United States Patent [19]

Lee et al.

[11] **3,769,624**

[45] **Oct. 30, 1973**

[54] **FLUID DROPLET PRINTER**

[75] Inventors: **Chen-Hsiung Lee**, Vestal; **Harold R. Lominac**, Endicott; **Charles O. Ross**, Endicott; **Bruce A. Wolfe**, Endicott, all of N.Y.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[22] Filed: **Apr. 6, 1972**

[21] Appl. No.: **241,601**

[52] **U.S. Cl.** **346/1**, 317/3, 346/75

[51] **Int. Cl.** **G01d 15/18**

[58] **Field of Search** 346/140, 75, 1; 317/3

[56] **References Cited**

UNITED STATES PATENTS

3,298,030 1/1967 Lewis et al. 346/75

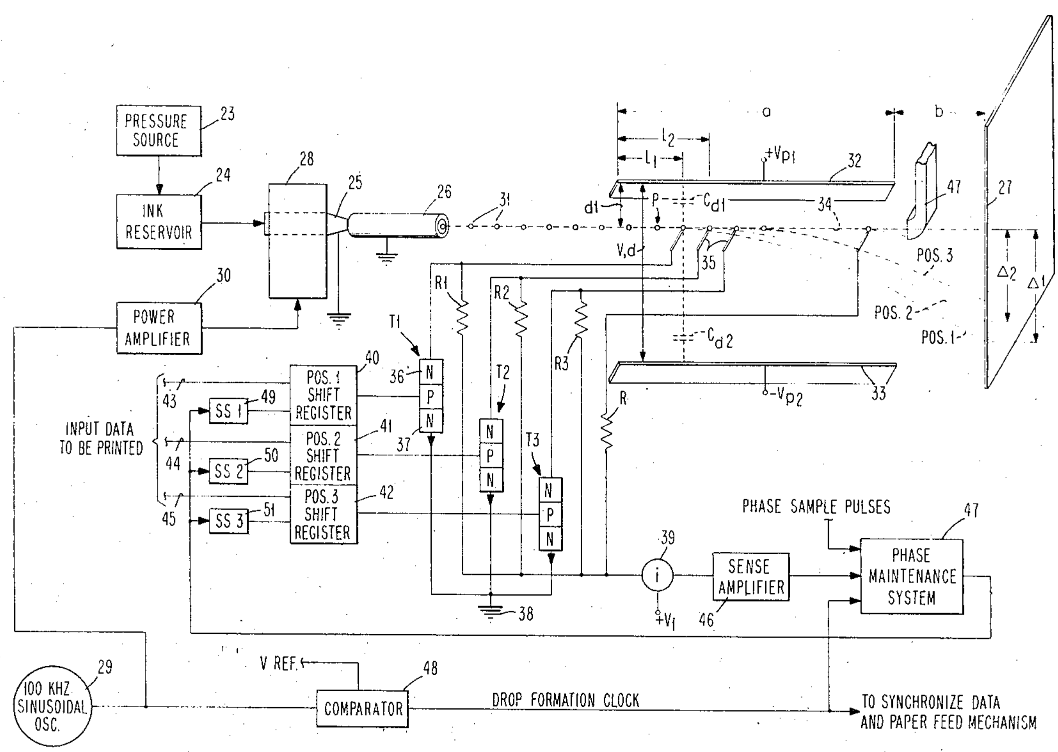
Primary Examiner—Joseph W. Hartary

Attorney—G. R. Gugger, et al.

[57] **ABSTRACT**

A fluid droplet printing system which writes on a record medium by projecting a stream of writing fluid in the form of a succession of uniformly spaced droplets. The droplets are given equal charges in accordance with input data to be printed by means of a row of spaced charging pins disposed along the path of the droplets. The charged droplets are then electrostatically deflected an amount depending upon the distance they travel between the time they are charged and the time they reach the record medium for deposition thereon in the desired printing position.

