United States Patent [19]

Carlise

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[54] **PHASE-SCANNED RADIATING ARRAY**

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[73] Assignee: **Rockwell International Corporation,** El Segundo, Calif.

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[21] Appl. No.: **405,992**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 250,945, May 8, 1972.

[52] **U.S. Cl.** **343/768,** 343/787, 343/854

[51] **Int. Cl.** **H01q 13/10**

[58] **Field of Search** 343/854, 768, 787

[56] **References Cited**

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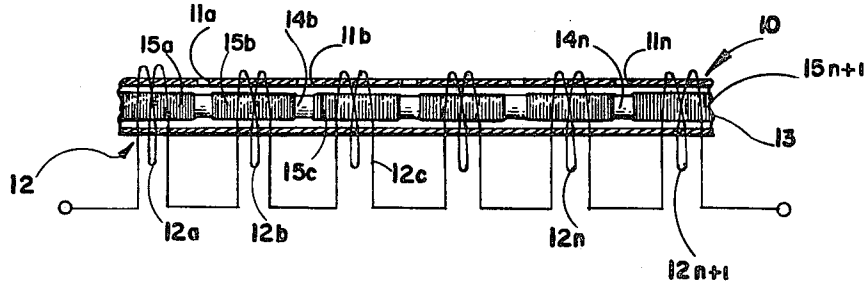
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[57] **ABSTRACT**

A phase-scanned radiating array employing an end-fed radiating waveguide having radiating apertures spaced along the length of one side of the waveguide. A series interconnected plurality of windings is wound about the waveguide and spaced intermediate successive ones of the radiating apertures. A longitudinal ferrite rod, inserted within the waveguide, has axially spaced interruptions in the ferrite material cross section thereof, the spacing corresponding to that of the radiating apertures of the waveguide.

