac{1}{\alpha m} - \frac{1}{\alpha m-2}\right)\right] \tag{25}$$

the following values of the three impedance elements Z_1, Z_2 and Z_3 are obtained from the equation (14):

$$Z_1 = -\frac{1}{2y_u} - \frac{y_b}{2(y_b^2 - y_a^2)} + \frac{I_3}{I_1}\left(\frac{1}{2y_u} - \frac{y_b}{2(y_b^2 - y_a^2)}\right) + \frac{I_2}{I_1} \cdot \frac{Y_a}{y_b^2 - y_a^2} \tag{26}$$

$$Z_2=Z_4=-\frac{y_b}{y_b^2-y_a^2}+\frac{I_1+I_3}{I_2}\cdot\frac{y_a}{2(y_b^2-y_a^2)} \quad (27)$$

and

$$Z_3=-\frac{1}{2y_a}-\frac{y_b}{2(y_b^2-y_a^2)}+\frac{I_1}{I_3}\left(\frac{1}{2y_a}-\frac{y_b}{2(y_b^2-y_a^2)}\right)$$

$$+\frac{I_2}{I_3}\cdot\frac{y_a}{y_b^2-y_a^2} \quad (28)$$

Calculating the values of the impedance elements Z_1, Z_2 and Z_3 with a quadratic binomial approximation for the directivity and the Chebishev approximation for various sublobe levels, the following solutions are obtained.

a. With $ReZ<0$ and $ReZ_3<0$, the directivity is at a maximum in the direction of the terminals 3*a* and 3*b*.

b. With $ReZ_1<0$ and $ReZ_3<0$, the directivity is at a maximum in the direction opposite from the terminals 3*a* and 3*b*.

c. With $ReZ_1<0$ and $ReZ_3<0$ and with a negative resistance region, the directivity is at a maximum in either of the directions (a) and (b).

In FIG. 3 there is depicted one example of the relation between the above directions and the sublobe level, in which the ordinate represents the sublobe level and the abscissa represents the value *kb*, which is the diameter 2*b* of the antenna loop 1 normalized with a wavelength, that is, $\pi\ 2b/\Lambda$. On FIG. 3, the reference numerals 4*a*, 4*b* and 4*c* indicate the regions in which the aforementioned solutions (a), (b) and (c) exist.

The antenna efficiency is as follows:

a. If $ReZ_1 \equiv R_{L1}<0$ and $ReZ_{\gamma+1} \equiv R_{L\gamma+1}>0$,

$$\eta=1+\frac{|I_{\gamma+1}|^2ReZ_{\gamma+1}+2\sum_{q=2}^{\gamma}|I_q|^2ReZ_q}{|I_1|^2ReZ_1} \quad (29)$$

b. If $ReZ_1>0$ and $ReZ_{\gamma+1}<0$,

$$\eta=1+\frac{|I_1|^2ReZ_1+2\sum_{q=2}^{\nu}|I_q|^2ReZ_q}{|I_{\gamma+1}|^2ReZ_{\gamma+1}} \quad (30)$$

c. If $ReZ_1<0$ and $ReZ_{\gamma+1}<0$, the antenna efficiency may be calculated from either of the equations (29) and (30).

FIG. 4 shows the results of calculations of the antenna efficiency with various approximate impedance values relative to the quadratic directivity. The region 4*c* in FIG. 3 represents the efficiency calculated from the equation (29) in the case where the characteristic impedance Ω of the antenna loop 1 is $2ln(2\pi\alpha¼b/a)=9$ ohms. There is a tendency for the efficiency to increase near the boundaries of the regions in FIG. 3, but the efficiency is determined primarily by the sublobe levels.

