

[54] **IMPEDANCE MATCHED WAVEGUIDE DEVICE**
[75] Inventor: **Jerome D. Hanfling**, Framingham, Mass.
[73] Assignee: **Raytheon Company**, Lexington, Mass.
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[51] Int. Cl. **H03h 7/38, H01p 1/16**
[58] Field of Search **333/33, 73 W, 24.1, 98 P**

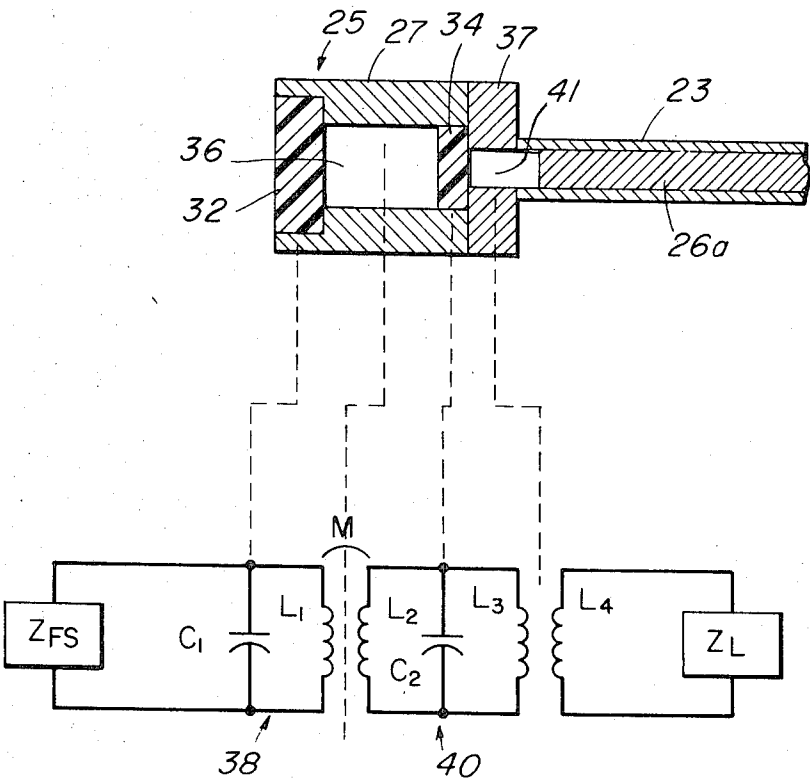
[56] **References Cited**

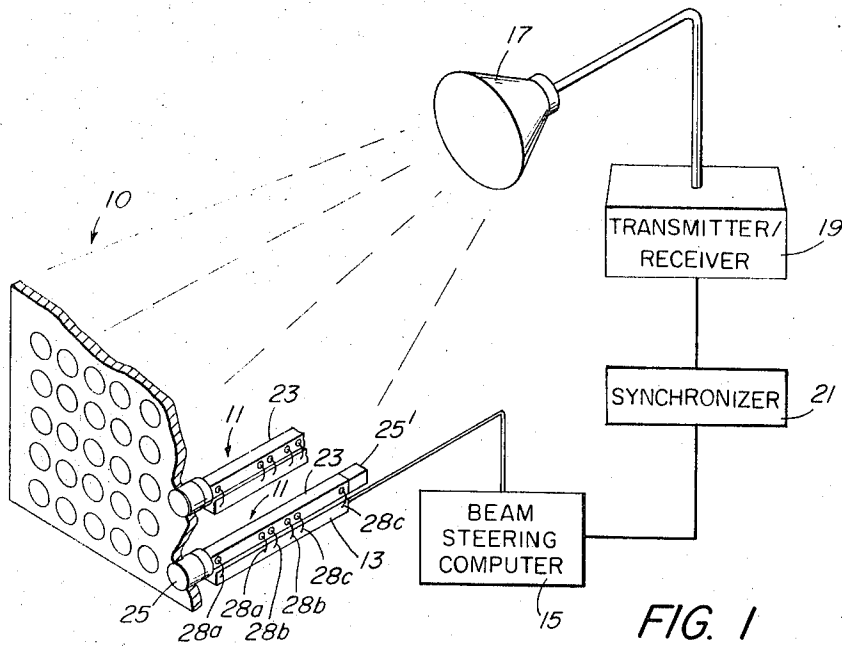
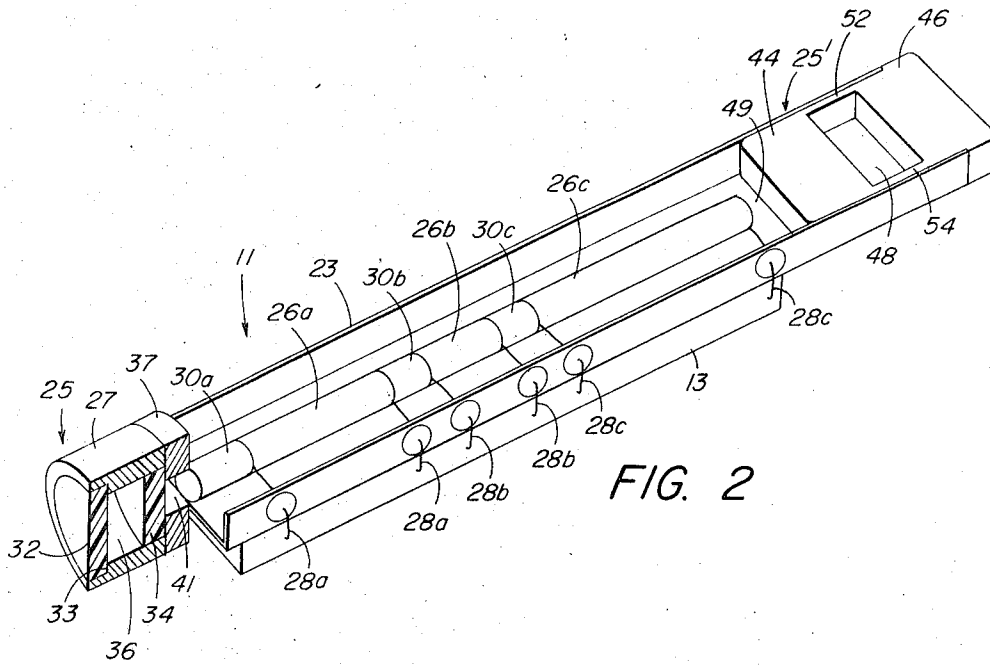
UNITED STATES PATENTS			
2,623,120	12/1952	Zobel.....	333/33
2,930,008	3/1960	Walsh.....	333/33 X
3,603,899	9/1971	Gyorgy et al.....	333/33 X
3,621,483	11/1971	Craven.....	333/81 B X
3,680,012	7/1972	Moreau.....	333/73 W

Primary Examiner—Paul L. Gensler
Attorney, Agent, or Firm—Richard M. Sharkansky;
Joseph D. Pannone; Philip J. McFarland

[57] **ABSTRACT**
A waveguide device is disclosed for matching, over a wide band of frequencies, the impedance of free space to the impedance of ferrite phase shifters disposed within the antenna element of a phased array antenna and for preventing higher order modes from propagating through such device. The device is comprised of a series of resonant circuits, including a waveguide structure, a first one of such