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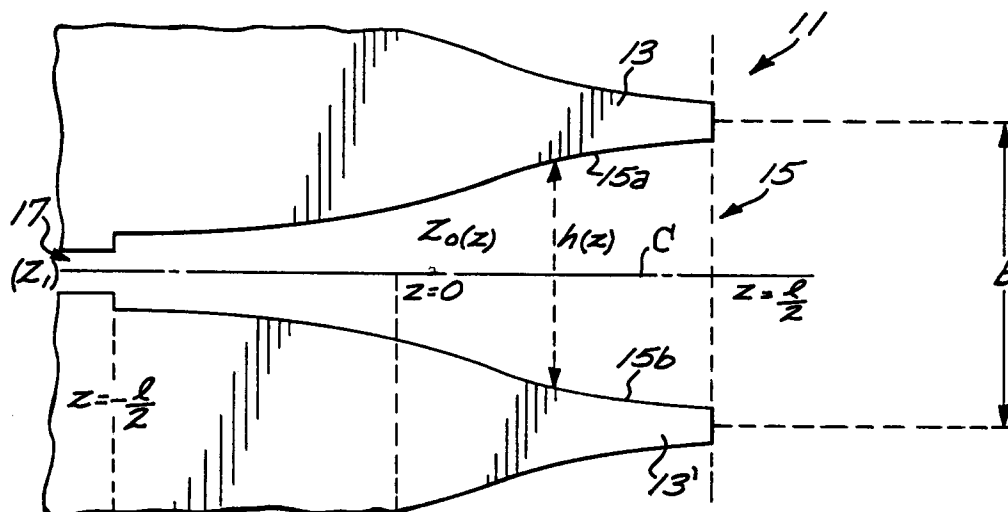
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Witte, Weller & Gahlert Patent- und
Rechtsanwälte Augustenstrasse 7
W-7000 Stuttgart 1(DE)(54) **Broadband continuously flared notch phased-array radiating element with controlled return loss contour.**

(57) A flared notch radiator (11) is disclosed. The radiator (11) comprises a first planar metallic conductor (13) having a first contoured edge (15a) extending from a feed line C and a second planar metallic conductor (13') co-planar with the first planar metallic conductor (13) and having a second contoured edge (15b) adjacent to the first contoured edge (15a) and extending from the feed line (17). The contoured edges (15a, 15b) diverge from each other with distance h from the feed line (17) and are shaped to provide a high-pass Tchebyscheff-like reflection coefficient versus frequency characteristic.

FIG. 1**EP 0 506 061 A1**

BACKGROUND OF THE INVENTION

The subject invention is directed generally to radiating elements for phased array antennas, and is more particularly directed to a broadband notched radiating element having a specially contoured flare opening.

5 The radiating elements of a phased array antenna function as transducers between transmission line propagation of RF energy and free-space propagation of energy. For transmission, the radiating elements concentrate the radiated energy into a shaped beam; and for reception the radiating elements collect energy and couple the energy to transmission lines.

10 Antenna radiating elements are the building blocks that allow construction of large antennas that can provide narrow beam, high gain, low sidelobe, electronically steerable radiation patterns. By controlling the excitations of the radiating elements the radiation pattern of the antenna can be tailored to provide desirable performance. The use of arrays of elements rather than reflector antennas, for example, permits the precise control of the antenna excitation, and by varying the phase of the element excitations permits electronic beam steering. Many different types of radiating elements are in use and the selection of element type
15 depends on antenna performance requirements such as polarization and bandwidth, as well as on physical constraints such as available space.

A known type of radiating element is the flared notch radiator that comprises first and second coplanar conductive elements electrically connected to a slotline and forming a notched opening that increases in size with distance along radiator axis from the slotline input.

20 Flared notch radiators are desirable in broadband arrays because the gradual transition of dimensions from the element feed point to the aperture tends to minimize reflections of waves between the feed point and the aperture.

The contours of known flared notch radiating elements comprise linear tapers, circular arcs, exponential curves, and stepped transformers. However, linear tapers, circular arcs and exponential curves require
25 greater lengths than the subject invention to provide an equivalent impedance match, and a stepped flared notch is a bandpass structure rather than a highpass structure. Moreover, the stepped structure is more difficult to manufacture.

The greater lengths of the linear tapers, circular arcs, and exponential curves for a given allowable peak reflection coefficient result in thicker arrays and are undesirable from the standpoint of array volume in
30 applications such as airborne radar systems where available space is at a premium.