Referring now to FIG. 5, it will be seen that a loop antenna making use of the foregoing theory may be comprised of an upper loop constituted by four arcuate, wire-like conductive elements 29,30,31 and 32 in end-to-end, spaced arrangement, and a lower loop constituted by three arcuate, wire-like conductive elements 33,34 and 35 also in end-to-end, spaced arrangement. The elements 33 and 35 of the lower loop are substantially coextensive with the elements 29 and 32 of the upper loop, and the elements 34 of the lower loop is substantially coextensive with the elements 30 and 31 of the upper loop. Further, conductive bars 41,42,43 and 44 extend between the mentioned elements of the upper and lower loops to hold such elements in the illustrated spaced relationship. More specifically, as shown, the spaced adjacent ends of elements 29 and 32 of the upper loop, which define a gap 18 therebetween are disposed a relatively small distance from the spaced adjacent ends of elements 33 and 35 of the lower loop and, similarly, the adjacent spaced ends of elements 30 and 31, which define a gap 25 therebetween, are disposed a relatively small distance from the underlying middle portion of the element 34 of the lower loop. Further, as shown, the adjacent spaced ends of elements 29 and 30 defining a gap 37 in the upper loop are disposed a relatively large distance from the adjacent spaced ends of elements 33 and 34 defining a gap 38 in the lower loop and, similarly, the adjacent spaced end of elements 31 and 32 defining a gap 39 in the upper loop are disposed a relatively large distance from the adjacent spaced ends of elements 34 and 35 defining a gap 40 in the lower loop.

An impedance element Z_3, for example having a resistance value of 1.2KΩ, is connected as a dummy load across the gap 25 in the upper loop, and output terminals are suitably connected to the ends of elements 29 and 32 at gap 18, that is, at a location on the upper loop diametrically opposed to the location of the dummy load Z_3. The conductive elements 41,42,43 and 44 extending between elements of the upper and lower loops are also operative as impedance elements. Further, the gaps 37 and 38 and the gaps 39 and 40 function as impedance elements Z_2 and Z_4, respectively, which are each of infinite value.

The above described loop antenna of FIG. 5 has several disadvantages. Since no supporting connections are provided between the adjacent ends of the conductive elements making up the upper and lower loops, for example, between the ends of elements 29 and 30 defining the gap 37 therebetween, it is difficult to maintain a fixed distributed impedance value of, for example, the impedance Z_2, because the gap distance may be changed, for example, by reason of mechanical shocks. Further, the illustrated antenna is difficult and costly to manufacture as it comprises a relatively large number of individual conductive elements 29–35 which have to be assembled together with the conductive elements 41–44.

Referring now to FIG. 6, it will be seen that, in a loop antenna 90 according to the present invention, the above disadvantages of the construction shown in FIG. 5 are avoided by providing two semi-circular antenna members 50 and 70 which are arranged to form a loop with gaps G_1 and G_2 defined between the ends of antenna members 50 and 70 at diametrically opposed locations in the loop. The antenna member 50 includes arcuate upper wire-like conductive elements 54 and 57 which, in the embodiment being described, are integrally joined together at the middle 51 of antenna member 50, and arcuate lower wire-like conductive elements 55 and 58 having their adjacent ends spaced from each other at the middle 51 of antenna member 50 to define a gap 60 therebetween. The upper and lower conductive elements of antenna member 50 are arranged so that a relatively small distance is provided between elements 54 and 55 and between elements 57 and 58 at the middle of antenna member 50, and further so that a relatively large distance is provided between elements 54 and 55 and between elements 57 and 58 at the ends 52 and 53, respectively, of antenna member 50.

Similarly, the antenna member 70 includes arcuate upper wire-like conductive elements 74 and 77 having their adjacent ends spaced from each other at the middle 71 of antenna member 70 to define a gap 81 therebetween, and arcuate lower wire-like conductive elements 75 and 78 which, in the embodiment being described, are integrally joined together at the middle 71 of the antenna member. The upper and lower conductive elements of antenna member 70 are also arranged so that a relatively small distance is provided between elements 74 and 75 and between elements 77 and 78 at the middle of antenna member 70, and further so that a relatively large distance is provided between elements 74 and 75 and between elements 77 and 78 at the ends 72 and 73, respectively, of antenna member 70.

