

[54] UNIPOLAR ACOUSTIC PULSE  
GENERATOR APPARATUS

3,715,710 2/1973 Bernstein et al. 340/15 X

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[22] Filed: Apr. 26, 1973

[57] ABSTRACT

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[52] U.S. Cl. 340/5 R; 310/8.1; 340/10;  
340/15

[51] Int. Cl. H04b 11/00

[58] Field of Search 340/3 A, 5 R, 10, 15;  
310/8.1, 8.2, 9.5, 9.6

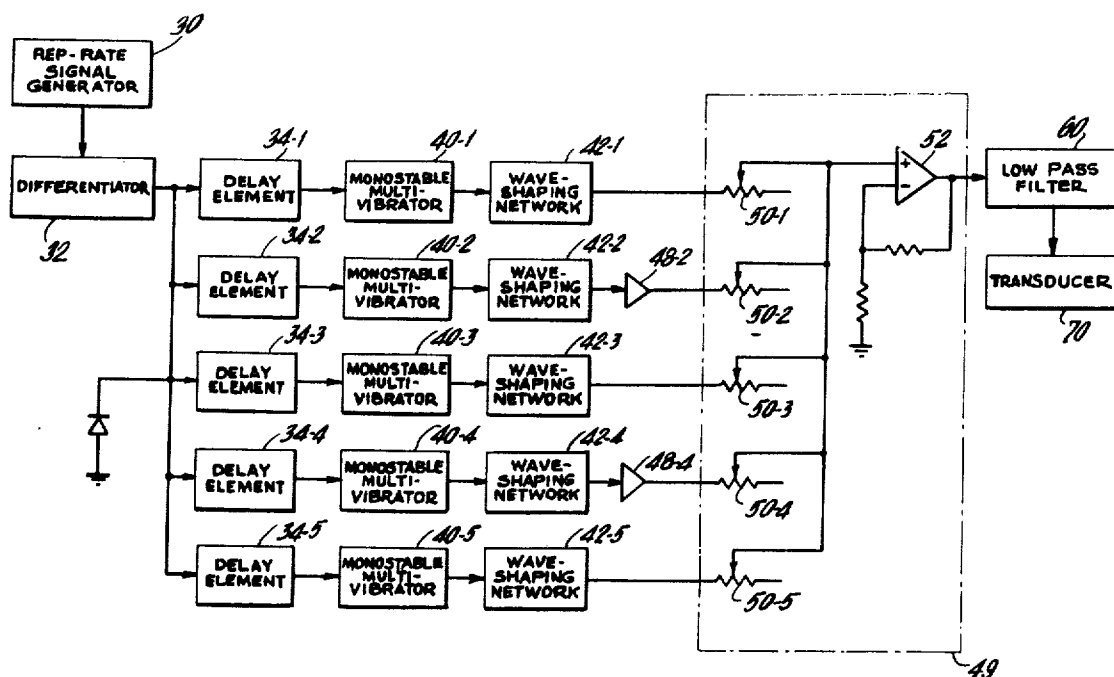
In apparatus for producing a unipolar displacement of the radiating face of an electroacoustic transducer to generate unipolar acoustic pulses in an acoustic medium, the transducer dimension perpendicular to the radiating face of the transducer is chosen to simplify the response of the transducer, thereby simplifying the required transducer driving signals and the apparatus required to generate those signals.

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20 Claims, 27 Drawing Figures

