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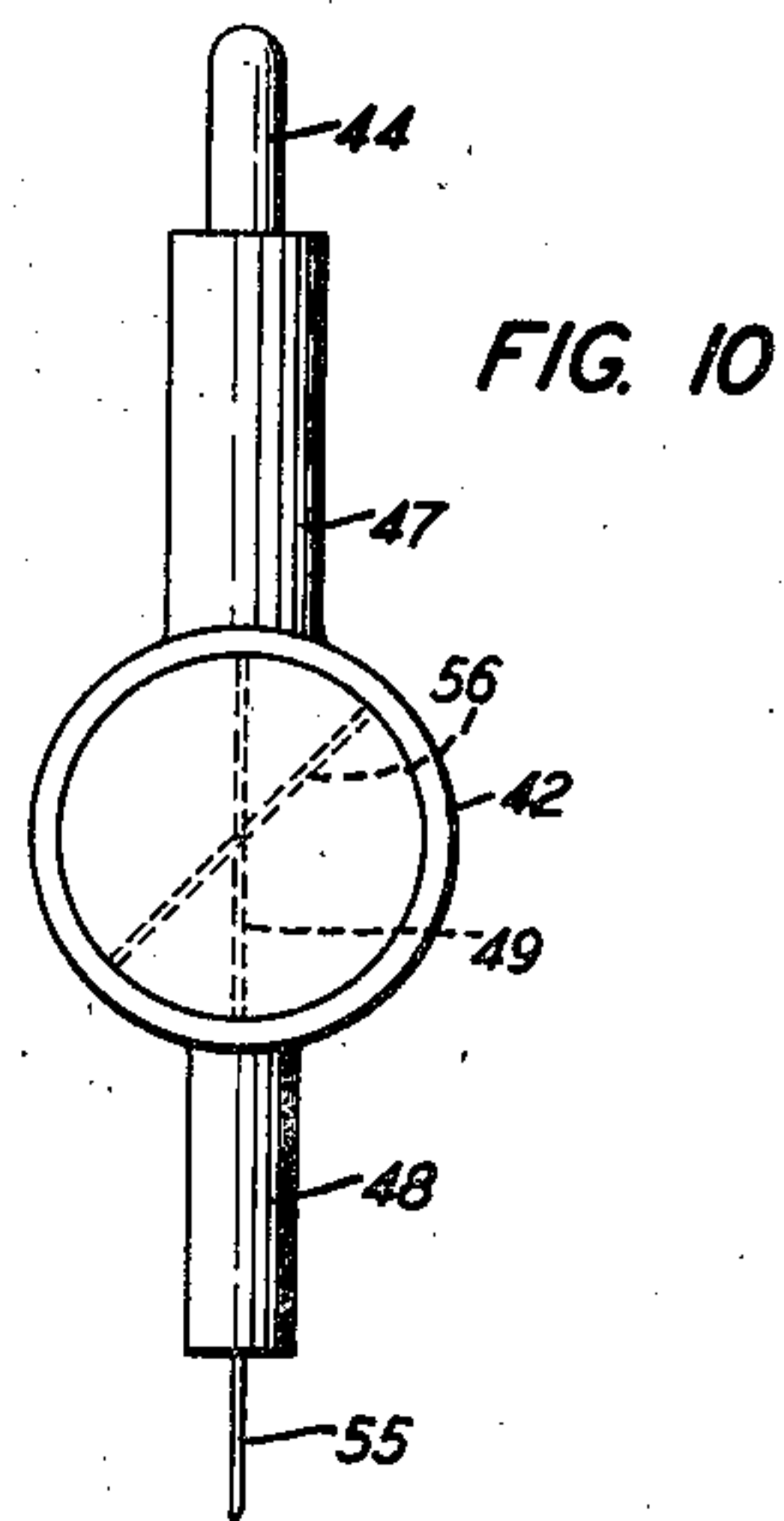
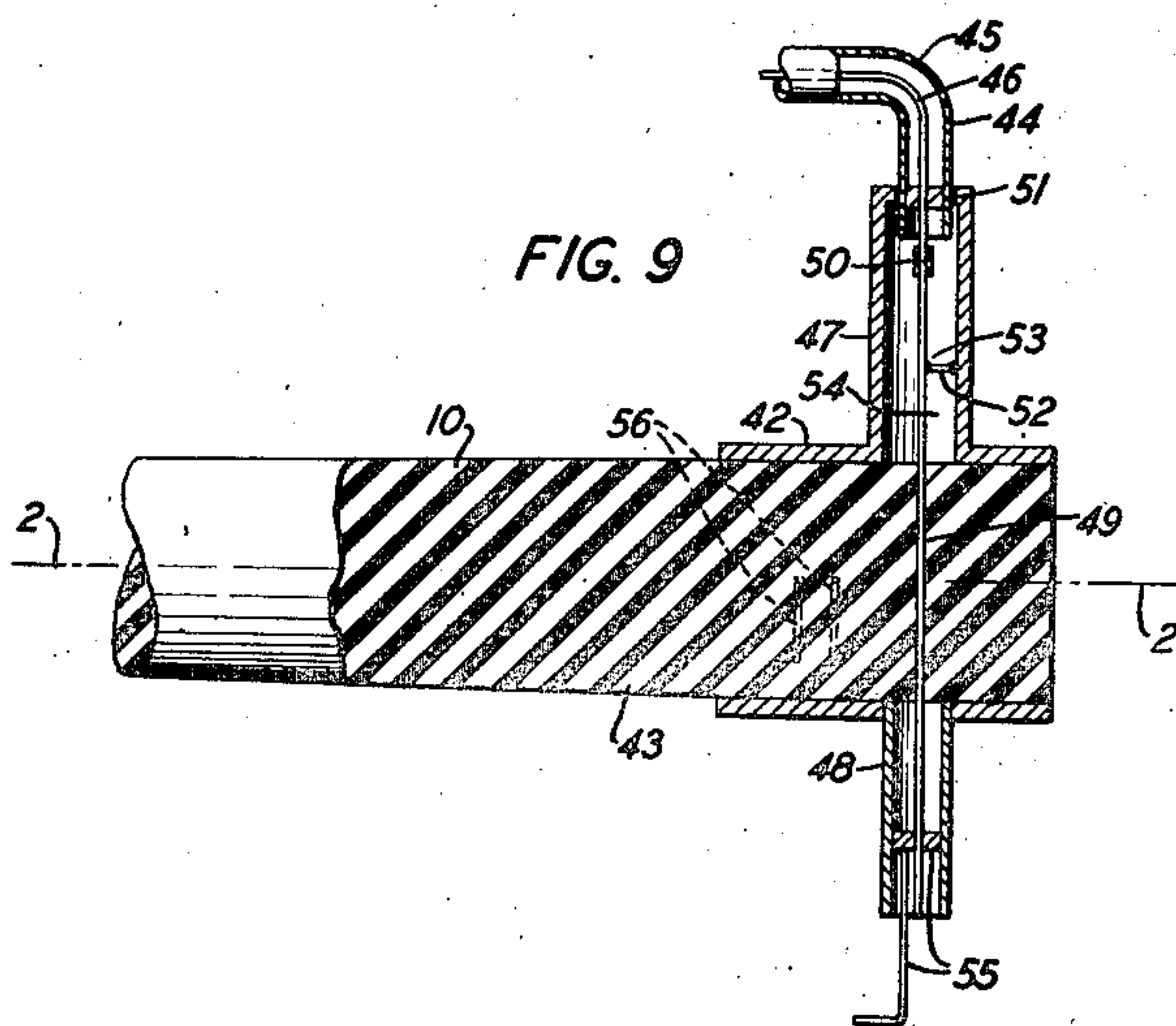