Further, in accordance with this invention, antenna member 50 includes interconnecting elements 56 and 59 extending between, and connected to the upper and lower conductive elements 54 and 55 and the upper and lower conductive elements 57 and 58, respectively, at the ends 52 and 53 of antenna member 50. Similarly, antenna member 70 includes inter-

connecting elements 76 and 79 extending between, and connected to upper and lower conductive elements 74 and 75 and upper and lower conductive elements 77 and 78, respectively, at the ends 72 and 73 of the antenna member. Preferably, as shown, the interconnecting elements 56 and 59 of antenna member 50 and the interconnecting elements 76 and 79 of antenna member 70 are also wire-like and conductive and are formed as integral extensions of the upper and lower wire-like conductive elements of the respective antenna members. Thus, it will be apparent that each of antenna members 50 and 70 may be formed of a suitably bent or shaped single length of wire, thereby to substantially facilitate and reduce the cost of manufacturing the loop antenna.

The loop antenna according to this invention, as shown on FIG. 6, further has output terminal leads 61 and 62 connected to the ends of lower conductive elements 55 and 58 which define the gap 60 at the middle of antenna member 50, and an impedance element 80, which may be a resistance, and which is connected to the adjacent ends of upper conductive elements 74 and 77 defining the gap 81 at the middle 71 of antenna member 70 so that impedance 80 will act as a dummy load. The antenna members 50 and 70 are suitably supported so that the interconnecting elements 56 and 59 of member 50 will be disposed in opposing, adjacently spaced relation to the interconnecting elements 76 and 79 of antenna member 70, that is, to define the gaps G_1 and G_2 between such interconnecting elements, with the gaps G_1 and G_2 being operative as impedance elements. It is also to be understood that each of the interconnecting elements 56,59,76 and 79 is operative as a reactive impedance on the loop antenna 90.

In a specific example of loop antenna 90 according to this invention, the diameter of the loop constituted by the semi-circular antenna members 50 and 70 may be 900 millimeters; the maximum distance between the upper and lower conductive elements, for example, between the elements 54 and 55 at the end 52, may be 150 millimeters, the minimum distance between the upper and lower conductive elements, for example, between the elements 57 and 58 at the middle 51 of antenna member 50, may be 50 millimeters, and the value of the impedance 80 may be 75 ohms. FIG. 7 shows the sensitivity of the loop antenna 90 having the foregoing measurements over the FM frequency band used in Japan, that is, over the frequency range of 76 to 90 MHz. FIG. 8 shows the front to back ratios for the same loop antenna 90 over the same frequency band. FIG. 9 shows the directional patterns for the described loop antenna 90. It is apparent from FIGS. 7,8 and 9 that the described loop antenna 90 exhibits excellent directivity characteristics for various frequencies within a wide frequency band width.

Referring now to FIG. 10, it will be seen that in a practical embodiment of the loop antenna 90 described above with reference to FIG. 6, the loop antenna 90 is supported or mounted on the upper end of a suitable pole 110 by means of a non-conductive or insulating bar 11 which extends across the upper end of pole 110 and is disposed diametrically within the loop constituted by antenna members 50 and 70. Clamping blocks 112 and 113 of non-conductive or insulating material are carried by the opposite ends of bar 111 and are secured, as hereinafter described, to antenna members 50 and 70 at the relatively narrow middle portions 51 and 71, respectively. Further, non-conductive or insulating clamping blocks 114 and 115 securely engage the interconnecting elements 56 and 76 and the interconnecting elements 59 and 79, respectively, of antenna members 50 and 70 for mechanically fixing the adjacent ends of the antenna members with respect to each other, and thereby establishing in a fixed manner the distances across the gaps G_1 and G_2.

As shown on FIG. 11, the clamping block 112 may include a pair of confronting plates 120 and 121 of insulating material, with the plate 121 being secured to, or formed integrally with the adjacent end of bar 111. The plate 120 has a pair of parallel, spaced apart horizontal grooves 122 and 123 formed in the surface thereof facing the plate 121, and the plate 121 has an aligned pair of parallel, spaced horizontal grooves 124 and 125 in the surface thereof confronting plate 120, with the grooves 122 and 124 and the grooves 123 and 125 defining respective bores for receiving the junction of upper conductive elements 54 and 57 and the adjacent terminal portions or free ends of lower conductive elements 55 and 58, respectively. The confronting surfaces of plates 120 and 121 further have aligned vertical grooves extending downwardly from grooves 123 and 125 to the lower edges of the respective plates and cooperating to define a bore 126 through which the output terminal leads 61 and 62 can extend from the adjacent spaced apart ends of lower conductive elements 55 and 58. The plates 120 and 121 are suitably secured to each other in confronting relation for clamping engagement with the upper and lower conductive elements of antenna member 50, for example, by a screw 127 passing through plate 120 into plate 121.

