Aug. 6, 1946. G. C. SOUTHWORTH **2,405,242**

MICROWAVE RADIO TRANSMISSION

Filed Nov. 28, 1941 8 Sheets-Sheet 1

FIG. 1

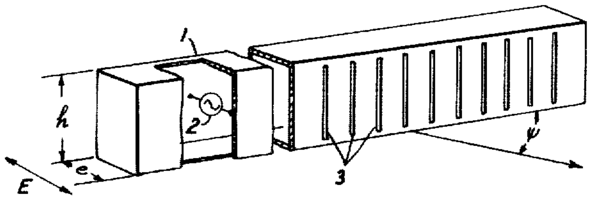


FIG. 2

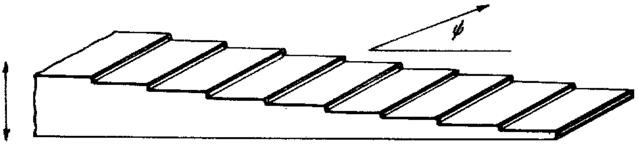


FIG. 3

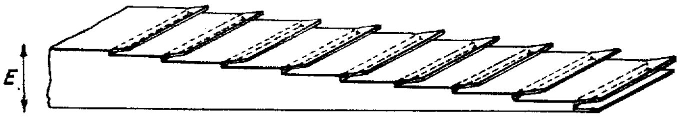
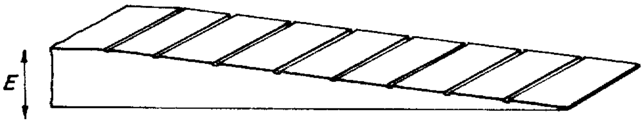


FIG. 4



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Aug. 6, 1946. G. C. SOUTHWORTH **2,405,242**

MICROWAVE RADIO TRANSMISSION

Filed Nov. 28, 1941 8 Sheets-Sheet 2

FIG. 5

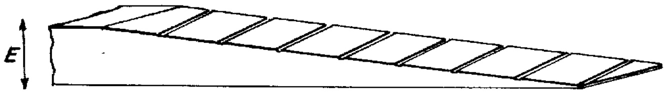


FIG. 6

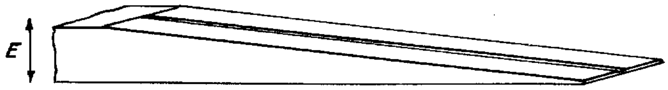


FIG. 7

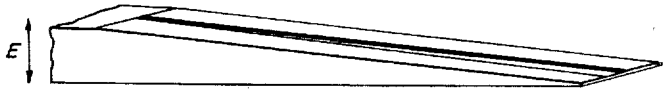


FIG. 8

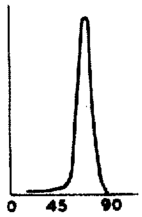


FIG. 9

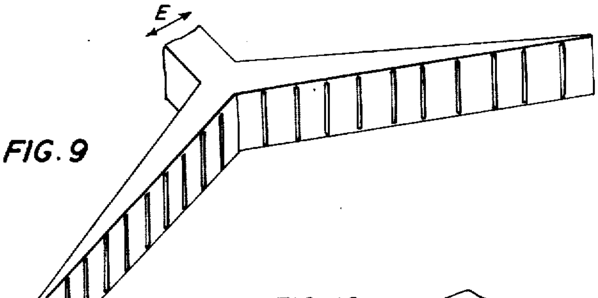
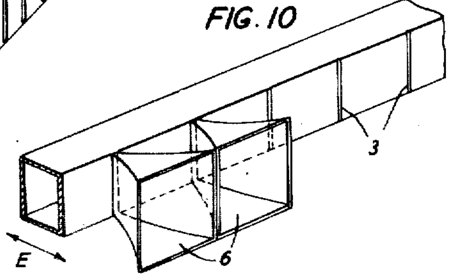


FIG. 10



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Aug. 6, 1946. G. C. SOUTHWORTH **2,405,242**

MICROWAVE RADIO TRANSMISSION

Filed Nov. 28, 1941 8 Sheets-Sheet 3

FIG. 11

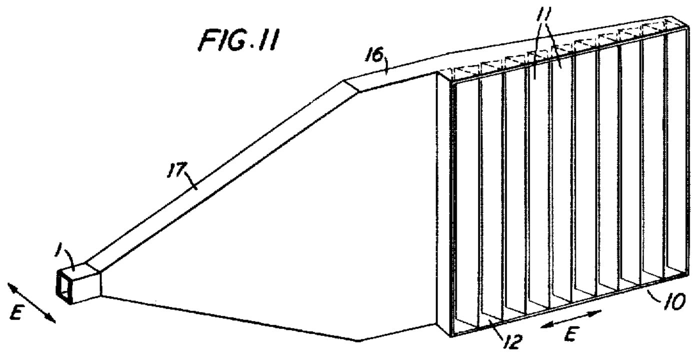


FIG. 12

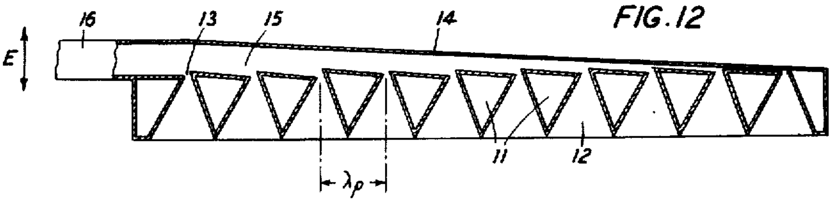


FIG. 13

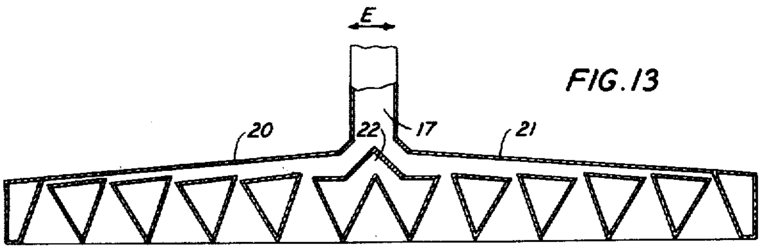


FIG. 14

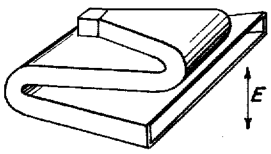
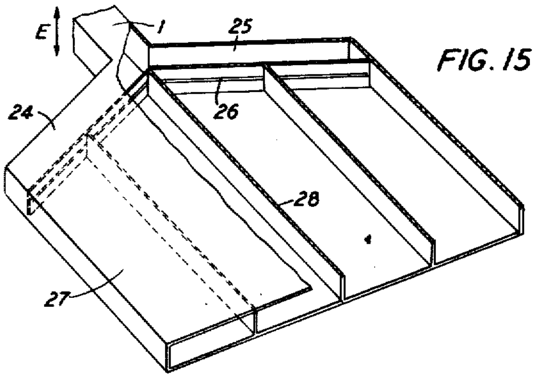


FIG. 15



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Aug. 6, 1946. G. C. SOUTHWORTH **2,405,242**

