United States Patent

[11] 3,623,110

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[73] Assignee **Sony Corporation**
Tokyo, Japan
[32] Priorities **Sept. 10, 1968**
[33] **Japan**
[31] **43/65131;**
Dec. 14, 1968, Japan, No. 43/91931

[54] **LOOP ANTENNA WITH SPACED IMPEDANCE ELEMENTS**
6 Claims, 22 Drawing Figs.

[52] **U.S. Cl.** **343/722,** 343/730, 343/744
[51] **Int. Cl.** **H01q 11/12**
[50] **Field of Search** 343/726, 728, 748, 730, 744, 722

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Primary Examiner—Eli Lieberman
Attorneys—Lewis H. Eslinger, Alvin Sinderbrand and Curtis, Morris and Safford

ABSTRACT: In a directional antenna, particularly for television receivers, in which a loop antenna element consists of at least three arcuate conductive members, output terminals are connected between two of the adjacent ends of the conductive members and impedance means are connected between the other adjacent ends of the conductive members so as to determine the distribution of a current flowing to the antenna element.

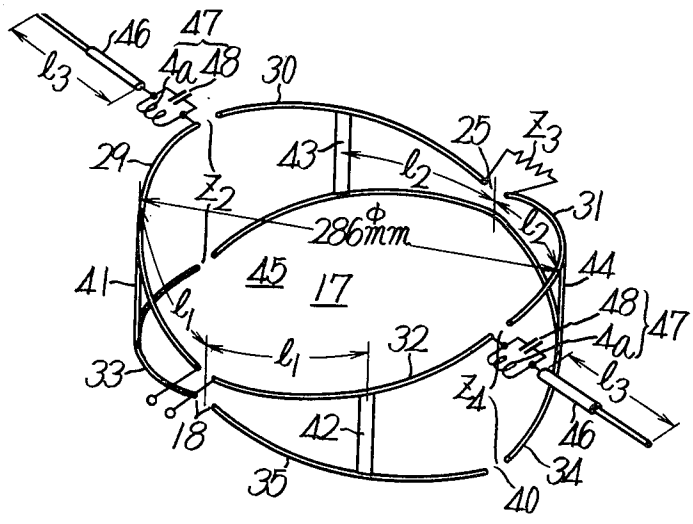


Fig. 1

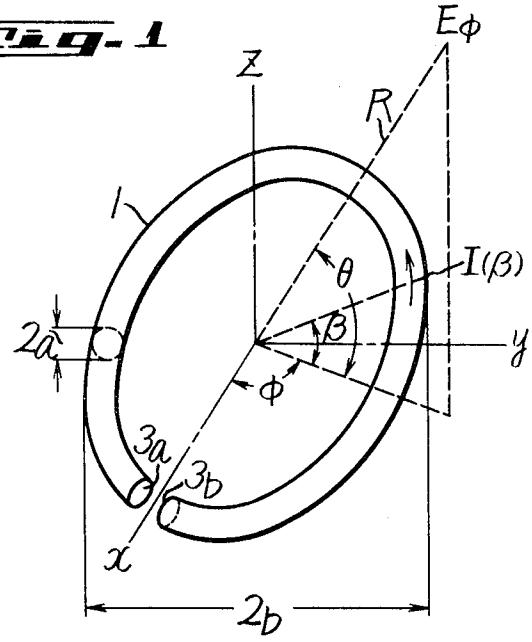
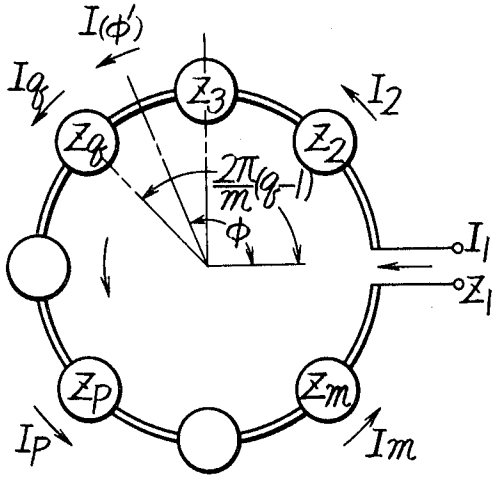