30 Claims, 5 Drawing Figures



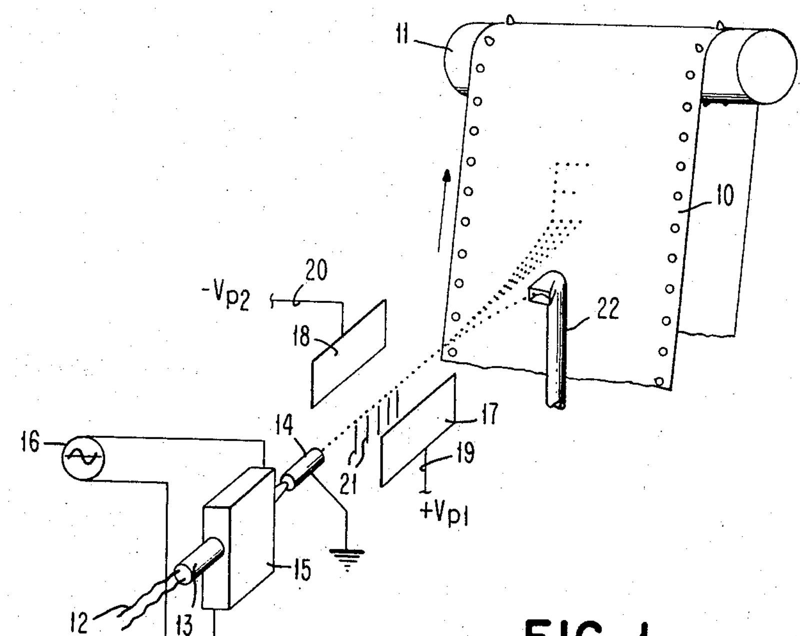

11
10
20
-Vp2
18
22
16
14
17
19
21
+Vp1
15
12
13

FIG. 1

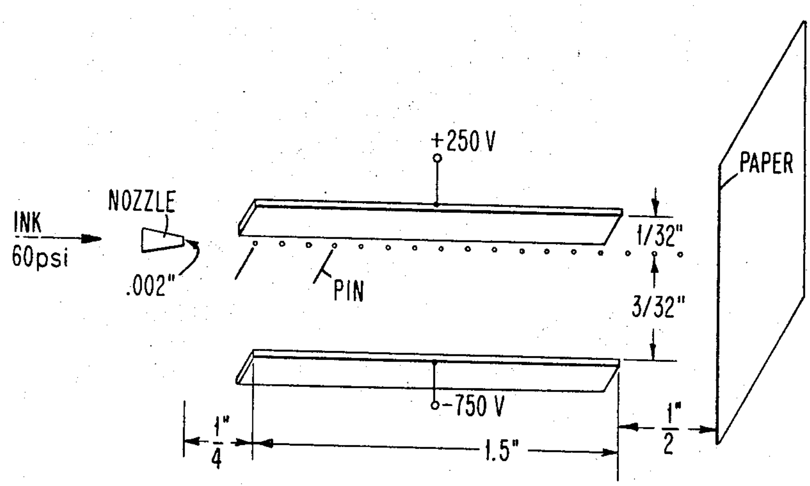

+250 V
PAPER
INK
60psi
NOZZLE
.002"
PIN
1/32"
3/32"
-750 V
1"/4
1.5"
1"/2

FIG. 5

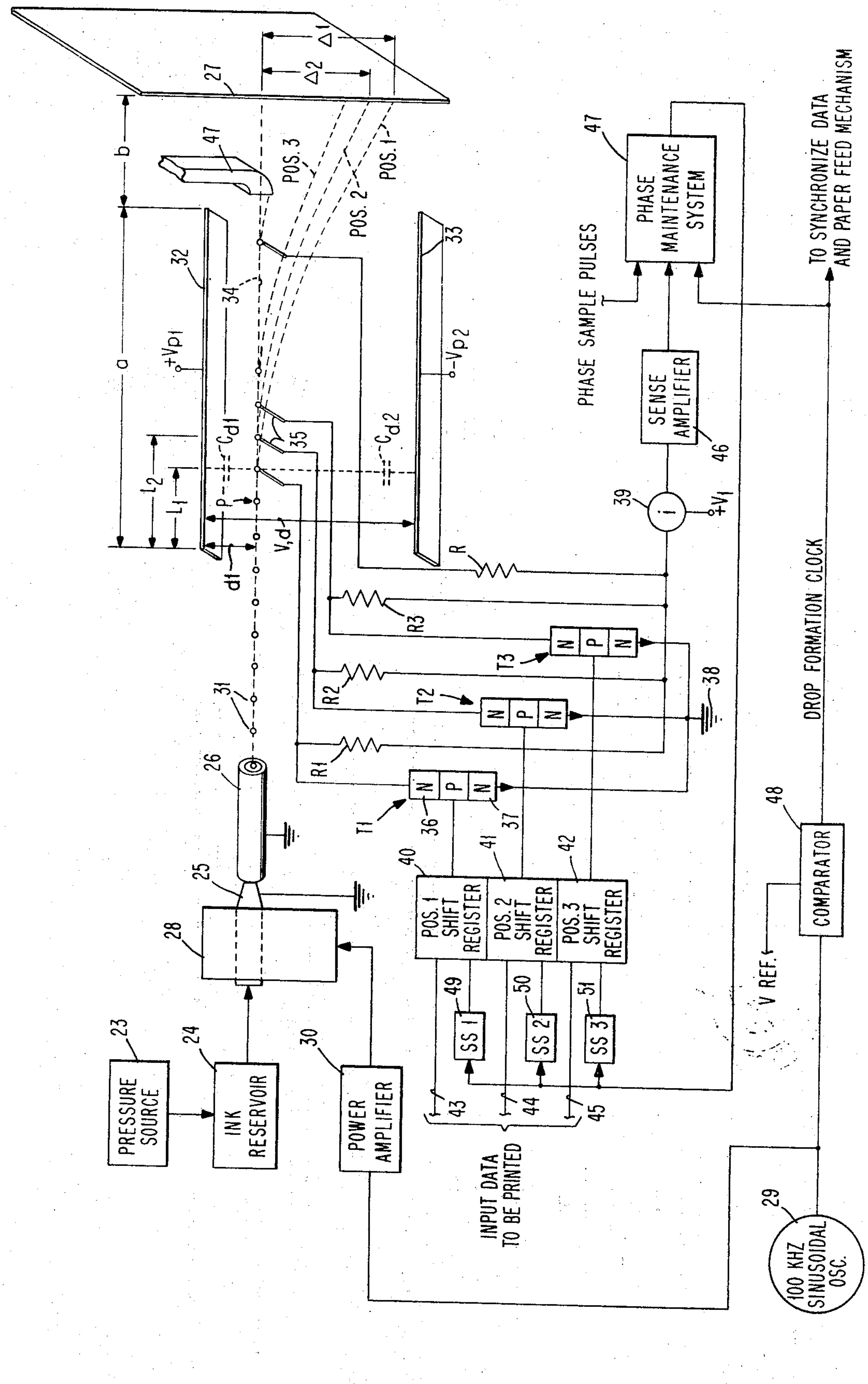

PRESSURE SOURCE
INK RESERVOIR
POWER AMPLIFIER
POS.1 SHIFT REGISTER
POS.2 SHIFT REGISTER
POS.3 SHIFT REGISTER
SS 1
SS 2
SS 3
INPUT DATA TO BE PRINTED
V REF.
COMPARATOR
100 KHZ SINUSOIDAL OSC.
DROP FORMATION CLOCK
