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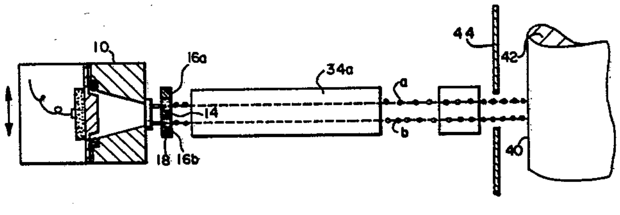
(54) **A multi-jet single head ink jet printer.**

(57) In a jet type printing system a plurality of ink jets are provided in line in the direction of carriage movement. The ink jets are deflected to print in a conventional manner and also pass by charging electrodes which charge individual droplets as they are broken off from the jets. The charging electrodes are provided with a charge to produce scanning transverse to the direction of carriage movement such that if no charge is provided, ink will be caught in a catcher and returned to the ink reservoir for reuse. By interlining the lines a faster more effective printing occurs. Interlining may be done in accordance with several stated methods. An alternative provides ink jets one above the other with deflection means causing deflection to occur in opposite directions so that one effectively scans up and the other scans down, this alternative preferably employing a pair of ink catchers for the respective jets.



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A MULTI-JET SINGLE HEAD INK JET PRINTER

The present invention relates to the use of more than one jet in a single head ink jet printer to accomplish faster and more effective printing, while maintaining an excellent print quality for serial printers. The multi-jet nozzles are aligned in a straight line parallel to the printing direction, while droplets from each jet (or nozzle) are deflected under the deflection electric field in a direction perpendicular to the printing direction. An interlacing technique is used to assure quality as good as that of a single continuous jet printer, but it yields a print speed n-times faster, where n is the number of nozzles in the ink jet array printer. The present invention also relates to the method of producing that printing.

At the present time there are available from various sources continuous single jet printer devices. Such a printer has an ink reservoir which is under a constant pressure of typically 16 to 80 pounds per square inch. The pressure causes the ink filament ejected from a small orifice of 20 to 50 microns in diameter toward a small well-defined area of the paper to be printed which paper is supported a fixed distance from the nozzle on a suitable platen. Under the stimulation of an ultrasonic wave, the filament is broken into a stream of well-defined ink droplets at a rate equal to the frequency of the superimposed ultrasonic wave. Through charge induction, droplets are charged one by one before break-up and the amount of charge causes each droplet to deflect generally perpendicular to the printing direction in proportion to the charge imposed. The droplet is deflected under the influence of an electrostatic field produced by deflection means to a predetermined position. In the course of each of the successive deflections a straight line, generally perpendicular to the print direction (usually a vertical line), or parts of a line, is drawn so that by drawing a series of closely spaced vertically oriented segments of lines the desired character is completed. The charge imposed on the droplets is varied in a predetermined stepwise fashion, but for each droplet there is the option of putting the charge at a level which causes the droplet to be directed to a gutter or ink catcher rather than impinging upon the paper.

Typically, these non-printing droplets are not charged and only the droplets used to draw the successive vertical line segments are charged. Successive vertical lines are drawn as a carriage supporting at least the ink jet orifice and charging electrode moves transverse to the jet deflection, usually horizontally across a line on the paper on the platen for a serial printer. The charge potential for successive droplets is increased or decreased in generally fixed predetermined steps so that if all of the droplets are allowed to impinge the paper, they will together draw a vertical line. Characters are produced by moving the carriage horizontally effectively drawing a successive sequence of vertical line segments at predetermined positions which are needed to form the sequence of selected characters. Particle charge information for each possible character capable of being printed is stored in a memory which typically at each voltage will either allow that deflection voltage to be imposed on the charging electrode or typically in most printers completely removes voltage to allow the ink to be caught in the ink gutter positioned to catch uncharged particles and recirculate them to the reservoir for reuse.

In the prior art, it has been understood that there can be electrostatic interaction between adjacent ink droplets but there is a certain tolerance to error which can be accommodated to the droplet placement. This is preferably less than 30 microns for a resolution of 240 dots per inch (or 10 dots/mm.) and less than 25 μ for 300 dots/inch printing (or 12 dots/mm.). In the prior art, various techniques were employed for minimizing this error. One of these was the use of guard drops as taught by U.S. Patent No. 3,562,757, issued February, 1971, to V. Bischoff. Also, there are charge compensation schemes such as illustrated by U.S. Patent No. 3,828,354, issued August 6, 1974, to H. T. Hilton. However, such known processes have also reduced the number of printing droplets by a factor of 2 to 3 depending, for example, upon the number of non-charged droplets placed between the printing droplets. If every other droplet is not charged, the printing speed is reduced by a factor of 2. If only every other third droplet is potentially capable of charge, printing speed is reduced by a factor of 3.

An ink jet printer of the present invention may be of the type shown in U.S. Patent No. 3,596,275, issued July 27, 1971, to R. G. Sweet or U.S. Patent No. 3,298,030, issued January, 1967, to A. Lewis and D. Brown. The process has produced 240 dots/inch (or 10 dots/mm.) printing at 92 characters per second at 12 pitch.

There is another approach using ink jet array. Numerous closely packed ink jet nozzles are aligned in a straight line perpendicular to the printing direction. The non-charged droplets are used to print on paper; while the non-printing droplets are charged and deflected into a common gutter and are recirculated into its ink system. The process was first taught in U.S. patent No. 3,373,437, issued March 12, 1968, to R. G. Sweet and R. C. Cumming. The process has been further developed at Mead Corporation as taught in U.S. patent No. 3,586,907 to D. R. Beam et al, U.S. patent No. 3,714,928 to R. P. Taylor, U.S. patent No. 3,836,913 to M. Burnett et al, and U.S Patent No. 4,010,477 to J. A. Frey.

In this approach, an array with up to 1200 nozzles have been aligned in a 25 cm. head in a direction perpendicular to the print direction. Since each nozzle is a single continuous jet and is printing in a binary mode, a paper roll up to 10 1/2 inches width has been printed after passing under the print head only once at a speed in excess of 1000 feet per minute which is the fastest electronic printer ever built to date.

The approach has all nozzles share a common ink system, a common ink reservoir, a common deflection electrode, and a common ink collector. The cost is substantially less than those of 1200 single continuous jets.

Limited by how closely we can pack nozzles per millimeter and by jet straightness obtained by today's fabrication technology (1 to 1/2 milliradian), the print quality has not exceeded an equivalent of 240 dots/inch (or 10 dots/mm.).

