May 19, 1953 H. GRUENBERG 2,639,383

MICROWAVE ANTENNA

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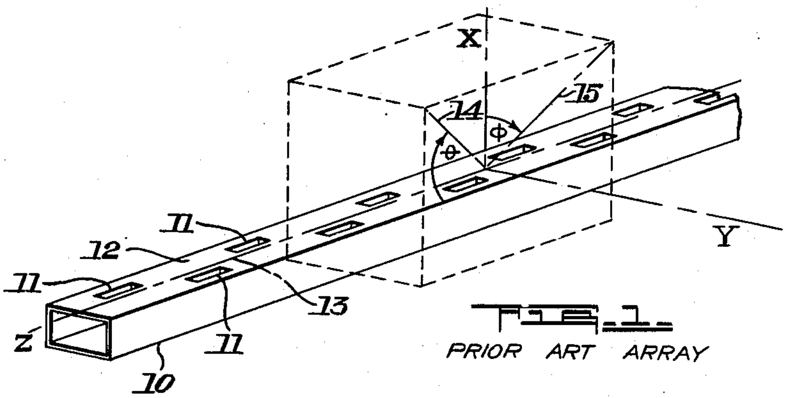
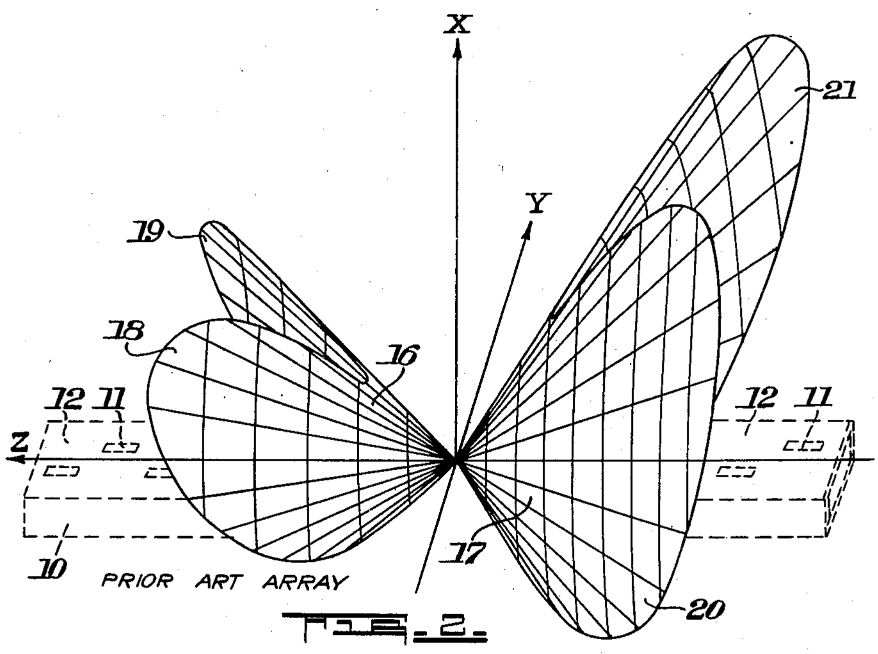


FIG. 1.
PRIOR ART ARRAY



PRIOR ART ARRAY

FIG. 2.

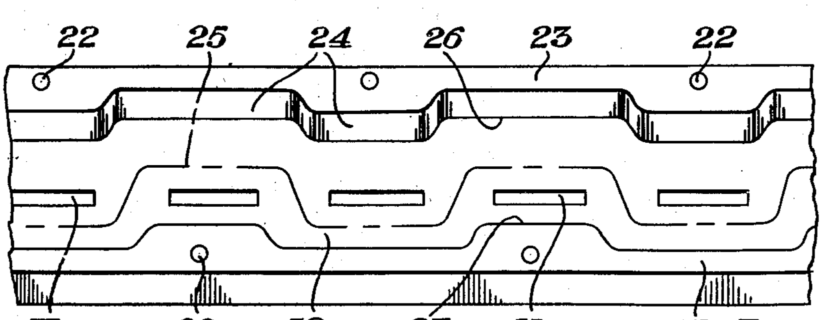


FIG. 3.