As shown on FIG. 12, the clamping block 113 may similarly include a pair of confronting, non-conductive or insulating plates 128 and 129 having a pair of parallel, spaced horizontal grooves 130 and 131 and an aligned pair of grooves 132 and 133 in their confronting surfaces, respectively, to define horizontal bores receiving the adjacent spaced apart ends of upper conductive elements 74 and 77 and the junction of the lower conductive element 75 and 78, respectively. The plate 128 is secured to, or formed integrally with the adjacent end of bar 111, and the plate 129 is suitably secured to plate 128, as by the screw 134, so as to clamp the upper and lower conductive elements of antenna member 70 in the respective bores of clamping block 113. Further, as shown on FIG. 12, a solid resistance element 135 may be disposed within the bore constituted by grooves 130 and 132 so as to constitute the impedance 80 on FIG. 6 connected between the adjacent ends of conductive elements 74 and 77.

As shown on FIG. 13 with respect to the clamping block 114, each of the clamping blocks 114 and 115 may include a pair of confronting, non-conductive or insulating plates 136 and 137 which are removably secured to each other, as by a screw 142, and which respectively have a pair of parallel, vertical spaced grooves 138 and 139 and a pair of aligned grooves 140 and 141 in their confronting surfaces to define vertical bores spaced in the horizontal direction from each other and adapted to receive and clamp the interconnecting elements, for example, the elements 56 and 76, as shown, at the adjacent ends of antenna members 50 and 70.

Referring now to FIG. 14, it will be seen that, in a loop antenna 290 according to another embodiment of this invention, and which is generally similar to the loop antenna 90 shown in FIG. 6, each of the semi-circular antenna members 250 and 270 is formed in two parts, that is, of two lengths of wire. As shown, one of the lengths of wire constituting antenna member 250 includes one-half 254 of the upper wire-like conductive element, one-half 255 of the lower wire-like conductive element and the interconnecting element 256 at one of the ends of antenna member 250, while the other or second length of wire similarly includes one-half 257 of the upper wire-like conductive element, one-half 258 of the lower wire-like conductive element and the interconnecting element 259 at the respective end of antenna member 250. Similarly, the antenna member 270 is composed of a first length of wire constituting one-half 274 of the upper conductive element, one-half 275 of the lower conductive element and the interconnecting element 276 at an end of the antenna member, and a second length of wire constituting one-half 277 of the upper conductive element, one-half 278 of the lower conductive element and the interconnecting element 279 at the other end of antenna member 270. Thus, each of antenna members 250 and 270 is simply formed by suitably bending or shaping two lengths of wire. In antenna member 250, the adjacent ends of the two lengths of wire in the upper conductive element are connected by a conductive lead 300 and, similarly, in antenna member 270, the adjacent ends of the two lengths of wire in the lower conductive element are connected by a conductive

lead **301**. Further, output terminal leads **261** and **262** are connected to the adjacent ends of the two lengths of wire in the lower conductive element, and an impedance **280** is connected to the adjacent ends of the two lengths of wire in the upper conductive element of antenna member **270**. The loop antenna **290** of FIG. **14** may be conveniently supported and mounted in the same manner as has been described with reference to FIG. **10**. Thus, in each of the described embodiments of this invention the stability of the stray impedance around each of the gaps G_1 and G_2 is ensured, as the width of each of those gaps is fixed by the clamping blocks **114** and **115**.

Further, each loop antenna according to this invention is strongly resistant to mechanical shocks as the distances between the upper and lower conductive elements of each antenna member **50** and **70**, or **250** and **270**, at the ends thereof are fixed by the interconnecting elements, for example, the elements **56** and **59**, and the distance between the upper and lower conductive elements, at the middle of the antenna members, are fixed by the blocks **112** and **113**.

Although illustrative embodiments of the invention have been described in detail herein, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention.