The present invention is directed to a print head containing from 2 to n jets. All jets are aligned in a straight line parallel to the printing direction. Each jet deflection is in a direction perpendicular to the print direction. Proper delay is provided to each jet during printing to maintain a good printing quality. By the use of the multiple jets the printing speed will be increased 2 to n times faster depending upon the number of jets used. At 12 characters per inch printing, a high resolution character needs 640 print droplets at 10 dots/mm (or 240 dots/inch) resolution; and needs 1000 print droplets at 12 dots/mm. (or 300 dots/mm.) resolution. While at 5 dots/mm. (or 120 dots/inch) resolution, only 160 print droplets are sufficient to form a character. A typical continuous ink jet operates at about 100,000 droplets a second. Hence, a typical single continuous jet printer prints about 50 characters per second at 12 dots/mm. resolution; about 80 characters per second at 10 dots/mm. resolution; and about 310 characters per second at 5 dots/mm. resolution. The following table lists the printing speeds as a function of process and a number of jets:

Table I Printing Speed Vs Number of Jets per Head at 132,000 droplets/second

Number of Jets/Head		1	2	4	n
12 dots/mm	2-guard-drop scheme	44 cps	88 cps	176cps	44n cps
	1-guard-drop scheme	66 cps	132 cps	264cps	66n cps
10 dots/mm	2-guard-drop scheme	68 cps	136 cps	272cps	68n cps
	1-guard-drop scheme	103 cps	206 cps	412cps	103n cps
5 dots/mm	2-guard-drop scheme	275 cps	550 cps	1100cps	275n cps
	1-guard-drop scheme	412 cps	825 cps	1650 cps	412n cps

At 12 dots/mm., a single continuous jet printer has a quality and speed comparable with that of a daisywheel printer. There is very little price performance advantage over a daisywheel printer. By adding multi-nozzle to the print head, the present invention offers a printing speed increase by n-times (where n is the number of nozzles in a single print head), while maintaining the same high resolution quality. Furthermore, the additional structure required in accordance with the present invention is relatively nominal. The parts are known and easily fabricated and many parts can be used in common such as the ink system, the deflection plates, the gutter and recirculation system. Hence, the process is cost effective.

The following are the descriptions of this invention.

The present invention has the ink jet nozzles aligned in a straight line and is in parallel with the relative print direction. Each nozzle is capable of producing a stream of ink droplets. Each droplet is properly charged to a pre-determined level and is able to be deflected by the deflection electric field to a maximum deflection of at least 1.35 times the character height perpendicular to the print direction. In other words, each nozzle in the ink jet printer prints exactly like the ink jet printer described in the Sweet patent and Lewis and Brown patent. When multi-nozzle print head is used as described, each nozzle will print a portion of the vertical matrices. The vertical matrices printed by different nozzles in the array will interlace to form a high resolution character.

For example, if the array head contains two nozzles, jet "1" will print every even number of vertical matrices, while the jet "2" will print every odd number of vertical matrices. There is a time delay for jet "2" with respect to jet "1" by (d ± 1/R)/10V seconds where:

d is the inter jet spacing in mm.,

R is the resolution in dots/mm., and

V is the printer head speed in cm./sec; or a spacial delay of (dR ± 1) dotted lines.

It will then be understood that the distance between centers of two nozzles must be a multiple integer of the inter-dot distance between centers for the given resolution.

If three nozzles are used, each nozzle prints only every third vertical matrices, i.e.,

jet "1" prints (3m ± 1)th dotted line;

jet "2" prints (3m ± 2)th dotted line;

jet "3" prints (3m ± 3)th dotted line; where m is an integer.

The time delays with respect to jet "1" are, (d ± 1/R)/10V seconds for jet "2"; and (2d ± 2/R)10V seconds for jet "3", or there are spacial delays with respect to jet "1" by (dR ± 1) dotted lines for jet "2", and (2dR ± 2) dotted lines for jet "3".

In general, if there are n nozzles in a single head separated by a distance d between centers (d is also an integer of 1/R), each nozzle will print every nth dotted line apart. In particular, the Kth jet in the array will print every (mn ± K)th dotted line, while the first jet will print every (mn ± 1)th dotted line, where n is an integer. There exists a time delay for the Kth jet with respect to the first jet by (K-1) [d ± 1/R]/10V second, or a spacial delay of (K-1) [dR ± 1] dotted lines.

Let us now examine the electrostatic interaction between charged droplets on flight between two adjacent jets which could effect the droplet placement error. Electrostatic Coulomb force between two charged particles of adjacent jets is

$$F = K \frac{q_1 q_2}{r^2}$$

where q is the charge contained in the droplet "i", r is the distance between the droplets of adjacent jets, and K is a constant. Note that the closest distance between charged droplets from 2 adjacents jets is the distance between the jet nozzles which as a practical proposition is taken to be 1 - 3 mm. At 132,000 droplets/sec. and a droplet velocity of 2000 cm./sec., the inter-droplet spacing for a single jet is .152 millimeters, the inter-droplet spacing is 7 to 20 times closer than the inter-jet spacing. Since Coulomb force is inversely proportional to the square of the distance, correction due to adjacent jet is very small. Hence, one can ignore both the electrostatic correction as well as the aerodynamic wake effect for droplets between jets.

More specifically, the ink jet printer apparatus of the present invention employs an ink chamber or reservoir having at least two matched orifice nozzles aligned parallel to one another. Means of constant pressure or of constant flow is employed to apply pressure to the reservoir to force ink out through each of said orifices in a thin filament, including means acoustic energy means generating waves of the same phase being preferred, acting on the ink to break the filament into droplets of predetermined size, each droplet being of a size to produce a dot of predetermined size in a raster of dots forming a printed character. Deflection plates are positioned so that all of the droplets pass in droplet paths from the respective nozzles each in planes transverse to the deflection plates. Deflection voltage supply means is connected to the deflection plates to impose an electrostatic field between the deflection plates. Charging electrode means is fixed relative to each orifice nozzle in position adjacent to the respective orifice nozzles along the droplet paths from that nozzle. Electrostatic shielding means may be interposed between adjacent charging electrodes to isolate charge effects imposed on droplets of one stream from droplets of another. A source of voltage is connected to the respective charging electrode means. Each charging electrode, in turn, is capable of inducing electrostatic charge on the individual droplets as they break off from the ink filament emerging from the orifice associated with the charging electrode. The droplets are then deflected into paths determined by their respective charges as they pass through the field imposed by the deflection plates. Voltage switching means is provided for applying in a prearranged order selected voltages (which may include zero voltage) to each charging electrode, as the individual droplets pass through. The selected level of voltage induces charge on each droplet determined by and different for each voltage and causes that droplet to follow a predetermined droplet path. Each droplet having the same charge will follow the same path, different from paths followed by droplets having other charges but all of which droplet paths lie in a common plane transverse to the deflection plates. Ink collector means is positioned for collection of non-print ink droplets for all nozzles moving along the predictable paths generated by a particular selected level of voltage typically at zero potential. Means is supplied for supporting paper in position such that droplets moving along paths in a plane from an orifice nozzle will impinge the supported paper at points along a line opposite that orifice nozzle and parallel to a line opposite another orifice nozzle upon which droplets from said other nozzle impinge. Carriage is also provided for moving the orifice nozzles and charging electrode means relative to the means supporting the paper transverse to the plane of droplet paths from a particular nozzle.

