

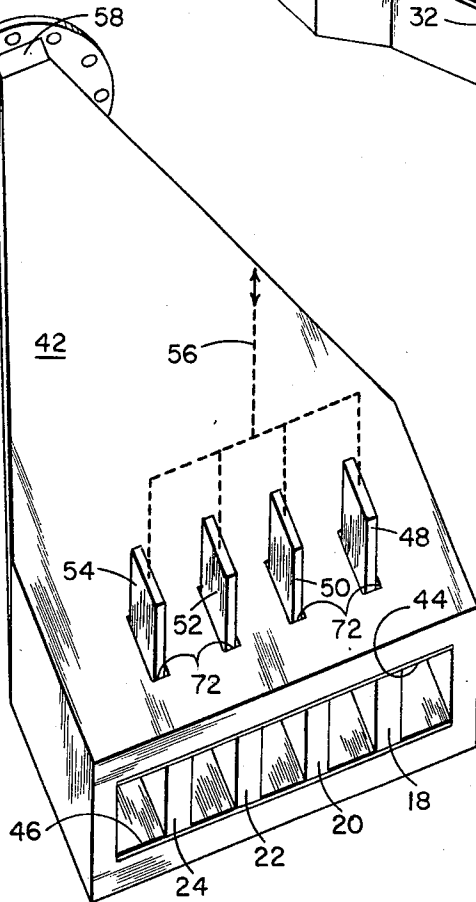
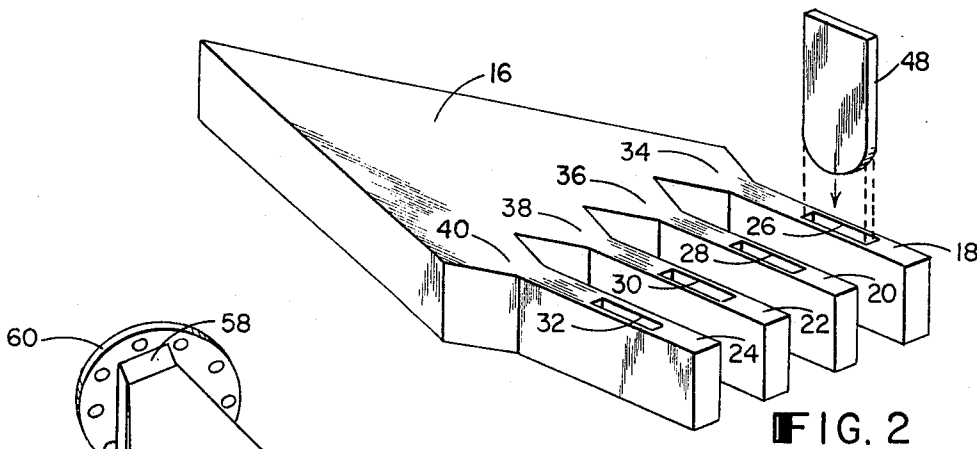
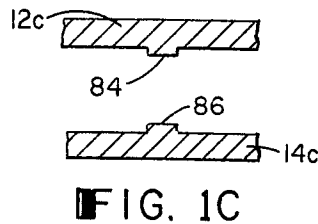
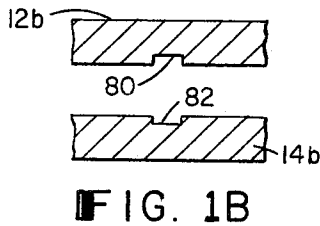
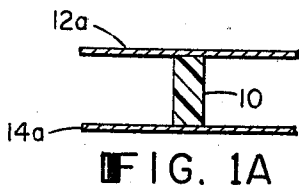
Oct. 4, 1966

L. L. BLAISDELL
MILLIMETER PHASED ARRAY

3,277,489

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3 Sheets-Sheet 1



INVENTOR.
LEONARD L. BLAISDELL
BY
Spencer E. Olson
ATTORNEY.