INVENTOR
HARRY GRUENBERG
BY- Smart & Biggar.
ATTORNEYS.

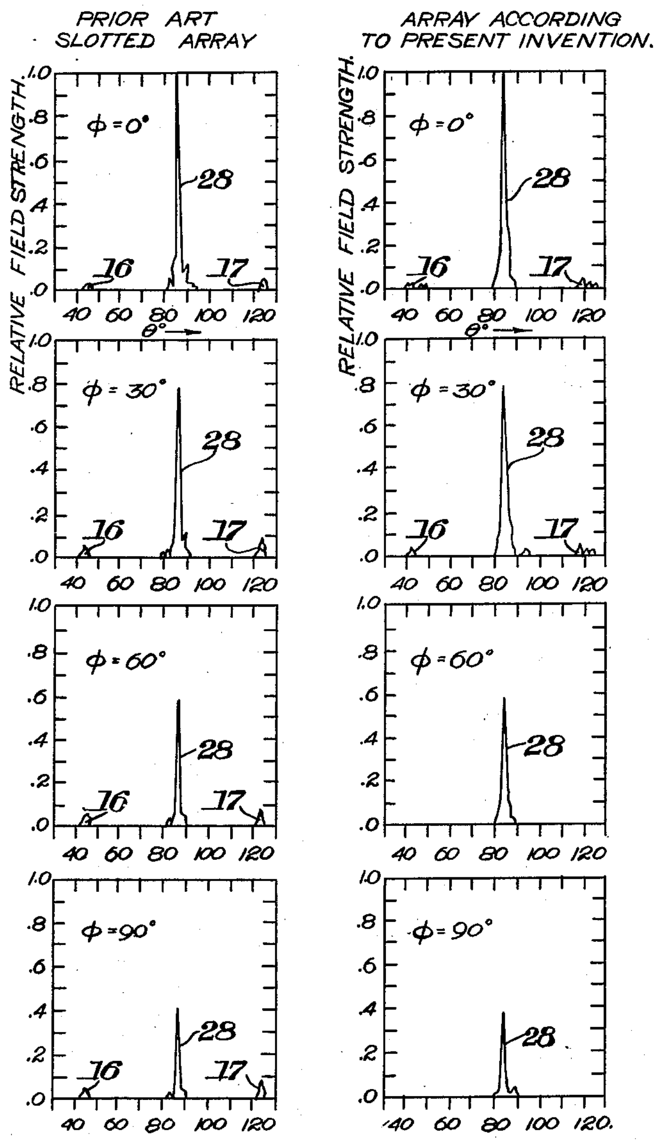


FIG. 4.

INVENTOR
HARRY GRUENBERG
BY- Smart & Biggar.
ATTORNEYS.

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MICROWAVE ANTENNA

Harry Gruenberg, Ottawa, Ontario, Canada, assignor to National Research Council, Ottawa, Ontario, Canada, a corporation of Canada

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7 Claims. (Cl. 250—33.63)

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The invention relates to directive antennas for microwaves, that is for electro-magnetic waves having lengths in free space of less than one meter.