3 Claims, 4 Drawing Figures



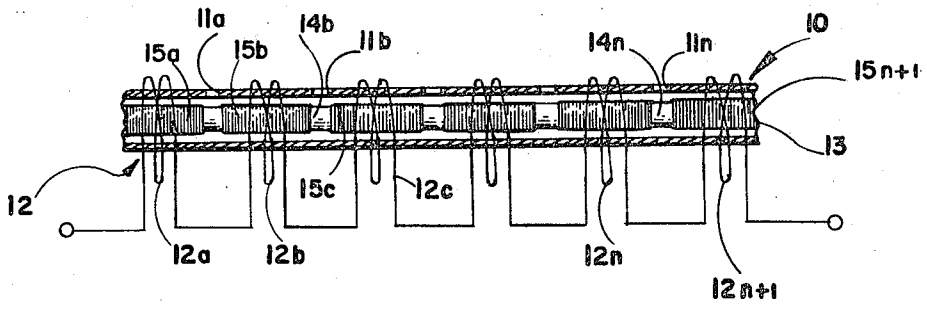

11a
14b
11b
14n
11n
10
15a
15b
15n+1
13
12
15c
12c
12a
12b
12n
12n+1

FIG. 1

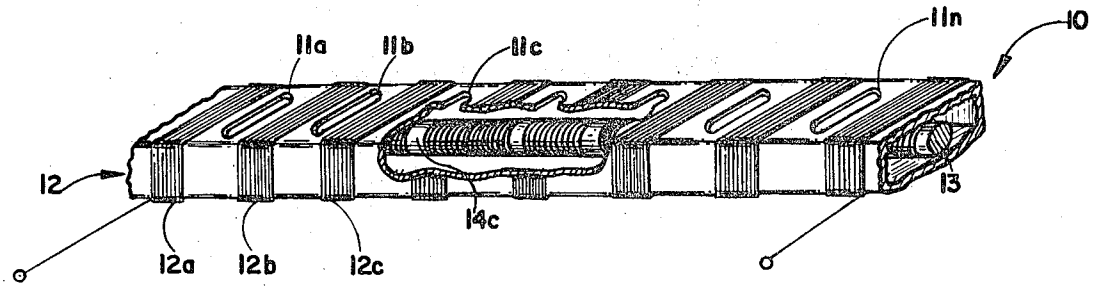

11n
10
11a
11b
11c
12
13
14c
12a
12b
12c

FIG. 2

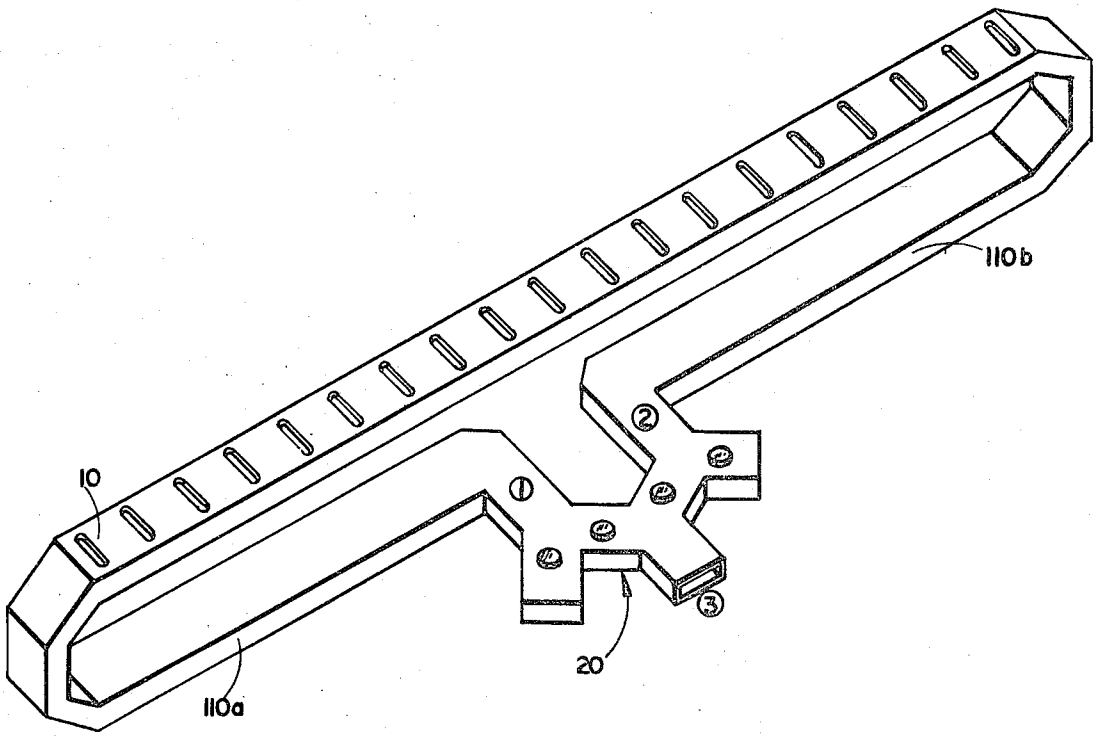


FIG. 3

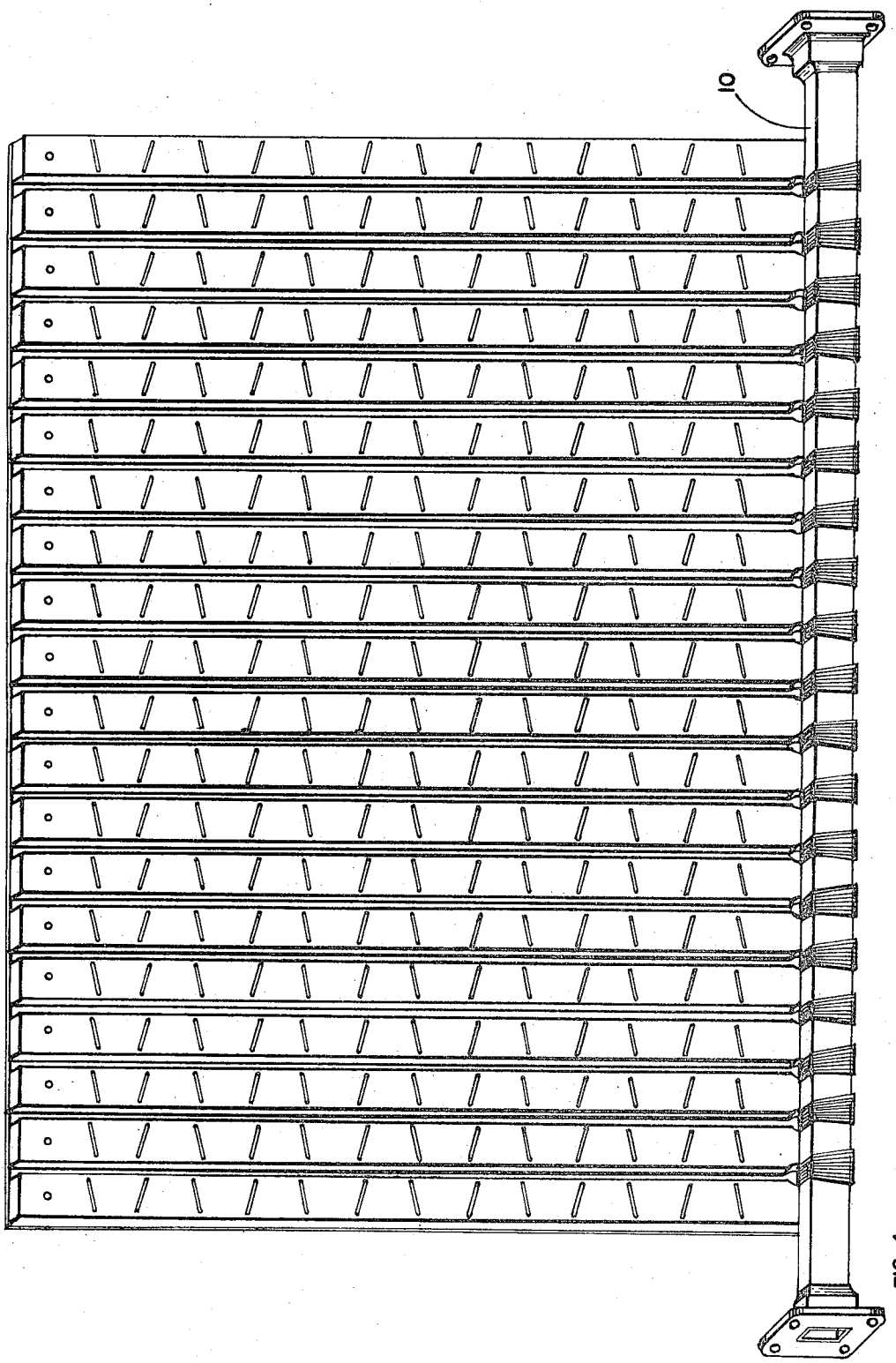


FIG. 4

PHASE-SCANNED RADIATING ARRAY

This application is a continuation-in-part of application Ser. No. 250,945 filed May 8, 1972 by Robert L. Carlise and entitled Phase-Scanned Radiating Array, now abandoned.

BACKGROUND OF THE INVENTION

The field of technology to which the subject invention relates is phase-scanned antenna arrays or radiating phase-shifters.

In the design of microwave phase-shifters, it has been known that a variation in magnetization of a ferrite rod inserted in a waveguide may be utilized to produce variations in the phase shift of microwave energy propagated through such waveguide. Such magnetization change may be produced by means of varying the excitation of a winding wound about the waveguide section. Such described assembly, while functioning as a microwave phase shifter (and known in the art as a Reggia-Spencer phase shifter), does not readily lend itself to functioning as a phase-scanned radiating array. In other words, where a longitudinal array of slots are placed in the waveguide, in an attempt to form a phased array antenna or phase-controlled radiating feedline, it is found that such structure is of limited efficiency, being useful over only a very narrow or restricted phase range. As increased phase-scanning is sought by increasing the magnetization of the ferrite rod, consequent approaching saturation of the rod reduces coupling to and radiation from the array of slots.

BRIEF DESCRIPTION OF THE INVENTION

By means of the concept of the subject invention, the above-noted adverse coupling effects are avoided, and an electronically-scanned radiating feedline is obtained which is of increased utility over a wider scan angle range without suffering the degree of attenuation associated with the prior art.

In a preferred embodiment of the invention, there is provided a modified Reggia-Spencer microwave delay line, comprising a rectangular waveguide section containing a ferrite rod structure and having a winding axially wound about the waveguide section. A longitudinal array of mutually spaced apertures or radiating slots is included in one face of the waveguide section, the windings being arranged between successive slots to avoid blockage thereof. Further modification of the Reggia-Spencer delay line includes axially spaced interruptions of a combined magnetic and dielectric nature in the ferrite material cross section of the ferrite rod, the spacing corresponding to that of the apertures of the waveguide.

By means of such arrangement of axially spaced interruptions, a saturated ferrite section is avoided in the vicinity of the radiating apertures, whereby improved energy coupling is obtained, particularly under condition of large scan angles or increased phase shift (as produced by increased ferrite magnetization). Accordingly, an object of the invention is to provide an improved phase-scanned array.

Another object of the invention is to provide a phase-scanned radiating feedline of reduced attenuation over a wider phase-shift range.

