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OPTICAL COMMUNICATION SYSTEM USING A CIRCULAR
ELECTROMECHANICAL MODULATOR
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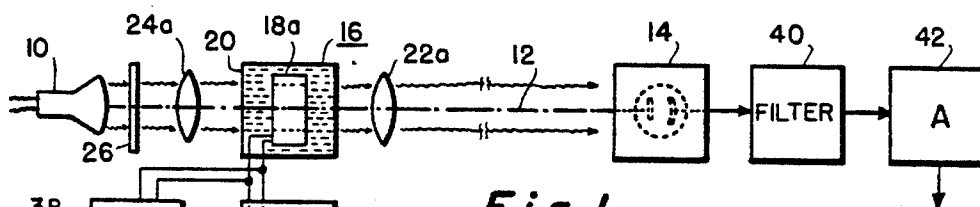


Fig. 1

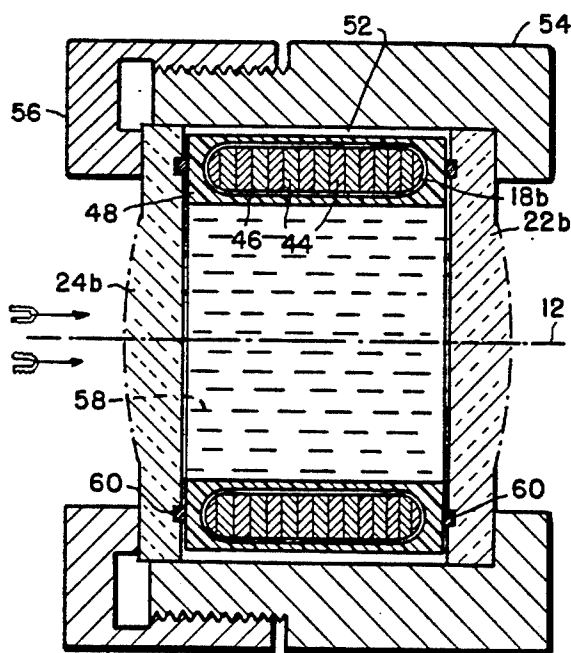


Fig. 2

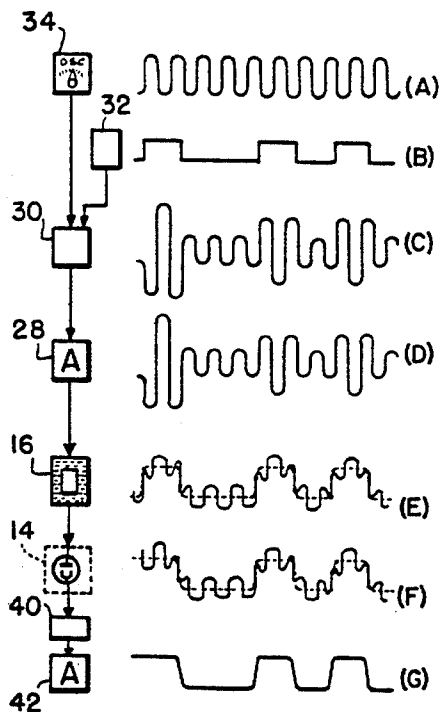


Fig. 4

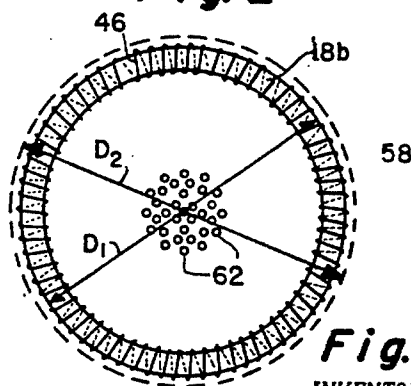


Fig. 3

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Fig. 5 *Webb, Mackey & Burden* BY
HIS ATTORNEYS

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OPTICAL COMMUNICATION SYSTEM USING A CIRCULAR ELECTROMECHANICAL MOD- ULATOR

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This invention relates to a transducer for modulating a light beam, especially at high frequency. Both visible light and other light such as black light are contemplated, and particularly light in the infrared portion of the light spectrum.