MICROWAVE RADIO TRANSMISSION

Filed Nov. 28, 1941 8 Sheets-Sheet 4

FIG. 16

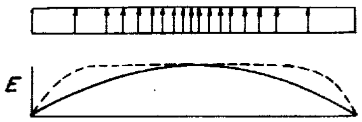

FIG. 17

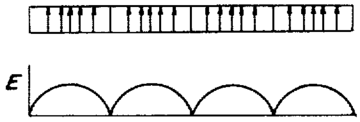

FIG. 18

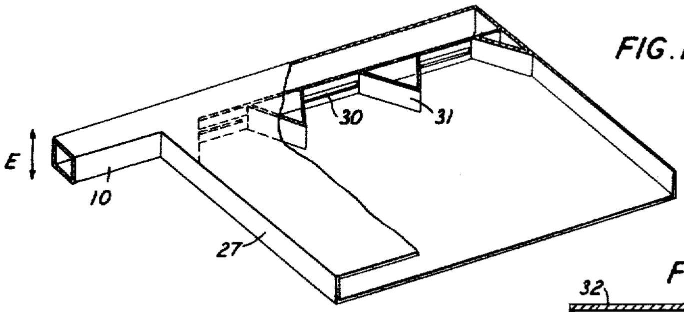

FIG. 19

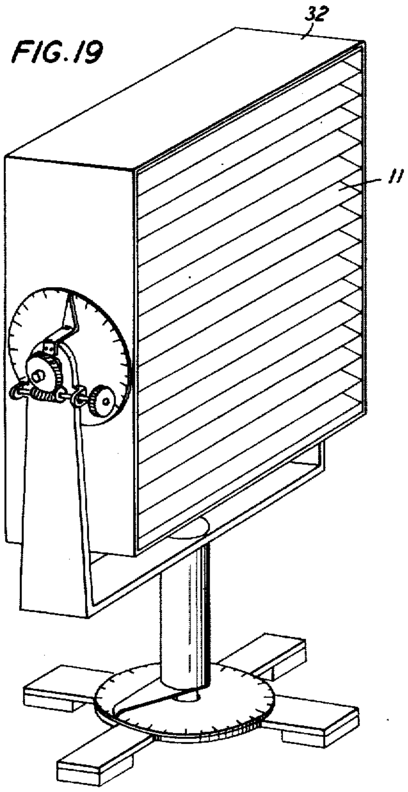

FIG. 20

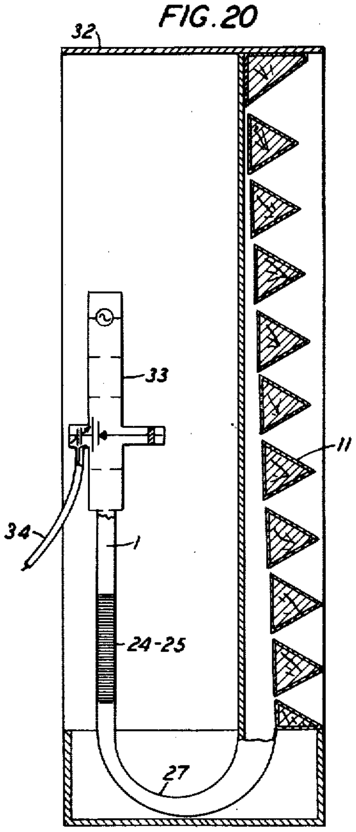

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FIG. 21

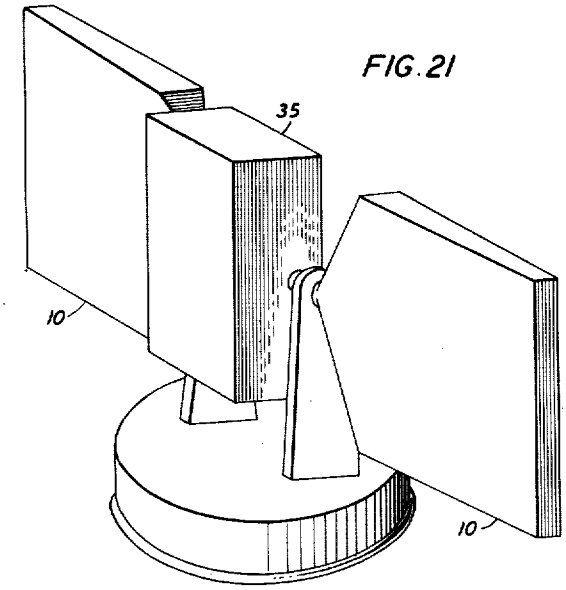
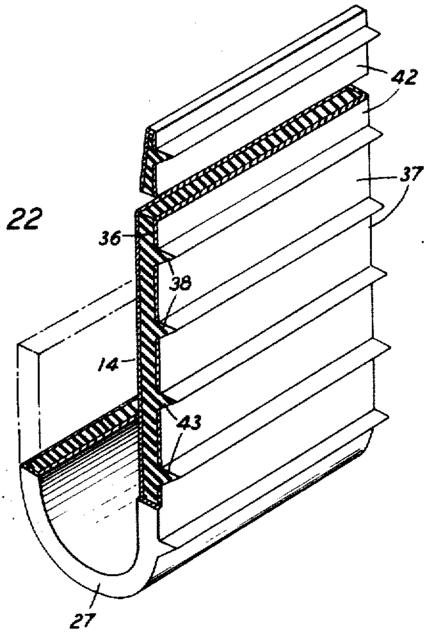


FIG. 22



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Aug. 6, 1946. G. C. SOUTHWORTH **2,405,242**