A further object is to provide a minimum bulk phase-scanned feedline having improved coupling performance.

These and other objects of the invention will become apparent from the following description, when taken together with the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic arrangement, in partial vertical central section, of a device embodying the concept of the invention;

FIG. **2** is a view in perspective, partially torn away, of the device of FIG. **1**;

FIG. **3** is a view in perspective showing an alternate (switchable) end-fed, phase-scanned line source, in which the concept of the invention may be advantageously employed; and

FIG. **4** is an antenna array for providing a uniplanarly electronically scanned pencil beam, employing the device of FIGS. **1** and **2.**

In the figures, like reference characters refer to like parts.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is illustrated a schematic arrangement, in partial vertical central section, of a device embodying the concept of the invention. There is provided a rectangular waveguide section **10** having a longitudinal array of spaced slots or radiating apertures **11***a*–**11***n* in an H wall thereof (more clearly seen in FIG. **2**). Although such slots are shown to be regularly spaced, such spacing may be selected to be otherwise for the purpose of effecting a desired beam shape, as is understood by those skilled in the art. Axially wound about waveguide **10** is a winding **12**, so arranged as to avoid blocking apertures **11***a*–**11***n*. In other words, there is provided a series-interconnected plurality of component windings **12***a*–**12***n* each axially spaced intermediate successive ones of the radiating apertures **11***a*–**11***n*. An additional winding (not shown) may be included on each end of the waveguide to minimize the "end-effect" associated with long solenoids and to ensure a uniform magnetic field in the terminal axial sections of the ferrite rod relative to the central axial sections thereof.

A longitudinal structure or rod **13** is inserted within the waveguide section **10**, the rod **13** being comprised of a ferrite material and having regularly spaced interruptions **14***a*–**14***n* in the ferrite material cross-section, the spacing of the interruptions corresponding to that of the apertures. Such interruptions in such ferrite cross-sectional area may comprise air gaps or be filled with a solid dielectric material, the dielectric constant of such air gap or other dielectric material being substantially different than that of the ferrite material, whereby both a magnetic and dielectric perturbation are commonly provided by such spatial interruptions. As illustrated in FIG. **1**, such interruptions may be abrupt and total, and employ dielectric spacers **14***a*–**14***n* intermediate the ferrite axial sections **15***a*–**15***n*+1, the like axial dimension of each such dielectric spacer being preferably 0.03–0.04 free space wavelength. In manufacture, the mutually axially spaced axial ferrite sections or slugs may be potted or encapsulated in a dielectric compound which is cast so as to fit in and be conveniently positionable in the waveguide section, whereby the ferrite slugs **15***a*–**15***n*+1 are adequately supported. Alternatively, the ferrite slugs and dielectric spaces may be taped or

wrapped as an integral rod assembly, and the rod assembly potted in such dielectric compound. Although the rod assembly, as illustrated, has been shown as circular in cross section, obviously other cross section shapes may be used, such as rectangular for instance.

The spacing regularity of the series H wall slots **11***a*–**11***n* may be selected relative to an integer number of waveguide wavelengths ($n\lambda g$) to provide a back scan angle $-\beta$ (for the antenna beam), while a maximum magnetization state of the ferrite slugs corresponds to a broadside beam direction for an antenna beam formed by the combined radiation from the slots in response to end-fed RF excitation of waveguide **10.**

In normal operation of the above-described arrangement, the magnetic field within the ferrite slugs tends to be proportional to the current through solenoid winding **12.** Now, the velocity of propagation of the end-fed RF excitation introduced into the loaded waveguide is proportional to the magnetic field in the ferrite material and, therefore, tend to be proportional to the solenoid current in winding **12.** As is well understood in the art of electronically scanning antennas, the angle (relative to the radiating feed line **10**) at which a beam pattern is radiated from slotted line **10** is a function of the slot spacing and the RF propagation velocity within the waveguide. By merely changing the solenoid current (through winding **12**), the propagation velocity and, hence, the associated beam angle may be correspondingly changed.