More particularly, this transducer invention is embodied in a liquid-sealed, lens structure, the internal optics of which are controlled at desired frequencies up to 20 kc. and sometimes higher. Energy input causes a rapidly appearing and disappearing cloud of liquid cavitation bubbles to be generated and sonically brought into focus by the transducer itself, so that these bubbles localize along the axis of the lens and cause the intensity of light transmitted to vary in dependence on the hydraulic power input. Such bubbles can be localized with fairly simple designs of the transducers, which are made of magnetostrictive material or piezoelectric material and which are shaped for sonically focusing hydraulic energy either by themselves or else provided with a reflector therebehind such as a parabolic reflector to create the same effect.

With opaque or semi-opaque liquids, the instantaneous appearance therein of a cloud of cavitation bubbles reduces the light absorbing characteristics of the liquid to a point where a detectable light level passes from one side through and beyond the opposite side of the liquid. The instantaneous appearance of localized cavitation bubbles in a transparent liquid has the opposite effect; i.e., the normally undiminished light is subjected to scattering and/or absorption because of the different indices of refraction as between the vapor bubbles and the transparent liquid itself, and hence the level of the light transmitted is diminished.

The high frequencies achievable by my system are due to a combination of high frequency phenomena. The transducer itself operates at known high electrical frequencies and its size can be readily selected and proportioned for natural resonance at any of those frequencies. The instantaneous response of the transducer itself is, as a practical matter, matched by the instantaneous response of cavitation bubbles which result each time an electrical impulse is transduced mechanically through a sonic medium into hydraulic cavitation energy. Finally, the frequencies of the light beam modulated are high in the spectrum so that the use of a lamp's beam is in no way a drawback from standpoint of speed and instantaneous response.

My invention is primarily adapted to use a light beam for establishing the line of transmission to a photosensitive surface which I provide for sensing the modulated light. Generically, however, any optical radiation is contemplated, i.e., wave energy which can, for the instant purpose, be controlled generally in accordance with the laws of optics.

Features, objects and advantages of the invention will either be specifically pointed out or become apparent when for a better understanding thereof, reference is made to the following description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a block diagram of a system embodying the present invention;

FIGURE 2 is a longitudinal sectional view of a preferred embodiment of the transducer device;

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FIGURE 3 is a schematic operational view taken transversely to show the transducer action; and

FIGURES 4 and 5 are companion views correlating illustrative wave shapes (FIGURE 5) with the blocks appearing in FIGURES 1 and 4.

In FIGURE 1, the beam from an electric spot lamp 10 is focused so as to be highly directive and has an axis establishing a line of transmission 12. The beam falls on the photosensitive surface of a photocell device 14, or other appropriate radiation detecting device, preferably located at a remote point which is reached by the light beam.

A light valve 16 interposed in the line of transmission comprises a transducer element 18a immersed in the liquid within a transparent container 20. The light valve 16 constitutes part of a lens system including a posterior lens 22a, an anterior lens 24a, and one or more filters 26 between the anterior lens 24 and the spot lamp 10; the filter 26 preferably has a narrow pass band measured in terms of the spectrum, either visible or invisible.

Means for applying power to oscillate the immersed transducer element 18a is provided as follows. An input power amplifier 28 couples an amplitude modulator 30 in the input of the transducer element 18a. Connected to modulator 30 is a modulating device 32 which modulates input to the transducer element 18a and which does so, for example, with code signals, with voice signals, or with other suitable signals, preferably within the audio frequency range.

Also connected to the modulator 30 is an oscillator 34 having an adjustment 36 by which it can be adjusted to the frequency desired. It is preferably adjusted to oscillate at a fixed electrical frequency equal to the natural resonant frequency of the transducer element 18a, thus producing a maximum effect with relatively low input power.