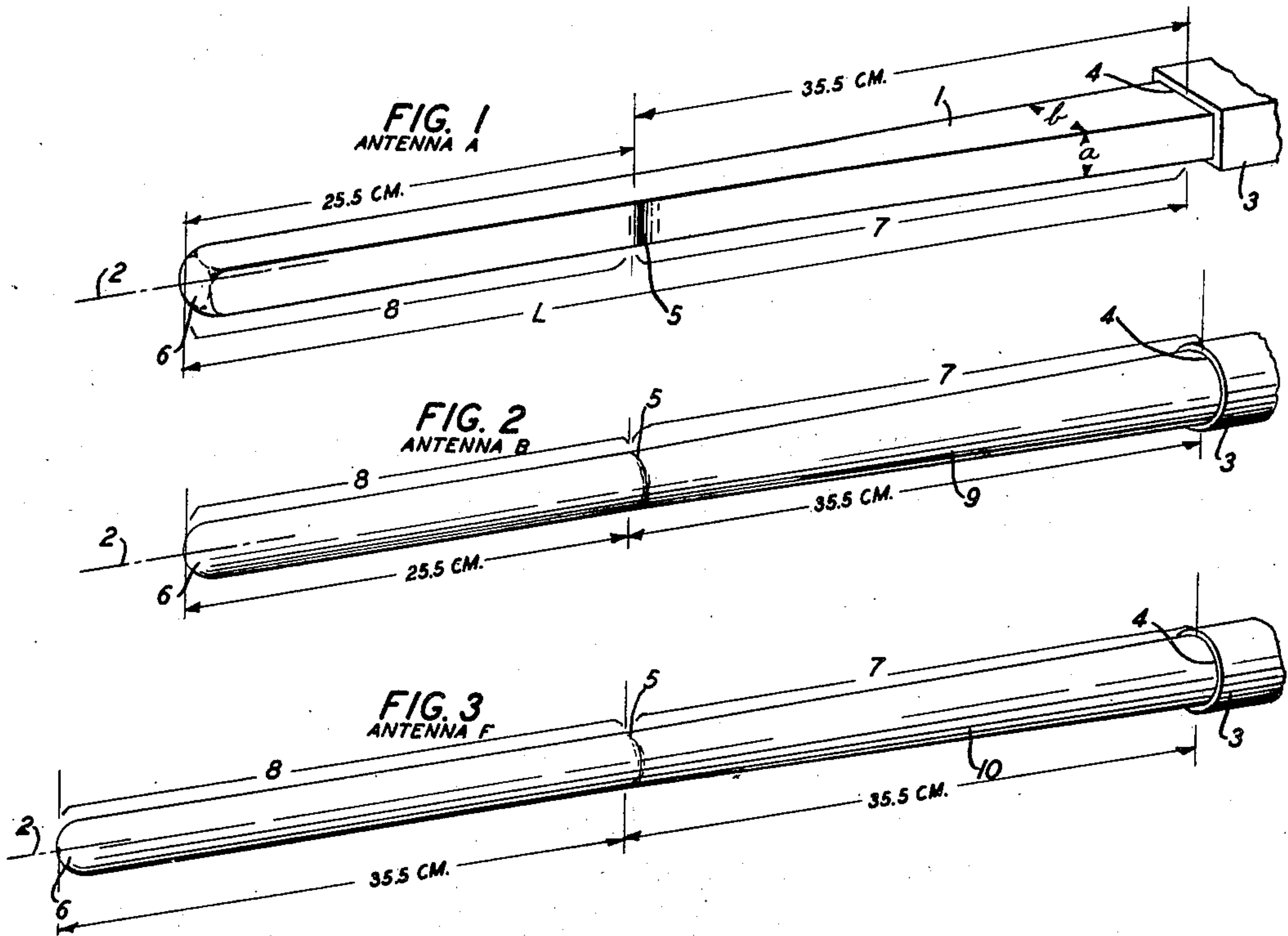
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2,425,336