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FIG. 4

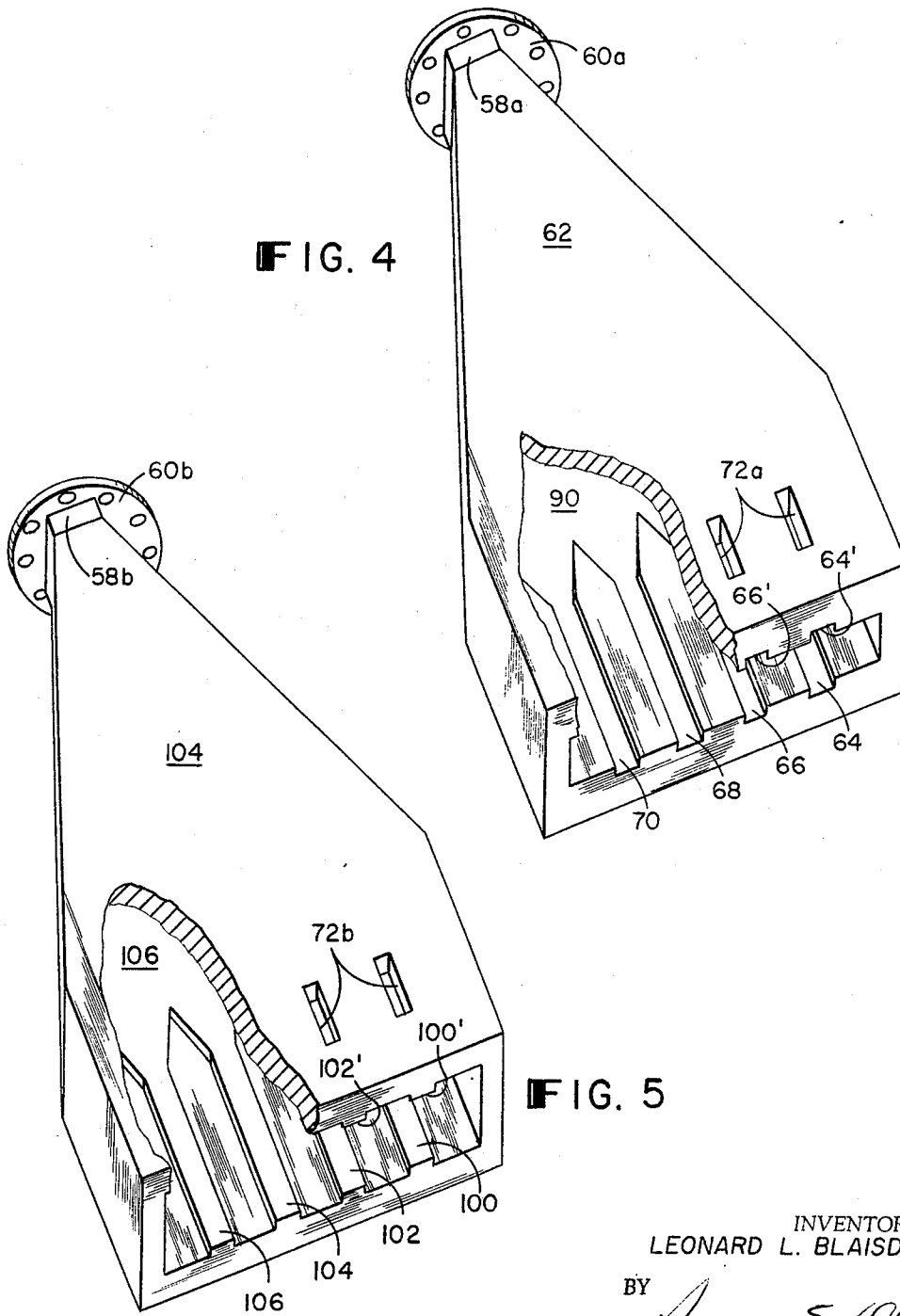


FIG. 5

INVENTOR.
LEONARD L. BLAISDELL

BY

James E. Olson

ATTORNEY.