For the backscanned mode described above, the initial back-scan angle, $-\beta_o$, is reduced by increasing the applied excitation of solenoid **12** from zero, a maximum excitation producing a broadside angle (direction normal or perpendicular to the axial extent of radiating feedline **10**). By then reducing the solenoid excitation to zero and applying the RF excitation to the opposite end of feed **10** (by means of a double-throw RF switch such as that described in my copending application Serial No. **244,815** forwarded Apr. 14, 1972 now U.S. Pat No. 3,768,041, the antenna may be made to "look" at an opposite angle, $+\beta_o$ (displaced from the initial angle, $-\beta_o$, by the amount 2β); then by again increasing the solenoid excitation, the look angle is back-scanned or reduced to broadside (or zero). Thus, by such two oppositely end-fed scanning intervals, a full scanning cycle is completed by which the antenna is scanned over the range $\mp\beta_o$. Such alternate (switchable) end-fed arrangement is shown more particularly in FIG. **3** by means of a four pin diode, double-throw RF switch **20** having switched ports①and②coupled to respective ends of radiating waveguide **10** by guide sections **110***a* and **110***b*, and further having a common port③(which may be selectively coupled to an alternate one of ports ①and②, as explained more fully in my above noted copending application Ser. NO. 244,815 now U.S. Pat. No. 3,768,041.

Although the coupling between the radiating slots and the magnetizable ferrite rod assembly has been described as periodic magnetic and dielectric structured interruptions corresponding to the spatial periodicity of the radiating slots and comprising removals of or reductions in the ferrite crosssectional area, the concept or the invention is not so limited, and such coupling may be comprised of metallic probes radially extending from the rod assembly toward the slots and insulated from both the waveguide wall **10** and the ferrite rod.

The device of FIGS. **1** and **2,** having a large system aperture dimension in the scanning plane or longitudinal direction of the single line array and having a narrow system aperture direction normal to the scanning plane, provides a (horizontally) scanning fan beam (wide vertical beam width and narrow horizontal beam width). A uniplanarly scanning pencil beam may be obtained by employing a system of coplanar stacked or mutually parallel radiating feeds **15***a*–**15***n* each end-fed from a corresponding slot of the radiating phase-shifter line source **10** of FIGS. **1** and **2,** as shown more particularly in FIG. **4.** By means of such arrangement, the plane of the ultimate radiating slots of the antenna is at 90° to the plane of the slots of the phase shifter, the scanning direction or plane being substantially parallel, however, to the longitudinal direction of the phase shifter line source **10.** Because of the large aperture dimension in each direction of the array, a pencil beam slope results, as is understood in the art. Obviously, the alternate end-fed switching arrangement of FIG. **3** may be employed with line **10** of FIG. **4.**

Accordingly, there has been described an improved electronically scanned array comprising an end-fed slotted waveguide and modified Reggia-Spencer type phase shifter, which is of minimum bulk, low-cost and high performance.

Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. A phased-scanned radiating array comprising in combination

an end-fed radiating rectangular waveguide having radiating apertures spaced along the length of a side thereof,

a series interconnected plurality of windings wound about said waveguide and axially spaced intermediate successive areas of said radiating apertures, and

a longitudinal ferrite rod inserted within said waveguide, said rod having regularly spaced magnetic and dielectric interruptions in the ferrite material cross-section thereof, the spacing of said interruptions corresponding to that of said apertures,

said interruptions in said ferrite material cross-section being filled with a dielectric material having a dielectric constant substantially different from that of said ferrite.

2. A phased-scanned radiating array comprising in combination

an end-fed radiating rectangular waveguide having radiating apertures spaced along the length of a side thereof,

a series interconnected plurality of windings wound about said waveguide and axially spaced intermediate successive areas of said radiating apertures, and

a longitudinal ferrite rod inserted within said waveguide, said rod having regularly spaced magnetic and dielectric interruptions in the ferrite material cross-section thereof, the spacing of said interruptions corresponding to that of said apertures,

said rod being comprised of successive axial sections alternately of ferrite and of a dielectric material,

the dielectric material being preselectively axially phase spaced relative to said regularly spaced apertures and having a dielectric constant substantially different from that of said ferrite.

3. A phase-scanned radiating array comprising in combination

an end-fed radiating rectangular waveguide having radiating apertures spaced along the length of a side thereof,

a series interconnected plurality of windings wound about said waveguide and acially spaced intermediate successive areas of said radiating apertures,

a longitudinal ferrite rod inserted within said waveguide and parallel to said side, said rod having regularly axially spaced interruptions of a combined magnetic and dielectric nature in the ferrite material cross-section thereof, the spacing of said interruptions corresponding to that of said apertures,

said rod being comprised of successive axial sections alternately of ferrite and of a dielectric material, the dielectric material axial sections being between 0.03-0.04 free space wavelength in length.

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