circuits including the impedance of free space and a last one thereof including the impedance of the ferrite phase shifter, adjacent ones of such resonant circuits being inductively coupled. The resonant circuits are tuned to a nominal operating frequency of the antenna, thereby inductively coupling the energy in a band of frequencies about such operating frequency through the device. The waveguide structure is dimensioned so that its cutoff frequency for the dominant mode is higher than the highest frequency in the band of frequencies, thereby preventing the higher order modes from passing through the device.

3 Claims, 4 Drawing Figures





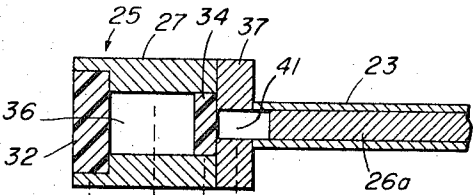


FIG. 3A

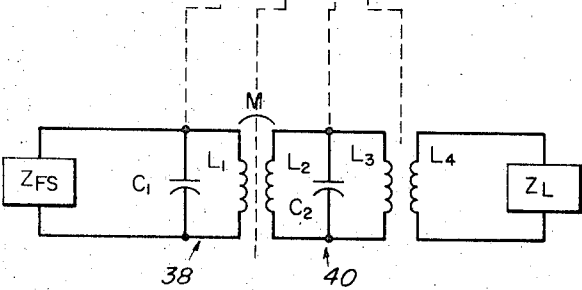


FIG. 3B

IMPEDANCE MATCHED WAVEGUIDE DEVICE

The invention herein described was made in the course of or under a contract or subcontract thereunder, with the Department of Defense.

BACKGROUND OF THE INVENTION

This invention relates generally to waveguide devices and more particularly to phased array antenna elements wherein such devices are used to match the impedance of free space to the impedance of a ferrite phase shifter disposed within such antenna element.