Oct. 4, 1966

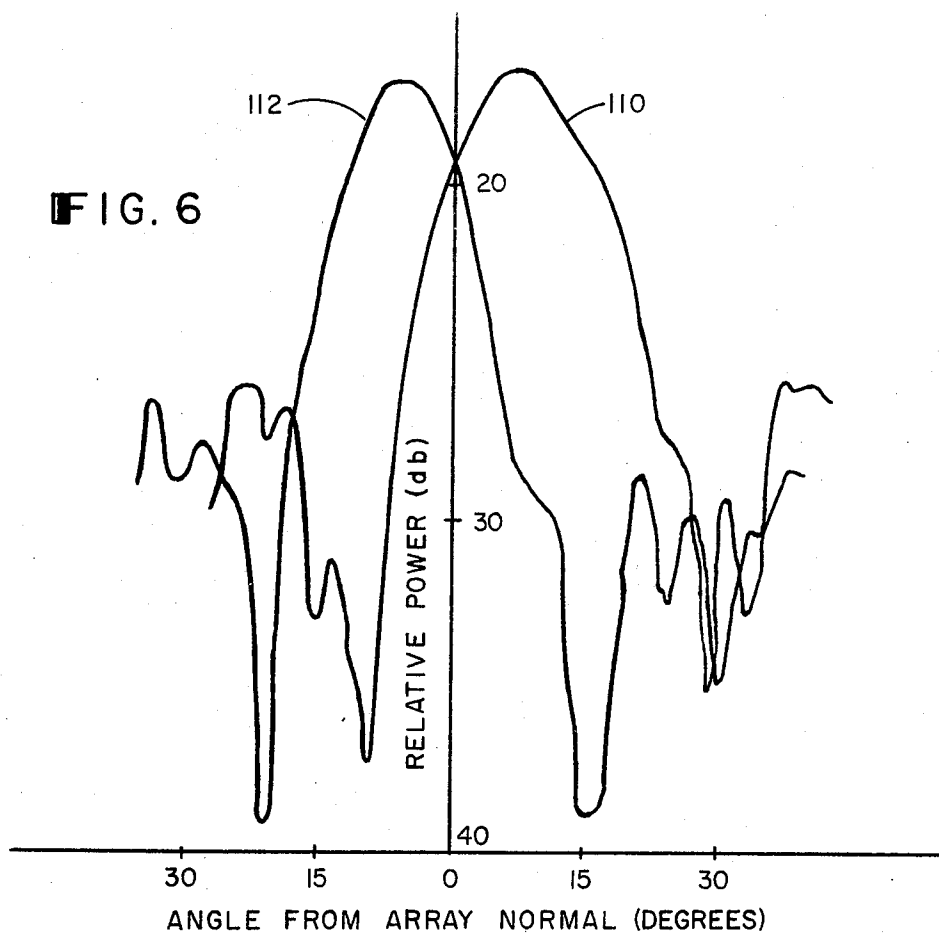
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FIG. 6



INVENTOR.
LEONARD L. BLAISDELL

BY

James E. Olson

ATTORNEY.

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3,277,489

MILLIMETER PHASED ARRAY

Leonard L. Blaisdell, Medway, Mass., assignor to Syl-
vania Electric Products Inc., a corporation of Delaware

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This invention relates to antennas and more particularly to electronically steerable antennas which are especially suited for operation in the millimeter wavelength region.

Phased array antennas for communications and radar are well known and have gained prominence in recent years since they provide rapid, accurate, inertialess beam steering. The accuracy of these arrays, as is the accuracy of all antenna systems, is ultimately limited by the frequency at which the antenna system operates. In order to obtain higher resolution, higher operating frequencies must be used; however, at extremely high frequencies, for example, in the millimeter wavelength region above 20 gigacycles per second (gc.), antennas constructed by known microwave techniques are difficult and costly to build due to the small physical dimensions of microwave components at these frequencies, and the dimensional accuracy required. It is, therefore, an object of the present invention to provide an efficient, relatively simple, extremely accurate phased array particularly suited for operation in the millimeter wavelength region. Such an array would have specific application, for example, in space vehicles.

Another object of the invention is to provide a phased array having a feed structure integral with the antenna elements.

Another object of the invention is to provide an antenna array which is fabricated in a single integral member.

Still another object of the invention is to provide a phased array having improved radiating elements at millimeter wavelengths.