MICROWAVE DIRECTIVE ANTENNA

Filed Dec. 17, 1942

3 Sheets-Sheet 1



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FIG. 4

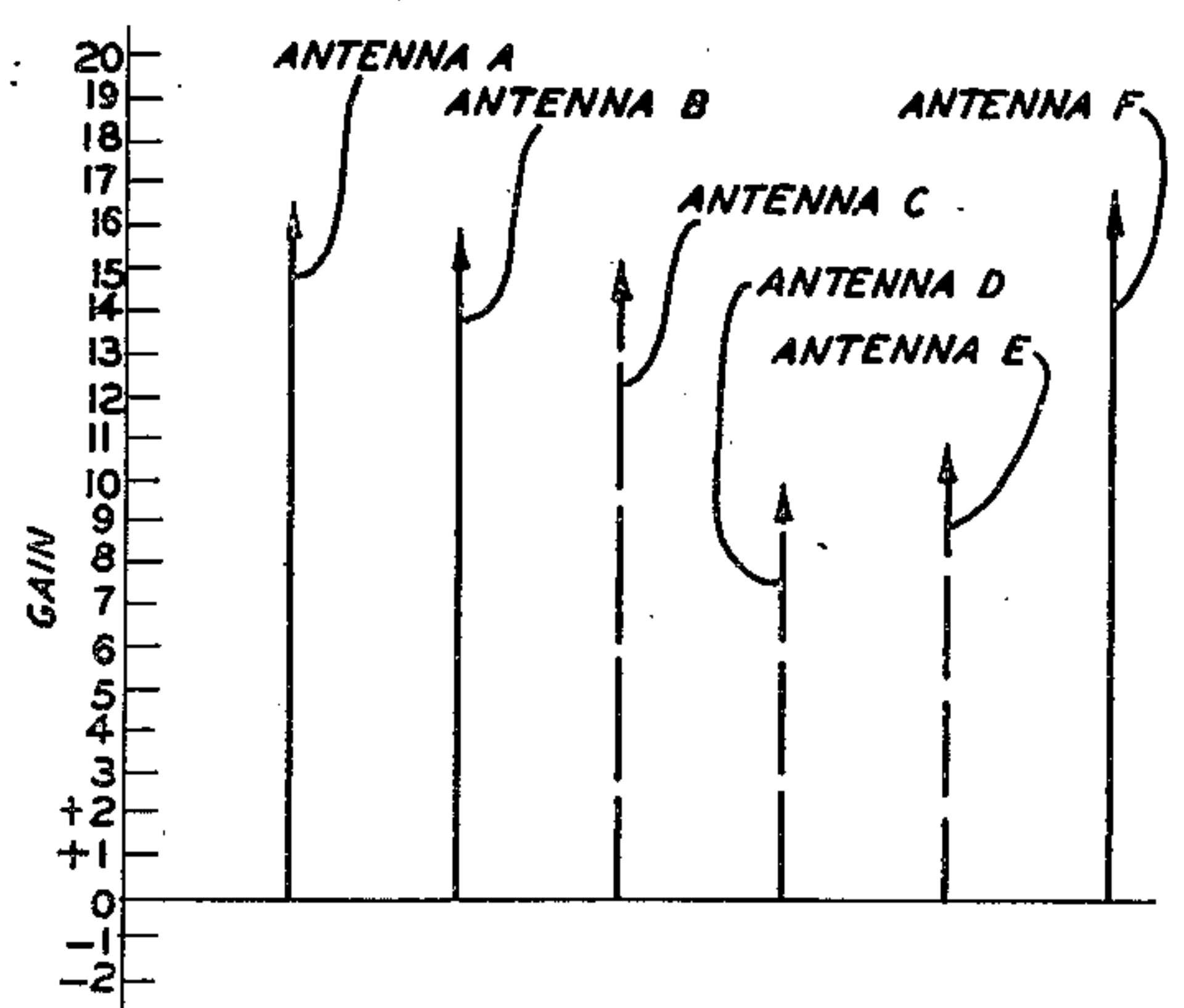
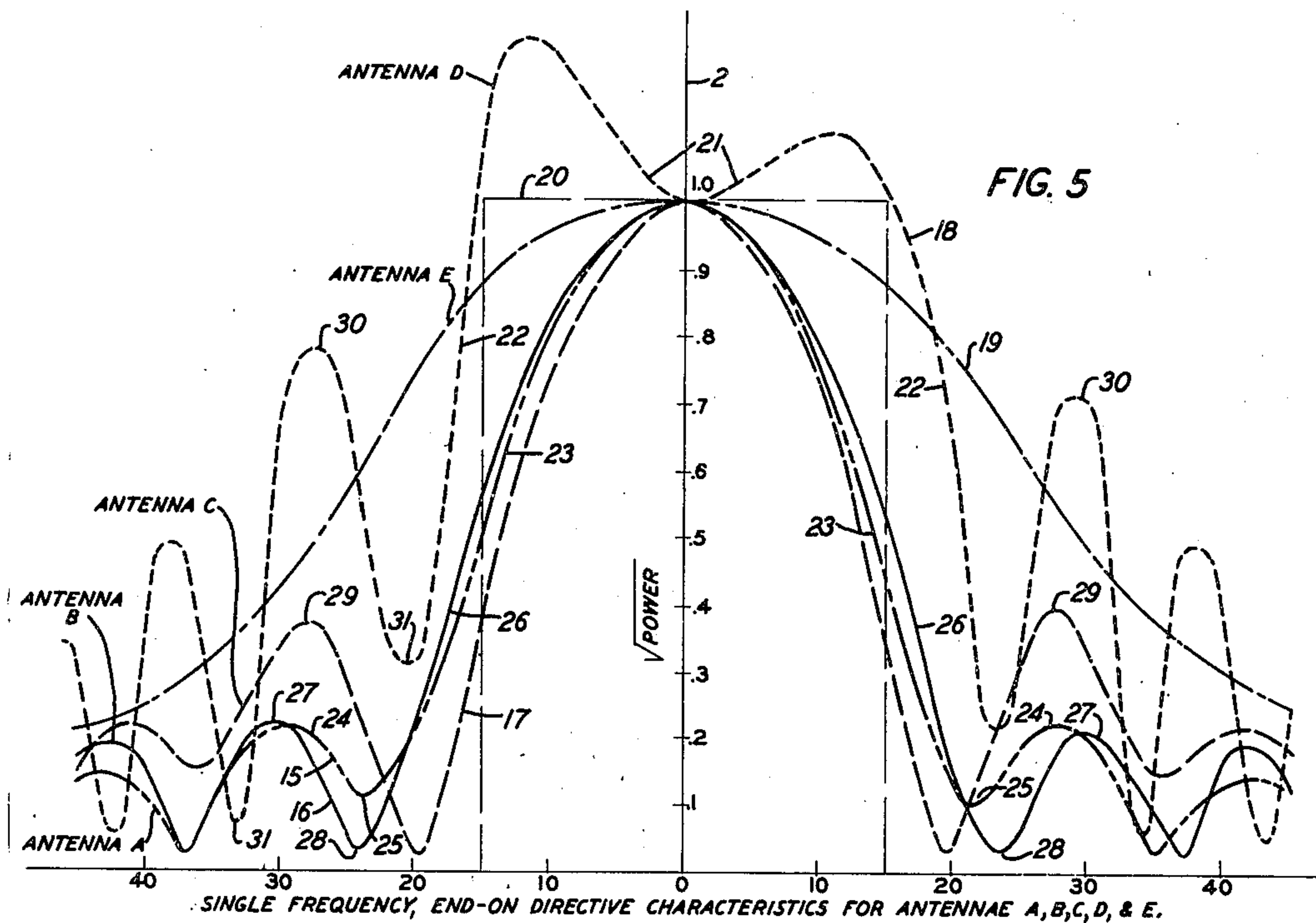
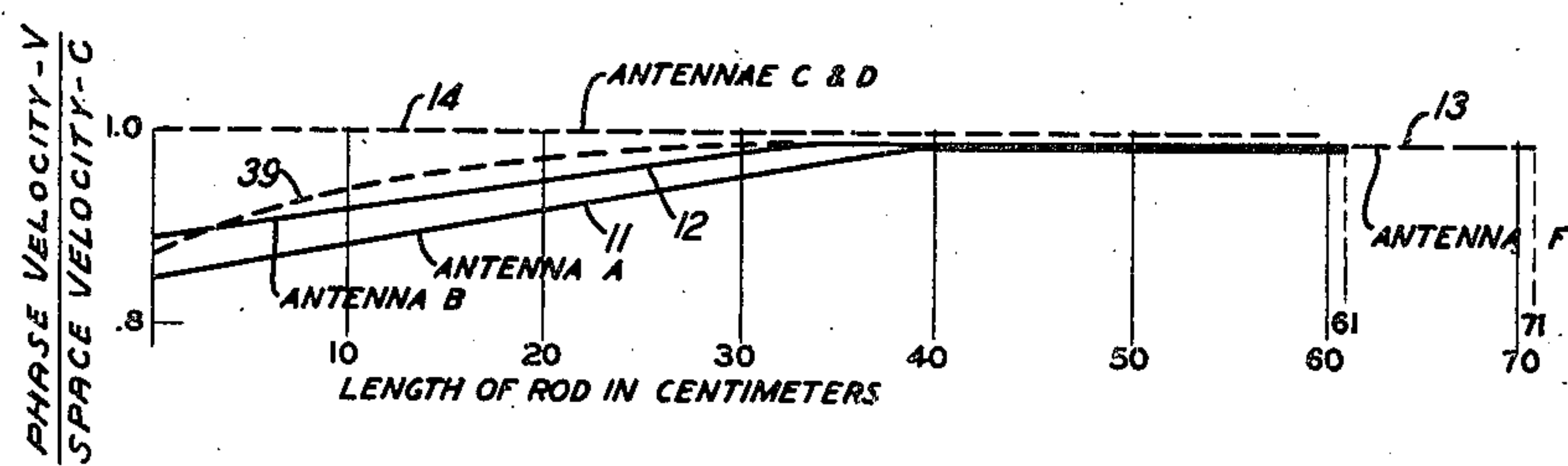