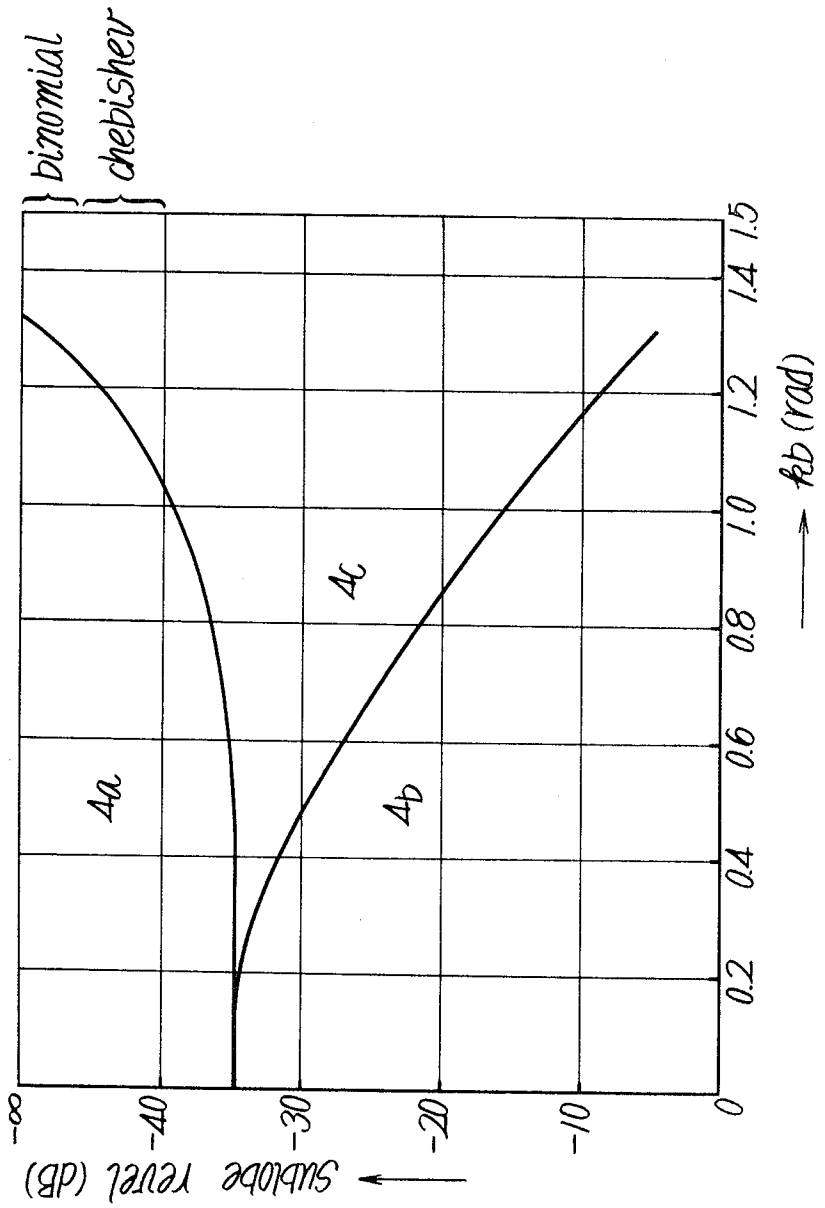
Fig. 2



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FIG. 4

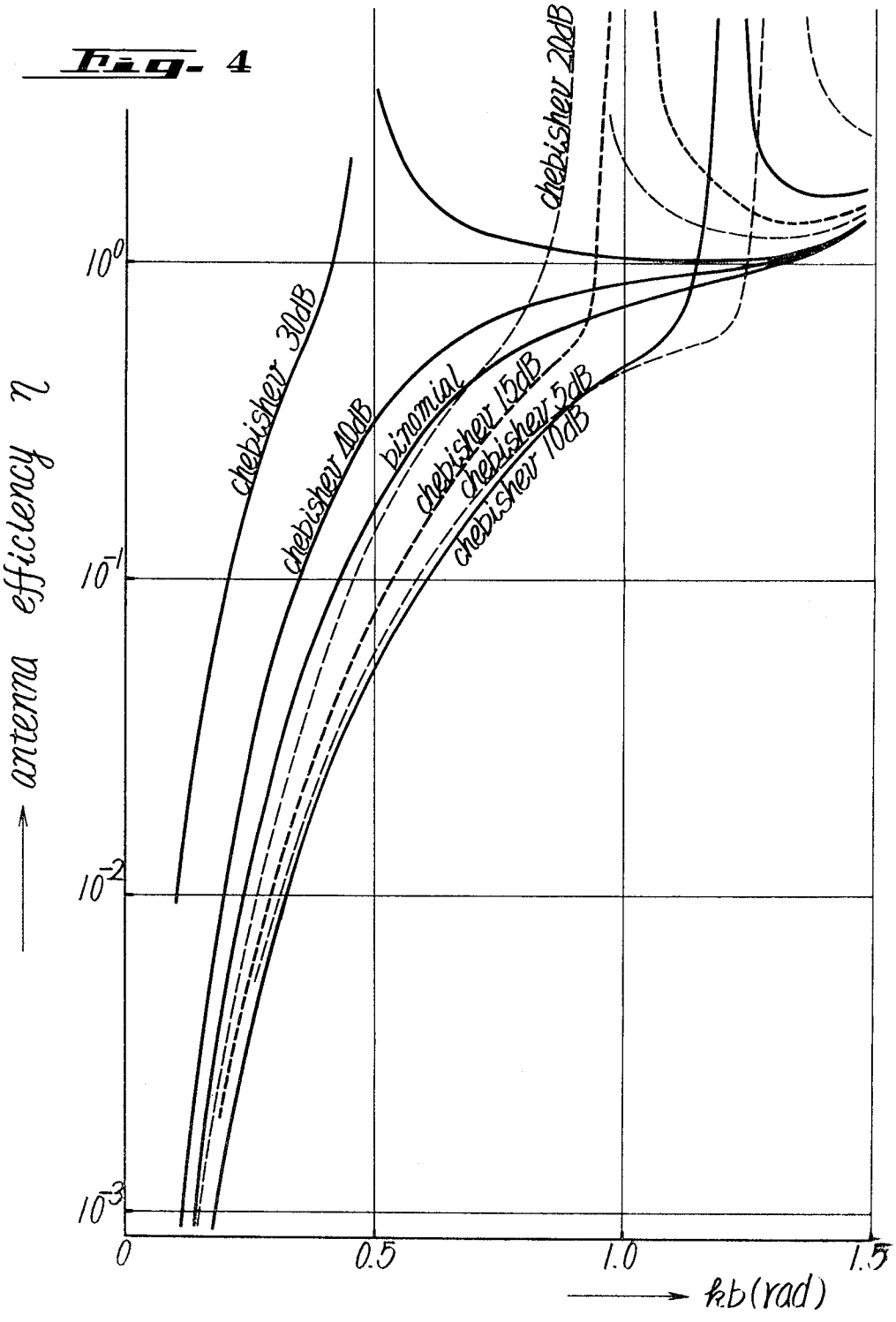


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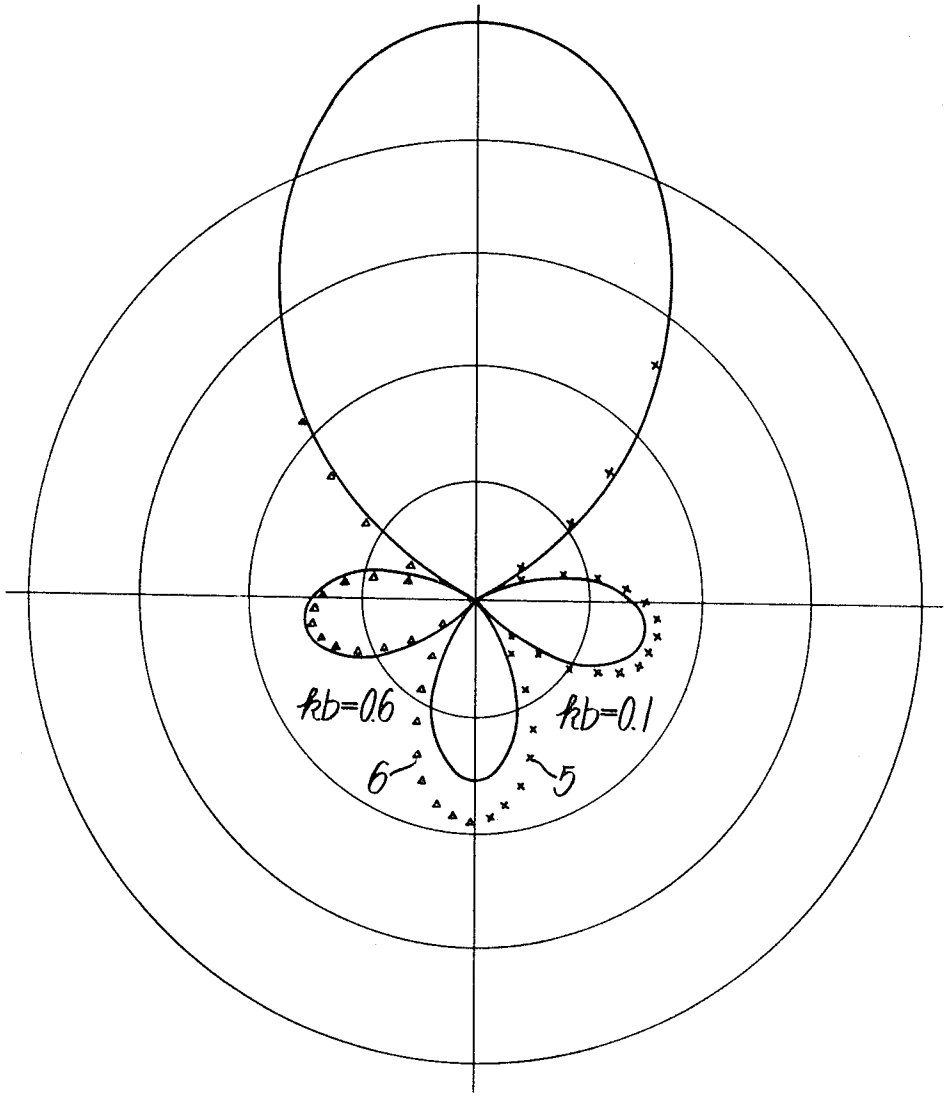
Fig. 4



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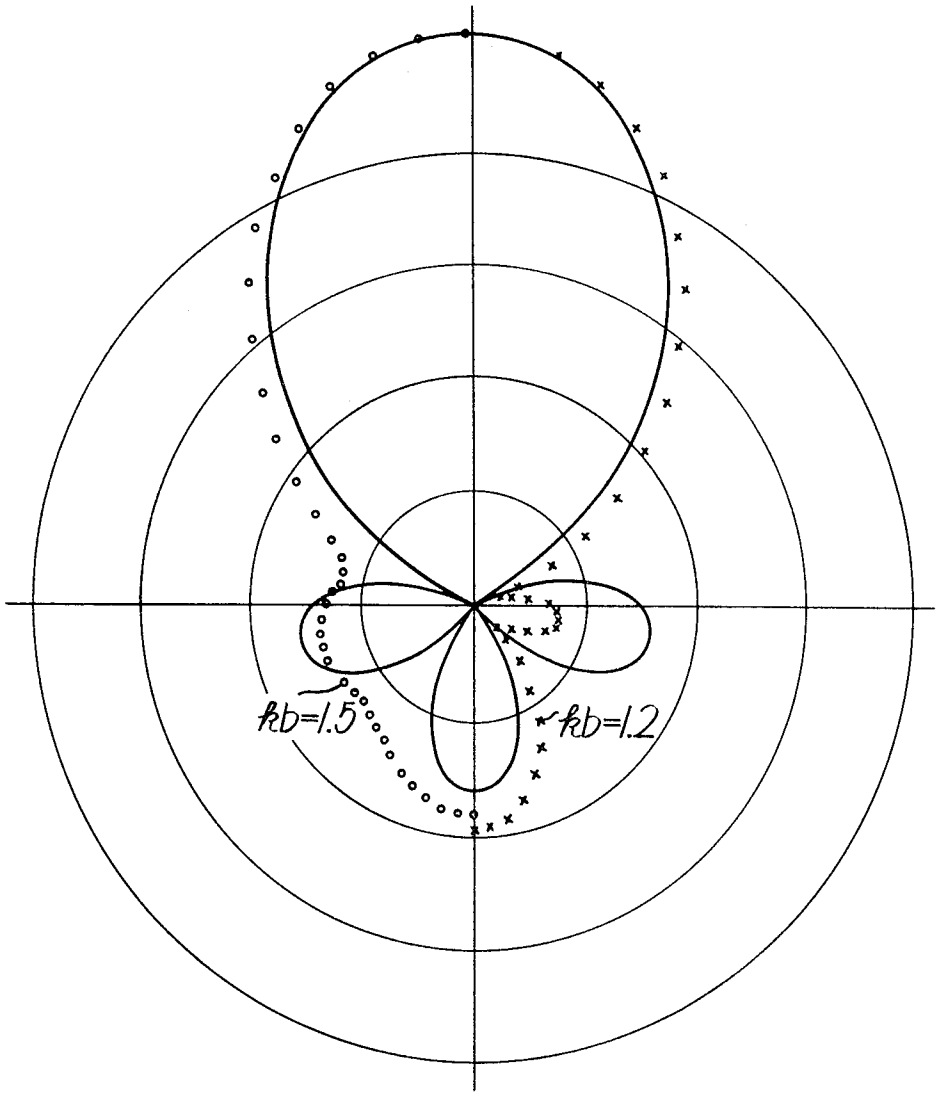
Fig. 5