A further object of the invention is to provide a phased array in which phase shifters are incorporated into the radiating elements.

Briefly, the invention comprises a phased array in which the radiating elements are field-constrained parallel plate waveguides wherein radiation is concentrated at discrete locations within a single pair of ground planes. Typical examples of such waveguide are H-guide, ridge guide, or a pair of confronting grooves cut in a respective pair of ground planes. Power division between the elements of the array is provided by a power divider/combiner which may be integral with the antenna elements, and which supplies energy from an energy source to the respective antenna elements when the array is operating in the transmitting mode, or which combines energy received by the respective antenna elements when the array is operating in the receiving mode. Suitable phase shifters are provided in each antenna element to produce the requisite phase shift to appropriately steer the antenna beam.

The foregoing, together with other objects, features, and advantages of the present invention will be more apparent from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIGS. 1A, 1B and 1C are elevation views of three field-constrained parallel plate waveguide useful in the present invention;

FIG. 2 is a pictorial view of a dielectric power divider and multiple radiating elements constructed in accordance with the invention;

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FIG. 3 is a pictorial view of one embodiment of the present invention;

FIG. 4 is a partly cut away pictorial view of another embodiment of the invention;

FIG. 5 is a partly cut away pictorial view of a further embodiment of the invention; and

FIG. 6 is the measured antenna pattern of a phased array constructed in accordance with the invention.

Referring to FIGS. 1A, 1B, and 1C there are shown three electrically equivalent types of field-constrained parallel plate waveguide. The dielectric loaded waveguide, or H-guide shown in FIG. 1A comprises a dielectric slab 10 of rectangular cross section, disposed between a pair of parallel ground planes 12a and 14a with its long axis at right angles thereto. The groove guide illustrated in FIG. 1B comprises a pair of parallel ground planes 12b and 14b having confronting grooves 80 and 82, respectively, cut in each ground plane. The ridge guide shown in FIG. 1C comprises a ground plane 12c having a ridge 84 formed thereon and facing a like ridge 86 formed on a second ground plane 14c. In the case of the H-guide, it is well known that radiation between the ground planes can be confined to the region within and immediately adjacent dielectric slab 10 by proper choice of a dielectric material having a suitable dielectric constant and slab thickness. Radiation in a groove guide and in a ridge guide can be confined to the region between the grooves or ridges by suitably dimensioning the width and depth of the grooves or ridges, as the case may be. Since radiation within the waveguide is confined to discrete regions, no side walls are needed to prevent radiation from the edges of the guide. Side walls can, of course, be provided to satisfy mechanical considerations, although electrically, the waveguide functions equally as well with or without them. A plurality of dielectric slabs, confronting grooves, or ridges can, therefore, be arranged side by side between a pair of ground planes and can be suitably energized to function as an antenna array.

The construction of an H-guide array, with the ground planes removed for clarity, is shown in FIG. 2, and includes a tapered dielectric member 16 which is shaped at one end to form fingers or radiating elements 18, 20, 22, and 24. Of course, more or less than four radiating elements can be provided to suit the intended requirement. Tapered sections 34, 36, 38, and 40 between the tapered section 16 and the fingers provide impedance matching to prevent unwanted energy reflection from the radiating elements. The dimensions of the tapered sections are chosen to suit the frequency of operation. Slots 26, 28, 30, and 32 are cut in elements 18, 20, 22, and 24, respectively, near the outer end thereof, to accommodate phase shifting slugs, one of which is shown removed from the slot in FIG. 2, and designated by reference numeral 48. The slugs are shown in their operative position in FIG. 3. Tapered member 16 functions as a dielectric power divider and provides an expedient means of launching the desired energy mode from an energy source, and also provides a simple means of adjusting the illumination taper across the elements of the array by suitably apportioning selected amounts of energy to the several radiating elements. It is evident that power divider 16 and elements 18, 20, 22, and 24 can be fabricated as a single unit, such as by well known molding or milling techniques. The major portion of the array, therefore, can be economically and accurately constructed in a single integral piece.