As is known in the art, a collimated beam of radio frequency energy may be formed and steered by controlling the phase of the energy radiated from each one of a plurality of antenna elements in an array thereof. In such antenna it is necessary to efficiently match, over a wide band of frequencies, the impedance of free space to the impedance of the ferrite phase shifter disposed within each antenna element. One technique used to provide such impedance matching has been to dispose a stepped quarter-wave matching transformer within the waveguide feeding each antenna element. The use of such quarter-wave matching transformer, while adequate in many applications, has been found to be inadequate when it is required that the antenna be physically compact, yet operate over a relatively wide frequency band. This is so because although the bandwidth of the antenna increases in accordance with the number of steps in the quarter-wave matching transformer, the length of the antenna element also increases. Such technique is, therefore, impractical in applications wherein the size of the antenna is critical, as when the antenna is to be used in a missile.

As is also known in the art, mutual coupling may exist between adjacent antenna elements in a phased array because radio frequency energy emitted by one antenna element may couple into adjacent antenna elements. The coupled energy is not normally in phase with the energy emitted by the adjacent antenna elements. Consequently, higher order modes are generated within the adjacent antenna elements. These generated higher order modes may be reflected within the adjacent antenna elements to thereby radiate into free space. The reradiation of such higher order modes of energy severely degrades the beam pattern and scanning performance.

One technique used to increase the useful bandwidth of an antenna has been to use a circular waveguide antenna element with a cutoff frequency lower than the frequency of the dominant mode of the energy passing therethrough. A series of dielectric discs within such a waveguide are disposed to increase the separation between the dominant mode cutoff frequency and the cutoff frequency of the higher order modes. While such technique has been found to increase the useful bandwidth of the antenna, no impedance matching between free space and the phase shifter is thereby provided to improve the radiating efficiency of the antenna over a broad band of frequencies.

SUMMARY OF THE INVENTION

With this background of the invention in mind, it is an object of this invention to provide an improved waveguide impedance matching device for coupling, over a wide band of frequencies, radio frequency en-

ergy introduced into such device to a load terminating such device.

It is another object of the invention to provide an improved phased array antenna having impedance matching, over a wide band of frequencies, between free space and a ferrite phase shifter disposed within each antenna element thereof and higher order mode suppression.

These and other objects of the invention are attained generally by providing a device comprising a series of adjacent resonant circuits including a waveguide structure, a first one of such circuits including the impedance of free space and the last one of such circuits including the impedance of a load, adjacent ones of such resonant circuits being inductively coupled. In a preferred embodiment of the invention, the waveguide structure is so dimensioned that its cutoff frequency for the dominant mode of radio frequency energy to be propagated therethrough is higher than the frequency of the radio frequency energy actually applied.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing features of this invention, as well as the invention itself, may be more fully understood from the following detailed description read together with the accompanying drawing in which:

FIG. 1 is a simplified sketch of a radar system using an array of antenna elements, each one thereof being connected to a ferrite phase shifter element, to radiate a collimated beam of radio frequency energy and to receive echo signals from targets illuminated by such radiated energy;

FIG. 2 is a cross-section of the impedance matching device of an antenna element of the type shown in FIG. 1 with the cover thereof removed; and

FIGS. 3A and 3B are diagrams useful in the understanding of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, it may be seen that phased array antenna 10, according to this invention, includes a number of fixed antenna elements 11, each such element having associated therewith driver circuitry 13. The antenna elements 11 and associated driver circuitry 13 may be mounted in any conventional manner (not shown in detail) to form a space-fed planar array antenna. Appropriate connections are made, as indicated, between each current circuitry 13 and the ferrite phase shifters included within antenna element 11 (shown in FIG. 2) to control such antenna element 11 in accordance with digital control signals supplied by beam steering computer 15. As is known, such an arrangement permits radio frequency energy from a feed horn 17 to be collimated in a beam and directed as desired and echo signals returning to the individual antenna elements 11 of the antenna array 10 to be focused on the feed horn 17. The feed horn 17 is connected in any convenient manner, as by waveguide (not numbered) to a transmitter/receiver 19. The operation of the transmitter/receiver 19 and the beam steering computer 15 is controlled by a conventional synchronizer 21.