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Fig. 6



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Fig. 7

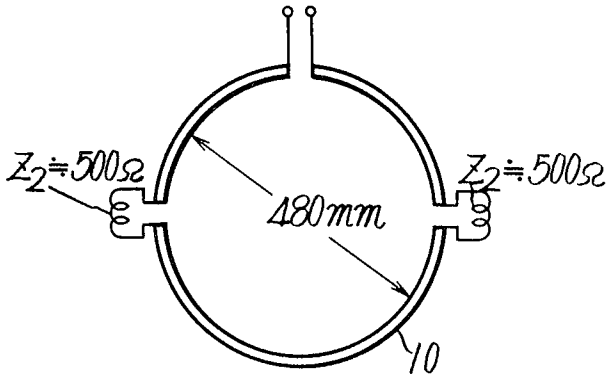
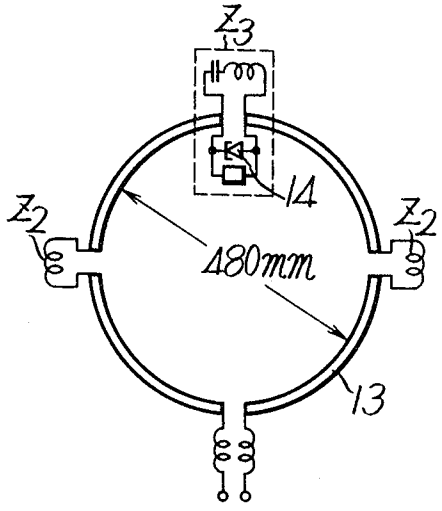


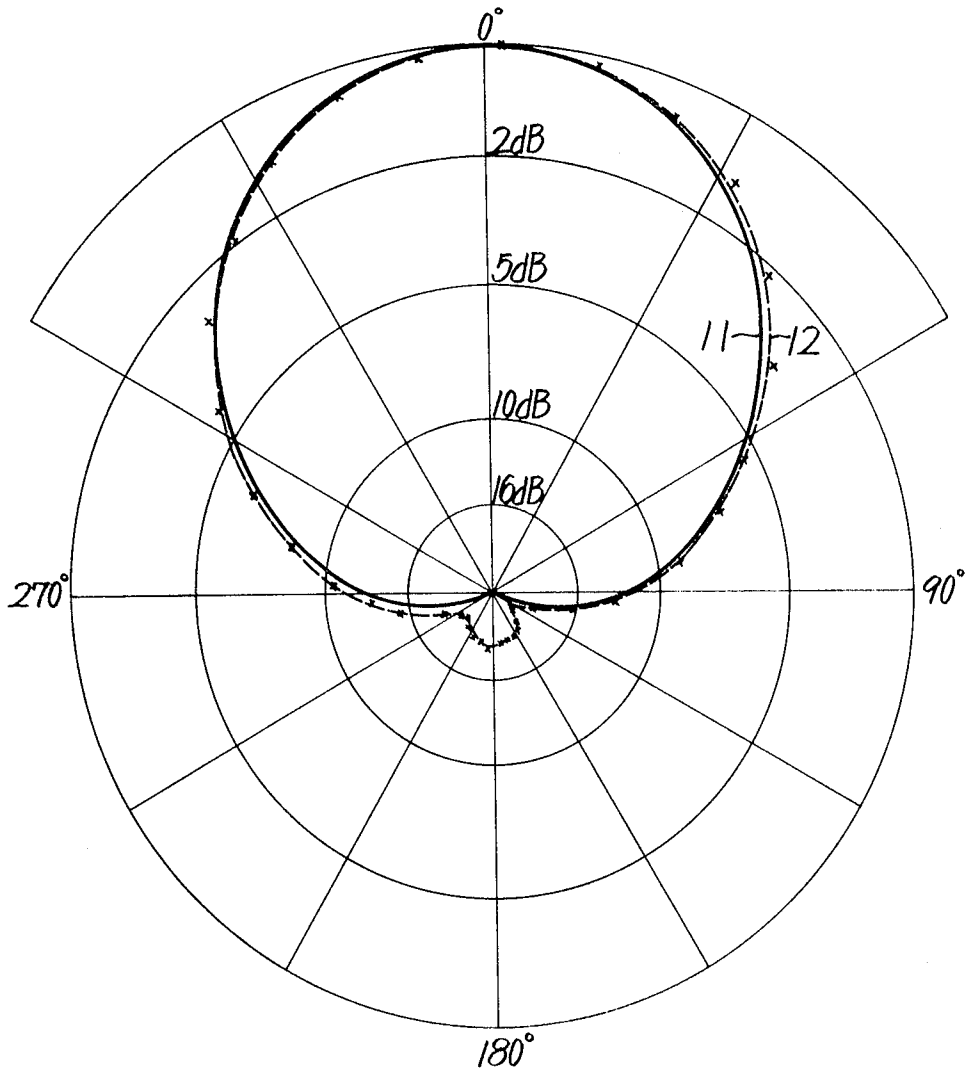
Fig. 9



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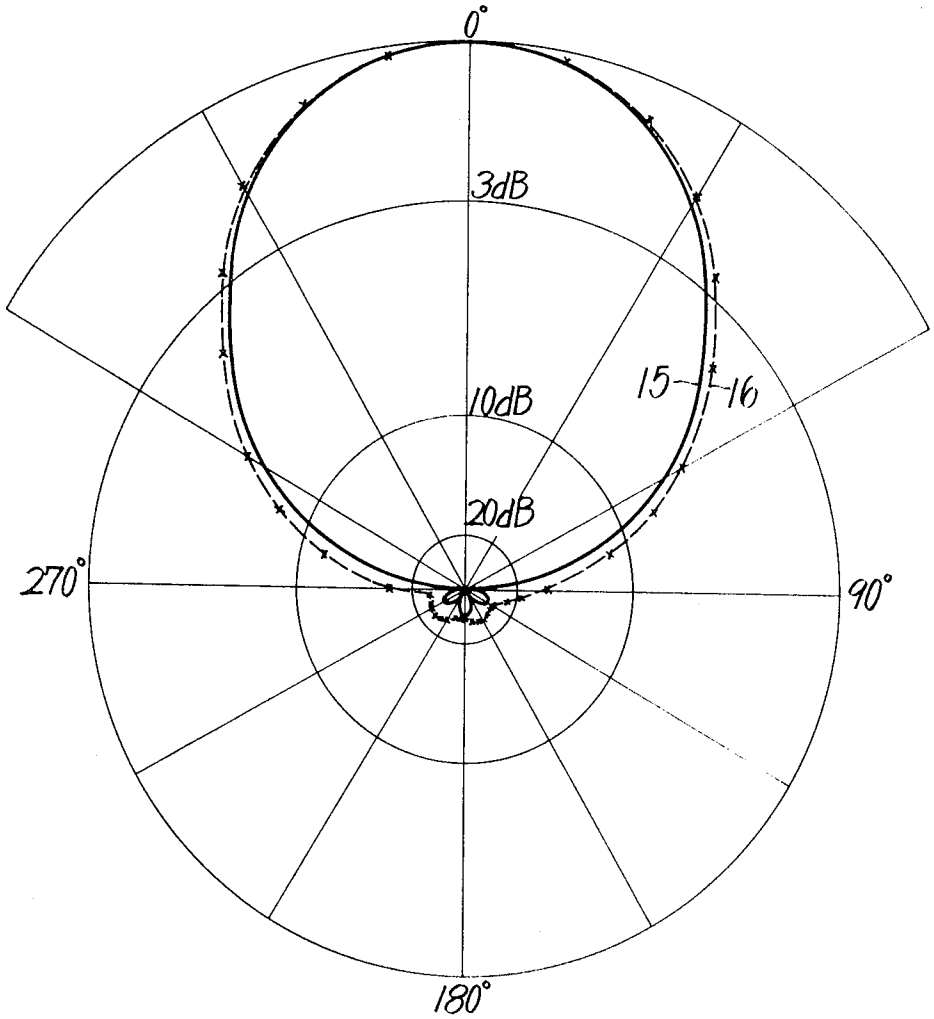
Fig. 8