The complete array embodying the dielectric structure of FIG. 2, is illustrated in FIG. 3. The dielectric power divider and radiating elements are enclosed in a housing 42, which, for example, may be fabricated from epoxy resin with ground planes 44 and 46 disposed on the upper

and lower inside faces thereof, respectively. Alternatively, housing 42 may be fabricated of copper or other conductive material. Since electrical performance of the array is unaffected by the presence or absence of conductive side walls, it makes no difference whether or not the ground planes are insulated from each other. Dielectric slugs 48, 50, 52, and 54 are slidably mounted in slots 26, 28, 30, and 32, respectively, in the dielectric member, extending through suitable holes 72 provided on one face of housing 42. A suitable mechanism, schematically indicated at 56, is provided to move the slugs in or out of the slots to vary the phase of signals in the radiating elements, as the situation requires. Dielectric slugs 48, 50, 52, and 54 have a curved lower surface as shown in FIG. 2, to provide impedance matching. Other suitable impedance matching configurations may, of course, be used equally as well.

A section of rectangular waveguide 58, and a mounting flange 60 are connected at the apex end of the power divider to couple energy from an energy source to the array, if the array is used for transmitting; or, if the array is used for receiving, to couple received energy to appropriate signal utilization means.

The operation of the array will be described in the transmitting mode, it being understood, however, that it is a reciprocal device and can be used equally well in the receiving mode. In operation, a signal from an energy source is applied to the input terminal of the array by any well known means, for example by means of waveguide 58. Energy propagates through power divider 16 and is divided among radiating elements 18, 20, 22, and 24, which radiate the energy into space. The electrical length of the radiating elements, and thus the phase of signals propagating therethrough, is dependent upon the distance that slugs 48, 50, 52, and 54 are inserted into their respective radiating elements. The electrical path length through the radiating elements increases with the depth of insertion of the slugs; consequently, the change in the phase of a signal propagating through elements 18, 20, 22, and 24 can be adjusted to steer the antenna beam in any desired direction. The differential phase shift, which determines the angular extent the beam moves away from its zero scan reference position, depends upon the dimensions and dielectric constant of the dielectric slugs.

Another embodiment of the invention is suggested by remembering that a pair of confronting grooves cut in opposite surfaces of a pair of ground planes is electrically equivalent to an H-guide. As shown in FIG. 4, a plurality of radiating elements can thus be provided by simply cutting suitable grooves in a pair of confronting ground planes; power division is provided by cutting a grooved structure of the same shape as the tapered dielectric power divider 16 of FIG. 2. More specifically, tapered groove 90 formed in the lower face of metal housing 62, is divided into groove 64, 66, 68, and 70. A similar configuration of grooves is provided on the upper face, only grooves 64 and 66 being visible in the figure. The energy is constrained in the region between pairs of confronting grooves by suitably dimensioning the groove width and depth. Slots 72a are provided in the upper face of housing 62 to accommodate phase shifting slugs, as in the embodiment of FIG. 3. The slots are disposed such that the slugs extend into the region between confronting grooves where the energy is confined. Since the wave propagation occurs in air rather than in a solid dielectric material, this embodiment has lower dielectric loss than an embodiment of the type shown in FIG. 3, and is therefore, electrically more efficient.

The operation of the array shown in FIG. 4 is identical to that of the array of FIG. 3. Energy is applied to the input by means of flange 60a and waveguide section 58a, and is guided by the groove power divider formed by groove 90 and its counterpart on the upper face of housing 62, to the radiating elements consisting of grooves

64, 66, 68, and 70 and their confronting counterparts, only two of which, 64' and 66', are illustrated. Dielectric slugs (not shown) are slidably mounted in respective slots 72a, as in the embodiment of FIG. 3, to alter the phase of signals propagating in the region of the confronting grooves to thereby steer the antenna beam.

A further electrically equivalent embodiment of the invention can be made using ridge guide, such as that illustrated in FIG. 1C. As shown in FIG. 5, a plurality of ridges 100, 102, 104, and 106 are formed in the lower face of metal housing 104, and a like plurality of ridges are formed on the upper face, only ridges 100' and 102' being visible in the figure. A tapered ridge 106 formed in the lower face of housing 104, and a similar tapered ridge provided in the upper face, comprise the power divider. Slots 72b are provided in the upper face of housing 104 to accommodate phase shifting slugs, as in the embodiments of FIG. 3 and FIG. 4.