If the modulating device 32 consists of a simple key, the input to the transducer element 18a can be controlled by hand. If the modulating device is a tape reader, the tape can be encoded in suitable code as desired and transmitted fairly rapidly on the line of transmission 12. If the modulating device is a microphone, the input can be either modulated at voice frequencies or modulated otherwise within the AF and near AF range or a combination of the two.

If the transducer element 18a is made of one of the magnetostrictive materials having the not too uncommon property of exhibiting, say, negative elongation under weak flux followed by positive elongation under stronger flux, it is desirable that a source of D.C. power 38 be connected to the input of the transducer element so as to maintain a positive biasing flux through the core of the element at all times. Nickel has such magnetostrictive characteristics, in which case it is biased with a fixed flux of appreciably higher density than required to make the nickel take its minimal dimension (maximum negative elongation). Changes in elongation will then be consistent, corresponding both in sense and magnitude with the flux produced by the modulated input to the transducer element. In other words, increase in modulated input causes increase of the elongation of this example of transducer material and decrease of modulated input causes a lengthwise decrease of the transducer material.

An electronic filter 40 couples the photocell device 14 to a combined demodulator and output power amplifier unit 42 which reproduces the same input signal originating from the modulating device 32. The electronic filter 40 is adjusted to pass only frequencies at or near the carrier frequency of oscillator 34; hence, it prevents other flashing light or stray light from interfering with the transmission, at least when the interfering light is in moderate

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quantities. The natural frequency for the transducer element 18a is predetermined according to its mass, and shape and distribution of the material selected, so as to correspond to the carrier frequency wanted. Accordingly, the power input required will be of the order of a one-thousandth of the power that might otherwise be required to produce a like amplitude of vibration.

Following is an example of the specifications for the transducer element of light valve 16:

Element 18a	Cylindrical shape.
Outside diameter	3 inches O.D.
Cylindrical length	1½ inches.
Radial thickness	½ inch.
Material	Laminated nickel.
Element 18a input	70-80 watts power

If the optical filter 26 is selected so as to have a pass band limited to the infrared frequencies, the beam of light will be inconspicuous which passes through the lens system and beyond. It is preferred for that reason.

In FIGURE 2, the principal components of the lens system of FIGURE 1 are identified by new subscripts as elements 18b, 22b and 24b; in practice, they are combined so as to constitute a single transducer unit all in one. The transducer element 18b itself is actually a consolidation of elements consisting of a laminated series of individual nickel rings 44, an electrical coil 46 toroidally wound thereabout, and an epoxy encapsulation 48 constituting a thin-walled plastic cylinder thereabout. The transducer element 18b fits within a generally cylindrical housing with an annular clearance space 52 therebetween, said housing including a clamping body 54 with a screw-on clamping cap 56 and each presenting end flanges.

The lenses 22b and 24b are concentric to the line of transmission 12 and are effective as walls to form transparent end plates of a container for the sonic liquid 58. Each lens is clamped between one end of the transducer element 18b and the confronting clamping flange of the housing at that end.

An O-ring seal 60 carried in a groove in each interface of the lenses establishes a liquid-tight joint at each end of the transducer element 18b, at the same time enabling the element to vibrate radially without leakage. The clearance space 52 likewise accommodates radial expansion of the transducer but in practice, this clearance is slight inasmuch as the total amplitude of vibration is adjusted so as to be barely perceptible, if at all.

In assembly of the structure of FIGURE 2, the clamping body 54 of the housing is placed in a vertical position resting on its end flange. The lens 22b and the transducer element 18b are inserted, with the interposed O-ring seal 60 disposed therebetween and resting in the annular groove in the lens 22b. The body of liquid 58 is then introduced to a point level with the upper edge of the unit 50 whereupon the lens 24b and the interposed O-ring seal are placed in a covering position thereover. After it is certain that all air bubbles have been excluded, the screw-on cap 56 is applied to complete the bipartite housing, thus clamping the seals 60 in fluid-tight relation.