SUMMARY OF THE INVENTION

35 It would therefore be an advantage to provide a flared notch radiating element that comprises a high pass device and requires less length to provide an equivalent impedance match

Another advantage would be to provide a flared notch radiating element that is easily fabricated.

The foregoing and other advantages are provided by the invention in an array radiating element which includes a first planar metallic conductor having a first contoured edge extending from a feed line, a second planar metallic conductor co-planar with the first planar metallic conductor and having a second contoured
40 edge adjacent the first contoured edge and extending from the feed line, wherein the contoured edges diverge from each other with distance from the feed line and are shaped to provide a high-pass Tchebyscheff-like reflection coefficient versus frequency characteristic.

BRIEF DESCRIPTION OF THE DRAWINGS

45 The advantages and features of the disclosed invention will readily be appreciated by persons skilled in the art from the following detailed description when read in conjunction with the drawing wherein:

FIG. 1 is a schematic elevational view of a flared notch radiator for use in an array in accordance with the invention.

50 FIG. 2 is a schematic perspective view of a portion of an array comprising a plurality of the flared notch radiators of FIG. 1.

FIG. 3 is an end view schematically depicting the array of identical lattice cells for each of the flared notch radiators of FIG. 3.

FIG. 4 schematically depicts an illustrative example of a radiator contour for the flared notch radiators in
55 an array in accordance with the invention.

FIG. 5 is a schematic perspective view of a portion of an array of interleaved, orthogonally oriented notched radiators of FIG. 1 that provides arbitrary polarization.

DETAILED DESCRIPTION OF THE DISCLOSURE

In the following detailed description and in the several figures of the drawing, like elements are identified with like reference numerals.

Referring now to Fig. 1, shown therein is a flared notch radiator 11 comprising a pair of planar metallic conductors 13, 13' having a contoured notch 15 formed therebetween. The contoured notch 15 includes contoured edges 15a, 15b that form a mirror image of each other and which diverge away from each other with a distance h along a centerline axis C from the connection of the radiator 11 to a feed slotline 17. For purposes of later analysis, the radiator 11 has a total length l, and position z along the centerline axis C is specified relative to a 0 reference point selected to be at the center of the length l of the radiator 11. The shape of the contoured edges 15a, 15b is defined by the distance h between the contoured edges 15a, 15b of the radiator 11.

By way of illustrative example, the flared notch radiator 11 can be etched on a dielectric substrate or machined from metal plate.

Referring now to FIG. 2, shown therein is an array of notched radiators 11 for use as an electronically steered array. In the array configuration, the slotline feeds and the flared sections form coupled transmission lines whose characteristic impedances and propagation constants are functions of the phase differences between them and, consequently, of the scan angle.

Referring now to FIG. 3, associated with the radiator elements in the array of FIG. 2 are respective identical lattice cells comprising rectangular areas symmetrically disposed about respective radiators. The lattice cell dimension (a) in the E-plane and the lattice cell dimension (b) in the H-plane are pertinent to calculating the aperture characteristic impedance which is utilized to determine the shape of the radiator edges 15a, 15b.

The flared radiators operating in an array may be regarded as an array of coupled non-uniform transmission line transformers that provide matching between the known characteristic impedance of the feed lines and the known characteristic impedance of a scanned plane wave at the aperture. To provide such matching, the edge flare or contour is selected so that the characteristic impedances of such non-uniform transmission lines vary with distance from the feed lines to transform the feed-line impedance to that of the dominant plane-wave mode impedance. In particular, the profile of characteristic impedance versus distance from element feed points is determined using the approach as set forth in "A Transmission Line Taper of Improved Design", Klopfenstein, PROC. IRE, January 1956, for the design of transmission line impedance transformers, so as to provide a high-pass, equal-ripple, Tchebyscheff-like reflection coefficient versus frequency characteristic. It is noted that the fact that the impedances of the flares vary with scan angle helps to maintain the input match as the array is steered, since the aperture impedance also varies with scan angle.

The contour of the edges of the radiators is determined as follows, relative to the coordinate system set forth in FIG. 1.