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SHEET 1 OF 5

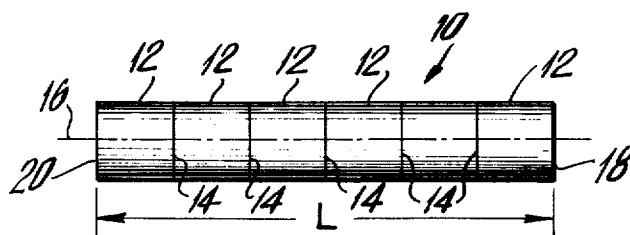


FIG. 1

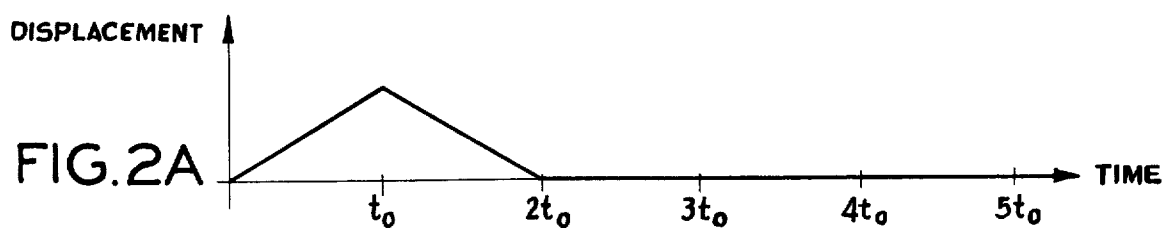


FIG. 2A

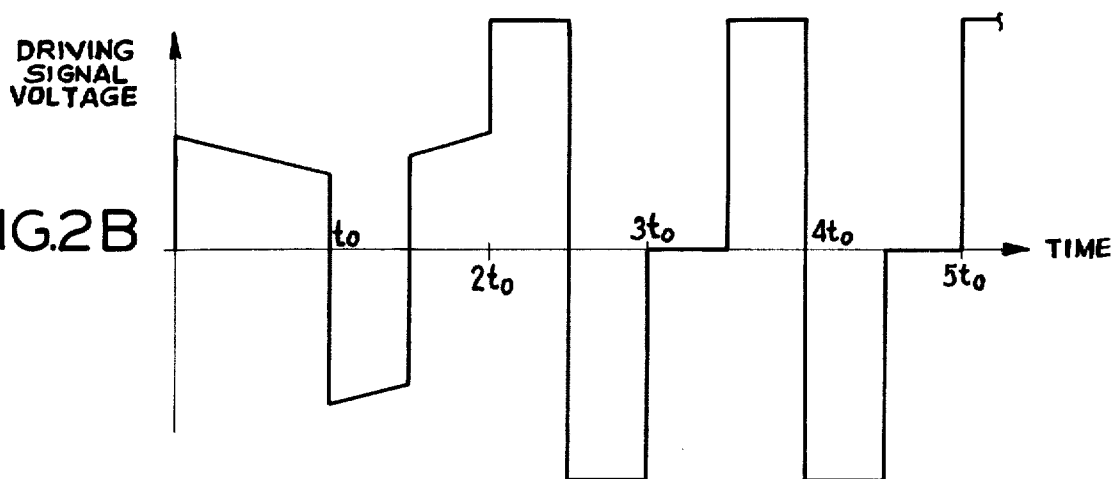


FIG. 2B

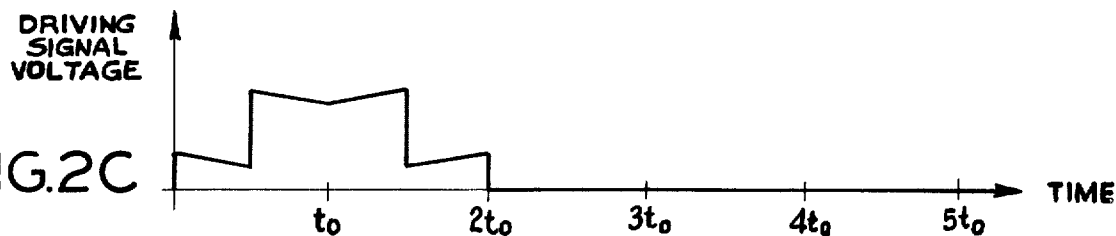


FIG. 2C

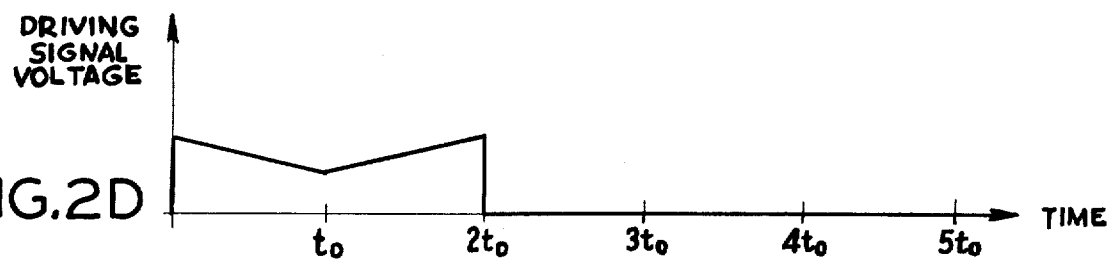
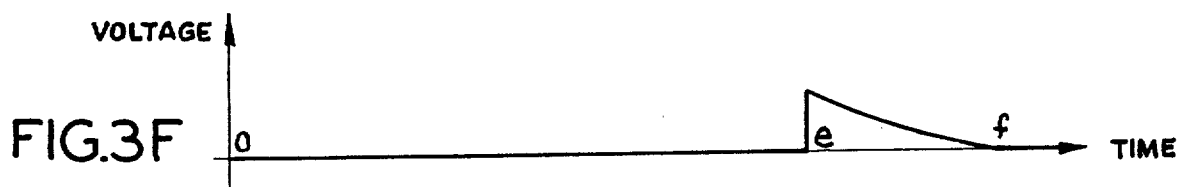
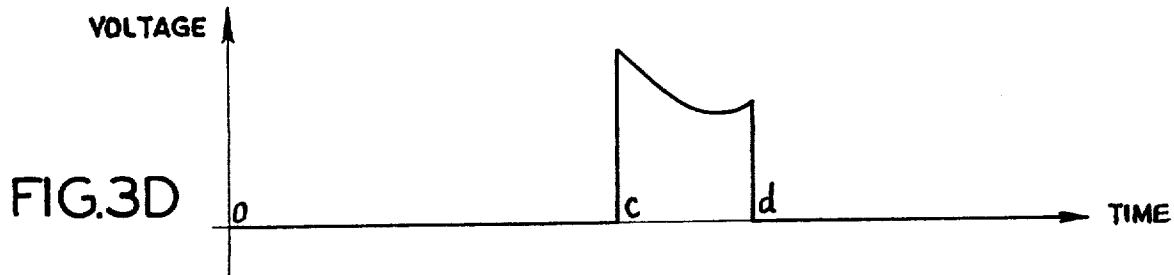
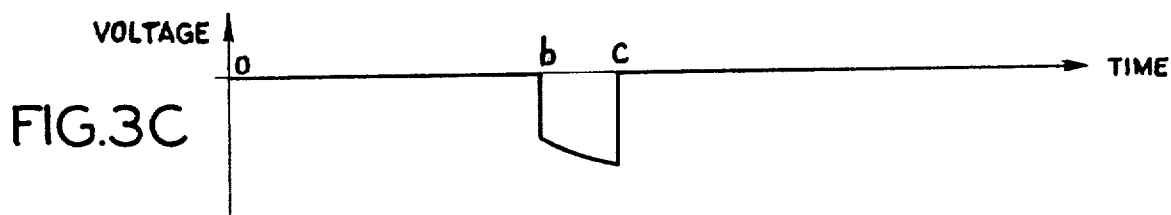
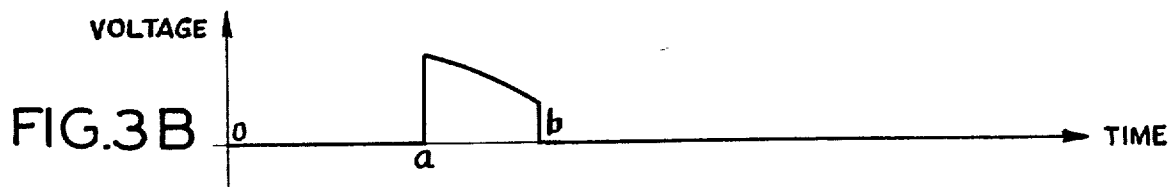
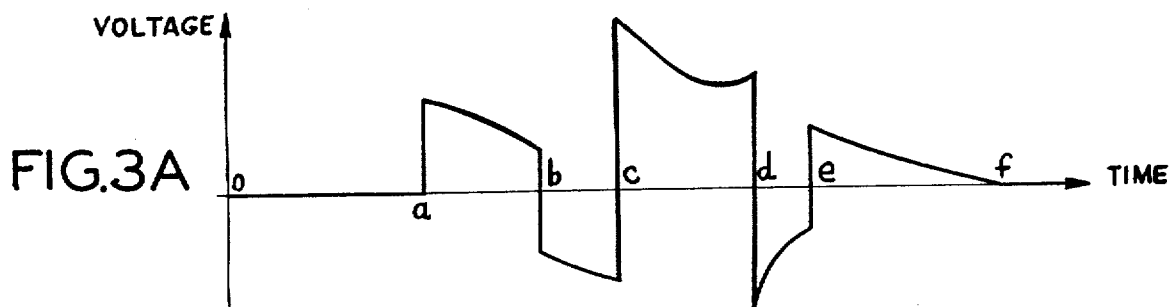