MICROWAVE RADIO TRANSMISSION

Filed Nov. 28, 1941 8 Sheets-Sheet 6

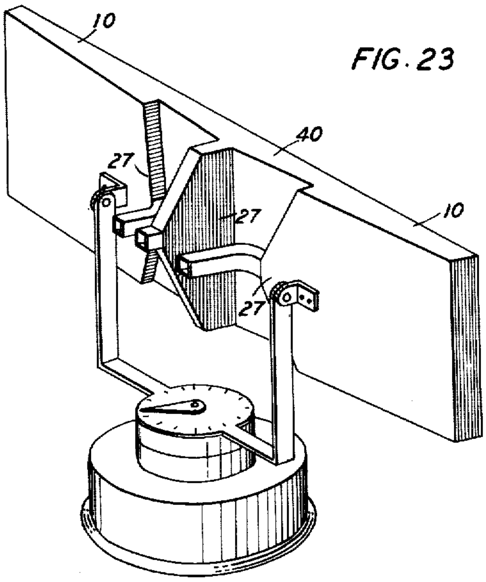

FIG. 23

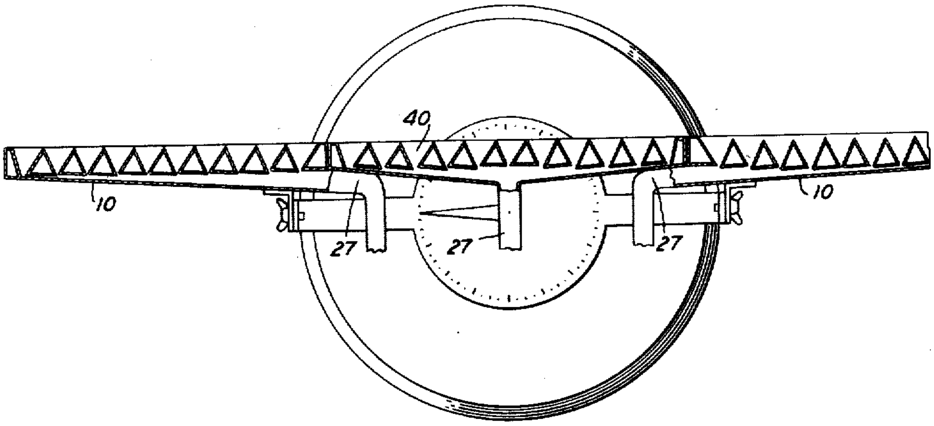

FIG. 24

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FIG. 25

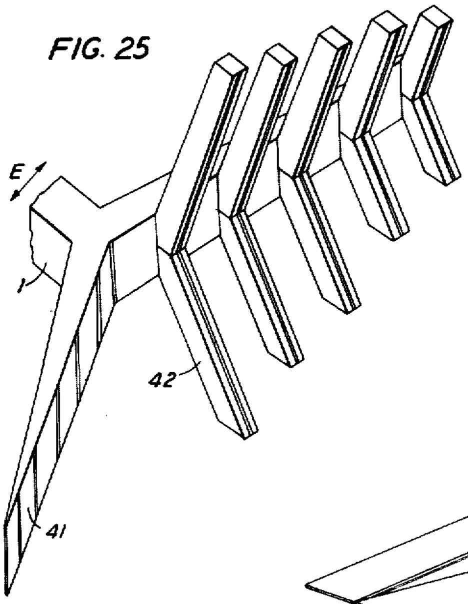


FIG. 26

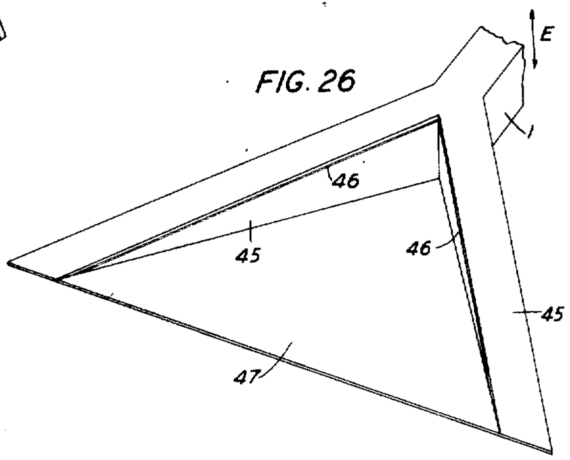
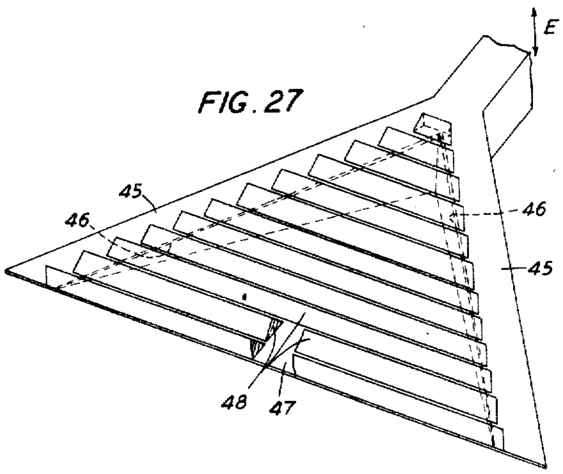


FIG. 27



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Aug. 6, 1946. G. C. SOUTHWORTH **2,405,242**

MICROWAVE RADIO TRANSMISSION

Filed Nov. 28, 1941 8 Sheets-Sheet 8

FIG. 28

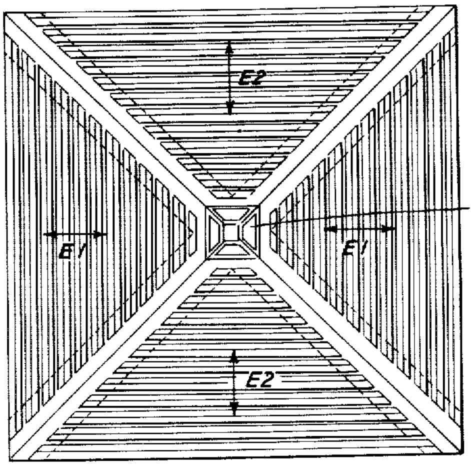
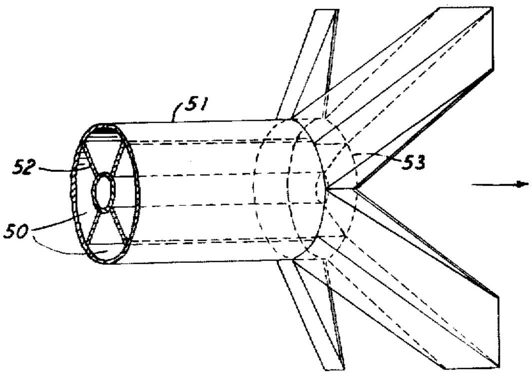


FIG. 29



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Patented Aug. 6, 1946 **2,405,242**

UNITED STATES PATENT OFFICE

2,405,242

MICROWAVE RADIO TRANSMISSION

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to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application November 28, 1941, Serial No. 420,747

34 Claims. (Cl. 250—11)

This invention relates to the transmission of ultra-high frequency electromagnetic waves and more particularly but not exclusively to apparatus for the launching of radio waves into space and for the interception and detection of such waves.

Objects of the present invention are to improve the efficiency with which radio waves are launched into space or received therefrom, to increase the directivity obtainable in the beam transmission of such waves, and to facilitate control of the direction of radiation or reception. Other objects are to provide radio antennas, that is, radio wave interceptors and radiators, having special shapes adapting them for use in circumstances where space and shape are significant factors. For example, one object is to provide an antenna that is of substantial expanse and highly directive but that is shallow enough for use in the fuselage or wings of aircraft, for example. Further objects are to permit ready adjustment or cyclic variation of the angle of fire of a directive radiator or interceptor apart from control of the orientation of the structure, so that, for example, a fixed structure may be employed to scan the surrounding space as is required in systems for the detection and location of aircraft or ships at sea.

In accordance with a feature of the invention a leaky wave guide is employed in a particular manner as a radiator or intercepting device, the leaky wave guide being defined as a wave guide structure that is adapted to permit the escape of guided wave power substantially continuously along its length, as for example by reason of a continuous longitudinal aperture in its outer wall or a multiplicity of discrete apertures the longitudinal spacing of which is substantially less than the length of the waves within the guiding structure. In accordance with another feature, a leaky wave guide or a wave guiding structure having a multiplicity of longitudinally spaced apertures is tapered or otherwise progressively reduced in size, that is, in transverse dimensions, to reduce transmission losses in the guiding structure and to improve the efficiency of coupling with free space. A related feature contributing to the same objective has to do with the effect of the total area of the aperture or apertures on impedance matching.

In accordance with another feature there is provided a panel antenna that is shallow but of substantial expanse, comprising a tapered wave guiding structure or distribution passage of elongated cross section having on one face a multiplicity of parallel, elongated apertures or slits. Other features reside in a wave collimator adapted to translate a wave from a guiding passage of restricted cross section to one of elongated cross section, and in the intimate association of such a collimator with a panel type antenna.