TO SYNCHRONIZE DATA AND PAPER FEED MECHANISM
PHASE MAINTENANCE SYSTEM
SENSE AMPLIFIER
PHASE SAMPLE PULSES
POS. 1
POS. 2
POS. 3
+Vp1
-Vp2
+V1
V,d
d1
Cd1
Cd2
T1
T2
T3
R
R1
R2
R3

FIG. 2

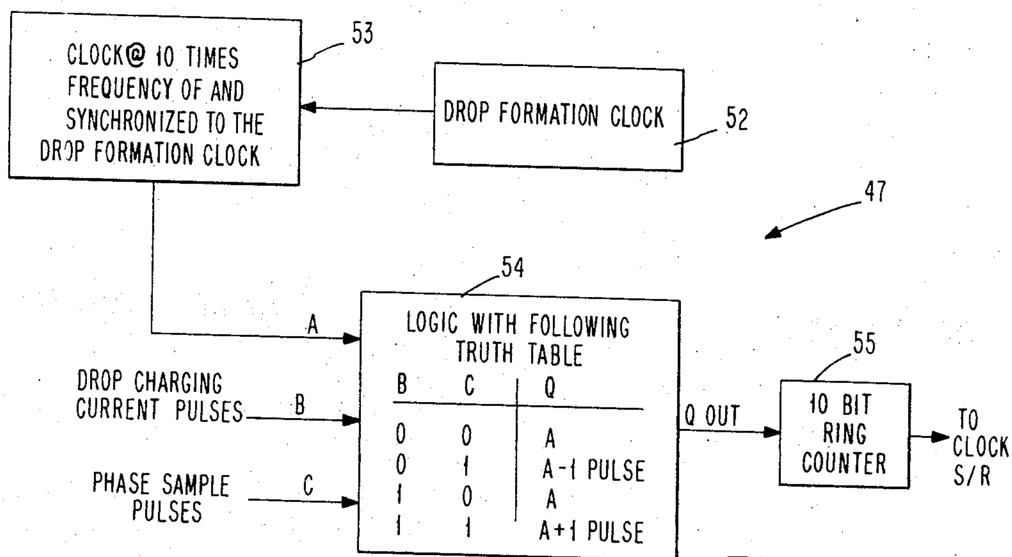

CLOCK @ 10 TIMES FREQUENCY OF AND SYNCHRONIZED TO THE DROP FORMATION CLOCK
53
DROP FORMATION CLOCK
52
47
54
LOGIC WITH FOLLOWING TRUTH TABLE
B C Q
0 0 A
0 1 A-1 PULSE
1 0 A
1 1 A+1 PULSE
A
DROP CHARGING CURRENT PULSES
B
PHASE SAMPLE PULSES
C
Q OUT
55
10 BIT RING COUNTER
TO CLOCK S/R