FIG. 6

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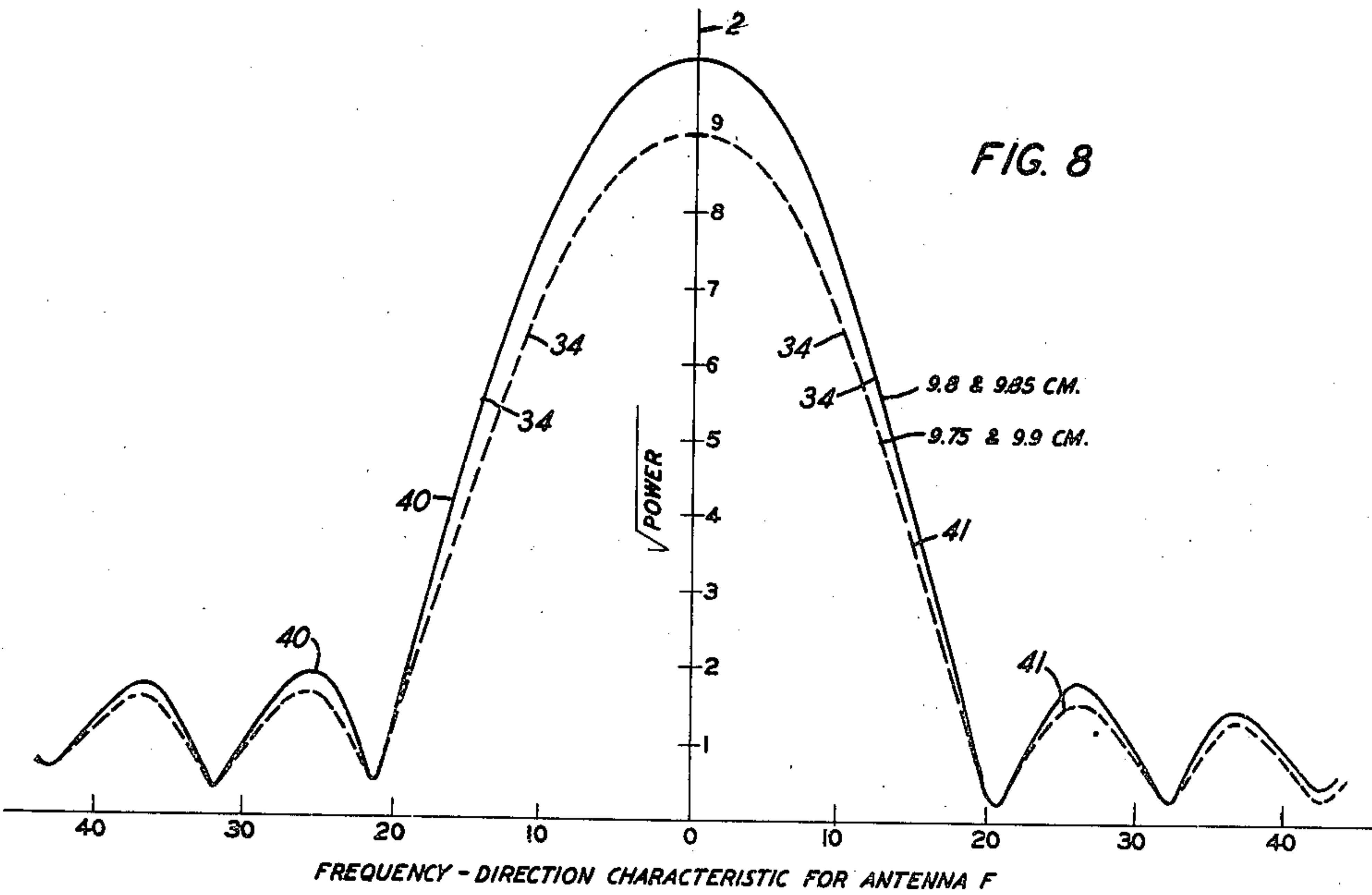
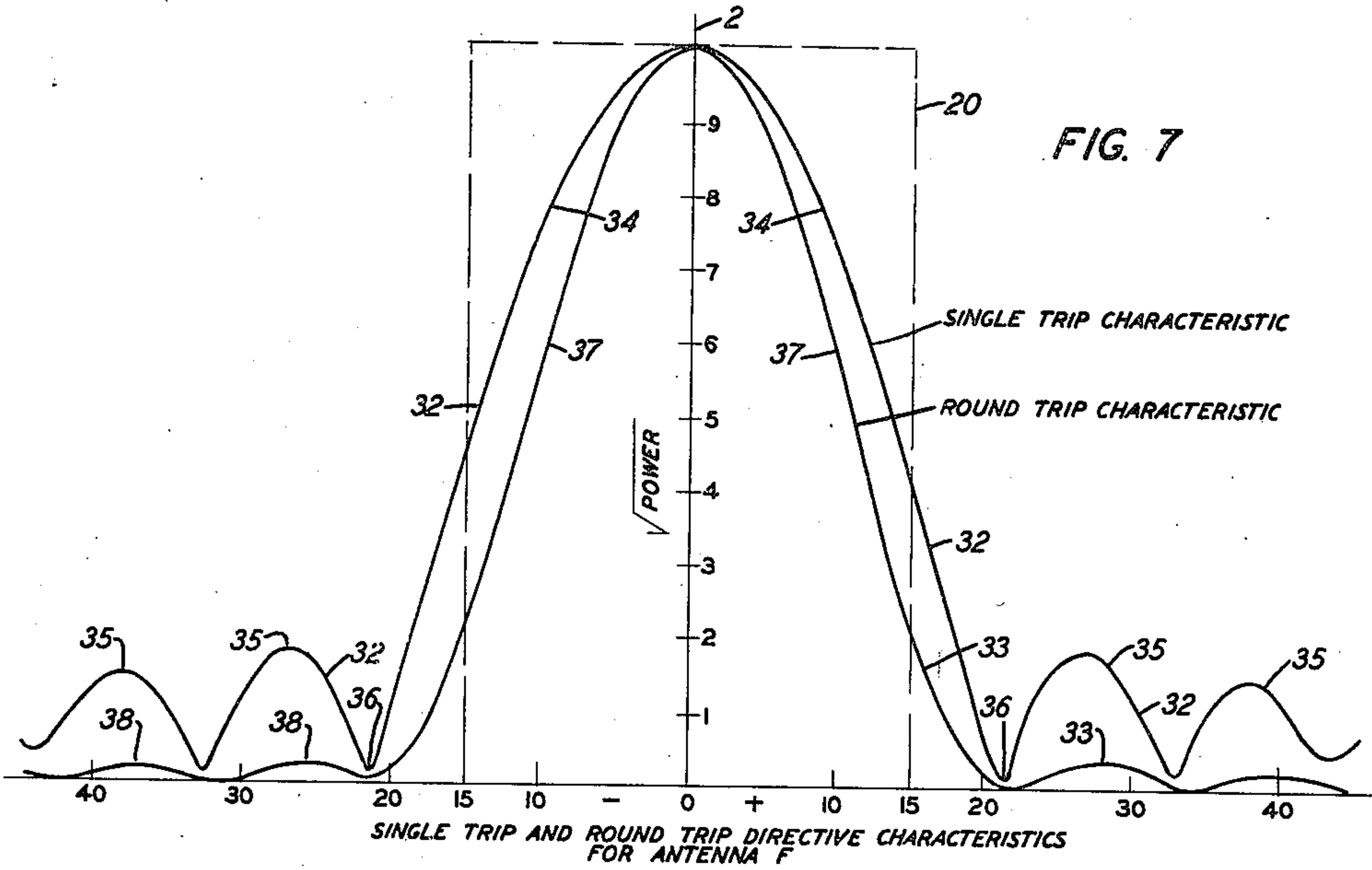
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MICROWAVE DIRECTIVE ANTENNA