The nature of the present invention and various features, objects and advantages in addition to those pointed out above will appear more fully from the following description of the embodiments illustrated in the accompanying drawings.

In the drawings:

Figs. 1 to 10 relate to elementary wave guiding and radiating structures embodying various features of the present invention; Figs. 11 to 24 relate to a louver type of radiator and wave collimators therefor; and Figs. 25 to 29 relate to modifications and extensions of structures shown in preceding figures.

Referring now to Fig. 1 there is illustrated an embodiment of the present invention that is at once simple and effective for the purposes intended and that will serve as a basis for the exposition of certain principles and features that are involved in other more complex embodiments hereinafter to be described. This embodiment as well as many of the others makes use of the so-called hollow pipe guide, which is a structure adapted for the guided propagation of ultra-high frequency electromagnetic waves of various field configurations, and which is characterized at least in part in that transmission through electrically long sections of it takes place substantially only at frequencies exceeding a predetermined critical or cut-off frequency that is determined by the transverse dimensions of the guide and the index of refraction of the dielectric medium within the pipe. In general, the higher the dielectric constant, or index of refraction of the dielectric medium within the hollow pipe guide, the lower are the cut-off frequency and the phase velocity. Although in some of its broader aspects the present invention is not limited with respect to the cross-sectional shape of the guide or the type of wave employed, as will be evident to those skilled in the art, the so-called dominant type of wave in a guide of rectangular cross section offers various advantages and will be assumed in most of the embodiments to be described. Whereas, also, it is found convenient to describe the various embodiments in terms of their application to the radiation of electromagnetic waves, it is to be understood that in each case the structure is adapted also for the interception or reception of radio waves, and that the directional properties are substantially the same in the two cases.

Fig. 1 shows a wave guide in the form of a hollow metal pipe 1 of rectangular cross section with air dielectric and an ultra-high frequency source 2 that is connected near one closed end of the pipe to establish waves of dominant type therein. The wave source 2 is so oriented that the electric vector of the guided waves lies parallel with the shorter transverse dimension of the pipe and at right angles to the longer dimension. In view of their space relation to the electric and magnetic fields these dimensions will be referred to as the *e* dimension and the *h* dimension, respectively. Along one of the wider or *h* faces of the pipe is a series of closely spaced transverse slits 3 each normal to the length of the pipe. The other or far end of the pipe is or may be closed to preclude the escape of wave power.

As the guided waves move toward the far end of the pipe, wave power escapes through each of the slits 3 until at the far end of the guide little or no wave power is left unradiated. At each slit the waves issue with the electric vector lying across the slit, that is, substantially parallel with the axis of the guide, hence if the guide is so positioned that the slits are vertical the radiated waves are horizontally polarized. With the slits horizontal, as would be the case if the guide were vertical, the waves radiated are vertically polarized. The radiation from any given slit, assuming horizontal polarization for specific example, would be fairly sharply confined or concentrated in the vertical plane but fairly widespread in horizontal planes. In other words, the vertical directivity is much sharper than the horizontal directivity. With respect to the array of slits, directivity in the horizontal or *e* plane is largely controlled by the spacing of the slits, as measured in terms of free space wave-length at the operating frequency, and by the relative phases of the waves issuing from the several slits. If the slits are so closely spaced that there are a large number of them in each wave-length section of the slitted guide portion, or, in other words, if this portion constitutes a leaky pipe guide as hereinbefore defined, the radiation will be directed principally in the horizontal plane at an angle ψ from the axis of the guide, as indicated in Fig. 1. The angle ψ in this case is such that

$$\cos \psi = \frac{c}{v_p} \qquad (1)$$

where v_p is the phase velocity of the guided waves in the leaky guide portion and *c* is the velocity characteristic of light in the surrounding space.

In a typical case in accordance with Fig. 1 the dielectric medium within the pipe was air, dimension *h* was 5.8 centimeters, dimension *e*, 2.5 centimeters, and the frequency of the wave source 2 was 3,000 megacycles per second corresponding to a free space wave-length of 10 centimeters. The slits were 2 millimeters wide and spaced 5 centimeters apart. The phase velocity v_p was found to be approximately 2.75 times *c*, which compares with a phase velocity of 2*c* in the unslitted portion, and the angle ψ was approximately 68 degrees. If the total area represented by the aggregate of slits is not such as to provide critical or reflectionless termination for the guide 1, the far end of the guide may be terminated in an energy absorber. In general the sum of the areas of the various apertures in a multiple apertured pipe guide of rectangular cross section should be equal to the cross-sectional area of the main guide for impedance match and high gain, or, more specifically, the sum of the slit widths should be equal to the *e* dimension of the unslitted guide portion. This rule does not quite hold true, however, if extremely narrow slits are employed, having a width of less than one millimeter for example, for it appears that such slits radiate more effectively per unit area than wide slits. In such cases the slits may be closed off progressively from one end of the guide until measurements indicate minimum reflection in the guide or maximum gain. Some increase in the total effective aperture may be obtained by progressively increasing the width of the slits towards the far end of the guide so that more nearly the same wave power is radiated from each slit.

In the modification of the invention illustrated in Fig. 2 the radiating structure comprises a hollow pipe guide of rectangular cross section as in Fig. 1 in which the *e* dimension, that is, the dimension parallel to the electric vector, is reduced in steps toward the far end of the guide. At each step as well as at the far end of the guide a transverse slit or opening is left. These apertures are all normal to and face the direction of the axis of the guide, but radiation may take place at an angle ψ determined as in Fig. 1 by the spacing of the apertures and the relative phases of the waves issuing from the several apertures. It is to be noted that at each step the guided wave is separated by the longitudinal portion of the step into two portions one of which issues through the slit and the other of which proceeds through the forwardly extending portion of the guide. This is in accordance with principles of wave guide branching with impedance match. With the guide in the horizontal position indicated in Fig. 2 radiation is at an angle upward.

To facilitate an impedance match between the several slits and free space, an outwardly flaring metallic extension may be placed over each slit as in Fig. 3 to provide substantially the effect of a small impedance matching horn. This feature is useful primarily where the interslit spacing is comparable with the wave-length in the guide as in certain cases to be considered hereinafter.

In lieu of the discrete steps indicated in Figs. 2 and 3, the *e* dimension may be reduced at a linear rate to form the wedge-like structure of Fig. 4 in which the slits lie crosswise in the upper, sloping face of the wedge as illustrated. It may be noted that the smooth tapering of the radiating guide portion is calculated to add materially to the finesse of electrical smoothness.

In the modification of Fig. 4 that is illustrated in Fig. 5 the slits are somewhat inclined in the upper face of the wedge so that the radiation takes place more nearly continuously along the length of the wedge. Fig. 5 partakes somewhat of the characteristics of the Fig. 6 structure which is a tapering or wedge-shaped radiator like that in Fig. 4 except that a single longitudinal slit takes the place of the multiplicity of transverse slits. In Fig. 6 radiation takes place continuously throughout the length of the slit and the angle of fire relative to the axis of the guide is substantially that defined in Equation 1 supra.