FIG. 2D



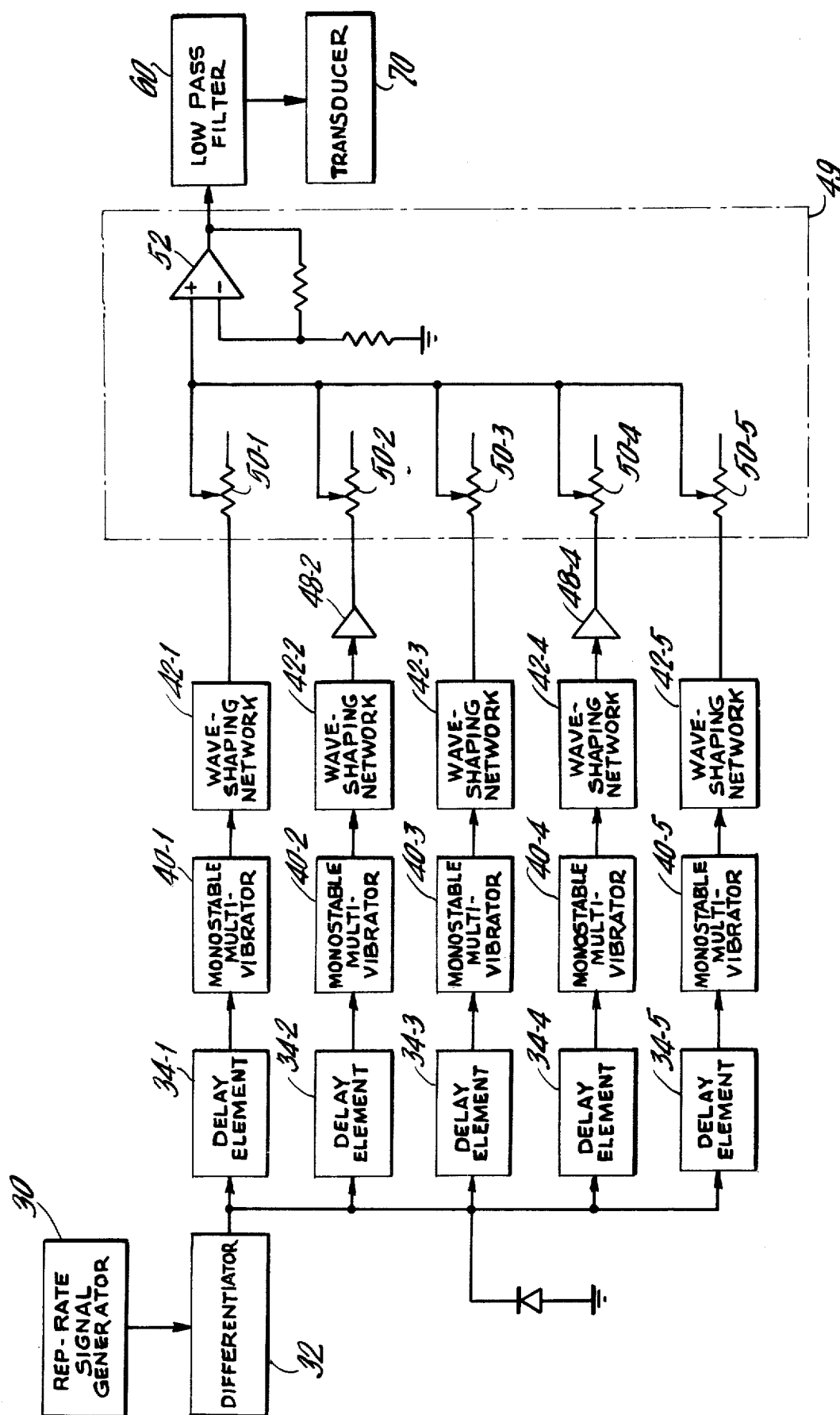


FIG. 4



FIG. 5L

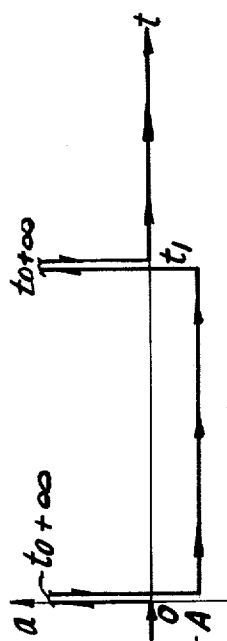


FIG. 5M

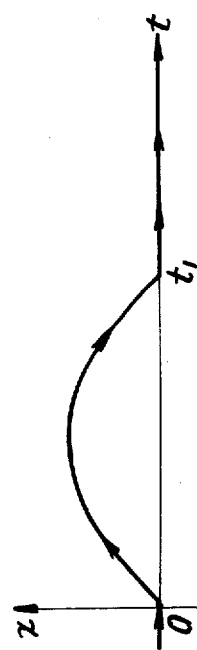


FIG. 5N

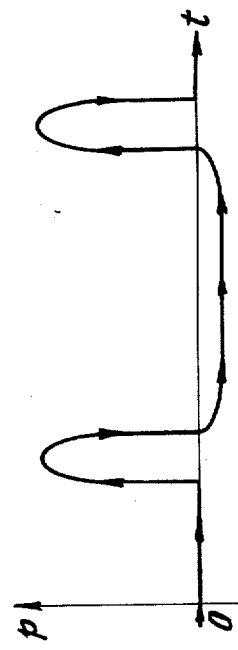


FIG. 5P

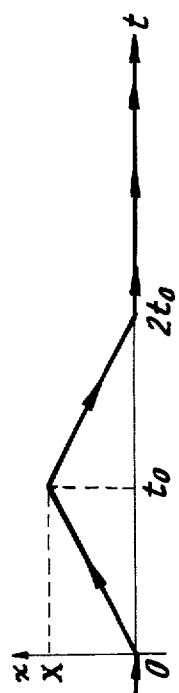


FIG. 5I

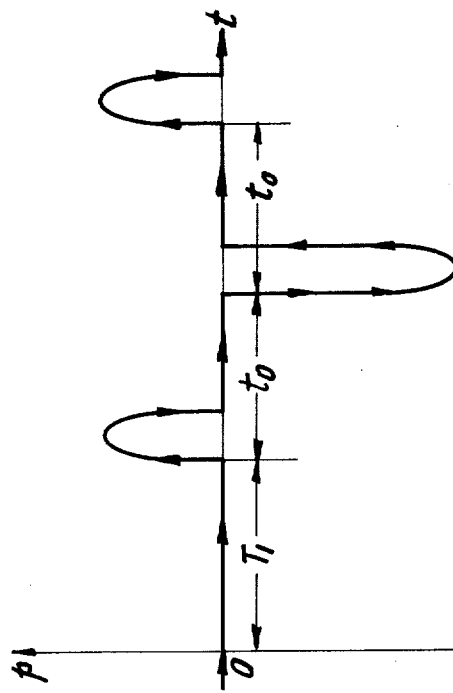


FIG. 5J

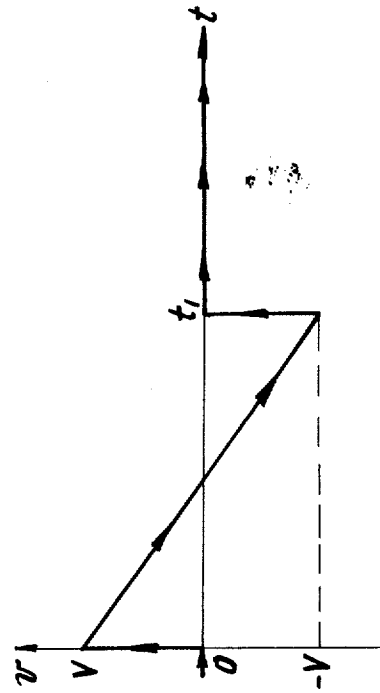


FIG. 5K

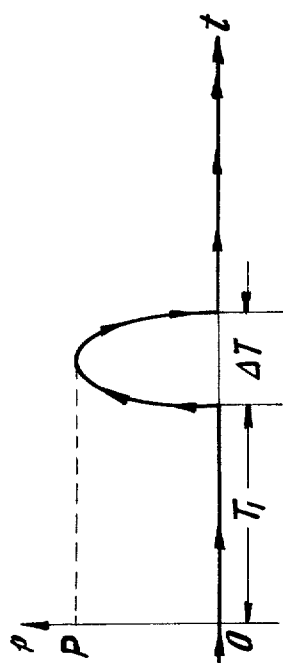


FIG. 5A

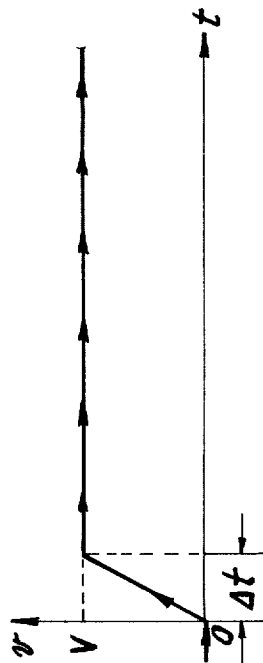


FIG. 5B

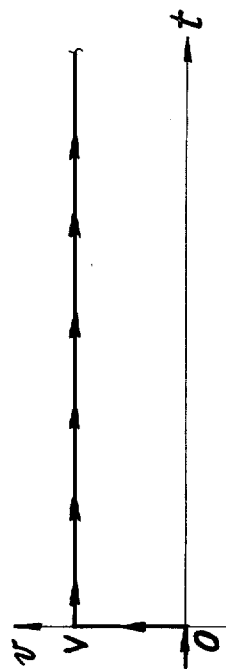


FIG. 5C