In FIGURE 3, the laminated transducer element 18b under high frequency flux stress from the coil 46 vibrates rapidly between its expanded and contracted positions, the former having the dotted line position shown with the diameter D_2 and the latter shown in the solid lines with the diameter D_1 . The resulting condensations and rarefactions in the body of liquid 58 travel at the speed of sound toward and away from the geometric center of generation of the element 18b with the result that each time the element assumes its expanded diameter D_2 there is an instantaneously appearing core or column of cavitation bubbles 62 which localizes about the line of transmission 12 (FIGURE 2); the diameter of this core of bubbles 62 is only some fractional part of the diameter D_1 , amounting in the general case to a cloud of approximately ¼ of that diameter.

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If a body of clear liquid 58 is used such as water, alcohol, or oil, a light beam following the line of transmission will be scattered and/or absorbed each time the liquid is clouded by the instantaneous core of cavitation bubbles, due for one reason to the fact that these cavitation (vapor) bubbles have a different index of refraction from the liquid phase. Hence the light level on the output side of the transducer element 18b will diminish in correspondence with the concentration of localized bubbles.

If the body of liquid 58 in the light valve is opaque so as to rely primarily upon its absorptive properties, then I prefer a solution of light-absorbing dye and alcohol or water, for example. The dye selected should have a different vapor pressure from the liquid in the main solution; in that way the cavitation bubbles will consist predominantly of transparent vapor thus reducing the light absorbing properties of the solution. When the amplitude of vibration of the element 18b is high, a good concentration of the localized cavitation bubbles can cooperatively transmit a noticeable level of light to the output side of the transducer. Certain inks can be employed as the proper liquid solution so long as they are diluted sufficiently to be of a semi-opaque or near semi-opaque state.

Following each of the block elements of FIGURE 4 are examples A, B, C, D, E, F, G of FIGURE 5 illustrative of the respective modulated wave and light intensity shapes for code transmission. Voice transmissions and other transmissions, particularly in the audio range, can be equally well handled by the present device but for the sake of brevity, these further examples of wave forms are not illustrated.

As herein disclosed, according to FIGURE 2, the magnetostrictive material of the body of the transducer element 18b is nickel. It is evident that a large group of magnetostrictive materials is available for these bodies including powder iron-nickel products, ferroceramic products such as "ferrox-cube" as it is commercially known by its proprietary name, Alnifer, and various compositions of iron-nickel alloys. Each time the element vibrates, it physically disturbs the immediate film of medium in contact with its circular interface, thereby focusing energy waves in the medium which travel at the speed of sound towards the geometric center. The size and concentration of cavitation bubbles created at the focal point correspond to the amplitude of the vibration. The core of bubbles is approximately coextensive in length with the transducer element along its axis.

So also the drawing discloses that the O-ring seals 60 are recessed in a groove so as to protrude slightly into contact with a flat confronting surface on the transducer unit 50; this seal construction and contact enables the transducer unit 50 to float as it vibrates; self evidently there are other seal arrangements which can satisfactorily be employed, or no seals at all as schematically represented by the container 20 of FIGURE 1 wherein the transducer element 18a is completely immersed within a container.

Variations within the spirit and scope of the invention described are equally comprehended by the foregoing description.

I claim:

1. In a device of the character described, a container with opposite transparent walls for holding liquid and adapted to have a light beam directed on an axis through the walls of the container, and a transducer ring of magnetostrictive material in said container and energizable with pulsating magnetostrictive power input for creating with respect to the oscillating circumference within the ring a cloud of instantaneously appearing and disappearing liquid cavitation bubbles in the geometric center of the ring in the area of said axis to vary the percentage of light transmitted between said walls.

2. In a device of the character described, a container with opposite transparent walls for holding liquid and

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adapted to have a light beam directed normal to and through said walls, and a ring of transducer material in said container, and energizable with pulsating transducer power whereby the entire circumference of the ring oscillates for creating with respect to the circumference within the ring, liquid cavitation bubbles in the geometric center of the ring in the area between said walls to vary the intensity of light transmitted from one wall to the other, said walls constituting optical lenses.

