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3,369,199

DISPERSIVE DELAY LINE

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2 Sheets-Sheet 2

FIG. 2

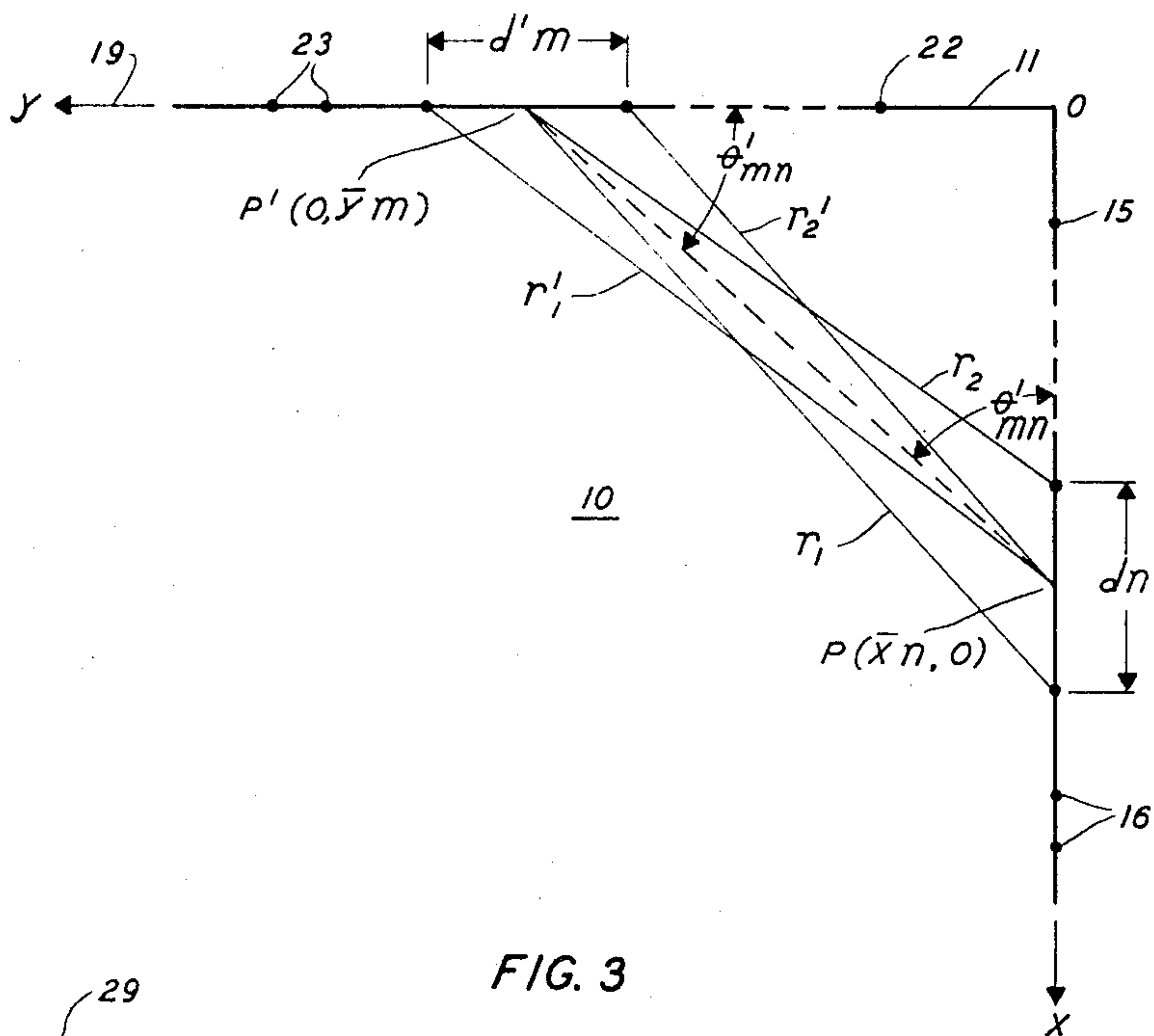
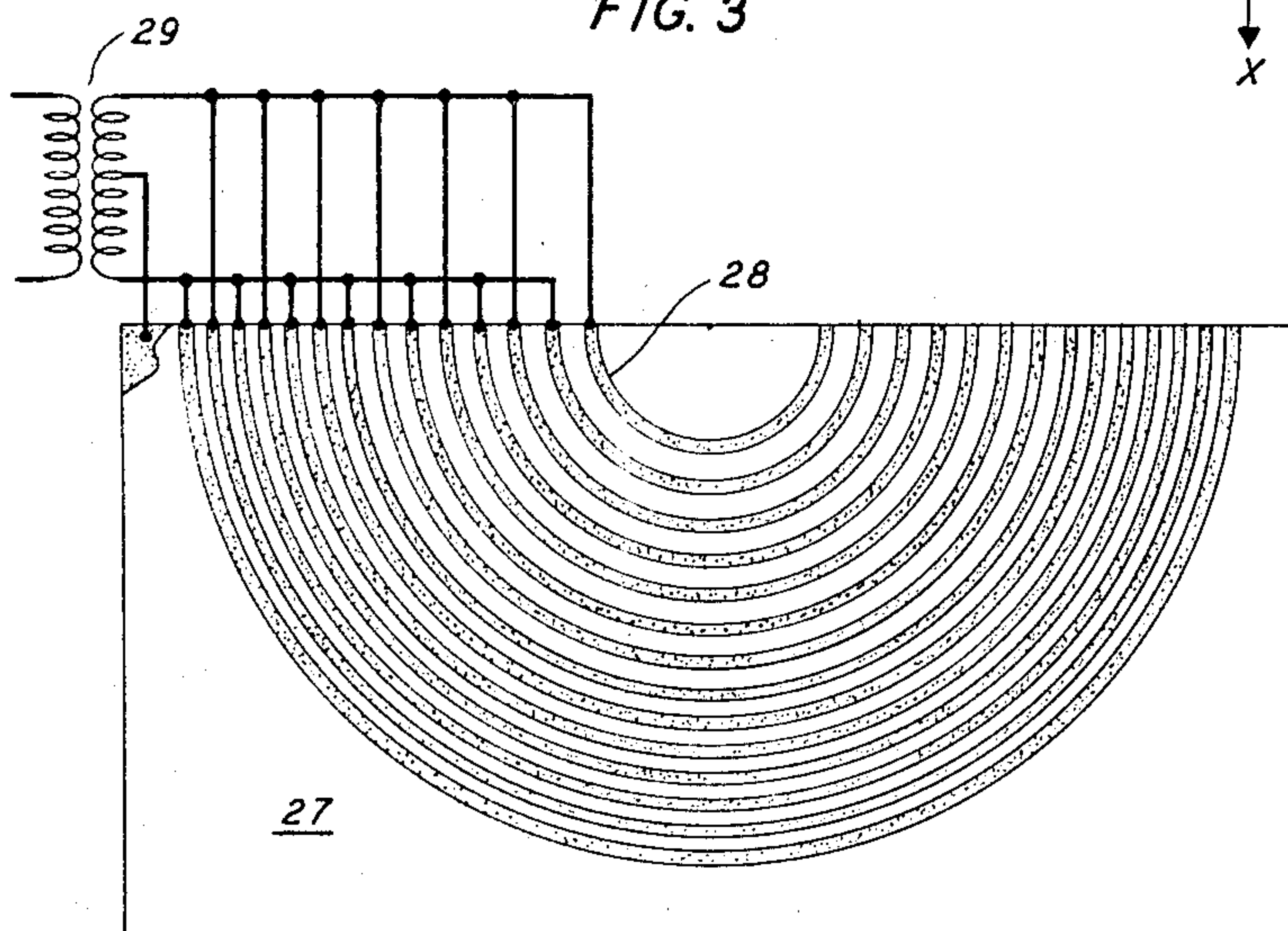