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Fig. 10



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Fig. 11

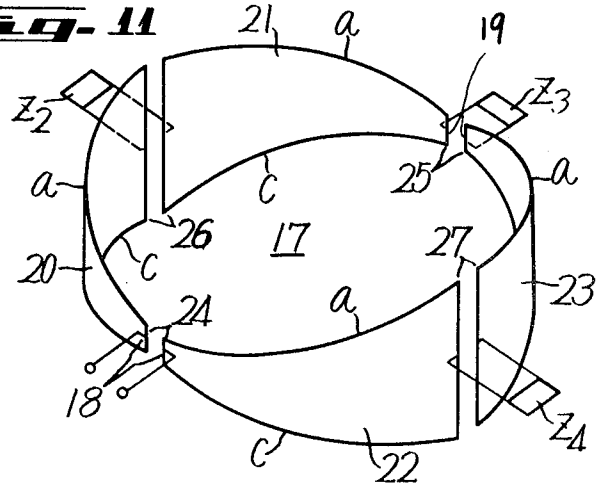


Fig. 12

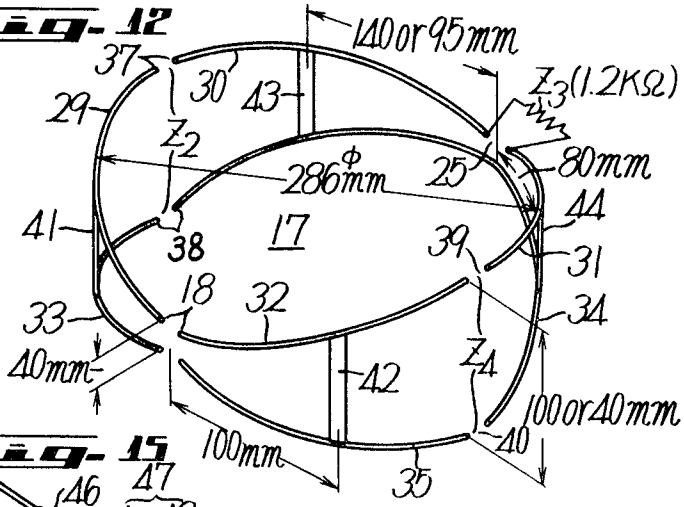
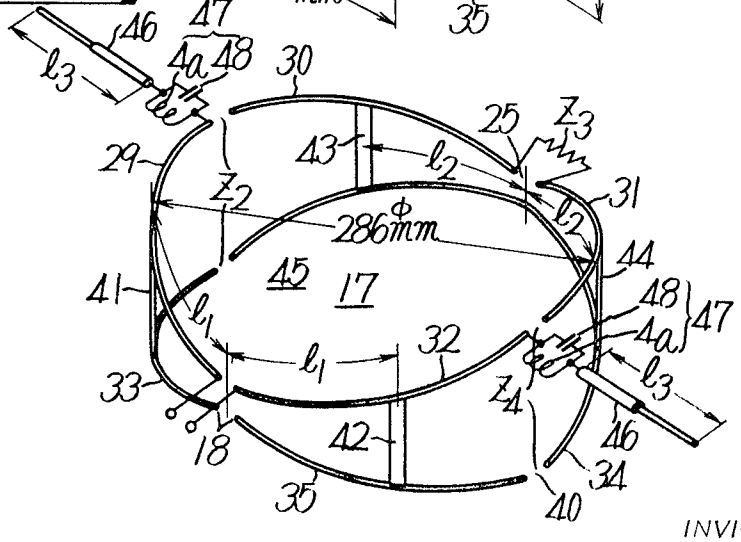


Fig. 13



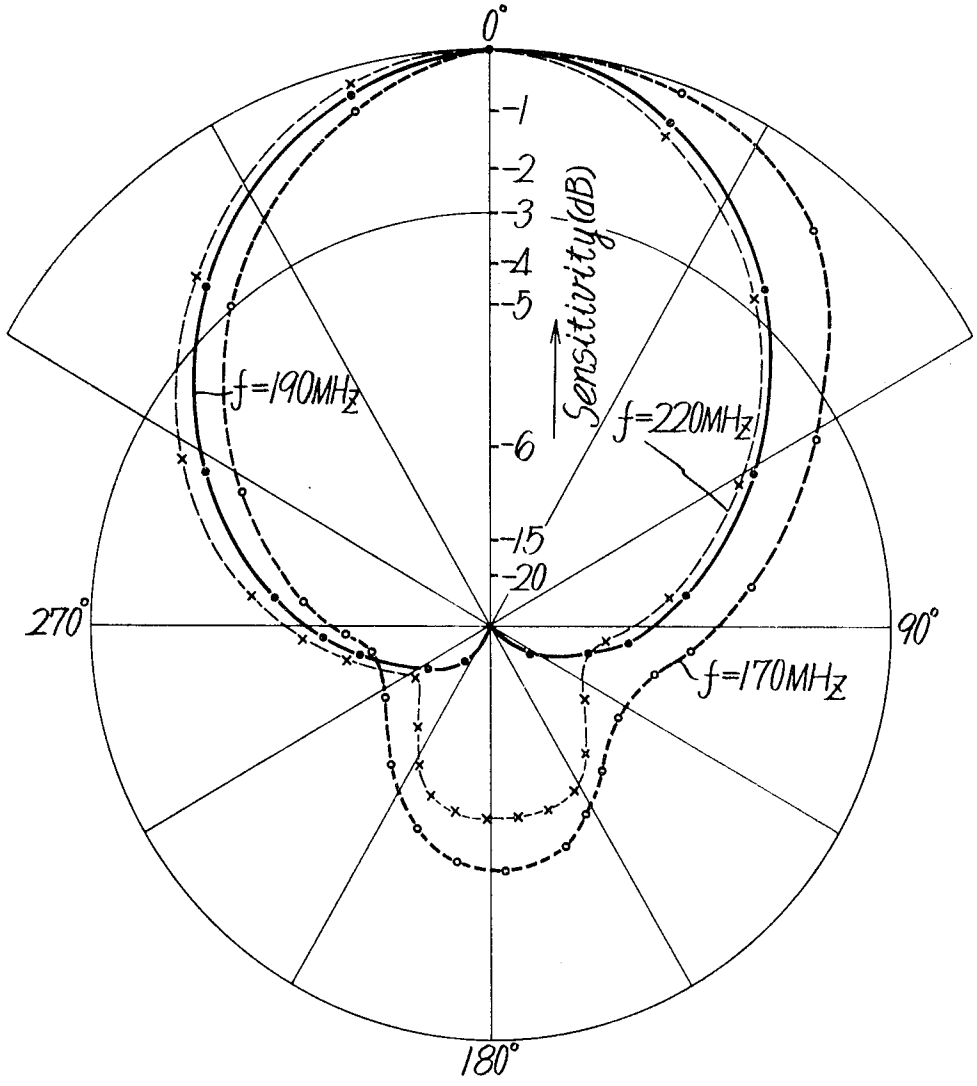
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Fig. 13



