

April 20, 1965

F. R. ABBOTT

3,179,937

TWO-DIMENSIONAL ELECTROMAGNETIC DELAY LINE

Filed June 21, 1960

2 Sheets-Sheet 1

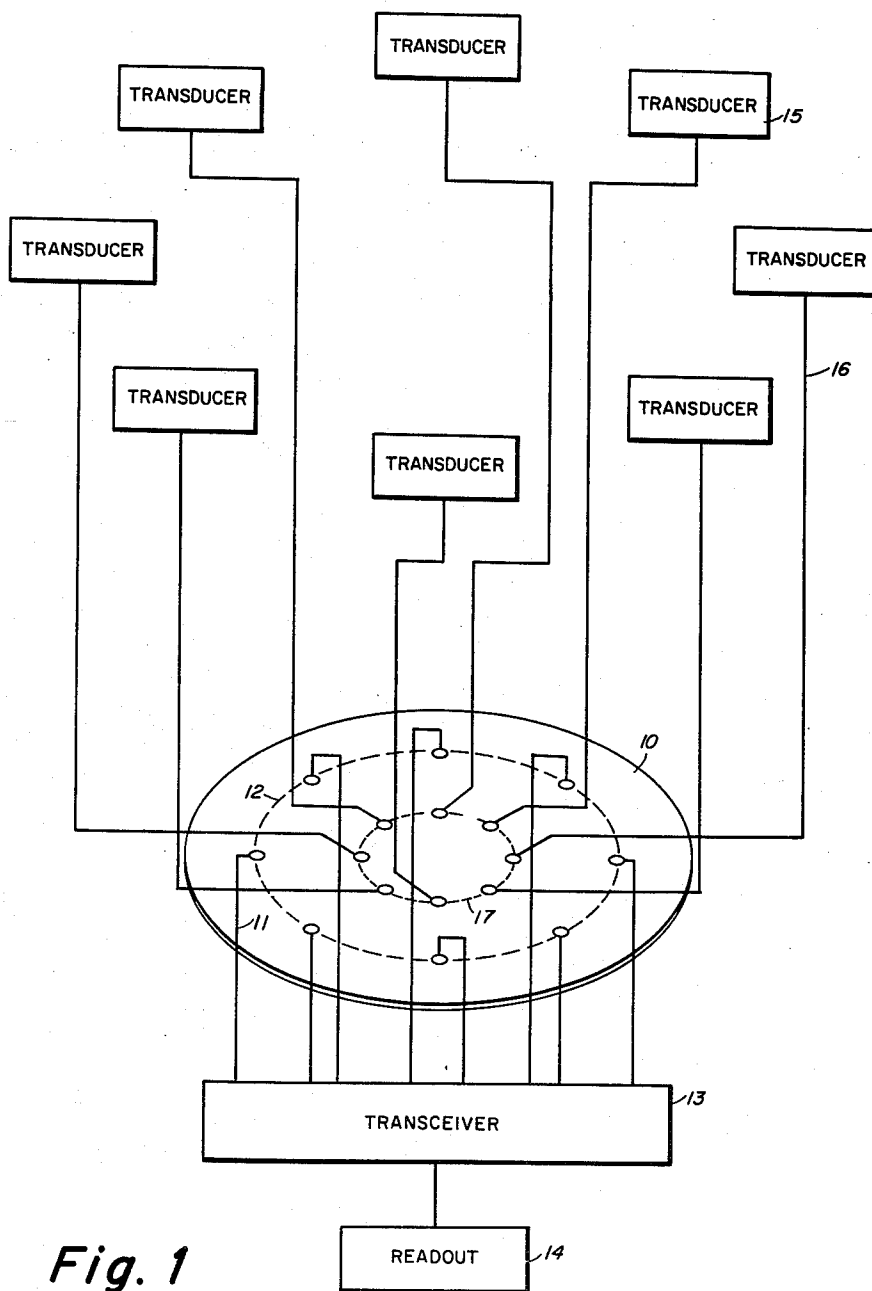


Fig. 1

INVENTOR.
FRANK R. ABBOTT

BY

James W. Satchell
John D. Doty
ATTORNEYS

April 20, 1965

F. R. ABBOTT

3,179,937

TWO-DIMENSIONAL ELECTROMAGNETIC DELAY LINE

Filed June 21, 1960

2 Sheets-Sheet 2

Fig. 2

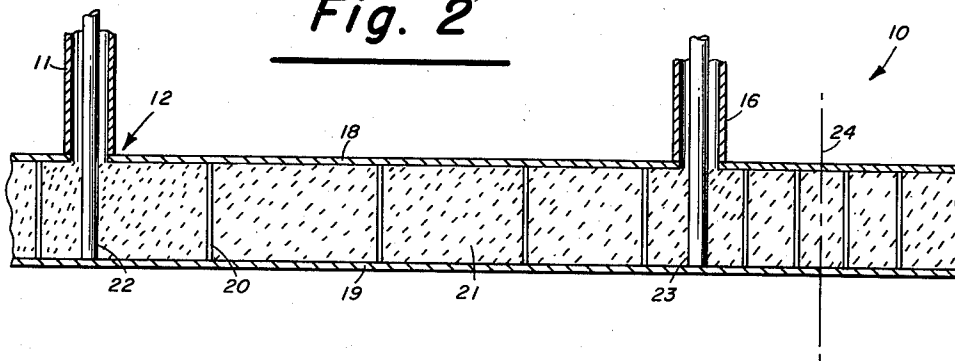
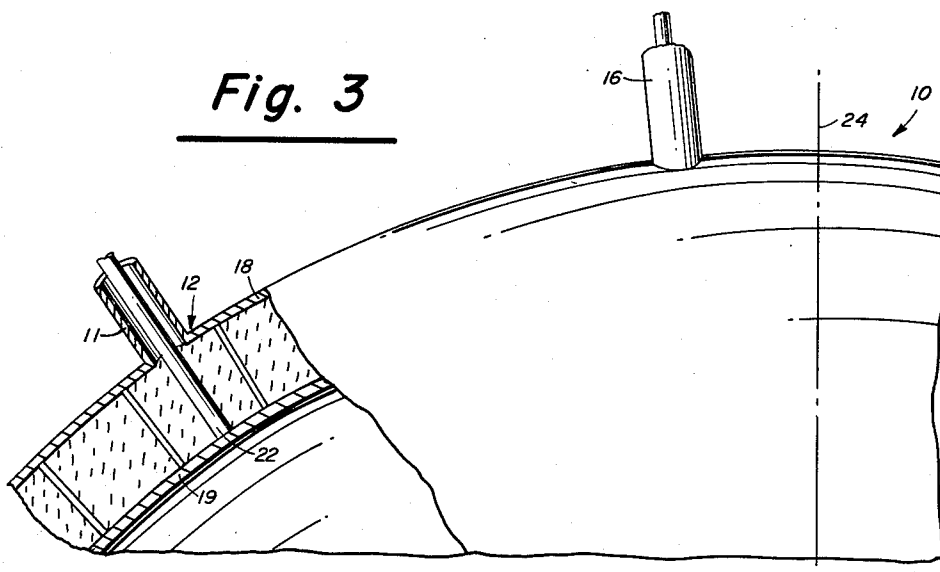


Fig. 3



INVENTOR.
FRANK R. ABBOTT

BY

Paul W. Mitchell
Don D. Doty
ATTORNEYS

1

3,179,937

TWO-DIMENSIONAL ELECTROMAGNETIC DELAY LINE

Frank R. Abbott, 3953 Wildwood Road, San Diego, Calif.
Filed June 21, 1960, Ser. No. 37,812

17 Claims. (Cl. 343-100)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates generally to passive means for changing the velocity of high and low frequency electro-magnetic waves and in particular to a radio system incorporating a two-dimensional electromagnetic delay line having no moving parts for delaying and reproducing in miniature the electromagnetic energy radiation patterns of radio waves broadcast or received by a predetermined transducer array operating in conjunction with a transceiver.

The devices of the prior art usually effect the formation of desired radiation patterns by means of phase or time compensation networks employed in conjunction with appropriate beam scanning operations. In many instances this arrangement is objectionable because the rotation or scanning operation of an otherwise substantially unidirectional beam is time consuming and the phase compensation networks are space consuming and physically cumbersome. In addition, the scanning operation is ordinarily restricted to a single frequency.

The present invention overcomes these objections in that scanning or rotation of a single beam is not employed which, of course, obviates the requirement for moving parts and associated burdensome power machinery. Furthermore, in combination with a multibeam display unit, it is possible to simultaneously present at a readout means the signals received from or broadcast to any or all directions as desired. Also, the present invention enables beam formation of signals over a broad band of frequencies. Moreover, the transmission of electromagnetic energy is delayed in time by appropriate manipulation thereof within a relatively small, compact, passive unit, the components of which may be structurally arranged to provide controlled wave velocities and corresponding time delays.

