Sept. 4, 1951 H. IAMS 2,566,703

RADIO WAVE FOCUSING DEVICE

Filed May 14, 1947 3 Sheets-Sheet 1

FIG. 1

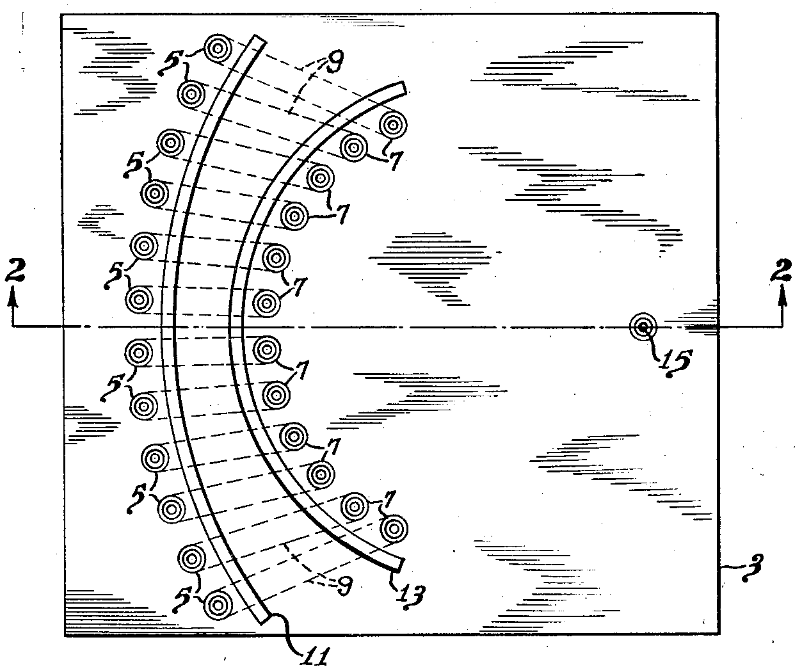
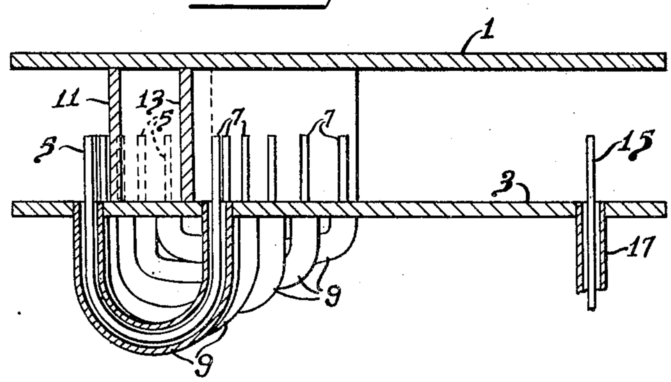


FIG. 2



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RADIO WAVE FOCUSING DEVICE

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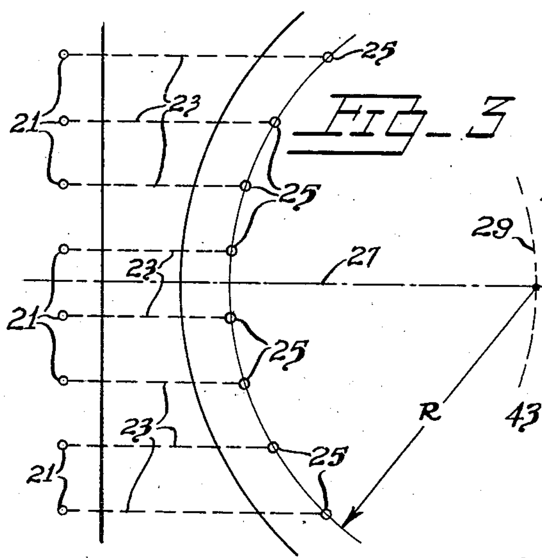