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Application December 17, 1942, Serial No. 469,284

11 Claims. (Cl. 250—33)

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This invention relates to microwaves or centimetric antennas and particularly to end-on high gain directive dielectric antennas.

As disclosed in the article "Hyper-frequency wave guides—Mathematical theory" by S. A. Schelkunoff et al., published in the Bell System Technical Journal, April 1936, a solid dielectric wire or rod immersed in another dielectric medium such as air, functions as a guide for microwaves provided the dielectric constant of the solid element is higher than that of the medium. At the lowest frequency conveyed by the element, the phase velocity is equal to that of light and the field extends to great distances outside the guide so that the element functions as an antenna. Also as disclosed in the copending application of G. C. Southworth, Serial No. 420,747, filed November 28, 1941, maximum radiant action in the end-on direction may be secured from a solid dielectric rod having a circular or rectangular cross-section by selecting, for the transverse dimension parallel to the electric vector of the wave component (H_{11}) utilized, a value such that the phase velocity is equal to that of light and is constant or uniform throughout the linear rod. If, as disclosed in the Southworth application, the rod is composed of polystyrene having a dielectric constant of 2.5, the "gain" of the element considered apart from its directive characteristic is fairly high. Also as disclosed in the Southworth application, in the special case of a rectangular antenna element of resilient material, such as rubber, the electric plane transverse dimension may be tapered uniformly throughout the entire length of the rod for the purpose of obtaining a flexible radar or scanning antenna element, the magnetic transverse dimension of the rod being maintained constant. While the above-mentioned polystyrene rod having a uniform cross-section and a uniform phase velocity has been used in the past with success, it now appears desirable to secure a dielectric antenna element having not only a higher gain but also a directive characteristic which is more satisfactory for use in single element and multiple element radar systems.

It is one object of this invention to obtain a dielectric antenna element having a relatively high gain.

It is another object of this invention to obtain a dielectric antenna rod, the directive characteristic of which includes deep nulls adjacent the maximum lobe and relatively small minor lobes.

It is another object of this invention to obtain a dielectric antenna element having a directive

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characteristic which coalesces in an optimum manner with the space factor characteristic of a multiple unit steerable antenna designed to scan a given territorial angular sector as, for example, a 30-degree sector.

It is another object of this invention to obtain a dielectric antenna element having at the half power point of its maximum lobe a width of 25 to 30 degrees.

As used herein, the term "end-on," as applied to an antenna or its direction of maximum action, signifies that the antenna has a direction of maximum action aligned substantially with the longitudinal axis of the antenna. The terms "directivity" and "directive characteristic" denote the ability of an antenna element to transmit or receive in a certain direction or directions included in a given plane, as compared to its ability or action in the remaining directions in the aforementioned plane. In short, the terms "directivity" and "directive characteristic" refer to the antenna ability to discriminate as to direction in its performance regardless of its gain as compared to another antenna. The term "gain," as used herein, denotes the action or performance of the antenna in a given plane and in a particular direction as, for example, the end-on direction in the case of a linear dielectric element, as compared to the action in the aforesaid particular direction of a standard reference antenna having a non-directional characteristic in said plane. The gain and directivity are related in the sense that an antenna having a gain greater than the standard antenna must necessarily be directive to some degree. Conceivably, if the heat losses are sufficient, a highly directive antenna may have a negative gain as compared to the action of the standard non-directional antenna. Broadly considered, the directivity is a function of the shape, contour, length, etc. of the element and, in the case of an array, of the spacing or arrangement of the unit antennas, whereas the gain is a function not only of the above parameters but also of the impedance, dielectric constant and other properties of the material forming the antenna. To illustrate, two vertical quarter wave wire antennas, one of copper and the other of iron, have in general the same directive characteristic but different gains, since their ohmic or heat losses are substantially different.