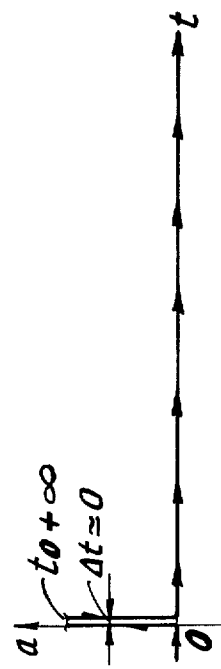


FIG. 5D

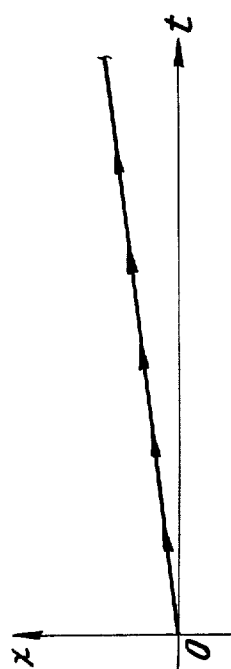


FIG. 5E

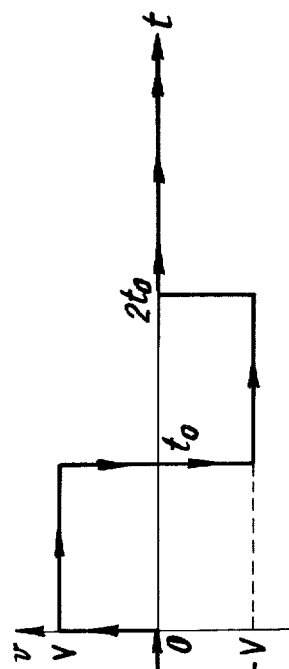


FIG. 5F

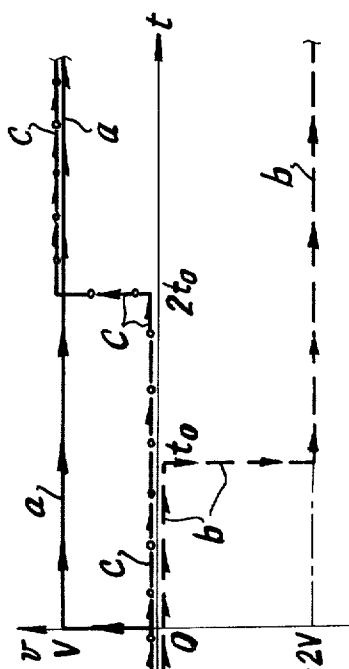


FIG. 5G

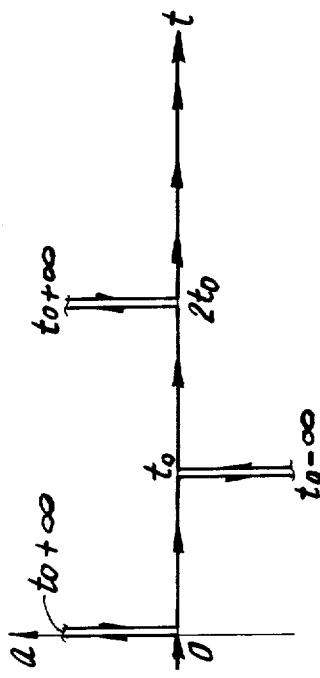


FIG. 5H

## UNIPOLAR ACOUSTIC PULSE GENERATOR APPARATUS

### BACKGROUND OF THE INVENTION

This invention relates to electroacoustic transducer apparatus and, more particularly, to electroacoustic transducer apparatus for producing high energy unipolar pressure pulses in an acoustic medium (e.g., air or water).