In copending United States application Serial Number 626,738, filed November 5, 1945, by W. H. Watson and E. W. Guptill for "Directive Antennas for Micro-Waves" (Patent Number 2,573,746, granted November 6, 1951), (see also a paper entitled "Resonant slots" by W. H. Watson, appearing at pages 747 to 777 of volume 93, part IIIA, Number 4 of the Journal of the Institution of Electrical Engineers, and the book "The Physical Principles of Wave Guide Transmission and Antenna Systems," by W. H. Watson, 1947, Oxford, at the Clarendon Press) there is disclosed an antenna structure comprising a waveguide formed with an array of radiators consisting of slots in special arrangements. The present invention is concerned with the arrangement in which adjacent slots are located on opposite sides of the centre line of a broad face of the waveguide and in the present application, an antenna with this arrangement of slots will be called the Watson and Guptill antenna. The Watson and Guptill antenna takes into account the well-known design considerations for linear arrays of radiators and the fact that the wavelength in the guide differs from that in free space. For many purposes, for example radar, it is essential that there should be only one effective beam from the array, and it is also desirable that this beam should be substantially normal to the axis of the array, that is normal to a straight line passing through all the radiators. In order that the beam should be normal to the axis of the array, the radiators must radiate in phase. This could be achieved by spacing the radiators along the axis of the array at intervals equal to the wavelength in the guide (λg) of the wave to be radiated, but, owing to the higher phase velocity in the guide, at least in the usual case where the dielectric is air, such a spacing would, in a guide having a normal width of about ¾ of the wavelength in free space (λs), be equal to the spacing of about $1\frac{1}{2}\lambda s$. Such an array would be unsatisfactory because its radiation pattern would contain second-order beams of substantially the same intensity as the main beam making angles of approximately 45 degrees with the latter (see pages 101 to 107, Aerials for Centimetre Wavelengths, by Fry and Goward, published in 1950 by the Cambridge University Press). The beam could also be made normal to the axis of the array by coupling adjacent radiators in reversed phase relation, that is, in such a way that if the adjacent radiators were situated in the same transverse plane in the guide, they would be excited by currents or voltages 180° out of phase with each other, and by spacing the radiators at intervals of $\frac{1}{2}\lambda g$. A spacing of $\frac{1}{2}\lambda g$ is, in the normal case of a guide of a width of about $\frac{3}{4}\lambda s$, equivalent to a spacing of about $\frac{3}{4}\lambda s$, and is consequently satisfactory from the point of view of the radiation pattern. When the spacing of the radiators coupled in reverse phase relation is different from $\frac{1}{2}\lambda g$, the angle of the beam to the axis of the array becomes acute and decreases with increasing departure from $\frac{1}{2}\lambda g$ spacing, the beam being directed in the direction of wave propagation in the guide when the spacing is greater than 180° and in the opposite direction when the spacing is less than 180°.

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The present invention resulted from the discovery that even when the above conditions are observed in the design of a slotted waveguide antenna such as the Watson and Guptill antenna, there remain second order beams making angles of approximately 50° with the main beam and having levels of about 10 per cent of that of the main beam. In many types of radar work, this spurious radiation is not troublesome, for example in the case of navigation on open waters where the radar equipment is not ordinarily used to locate nearby objects. However, in the case of navigation on narrow waters, for example in a canal or a river many nearby objects may be encountered, such as other boats or the banks of the canal or river, and, if second order beams cause reflections from these nearby objects, serious errors in interpretation of the radar patterns may result. In some cases the second order beams may cause the patterns to be blurred and unreadable. It is thought that the reason these second order beams have remained undiscovered, prior to the present invention, is that, as mentioned above, they are not noticeable except in the presence of nearby objects and moreover they occur in planes in which radiation patterns are not usually taken. Although it was previously appreciated that a directive antenna obtained by spacing the slots about a guide wavelength on one side of the centre line and exciting them approximately in phase would result in large second order beams due to the slot spacing being greater than a free space wavelength, it was generally thought that this defect was overcome and at the same time the directive feature of the array was retained by spacing the slots approximately half a guide wavelength apart and reversing the phase of alternate slots by staggering them about the centre line. This reasoning was based on the theory of linear arrays and tacitly assumed that the same displacement of the slot radiators from a straight line has negligible effect on the radiation pattern. By the discovery which led to the present invention, it was found that this assumption, in general, is not justified, since such an array actually has second order beams even for slot spacings of half a guide wavelength.