It is, therefore, an object of this invention to provide a two-dimensional passive electromagnetic delay line.

Another object of this invention is to provide a means for timely transmitting and receiving multi-beam electromagnetic energy waves by a plurality of broadband transducers.

A further object of this invention is to provide an improved passive rapid beam steering apparatus.

Another object of this invention is to provide an improved delay line.

Another object of this invention is to provide an improved means for delaying the transmission of high and low frequency electromagnetic energy in accordance with a predetermined requirement.

Another object of this invention is to simulate actual electromagnetic radiation patterns in space in miniature form within confined, relatively small limits.

A further object of this invention is to provide an improved method and means for controlling the electromagnetic energy broadcast by an assemblage of predisposed transducers.

Another object of this invention is to provide an improved method and means for controlling the electromagnetic energy received by an assemblage of predisposed transducers.

2

A still further objective of this invention is to provide a method and means for obtaining high bearing resolution from an extended arbitrary array of radiating and receiving elements without using mechanically moving parts.

Another object of this invention is to provide an improved delay line means for effecting time compensation of combined signals timely received and broadcast by a plurality of predisposed transducers.

A further object of this invention is to provide an improved method and means for transforming high velocity electromagnetic wave energy into relatively low velocity electromagnetic wave energy without adversely affecting the characteristics thereof.

Another object of this invention is to reconstruct and time compress predetermined electromagnetic radiation patterns in a compact, finite space by means of an improved two-dimensional wave-guide system.

A further object of this invention is to provide an improved method and means for beam-forming signals over a broadband of frequencies.

Another object of this invention is to provide a new and improved broadband electromagnetic delay line that is easily and economically manufactured and maintained.

Another object of this invention is to provide an improved delay line that may be easily incorporated in radio, radar, and sonar systems for appropriately controlling the broadcast and reception of high and low frequency electromagnetic energy thereby, respectively.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic diagram illustrating the unique incorporation of a two-dimensional electromagnetic delay line of the type disclosed herein in a broadcasting and receiving system adapted for response to and generation of electromagnetic radiation patterns;

FIG. 2 is an exemplary cross-sectional view, with parts broken away, of a flat disc embodiment of the electromagnetic delay line constituting this invention; and

FIG. 3 is a perspective view, with parts broken away, of a curved embodiment of this invention.

Referring now to the drawings, wherein like reference characters designate like or corresponding parts throughout the several views, there is shown in FIG. 1 a preferred embodiment of a broadband two-dimensional electromagnetic delay line 10 having a first plurality of matched coaxial cables 11 having one of the ends thereof respectively connected thereto about a ring 12 and the other ends thereof electrically coupled to a like plurality of channels of a multi-channel radio or radar transceiver 13 or the like for timely receiving and transmitting electromagnetic wave energy. Connected to said transceiver is a readout 14 such as, for instance, a multi-channel drum recorder or the like for indicating and recording the amounts of electromagnetic energy being received or broadcast thereby.

A plurality of transducers 15 such as, for example, electromagnetic antennas or the like is arranged in a special array for broadcasting and receiving predetermined electromagnetic radiation patterns both individually and collectively. Interconnecting said transducers and said delay line is a second plurality of matched coaxial cables 16. The ends of said coaxial cables connected to delay line 10 are arranged thereat in such manner as to form a miniature replica 17 of the aforementioned transducer array.

Although the preferred embodiment of FIG. 1 shows the transducer array and miniature replica thereof at the delay line as being substantially circular in form, it is to be understood that any desired forms may be used to achieve radiation patterns warranted by any given opera-

tional circumstances without violating the scope and spirit of this invention. Likewise, the shape of the ring formed by the delay line connections of coaxial cables 11 may be varied as necessary to provide the desired operational results. In addition, it should be noted that although the overall shape of the preferred embodiment of the delay line illustrated in FIG. 1 is in flat disc form, any shape may be employed to make the aforementioned miniature replica proportionally conform with the actual transducer array. Thus, it can be seen for example, that the delay line disc may be spherically shaped or shaped in accordance with geographical terrain in order to provide, insofar as it is practical, similarity between said array and replica arrangements.