Unipolar acoustic pulses are useful in a wide variety of applications. In underwater sonar, for example, unipolar acoustic pulses radiating from a transducer can be used for high resolution object detection, identification, and the like. Unipolar acoustic pulses are typically generated by producing a unipolar displacement of the radiating face of a transducer device (e.g., an electroacoustic transducer device) which is immersed in or otherwise contiguous with an acoustic medium. In general, the unipolar displacement of the radiating transducer face (sometimes referred to herein as a unipolar transducer displacement or unipolar transducer response) results in a sequence of unipolar acoustic pulses in the acoustic medium. The individual pulses in such a sequence do not generally correspond to the amplitude and duration of the unipolar transducer displacement. Rather, the sequence of the acoustic pulses usually corresponds more nearly to the second derivative of the displacement of the radiating transducer face (i.e., the acceleration history of the radiating transducer face). Unipolar transducer displacements are employed not because they uniquely result in unipolar acoustic pulses, but because the acoustic pulse sequences produced are relatively uncomplicated and of short duration (i.e., not substantially longer than the transducer displacement pulse). This latter feature is particularly desirable for pulse repetition purposes. In reading this specification, the distinction between unipolar transducer displacement and unipolar acoustic pulses must be kept clearly in mind.

In U.S. patent application Ser. No. 92,798, now U.S. Pat. No. 3,715,710, J. Bernstein, et al., disclose apparatus for producing unipolar displacement of the radiating face of an electroacoustic transducer. In accordance with the principles of that invention, a transducer (e.g., a cylindrical piezoelectric transducer) is driven by an electrical signal having discontinuities in amplitude which initially stimulate vibration or mechanical oscillation of the transducer and then, after a half cycle of transducer oscillation in the fundamental mode, substantially dampen the oscillations of the transducer. Transducer oscillations are damped by applying signal discontinuities to the transducer which would produce oscillations of the same amplitude as the oscillations to be damped, but in phase opposition thereto, thereby interfering with and tending to cancel out the undesired oscillations. Since transducers of the type described may exhibit more than one mode of vibration in each physical direction, it is appropriate to provide a driving signal having discontinuities for damping oscillation in several of the more significant modes in order to produce a "clean" (i.e., sharply defined) unipolar transducer response. In general, even for very simply shaped transducer responses, the required driving voltage waveforms are quite complex and so will be the electrical or electronic apparatus used to generate these waveforms.

It is therefore an object of this invention to improve and simplify unipolar acoustic pulse generating apparatus of the type described in the above-mentioned patent application of J. Bernstein, et al.

It is more particular object of this invention to provide apparatus for generating sharply defined unipolar transducer responses without the need for complex transducer driving signals or the complicated apparatus required to generate such signals.

### SUMMARY OF THE INVENTION

These and other objects of the invention are accomplished in accordance with the principles of the invention by unipolar acoustic pulse generator apparatus in which a certain dimension of the electroacoustic transducer is chosen to simplify the response of the transducer, thereby simplifying the required transducer driving signals and the apparatus required to generate those signals. More particularly, the length  $L$  of the transducer is chosen so that a time parameter  $t_0$  of the desired unipolar transducer response is an integer multiple of the time required for an acoustic wave to propagate through the transducer along its length  $L$ . In the case of a transducer without end masses, the time required for an acoustic wave to travel the length of the transducer is given by the quotient  $L/c$ , where  $c$  is the velocity of acoustic waves in the material of the transducer. In that event the transducer is designed in accordance with the principles of this invention so that  $t_0$  is an integer multiple of the quotient  $L/c$ .

Further features and objects of the invention, its nature, and various advantages will be more apparent upon consideration of the attached drawing and the following detailed description of the invention.

### BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 illustrates a transducer of the type used for generating unipolar acoustic pulses in an acoustic medium;

FIG. 2A is a diagram of an idealized unipolar displacement of the radiating face of the transducer of FIG. 1 plotted against time;

FIG. 2B illustrates the driving signal voltage waveform required to generate the unipolar transducer response of FIG. 2A in the general case;

FIGS. 2C and 2D illustrate driving signal voltage waveforms required to generate the unipolar transducer response of FIG. 2A when the longitudinal transducer dimension is chosen in accordance with the principles of this invention;

FIG. 3A illustrates a generalized transducer driving signal voltage waveform;

FIGS. 3B through 3F illustrate individual voltage pulses which can be combined to produce the waveform of FIG. 3A;

FIG. 4 is a schematic block diagram of apparatus for generating transducer driving signals of the type shown in FIGS. 2C, 2D, and 3A; and

FIGS. 5A through 5N and 5P are a series of diagrams useful in understanding the principles of this invention.

### DETAILED DESCRIPTION OF THE INVENTION

As shown in FIG. 1, a typical cylindrical electroacoustic transducer 10 is made up of a plurality of discs 12 interspersed with electrodes 14 and bonded together with adhesives or the like. Discs 12 are a piezoelectric material (e.g., barium titanate or lead zirconate

titanate) polarized to operate in the "33 mode" wherein the mechanical stresses in the transducer material are parallel to the longitudinal axis 16 of the transducer and perpendicular to the electrodes. Electrodes 14 are interconnected by well-known wiring arrangements (not shown). When transducer 10 is energized by a suitable driving signal applied to electrodes 14, one or more acoustic pulses radiate from face 18 of the transducer into a surrounding acoustic medium, e.g., air or water. The opposite end 20 of transducer 10 (i.e., the non-radiating end) is shown as free, but the principles of the invention apply with only minor modifications to transducer configurations in which the non-radiating end is either clamped, attached to springs, or otherwise restrained in any manner.