According to one embodiment of the invention, the cross-sectional area of one longitudinal portion of a circular or rectangular bare, that is, unsheathed, polystyrene antenna element is linear-

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ly tapered, and the cross-sectional area of the remaining longitudinal portion is maintained uniform. Preferably, but not necessarily, the tapered and untapered portions are equal in length so that the change or variation in the magnetic plane dimension for the element, considered as a whole, is almost exponential. In the case of the circular rod, the diameter, and therefore the cross-sectional area, is tapered; and in the case of the rectangular rod, the magnetic plane or the electric plane transverse dimension is tapered although, if desired, both the electric and magnetic plane dimensions may be tapered or graded. The phase velocity linearly changes in the tapered portion but is constant in the untapered portion. As a result both a highly desirable directive characteristic and an exceedingly high gain are obtained. As compared to the uniform velocity element of the prior art, the maximum lobe is more blunt, the nulls adjacent thereto more pronounced and the minor lobes smaller. Ordinarily, the tapering does not produce flexibility in the element since the element is composed of a stiff dielectric material.

In accordance with another feature of the invention, means are provided for efficiently coupling a coaxial line to the base or butt of the polystyrene element. Also in accordance with another feature, means are included within the dielectric element near the butt for converting the fixed linear polarization of a wave supplied thereto by a coaxial line or wave guide, to a rotating (circular) polarization; and conversely, for changing the circular polarization of a wave received by a dielectric antenna element and supplied to the line, to a fixed linear polarization.

The invention will be more fully understood from a perusal of the following specification taken in conjunction with the drawing on which like reference characters denote elements of similar function and on which:

Figs. 1 and 2 are perspective views, respectively of a rectangular dielectric antenna rod and a circular dielectric antenna, each having unequal tapered and untapered portions in accordance with the invention; and Fig. 3 is a perspective view of a circular dielectric antenna having in accordance with the invention equal tapered and untapered portions;

Fig. 4 is a set of curves illustrating the phase velocity characteristic for the rods of Figs. 1, 2 and 3;

Fig. 5 illustrates the single-frequency directive characteristic for the antenna rods of Figs. 1 and 2;

Fig. 6 is a set of gain curves for the antennas of Figs. 1, 2 and 3;

Figs. 7 and 8 illustrate, respectively, the single-frequency and multiple-frequency directive characteristics for the rod antenna of Fig. 3; and

Figs. 9 and 10 are, respectively, an elevational cross-sectional view and an end view of a holder or mounting for coupling the cylindrical antenna rod of Figs. 2 or 3 to a coaxial line.

Referring to Fig. 1, reference numeral 1 denotes a bare polystyrene rectangular antenna rod having a longitudinal axis 2 and a length L of about 60 centimeters (24 inches). At the mean operating wave-length of 9.80 centimeters, the rod 1 is about six wave-lengths long. The polystyrene rod, hereinafter for convenience called a "polyrod," is mounted in a holder, which functions as an air-filled wave guide or dielectric channel, 3, and is connected to a translation device (not shown) such as a transceiver, a transmitter or a

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receiver. The connection between the antenna rod 1 and the translation device may include an air-filled wave guide, a coaxial line or both. The rod 1 has a uniform electric plane transverse dimension a throughout its length L and a magnetic plane transverse dimension b which linearly decreases or tapers from 4.45 centimeters at the base 4 to about 2.54 centimeters at the intermediate point 5. The b dimension is uniform from point 5 to the far end or tip 6. Point 5 is located approximately 35.5 centimeters (14 inches) from the base 4 and approximately 25.5 centimeters (10 inches) from the tip 6. Thus the rod comprises a tapered portion 7 and an untapered portion 8, or stated differently, the b dimension is non-uniformly tapered. At and near point 5 the tapering is extremely smooth, and preferably, but not necessarily, the tip 6 is rounded as shown. The butt portion of rod 1 inserted in the holder 3 has uniform a and b dimensions.

Referring to Fig. 2, antenna rod 9 is six wave-lengths long and is in general the same as rod 1 except that it has a circular instead of a rectangular cross-section. The diameter of the tapered portion of rod 9 linearly decreases from 4.44 centimeters (1.75 inches) at the base 4 to 3.2 centimeters (1.2 inches) at point 5. Referring to Fig. 3, the circular rod 10 is in general the same as circular rod 9, Fig. 2, except that the untapered portion is 35.5 centimeters (14 inches) long instead of 25.5 centimeters long, so that the tapered portion 7 and the untapered portion 8 are of equal length and the rod 10 has an over-all length of 71 centimeters (28 inches) corresponding to 7.23 wave-lengths.

In operation, Figs. 1, 2 and 3, the dielectric rod is energized by transverse electric (H_{11}) waves polarized in the plane of the transverse rod dimension a , the waves being either received from a distant point or supplied by the associated translation device. Referring to Fig. 4, reference numeral 11 denotes the non-uniform measured phase velocity characteristic for the waves propagated through rectangular rod 1. The phase velocity v , and therefore the ratio of v to the space velocity c , that is, the propagation velocity of light waves and radio waves, varies along the rod inasmuch as, already indicated, the phase velocity at any point along the rod is directly related to the cross-sectional area at the said point. Numeral 12, Fig. 4, denotes the non-uniform measured phase velocity characteristic for rod 9, the phase velocity at any point along the circular rod being a function of the diameter at the aforementioned point. The phase velocity characteristic for rod 10, Fig. 3, is the same as that of rod 9 except that the flat portion of the characteristic extends, as shown by the dotted line 13, beyond the flat portion of the characteristic for rod 9. Fig. 4 also illustrates, for the purpose of comparison, the constant or uniform phase velocity characteristic 14 of the prior art polystyrene rod disclosed in the Southworth application.