FIG. 3



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DISPERSIVE DELAY LINE

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ABSTRACT OF THE DISCLOSURE

A diffraction delay line in which the input transducer is formed as an array of concentric circular line sources and the output transducer array as a straight line array extending axially with respect to the concentric array. Since this input array focuses its radiation upon the output array which is in turn selective against unfocused radiation, a high degree of spurious signal suppression is possible.

This invention relates to elastic wave transmission structures having special delay versus frequency or signal dispersion characteristics. More particularly the invention is an improvement upon the dispersive delay devices disclosed and claimed in the copending application of R. S. Duncan, M. R. Parker, Ser. No. 296,212, filed July 19, 1963.

In general, the devices disclosed and claimed in the above-noted application disperse the frequency components of an input wave spatially in a delay medium and convert the dispersion in space to a dispersion in time. In a preferred embodiment the input wave is launched from a transducer array so arranged that different frequency components are radiated with different dispersion angles along paths with different path lengths, toward an output array which accepts the incident signals and combines the frequency components in a way which preserves the introduced delay.

It has been recognized that the series of dispersion angles for each frequency produces not only the useful first order lobe of the radiation pattern of the array, but also undesired higher order lobes for each individual frequency. It is therefore desirable to minimize these higher order lobes since the power lost to them increases the insertion loss of the device. Furthermore, since energy in the higher order lobes arrives at the output array after multiple reflections from the boundaries of delay medium, rejection of spurious signals is made difficult.

It is therefore an object of the present invention to increase the concentration of the total energy in the wanted transmission lobe and to simultaneously decrease undesired transmissions leading to spurious signals.

In accordance with the present invention an input transducer is formed as an array of concentric circular line sources or segments thereof which launch an elastic wave having its energy distributed over a large area. Conversely, an output transducer is formed from a straight line array which receives elastic wave energy restricted to a narrow, elongated area extending axially with respect to the concentric array. The concentric array has the property of focusing both the first order lobe as well as other order lobes along the line through its axis with the several lobes coming to a focus at different distances from the array. When the output transducer is restricted to that portion of the line on which the first order lobe is focused, other order lobes and spurious signals can only arrive at the output transducer defocused after multiple reflections and are thus discriminated against as a result of the small intercept area of the straight line array. Furthermore, within each lobe components of a broadband signal applied to the concentric array are dispersed along the line on the basis of frequency. It is therefore possible to modify

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the delay time versus frequency arrangement of these components as desired.

These and other objects and features, the nature of the present invention and its various advantages, will appear more fully upon consideration of the specific illustrative embodiments shown in the accompanying drawings and described in detail in the following explanation of these drawings in which:

FIG. 1 is a perspective view of an illustrative embodiment of the invention;

FIG. 2, given by way of explanation, is a schematic representation of ray paths through a cross-section of the structure of FIG. 1; and

FIG. 3 is a plane view of a modified arrangement of the end face electrodes of the embodiment of FIG. 1.

Referring more particularly to FIG. 1, an illustrative embodiment of the invention is shown comprising a basically rectangular block 10 of any suitable elastic wave propagation material. For example, block 10 may be formed of an isotropic material such as glass or vitreous silica or of a metal alloy of grain size small compared to the wavelength of the elastic wave to be carried. Block 10 has a top surface 11 and a right-hand surface 12 that are plane and substantially perpendicular to each other. The remaining surfaces of block 10 are not critical to the invention and may be acoustically treated in known ways to absorb and dissipate elastic wave energy reaching them.

Means are provided upon the right-hand face 12 for launching a multifrequency wave of elastic wave energy with the energy initially radiated from a large plurality of spaced, substantially concentric, semicircular bands having a common center point 18 falling on an axis 19 of surface 11. This unusual wavefront which is distributed over a major portion of surface 11 may be produced, for example, by a source 17 of multifrequency components including at least the band of frequencies $f_1 \dots f_2$ applied to a specially designed elastic wave transducer assembly 25 suitably bonded to face 12. According to a preferred embodiment, transducer 25 is formed to a thin piezoelectric crystal or piezoelectric ceramic member 13, poled to produce vibrations in the mode conventionally designated as the longitudinal or compressional mode, and provided with a single thin conductive electrode 14 upon one surface of member 13 and an electrode array in the form of a plurality of concentric, semicircular, conductive bands 15 through 16 upon the other surface of member 13. Bands 15 through 16 are connected together in parallel to one side of source 17 while electrode 14 is connected to the other. The spacing between the centers of adjacent bands varies with distance along the radius from their center point 18 according to the function which it is desired to reproduce as the frequency versus delay characteristic in the output energy as will be described hereinafter. The array thus described may be most readily formed by plating a uniform layer of conductive material over the entire face of member 13 and then etching away portions of it to leave the desired plurality of conductive areas 15 through 16.

An output transducer assembly 26 is located along axis 19 of face 11 and has such design that a plurality of acoustically separate responses combine electrically to produce a condition of constructive interference that progressively varies with frequency along the transducer in response to the wavefront received from transducer 25. Transducer 26 comprises a thin, narrow member 20 of crystal or ceramic piezoelectric material having a longitudinal axis extending parallel to axis 19 and poled to respond to the same mode of vibration produced by the input transducer. A single conductive electrode 21 is located upon one surface of member 20. A large plurality of electrodes 22

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through 23 are located at longitudinally spaced points along the other surface thereof which are then connected in parallel to form an array. Like the multiple electrodes of transducer 25 these are preferably formed by plating a uniform layer of conducting material on member 20 and then etching away portions to leave thin narrow rectangular strips extending across member 20. The spacing between the centers of adjacent electrodes varies with distance from point 18 according to the function to be described hereinafter.