The method of the present invention involves either manually or automatically, as by computer, delaying the printing of intermediate lines until the second nozzle orifice catches up with the position adjacent to that the first nozzle orifice was in when it printed the line adjacent to which the new line is to be printed by the second nozzle. In accordance with the present invention, the pattern of dots in the (2n ± 1)th dotted line printed by the second jet is delayed from the time of the printing of the 2nth dotted line by the first jet by (d ± 1/R)/10V seconds where "d" is in the inter-jet spacing in millimeters, "V" is the print speed in cm./sec., and "R" is resolution in dots per millimeter. The spacial delay is expressed (dR ± 1) dotted lines.

The present invention will be better understood by reference to the accompanying drawings in which:

Fig. 1 is a side elevational view of a two jet version of the present invention in a partial sectional view or in the section as taken through the charging eletrode ring and deflecting plate along the paths from one orifice;

Fig. 2 is a plan view from above partially in section showing a section through the jet path at orifice level at both orifices and the bottom plate of the deflection plates;

Fig. 3 is an alternative construction shown in a view similar to that of Fig. 1;

Fig. 3A is a sectional view taken along line 3A of Fig. 3 showing one form of deflection electrodes;

Fig. 3B is a similar view to that of Fig. 3A but showing an alternative form of electrode;

Fig. 4 is a detail view taken along line 4-4 of Fig. 3 showing a modified ink collector means;

Fig. 5 is a side sectional view of printer head in Fig. 1;

Fig. 6 is sectional view taken along line 6-6 of Fig. 5;

Fig. 7 is a front view of the ink jet head as seen from line 7-7 of Fig. 6;

Fig. 8 is a sectional view taken along line 8-8 of Fig. 5;

Fig. 9 is a schematic drawing representing a five jet version of the present invention;

Fig. 10 is a side sectional view across any one of the jets in Fig. 9;

Fig. 11 illustrates how a letter "T" is printed by the five jet printer; and

Figs. 12a, b and c are fragmentary perspective views of different configurations of charging electrodes.

Referring how to the drawings, Figs. 1 and 2, 5, 6, 7 and 8 illustrate a preferred embodiment. Much of the system is known to be conventional. Much of it has been shown in schematic form since the actual physical form is well known. Thus, for example, in Figs. 1 and 2, the ink chamber 10 is shown schematically. The orifice nozzles through which ink filaments are ejected from the reservoir are best seen as nozzles 12a and 12b in an orifice plate 12. The use of two nozzles in this configuration is new. A support structure 18 of insulating material supports ring charging electrodes 16a and 16b, between which is provided a conductive electrostatic shield 14 of conductive material.

Considering Figs. 5 and 6 briefly, it will be seen that the reservoir structure is more representative of an actual form which would be employed. The reservoir provides a cone-shaped cavity in a block 20 provided with a cylindrical extension 20a the outside surface of which is threaded to engage the threads of a cap 22. The cap closes the narrow end of the conical cavity and is provided with the orifices 12a and 12b on an orifice plate 12. Ink is fed into the cavity 10 through a conduit 24, preferably from a sump fed from the return means from the gutter (to be described) through a suitable pump which supplies pressure at a constant rate, typically about 16 to 80 pounds per square inch. The ink is fed into the ink chamber by way of a cavity 26 adjacent to back plate 28 mounted on the reservoir plate 20 using a sealing gasket 30 and suitable fasteners and supporting an ultrasonic transducer 32. A filament of ink on the order of 20 to 30 microns in diameter is ejected under the pressure through the orifice nozzle and is broken into well-defined ink droplets in the charge rings 16 at a rate equal to the rate of the frequency of the ultrasonic source, thus, enabling each individual droplet to be separately and differently charged by the charging means 14.

Specifically the two jets involved here are charged by the charging ring electrodes 16a and 16b which surround the paths of the droplets close to the orifice and before they are deflected by the electrostatic plates 34a and 34b. The amount of deflection of an individual droplet depends upon the charge imposed upon that droplet by its charging ring electrode 16a or 16b. In the usual configuration, uncharged droplets are allowed to proceed undeflected through the electrostatic field between the plates 34a and 34b into the gutter or catcher 36. They are returned by drain 38 to a sump and by the pump back to the reservoir through the line 24 as described all in conventional manner. If instead of not being charged the droplets are charged, the electrostatic field will act upon them to deflect them. The arrangements shown in the drawings requires an upward deflection such that the greater the charge, the more upward the deflection would be. By varying the amount of charge in steps, a line of dots can be drawn by successive droplets on a piece of paper 40 carried on a platen 42 on a printer. The ink must pass through an elongated slot 44a in a shield 44 and the slot is gauged to permit the full length of the character to be drawn or printed on the paper 40. In practice, although they are shown as elements broken-away, suggesting their extension the length of the platen, the deflection electrodes 34a and 34b may be short and carried on the print head carriage or may be made optionally long and extend the length of the printer platen. The same is true of the catcher or gutter 36. The rest of the structure, the charging electrodes 16a and 16b and their support 14 are effectively mechanically integral with the reservoir and orifices and are part of the laterally moving print head which moves parallel to the length of the platen. The print head therefore is designed to sequentially print as it moves along the structure, parallel to the platen.

Some dimensions actually used in a two jet construction are helpful in visualizing the size of the structure. The two orifice nozzles located along the horizontal diameter (or axis) are spaced on the order of 3 to 4 mm apart. The tip of the cone in the ink chamber 10 is elongated in the horizontal direction, the direction of head traverse to a dimension of 6 mm as opposed to 3 mm in the vertical dimension. The elongated cone tip is recommended to focus the acoustic energy and to assure an efficient non-perturbed acoustic wave reaching at the orifice nozzles with identical energy density and at identical phase. The back of the cone has a diameter of 8 mm and is closed by a stainless steel plate 28 with a circular disc transducer 32, 8-10 mm in diameter, mounted in the other side of the metal cover for stimulation. For maximum transfer of acoustic energy, the distance between the orifice plate and the back plate for stimulation should be $(2m + 1)\ \lambda/4$ where λ is the acoustic wave length of the ink, and m is an integer. Other than two orifice nozzles at the orifice plate and an elongated cone tip, the head structure remains identical with that of a single jet head structure.