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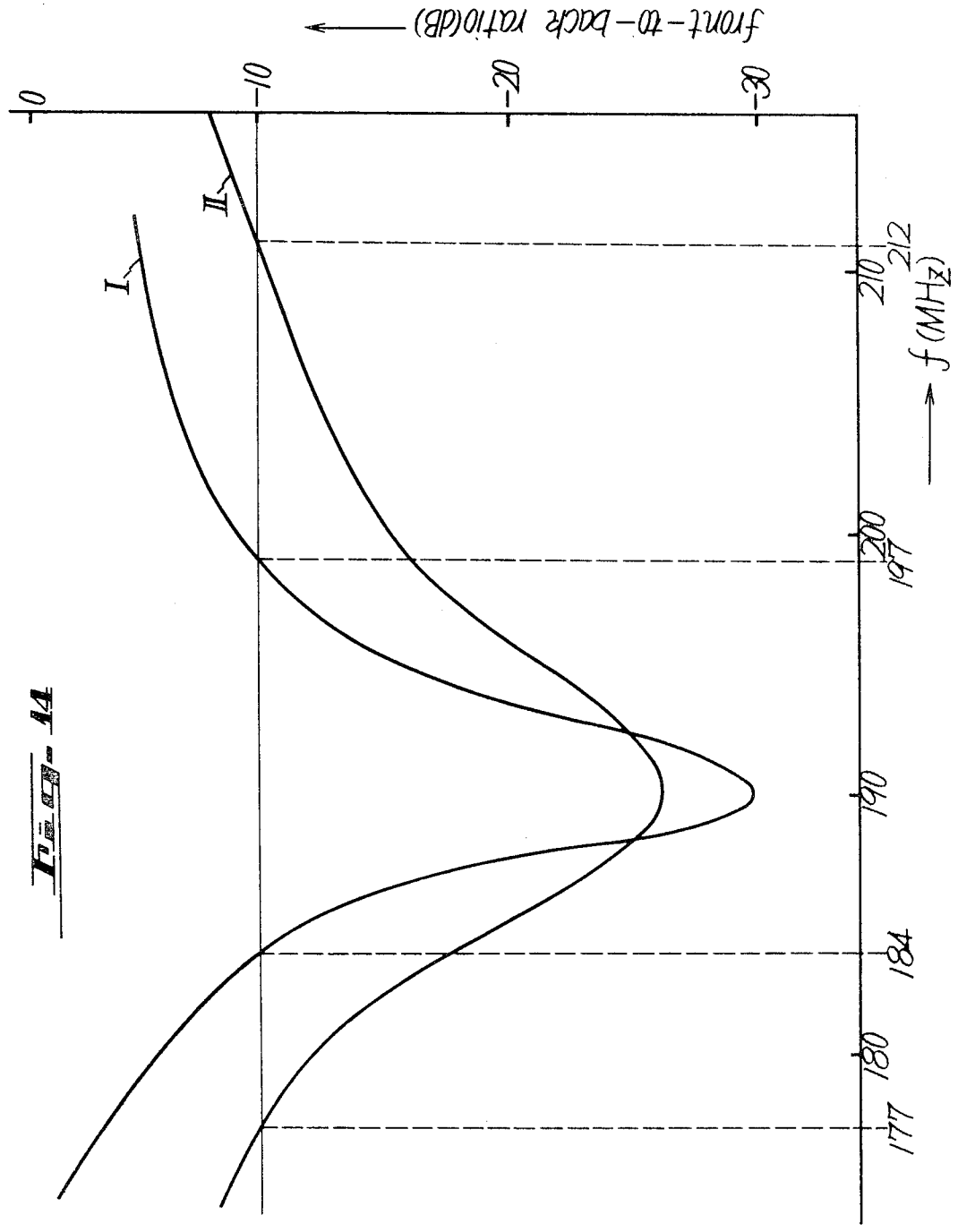


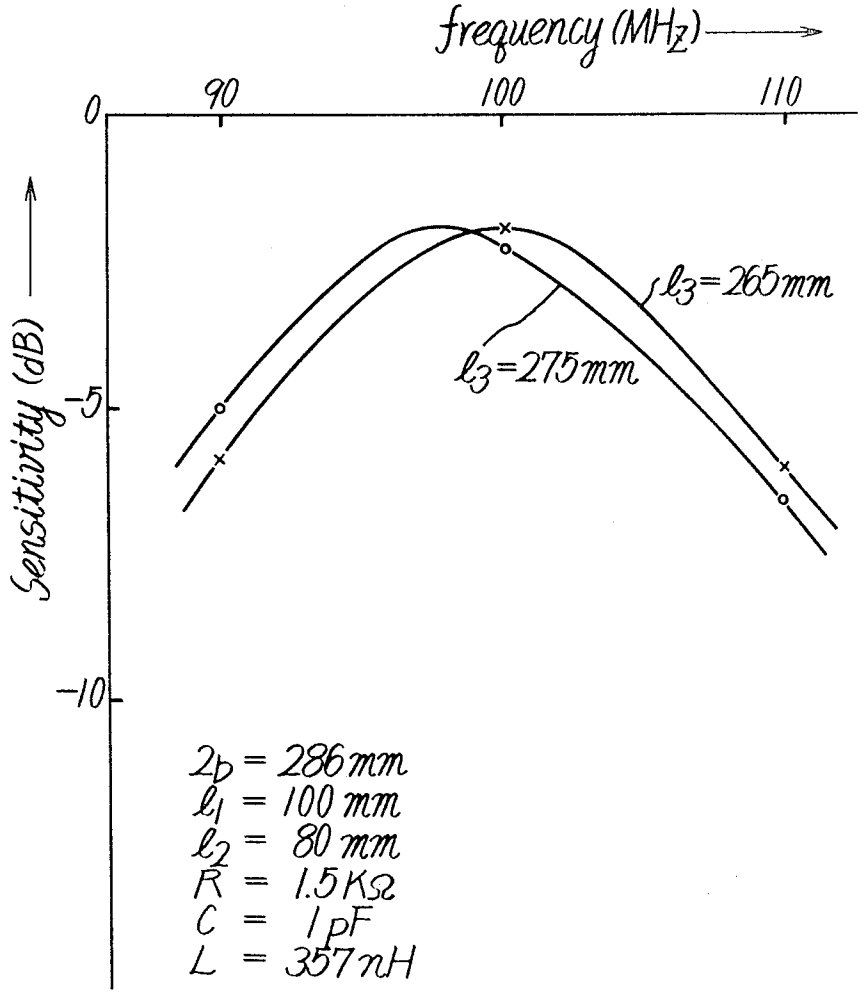
Fig. 14

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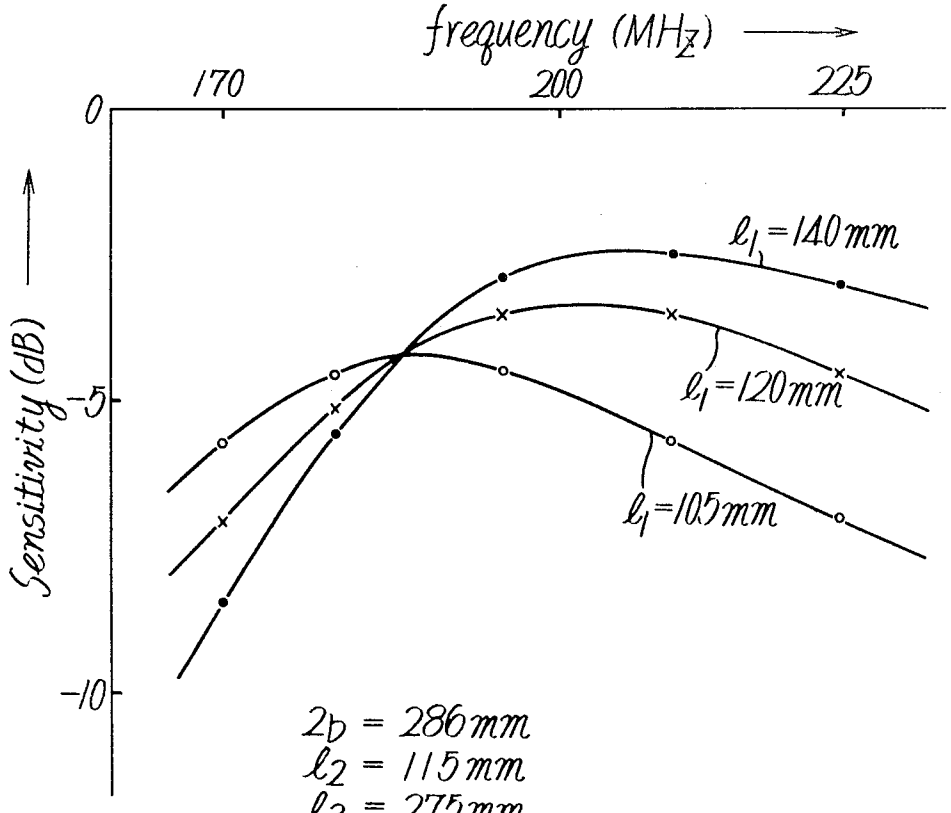
Fig. 16



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Fig. 17



$2b = 286mm$
$\ell_2 = 115mm$
$\ell_3 = 275mm$
$R = 510\Omega$
$C = 1pF$
$L = 357nH$