1. The peak acceptable input reflection coefficient $\rho_{\max}$ in the operating band is selected.
2. The DC limiting value of reflection ρ_0 is determined from the following:

$$\rho_0 = \frac{1}{2} \ln(Z_2/Z_1)$$

where Z_1 is the characteristic impedance of the input feed line and Z_2 is the characteristic impedance of the aperture. The aperture characteristic impedance for a broadside beam is

$$Z_2 = (b/a)\eta_0$$

where b is the array lattice dimension in the E-plane, a is the lattice dimension in the H-plane, and η_0 is the impedance of free space.

3. A parameter A which is a measure of location of operation on the Tchebyscheff-like reflection coefficient versus frequency characteristic defined in Klopfenstein is determined from:

$$A = \cosh^{-1}(\rho_0/\rho_{\max}) \equiv \ln[(\rho_0/\rho_{\max})^2 - 1]^{\frac{1}{2}} + \rho_0/\rho_{\max}$$

4. The required impedance variation along the contour is determined from the expression:

$$\ln[Z_0(z)] = \frac{1}{2} \ln(Z_1 Z_2) + (\rho_0 A^2 / \cosh A) [\phi(2z/l, A)]$$

where

$$\phi(y,A) \equiv \int_0^y [I_1[A(1-x^2)^{\frac{1}{2}}]/A(1-x^2)^{\frac{1}{2}}]dx$$

is the axial length of the flare, and $I_1(y)$ is the modified Bessel function of the first kind and of order 1.

5. From the results of step 4 and from the relationship between the cross-sectional dimensions of the coupled slotlines and their characteristic impedance, the contour of the radiator edges is calculated as a function of z/ℓ . This calculation requires an analysis of the electromagnetic characteristics of the array of coupled slotlines and is achieved by persons skilled in the particular art pursuant to standard analytical techniques. The resulting contour will not comprise a linear taper, circular arc, or exponential curve.

6. The minimum length, ℓ , is determined by the requirement that:

$$\beta_1 \ell = A$$

at the lowest frequency of operation, where β_1 is the phase constant of the input slotline. Therefore:

$$\ell = (A/2\pi)\lambda_{1\ell}$$

where $\lambda_{1\ell}$ is the wavelength in the input slotline at the lowest frequency of operation. It may be desirable to make ℓ somewhat larger than this value to allow for other considerations such as use of the array as an electronically steered antenna in which the effective wavelength in the array structure increases as the beam is steered away from broadside.

The foregoing procedure completes the determination of the contour of the radiator edges if β , the phase constant of the flare, is independent of z , which is the case for TEM transmission lines. However, for quasi-TEM lines β may vary along the flared notch. This variation occurs when the notches are etched on dielectric sheets with relative permittivities greater than unity. In this case the contour arrived at in step 5 must be modified to achieve the proper phase gradient along the notch. This modification is a non-uniform "stretching" that replaces the z values in the curve obtained in step 5 by a new set of z' values which are given by the following equation:

$$z' = \int_{-\ell/2}^z (\beta_1/\beta(y)) dy - (\ell/2)$$

in which the integration can be carried out numerically if necessary. This modification tacitly assumes that β_1/β is essentially independent of frequency over the band of interest.

FIG. 4 depicts the contour resulting from the application of the foregoing procedure to an array made from machined metal plates and having the following pertinent dimensions

a	= 0.313 inches
b	= 0.414 inches
plate thickness	= 0.150 inches
height of input slotline	= 0.032 inches

The variable along the vertical axis is the total height from bottom plate edge to top plate edge and the distance x represented on the horizontal axis is measured along the centerline axis C from the notch input:

$$x = z + (\ell/2)$$

FIG. 5 schematically depicts a portion of an array of interleaved, orthogonally oriented notched radiators of FIG. 1 that provides arbitrary polarization.

The foregoing has been a disclosure of a broadband, well matched radiating element that has the shortest optimum length for a given maximum mismatch over the band of interest, and can be used advantageously in electronically steered arrays that have a wide range of applications in radar and communications, for example. In other words, for a given peak reflection coefficient, the flared notch radiator as described above provides for the shortest length. It can be made in lightweight configurations for use in both active and passive airborne systems. The well matched characteristics of the radiating element can

also provide a low RCS (radar cross section) capability to the arrays in which it is utilized.

Although the foregoing has been a description and illustration of specific embodiments of the invention, various modifications and changes thereto can be made by persons skilled in the art without departing from the scope and spirit of the invention as defined by the following claims.