FIG. 3

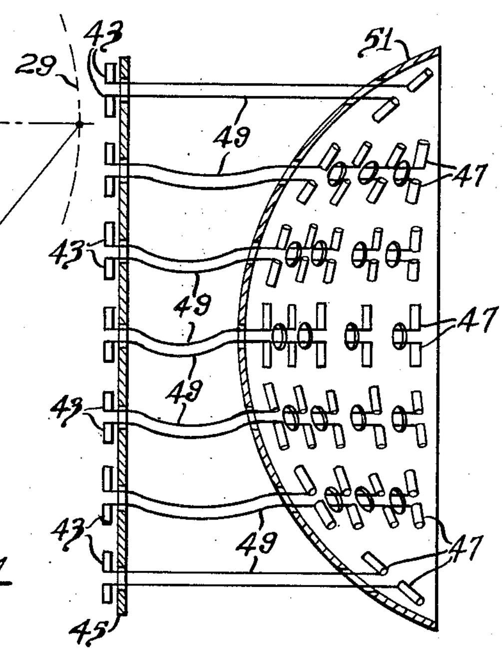

FIG. 5

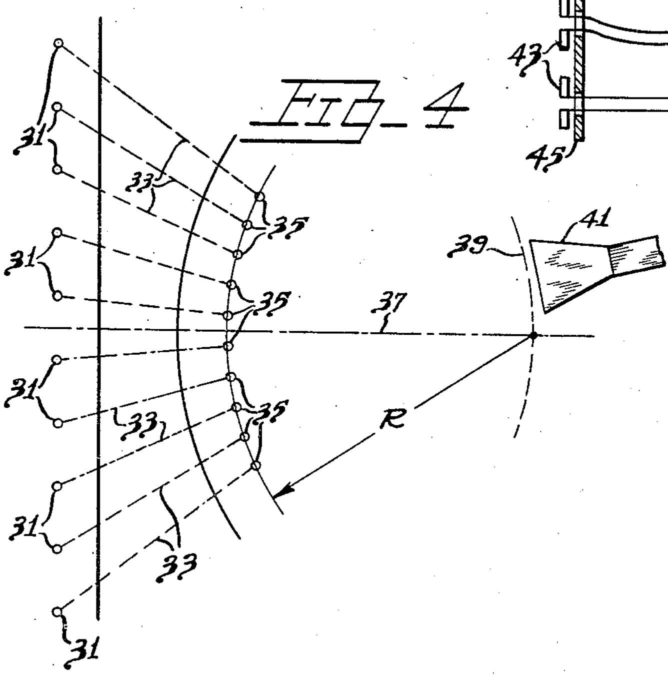

FIG. 4

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FIG. 6

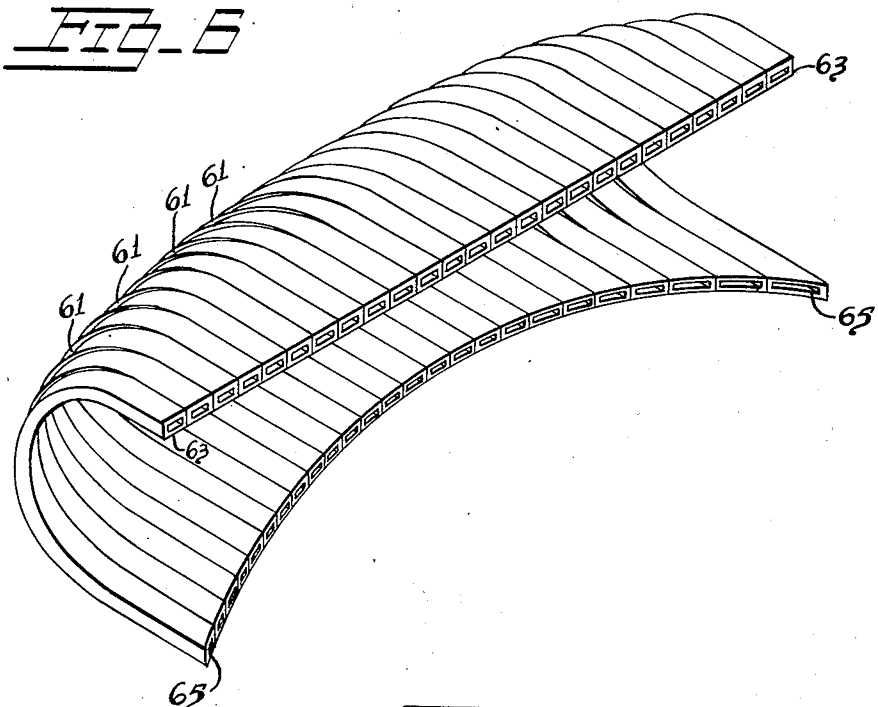
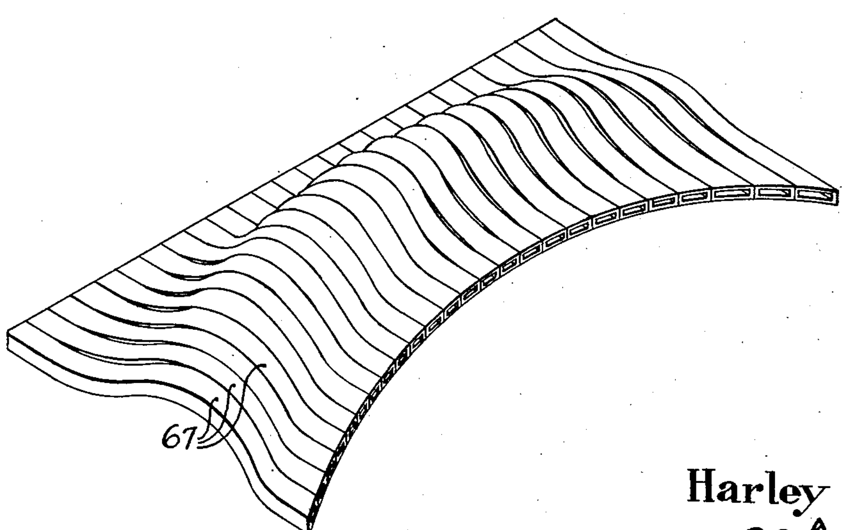


FIG. 7



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UNITED STATES PATENT OFFICE

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RADIO WAVE FOCUSING DEVICE

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Application May 14, 1947, Serial No. 747,889

13 Claims. (Cl. 250—33.65)

This invention relates to the art of focussing radio and similar waves, and more particularly to devices of the type in which the different parts of a wave front are made to follow paths of such length as to bring them into phase at a focal point. It is known that lenses, designed like those used for optical purposes, may be used for focussing radio waves. Such lenses may be made of dielectric material, such as paraffin wax. The present invention differs in that it contemplates the use of a plurality of conduits, for example waveguides or transmission lines, arranged to change the shape of a wave front by accepting the wave energy at points lying in one line or surface and radiating the energy from corresponding points lying in another line or surface. These structures exhibit the properties of lenses, such as the ability to focus and form images, but operate on principles somewhat different from those used in optical devices.

The invention will be described with reference to the accompanying drawings, wherein:

Figure 1 is a plan view of a portion of a focussing device which embodies the present invention,

Figure 2 is a section of the device in Figure 1 taken in the plane designated by the line 2—2 of Figure 1,

Figure 3 is a schematic representation of a modification of the device of Figure 1,

Figure 4 shows schematically a further modification of the device of Figure 1,

Figure 5 shows a device similar to that of Figure 3 but extended to provide two-dimensional images,

Figure 6 is a perspective view of a focussing device constructed in accordance with the instant invention, using hollow waveguides, and

Figure 7 is a perspective view of a device like that of Figure 6 but of slightly different design.

The device illustrated in Figures 1 and 2 is for focussing waves guided between parallel conductive sheets. Both the upper and lower sheets 1 and 3 respectively are shown in Figure 2. In Figure 1 the upper sheet is omitted to reveal the structure. A plurality of rod-like antenna elements 5 are disposed in a circular arc extending across the sheet 3. The rods 5 extend approximately one-quarter wavelength from the surface of the sheet 3, and are spaced along the arc at equal intervals of about one-half wavelength.

A second group of antenna elements 7 is arranged similarly along another circular arc, at half wavelength intervals. The elements 7 are equal in number to the elements 5, and each element 7 is connected to a corresponding one of the elements 5 by a respective transmission line 9. The lines 9 are all of the same length, or all have the same effective or electrical length on a wavelength scale for the energy propagated therethrough.