Charging electrodes 16a and 16b consist of two metal rings with 1.0 mm inner diameter. The thickness of the charging electrode or the length of each ring is about 0.9 to 1.0 mm. The distance between centers of the charging rings is identical to the distance between centers of the orifice nozzles.

Both the orifice nozzles 12a and 12b and two charging rings 16a and 16b are located an equal distance above the bottom of the deflection plates 34a.

In operation nozzles 12a and 12b produce jets that are as close to identical twins as possible. As the printer head traverses along its carrier rod (not shown), for example, from left to right, for any given spot on the paper, jet a will reach there first, while jet b is 3 mm. away. The printed dot from a droplet in jet a will be 3mm. away from the one in jet b, plus additional error caused by the jet straightness. Hence jet straightness is a major concern for a high resolution printing ink jet array. For a printing resolution of 300 dots per inch, the droplet placement error should be within 25 microns. The corresponding jet straightness is less than 1 milliradian.

For a given vertical printed dotted line, there are 40 printing positions vertically for each jet. Signal voltage plus the charge compensation control are used to assure that droplet is placed within a 25 micron radius of the predetermined spot position.

In a regular text printing mode with a resolution of 300 dots per inch (or 12 dots/mm.), jet a will print the 2nth dotted line, while jet b will print the (2n ± 1)th dotted line. There is a delay of 3 x 12 ± 1 dotted lines between jets, or a time delay of (3 ± 1/12)/10V seconds before jet b starts printing next to the dotted line printed by jet a, where "V" is the velocity of the carrier in cm./second. For bi-directional printing, jet a lags behind jet b by 3 x 12 ± 1 dotted lines or lags by a time of (3 ± 1/12)/10V seconds.

For a resolution of 240 dots/inch (or 10 dots/mm), each jet prints 32 positions. Jet a prints the even number 2n th dotted lines and jet b prints the odd (2n-1)th dotted lines. Time delay between these two jets is (3 ± 1/10)/10V seconds or 3 x 10 ± 1 dotted lines.

In general, if "d" is the inter-jet spacing in mm. and resolution is R dots/mm., then the time delay between two jets is

$$(d \pm 1/R)/10V \text{ seconds;}$$

or a spacial delay of

$$(dR \pm 1) \text{ dotted lines.}$$

In a draft printing mode, the electronics takes a slightly different sequence. Jet a will print at the 2(2m)th dotted lines; while jet b prints at the 2(m - 1)th dotted lines. All odd number of dotted lines are omitted. The time delay between two jets is always

$$(d \pm 2/R)/10V \text{ seconds;}$$

or a spacial delay of

$$(dR \pm 2) \text{ dotted lines away.}$$

"d", "R" and "V" have been defined in Section (1).

Since each jet is basically the same as a regular single continuous jet used in regular printing, droplet charging, charge compensation, and guard drop scheme are the same. To minimize the cross talk between jets, electrostatic shielding between charging electrodes is recommended.

Referring now to Fig. 9, a configuration is shown in which a 5-nozzle jet configuration is employed. The structure is very similar as that for the 2-jet array shown in Figs. 1, 2, 5 through 8 and therefore similar numbers with the addition of primes thereto are employed in the structure. The ink reservoir 10' is modified somewhat in shape and elongated within plate 20' in order to accommodate three transducers 32', 32b', 32c'. The back plate 28' supports the transducers distributed longitudinally and the transducers are interconnected in such a way that they will be cumulative or additive in their effect rather than counteracting the effect of other transducers. Specifically, they all act to generate a pulse which is in phase and they are selected to be of such a frequency as to avoid standing waves or other effects counterproductive to the generation of the droplets. The orifice plate 12' in this case has five separate orifices 12a', 12b', 12c', 12d', and 12e'. The orifices are carefully aligned so that they produce jets which are directed in parallel paths. The jets pass through charging rings 16a', 16b', 16c', 16d', and 16e' and they are each supported on an insulating charge plate 18'. Fig. 9 is a sectional view through the structure so that only the lower deflection plate 34b' is seen but it will be understood that an upper deflection plate 34a' is also employed as in the prior structure. Furthermore, an ink collector means 36' is positioned so that if no charge is placed upon the droplets, they will be collected by the collection means. However, as in the prior arrangements, if charges are placed upon the droplets, they will be suitably deflected onto paper 40' on a platen 42'.

Fig. 11 shows a typical pattern printed by the 5-nozzle printer of Fig. 9 to print a character "T". Jet "1" prints the 1st, 6th, 11th, 16th and 21st dotted lines; jet "2" prints the 2nd, 7th, 12th, 17th, and 22nd dotted lines; ...; and jet "5" prints the 5th, 10th, 15th, 20th, and 25th dotted lines. The interlacing of all printed dotted lines forms the character "T". Note that all 5 nozzles must be identical in every practical means. Jet straightness must be within acceptable level. The interlacing scheme blends all 5 jet printing in every portion of the character. Hence, it produces a more homogeneous appearance, and every slight misalignment will be averaged out. The vertical positional accuracy are precisely taken care of by electronic compensation on the amount of charge given to each individual droplet.

Note that the printing sequence by the 5-jet array is shown on the top of Fig. 11 where kth jet prints every (5m + K)th dotted lines, if we choose a time delay for the Kth jet with respect to the 1st jet by (K-1) (d + 1/R)/10V seconds, where d, R, m, and V are as defined above. The corresponding spacial delay is (K-1) (dR + 1) dotted lines for th Kth jet. Another printing sequence is shown in the bottom of Fig. 11 where the Kth jet prints every (5m - K)th dotted lines, if we choose the time delay for the Kth jet with respect to the first jet by (K-1) (d - 1/R)/10V seconds. The corresponding spacial delay is (K-1) (dR - 1) dotted lines.

Character printing is done through a character generator on a ROM chip. The signal from each dotted column will first go through a specific shift register to provide a proper spacial delay (or time delay) before being sent to the driving electronics for the Kth jet charge electrode. In Fig. 9 the printer head assembly starts with a transducer array 32a', 32b', 32c' of rectangular shape mounted on a back plate 28' opposite to the rectangular pads 31a', 31b' and 31c'. A transducer array is necessary when the total length of the ink jet array exceeds $\lambda/2$, the half acoustic wavelength of the ink. The acoustic wave generated by the transducer array must have the same amplitude and phase to avoid generating a longitudinal acoustic standing wave along the direction of the orifices. Transducers are mounted by epoxy on the back plate 28', which may be a flat thin plate, or with a number of corresponding pads. The structure separates the transducer array from direct contact with ink, while transmitting acoustic energy effectively to the ink chamber.