Referring also to FIG. 2, an exemplary one of the antenna elements 11 includes a section of rectangular waveguide 23 with the ends (not numbered) thereof matched to free space by impedance matching devices

25, 25', the details of which will be described later. In the particular embodiment illustrated the exemplary antenna element 11 has disposed within the rectangular waveguide 23 three serially arranged ferrimagnetic toroids 26a, 26b, 26c (FIG. 2) (sometimes referred to as "ferrite phase shifters 26a-c") to operate in response to a three bit control signal supplied by beam steering computer 15. Obviously, however, the number of toroids (or phase shifters) may be changed without departing from any inventive concepts. A different bit of a three bit control signal is applied to a different one of three identical current drivers, collectively referred to herein as current driver 13. A different one of the current drivers is coupled to a different one of the ferrimagnetic toroids 26a to c via current drive cables 28a to c. The toroids 26a to 26c are separated from each other and from impedance matching element 25 in a conventional manner by insulating spacers 30a to c, as shown. Here such spacers 30a-c are magnesium titanite dielectric spacers. A conventional support structure, not shown, fastens toroid 26c within waveguide 23.

Impedance matching devices 25, 25' are used to efficiently match, over a wide band of frequencies, the impedance of free space to the impedance of the ferrite phase shifters 26a-c disposed within rectangular waveguide 23. Impedance matching device 25 here includes a circular waveguide structure 27 having disposed therein two dielectric slabs 32, 34, here discs made of Beryllia. The dielectric slabs 32, 34 are spaced from each other and from the ferrimagnetic toroid. Dielectric slab 32 is fastened on a shoulder 33 within circular waveguide 27 by a suitable epoxy, not shown. The impedance matching device 25 is coupled to the rectangular waveguide 23 by coupling device 37. Coupling device 37 is of conducting material and is circular in shape, having a rectangular slot, 41, formed therein to provide coupling between the rectangular and circular waveguides. The coupling device 37 is welded to waveguides 27 and 23. The coupling device 37, together with epoxy, not shown, is used to hold slab 34 within circular waveguide 27. The slot within such coupling device 37 also provides an air space between slab 34 and spacer 30a. An air-filled cavity 36 is formed between the dielectric slabs 32, 34. Further, the circular waveguide structure 27 has a cutoff frequency higher than the highest frequency in a desired band of frequencies about the frequency of the dominant mode of the radio frequency energy to be passed through the antenna element, that is, higher than the highest frequency in a desired band of frequencies about the nominal operating frequency of the antenna 10 (FIG. 1).

The mechanism of impedance matching device 25 may be described with the aid of FIGS. 3A, 3B. Impedance matching device 25 may be viewed as a series of resonant circuits 38 to 40, a first one thereof, 38, being coupled to free space and a last one thereof, 40, being coupled to the ferrite phase shifters 26a-c. Further, the ferrite phase shifters 26a-c may be viewed as being a load for the impedance matching device 25. The impedance of such load is represented in FIG. 3B by the term Z_L . Likewise, the impedance of free space is represented in FIG. 3B by Z_{FS} . Dielectric slabs 32 and 34 may be viewed as providing a dielectric medium within the circular waveguide structure 27 which is different from the dielectric medium provided by the air-filled cavity 36. Therefore, the impedance of the dielectric medium associated with dielectric slabs 32, 34 may be

represented by a capacitor, C_1 , for the desired band of frequencies. Because the circular waveguide has a cut-off frequency higher than the highest frequency in the band of frequencies, the impedance of the dielectric medium associated with the portion of the cavity 36 adjacent slab 32 may be represented as an inductor, L_1 , for such band of frequencies. It follows, then, that the impedance of dielectric slab 34 may also be represented by capacitor C_2 and the portion of the circular waveguide structure 27 defining air-filled cavity 36 adjacent slab 34 may also be represented by an inductor L_2 . Further, the separation between dielectric slabs 32 and 34 is here such that the resonant circuits 38, 40 are inductively coupled, the coefficient of mutual inductance being represented by M. Ferrite phase shifter 26a is coupled to impedance matching device 25 by inductive coupling within air-filled slot 41, as shown in FIG. 3A. This slot 41 is a section of rectangular waveguide having a cutoff frequency higher than the highest frequency of the band of frequencies and, therefore, is represented in FIG. 3B as a pair of mutually coupled inductors, L_3 and L_4 .

By selecting proper dimensions for dielectric slabs 32 and 34, the spacing therebetween, and the size of the circular waveguide structure 27, the resonant circuits 38 and 40 may each be tuned to the nominal operating frequency of the antenna, thereby coupling, by mutual coupling between the resonant circuits 38, 40, the energy at such frequency through the impedance matching device 25. (Because of the mutual inductive coupling between the resonant circuits 38 and 40, matching device 25 may be considered as a double-tuned circuit.) Further, the Q of resonant circuits 38 and 40 determines the band of frequencies about the nominal frequency which will readily inductively couple through the impedance matching device. The Q is selected so that the frequencies associated with the higher order modes will not be within the band of frequencies and hence will not readily couple through the device by the mechanism of inductive coupling. Such higher order frequency modes will also be prevented from passing through the impedance matching device 25 because the circular waveguide structure 27 and rectangular waveguide structure 37 in such matching device 25 have cutoff frequencies higher than the highest frequency of the band of frequencies about the nominal operating frequency of the antenna.