Reflectors 11 and 13 are provided between the rows of antennas 5 and 7. The reflector 11 is curved substantially like the arc along which the antennas 5 are disposed, and is located about one-quarter wavelength away from it. The reflector 13 corresponds in shape to the arc defined by the antennas 7, and lies about one-quarter wavelength outside said arc.

The radius of the arc formed by the antennas 5 is approximately twice that of the antennas 7. A further antenna 15 is provided at a point which is approximately on the circle drawn through antennas 7. The antenna 15 is connected by a transmission line 17 to a utilization device such as a transmitter or a receiver, not shown.

The operation of the described device is substantially as follows: Suppose a plane wave, such as that from a distant source, to be arriving from the left of Figure 1. A phase front, or line of points of equal phase, in such a wave is a straight line perpendicular to the direction of travel. Any particular phase front arrives first at the central antennas 5, and progressively later at the others, reaching finally the outermost of the antennas 5. The phases at the antennas 7 lag those at the corresponding antennas 5 by equal amounts, since the lines 9 are of equal lengths. Thus the excitations of the antennas 7 are progressively more lagging, going from the center to the outside of the group.

The resultant phase front formed by radiation from the antennas 7 is curved with a radius 2R, where R is the radius of curvature of the locus of the antennas 7 and 2R is the radius of the locus of the antennas 5. The center of curvature of this phase front is at the antenna 15, so that substantially all of the energy picked up by the antennas 5 arrives in phase at the antenna 15.

The device also operates for transmission; if the antenna 15 is supplied with energy from a source connected to the line 17, the portion of the resulting circular wave front which strikes the antennas 7 is converted to a plane wave travelling to the left from the antennas 5.

The uses are not limited to conversion between a plane wave and a curved wave of radius 2R. As in optical lens systems, a wave front of one curvature may be converted to one of a different curvature. The distance 2R may be considered as the focal length F of the system. A wave front of any radius R_a arriving at one row of antennas is radiated from the other row as a wave front of radius R_b, where R_a and R_b are related as follows:

$$\frac{1}{R_a}+\frac{1}{R_b}=\frac{1}{F}$$

Preferably the system should be arranged so that the wave front of greater radius should be associated with the antennas **5**, in order to minimize aberration.

The invention is not restricted to the particular dimensional relationships shown in Figure 1. For example, as shown schematically in Figure 3, one row of antennas **21** may be disposed at equal intervals along a straight line, and connected by equal-length lines **23** to corresponding antennas **25** which lie on an arc of radius R. In this example, the antennas are placed at equal intervals from the axis **27** instead of equal intervals along the arc.

The device of Figure 3 exhibits substantially the same characteristics as that of Figure 1, with the exception that it focal length is R rather than 2R. The focal line, which is the locus of focal points for plane waves arriving at the antennas **21** at various angles to the axis **27**, is curved, as indicated by the dash line **29** in Figure 3. This effect is analogous to that of curvature of the field in optical systems.

In the system of Figure 4, the antenna elements **31** are located at equal intervals along a straight line, like the elements **21** in Figure 3. Elements **35** are arranged along an arc of radius R, like the elements **25** of Figure 3, and are connected to the corresponding elements **31** by lines **33**. The distance of the elements **35** from the axis is however, $1/n$ times that of the corresponding elements **31**.

The structure of Figure 4 operates as a lens of focal length R, like the device of Figure 3. In addition, it has the property of multiplying any deviation of the direction of travel of a wave by the factor n or $1/n$, depending upon whether the wave goes from left to right or from right to left in Figure 4. This function is particularly useful in devices for scanning, where it is desirable to have a short focal length to minimize the dimensions of the apparatus, and yet a large aperture to minimize the beam width. Also, for direction finding it is convenient to have the angular position of an antenna device, such as a horn **41**, change by a factor of approximately $n\theta$ where the position of a target moves through an angle θ.

The devices thus far described are all intended for operation with energy confined to substantially a single plane, such as the space between the upper and lower sheets **1** and **3** in Figure 2, and the wave fronts may be regarded as lines. When propagation occurs in more or less unconfined space, the wave fronts are generally surfaces, rather than lines. Such waves can be handled by structures analogous to those of Figures 1, 3 and 4, but extended in another dimension.