What is claimed is:

1. A directional antenna comprising a pair of semicircular antenna members arranged to form a loop; each of said antenna members including arcuate upper and lower wire-like conductive elements having a relatively small distance therebetween intermediate the ends of the respective antenna member and a relatively large distance between said conductive elements at each of said ends of said respective antenna member, and interconnecting elements extending between, and connected to said upper and lower conductive elements at said ends of the respective antenna member; output terminal means connected to one of said antenna members at a location where said conductive elements have said relatively small distance therebetween; and impedance means serving as a dummy load connected to the other of said antenna members at a location where said conductive elements of said other antenna members have said relatively small distance therebetween; said interconnecting elements at the ends of said one antenna member being disposed in opposing, adjacently spaced relation to said interconnecting elements at the ends of said other antenna element to form impedance means therebetween for determining the distribution of current flow in the directional antenna.

2. A directional antenna according to claim **1**, in which said interconnecting elements are also wire-like and are integral extensions of said upper and lower wire-like conductive elements of the respective antenna member.

3. A directional antenna according to claim **2**, in which each of said antenna members is constituted by a single length of wire having its terminal portions spaced apart in one of said conductive elements at said location where said conductive elements have said relatively small distance therebetween, said output terminal means are connected to said spaced terminal portions of said length of wire constituting said one antenna member, and said impedance means serving as a dummy load is connected to said spaced length of wire constituting said other antenna member.

4. A directional antenna according to claim **2**, in which each of said antenna members includes first and second lengths of wire, said first length of wire constitutes one half of each of said upper and lower conductive elements and said interconnecting element at one of said ends of the respective antenna member, and said second length of wire constitutes the other half of each of said upper and lower conductive elements and said interconnecting element at the other end of said respective antenna member.

5. A directional antenna according to claim **4**, in which said first length of wire has terminal portions spaced from respective terminal portions of said second length of wire at said location of the respective antenna member where said upper and lower conductive elements have said relatively small distance therebetween said output terminal means are connected to one terminal portion of said first length of wire and the respective terminal portion of said second length of wire constituting said one antenna member and the other terminal portions of said first and second lengths of wire in said one antenna member are conductively connected to each other, and said impedance means serving as a dummy load is connected to one terminal portion of said first length of wire and the respective terminal portion of said second length of wire constituting said other antenna member and the other terminal portions of said first and second lengths of wire in said other antenna member are conductively connected to each other.

6. A directional antenna according to claim **2**, further comprising clamping means of insulating material securely engaging said wire-like interconnecting element at each of said ends of said one antenna member and at the adjacently spaced end of said other antenna member for maintaining said adjacently spaced ends in a predetermined position with respect to each other.

7. A directional antenna according to claim **6**, in which each of said clamping means includes a pair of confronting plates of said insulating material, each of said plates having a pair of parallel, spaced grooves in the surface thereof facing the other of said plates and being aligned with the pair of grooves in said other plate to define bores for receiving said wire-like interconnecting elements at the respective adjacently spaced ends of said antenna members, and means for securing together said plates in confronting relation.

8. A directional antenna according to claim **6**, further comprising second clamping means of insulating material securely engaging said upper and lower wire-like conductive elements of each of said antenna members at said location when said upper and lower wire-like conductive elements have relatively small distance therebetween for maintaining said small distance.

9. A directional antenna according to claim **8**, in which each of said clamping means includes a pair of confronting pleates of said insulating material, said plates having aligned pairs of parallel grooves in their confronting surfaces cooperating to define bores receiving said upper and lower wire-like conductive elements of the respective antenna member, and means for securing together said plates in confronting relation.

10. A directional antenna according to claim **9**, in which said plates of the second clamping means associated with said one antenna member further have aligned grooves in their confronting surfaces defining an additional bore extending from one of the first mentioned bores to a margin of said plates for receiving leads connecting said one antenna member to said output terminal means, and said impedance means serving as a dummy load is disposed in one of said bores of the second clamping means associated with said other antenna member.

11. A directional antenna according to claim **8**, further comprising mounting means for said loop including an insulating bar extending diametrically across said loop and connected, at the ends of said bar, to said second clamping means.

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