Referring to Fig. 5, reference numerals 15 and 16 denote, respectively, the measured directive characteristics, in a plane containing the longitudinal axis 2, of the rectangular rod 1 and of the circular rod 9, both constructed in accordance with the invention. Also for the purpose of explanation, Fig. 5 includes three curves representing the directive characteristics for three polyrods of the uniform velocity type disclosed in the Southworth application mentioned above. Thus numerals 17, 18 and 19 denote respectively the measured directive characteristic for a prior art

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rectangular rod six wave-lengths long, a prior art square rod nine wave-lengths long, and a prior art rectangular rod having a length of six wave-lengths and a uniformly tapered *b* dimension, but not a tapered *a* dimension. For convenience, the rods constructed in accordance with the invention and corresponding to curves 15 and 16, and the prior are rods corresponding to curves 17, 18 and 19, will hereafter be denoted antennas A, B, C, D and E, respectively. Numeral 20 denotes a unit antenna characteristic which is ideal or optimum for use in a multiple unit steerable radar antenna of the type disclosed in the copending application of C. B. H. Feldman, Serial No. 464,-479, filed November 4, 1942.

As shown by numerals 15 and 16, maximum action for antennas A and B occurs end-on in a direction coincident with the longitudinal axis 2 of the antenna. The same is true for prior art antennas C and E and is substantially true for the prior art antenna D although, because of the dip 21 in the maximum lobe 22 of characteristic 18, antenna D has two directions of maximum action which extend at equal and opposite angles relative to the axis 2. In other words the maximum lobe for antenna D is bipenate or bipartite whereas the maximum lobes for antennas A, B, C and E are each penniform or unipartite. It may be stated here that while the theory explaining the end-on action of the polyrod is not thoroughly understood, according to one theory, the rod is composed of an infinite number of infinitesimal antenna segments or apertures spaced apart an infinitesimal distance along the length dimension *L* of the rod. With the phase velocity equal to the velocity of light, the energies radiated by the segmental antenna apertures add in-phase for the end-on direction. For a more complete discussion relative to end-on antenna action, see Patent 2,236,393, A. C. Beck et al., March 25, 1941, especially Figs. 14 and 15 which relate to end-on arrays and lines therefore having uniform and non-uniform wave velocities.

Regardless of the above theory, applicant has found that by deviating a proper amount from a uniform velocity characteristic, that is, by non-linearly tapering the cross-sectional area of the rod for the purpose of securing a non-uniform phase velocity as explained above, an end-on directive characteristic may be obtained which is optimum for utilization in a radar system of the single polyrod type or the broad side multiple unit steerable type disclosed in the above-mentioned Feldman application. Thus the characteristic 15 for applicant's rod 1 includes a maximum lobe 23 having a highly desirable, that is, blunt, shape which conforms reasonably well with the ideal unit lobe 20. Over the 30-degree scanning range corresponding to the width of the ideal lobe 20, the intensity of lobe 23, as measured in square root power values is greater than one-half the unity value. Outside the 30-degree range, the lobe intensity rapidly decreases. Also, the minor lobes 24 of characteristic 15 adjacent the maximum lobe 23 are small and the null 25 between each minor lobe 24 and the maximum lobe 23 is very deep. The characteristic 16 for the optimum rod 9 similarly includes a maximum lobe 26 having a desirable shape, small minor lobes 27 and extremely deep nulls 28. In contrast, the directive characteristic 17 for the prior art uniform-velocity antenna C includes the large undesired minor lobes 29 and is, therefore, not satisfactory for utilization in a micro-wave multiple unit radar system. The directive characteristic 18 for the nine

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wave-length uniform-velocity prior art antenna D not only includes large undesired minor lobes 30, but also contains a maximum lobe 22, which is highly undesirable because it is bipenated or bipartite and wider than the 30-degree sector. Moreover, the nulls 31 of characteristic 18 are relatively shallow, and therefore have the effect of increasing the width of the lobe 22. The directive characteristic 19 for the uniform velocity antenna E consists only of a maximum lobe which is altogether too wide for highly directive radar action.

In addition, as shown in Fig. 6, the gains of antennas A and B as compared to a standard spherical antenna are respectively 16.5 decibels and 16 decibels, whereas the gains of the prior art antennas C, D and E are respectively 15.25 decibels, 10 decibels and 11 decibels. Hence, in accordance with applicant's invention, a dielectric antenna rod is obtained having a high gain, which characteristic or quality is particularly advantageous in connection with long range multiple unit radar systems. Again, when the antenna element of the invention is used in a linear array, the polyrods may be placed as close together as six inches since the cross-talk is not excessive and the mutual impedance is extremely low whereby an efficient high gain array is secured.

Referring to Fig. 7, reference numeral 32 denotes the one-way or single trip measured directive characteristic and numeral 33 denotes the round trip measured directive characteristic for the 7.32 wave-length circular antenna rod 10, Fig. 3, hereafter denoted antenna F. The characteristic 32 includes a maximum lobe 34 which approaches very closely the ideal unit lobe 20 and includes the very small minor lobes 35 and the very deep nulls 36. The round trip characteristic 33 includes a maximum lobe 37, which is somewhat sharper than lobe 34, and includes the negligible minor lobes 38. It should be noted that the characteristic 32 for the antenna F is more satisfactory for use in a multiple unit steerable antenna than the characteristic 15 for antenna A, or the characteristic 16 for antenna B, since nulls 36 of characteristic 32 are deeper than the nulls 25 and 28, the minor lobes 35 are smaller than the minor lobes 24 and 27 and the shape of the maximum lobe 34 is more conformable to the rectangular ideal lobe 20 than the shape of lobe 23 or lobe 26. In addition, as shown by Fig. 6, the gain of antenna F is one-half decibel and one decibel greater, respectively, than the gain of antenna A and the gain of antenna B. Hence, antenna F, Fig. 3, comprising tapered and untapered portions of equal length and having a nonuniform phase velocity characteristic approaching an exponential characteristic, as illustrated by 39, Fig. 4, is the preferred embodiment of applicant's invention. It may be noted that the characteristic 32 for antenna F and the ideal unit characteristic 20, Fig. 7, are substantially the same as characteristics 114 and 131, respectively, illustrated by Fig. 8 of the drawing in the above-mentioned Feldman application.

Referring to Fig. 8, numeral 40 denotes the measured directive characteristic of antenna F at the intermediate frequencies corresponding to 9.80 centimeters and 9.85 centimeters, and numeral 41 denotes the measured characteristic at the extreme frequencies corresponding to 9.75 centimeters and 9.90 centimeters. As is apparent from these two curves, the directive characteristic for applicant's end-on antenna is highly stable over a band of microwave frequencies such

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as are employed in centimetric radar systems. In more detail, as the wave-length varies from 9.75 to 9.90 centimeters, the shape of the maximum lobe 34 does not change materially, the intensities of the minor lobes 35 vary only slightly and the nulls remain exactly the same. Hence, in accordance with the invention, a dielectric antenna having a highly desirable band width or frequency-direction characteristic is obtained.