Referring to Figure 5, a plurality of antennas **43** are distributed uniformly near the surface of a flat reflector **45**. Each antenna **43** is connected through a line **49** to a corresponding one of a group of antennas **47**, disposed adjacent a spherical reflector **51**. The lines **49** are all of the same electrical length.

The device of Figure 5 is analogous to that of Figure 3, and each elementary row of antennas functions like the structure of Figure 3. The complete structure will accept a wave front in the form of a surface of one curvature and deliver a wave front whose surface is of a different curvature. The focal length of the device, considered as a lens, is equal to the radius of curvature of the reflector **51**. It will be apparent without further discussion that similar analogies exist for the devices of Figures 1 and 3.

Referring to Figure 6, a number of waveguides are assembled so that their openings at one end form a straight line **63**, while the other ends form a curved line **65**. The waveguides **61** are of equal lengths, so that a rectilinear wave front striking the line **63** produces a curved wave front at the line **65**, bringing energy to a focus at the center of curvature of the line **65**.

Figure 7 shows a structure differing from that of Figure 6 only in that the waveguides **67** are curved back so that energy passing through the devices continues in the same general direction instead of travelling back toward the source. The electrical characteristics of the device of Figure 7 are substantially identical with those of the structure of Figure 3. The mouths or openings of the waveguides function as antennas, and the waveguides act as transmission lines.

The proportions which have been given in this discussion are those of radio wave focusing devices which have low aberration, even for points at considerable distance from the optic axis. For some purposes it is not necessary to meet this requirement, and other radii or shapes may be used for the surfaces on which the wave collecting and radiating elements are placed. The focal length F of the device may then be found from the following formula:

$$\frac{1}{F}=\frac{1}{R_1}+\frac{1}{R_2}$$

where R_1 and R_2 are the radii of the two surfaces.

I claim as my invention:

1. A system for focussing radiant energy, comprising a plurality of wave collector elements disposed at substantially equally spaced points on a surface, a reflector positioned with said collector elements between it and the source of the incident energy to be focused, a plurality of radiator elements disposed at substantially equally spaced points on a second surface, a second reflector positioned with said radiator elements between it and the place toward which the energy is to be radiated by said radiator elements, at least one of said surfaces being curved, and respectively separate and independent means connecting each of said collector means which occupies a position on said first surface to the one and only one of said radiator means which occupies the corresponding position on said second surface, said connecting means being of equal effective electrical lengths whereby said energy is focused by said radiator elements.

2. A system for focussing radiant energy, comprising a plurality of wave collector elements disposed at substantially equal intervals along a line, a reflector positioned with said collector elements between it and the source of the incident energy to be focused, a plurality of radiator elements disposed at substantially equal intervals along a second line, a second reflector positioned with said radiator elements between it and the place toward which the energy is to be

radiated by said radiator elements, at least one of said lines being curved, and respectively separate and independent means connecting each of said collector means which occupies a position along said first line to the one and only one of said radiator means which occupies the corresponding position along said second line, said connecting means being of equal effective electrical lengths whereby said energy is focused by said radiator elements.

3. A system for focussing radiant energy, comprising a plurality of wave collector elements disposed at substantially equal intervals along a line, a reflector positioned with said collector elements between it and the source of the incident energy to be focused, a plurality of radiator elements disposed at substantially equal intervals along a second line, a second reflector positioned with said radiator elements between it and the place toward which the energy is to be radiated by said radiator elements, said intervals along said second line being different from those along said first line, at least one of said lines being curved, and means connecting each of said collector means which occupies a position along said first line to the one and only one of said radiator means which occupies the corresponding position along said second line, said connecting means being of equal effective electrical lengths whereby said energy is focused by said radiator elements.

4. A system for focussing radiant energy comprising a plurality of energy collector means at point defining a first surface, a reflector positioned with said collector means between it and the source of the incident energy to be focused, a plurality of radiator means at points defining a third surface, a second reflector positioned with said radiator means between it and the place toward which the energy is to be radiated by said radiator means, at least one of said first and third surfaces being curved, and a plurality of linear wave transmission devices, each connecting only one of said collector means on said first surface to only one of said radiator means at a corresponding position on said third surface, said wave transmission devices being of substantially equal effective electrical lengths whereby said energy is focused by said radiator means.