A generally desirable type of unipolar pressure pulse in an acoustic medium is shown in FIG. 5A. FIG. 5A shows the time history of the pressure, relative to that in the quiescent condition, at a typical point in the acoustic medium. Generally, any other point in the medium will undergo similar pressure changes but with different values of maximum pulse pressure  $P$ , starting time  $T_1$ , and pulse duration  $\Delta T$ , depending on the location of the point relative to the radiator, i.e., the mechanism producing the pulse. The positive unipolar pressure values shown in FIG. 5A signify that the medium suffers only compressive stresses, as opposed to negative tensile stresses which, in a liquid medium, are conducive to cavitation and, therefore, generally undesirable. In most applications, it is desired to make the maximum pulse pressure  $P$  as large as possible, while maintaining relatively small values of the pulse duration  $\Delta T$ . In general, the pressure pulse experienced at any point in the medium depends on the geometry of the radiator, the geometry of the medium's boundaries, and on the motion of the radiator, more specifically, its acceleration. Well known acoustical theory shows that a unipolar acoustic pulse, of the type shown in FIG. 5A, can be produced by a radiator in the form of a rigid, planar, circular piston, as shown in FIG. 1, set in a large coplanar rigid baffle acting as a boundary of the medium, when said piston undergoes an axial motion described by the theoretical ramp-type velocity function shown in FIG. 5B. Larger peak pressures  $P$  in the medium result both from larger peak velocities  $V$  and from shorter velocity rise-times  $\Delta t$ , and such shorter rise-times  $\Delta t$  also result in shorter pulse durations  $\Delta T$ . If, as is generally desirable,  $\Delta t$  is made extremely small, the corresponding piston motion can be closely approximated by a theoretical impulsive, i.e., step-type velocity function, shown in FIG. 5C. FIGS. 5D and 5E show the theoretical piston acceleration and displacement functions corresponding to the velocity function to FIG. 5C. The notation "to  $+\infty$ " in FIG. 5D indicates that the theoretical acceleration is extremely large. The theoretical displacement (FIG. 5E) has both unrealistic and undesirable features in that the piston displacement increases uniformly with time, meaning that the piston never stops moving and, by the same token, never returns to its original position ( $x = 0$ ). In particular, the latter feature would prevent its suitability for all known practical applications, which require repetition of pulses. These objections can be overcome by incorporating reversal of the piston's motion, but then only at the expense of introducing negative portions into the pressure response time histories. One obvious way of doing this is to use the (theoretical) piston motion

whose time history is illustrated by the velocity, acceleration, and displacement functions of FIGS. 5F, 5G, 5H, and 5I. FIG. 5G illustrates the fact that the bipolar, rectangular-type velocity function of FIG. 5F is equivalent to the superposition of three step-type functions displaced in time, of which the intermediate one has a (negative) polarity opposite to that of the other two. The time history of the pressure response at a typical point in the medium to the piston motion of FIGS. 5F through 5I consists of the bipolar pulse sequence shown in FIG. 5J which in addition to the two desirable high pressure pulses, also contains an undesirable high negative pulse. Such high negative pressure pulses can be virtually eliminated by use of a (theoretical) piston motion such as that illustrated in FIGS. 5K, 5L, 5M, and 5N. FIG. 5L shows how the velocity function of FIG. 5K may be regarded as the superposition of four "on-going" functions, two of which are ramp-type functions such as that previously illustrated in FIG. 5B, the other two being step-type functions similar to the one previously illustrated in FIG. 5C. As shown in FIG. 5P, at any typical point in the medium the pressure response to the piston motion of FIGS. 5K through 5N consists of a sequence of two very high positive pressure pulses separated by a time interval during which the pressure is negative but of such low amplitude that cavitation in liquid media can be precluded. In summary, the preceding shows that, through proper control of the motion of a flat piston, pressure pulse sequences can be achieved, using piezoelectric transducers, which contain the desirably high positive pressure peaks and which are still essentially cavitation free. Although, technically, these are "bipolar" pulse sequences, from a practical viewpoint they can be regarded as "unipolar" ones.

FIGS. 5G and 5L show that the genuinely bipolar pulse sequence is inherently less complex than the "practically unipolar" one because the former only involves step-type velocity functions. For that reason, and although the principles of this invention are applicable to a wide variety of practically unipolar piston motions such as that illustrated in FIGS. 5K through 5N, the invention will be most readily understood from an explanation of its application to generating the transducer response (piston motion) of FIGS. 5F through 5I. Thus, the particular piston displacement history of FIG. 5I is selected for convenience in illustrating the basic principles of the invention and not necessarily because the resulting acoustic pulses are the most desirable for any particular application.

In general, without the benefit of the present invention, the driving signal voltage required to produce a transducer response of the type shown in FIG. 2A (similar to FIG. 5I) has a complicated shape of which the one shown in FIG. 2B is typical. The waveform of FIG. 2B includes a sudden rise at  $t = 0$  followed by several segments of varying amplitude separated by further discontinuities. After  $t = 2t_0$  the waveform consists of a repetition of a rectangular type wave pattern which in theory continues indefinitely. This latter portion of the waveform of FIG. 2B is required to dampen oscillation of transducer 10 in its longitudinal mode of oscillation, as previously explained. The waveform of FIG. 2B has the disadvantage of being relatively complex, and can only be generated by extremely sophisticated circuitry. In addition, the waveform of FIG. 2B has the undesirable feature that it continues indefinitely, or at least for

some time after the desired unipolar transducer output pulse has been generated. This makes it very difficult to use transducer 10 to generate successive output pulses, as may be desirable in certain applications.

In accordance with the principles of this invention, the driving signal waveform required to produce a transducer response of the type shown in FIG. 2A can be considerably simplified by choosing the transducer dimension  $L$  perpendicular to the radiating face 18 of the transducer so that the half pulse duration time parameter  $t_0$  is an integer multiple of the quotient  $L/c$ , where  $c$  is the velocity of acoustic waves in the material of transducer 10. The quotient  $L/c$  is a time parameter corresponding to the time required for an acoustic wave to propagate through the transducer along its length  $L$ .

FIG. 2C shows the driving signal waveform required to produce the transducer response of FIG. 2A when  $t_0 = 2L/c$ . FIG. 2D shows the waveform required when  $t_0 = L/c$ . All of FIGS. 2B through 2D have approximately the same vertical scale. Not only are the waveforms of FIGS. 2C and 2D considerably simpler than the waveform of FIG. 2B, they also involve smaller signal amplitudes and have zero amplitude after  $t = 2t_0$ . Accordingly, very much simpler apparatus can be used to generate the required driving signals. In addition, since the input pulse duration is the same as the duration of the desired transducer response (i.e.,  $2t_0$ ), transducers constructed in accordance with the principles of this invention are conveniently employed in applications requiring output pulse repetition at small time intervals.

The greatest advantage is gained by choosing  $L$  such that  $t_0 = L/c$ . In that case the simplest driving signal waveform (FIG. 2D) is required and the driving signal pulse amplitudes are further reduced. The condition  $t_0 = L/c$  can be achieved for reasonable values of  $L$  provided that  $t_0$  is not excessively small. For example, with the piezoelectric transducer materials presently in use, the optimum transducer lengths corresponding to a transducer response duration ( $2t_0$ ) of 50 microseconds are between  $8\frac{1}{2}$  and 11 inches, a range common to many existing transducers.

More generally, for a single unipolar transducer response having a half pulse duration time parameter  $t_0$  and having a shape other than the triangular shape shown in FIG. 2A (e.g., the shape shown in FIG. 2N), the same principles discussed above apply. That is, the production of one such displacement pulse is most efficiently achieved by means of a specific curved input voltage waveform of the same duration in conjunction with a transducer of length  $L = ct_0$ .