Referring now to more detailed portions of the delay line 10 depicted in FIGS. 2 and 3, there is shown a top metallic plate 18 and a bottom metallic plate 19 both of which are composed of electrically conducting material such as copper, aluminum, silver, or the like. Within the intervening space therebetween, is a plurality of orderly spaced dielectric pins 20 electrically and structurally connected to and extending from the inner surfaces of said top and bottom plates. Pins 20 are of such material as the complex titanates, such as, for example, barium titanate, strontium titanate, stannous titanate, lead zirconate or the like. The spaces between the pins are filled with a sintered or pressed matrix 21 of low loss, high permeability material such as nickel ferrite, nickel zinc ferrite, or other comparable ferrite substances, which in conjunction with the aforesaid pins may assist in providing structural supporting effects to the assembled delay line as well as contributing to electromagnetic characteristics thereto, as will be further explained below.

The above mentioned coaxial cables 11 and 16 are respectively connected to the subject delay line in any conventional or otherwise suitable manner so that the outer cable is electrically connected to one plate while the inner cable extends through said space and is electrically connected to the other plate with each of said plates being electrically insulated from the other. However, if desired, the inner cable need not be electrically connected to either of said plates and may even be insulated therefrom. Said inner cables need only be disposed so that they become electrodes 22 and 23 of the aforesaid first and second pluralities of coaxial cables, respectively, where they pass through the space interposing said top and bottom plates.

The composite formed by the combination plates, pins, and ferrite matrix has the resulting property of conveying both high and low frequency electromagnetic waves as in a wave guide but at a velocity that is small compared to the velocity of said waves in air. Specifically, if the composite is a reasonably good insulator, the velocity of the wave energy within the subject delay line is that in space divided by the square root of the product of the resulting dielectric constant and the permeability of the composite material. Mathematically this may be represented by the following equation:

$$\frac{V_o}{V_s} = \frac{\sqrt{E_s U_s}}{\sqrt{E_o U_o}}$$

where

V_o =velocity of the energy wave in the composite.
 V_s =velocity of the energy wave in free space.
 E_o =dielectric constant of the composite.
 E_s =dielectric constant of the free space.
 U_o =permeability of the composite.
 U_s =permeability of the free space.

Depending upon the materials and arrangement thereof, the composite formed may reduce the electromagnetic wave velocity as low as a thousandth of the velocity in air.

The zone of the delay line outside the central area is so constituted by appropriate arrangement of said pins that the electromagnetic wave passing through the composite is focused at the outer electrodes 22, herein called the focal ring. The rate of variation of the dielectric constant-permeability product causes such focusing to be effected, and in the preferred embodiment, it has been found to be advantageous to have the locus of the points of focus to occur at the radial distance from a center 24 where the outer ring of electrodes is disposed and where the electromagnetic wave velocity is about 40% greater than in the center. This appears to be most easily accomplished by gradual decrease of the density of the titanate pins with increased radial distance from said center, although the spacing therebetween should not exceed approximately a sixth of a wave length or beam degeneration will result. Exemplary average spacing of the titanate pins which provides substantially optimum operation is presented as follows:

Radial Position of Pins (Inches from center of delay line)	Average Spacing Between Pins (Inches)
0.5	.12
1	.13
1.5	.15
2	.17
2.5	.19
3	.20
3.5	.21
4	.23
4.5	.27
5	.30
5.5	.36
6	.40

The radial zone outside the focal ring is deliberately made dissipative to absorb the passing electromagnetic wave and avoid or considerably reduce boundary reflections.

Other means of accomplishing the delay of wave energy as it traverses the subject delay line are possible. For instance, varying the density or the materials of the ferrite matrix, or contaminating same with sand or some other suitable substance will vary the velocities of high and low frequency electromagnetic energy waves in their travel therethrough, since the propagation constant thereof will be varied accordingly. Moreover, deletion of the titanate pins entirely or varying the material thereof would obviously vary the physical impedance acting on the traversing energy waves and, hence, change the velocity thereof in accordance therewith.