Whereas the wedge-shaped configuration of the Fig. 6 structure contributes to efficient operation as described with reference to Fig. 4, more nearly uniform distribution of the wave power radiated along the slit may be promoted by progressively flaring or widening the slit toward the narrow edge of the wedge as illustrated in Fig. 7.

The structures described with reference to Figs. 1 to 7 may differ somewhat in respect to the presence and magnitude of secondary lobes in the directional pattern, that is, in the distribution of radio wave power in directions other than the principal or preferred direction of radiation. The directional pattern represented in Fig. 8 is typical of those obtainable with the structures shown in Figs. 1 to 4 and is specifically applicable to the Fig. 4 structure. As shown by this diagram the radiation is maximum for a value of ψ of 68 degrees. The pattern is highly favorable in that it shows zero radiation in the broadside or 90-degree direction as well as for larger values of ψ, and in that no secondary lobes appear. Substantial secondary lobes are highly undesirable for many purposes for in any beam transmission system they represent a waste of power radiated, impairment of secrecy of transmission, and susceptibility to interference.

Any of the structures hereinbefore described may be paired to form a balanced structure with the angle between the components adjusted so that each radiated beam coincides with the other. Fig. 9 illustrates the application of this principle to the Fig. 4 structure. The two wedges are fed from a common wave guide and are angularly separated by twice the angle ψ applicable to the individual components. The arrangement illustrated in Fig. 9 serves also to reduce the relative intensity of any secondary lobes that may tend to appear in the directional pattern.

In lieu of air or other gaseous medium, the radiating pipe guide in any of the examples considered may be filled or "loaded" with a dielectric material having a dielectric constant greater than unity. The addition of such a dielectric material reduces the phase velocity v_p and the ratio v_p/c, and it therefore affects the angle of radiation. By properly relating the cross-sectional dimension h of the pipe, which affects the phase velocity v_p, with the dielectric constant of the medium, v_p can be reduced to equality with c. Equation 1 indicates then that the angle ψ is zero, or in other words that the major radiation lobe lies along the axis of the guide. Radiation in this direction may be appropriately termed "end-fire" radiation.

With a leaky guide structure such as that described with reference to Figs. 1 to 4 in which there are many slits per wave-length, the results obtained are much the same as if a single longitudinal slit were employed. Quite different results may be obtained, however, if the space between slits is comparable with the operating wave-length within the guide. More particularly, if the slits in the Fig. 1 structure, for example, are spaced a wave-length apart so that the waves issuing from the several slits differ in phase by 360 degrees, or a multiple thereof, the effect is as though the wave traveled through the pipe with infinite velocity. In accordance with Equation 1 the angle of radiation in this case is 90 degrees or, in other words, broadside. It happens, however, that even though the radiating slits are thus equiphased a single highly directive lobe will not be obtained if the interslit spacing is too great. The maximum permissible spacing depends on the total number of radiating elements but in many practical cases it is less than 0.87 of the wave-length in air. The principles involved are set forth in detail in a paper by applicant appearing in the September 1930 issue of the Proceedings of the Institute of Radio Engineers. For the practical case cited hereinbefore where $v_p=2.75c$ the spacing that would be required for equiphasing is 2.75 times the wave-length in air, and for the case where $v_p=c$ the interval between slits would have to be equal to the free space wave-length. These spacings, however, would be so large as to give rise to substantial secondary lobes.

A similar effect tends to appear in the multiple-apertured leaky pipe guide, that is, secondary lobes are developed if the apertures are not spaced closely enough together in relation to the wave-length. In the Fig. 1 system, for example, it was found that whereas the directional pattern was substantially single-lobed when there were four or eight slits per wave-length, the subordinate lobes were judged to be excessive for spacings greater than about 0.6 wave-length.

The restriction last discussed is overcome in the broadside radiator illustrated in Fig. 10 by surmounting each of the transverse slits with a metal horn 6. Each horn is proportioned in accordance with principles now known in the art and so aligned as to produce a radiated beam that is largely confined to the broadside direction and free of secondary lobes. The horns may be of rectangular cross section and contiguous with each other at their mouths as shown. Thus despite the tendency for the widely spaced slits to produce a radiation pattern with secondary lobes, the horns suppress radiation in non-broadside directions from each slit and produce an array with a sharply directed broadside characteristic.

Another device that may be used in lieu of the horns in Fig. 10 to reduce secondary lobes is to fill the radiator section of the guide with a low loss insulating material having an effective dielectric constant ϵ that is sensibly greater than unity. When this is done the phase velocity within the pipe is reduced so that

$$\lambda_p=\frac{\lambda_a}{\sqrt{\epsilon}\sqrt{1-\left(\frac{\lambda_a}{\lambda_c}\right)^2}} \qquad (2)$$

where λ_p is the wave-length within the pipe, λ_a is the corresponding free space wave-length, and λ_c is the free space wave-length at transmission cut-off, viz.,

$$\lambda_c=2h\sqrt{\epsilon} \qquad (3)$$

One of the various materials suitable for use as the dielectric is a polystyrene having a dielectric constant ϵ of about 2.6 known as and sold under the trade name "Amphenol." If this material is used in connection with the example cited hereinbefore where the wave-length in air is ten centimeters and the pipe guide has a dimension h of 5.8 centimeters then the wave-length within the guide is reduced to 7.33 centimeters. This is also the proper distance between slits for broadside radiation. Under these circumstances the elements have an axial spacing of 0.733 times the free space wave-length, which is small enough to avoid any substantial secondary lobes. It is to be expected that the radiation will tend to increase the phase velocity beyond that otherwise to be expected, hence preliminary study with a traveling detector may show that the actual spacing should be somewhat greater than specified.

In any of the embodiments of the invention hereinbefore described, the angle ψ is a function of frequency inasmuch as the velocity of propagation through the guide, i. e., the phase velocity, also is a function of frequency. Accordingly, it is possible to operate at various angles ψ merely by shifting the operating frequency. Alternatively, however, the angle ψ may be altered without changing the frequency by adjusting the h dimension of the guide and thus adjusting the velocity of propagation.

Referring now to Figs. 11 and 12 there is illustrated a panel type of radiating structure, broad and high but very shallow, that embodies various important features of the present invention. Excellent broadside gain and directivity have been obtained in practice with this structure, and it is obvious that its shape adapts it for use in many locations where other and bulkier devices of comparable performance could not be used. In view of its general appearance the radiator portion proper, represented at **10** in Fig. 11 and shown in cross section in Fig. 12, will be referred to as the louver. As will appear from these two figures, the louver comprises a multiplicity of parallel metallic prisms **11** of triangular cross section arranged in a row on a metallic base plate **12** and spaced apart to leave elongated apertures or slits **13** between them. The rear faces of the prisms are approximately aligned and, together with a metallic back plate **14**, base plate **12** and a corresponding top plate, define a wave distribution passage **15** that extends across the back of the array of slits.

Distribution passage **15** is tapered from a maximum e dimension at the left-hand end of the louver to a minimum at the right, in the manner and for the purpose described with reference to Figs. 2 to 4. It is advantageous to have the rear faces of the prisms **11** sufficiently misaligned that each is substantially parallel to the back plate **14** thus making the distribution passage equivalent in a sense to the stepped guide radiator described with reference to Fig. 2 and in the same manner contributing to effective operation. At the left, passage **15** continues through an optional extension **16** of the same elongated cross section and a collimator **17** to the hollow pipe feed guide **1**. The waves supplied through the latter are polarized in the manner shown so that the electric field in the distribution passage **15** is normal to the back plate and appears crosswise of the slits **13**.