Transducer assemblies 25 and 26 may be bonded to block 10 with either the single electrode as illustrated or the multiple electrode adjacent to the faces of the block. Furthermore, the selected adjacent electrode may be formed directly upon the faces of block 10 rather than upon the face of the piezoelectric member as described above.

Regardless of the manner in which assembled, when an alternating voltage is applied to transducer 25 between the single electrode on one hand and the plurality of concentric electrodes on the other, member 13 responds piezoelectrically to produce elastic wave radiation in a plurality of bands each corresponding to one of the electrodes. It is therefore convenient to refer to the energy band by the same reference numeral which designates the associated electrode.

The present invention is based in part upon the recognition that elastic wave energy radiated from each infinitesimal segment of a given one of these semicircular energy bands combines in constructive interference only along axis 19 because each point along this axis is equidistant from every segment of the given band. Thus, it has been recognized that an elastic wave line source bent into a circular segment tends to focus a major portion of its energy upon the circular axis of the segment. When the situation is extended to a plurality of unequally spaced concentric bands excited by a broad band of frequencies, the interference phenomena becomes much more complicated but may be analyzed by recognizing that the interference that exists in one arbitrary radial plane passing through axis 19 and intercepting one infinitesimal segment of each of the bands 15 through 16 is duplicated in every other similar radial plane. Thus, FIG. 2 is schematic of the ray paths in one such arbitrary radial plane or cross-section. Points 15 through 16 represent the intercepted segments of correspondingly numbered bands as point sources along an axis designated x and the similar points 22 through 23 represent point receivers on surface 11 along an axis designated y . Two of these point sources are separated by a distance d_n , equally spaced on either side of a point P which, in turn, has coordinates $(\bar{x}_n, 0)$. The interference that takes place on the receiving array at a point P' having coordinates $(0, \bar{y}_n)$ may now be analyzed. Thus, the difference in path lengths between these two sources and point P' is approximately

$$r_2 - r_1 \cong d_n \cos \theta_{mn} = \frac{\bar{x}_n d_n}{r_{mn}} \quad (1)$$

where θ_{mn} is the angle of P' from P. Similarly, the difference in path lengths between two point receivers separated by d'_m and located on either side of P' and the point P is

$$r_2' - r_1' \cong d'_m \cos \theta'_{mn} = \frac{\bar{y}_m d'_m}{r_{mn}} \quad (2)$$

where θ'_{mn} is the angle of P from P'. For constructive interference,

$$\frac{\bar{x}_n d_n}{r_{mn}} = \frac{\bar{y}_m d'_m}{r_{mn}} = p\lambda \quad (3)$$

where $p=0, 1, 2, \dots$ is the order of interference and λ is the elastic wavelength.

Now let a number of sources and receivers be distributed along the x -axis and y -axis respectively, with all sources excited in phase and all receivers connected in

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parallel. Equation 3 is satisfied at any given frequency if the spacings are such that

$$\bar{x}_n d_n \bar{y}_m d'_m = C \quad (4)$$

where C is a constant. Then all source-receiver pairs which interfere constructively will be separated by the same distance r , with

$$r = \frac{C}{p\lambda} = \frac{Cf}{pv_s} \quad (5)$$

where f is the frequency and v_s is the phase velocity of waves in the delay medium between the arrays. The delay time τ of the output as a function of frequency will be

$$\tau = \frac{r}{v_s} = \left(\frac{C}{pv_s^2} \right) f = Kf \quad (6)$$

where K is the function determining the desired variation of delay with frequency.

Assume, for example, that the intended dispersion characteristic is one for which the delay decreases with increasing frequency according to a linear function. The larger spacing between output electrodes 22 nearest to transmitting assembly 25, the spacing between input electrodes 15 nearest to receiving assembly 26, and the minimum r between assemblies 25 and 26 will be determined from Equations 4 and 5 at the highest frequency f_1 in the band. Similarly, the smaller spacing between the farther output electrodes 23, between the farther input electrodes 16, and the maximum r will be determined at the lower frequency f_1 in the band. Between these extremes the spacing will be varied according to a linear function represented by a constant K in Equation 6. It should be understood that this spacing may alternatively be varied according to any geometric, exponential, logarithmic or other progression if such represents the desired dispersion variation. Theoretically, each electrode should have a dimension parallel to the longitudinal extent of the array that is comparable to one-half of the electrode spacing but in a practical application it has been found that a uniform dimension less than one-half wavelength of the highest frequency under consideration is satisfactory and is substantially more easily formed.