Briefly, the operation of the receiving and broadcast system and the two-dimensional electromagnetic delay line incorporated therein is as follows:

Assuming that the system is being used as a receiving system, incoming electromagnetic wave energy is sensed by each of the transducers and fed respectively through matched coaxial cables to the electrodes mounted in the delay line to simulate in miniature the transducer array. By virtue of the electrical similitude between the actual transducer array and the miniature replica thereof, a plane wave from any direction passing the transducer array will generate signals in the miniature replica of coherent phase and in the same direction and thus generate a comparable new plane wave in the two-dimensional delay line. By means of waveguide action, this new plane wave travels radially from the input electrodes through the subject delay line and while so traveling the velocity thereof is reduced. Hence, within the delay line, the new electromagnetic plane wave pattern travels a distance that is proportional to but considerably smaller than the distance that the incoming electromagnetic plane wave is traveling in the atmosphere during the same period of time. Of course, delay thereof is effected within the delay line due to the impeding composite of titanate pins and ferrite

matrix, and is controlled by proper physical disposition of coaxial cable electrodes therein.

During receiving operations, the inner assembly of electrodes will act as the inputs to the delay line and the outer assembly of electrodes act as the outputs from the delay line. Said output electrodes are then electrically coupled through matched coaxial cables to the transceiver which, in turn, applies the delayed signals in appropriate form to the multi-channel readout for indication and recording thereof for evaluation and other control purposes as desired.

In event that electromagnetic signal strengths are too weak or too erratic to provide optimum receiving and readout operations, it would be obvious to one skilled in the art to include amplifiers and rectifiers as necessary to overcome these adversities, and so doing should, therefore, be considered as being included in this teaching.

The reverse process substantially occurs during broadcast operations. Since the transceiver employed herein is of conventional type it includes the proper switching means for timely converting it from a receiver to a transmitter and vice versa. When acting as a transmitter, it simultaneously applies the generated electromagnetic waves to the readout means and to the appropriate outer ring electrodes through the interconnecting coaxial cables. These waves then combine to form a resultant pattern within the delay line and are delayed as they travel toward the inner ring electrodes. Upon reaching the inner ring electrodes they are respectively conducted by means of coaxial cables to their associated transducers for transmission into space as a reconstructed beam pattern which is substantially similar in shape but considerably larger in size than the aforementioned resultant pattern generated within the subject delay line.

When the subject delay line is being used in conjunction with energy in the acoustical frequency range, the operation is similar to that when used in electromagnetic systems with the exception that the frequencies are lower and the transducers, transceiver, and readout are such as to accommodate said lower frequencies.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed and desired to be protected by Letters Patent of the United States is:

1. A two-dimensional electromagnetic delay line comprising a top plate, a bottom plate spacially disposed from said top plate, a plurality of titanate pins interconnecting said top and bottom plates, a ferrite matrix disposed between said plates and said pins, and a pair of electrodes disposed within said ferrite matrix a predetermined distance from each other.

2. A broadband radio system comprising in combination, means for timely transmitting and receiving a plurality of electromagnetic signals to and from a predetermined distance from the surface of the earth, means coupled to said transmitting and receiving means for effecting a miniature pattern of the electromagnetic signals transmitted and received therefrom, means connected to said miniature pattern effecting means for timely generating and supplying said electromagnetic signals thereto and for receiving said electromagnetic signals therefrom a predetermined time prior to transmission thereof by said transmitting and receiving means and subsequent to the reception thereof by said transmitting and receiving means respectively, and means coupled to said last mentioned means for reading out the electromagnetic signals generated and received thereby.

3. A two-dimensional electromagnetic wave guide comprising in combination, a first conductor having a predetermined area, a second conductor likewise having a predetermined area spacially disposed from said first conductor, a pair of coaxial cables each having an outside con-

ductor connected to said first conductor and an inside conductor connected to said second conductor, a plurality of dielectric pins predisposed between said first and second conductors, and an electrically nonconductive, low loss, high permeability matrix disposed within the space between said first and second conductors not occupied by said inner conductors and the aforesaid pins.

4. The device of claim 3 wherein said first and second conductors consist of substantially parallel metallic flat plates.

5. The device of claim 3 wherein said first and second conductors consist of substantially concentric metallic plates.

6. The device of claim 3 wherein said first and second conductors consist of substantially spherically shaped metallic plates.

7. The device of claim 3 wherein said plurality of dielectric pins predisposed between said first and second conductors are of barium titanate.

8. The device of claim 3 wherein said plurality of dielectric pins predisposed between said first and second conductors are of strontium titanate.

9. The device of claim 3 wherein said plurality of dielectric pins predisposed between said first and second conductors are of lead zirconate.

10. The device of claim 3 wherein said electrically nonconductive, low loss, high permeability matrix is of nickel ferrite.