The louver is so proportioned in relation to the operating frequency that the distance between slits is equal to the wave-length within the distribution passage, hence the slits are cophased and the radiated beam is broadside or normal to the panel. The length of the individual slits is large compared with the free space wave-length as is also the h dimension of the distribution passage. In one illustrative example of practice, the louver was approximately 100 centimeters square and comprised ten slits **13** each about 5 millimeters wide and spaced 10 centimeters apart for operation at a frequency of 3,000 megacycles per second. The distribution passage was approximately 100 centimeters by 5 centimeters at its input end, the latter dimension being equal to the sum of the slit widths. Under these conditions the phase velocity is substantially equal to the velocity of light. The restriction of the maximum e dimension to a half wave-length suppresses wave types of higher modes and is for that reason a desirable feature. In the forward direction, that is, normal to the panel and in the direction of radiation, the prisms **11** define outwardly flaring passages extending from the respective slits **13** and constituting short but extremely wide electromagnetic horns which contribute to the substantial elimination of secondary lobes as discussed with reference to Fig. 10. The relative widths of the several slits have a bearing on the radiation pattern. Thus, for example, the elimination of secondary lobes may be facilitated by making the outermost slits comparatively narrow and the others progressively wider to a maximum at the central slit or slits.

Although broadside radiation has been assumed in the description of Figs. 11 and 12, the structure is fairly well adapted for non-broadside radiation within angular limits fixed by the radiation patterns of the flaring passages or horns defined by the prisms. The spacing of the slits or the operating frequency may be adjusted to secure the desired angle of radiation.

The function of collimator **17** is in part to reduce reflection loss in the transition from the comparatively small cross-sectional area of the pipe guide **1** to the large cross-sectional area of distribution passage **15**. In greater part, however, the collimator is intended to induce an expansion of the transmitted waves such that the excitation of the slits **13** is distributed more or less uniformly and in the same phase along their respective lengths. A simple flaring section of wave guide might serve these purposes very well but even better results can be had with collimators of a type to be described hereinafter with reference to Figs. 15 to 18.

Fig. 13 shows in a cross-sectional view corresponding with Fig. 12, a balanced radiator made up of two louver radiators of the kind described connected to a common collimator **17**. The two louvers **20** and **21** are arranged with their faces in the same plane to form a unitary array having an area approximately twice that of either louver alone. At the junction of the two louvers and the collimator **11** a short Y-branch is interposed to facilitate transmission of power from the collimator into the two louvers.

Fig. 14 illustrates how a collimator, such as **17** in Fig. 11, may be folded upon itself to reduce its over-all dimensions for instances of practice where space requirements, for example, make such reduction desirable.

In Fig. 15 there is shown a collimator that is especially well adapted for use in conjunction with the louver radiator of Fig. 11 and it may be understood that the elements **16**—**17** of the latter showing may take the form here illustrated and now to be described. In this case the feed guide **1** is terminated in a pair of branch wave guide sections **24** and **25** of rectangular cross section, which are angularly separated from each other by an amount 2ψ. Each of the branches **24** and **25** has on its inner or forward e face a longitudinal slit **26**. With the parts proportioned in accordance with principles discussed with reference to Fig. 9, for example, waves received from the guide **1** issue from the two slits **26** to form a substantially plane wave front normal to the axis of the guide. The waves so issuing are received into the end of a pipe guide **27** of elongated rectangular cross section which extends forward from the slitted faces of the branches **24** and **25**. The forward end of the guide **27** may be connected as in Fig. 11 to the distribution passage of a louver radiator or it may be used directly as a radiating orifice.

The normal intensity distribution of a wave of dominant type in a pipe guide of rectangular cross section is represented by the solid line curve in Fig. 16 which shows how the electric intensity varies along the h dimension of the guide. It is evident that the field intensity drops off markedly from a maximum value at the central *e* plane of the guide, and it will be appreciated that if the same distribution obtained in the distribution passage of the louver radiator the excitation of each slit would be quite non-uniform over its length. The branch guides **24** and **25** of Fig. 15, however, force in the guide **27** an initial intensity distribution that is not normal but more nearly uniform along the *h* dimension, as indicated by the dotted line curve in Fig. 16. Whereas this favorable distribution would not be maintained and normal distribution would appear, if the waves were to be transmitted any considerable distance through the guide **27**, the latter is or can be made so short that no substantial degeneration of the intensity distribution appears at the feed end of the louver distribution passage. Accordingly, by thus intimately associating the collimator with the distribution passage of Fig. 11 each slit **13** may be supplied with power more or less uniformly throughout its length.

As a further or alternative feature the Fig. 15 collimator may include a longitudinal metallic baffle plate **28** which extends forward from the junction of the forward faces of branch guides **24** and **25** and which lies parallel with the *e* faces of the guide **27**. The baffle **28** separates guide **27** into two subguides of equal widths, and the latter may be further subdivided by additional baffles as shown. If each subguide receives substantially the same amount of wave power from the feed guide **1**, the field intensity at the forward end of guide **27** and at the entrance to the louver distribution passage will be more nearly equally distributed along the *h* dimension than would otherwise be the case. Fig. 17 shows the normal distribution of electric intensity across a guide with three equally spaced baffles, but does not take into account the improvement due to the manner in which the subguides are excited. Preferably the central baffle **28** is extended through the distribution passage **15** of the louver to inhibit or retard degeneration of the transmitted wave into a wave with normal distribution, thus preserving approximately uniform excitation for the slits **13** that are farthest from the collimator. It will be understood that the *h* dimensions of the subguides should not be so small as to produce transmission cut-off at a frequency higher than the operating frequency.

In the collimator illustrated in Fig. 18, the guide section **27** forms with the feed guide **1** an L-shaped structure with the end of guide **27** closed over a longitudinal slit **30** in one of the *e* faces of the guide **1**. The slit **30** is discontinuous with the separate portions thereof spaced about a wave-length apart so that the waves issuing therefrom into the guide section **27** are cophased. Between the slit portions are short triangular prisms **31** which form flaring passages connecting the respective slits with the main body of the guide section **27**. Baffles may be extended through guide **27** from the forward edges of the prisms **31** in the manner and for the purpose described with reference to Fig. 15.

In Fig. 19 a louver radiator is shown set up for convenient adjustment of its angular orientation. The rectangular chamber **32** in which the louver proper is mounted rotates therewith and may house the transmitting oscillator or receiver and associated equipment. One convenient structural arrangement is shown in cross section in Fig. 20. In this case the chamber **32** is high enough to accommodate the collimator section **27** which curves from the lower end of the louver distribution passage and connects with collimator section **24**—**25** and the wave guide **1** which extends up into the chamber **32** to the terminal apparatus **33**. The latter is represented schematically as being the first stage of a double-detection wave receiver, the output of which is delivered through a coaxial conductor line **34** to subsequent receiving apparatus.

Another convenient structural arrangement is illustrated in Fig. 21 where two coplanar louver radiators **10** are integrally and rotatably mounted with an apparatus chamber **35** between them. One of the louvers **10** may be a radiator and the other a receiver, or both may be either radiators or receivers.