Matching device 25' operates in an equivalent manner to matching device 25. Matching device 25' here is coupled to rectangular waveguide structure 23. Such rectangular waveguide structure 23 has associated therein, as shown, a pair of dielectric slabs 44, 46, here rectangular in shape. Such slabs 44, 46 are separated from each other by an air-filled cavity 48. Dielectric slab 44 is separated from toroid 26c by an air-filled cavity 49. The dielectric slabs 44, 46 are separated from each other by means of integrally formed spacer sections 52, 54. The spacer sections 52, 54 and the slabs 44, 46 are a dielectric material, here Rexolite. The rectangular waveguide defining such cavity 48 (including spacer sections 52, 54) has a cutoff frequency higher than the highest frequency within the band of frequencies passing through the structure. Therefore, a first resonant circuit, coupled to free space, includes dielectric slab 46 (which provides the required capacitance) together with both cavity 48 and spacer sections 52, 54 (which provide the required inductance). The

last resonant circuit, coupled to ferrite phase shifters 26a-c (via a cavity 49) includes dielectric slab 44 (which provides the required capacitance) together with both cavity 48 and spacer sections 52, 54 (which provide the required inductance).

The thickness of the dielectric slabs 32 and 34 (or likewise the dielectric slabs 44, 46) may be determined in the following manner. A planar wave of radio frequency energy is made incident to the face of the antenna element 11. The VSWR is measured for each one of a series of different dielectric slabs 32, each one having a different thickness. The slab having the optimum thickness is that which produces a VSWR measurement indicating that a resonance occurs. A similar procedure is used for determining the optimum thickness of slab 34; however, the energy is introduced into the antenna element through the ferrite phase shifter end thereof. The spacing between the two dielectric slabs 32 and 34 (or dielectric slabs 42, 46) and therefore the amount of inductive coupling, M, between the two resonant circuits 38, 40 is also determined by VSWR measurement. It is noted that such measurements are made over the band of frequencies about the nominal operating frequency and also over a variety of scan angles to determine the optimum spacing. It is also noted that the Q of circuit 40 may be adjusted by the spacing between the ferrite phase shifters and dielectric slab 34.

Having described a preferred embodiment of this invention, it is now evident that other embodiments incorporating its concepts may be used. For example, while two dielectric slabs have been shown to be included in each matching device, wider bandwidth requirements may be satisfied by using additional dielectric slabs and cavities and by modifying accordingly either the operating frequency of the antenna (and hence tuned frequency of the resonant circuits) or the cutoff frequency of the waveguide, or both, thereby providing a multi-tuned circuit. Such wider bandwidth improves the scanning capability of the antenna. It is felt, therefore, that the invention should not be limited in scope

to the particular embodiment here shown, but rather by the spirit and scope of the appended claims.

What is claimed is:

1. In a system for transmission of radio frequency energy within a band of frequencies from a source of such energy to a load, the impedance of the source being different from the impedance of the load, apparatus for matching the impedance of such source and such load and for preventing modes higher than the dominant mode of such energy from passing between such source and such load, such apparatus comprising:
 - a. a section of waveguide dimensioned so that its cut-off frequency is higher than the highest frequency of any radio frequency energy passing through such apparatus; and
 - b. a pair of dielectric mediums partially separated by such section of waveguide to form a pair of inductively coupled resonant circuits:
 - i. a first one of such circuits including the source, one of the dielectric mediums, and a portion of such waveguide; and
 - ii. a second one of such circuits including the load, a separate one of the dielectric mediums and a portion of such waveguide, the center frequency of each one of such resonant circuits corresponding to the frequency of the dominant mode and the bandwidth of said resonant circuits corresponding to the band of frequencies of radio frequency energy to be passed between such source and such load; and,
 - iii. wherein the dielectric medium in the first one of such circuits provides a different propagation time delay to the passed radio frequency energy from the propagation time delay provided to such passed energy by the dielectric medium in the second one of such circuits.
2. The apparatus recited in claim 1 wherein the dielectric mediums are solid dielectric materials.
3. The apparatus recited in claim 2 wherein the solid dielectric materials have different thicknesses.

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