11. The device of claim 3 wherein said electrically nonconductive, low loss, high permeability matrix is of nickel-zinc ferrite.

12. A two-dimensional electromagnetic delay line comprising in combination, a pair of spacially disposed electrically conductive plates, a plurality of titanate pins electrically connected between said plates, said pins being disposed within the space interposing said plates in gradual decreasing density with increased radial distance from a predetermined center located on said plates, a ferrite matrix filling the space between said plates and said pins, a first plurality of matched coaxial cables having the outer conductors thereof electrically connected to one of said pair of plates and the inner conductors thereof extending through said matrix and electrically connected to the other of said pair of plates, said first plurality of matched coaxial cables being predisposed about said center in such manner as to form a pattern adapted to simulate a transducer array electrically coupled thereto, and a second plurality of matched coaxial cables having the outer conductors thereof electrically connected to said one plate and the inner conductors thereof extending through said matrix and electrically coupled to said other plate at a predetermined focal ring located more remote from said center than the aforesaid first plurality of coaxial cables.

13. In a radio receiving system, an antenna array adapted to receive an electromagnetic plane wave pattern, means connected to said antenna array for simultaneously delaying and reconstructing a miniature replica of the electromagnetic plane wave pattern received thereby, and means coupled to said delaying and reconstructing means for receiving and reading out said delayed miniature electromagnetic plane wave pattern replica.

14. In a radio transmitting system, a transmitter means adapted to generate a plurality of electromagnetic plane waves, readout means coupled to said transmitter means for indicating and recording the electromagnetic plane waves generated thereby, means connected to said transmitter means for simultaneously delaying said generated electromagnetic plane waves at a varying rate and constructing same in a predetermined pattern, antenna means coupled to said delaying and constructing means adapted for broadcasting said delayed and constructed electromagnetic plane wave pattern as an enlarged electromagnetic plane wave replica thereof.

15. In a sonar system, a transducer array adapted to

transmit and receive an acoustical energy radiation pattern, means connected to said transducer array for simultaneously delaying and reconstructing a miniature electromagnetic replica of the acoustical energy radiation pattern transmitted and received thereby, and means coupled to said delaying and reconstructing means for reading out said delayed miniature acoustical energy radiation pattern replica.

16. A broad band energy broadcasting and receiving system comprising in combination, a plurality of transducers, delay means including a top plate, a bottom plate spatially disposed from said top plate, a plurality of titanite pins interconnecting said top and bottom plates, a ferrite matrix disposed between said pins and within said top and bottom plates, a plurality of electrodes disposed within said ferrite matrix at a predetermined distance from each other, a first plurality of coaxial cables respectively connecting a like number of said electrodes to said plurality of transducers, transceiver means, a second plurality of coaxial cables connected between said transceiver means and the remaining plurality of electrodes of said delay means, and readout means connected to said transceiver means.

17. A broadband radio system comprising in combination, a plurality of electro-magnetic transducers disposed in a predetermined pattern in space, means coupled to said plurality of transducers for effecting a miniature pattern of the electro-magnetic signals received or transmitted thereby consisting of a pair of electrically conductive plates, a plurality of titanite pins interconnecting said plates in a predetermined density configuration, a

ferrite matrix filling the space between said plates and said pins, a first plurality of electrodes disposed within said ferrite matrix in such manner as to form a physical pattern substantially similar to the aforesaid spatial pattern of electromagnetic transducers, a first plurality of electrical conducting means respectively interconnecting said plurality of electrodes and said plurality of electro-magnetic transducers, a second plurality of electrodes disposed within said matrix at a predetermined location around said first plurality of electrodes, a transceiver, a second plurality of electrical conducting means respectively connected between said second plurality of electrodes and the inputs to said transceiver, and a readout means coupled to said transceiver for indicating the pattern of electro-magnetic signals received or transmitted by said plurality of transducers.

References Cited by the Examiner

UNITED STATES PATENTS

2,245,660	6/41	Feldman et al.	343—100
2,776,411	1/57	Anderson	333—29
2,786,193	3/57	Rich	340—6
2,832,935	4/58	Tank	333—29
2,852,772	9/58	Gitzendanner	343—100
2,898,589	8/59	Abbott	340—6
3,074,048	1/63	Turner.	

CHESTER L. JUSTUS, *Primary Examiner.*

FREDERICK M. STRADER, *Examiner.*