The ink chamber contains ink inlet 24' and an ink outlet 25', preferably with a controlled valve (not shown). The tapered slot shape ink chamber block has transducer array mounted on the larger crossection end, and the orifice plate at the tapered end. Mechanical clamping, soldering, or gluing by epoxy are methods of mounting. A tapered shaped ink chamber is to focus the acoustic energy toward the orifice plate. The length of the ink chamber should be at least $\lambda/2$ longer than the total length of the orifice array. The width of the slot in the ink chamber should not exceed half wavelength $\lambda/2$ to avoid higher order standing wave generation. For the best stimulation, the depth of ink chamber between the back plate and the orifice plate should be kept at $(2m + 1)\ \lambda/4$, where m is an integer and λ is the acoustic wavelength of the ink at the stimulation frequency.

The fabrication of the orifice plate 12' is one of the most critical parts of the ink jet printer. Although it is possible to drill a series of identical holes on a thin metal plate, (preferably a 5+ to 10 mils stainless or nickel plate) it is better recommended to use photo-fabrication process to control precisely the dimension and the shape. Silicon single crystal wafer can be made as an orifice plate through oxidation then preferentially etch nozzles at predetermined positions using photo-resist. One can also use electroform process to fabricate a precision orifice plate, where a photoresist image is first made on a conductive substrate before electrodeposition. Care must be exercised to assure perfectly round holes with identical dimensions to minimize the droplet placement error.

The charge plate 18' has equal number of holes lined-up concentrically with the orifices as shown in Fig. 12a. Conductive rings 16a', 16b', 16c', 16d' and 16e' are made on the holes in the charge plate and is individually connected to the driving circuit for charging electrode. Electrostatic shields between nearest charge rings are recommended through not necessary. Another configuration of the charge plate consists of an array of conductive U-shaped channels 18a (see Fig. 12b) or semi-circles 18b (see Fig. 12c) on the charge plate. Each channel is connected to the driving electronic circuit. Although the former configuration has superior shielding against cross-talk between jets, the latter has advantages in operation especially during the start-up and shut down.

The width of the deflection plates and catcher 36' have to be widened to cover beyond the entire jet array in the present invention. Otherwise, they are identical with that of a single jet printer. The ink chamber, deflection plates, catcher and ink system including pump, filtration, ink supply and tubings are common to all jets.

Attention is now directed to Figs. 3 and 4 which shows a modified construction wherein two jets are employed but the jets are provided one above the other instead of in lateral alignment.

Fig. 3 is the side view of another type of 2-jet configuration, where two jets are aligned 3 to 6 mm apart one on each side of printing area. The charge electrodes for jet a and jet b have opposite polarities. Under the deflection electric field given in Fig. 3, charged droplets from jet a will be positively "+" charged, hence deflected downward; while droplets from jet b will be negatively charged "-" and are deflected upward. A dual catcher is shown in Fig. 4 which is a sectional view from line 4-4 in Fig. 3. The upper catcher catches the non-print droplets from jet a and the lower catcher catches the non-print droplets from jet b. The aperture between the catcher fingers is the window for printing. It is at least 0.1 inch in height. One may interlace droplets from jet a to droplets from jet b to form a single line (each jet needs only 1/2 the number of steps per vertical line), or interlace the dotted lines printed by each jet to form a character. In either scheme, the 2-jet head printer will print twice the speed of a single jet printer.

Furthermore, the jet a and jet b in Fig. 3 may be replaced by two rows of ink jet array, each array is parallel to the print direction. Row a is located above the print area and row b is located below the print area. The polarities of the matched charge electrodes for row a is opposite to that of row b so that the print droplets from each row of ink jet array are deflected in opposite direction into the print area to form the predetermined characters or images. Using the interlacing schemes described previously, high resolution images can be obtained at a printing speed n times faster than a single jet printer, where n is the total number of jets in the print head.

CLAIMS:

1. Ink jet printer comprising;

an ink chamber (10; 10'; 10") having an orifice nozzle (12a; 12a') aligned parallel to a print direction,

means to apply pressure to the ink chamber (10; 10'; 10") to force ink out through said orifice nozzle (12a; 12a') in a thin filament, including means (32; 32') acting on the ink to break the filament into droplets of predetermined size,

charging electrode means (16a; 16a'; 16a") fixed relativ to the orifice nozzle (12a; 12a') in position adjacent to the orifice nozzle (12a; 12a') along the droplet path from that orifice nozzle (12a; 12a'), and

deflection plates (34a, 34b; 34a', 34b'; 34a", 34b") between which all of the droplets pass in a droplet path from the orifice nozzle (12a; 12a') in a path transverse to the deflection plates (34a, 34b; 34a', 34b'; 34a", 34b"),

characterized in that the ink chamber (10; 10'; 10") has at least one further orifice nozzle (12b; 12b', c', ... e') matched with said first orifice nozzle (12a; 12a') and aligned parallel to the print direction and in that charging electrode means (16b; 16b', c', ... e'; 16b") fixed relative to the at least one further orifice nozzle (12b; 12b', c', ... e') respectively in position adjacent to the at least one further orifice nozzle (12b; 12b', c', ... e') along the droplet path from that orifice nozzle (12b; 12b', c', ... e') are provided.

2. Ink jet printer according to claim 1, characterized by

deflection voltage supply means connected to the deflection plates (34a, 34b; 34a', 34b'; 34a", 34b"),

a source of voltage connected to the respective charging electrode means (16a, 16b; 16a', b', ... e'; 16a", 16b") each of which in turn is capable of inducing electrostatic charge on the individual droplets as they break off from the filament emerged from the orifice nozzle (12a, 12b; 12a', b', ... e') associated with the charging electrode (16a, 16b; 16a' b', ... e'; 16a", 16b"),

voltage switching means in a prearranged order applying selected voltage to each charging electrode (16a, 16b; 16a', b', ... e'; 16a", 16b") as individual droplets break off from ink filaments within the charging electrode (16a, 16b; 16a', b', ... e'; 16a", 16b") to induce a charge on each droplet,

ink collector means (36; 36'; 36a", 36b") positioned for collection of non-print ink droplets for all jets moving along the paths generated by a particular level of voltage,

means for supporting paper (40, 40', 40") in position such that droplets moving along paths in a plane from an orifice nozzle (12a or 12b; 12a', b', ... or e') will impinge the supported paper at points along a line opposite that orifice nozzle (12a or 12b; 12a', b', ... or e'), and

carriage means for moving the orifice nozzles (12a, 12b; 12a', b', ... e') and charging electrode means (16a, 16b; 16a', b', ... e'; 16a", 16b") relative to the means supporting paper (40, 40', 40") transverse to the plane of droplet paths from a particular orifice nozzle (12a or 12b; 12a', b', ... or e'),

in which preferably the deflection plates (34a, 34b; 34a', 34b'; 34a", 34b") and the ink collector means (36; 36'; 36a", 36b") are also carried on the carriage means, and especially in which the ink collector means (36; 36'; 36a", 36b") is connected by recirculation means back to the ink chamber (10; 10'; 10").