Operation of the device may now be qualitatively described. Electrical energy from source 17 will be converted into elastic wave vibrations originating in the several concentric bands by transducer 26. As this energy propagates into body 10 constructive and destructive interference occurs between not only the energy derived from each band but also between energy derived from different segments of the same band. A series of dispersion angles for each frequency is produced such that a first order lobe represented by $p=1$ in the foregoing equations is focused upon transducer 26 with the lowest frequency component being directed upon the nearer electrodes 22 as represented by the lines f_1 on FIG. 1, and the highest frequency component being directed upon the farther electrodes 23 as represented by the lines f_2 . At the same time, transducer 26 has been proportioned to have a first order receiving lobe for the lowest frequency component along the lines f_1 and the highest frequency component along the lines f_2 .

Thus, elastic wave energy at the frequency f_2 will be detected by the nearer electrodes 22, a wave at the frequency f_1 will be detected by the further electrodes 23 and waves of intermediate frequencies will be detected by intermediate electrodes. Each component frequency has a time delay proportional to the distance from transducer 25 to the point on transducer 26 where it is detected. The order in which the highest frequency component, the lowest frequency component, or any intermediate component is detected and the distance from transducer 25 at which this detection occurs may be arbitrarily selected by proper arrangement of the electrodes of transducer 26 to produce any desired delay characteristic.

A principal advantage of the present invention over prior art structures stems from the focusing aspects of transmitting transducer 25 used in combination with the narrow intercept area of receiving transducer 26. Thus, energy in the lobe of the desired first order is highly concentrated along the narrow line of transducer 26 which therefore responds efficiently to this energy. Components of lobes of other orders, that is, those for which p is different from 1 in the foregoing equations, come to focus along portions of axis 19 that are different from those of components of the first order lobes. Components of the other order lobes can only arrive at transducer 26 after multireflection from the boundaries of block 10 during which they will become so diffused and dissipated as to have little concentration along the narrow area of transducer 26.

Further discrimination against all even order lobes including the zeroth is obtained by the modification shown in FIG. 3. Modification resides in doubling the number of concentric conductive bands 28 of transducer 27, connecting alternate bands together and driving the resulting interlaced arrays out of phase by suitable means such as transformer 29. The improvement afforded may be understood by recognizing that each of the interlaced arrays will have virtually the same radiation characteristic since their respective element spacings are approximately the same. However, since the interlaced arrays are driven out of phase, all even order lobes cancel with each other while the odd order lobes constructively interfere.

While only a relatively few electrodes have been illustrated in the drawing as comprising each array of both embodiments, it should be noted that in practice the number of electrodes may vary from several hundred to several thousand depending upon the design requirements of a given application. Further consideration concerning the number of electrodes, equivalent physical constructions therefor, alternative spacing arrangements to produce other frequency selective and nonfrequency selective characteristics, and several specific uses for these characteristics may be found in the above-mentioned application of R. S. Duncan and M. R. Parker and in the copending application of M. R. Parker, Ser. No. 374,544, filed June 11, 1964.

In all cases it is to be understood that the above-de-

scribed arrangements are merely illustrative of a small number of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An elastic wave transmission system comprising a body of elastic wave propagation material having a pair of perpendicular faces, means for launching a multifrequency elastic wave in said body distributed over a given area on one of said faces in a plurality of spaced bands formed as circular segments concentric about a common axis that lies on the other of said faces, said bands being spaced from each other to direct wave energy launched thereby and to disperse the frequency components thereof along a narrow elongated region extending on said other face along said axis, and elongated elastic wave transducer means for receiving said directed energy extending along said narrow elongated region.

2. The system according to claim 1 wherein said elongated region is narrow in comparison to said given area and wherein said transducer means extending along said region includes an electrode in the form of a plurality of conductive elements distributed along said axis.

3. The system according to claim 1 wherein the spacing between said bands varies as a function of distance along the common radius of said concentric bands to focus different frequency components of said energy upon different points along said axis.

4. The system according to claim 3 wherein said second transducer includes an electrode in the form of a plurality of elements spaced from each other as a function of distance along said axis.

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