3. In a device of the character described, a container with opposed transparent walls for holding liquid, said container adapted to have a light beam directed there-through between said walls, said walls constituting optical lenses, a vibratile transducer ring in said container effective when actuated with fluctuating energy for creating instantaneously appearing and disappearing liquid cavitation bubbles to vary the intensity of light transmitted between said walls, said ring being encapsulated in a thin-walled plastic cylinder, and annular seals disposed one between each of the opposite ends of said cylinder and the wall at that end creating a liquid-tight joint whereby the cylinder is capable of limited movement with the transducer ring without incurring leakage at the joint with the walls.

4. In a device effective to hold liquid for the purposes described, a generally cylindrical housing and a generally cylindrical transducer element arranged one within another and with an annular space between, and transparent plates disposed at opposite ends of the transducer element and each clamped between an end of the transducer element and the housing at that end for holding the liquid in said device in contact with the transducer element, said transducer element having an electrical coil wound thereon for receiving electrical impulses at the natural frequency of said element and causing said element to vibrate at resonance.

5. In a device of the character described for holding fluid, a generally cylindrical housing and a generally cylindrical transducer element arranged one within another with an annular space between, transparent plates disposed at opposite ends of the transducer element and each clamped between an end of the transducer element and the housing at that end, said transducer element having a toroidal coil wound thereon for receiving electrical impulses at the natural frequency of said transducer element for causing the same to vibrate, and seals interposed between the transparent plate at each end of the transducer element and the transducer element at that end for holding the fluid liquid-tight within the device.

6. In a system which transmits on a beam of light as the line of transmission, a lens system in the line of transmission including a confined liquid, a generally annular body of material selected from the class consisting of piezoelectric and magnetostrictive materials, said body being immersed in said liquid in a disposition with its geometric center of generation at a point generally concentric with the area through which the beam passes, and energy applying means connected to apply energy to the body for imperceptibly changing the physical dimensions of said body at high frequencies so as to physically disturb the immediate film of liquid in contact therewith, thereby focusing energy waves in the liquid at the geometric center of generation of said body for causing a cloud of cavitation bubbles to repetitively appear and disappear in line with the light beam.

7. In a system for transmitting on a beam of light as the line of transmission, a lens system in the line of transmission including a confined fluid sonic medium, a generally annular transducer body for converting electrical energy to sonic energy and immersed in said medium with its geometric center of generation at a point concentric to the area through which the light beam passes, and tuned electrical means connected to apply

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electrical energy to the transducer body for imperceptibly changing the physical dimensions of said transducer body at its natural resonant frequency so as to physically disturb the immediate film of medium in contact therewith, thereby focusing energy waves in the medium which travel at the speed of sound to the geometric center of generation of said transducer body thereby causing a concentrated cloud of cavitation bubbles to repetitively appear and disappear in line with the light.

8. A lens system for controlling the transmission of light, comprising means for restricting the amount of light in said system to a limited pass band of frequencies and including a light filter, means for focusing said light as a beam for effective directivity at a distance and including lenses made of solid transparent material, means in which there is repetitively introduced a rapidly appearing and disappearing cloud to vary the quantity of light scattering away and/or absorbed from said beam and including an incompressible transparent fluid, and sonic energy emitting means for repetitively creating a group of temporary cavitation bubbles in said fluid so as to form the rapidly appearing and disappearing cloud aforesaid, said sonic energy emitting means comprising transducer means in contact with said fluid and shaped to provide a focusing point so as to concentrate said bubbles at a common spot, said transducer means being geometrically arranged with respect to the filter, lenses, and fluid so that the filter, lenses, and common spot of bubbles are optically aligned with the light in the system.