According to the present invention, these second order beams from a slotted waveguide antenna are reduced to an amount dependent only on a asymmetries in excitation of the slots and on the limits in the accuracy of construction of the slotted waveguide by having the longitudinal centre lines of the slots in a broad face of the waveguide collinear and the narrow faces of the waveguide shaped so that the centre line between them in the plane of said broad face of the waveguide is sinuous and lies between each slot and the next adjacent slots.

A microwave antenna according to the present invention comprises a waveguide of substantially rectangular cross-section having two opposite narrow faces and two relatively broad faces, the waveguide having formed in a broad face thereof a series of slots substantially resonant for a wave of given wavelength and of substantially greater length than width, the centres of the slots of the series being spaced along the waveguide at intervals of less than substantially seven-eighths of said wavelength in free space, the longitudinal centre lines of the slots being substantially collinear, the narrow faces of the waveguide being shaped so that the centre line between the narrow faces is sinuous and lies on opposite sides of adjacent slots, and the distance of substantially every slot from the centre line between the narrow faces being at least substantially the same as said distance for either adjacent slot.

The invention will be further described with reference to the accompanying drawings which illustrate certain embodiments of it, and in which:

Figure 1 is a perspective diagrammatic view of a slotted waveguide micowave antenna according to the prior art;

Figure 2 is a perspective representation of second order beams produced by a prior art antenna as shown in Figure 1;

Figure 3 is a perspective view of a section of a slotted waveguide microwave antenna according to the present invention, with its rear broad face removed; and

Figure 4 is typical radiation patterns for a prior art antenna and for an antenna according to the present invention.

A prior Watson and Guptill slotted waveguide antenna is shown in Figure 1, where a slotted rectangular waveguide **10** has longitudinal slots **11** in one of its broad faces **12**. Adjacent slots **11** are staggered about the centre line **13** of the broad face **12**. As explained in the Watson and Guptill copending application, as well as in the paper and book by W. H. Watson, referred to above, the dimensions of the slots **11** should be such that they are resonant for the wavelength of the microwave to be radiated and are of substantially greater length than width. It is also explained in the references mentioned that the distance of the slots **11** from the centre

line **13** controls the amount of radiation from the slots **11**. The usual X, Y and Z axes are shown in Figure 1, and vectors **14** and **15** respectively at angle θ from the Z axis and at angle ϕ from the X axis define the usual polar and azimuthal angles in a spherical co-ordinate system.

The prior art antenna of Figure 1 is shown in dotted line in Figure 2 with the second order beams **16** and **17** shown in full line. The second order beams **16** and **17** have, respectively, broad maxima **18**, **19** and **20**, **21** of which the axial planes are symmetrically located about the axial plane through the main beam, making angles of approximately 50° with the latter. The maxima are at (θ and ϕ as indicated in Figure 1):

$$\theta_1=\cos^{-1}\left(\frac{\lambda s}{\lambda g}\right)\approx 45°,\ \phi\approx\pm 50°$$

$$\theta_{-1}=\cos^{-1}\left(\frac{\chi-\pi}{\chi+\pi}\frac{\lambda s}{\lambda g}\right)\approx 135°,\ \phi\approx\pm 50°$$

where λs and λg are the free-space and guide wavelengths, respectively, and χ is the deviation of the slot spacing from π radians. The maximum values expressed as fractions of the peak of the main beam are approximately:

$$s\approx 1.5\frac{\delta}{\lambda s}$$

where δ is a weighted mean slot offset. This weighted mean is close to the amount of offset of the slot which is most strongly excited.

For a typical waveguide array the second order beams **16** and **17** may be ten per cent of the main beam.

A slotted waveguide antenna according to the present invention is shown in Figure 3. As shown in Figure 3, a series of slots **11** are arranged with their longitudinal centre lines collinear and with their centres spaced along a broad face **12** of a waveguide. As explained above, the spacing between the centres of adjacent slots **11** must be less than substantially seven-eighths of the wavelength in free space of the microwave to which the slots **11** are resonant. In the embodiment shown in Figure 3, it is assumed that the slots **11** are spaced at one-half the wavelength in the waveguide. In Figure 3, the rear broad face of the waveguide is not shown so that the inner construction of the waveguide can be seen. The rear broad face can be secured in position by screws which are driven into tapped holes **22** and the rear broad face is then sweated to the edges **23** of the narrow faces **24** to secure good electrical contact throughout the lengths of the faces. The front broad face **12** is mounted in the same manner.