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Claims

1. A radiating element for use in an electronically steered antenna array, comprising a radiator (11) having:
 - a first planar metallic conductor (13) having a first contoured edge (15a) extending from a feed line (17); and
 - a second planar metallic conductor (13') co-planar with said first planar metallic conductor (13) and having a second contoured edge (15b) adjacent to said first contoured edge (15a) and extending from the feed line (17), said contoured edges (15a, 15b) diverging from each other with distance h from the feed line (17);
 characterized in that said contoured edges (15a, 15b) are shaped to provide a high-pass Tchebyscheff-like reflection coefficient versus frequency characteristic.
2. The radiating element of claim 1, characterized in that the axial length l of the radiator (11) as measured from the feed line (17) is the shortest possible for a selected peak reflection coefficient.
3. The radiating element of claim 1 or 2, characterized in that said first and second planar metallic conductors (13, 13') are formed on a dielectric substrate.
4. The radiating element of any of claims 1 - 3, characterized in that said first and second planar metallic conductors (13, 13') comprise machined metal plate.

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FIG. 1

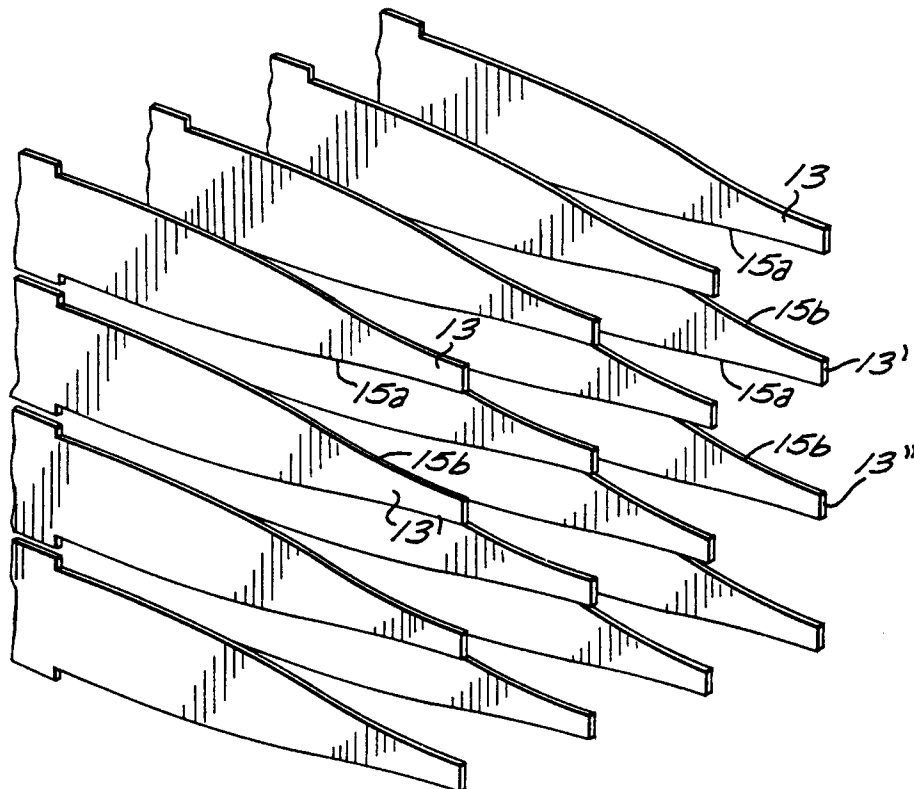
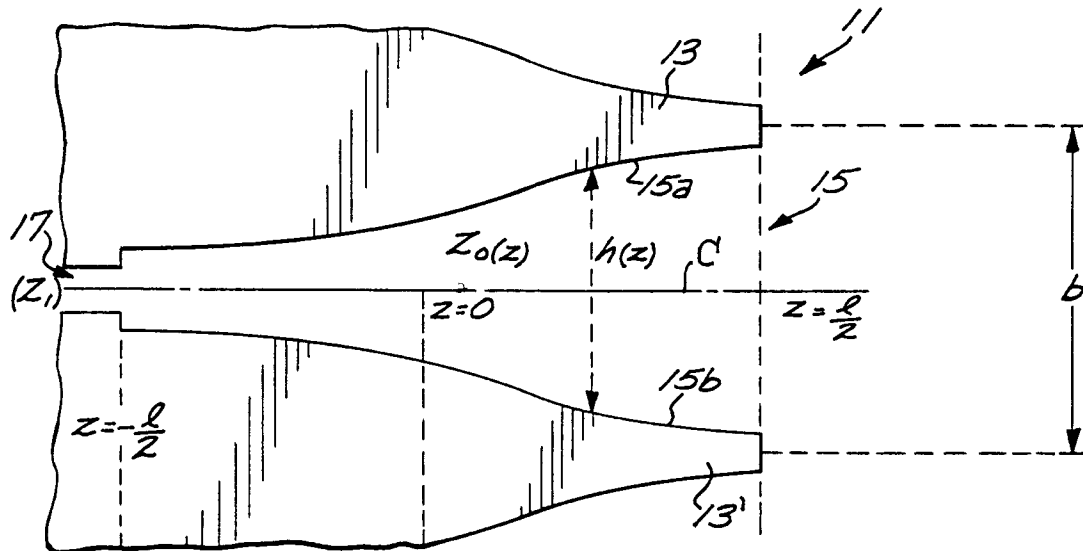