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Fig. 18A

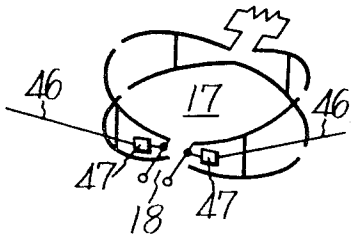


Fig. 18B

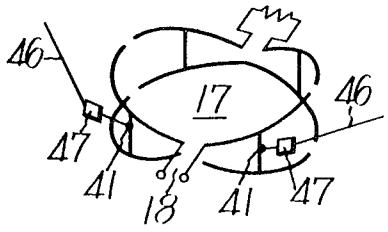


Fig. 18C

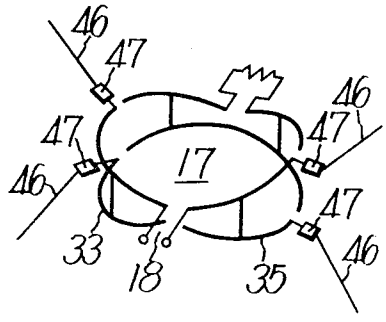


Fig. 18D

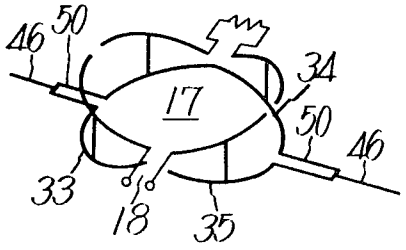
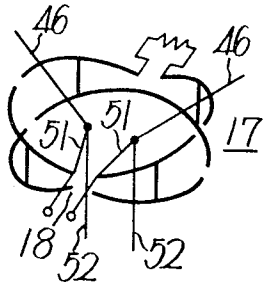


Fig. 18E



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LOOP ANTENNA WITH SPACED IMPEDANCE ELEMENTS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a directional antenna, and more particularly to an antenna used for television receivers.

2. Description of the Prior Art

With the development of transistors, semiconductor integrated circuits or other electronic parts, electronic communication instruments have been miniaturized more and more, and a demand has also been made for a miniaturized antenna for use with the electronic communication instruments. While, the directivity of the antenna is required to be sharp so as to provide excellent communication unaffected by the interference of multiple-reflected waves, city noise, and so on in cities and mountain districts. Further, communication instruments such as television receivers are required to be of sharp directivity over a wide band. To comply with this requirement, the broadband Yagi antenna has been proposed but this type of antenna is inherently bulky and hence is not suitable for use with portable television receivers. In addition, the so-called loaded loop antenna, in which a loop is made up of a pair of semicircular conductive members and a dummy load is connected to a point opposite to a feeding point, has been proposed in U.S. application, Ser. No. 797,513, filed Feb. 7, 1969, entitled "Loop Antenna" and assigned to the assignee of the present invention. This antenna is small in size but has no satisfactorily sharp directivity.

SUMMARY OF THE INVENTION

In accordance with this invention an antenna is made up of arcuate antenna elements and a plurality of impedance elements are respectively connected between two of adjacent ends of the antenna elements so as to define the distribution of a current flowing to the elements. Namely, the value of the impedance elements connected to the antenna loop are selected such that when the current distributions on the loop is decomposed into current distributions respectively showing non-directional pattern and directional patterns of symmetrical two, three, four, ... lobes, currents producing radiation electric fields based upon these decomposed current distributions are substantially the same in phase and have such amplitudes as to provide a desired composite directivity.

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

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

Another object of this invention is to provide an antenna which is small and broadband antenna.

Still another object of this invention is to provide an antenna which is suitable for use with television receivers.

Other objects, features and advantages of this invention will become apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a loop antenna, for explaining the present invention;

FIG. 2 schematically shows one example of an antenna of this invention;

FIG. 3 is a graph showing its sublobe level characteristic relative to the diameter of its loop;

FIG. 4 is a graph showing its antenna efficiency characteristic relative to respective approximations;

FIGS. 5 and 6 are graphs showing one example of the directional characteristic of the antenna of this invention;

FIG. 7 is a schematic diagram showing another example of this invention in which reactance elements are connected to the loop;

FIG. 8 shows a directional pattern of the antenna depicted in FIG. 7;

FIG. 9 is a schematic diagram showing another modified form of this invention in which at least one negative resistance element is connected to the loop;

FIG. 10 shows a directional pattern of the antenna depicted in FIG. 9;

FIG. 11 is a perspective view illustrating a further modification of the antenna of this invention which is adapted to cover a wide frequency bandwidth;

FIG. 12 is a perspective view of still a further modified form of the antenna of this invention;

FIG. 13 shows directional patterns of the antenna of FIG. 12 at respective frequencies;

FIG. 14 is a graph showing the frequency vs front-to-back ratio characteristic of the antenna of FIG. 12;

FIG. 15 is a diagrammatic view illustrating another example of the antenna of this invention designed to cover a wide frequency bandwidth;

FIGS. 16 and 17 are graphs showing the frequency-sensitivity characteristics of the antenna depicted in FIG. 15; and

FIGS. 18A–18E illustrate other modified forms of the antenna of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1 there is illustrated a loop antenna, the antenna loop 1 of which has a diameter $2b$ and is formed of a arcuate conductive member having a diameter $2a$ and to which a current is supplied from terminals $3a$ and $3b$. Where the loop 1 is arranged in such a manner that its plane lies on a plane defined by x and y-axes of rectangular coordinates x, y, and z and that the center of the loop 1 lies at the origin 0 and a certain current distribution $I(\beta)$ exists on the loop 1, a radiation electric field $E_\phi(R, \theta, \Phi)$ based upon the current distribution is expressed by the following equation:

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

where $k=2\pi/\lambda$

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

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:

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

where $\zeta = \sqrt{\mu_o/\epsilon_o}$

Since the terms of the 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:

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

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

Further, if a power source connected to the terminals $3a$ and $3b$ 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:

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

where

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

Assume a loop antenna having connected thereto impedance elements Z_2, Z_3, ... Z_q, ... Z_m of a number of $(m-1)$ in such a manner that the impedance elements and the terminals 3*a* and 3*b* may be arranged at substantially equal intervals as shown in FIG. 2. In this case, electromotive forces at the impedance elements Z_2, Z_3, ... Z_q, ...Z_m are as follows:

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

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

$$I'(\phi)=-\sum_{q=1}^{m}y_m(\phi,\ q)I_qZ_q \quad (9)$$

$$I_p=-\sum_{q=1}^{m}y_m(P,\ q)I_qZ_q \quad (10)$$

where

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

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

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, ... Z_q, ... Z_m such that the current distribution of the antenna of FIG. 2 obtainable from the above equations (9) and (10) may agree with that of the equation (5). However, this requires an in-

finite of impedance elements because the equation (11) is an infinite series. Accordingly, suitable approximation is required in practice. If the sampling theorem is used, sampling is achieved at 2ν points between $0\leqq\Phi\leqq2\pi$ 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, ... Z_m are made to be equal to one another. In this case the required number of the impedance elements is 2ν.

As a result of this, currents I_1 to I_m at the 2ν sampling points are specified and if $m=2\nu$, 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*,

$$I_p=I_{m\cdot TE\cdot P+2}\quad Z_p=Z_{m\cdot TE\cdot P+2}\quad (2\leqq P\leqq m/2)$$

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

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

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

Accordingly, it follows from the Equation 9 that

$$I'(\phi)=-\frac{I_1Z_1+2\sum_{q=2}^{\nu}I_qZ_q+I_{\nu+1}Z_{\nu+1}}{j\pi\rho d_o}-\frac{2}{j\pi\rho}\sum_{n=1}^{\infty}\left(I_1Z_1+2\sum_{q=2}^{\nu}I_qZ_q\cos\frac{n(q-1)}{\mu}\pi+(-1)^nI_{\nu+1}Z_{\nu+1}\right)\frac{\cos n\phi}{\alpha_n}\sum_{n=0}^{\infty}i_n'\cos n\phi \quad (12)$$