9. In a system of optical beam communication adapted to modulate a beam of optical radiations establishing a line of transmission through the atmosphere, an interposed fluid medium in the line of transmission, means to introduce from a ring of points sonic waves in said medium comprising high frequency transducer means in communication with the fluid of said medium in the ring of points aforesaid, said transducer being vibratable to introduce from the respective directions of said points streams of waves in impingement against one another in the sole region of confluence common thereto to create a concentrated cavitation disturbance therein and having an input, and power delivery means for applying power to vibrate said transducer comprising carrier means to impress in the input of said transducer a fundamental carrier frequency which at least approximates the natural resonant frequency of the transducer.

10. In a system of optical beam communication provided with means for emitting a beam of optical radiations to establish the line of transmission, the combination comprising: interposed means in the line of transmission having an electrical input and varying in its transmitting property in response to said input; said interposed means including a body of liquid; means to direct sonic waves in different directions into the body of said liquid comprising high frequency transducer means having general, hollow cylindrical shape and being within the cylindrical interior thereof in communication with the body of liquid; said transducer means being vibratable, in response to input to the interposed means, to introduce from the locus of points defined by its cylindrical interior streams of waves in impingement against one another in the sole region of confluence common thereto thereby to create a locally concentrated cavitation disturbance therein; and a modulator device comprising modulating means and carrier means having a frequency higher than said modulating means, said carrier means developing a fundamental carrier frequency and being modulated by said modulating means; and means comprising a power amplifier coupled between the modulator device and said interposed means for impressing a modulated carrier signal in the input of said interposed means.

11. A lens system for controlling the transmission of light to a remote demodulator type utilization apparatus

in photosensitive relation thereto, said system comprising means for restricting the amount of light in said system to a limited pass band of frequencies and including a light filter, means for focusing said light as a beam for effective directivity at a distance and including lenses made of solid transparent material, means in which there is repetitively introduced a rapidly appearing and disappearing cloud to vary the quantity of light scattering away and/or absorbed from said beam and including an incompressible transparent fluid, high frequency sonic energy emitting means for repetitively creating a group of temporary cavitation bubbles in said fluid so as to form the rapidly appearing and disappearing cloud aforesaid, said filter, lenses, fluid, and high frequency sonic energy emitting means being in optical alignment with the light, said high frequency sonic energy emitting means comprising transducer means in contact with the fluid and conforming to the arc of a circle and arranged in a location to provide a focusing region at the center concentrating said bubbles at a common region in the line of the light, said high frequency sonic energy emitting means operating in response to an input signal.

12. For use with a system of optical beam communication utilizing optical radiations for establishing a beam of transmission along a line: a beam valve comprising a beam-obstructing, fluid medium adapted to be interposed in the line of transmission to modulate said optical beam; means to introduce from a ring of points sonic waves in said medium, including high frequency transducer means in communication with the fluid of said medium in the ring of points aforesaid; said transducer means being vibratable to introduce from the respective directions of all of said points streams of waves in impingement against one another in a common area of confluence thereby to create locally concentrated cavitation disturbances therein and having an input; and power delivery means for applying power to vibrate said transducer, including carrier means to impress in the input of said transducer a fundamental carrier frequency which at least approximates natural resonant frequency of the transducer means.

13. For use with a system of optical beam communication provided with means for emitting a beam of optical radiations to establish the line of transmission: the combination comprising means for interposition in the line of transmission having an electrical input and varying in its transmitting property in response to said input, said interposed means including a body of beam obstructing liquid; means to direct sonic waves in different directions into the body of said beam obstructing liquid, including high frequency transducer means curved on the arc of a circle, and being in communication with the liquid along a circular locus of points; said transducer means being vibratable, in response to input to the interposed means, to introduce in the respective directions aforesaid streams of waves from the circular locus of points in impingement against one another in a common area of confluence thereby to create locally concentrated cavitation disturbances therein; and a modulator device comprising modulating means and carrier means having a frequency higher than said modulating means, said carrier means developing a fundamental carrier frequency and being modulated by said modulating means; and means including a power amplifier coupled between the modulator device and said interposed means for impressing a modulated carrier signal in the input of said interposed means.