The louver radiator may comprise a dielectric material having a dielectric constant substantially greater than that of air. Where a solid dielectric material, such as polystyrene, is employed, the louver may take the form illustrated in Fig. 22. In this case the distribution passage is filled with the solid dielectric **36**, a metallic back plate **14** is provided as before and on the front face metallic plates **37** are spaced apart to define the multiplicity of parallel transverse slits. To facilitate radiation of wave power through the slits the solid dielectric material may be extended out in the form of protuberances **43**. These may be, as shown, wedge-like and in some cases may extend out as much as a wave-length. Since the dielectric material **36** operates to reduce the velocity of wave propagation through the distribution passage, the slits may be spaced closer together than would be true if the dielectric material were air and still produce a broadside directional pattern. The Fig. 22 structure is well adapted for non-broadside radiation or reception and with a given installation it is only necessary to change the operating frequency to alter the angle of fire. The collimator connection **27** may also comprise a solid dielectric material and be fed from any of the collimators hereinbefore described.

Figs. 23 and 24 show an arrangement of three louver radiators combined as a single panel but provided with three independent outputs or feed guides. The central unit **40** is essentially that shown in Fig. 13 while the two louvers **10** on the outside are each of the form described with reference to Figs. 11 and 12. The respective outputs taken off through the collimators **27** may be combined in various ways as may be needed. It will be noted that the collimators of the two outside units can be made to overlap the central louver **40** in view of the tapering of the distribution passages, thereby making the three louvers appear as one continuous array. This leads to a considerable saving of space and such structural simplicity that a rigid unit can readily be obtained. Although the three louvers may be used as a unit for transmitting or receiving they may alternatively be used separately. For example, the central unit may be used as a transmitter in an object locating system while the two outer units are used as receivers for intercepting the waves reflected back from the distant object. Binaural reception may be practiced in this connection and by phasing or angular displacement the outer units may be used to project the overlapping beams sometimes employed for accurate object location, or by frequency wobbling and proper phasing of the waves supplied to the two louvers the two radiated beams can be made to variably diverge or converge.

The radiator illustrated in Fig. 25 comprises at the end of the feed guide **1**, a pair of branched tapering guides **41** disposed at an angle to each other and provided with spaced transverse slits as described with reference to Fig. 9. Fed from each slit is a pair of diverging guide sections **42** which have respective longitudinal slits on their inner faces and which are angularly separated to concentrate a beam in a direction parallel with the guide **1**. The pairs of branch guides **42** are of different lengths and more particularly their lengths are progressively reduced toward the outer ends of the guide sections **41**. Furthermore, the slits in the branch guides **41** that are associated with the longer branch guides **42**, are made wider so as to permit more wave power to escape through them. By proper proportioning of the various parts a fairly large plane wave front may be fabricated thereby producing high directivity. Some of the pairs of guide sections **42** may be omitted, if desired, so that radiation takes place directly from the transverse slits, and in one embodiment only the central or axial pair of guide sections **42** is retained.

The structure illustrated in Figs. 26 and 27 may be regarded as an intimate combination of a modified form of the Fig. 15 collimator and a modified form of louver radiator. The collimator connected to the feed guide **1** comprises two wedge-like branch guides **45** which have respective longitudinal slits **46** along the upper edge of their inner or *e* faces and which are arranged at an angle of 90 degrees with reference to each other. The branches **45** are so proportioned that the phase velocity $v_p=c \cos 45°=1.414\ c$, or in other words so that the slits yield a substantially plane wave front normal to the axis of guide **1**. The waves issuing from these slits enter a triangular chamber that is bounded in part by a triangular metallic base plate **47** and that is closed at the top by a plurality of triangular metallic prisms **48** which are of different lengths and spaced apart to form a triangular louver. To secure substantially uniform distribution of wave power over the face of the louver, the longitudinal slits **46** may be tapered so that more power escapes in the vicinity of the shorter radiating slits of the louver. Radiation normal to the face of the louver is secured by proportioning the parts in accordance with the principles hereinbefore discussed.

In Fig. 28 is illustrated schematically a unitary array made up of four of the Fig. 27 triangular louvers arranged as a square. The four feed guides **49**, here shown as of trapezoidal cross section, are brought out together in one direction or the other normal to the plane of the array. It will be noted that one pair of the triangular louvers is adapted for the radiation or reception of horizontally polarized waves **E1** while the other pair is adapted for vertically polarized waves **E2**. One pair may be used for transmission and the other for reception in a two-way communication system, for example.

Fig. 29 is similar to Fig. 28 in that it comprises four of the Fig. 27 90-degree louvers arranged to form a square panel but it differs therefrom principally in regard to the manner and means of excitation. The four feed guides in this embodiment comprise quadrantal subdivisions **50** of a cylindrical pipe **51** that are formed by radial baffles **52**. The four pairs of branching wedge-shaped guides that comprise the louver array are arranged radially around one end of the pipe **51** with each pair connected laterally to one of the feed guides **50**. A metallic disc **53** to which the baffles **52** extend closes the end of the feed guides so that wave power supplied through any one of the latter can escape only into the pair of slitted guides constituting the corresponding louver.

What is claimed is:

1. A hollow pipe guide for ultra-high frequency electromagnetic waves a section of which constituting an antenna has a plurality of apertures longitudinally spaced therein, the total effective area of said apertures being substantially equal to the cross-sectional area of said guide at one end thereof, whereby the impedance of said antenna section is matched to that of the guide.

2. A louver antenna comprising a hollow pipe guide one cross dimension of which is many times the other, said other dimension being tapered, one face of said guide comprising means defining a multiplicity of longitudinally spaced slits each substantially coextensive with the larger cross dimension, and conductive surface means at said slits defining respective flaring passages normal to and external of said face.

3. A combination in accordance with claim 2 in which said defining means comprises a multiplicity of conductive triangular prisms.

4. A combination in accordance with claim 2 comprising an unslitted wave guide extension from the end of said guide and translating means connected thereto.

5. A pair of oppositely extending coplanar louvers in accordance with claim 2 and a feed connection at their junction.

6. In combination with a hollow pipe guide, a wave collimator connected thereto comprising a pair of divergent leaky pipe guides and a wave guiding structure of elongated cross section connected to receive waves emanating from said leaky guides or to deliver waves thereto.

7. A combination in accordance with claim 6 comprising at least one conductive baffle subdividing said wave guiding structure into a plurality of wave guiding passages.

8. As an antenna, a wave guiding passage of elongated cross section comprising a conductive plate as one wide face thereof and a plurality of parallel conductive prisms spaced apart as the other face, said prisms being disposed with one plane face parallel to said conductive plate and set back progressively from said back plate whereby said passage is tapered in discrete steps.

9. A microwave antenna system comprising as the wave radiating or intercepting element a hollow pipe guide of substantially rectangular cross section having in one face thereof a multiplicity of longitudinally spaced transverse slits, means at one end of said guide for launching therein or receiving therefrom guided waves of dominant type with electric field normal to the said one face, the dimension of said guide normal to the said face being tapered from the said one end.

10. A combination in accordance with claim 9 in which the total effective width of said slits is substantially equal to the said dimension of the guide at the said one end thereof.

11. A combination in accordance with claim 9 in which the said one dimension at the said one end is not substantially greater than one half the length of the waves being transmitted.