Referring to Figs. 9 and 10, reference numeral 42 denotes a mounting for receiving the butt 43 of the circular rod 10 (or 9) and for coupling the dielectric rod to a coaxial line 44. The line 44 comprises an outer conductor 45 and the linear conductor 46. Numeral 47 denotes a stub or tubular tuning member attached to mounting 42 for receiving coaxial line 44 and numeral 48 denotes another stub or tubular tuning member positioned diametrically opposite stub 47. A pick-up or exciter conductor 49 extends coaxially in metallic members 47 and 48 and diametrically through the butt 43 of the polystyrene rod 9. The inner conductor 46 of line 44 is connected to one end of wire 49 through a sleeve 50 and the outer conductor is secured to the stub 47 through a screw and thread joint 51. Numeral 52 denotes a short metallic conductor which connects an intermediate point 53 of wire 49 to the tuning member 47 and the outer coaxial conductor 45. Conductor 52 and the portion of wire 49 included between conductor 52 and the piston 55 in stub 48 constitute a matching section 54 having a critical length, and therefore a critical impedance, as determined by the adjustment of piston 55, for terminating the line 44 in its characteristic impedance. In stub 48, the wire 49 is supported by the adjustable piston 55 so that wire 49 may be adjusted to full wave-length resonance. Preferably the wire 49 is tightly secured in rod 10.

In operation, considering the case of transmission, centimetric waves are supplied over line 44 to the exciter wire 49 which functions to establish in the polystyrene rod 10 linearly polarized transverse electric waves having a fixed polarization such as vertical or horizontal. These waves are conveyed through the rod 10 and thence radiated as explained above. In the case of reception, wave components polarized in the plane of the pick-up wire 49 are absorbed by wire 49 and supplied to line 44.

In accordance with another feature of the invention, circularly polarized waves may be utilized. Thus, if desired, a pair of critically spaced polar reactances or circularizer wires 56 of the type disclosed in the copending application of A. G. Fox, Serial No. 464,333, filed November 3, 1942, may be inserted diametrically in rod 10 and disposed at an angle of 45 degrees relative to wire 49, as more clearly shown in Fig. 10. Wires 56 function to produce from a wave of fixed linear polarization, as emitted by wire 49 or received by polyrod 10, two components having a space quadrature relation and a time quadrature relation; and these components when recombined in the rod 10 produce a rotating resultant vector. For radar operation, the use of circularly polarized waves eliminates the effects of fading which is due to discrimination against any particular fixed polarization. Moreover, since reflection from an object reverses the polarization, the echo wave will be polarized after passing through the circularizer wires 56 in a direction perpendicular to the polarization direction of the transmitted wave. Hence a transmitter

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and receiver may be connected for duplex operation to a single polyrod, the wires 49 for transmission and reception being located at right angles whereby cross-talk is eliminated.

Although the invention has been explained in connection with certain specific embodiments, it should be understood that it is not to be limited to the embodiments described since other apparatus may be satisfactorily employed in practicing the invention. Also, while the antenna of the invention is preferably formed of polystyrene, the rod may be composed of other dielectric materials such as styramic, hard rubber, and acetate butyrate.

What is claimed is:

1. An unsheathed dielectric linear unidirectional antenna rod having a non-uniformly tapered cross-sectional area and a length dimension extending several wavelengths in the direction of maximum radio action.

2. A linear unidirectional antenna rod composed of homogeneous dielectric material and having a length dimension of several wavelengths, the phase velocity characteristics of said antennas being non-uniform and said length dimension being aligned with the desired direction of radio action.

3. In combination, an unsheathed polystyrene linear antenna rod one portion of which has a uniformly tapered cross-sectional area and another portion of which has a constant cross-sectional area, means directly connected to the first-mentioned portion for coupling said antenna rod to a translation device, said antenna having only one maximum directional lobe, and said lobe being aligned with the longitudinal axis of said antenna.

4. A unidirectional linear antenna rod composed of a homogeneous substance and having a longitudinal dimension extending several wavelengths in the direction of its maximum radio action, said element having a tapered cross-sectional area along one half, and a uniform cross-sectional area along the other half, of its longitudinal dimension.

5. A rectangular dielectric linear antenna element connected to a dielectric channel for supplying to, or receiving from, said element waves linearly polarized in the plane of one transverse dimension of said element, said element being tapered in the plane of one or both transverse dimensions along at least a portion of its longitudinal dimension.

6. A bare solid dielectric antenna element having a circular cross-sectional area of varying diameter along at least a portion of its length, the ratio of said length to its greatest diameter being greater than thirteen, whereby its phase velocity characteristic varies along said portion and its directive characteristic includes a blunt narrow maximum lobe, negligible minor lobes and a null between the maximum lobe and each minor lobe.

7. In combination, a microwave antenna comprising an unsheathed polystyrene rod of circular cross-section, means at one extremity of said rod for coupling said rod to a translation device, the half portion of said rod adjacent said extremity having a cross-sectional area which is a maximum at said extremity and linearly decreases and the remaining half portion of said rod having a uniform cross-sectional area.

8. In combination, a polystyrene linear antenna element, a coaxial line conductor connected to one end thereof for supplying to said element and receiving therefrom waves having a fixed linear

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polarization, and a wave circularizer inserted in said element for changing the fixed linear wave polarization to a rotating linear wave polarization.

9. In combination, a polystyrene linear antenna element, means comprising a linear conductor connected to one end thereof for supplying to and receiving from said element waves having a fixed linear polarization, and means for changing the waves supplied to said element by said conductor from a linear fixed polarization to a linear rotating polarization and for changing the waves supplied to said conductor by said element from a linear rotating to a linear fixed polarization, said means comprising a pair of parallel metallic conductors extending through said element at an angle to said first conductor.

10. In combination, a dielectric linear antenna element, and means for coupling said element to a two-conductor coaxial line and to a transceiver, said means comprising a metallic wire extending through said element transversely at a point near one extremity of said element, the ends of said wire being conductively connected to one line conductor and an intermediate point of said wire being adjustably connected to the other line conductor, and means for varying the length of said wire.

11. In combination, a dielectric linear antenna element having a circular cross-section, a metallic wire extending diametrically through said ele-

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ment near one end thereof for supplying to or receiving from said element a wave of fixed linear polarization, a pair of parallel metallic wires spaced from said first metallic wire and extending diametrically through said element, said parallel wires being at an angle of 45 degrees relative to said first wire and spaced on the longitudinal axis of the antenna element, whereby in the case of transmission, a linear rotating or circularly polarized wave is produced in and radiated by said element from the wave of fixed linear polarization supplied by said first wire, and in the case of reception a linear wave of fixed polarization is produced in said element and supplied to said first wire from a received wave having a rotating linear polarization.

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