3. Ink jet printer according to claim 1 or 2, characterized in that electrostatic means is interposed between adjacent charging electrodes (16a, 16b; 16a', b', ... e'; 16a", 16b") to isolate charge effects imposed on droplets of one stream from droplets of another, and preferably in that a plurality of charge rings are molded in a single insulating block (18; 18', 18") and conductive members are placed between the charge electrodes (16a, 16b; 16a', b', ... e'; 16a", 16b") and are grounded eletrically to afford electrostatic shielding to isolate charge effects imposed on droplets of one stream of droplets of another.

4. Ink jet printer according to one of the claims 1 to 3, characterized in that the means to apply pressure to the ink chamber (10, 10', 10" to force ink out through the orifice nozzles (12a, 12b; 12a', b', ... e') is constant pressure or constant flow means and the means acting on the ink to break the filaments into droplets is at least one acoustic wave generator (32; 32a', 32b', 32c') positioned relative to the ink

chamber (10; 10'; 10") and the orifice nozzles (12a, 12b; 12a', b', ... e') to generate acoustic waves of the same amplitude and the same phase, and in that preferably the means to apply pressure to the ink chamber (10; 10'; 10") includes means for recirculating ink from the ink collector means (36; 36'; 36a", 36b").

5. Ink jet printer according to one of the claims 1 to 4, characterized in that the charging electrode means (16a, 16b; 16a', b', ... e'; 16a", 16b") are supported in a common insulating structure (18; 18'; 18"), and preferably in that the charging electrode means (16a, 16b; 16a', b', ... e'; 16a", 16b") are each ring-shaped, U-shaped, or semi-circular-shaped and precision-formed to be identical to one another.

6. Ink jet printer according to one of the claims 1 to 5, characterized in that the orifice nozzles (12a, 12b; 12a', b', ... e') are arranged side by side and in the same plane along which each is moved by the carriage means the path of droplets produced from different orifice nozzles (12a, 12b; 12a', b', ... e') at any given time lying in parallel planes transverse to the deflection plates (34a, 34b; 34a', 34b') such that the droplets impinging the supported paper (40, 40', 40") form lines parallel to lines formed by other orifice nozzles, and preferably in that the spacing of the orifice nozzles (12a, 12b; 12a', b', ... e') and the movement of the carriage means is such that lines drawn by droplets form the respective orifice nozzles are interlaced with one another.

7. Ink jet printer according to one of the claims 1 to 6, characterized in that the orifice nozzles of the ink chamber (10") are alined one above the other so one orifice is above the character printing and the other orifice lies below the character printing, and in that the source of voltage connected to the respective charging electrode means (34a", 34b") imposes a positive signal upon one stream of droplets and a negative signal upon the other so that the droplets are deflected in opposite directions, and preferably in that seperate ink collector means (34a", 34b") positioned above and below respective orifice nozzles are employed to collect the non-print ink droplets from the respective orifice nozzles.

8. Ink jet printer according to claim 7, characterized in that the orifice nozzles are in two rows of ink jet array located above and below the print area, each parallel to the print direction, the signals for the charging electrodes (16) having opposite polarities between the two rows orifice nozzles so that print droplets from said two rows of orifice nozzles are deflected in opposite direction into the print area to form a predetermined character or image.

9. Method of printing with an ink jet printer according to one of the claims 1 to 8, characterized by

generating droplets from adjacent orifice nozzles,

charging droplets in accordance with selected character patterns of characters selected from a memory,

deflecting charged droplets to draw parallel lines or partial lines needed for a selected character, and

timing delay between the droplet line patterns for adjacent nozzles to (D + 1/R)/10V seconds where R is the resolution defined in dots per millimeter and D is the spacing in millimeters between adjacent nozzles which is an integer multiple of interdotted line spacing 1/R and "V" is the print speed in cm/s so that interlaces lines properly complete the selected characters, or subjecting droplets generated from a lagging adjacent jet to form adjacent interlace lines in a character to a spacial delay of (DR±1) dotted lines and repeating the process along each line of characters.

10. Method of printing with an ink jet printer according to one of the claims 1 to 8, characterized in that droplets are generated and deflected by conventional jet orifice structure onto a paper to print an nth line in a character and, after a timed delay of either (D - 1/R)/10V or (D + 1/R)/10V seconds where resolution is R dots per millimeter and D represents spacing between centers of adjacent nozzles in millimeters, droplets are generated from a second adjacent jet orifice to print an (n-1)th line or (n+1)th line of the character.

11. Method of printing with an ink jet printer according to one of the claims 1 to 8, characterized in that droplets are generated and de-

flected by conventional jet orifice structure onto a paper to print at the 2(2n)th line while a second jet prints at the 2(2n-1)th line and, after a timed delay of (D±2/R)/10V seconds where resolution is R dots per millimeter and D represents spacing between centers of adjacent nozzles in millimeters, droplets are generated from a second adjacent jet orifice to print after a spacial delay of (DR±2).