It can be shown that if a transducer equipped with end masses is used, the quotient  $L/c$  appearing in the preceding discussion must be replaced by an effective time parameter value which accounts for the time required for an acoustic wave to traverse the lengths of the end masses as well as the length of the transducer material. Similarly, effective traversal times for more complex transducer configurations, such as those employing bias bolts and the like, can be readily established by those skilled in the art.

Similar principles also apply to transducer shapes other than the cylindrical shape discussed above. Generally, each transducer shape utilizes a particular arrangement of electrodes such that an alternating input voltage whose frequency lies within a predetermined range causes the transducer to vibrate or resonate in a

specific mode of oscillation. For such other transducer shapes to furnish unipolar acoustic output pulses in an optimum manner, it is necessary that certain of the transducer dimensions be specifically related to the duration of the desired transducer response, that the input voltage pulse duration be the same as that of the transducer response, and that the shape of the input pulse bear a specific relation to that of the transducer response.

Similar considerations also apply to those transducers which exhibit more than one natural mode of oscillation. A well-known and frequently occurring example is in certain mass-loaded cylindrical transducers wherein, in addition to the basic longitudinal or axial vibrations, the transducer head can execute bending oscillations by virtue of the head flexibility, this motion being generally coupled to the basic longitudinal vibrations. In such cases, the simultaneous presence of multiple modes will generally make it necessary for optimization that specific values for more than one specific transducer dimension be used. These aspects of transducer design are discussed in greater detail in my concurrently filed patent application Ser. No. 354,519.

In general, the voltage waveforms needed to drive transducers of the type described above consist of a succession of straight or curved segments of predetermined duration connected by sudden voltage changes. A generalized illustrative waveform of this type is shown in FIG. 3A. A waveform of this type is conveniently generated as the linear sum of a set of pulses of the type shown in FIGS. 3B through 3F.

Apparatus for generating a transducer driving waveform of the type shown in FIG. 3A is shown in schematic block diagram form in FIG. 4. In overall terms, the apparatus of FIG. 4 develops the partly discontinuous, curved type waveform of FIG. 3A by generating individual curved pulses of the type shown in FIGS. 3B through 3F. These individual pulses of adjustable shape, amplitude, polarity, duration, and relative time occurrence are then linearly summed to develop the composite signal of FIG. 3A.

The apparatus of FIG. 4 includes a rep-rate signal generator 30 and differentiator 32 for generating an output trigger pulse, e.g., at a time corresponding to time 0 in FIGS. 3A through 3F. This trigger pulse is produced at the desired repetition rate for transducer output pulses. Each trigger pulse is applied to a plurality of pulse developing channels, these being five in number in the illustrative embodiment shown in FIG. 4, to develop the signals of FIGS. 3B through 3F. Each channel includes a delay element 34, e.g., a monostable multivibrator, for timing the leading edge of the pulse produced by that channel relative to the trigger pulse. Thus the delay element 34-1 in the upper channel, which develops the waveform of FIG. 3B, produces a delay corresponding to the interval  $0 - a$ . (Delay element 34-1 may be deleted if the output wave is to begin concurrent with the trigger pulse.) Similarly, delay element 34-2 produces a delay corresponding to the interval  $0 - b$ , the second channel in the apparatus of FIG. 4 producing the pulse of FIG. 3C, and so forth. The delayed trigger in each channel is applied to a timed pulse generating circuit comprising a combination of a monostable multivibrator 40 and a variable wave-shaping network 42. Each of multivibrators 40 produces a rectangular output pulse of the desired duration while the associated wave-shaping network acts to

modulate that rectangular pulse to the desired curved pulse shape. Thus multivibrator 40-1, for example, acts in conjunction with wave-shaping network 42-1 to produce the curved pulse of duration  $a - b$ , (see FIG. 3B). Similarly, elements 40-2 and 42-2 produce the curved pulse of duration  $b - c$  (see FIG. 3C), and so forth through the fifth channel which produces an output pulse of duration  $e - f$  (see FIG. 3F). The output pulse of each combination of elements 40 and 42 is applied to linear summing network 49, either directly or by way of an inverting amplifier 48 where a pulse of negative polarity is required. Linear summing network 49 comprises a plurality of potentiometers 50 having a common output node. Potentiometers 50 adjust the amplitudes of the individual pulses to the desired values. This same effect can be achieved, if desired, by incorporating potentiometers in wave-shaping networks 42 and eliminating potentiometers 50. A following operational amplifier 52 may be used for buffering and drive signal amplitude implementation and adjustment.

In accordance with one aspect of the invention it has been found that improved transducer performance results when the driving voltage waveform, such as that of FIG. 3A is passed through a low pass filter 60 before being applied to the transducer 70. The filter may, of course, be included as part of the linear summing network in any well-known manner to provide a frequency attenuating characteristic beginning at a relatively low frequency. The use of such a low pass filter has been found to improve the overall transducer output waveform by suppressing undesirable cross resonances and the like which occur in three-dimensional devices.

It will be evident that although apparatus of the type shown in FIG. 4 can be used to generate the general voltage waveform of FIG. 3A, the simpler the required waveform the simpler the apparatus required to generate it. In particular, the smaller the number of individual pulses which must be summed to produce the waveform applied to the transducer, the fewer the pulse generating channels required in the apparatus of FIG. 4. Further simplification results if the required transducer driving waveform can be made up of individual pulses of uniform polarity. In that event, none of inverters 48 are required. Thus the transducer driving waveforms of FIGS. 2C and 2D can be generated with considerably less apparatus than is required to generate the waveform of FIGS. 2B or 2A. Moreover, the waveform of FIG. 2D is the most desirable since it can be generated by summing two successive pulses of like polarity, each of duration  $t_0$ .

It is to be understood that the embodiments shown and described herein are illustrative of the principles of this invention only and that various modifications can be implemented by those skilled in the art without departing from scope and spirit of the invention. For example, various modifications of the driving signal generating apparatus of FIG. 4 will be apparent to those skilled in the art. Multivibrators 40 and the associated wave shaping networks 42 can be made manually or remotely adjustable to permit generation of individual pulses having a wide range of durations and shapes; many channels and associated channel switches can be provided so that any channel not used in a particular application can be switched out; each channel can be equipped with its own inverting amplifier and associated switch permitting the amplifier to be switched out whenever it is not required. One modification of the

driving signal generating apparatus includes use of an additional automatic control or feedback loop whereby the actual voltage waveform occurring, for example, between elements 60 and 70 in the apparatus of FIG. 4 is measured and compared with the one desired, the differences then being used to control the adjustable elements in the basic apparatus in such a way as to minimize these differences. As has been made clear in the preceding discussion, the use of an optimally dimensioned transducer will generally permit simplification of the pulse generating apparatus such as reduction of the number of required channels, simplification or elimination of some of the wave-shaping networks, elimination of inverting amplifiers, and reduction of required voltage magnitudes.