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

$$i_0=i'_o,\quad i_1=i'_1,\quad \ldots i_\nu=i$$

and solve the following equation:

$$\begin{bmatrix}Z_1\\ \vdots\\ Z_{\nu+1}\end{bmatrix}=j\pi\rho\begin{bmatrix}I_1 & & & 0\\ & I_2 & & \\ & & \ddots & \\ 0 & & & I_{P+1}\end{bmatrix}^{-1}$$

$$\begin{bmatrix}1 & 2 & 2 & \cdots & 2 & 1\\ 1 & 2\cos\frac{\pi}{\nu} & \cdots & \cdots & 2\cos\frac{\nu-1}{\nu}\pi & -1\\ 1 & 2\cos\frac{2\pi}{\nu} & \cdots & \cdots & 2\cos\frac{2(\nu-1)}{\nu}\pi & 1\\ \vdots & \vdots & & & \vdots & \vdots\\ 1 & \cos\pi & \cdots & \cdots & 2\cos(\nu-1)\pi & (-1)\end{bmatrix}\begin{bmatrix}\alpha_0 & i_0\\ \alpha_1 & i_{1/2}\\ \vdots & \vdots\\ \alpha_\nu & i_{\nu/2}\end{bmatrix} \quad (13)$$

The other method is to put

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

and solve the following equation:

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

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:

$$D(\phi)=A_0+A_1\cos\phi \quad (15)$$

$$I(\phi)=o_0+i_1\cos\phi \quad (16)$$

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

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

If admittances are defined as follows:

$$y_b=\frac{2}{J\pi\rho}\sum_{n=-\infty}^{\infty}\frac{1}{\alpha_{2n}} \quad (19)$$

$$y_u=\frac{2}{J\pi\rho}\sum_{n=-\infty}^{\infty}\frac{1}{\alpha_{2n-1}} \quad (20)$$

it follows that

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

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:

$$Z_2=-\frac{y_b+y_u}{2y_by_u}+\frac{y_b-y_u}{2y_by_b}-\frac{I_1}{I_2} \quad (22)$$

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

$D(\Phi)=A_0+A_1\cos\Phi+A_2\cos 2\Phi$ (23)

and

$I(\Phi)=i_0+i_1\cos\Phi+i_2\cos 2\Phi$ (24)

Defining

$$y_q=\frac{2}{J\pi\rho}\left[\frac{1}{\alpha_0}+\sum_{n=1}^{\infty}\left(\frac{1}{\alpha_m}-\frac{1}{\alpha_{m-2}}\right)\right] \quad (25)$$

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

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

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

and

$$Z_3=-\frac{1}{2y_u}-\frac{y_b}{2(y_b^2-y_q^2)}+\frac{I_1}{I_2}\left(\frac{1}{2y_u}-\frac{y_b}{2(y_b^2-y_q^2)}\right)+\frac{I_2}{I_3}\cdot\frac{y_q}{y_b^2-y_q^2} \quad (28)$$

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 $ReZ_1<0$ 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 the value *kb* that the diameter 2*b* of the antenna loop 1 is normalized with a wavelength, that is $\pi 2b/\lambda$ and reference numerals 4*a*, 4*b*, and 4*c* indicate 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 $ReZ_{\nu+1}\equiv R_{L\nu+1}>0$, η

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

(b) If $ReZ_1>0$ and $ReZ_{\nu+1}<0$,

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

(c) If $ReZ_1<0$ and $ReZ_{\nu+1}<0$, 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 $2ln2\pi b/a=9$ ohms. There is a tendency that the efficiency increases near the boundaries of the regions in FIG. 3 but the efficiency is determined primarily by the sublobe levels.

FIGS. 5 and 6 illustrate directional patterns when the characteristic impedance Ω of the antenna loop 1 is 9 ohms and 10 db. is given to the Chebishev approximation, that is, the sublobes are −10 db. In FIG. 5 lines marked with crosses × and triangles Δ respectively show directivity patterns when $kb=0.1$ and $kb=0.6$, while in FIG. 6 lines with crosses × and circles *o* respectively indicate directivity patterns when $kb=1.2$ and $kb=1.5$. Full lines illustrate ideal directivity patterns. It will be understood from the figures that since the approximation is achieved with a finite number of impedance means, the

sublobes become larger than in the ideal case but that if *kb* 1.2, there is no trouble in practice. The impedance elements are arranged on the antenna loop at equal intervals.

FIG. 7 illustrates one embodiment of this invention, in which two impedance elements are connected to an antenna element **10** in place of the impedance elements connected at the terminals **3***a* and **3***b* in FIG. **1**. With the characteristic impedance of the antenna element **10** being 9 ohms, a given pattern being −40 db. in the Chebishev approximation and *kb* being 1.0 (at a frequency of 200 MHz.), the value of the impedance elements is such that $Z_2=Z_4=500$ ohms. In this case the impedance elements Z_2 and Z_4 are formed with reactances. Since the antenna element does not contain any resistance causing a loss, an antenna of low loss can be obtained. In FIG. **8** there are shown directional patterns of the antenna exemplified in FIG. **7**, in which a full line **11** indicates a given pattern and a broken line **12** an experimental pattern. As will be seen from FIG. **8**, the patterns almost agree with each other.

FIG. **9** shows another example of the antenna of this invention in which three impedance elements are connected to an antenna element **13** and the impedance means Z_3 is made up of a negative resistance element such as a Esaki diode **14**. With the characteristic impedance of the antenna element **13** being 9 ohms, a given pattern being −26 db. in the Chebishev approximation and *kb* being 1.0 (at a frequency of 200 MHz.), such a directional pattern as depicted in FIG. **10** is obtained. Full line **15** indicates a given pattern and broken line **16** an experimental pattern. Since the negative resistance element is employed in this case, the power gain is 7.9 db. and the S/N sensitivity is 6.8 db. as compared with a standard $\lambda/2$ dipole antenna. A unidirectional characteristic can be obtained by connecting impedance elements of equal value to the loop symmetrically at the terminals. The foregoing has discussed the directional patterns at particular frequencies and the following will describe an antenna adapted to exhibit an excellent directional pattern and have a wide frequency bandwidth.

The loop antenna element **17** depicted in FIG. **11** is designed such that the equivalent radii of conductive members at points therealong between terminals **18** and points **19** symmetrical therewith exceed the equivalent radii at the terminals **18** or in the vicinity thereof. Namely, the upper edge *a* of the loop antenna element **17** corresponds to one cycle of a waveform, while the lower edge *c* is symmetrical with the upper edge *a*. In other words, the widths of the conductive members are varied between their middle and end portions in directions that are perpendicular to the direction of curvature thereof in such a manner that the conductive members have relatively wide middle portions and relatively narrow end portions, as illustrated in the figure. The equivalent radius mentioned above is a distance between the upper and lower edges *a* and *c* of the conductive members. The loop antenna element **17** may be formed of conductive plates defined by the upper and lower edges *a* and *c*, irrespective of their thickness.

In the example of FIG. **11** the conductive plates of the above construction are arranged in opposing relation with their concave sides facing each other to provide a loop and the loop is divided, at the feeding points or output terminals **18**, at the points opposite thereto and the points of the widest middle portions of the conductive members, into four parts **20**, **21**, **22**, and **23**, defining gaps **24**, **25**, **26**, and **27** between adjacent ends thereof. An impedance element Z_3 serving as a dummy load and impedance elements Z_2 and Z_4 are respectively connected between adjacent ends of the divided conductive members which define gaps **25**, **26**, and **27**, respectively.

Since an effective current in the above conductive members is composed mainly of current components flowing on the upper and lower edges *a* and *c*, the conductive members may be replaced with, for example, wirelike elements of a shape that is similar to that of the perimeter of the conductive member, as exemplified in FIG. **12**. In this case two upper and lower loops are made up of loop elements **29**, **30**, **31**, **32**, **33**, **34**, and **35** and an impedance element Z_3 (having a resistance value of 1.2 KΩ) is connected as a dummy load between points **25** of the upper loop opposite to feeding points thereof. The loop element **34** corresponds to the lower edges of the conductive members **21** and **23** shown in FIG. **11**. Gaps **37**, **38**, **39**, and **40** are left as they are, and in this case the gaps **37** and **38** serve as an impedance element Z_2 having an infinite value and the gaps **39** and **40** act as an impedance element Z_4 having an infinite value. The loop elements **29** to **35** are respectively assembled together in pairs in such a manner that pairs of the elements **29** and **33**, **32** and **35**, **30** and **34**, **31** and **34** are held together by means of conductive bars **41**, **42**, **43**, and **44** respectively.

FIG. **13** shows the directional pattern of the antenna of FIG. **12**. As is apparent from FIG. **13**, the antenna exhibits an excellent directivity characteristic for various frequencies and covers a wide frequency bandwidth.