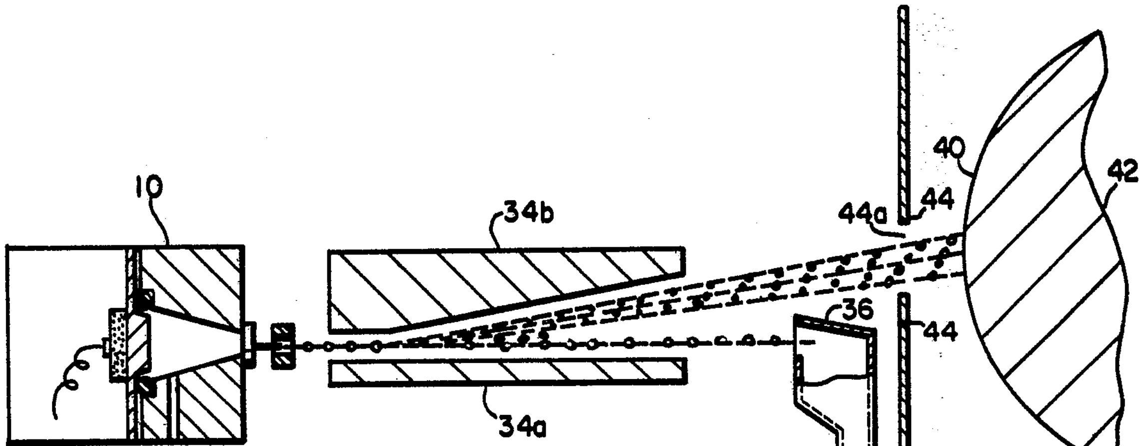

FIG. 1

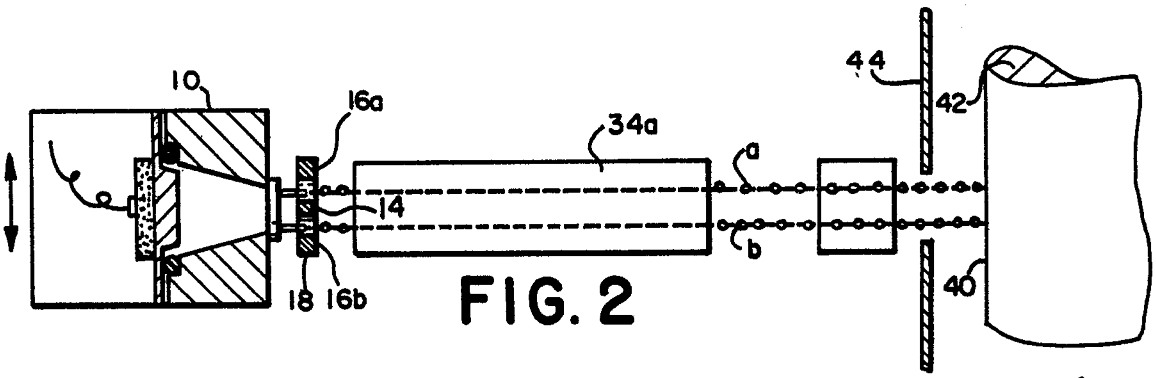

FIG. 2

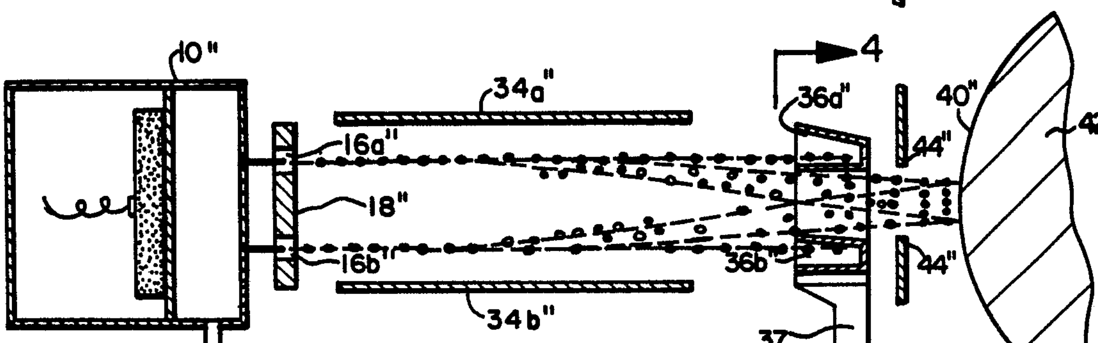

FIG. 3

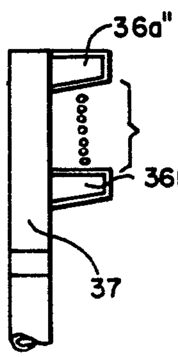

FIG. 4

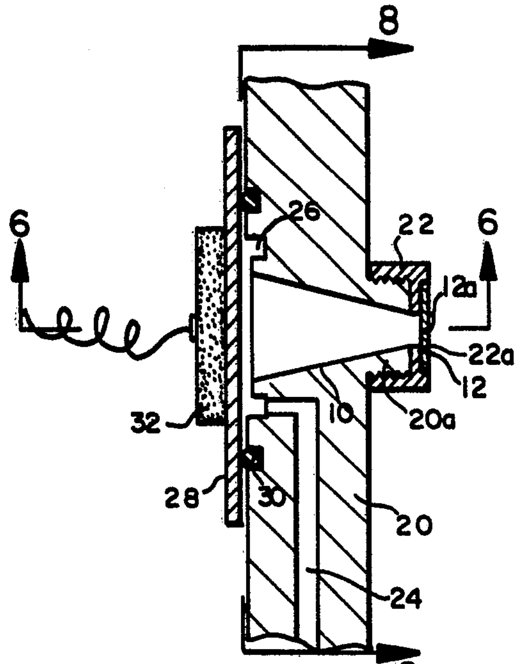

FIG. 5

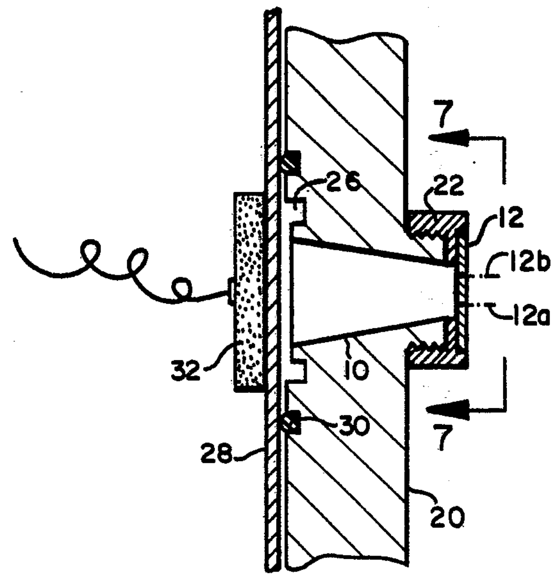

FIG. 6

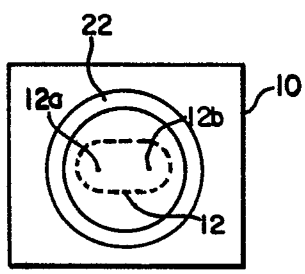

FIG. 7