12. In combination, a pair of elements in accordance with claim 9 disposed to form a V with the faces bearing the said slits forming the respective inner faces of the V.

13. In combination, a radio antenna comprising a pair of intersecting, angularly related, uni-

conductor pipe guides, said guides having respective walls that face each other, the said facing walls each having a multiplicity of apertures spaced apart along the length of the respective guide, and means for exciting radio frequency electromagnetic waves in said pair of guides or receiving such waves therefrom.

14. In combination, a pair of conductive-walled electromagnetic wave guides, each having a wall with a multiplicity of apertures spaced apart therein along the length of the respective guide, and exciting or receiving means common to said guides for exciting electromagnetic waves in both of said guides for transmission out through said multiplicity of apertures or for receiving from said guides electromagnetic waves entering through said multiplicity of apertures, said guides being disposed, with reference to three mutually perpendicular planes, substantially in a first of said planes, substantially symmetrically on opposite sides of a second plane passing between them, and with the said apertures in each of said guides spaced at progressively greater distances from both said second plane and the third of said planes.

15. An antenna system comprising conductive means defining a hollow pipe guide of elongated and substantially rectangular cross section having a multiplicity of longitudinally spaced slits disposed transversely of the axis of the guide in and substantially coextensive with one of the wider faces of the said guide, collimating wave guide means adjacent one end of said guide for launching therein or receiving therefrom guided waves of dominant type polarized with the electric field normal to said wider face, and means for substantially equalizing the field intensity across the said wider face.

16. A combination in accordance with claim 15 comprising baffle means disposed in said slitted guide for inhibiting degeneration of the field intensity distribution in collimated waves supplied thereto.

17. A combination in accordance with claim 15 comprising a conductive baffle disposed longitudinally in said slitted guide and normal to the said wider face.

18. An antenna system for ultra-high frequency waves comprising means defining a first hollow pipe guide of elongated cross section having a multiplicity of longitudinally spaced transverse slits in one of the wider faces thereof for the radiation or interception of radio waves, an antenna transmission line comprising a second hollow pipe guide, and a wave collimator coupling said first and second guides, said collimator comprising a pair of leaky pipe guides divergent from the end of the second hollow pipe guide.

19. A combination in accordance with claim 18 comprising a conductive baffle extending longitudinally from the point of divergence of said leaky pipe guides through said first hollow pipe guide.

20. In a system for the transmission of ultra-high frequency electric waves, a wave collimator comprising a pair of leaky pipe guides divergent from a common point, wave translating means coupled to both of said guides at said point, and wave guiding means connected laterally of both of said leaky guides in wave transfer relation therewith.

21. In combination, a pair of shielded electric transmission lines divergent from a common point in the form of a V, said lines being electrically leaky along the inner faces thereof, and conductive means defining a hollow pipe guide of elongated cross section the end of which is disposed to receive waves issuing through said leaky faces or to deliver waves to said faces.

22. An antenna for ultra-high frequency waves comprising a hollow pipe guide of elongated cross section having a multiplicity of longitudinally spaced apertures in a wider face thereof, said apertures extending substantially completely across the guide, an antenna transmission line comprising a hollow pipe guide and a wave collimator coupling the ends of the two guides and forming a continuation of each, said collimator comprising a pair of leaky pipe guides divergent from the end of said transmission line.

23. An antenna structure comprising conductive means defining a hollow pipe guide of elongated rectangular cross section having a multiplicity of longitudinally spaced transverse slits in one of the wider faces for the radiation or interception of radio waves, the smaller cross-sectional dimension of said guide being tapered with discrete steps at the successive slits.

24. An antenna structure in accordance with claim 23 in which the said conductive means defining the said wider face comprises a multiplicity of conductive prisms of at least approximately triangular cross section disposed with one plane face parallel to the other of the wider faces of the guide and spaced apart to form slits between them.

25. A directive radio antenna system comprising, in combination, a uniconductor pipe guide having a plurality of distinct faces, one of said faces having therein a multiplicity of longitudinally spaced transverse apertures affording a dielectric connection between the interior of said guide and free space, the successive portions of said one face that define said apertures being in stepped relation to each other, and means for exciting in said guide or receiving therefrom electromagnetic waves having lines of electric force that are substantially normal to said one face.

26. In combination, a radio antenna comprising a hollow conductive-walled passage of substantially rectangular cross section, one of the walls of said passage comprising longitudinally successive portions that are substantially parallel to the opposite wall of said passage and that are disposed, in stepped relation to each other, successively closer to said opposite wall, said one wall having a multiplicity of elongated transverse apertures each formed between a pair of said wall portions, and means for exciting in said passage or receiving therefrom electromagnetic waves having lines of electric force that extend between said one wall and said opposite wall.

27. A radio antenna system comprising a uniconductor pipe guide for electromagnetic waves, said guide having a multiplicity of apertures spaced along its length for the radiation or admission of radio waves, the size of said guide being reduced gradually between successive apertures, and means for exciting said guide with radio frequency waves or receiving such waves therefrom.

28. In combination, a radio antenna comprising a uniconductor guide enclosing a dielectric madium, said guide having at least one substantially flat side wall and said side wall having a multiplicity of openings therein spaced apart along the length of said guide, said guide having a transverse dimension normal to said side wall that tapers substantially continuously, and means for exciting said antenna with electromag-

netic waves of radio frequency or receiving such waves therefrom.

29. In combination, a radio antenna comprising a conductive-walled electromagnetic wave guiding passage of substantially rectangular cross section that tapers smoothly from one end of said passage to the other, one of the four conductive walls of said passage having therein a multiplicity of elongated transversely disposed openings spaced apart along the length of said passage for the emission or admission of radio frequency waves, and means for exciting radio frequency waves in said passage or receiving them therefrom.

30. In combination, a radio antenna comprising a leaky uniconductor pipe guide for electromagnetic waves, said guide having a face that contains a multiplicity of apertures spaced apart along the length of said guide, the spacing of said apertures being small compared with the operating wave-length and the said guide being tapered in size from one aperture to the next, and radio frequency wave exciting or receiving means connected to said guide.

31. A radio antenna system comprising a leaky wave guide and exciting or receiving means connected thereto for exciting waves in said guide for radiation therefrom or for receiving from said guide radio waves intercepted thereby, said guide having a transverse dimension that tapers substantially continuously along said guide from a larger value adjacent said exciting or receiving means.

32. In a combination, a leaky wave guide and means for exciting in said guide or receiving therefrom guided electromagnetic waves of a type in which the lines of electromotive force are substantially parallel to a transverse dimension of the guide, the said transverse dimension varying substantially continuously from point to point along said guide.

33. In combination, a leaky uniconductor pipe guide for electromagnetic waves, said guide having a substantially continuous taper, and radio frequency wave exciting or receiving means connected to the larger end of the tapered guide.

34. A radio antenna system comprising a multiplicity of panel antennas arranged to form a substantially continuous active forward surface, each panel antenna having a multiplicity of apertures in its forward surface and an individual tapered distribution passage that extends across its back surface, and at least one of said distribution passages being extended in overlapping relation along the back surface of a contiguous panel.

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Disclaimer

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Hereby enters this disclaimer to claims 13, 14, and 20 of said patent.

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