Turning now to FIG. **14**, a description will be given of the front-to-back ratio vs frequency characteristic of the antenna depicted in FIG. **12**. In FIG. **14** the abscissa represents frequency in MHz. and the ordinate the front-to-back ratio in db. A curve I indicates the characteristic of an antenna constructed such that its diameter is 286 mm.; the upper and lower loops are connected to each other at the feeding point and the point opposite thereto; the maximum distance between the feeding point and the conductive bar **41** or **42** is 100 mm.; and the distance between the point opposite to the feeding point and the conductive bar **43** or **44** is 140 mm. Since the front-to-back ratio of an antenna for television receivers is desired to be less than −10 db. a frequency band which provides a value of less than −10 db. in the curve I, is approximately 184 to 199 MHz. which is too narrow to cover all television channels.

A curve II shows the characteristic of the antenna of FIG. **12** which is constructed such that the maximum distance between the upper and lower loop elements is 100 mm.; the distances between the upper and lower loops at the feeding point and the point opposite thereto are 40 mm.; the distances between the feeding point and the neighboring conductive bars **41** and **42** are 100 mm.; the distances between the point opposite the feeding point and the neighboring conductive bars **43** and **44** are 95 mm.; and the dummy load is 1.2 KΩ. In the characteristic curve II the frequency band in which the front-to-back ratio is less than −10 db. is about 177 to 212 MHz., which covers high television channels. Also in this case, the directional characteristic is excellent.

With the present invention, it is possible to widen the frequency band by selecting relatively short the distance between the upper and lower loops at the point opposite to the feeding point and by selecting the distance between the upper and lower loops at the intermediate portion between the feeding point and the point opposite thereto to be longer than the aforementioned one.

The antennas **17** depicted in FIGS. **11** and **12** are sufficiently sensitive in a high-channel frequency band of VHF television broadcasting but they exhibit poor sensitivity in a low-channel frequency band.

Where the antennas are designed for the low-channel use, the dimensions in the respective directions become about twice as large as those for the high-channel use, and accordingly the volume dimension becomes approximately eight times greater, which prevents practical use of the antennas.

Referring to FIGS. **15** and those following it, a description will be given of antennas which are small but capable of covering a wide frequency band and exhibit excellent sensitivity and directivity for all VHF television channels.

In FIG. **15** reference numeral **45** designates generally an antenna and **17** an antenna element similar to that previously described with FIG. **12**. Accordingly, similar elements to those in FIG. **12** are identified by the same reference numerals and no description will be repeated.

The antenna element **17** is adapted to have a directional characteristic for a first frequency band, for example, a high-

channel frequency band of the VHF broadcasting and second antenna elements, for example, dipole antenna elements **46** are provided on the loop forming the antenna element **17** so as to provide for enhanced sensitivity for a second frequency band, for example, a low-channel frequency band of the VHF broadcasting. Namely, the dipole antenna elements **46** are respectively connected through trap circuits **47** to ends **29***a* and **32***a* of loop elements **29** and **32** which are remote from feeding points or output terminal **18**. Each trap circuit **47** consists of a parallel connection of a capacitor **48** and a coil **4***a* and the values of the capacitor **48** and the coil **4***a* are selected such that the trap circuit **47** exhibits a high impedance in the high-channel frequency band, for example, exceeding 160 MHz. and that the dipole antenna elements **46** do not exert any influence upon the characteristics of the antenna element **17**. Further, the value of the coil **4***a* is selected to permit the coil **4** *a* to act as a loading inductance of each of the dipole antenna element **46** so as to ensure shortening of the actual length of the dipole antenna element **46**. The dipole antenna elements **46** are so-called rod antennas which are expansible and hence are of variable effective length. In addition, the dipole antenna elements are rotatably mounted on the antenna element **17**.

With the antenna **46** of such a construction, in the high-channel frequency band the antenna element **17** supplies an output signal with excellent sensitivity and directivity as described above and output signals from the dipole antenna elements are removed by the trap circuits **47**. However, in the low-channel frequency band the antenna element **17** supplies substantially no output signal and the dipole antenna elements **46** exhibit a high degree of sensitivity and directivity and supply output signals to the feeding point. Accordingly, the antenna **45** is of high sensitivity and excellent directional characteristic for all VHF television channels.

FIG. **16** shows measured results of the sensitivity of the antenna **45** in the low-channel frequency band of the VHF television, that is, in a frequency range of 90 to 108 MHz. the abscissa representing the frequency and the ordinate the sensitivity and the length l_3 of the dipole antenna element **46** being a parameter. The measurements were achieved under the condition that the gain of the dipole antenna formed corresponding to a substantially center frequency of the low-channel frequency band was at zero level. Although not illustrated, the directivity of the antenna **45** in such low-channel frequency band is bilateral. Without the dipole antenna elements **46**, the output signal greatly decreased and the measurement of the sensitivity was impossible.

FIG. **17** shows measured results of the sensitivity of the antenna **45** in the high-channel frequency band, that is, in a frequency range of 168 to 222 MHz., the abscissa representing the frequency and the ordinate the sensitivity and the distance l_1 between the feeding point and the neighboring conductive bar being used as a parameter. The gain of the dipole antenna was similarly regarded as at zero level.

As will be apparent from FIGS. **16** and **17**, the antenna **45** exhibits a high degree of sensitivity in the low-channel frequency band of the VHF television. The sensitivity of the antenna can be adjusted a little by changing the lengths of the antenna elements **46**.

FIG. **18** schematically illustrates other modified forms of the antenna of this invention, in which parts corresponding to those in FIG. **15** are marked with the same reference numerals and no description will be repeated. In FIG. **18A** dipole antenna elements **46** are connected to feeding points **18** of an antenna **17** through trap circuits **47**; in FIG. **18B** dipole antenna elements **216** are connected through trap circuit **47** to conductive members **41** and **42** substantially at the center thereof; in FIG. **18C** pairs of dipole antenna elements **46** are connected through trap circuits **47** to loop elements **33** and **35** and to loop elements **29** and **32** at the ends thereof remote from the feeding points in the antenna depicted in FIG. **15**; and in FIGS. **18D** and **18E** trap circuits are formed with distributed constant circuits. In the antenna of FIG. **18D**, parallel lines **50**, each of which is short-circuited at one end and there connected to the dipole antenna element **46**, and each of which has a length of $\lambda/4$, are connected to the loop elements **33** and **34** or **34** and **35**, λ being the wavelength of the center frequency of the high-channel frequency band. Thus, the parallel lines **50** are nonconductive in the high-channel frequency band and serve as feeding lines in the low-channel frequency band. FIG. **18E** shows an antenna in which parallel lines **51** of a length of $\lambda/4$ are arranged to extend from the feeding points **18** toward the center of the antenna **17**, parallel lines **52** extend from the open ends of the lines **51** in a direction substantially perpendicular to a plane of the antenna **17** and dipole antenna elements **46** are connected to the connection points of the parallel lines **51** and **52**. With such an arrangement, the free ends of the parallel lines **52** are open, so that the connection points of the lines **51** and **52** are short-circuited for the high-channel frequency band and open for the low-channel frequency band.

With the present invention described above, output signals at high-channel frequencies derived from the conventional antennas and those at low-channel frequencies derived from the dipole antennas are combined together, so that although the antenna device is relatively small, it exhibits excellent sensitivity and directivity, as is apparent from the aforementioned measured results, and the antenna device is suitable for use as an antenna for VHF television reception, especially as a room antenna.

It will be apparent that many modifications and variations may be effected without departing from the scope of the novel concepts of this invention.

We claim as our invention:

1. A directional antenna comprising a loop antenna element including a plurality of arcuate conductive members arranged in a ring and shaped to provide relatively narrow portions at first diametrically opposed locations and relatively wide portions at second diametrically opposed locations at right angles to said first locations, said conductive members having adjacent ends thereof spaced apart at said first and second locations, output terminal means connected to the adjacent spaced ends of said conductive members at one of said first locations, impedance means connected between the adjacent ends of said conductive members at the other of said first locations to serve as a dummy load, and further impedance means at said second locations to determine the distribution of current flow in said antenna element.

2. A directional antenna as in claim **1**, in which said conductive members are wirelike.

3. A directional antenna as in claim **1**, further comprising a second antenna element connected to the first-mentioned antenna element and being resonant with a frequency different from the resonance frequency of said first antenna element.

4. A directional antenna as in claim **3**, in which trap means are connected between said first and second antenna elements to prevent the flow of current in said second antenna element except due to resonance of the latter.

5. A directional antenna as in claim **3**, in which said second antenna element is a dipole antenna.

6. A directional antenna as in claim **5**, in which said dipole antenna is telescopically adjustable.

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