14. The method of utilizing a sonic medium to control the transmission of light in a beam directed toward said medium, comprising the steps of generating along a circular locus of points, repetitive waves of energy in said medium traveling at the speed of sound, and convergently directing said energy waves through the sonic medium so as to focus in the precise region of the locus

center at which cavitation bubbles repetitively appear and disappear as a cloud due to the resulting condensations and rarefactions of wave energy in the medium.

15. Improved method useful in optically controlling a beam of electromagnetic radiations or the like following a line of transmission, including the steps comprising: generating from a circular locus of points defined by transducer means, waves of energy of controlled magnitude at electrical frequencies in a cavitatable medium having variable translucency; and projecting said waves from said circular locus of points so that they impinge in the medium upon one another creating a highly localized cavitation disturbance at a region therein which, when in optical coincidence in a line of radiation transmission, is effective to cause the radiation beam to be variably attenuated in passing through the cavitatable medium.

16. In a process useful in optically controlling a beam of electromagnetic communication radiations or the like following a line of transmission: the improved steps comprising interposing a cavitatable fluid medium in alignment with the line of transmission; and contacting the medium with the geometrically focused annular interior surface of a vibrating transducer so as to project waves of energy of controlled magnitude at the transducer frequency from the locus of points defined by said annular interior surface, into the medium for generating a repetitive cavitation disturbance which, when focused in a line of transmission, causes a radiation beam passed through the medium to be variably attenuated thereby as a function of the repetitive cavitation disturbance.

17. In a method of utilizing a sonic medium to control the transmission, for communication purposes, of a beam of optical radiations directed toward said medium: the improved steps comprising generating at a ring of points, repetitive waves of energy in said medium traveling at the speed of sound; and projecting said waves of energy in a mutually converging direction from each of the ring of points through the sonic medium and at right angles to said beam of optical radiations so as to focus said waves at a general region of concentration at which cavitation bubbles repetitively appear and disappear as a cloud for scattering and/or absorbing a portion of the optical radiations in said beam, said waves comprising a carrier component and a modulating signal component.

18. A method of communicating by means of a line of transmission through the atmosphere to a remote receiving point, comprising the steps of interposing a fluid medium aligned with the line of transmission, introducing from a ring of points on a common oscillating body waves of energy into the medium which are of controlled magnitude at electrical frequencies and which impinge on one another in a region at the geometric center constituting the sole region of confluence and being in the line of transmission, and projecting a beam of optical radiations along the line of transmission toward said remote receiving point and passing through said medium whereby the cavitation disturbances created in said sole region of confluence modulate the intensity of the beam as a function of the desired communication being transmitted.

19. A method of communication by means of a line of transmission through the atmosphere to a remote receiving point comprising the steps of interposing a fluid medium in alignment with the line of transmission, contacting the medium with the geometrically focused annular interior surface of a vibrating annulus of transducer material so as to introduce from the common annulus waves of energy into the medium which are of controlled magnitude at the vibrating frequency and which impinge on one another generating cavitation disturbances focused in a region at the geometric center constituting the sole region of confluence and being in the line of transmission, and projecting a beam

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of optical radiation in the atmosphere in the direction of said remote receiving point and passing in the line of transmission through said cavitation disturbances whereby the communication transmitted will be a function of said disturbances.

20. The method of utilizing a sonic medium to control the transmission of a beam of optical radiations directed toward said medium, said method comprising: generating along a circular locus of points, repetitive waves of energy in said medium traveling at the speed of sound; directing said waves of energy in a converging direction through the sonic medium and at right angles to said beam of optical radiations so as to focus said waves in the precise region of the locus center and with forced concentration by which cavitation bubbles repetitively appear and disappear as a cloud for scattering and/or absorbing a portion of the optical radiations in said beam, said waves comprising a carrier component

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and a modulating signal component; and sensing, by means of a photosensitive surface, and demodulating, by a demodulator, the remaining portion of optical radiations in said beam so as to reproduce said modulating signal component.

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