5. A system for focussing radiant energy comprising a plurality of energy collector means at points defining a line, a reflector positioned with said collector means between it and the source of the incident energy to be focused, a plurality of radiator means at points defining a second line, a second reflector positioned with said radiator means between it and the place toward which the energy is to be radiated by said radiator means, at least one of said lines being curved, and a plurality of linear wave transmission devices, each connecting only one of said collector means to only a corresponding one of said radiator means, said wave transmission devices being of substantially equal effective electrical lengths whereby said energy is focused by said radiator means.

6. In a radio device including at least two parallel conductive sheets forming waveguiding means, a reflector extending between said two sheets substantially transversely to the direction in which energy is to flow through said guide, a plurality of wave collector elements adjacent said reflector at spaced points defining a line, a second reflector between said sheets and substantially transverse to said direction of energy flow, a plurality of radiator elements adjacent said second reflector at spaced points defining a second line, and means of substantially equal electrical lengths connecting each of said radiators to a corresponding one of said collectors; at least one of the lines defined by said collector elements and said radiator elements being curved, whereby energy flowing through said device is focussed at points outside said two lines.

7. In a radio device including at least two parallel conductive sheets forming a waveguiding means, a plurality of wave collector elements at spaced points defining a line extending substantially transversely to the direction in which energy is to flow through said guide, a plurality of radiator elements at spaced points defining a second line substantially transverse to said direction of energy flow, and means of substantially equal electrical lengths connecting each of said radiators to a corresponding one of said collectors; at least one of the lines defined by said collector elements and said radiator elements being curved, whereby energy flowing through said device is focussed at points outside said two lines.

8. In a radio device including at least two parallel conductive sheets forming waveguiding means, a plurality of wave collector elements at spaced points defining a line extending substantially transversely to the direction in which energy is to flow through said guide, a plurality of radiator elements at spaced points defining a second line substantially transverse to said direction of energy flow, and means of substantially equal electrical lengths connecting each of said radiators to a corresponding one of said collectors; one of the lines defined by said collector elements and said radiator elements being curved, and utilization means substantially at the center of curvature of said line.

9. In a radio device including at least two parallel conductive sheets forming waveguiding means, a plurality of wave collector elements at spaced points defining a curve line extending substantially transversely to the direction in which energy is to flow through said guide, a plurality of radiator elements at spaced points defining a second curved line substantially transverse to said direction of energy flow, the radius of curvature of one of said lines being twice that of the other of said lines, and means of substantially equal electrical lengths connecting each of said radiators to a corresponding one of said collectors.

10. In a radio device including at least two parallel conductive sheets forming waveguiding means, a reflector extending between said two sheets substantially transversely to the direction in which energy is to flow through said guide, a plurality of wave collector elements adjacent said reflector at spaced points defining a curved line of radius 2R, a second reflector between said sheets and substantially transverse to said direction of energy flow, a plurality of radiator elements adjacent said second reflector at spaced points defining a second curved line of radius R, and means of substantially equal electrical lengths connecting each of said radiators to a corresponding one of said collectors; and a utilization device at a point distant substantially 2R from the center of said second line.

11. In a radio device including at least two parallel conductive sheets forming waveguiding means, a reflector extending between said two sheets substantially transversely to the direction in which energy is to flow through said guide, a

plurality of wave collector elements adjacent said reflector at spaced points defining a curved line of radius R_1, a second reflector between said sheets and substantially transverse to said direction of energy flow, a plurality of radiator elements adjacent said second reflector at spaced points defining a second curved line of radius R_2, and means of substantially equal electrical lengths connecting each of said radiators to a corresponding one of said collectors; and utilization means at a distance of substantially F from the center of one of said lines, where

$$\frac{1}{F}=\frac{1}{R_1}+\frac{1}{R_2}$$

12. The system claimed in claim 5, said transmission devices comprising waveguides.

13. The system claimed in claim 5, said transmission devices comprising waveguides, said lines each being a curve of substantially uniform radius.

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