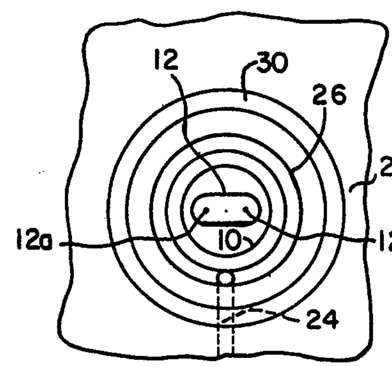

FIG. 8

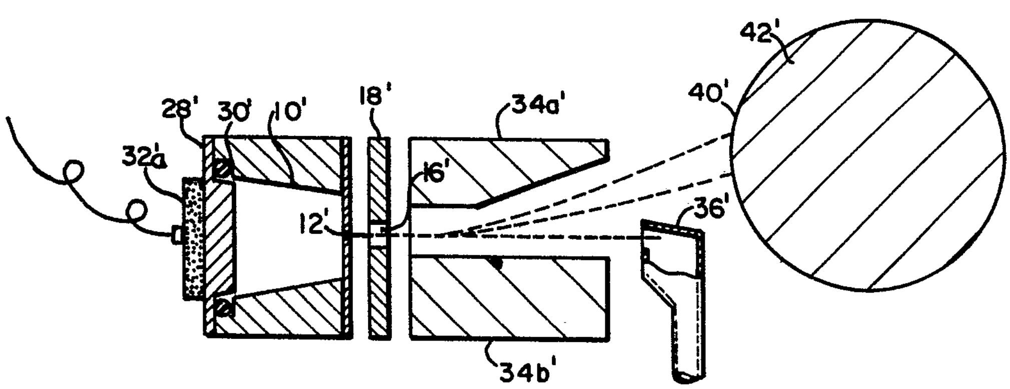

FIG. 10

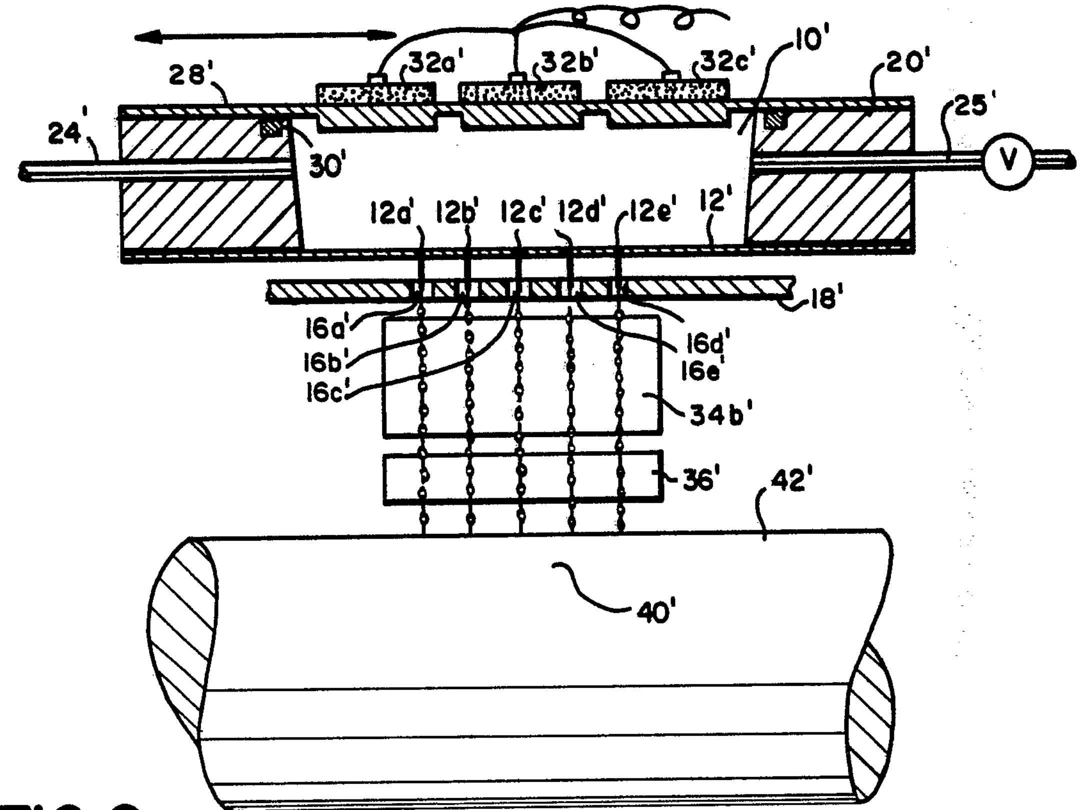

FIG.9

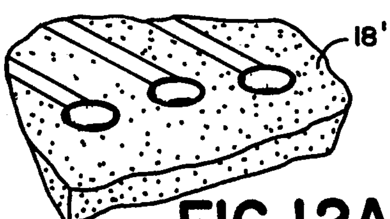

FIG.12A

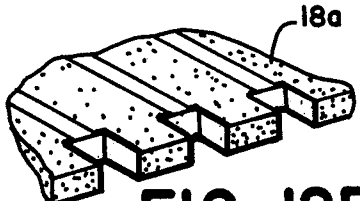

FIG. 12B

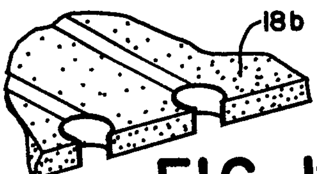

FIG. 12C

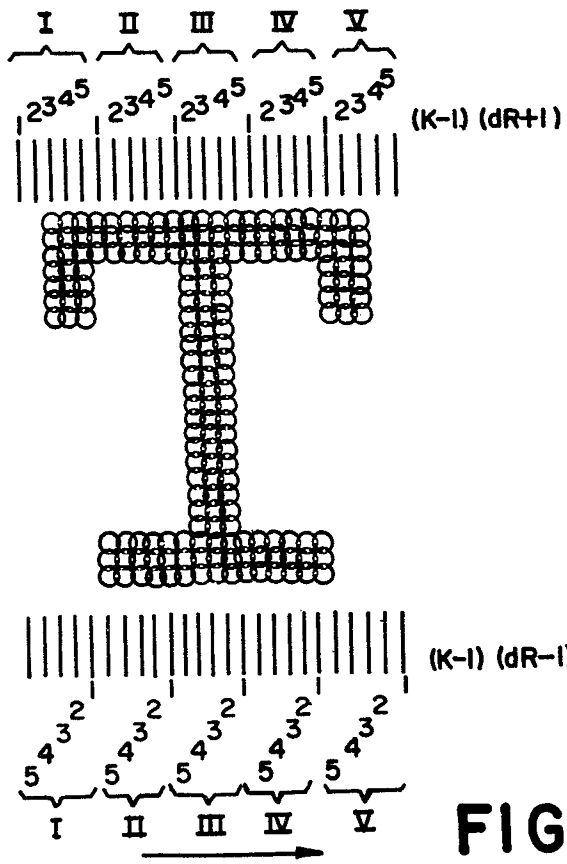

FIG. 11