What is claimed is:

1. Apparatus for producing a unipolar displacement of the radiating face of an electroacoustic transducer having opposite radiating and non-radiating faces, said unipolar displacement being characterized by a duration time parameter  $2t_0$ , characterized in that  $t_0$  is substantially equal to an integer multiple of the time required for an acoustic wave to travel from one face of said transducer to the other, means for generating a partly discontinuous signal waveform and means for applying said signal waveform to said transducer.

2. The apparatus defined in claim 1 wherein said means for generating comprises:

means for generating a trigger signal;

a plurality of shaped pulse generating channels responsive to said trigger signal, each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse; and

means for summing the shaped output pulses of each of said channels to produce said partly discontinuous signal waveform.

3. The apparatus defined in claim 1 wherein said means for generating comprises:

means for generating a trigger signal;

a plurality of shaped pulse generating channels responsive to said trigger signal each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse;

means for summing the shaped output pulses of each of said channels; and

means for low pass filtering the sum of the shaped output pulses to produce said partly discontinuous signal waveform.

4. The apparatus defined in claim 1 wherein  $t_0$  is substantially equal to the time required for an acoustic wave to travel from one face of said transducer to the other.

5. The apparatus defined in claim 4 wherein said partly discontinuous signal waveform is characterized by an initial signal discontinuity followed by a first pulse segment of decreasing signal amplitude, a second pulse segment of increasing signal amplitude, and a final signal discontinuity.

6. Apparatus for generating unipolar acoustic pulses in an acoustic medium comprising:

a transducer having a radiating face and an opposite non-radiating face and

means for applying a signal to said transducer for causing the radiating face of the transducer to displace from a rest position to maximum displacement during a first interval of time  $t_0$  and to return from maximum displacement to said rest position during a second subsequent interval of time  $t_0$ , wherein  $t_0$  is substantially equal to an integer multiple of the time required for an acoustic wave to propagate from one face of the transducer to the other.

7. The apparatus defined in claim 6 wherein said means for applying comprises:

means for generating a trigger signal;

a plurality of shaped pulse generating channels responsive to said trigger signal, each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse; and

means for summing the shaped output pulses of each of said channels to produce the signal applied to said transducer.

8. The apparatus defined in claim 6 wherein said means for applying comprises:

means for generating a trigger signal;

a plurality of shaped pulse generating channels responsive to said trigger signal, each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse;

means for summing the shaped output pulse of each of said channels; and

means for low pass filtering the sum of the shaped output pulses to produce the signal applied to said transducer.

9. Apparatus for generating unipolar acoustic pulses in an acoustic medium comprising:

a transducer having a radiating face and an opposite non-radiating face and

means for applying a signal to said transducer to cause the radiating face of the transducer to displace from a rest position to maximum displacement during a first interval of time  $t_0$  and to return from maximum displacement to said rest position during a second subsequent interval of time  $t_0$ , wherein  $t_0$  is substantially equal to the time required for an acoustic wave to propagate through the transducer from one face to the other.

10. The apparatus defined in claim 9 wherein said means for applying comprises:

means for generating a signal discontinuity of a first polarity at the start of said first interval of time  $t_0$  and

means for generating a signal discontinuity of a polarity opposite said first polarity at the end of said second interval of time  $t_0$ .

11. The apparatus defined in claim 9 wherein said means for applying comprises means for generating a

unipolar signal pulse having a leading edge timed to coincide with the start of said first interval of time  $t_0$  and a trailing edge timed to coincide with the end of said second interval of time  $t_0$ .

12. Apparatus for producing a unipolar displacement of the radiating face of an electroacoustic transducer, said transducer having an acoustic velocity  $c$  and a longitudinal dimension  $L$  perpendicular to its radiating face and said unipolar displacement being characterized by a duration time parameter  $2t_0$ , characterized in that  $t_0$  is substantially equal to an integer multiple of the quotient  $(L/c)$ , means for generating a partly discontinuous signal waveform, and means for applying said signal waveform to said transducer.

13. The apparatus defined in claim 12 wherein said means for generating comprises:

means for generating a trigger signal;

a plurality of shaped pulse generating channels responsive to said trigger signal, each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse; and

means for summing the shaped output pulses of each of said channels to produce said partly discontinuous signal waveform.

14. The apparatus defined in claim 12 wherein said means for generating comprises:

means for generating a trigger signal;

a plurality of shaped pulse generating channels responsive to said trigger signal, each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse;

means for summing the shaped output pulses of each of said channels; and

means for low pass filtering the sum of the shaped output pulses to produce said partly discontinuous signal waveform.

15. The apparatus defined in claim 12 wherein  $t_0$  is substantially equal to the quotient  $L/c$ .

16. The apparatus defined in claim 15 wherein said partly discontinuous signal waveform is characterized by an initial signal discontinuity followed by a first pulse segment of decreasing signal amplitude, a second pulse segment of increasing signal amplitude, and a final signal discontinuity.

17. Apparatus for generating unipolar acoustic pulses in an acoustic medium comprising:

a transducer having a radiating face and a longitudinal dimension  $L$  perpendicular to said radiating face, the material of said transducer having an acoustic velocity  $c$  and

means for applying a signal to said transducer for causing the radiating face of said transducer to displace from a rest position to maximum displacement during a first interval of time  $t_0$  and to return from maximum displacement to said rest position during a second subsequent interval of time  $t_0$ , wherein  $t_0$  is substantially equal to an integer multiple of the quotient  $L/c$ .

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18. The apparatus defined in claim 17 wherein  $t_0$  is substantially equal to the quotient  $L/c$ .

19. The apparatus defined in claim 17 wherein said means for applying comprises:

means for generating a trigger signal;  
a plurality of shaped pulse generating channels responsive to said trigger signal, each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse; and

means for summing the shaped output pulses of each of said channels to produce the signal applied to said transducer.

20. The apparatus defined in claim 17 wherein said

means for applying comprises:

means for generating a trigger signal;  
a plurality of shaped pulse generating channels responsive to said trigger signal, each of said channels comprising means for delaying said trigger signal, means responsive to the delayed trigger signal for generating a rectangular pulse of predetermined amplitude and duration, and means for shaping said rectangular pulse to produce a shaped output pulse;

means for summing the shaped output pulse of each of said channels; and

means for low pass filtering the sum of the shaped output pulses to produce the signal applied to said transducer.

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