The operation of this embodiment is identical to that of the previous embodiments. Energy is applied to the input by means of flange 60b and waveguide section 58b, and is guided by the power divider formed by ridge 106 and its counterpart on the upper face of housing 104, to the radiating elements consisting of ridges 100, 102, 104, and 106 and their confronting counterparts. As in the previously discussed embodiments, the phase of signals propagating in the region of the confronting ridges is altered by dielectric slugs (not shown) slidably mounted in respective slots 72b provided in the upper face of housing 104.

In a four element array, of the type illustrated in FIG. 3, constructed for operation at 45 gc, the power divider, radiating elements, and phase shifting slugs were fabricated of titanium dioxide-loaded polystyrene having a dielectric constant of 9. The radiating elements were .06 inch wide, .117 inch high, and the spacing between elements, as measured between element centers, was .17 inch. The overall dimensions of the array were 4 inches long, 1.25 inches wide, and .25 inch high. A maximum phase shift of 85 degrees was obtainable in each radiating element by moving the appropriate dielectric slug in or out of the corresponding radiating element. For a phase shift of 85 degrees, the calculated beam steering angle for the array geometry here under consideration is 7 degrees. This calculated beam steering angle was demonstrated experimentally, as shown by the antenna pattern of FIG. 6. Referring to FIG. 6, curve 110 is the measured antenna pattern when the antenna beam is steered to its maximum right-hand position, while curve 112 is the measured antenna pattern when the beam is steered to its maximum left-hand position. It is seen that the antenna beam is steerable up to an angle of approximately 7 degrees on either side of the array normal, or a total steering angle of approximately 14 degrees. Greater steering angles can, of course, be obtained by providing greater phase shifts in the antenna elements, and by suitable geometric design of the array.

From the foregoing, it is seen that a simple, compact, easily constructed phased array has been provided which is particularly suited for operation in the millimeter wavelength region.

While there have been described what are now thought to be preferred embodiments of the present invention, various modifications and alternative constructions will now occur to those skilled in the art without departing from the true scope of the invention. For example, electronically controlled phase shifters, such as those employing ferroelectric material may be inserted into each radiating element, and by applying appropriate control voltages across respective elements, the dielectric constant of the ferroelectric material, and hence the phase shift of signals through the radiating elements can be selectively changed to steer the antenna beam. Accordingly, it is not intended to limit the scope of the invention by what

has been specifically shown and described except as indicated in the appended claims.

What is claimed is:

1. A phased array comprising a dielectric member disposed between and in contact with a pair of ground planes, said member having an apex end which outwardly tapers to a predetermined width, at which point it divides into a plurality of fingers parallel to each other, each of said fingers having a slot cut therein, a like plurality of dielectric slugs each slidably mounted in a corresponding one of said slots, and means for moving said slugs in or out of said slots to thereby selectively alter the phase of signals propagating in the region of said fingers.

2. A phased array comprising a first and a second ground plane having a pair of confronting surfaces each surface having a field constraining element therein, said element having an apex end which outwardly tapers to a predetermined width, at which point it divides into a plurality of elongated field constraining elements parallel to each other, the tapered element and elongated elements of one ground plane confronting corresponding elements of the other ground plane, one of said ground planes having a plurality of slots therein with a slot communicating with each pair of respective elongated confronting elements, a like plurality of dielectric slugs each slidably mounted in a corresponding one of said

slots, and means for moving said slugs in or out of said slots to selectively alter the phase of signals propagating in the region of said confronting elongated elements.

3. A phased array according to claim 2 in which said field constraining element is a groove formed in each ground plane and confronting a like groove in the other ground plane.

4. A phased array according to claim 2 in which said field constraining element is a ridge formed in each ground plane and confronting a like ridge in the other ground plane.

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HERMAN KARL SAALBACH, *Primary Examiner.*

25 M. NUSSBAUM, A. R. MORGANSTERN,
Assistant Examiners.