FIG. 2

FIG. 3

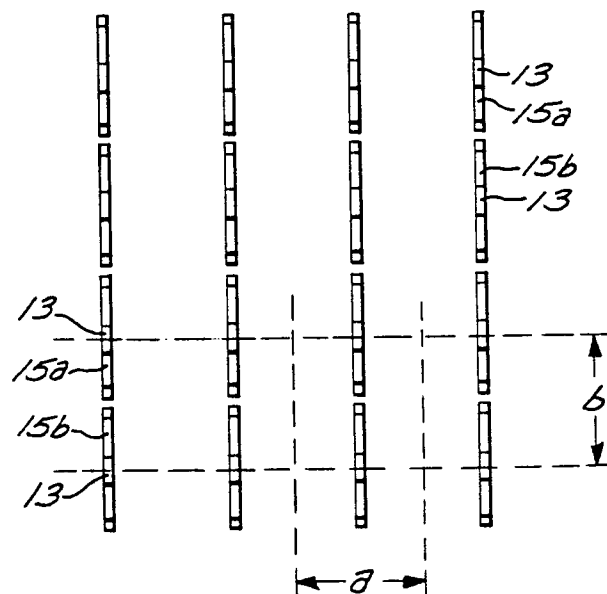


FIG. 5

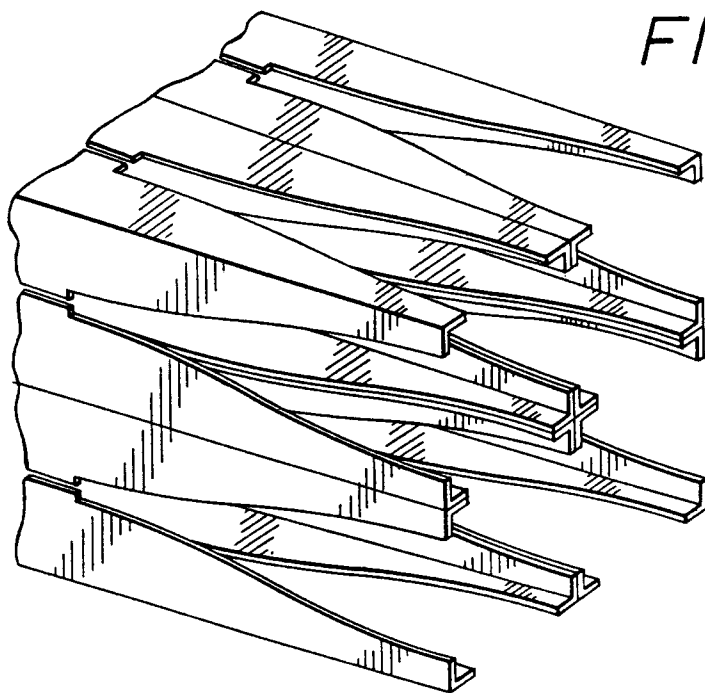
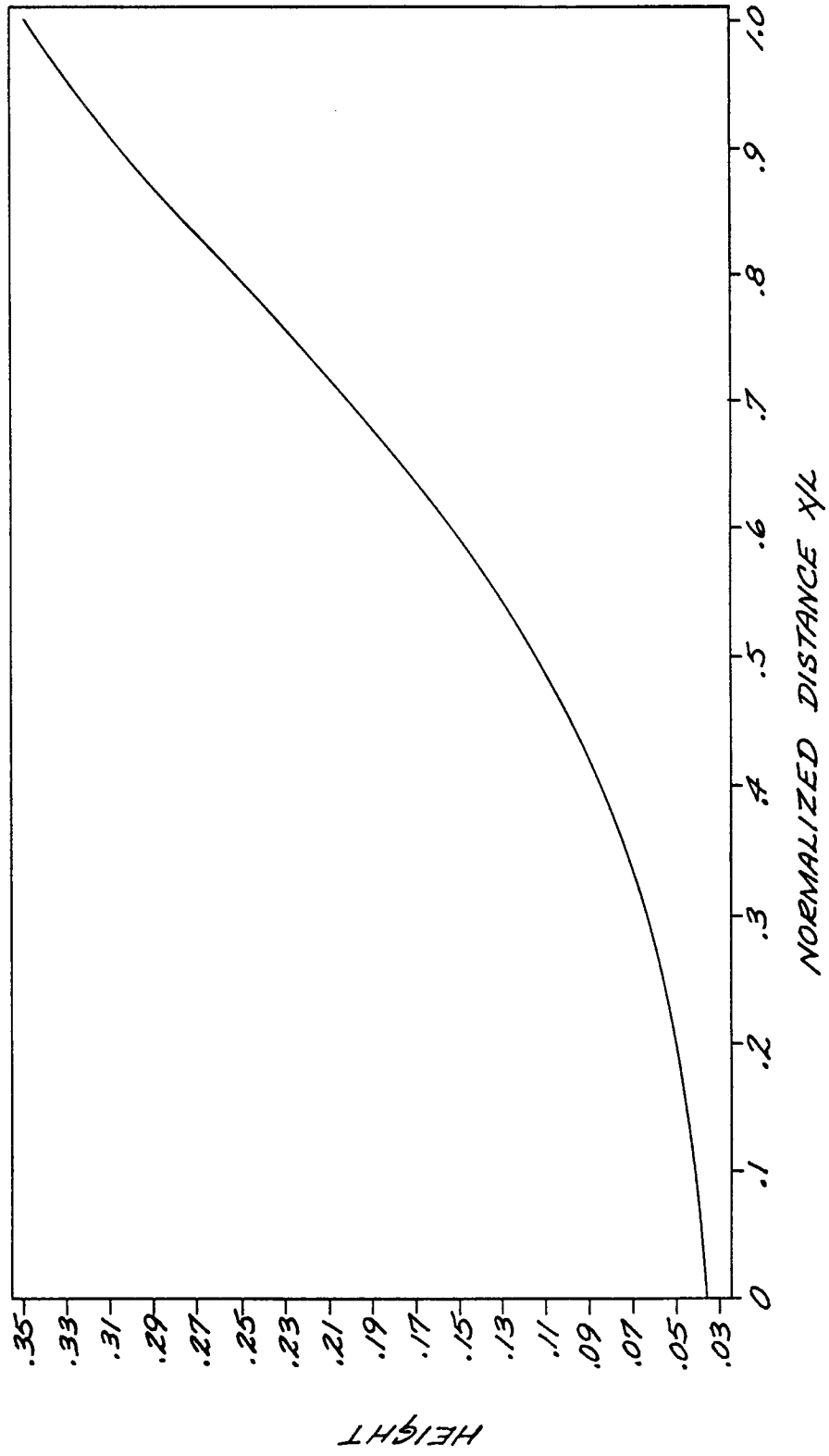


FIG. 4





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EUROPEAN SEARCH REPORT

Application Number

EP 92 10 5246

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	TOUTE L'ELECTRONIQUE, no. 520, January 1987, PARIS FR pages 56 - 62; HELIER ET AL.: 'ANTENNES PLANES' * the whole document *	1,3	H01Q13/08
Y	US-A-4 730 172 (BENGEULT) * abstract; figures 1,3 *	1,3	
A	IEE PROCEEDINGS H, MICROWAVES, ANTENNAS & PROPAGATION, vol. 130, no. 6, October 1983, STEVENAGE GB pages 403 - 409; EVANS ET AL.: 'TEM horn antenna: input reflection characteristics in transmission' * the whole document *	1	
A	US-A-4 905 013 (REINDEL) * claims 1-13; figure 4 *	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			H01Q
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 12 JUNE 1992	Examiner ANGRABEIT F. F. K.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	