The narrow faces **24** are each corrugated so that the sinuous centre line **25** lies on opposite sides of adjacent slots as shown in Figure 3, where a depression **26** in one of the narrow faces **24** is directly opposite a protuberance **27** in the other narrow face **24**.

In accordance with the usual practice the complete antenna would be terminated by a reflecting plunger, or other similar device, arranged in the waveguide at a distance, equal to one-quarter of the wavelength in the waveguide of the wave to which the slots **11** are resonant, from the centre of the slot **11** in the waveguide furthest from the point at which the waveguide is to be fed with a microwave.

According to the present invention as shown in Figure 3, the slots 11 are all in line and are excited at the desired amplitude and phase by the displacement of the sidewalls (narrow faces 24) from the collinear longitudinal centre lines of the slots 11. For a comparatively long array of slots the corrugations in the side walls may be relatively shallow. For best results, very close mechanical tolerances are required since small asymmetries in the excitation of every alternate slot may cause small second order beams in the axial plane of the main beam.

Figure 4 shows typical radiation patterns for a prior art slotted waveguide type of antenna and for a slotted waveguide type of antenna according to the present invention. Each of the graphs is relative field strength plotted against the angle θ (Figure 1) and each of the graphs for the same antenna is for a different angle ϕ (Figure 1). It is clear, from a comparison of the field strengths of the two antennas for the same angle ϕ, that, with an antenna according to the invention, the undesirable second order beams 16 and 17 are greatly reduced although the main beam 26 is practically unchanged.

What I claim as my invention is:

1. A directive antenna for microwaves comprising a waveguide of substantially rectangular cross-section with two opposite narrow faces and two relatively broad faces, the waveguide having formed in a broad face thereof a series of slots substantially resonant for a wave of a given wavelength and of substantially greater length than width, the centres of the slots of the series being spaced along the waveguide at intervals of less than substantially seven-eighths of said wavelength in free space, the longitudinal centre lines of the slots being substantially collinear, the narrow faces of the waveguide being shaped so that the centre line between the narrow faces in the plane of the broad face containing the series of slots is sinuous and lies on opposite sides of adjacent slots, and the distance of substantially every slot from the centre line between the narrow faces being at least substantially the same as said distance for either adjacent slot.

2. A directive antenna as claimed in claim 1 in which the centres of the slots are spaced along the waveguide at intervals of half the wavelength in the waveguide of the wave to which the slots are resonant.

3. A directive antenna as claimed in claim 1 in which the narrow faces of the waveguide are corrugated, each depression in one of said narrow faces being directly opposite a protuberance in the other narrow face, and the longitudinal centre lines of the slots are substantially collinear with a centre line between straight lines joining the innermost projections of the protuberances of said narrow faces into the waveguide.

4. A directive antenna as claimed in claim 3 in which the centres of the slots are spaced along the waveguide at intervals of half the wavelength in the waveguide of the wave to which the slots are resonant.

5. A directive antenna as claimed in claim 3 in which each corrugation in each of the narrow faces of the guide is rectangular in shape having its longer side substantially parallel and opposite to the longitudinal centre line of a slot and of substantially the same length as said slot.

6. A directive antenna as claimed in claim 5 in which the centres of the slots are spaced along the waveguide at intervals of half the wavelength in the waveguide of the wave to which the slots are resonant.

7. A directive antenna as claimed in claim 3, in which each corrugation in each of the narrow faces of the guide is rectangular in shape except for having rounded corners, and each corrugation has its longer side substantially parallel and opposite to the longitudinal centre line of a slot and is of substantially the same length as said slot.

HARRY GRUENBERG.

References Cited in the file of this patent

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Number	Name	Date
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