FIG. 3

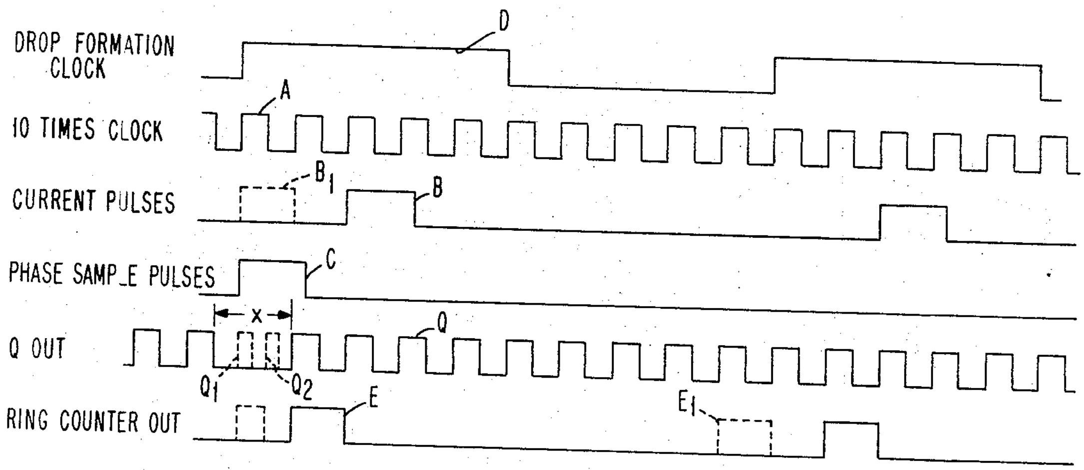

DROP FORMATION CLOCK
D
10 TIMES CLOCK
A
CURRENT PULSES
B1
B
PHASE SAMPLE PULSES
C
Q OUT
x
Q
Q1
Q2
RING COUNTER OUT
E
E1

FIG. 4

FLUID DROPLET PRINTER

BACKGROUND OF THE INVENTION

Fluid droplet printing has been known in the prior art as exemplified by the system shown and described in U. S. Pat. No. 3,596,275 which issued on July 27, 1971. In the system described in this patent, a jet of writing fluid or ink is caused to issue from a nozzle in the form of a succession of tiny individual droplets which are directed toward the surface of a record member. As the individual droplets are formed, they are given an electrostatic charge which is a function of the instantaneous value of an input signal which is to be recorded. The charged droplets are caused to pass between a pair of electrostatic deflection plates. A constant high voltage charge is applied to the deflection plates to produce a constant high voltage electric field between the two plates. As the charged droplets pass through the electric field, they are deflected from their normal path by an amount which is a function of the magnitude of the charge on each of the droplets and in a direction which is a function of the polarity of the charge on the individual droplets. Each droplet of the ink or writing fluid has its own unique charge characteristic for directing it to the desired print position on the record member.

In the above described patented system, it was found that several problems are presented. For example, the discrete droplets are formed within a region surrounded by a charging electrode which imparts the variable charges to the droplets. The droplet break-off point from the main stream in this region can vary as it travels making it difficult to synchronize the charging with the computer or input data control. As a result, the discrete charges may be inaccurate. Also, satellite droplets which form as a tail portion on the main droplets can also become charged and then deflected to the point where they break away from the main droplet and splatter on the electrostatic deflection plates. In addition, it was found that where successive droplets receive varying charges it is possible, due to coupling capacitance between successive droplets and between the droplets and the deflection plates, for a droplet to be attracted and catch up and merge with the preceding droplet which results in undesirable printing. The system circumvents this problem by not making use of every droplet for printing purposes.

In view of the above, it was considered desirable to devise a fluid printer system which embodied a different mode of operation and which would not present the enumerated problems.

SUMMARY OF THE INVENTION

In the fluid printer system of the present invention a jet of writing fluid or ink is caused to issue from a nozzle in the form of a succession of tiny individual droplets which are directed toward the surface of a record member. There is provided a pair of electrostatic deflection plates to which a constant high voltage charge is applied to produce a constant high voltage electric field between the two plates. The jet nozzle is aimed so that the flow of individual droplets passes along a virtual electrical ground path located between the deflection plates. Also positioned between the deflection plates is a row of spaced charge pins which extends along the path of the flow of droplets such that uncharged droplets will come in contact with all of the

pins including a gutter pin positioned at the end of the row.

The charge pins are used to selectively charge those droplets which are to be deflected to a print position on the record member and all unselected droplets will be charged by the gutter pin. The locations of the pins in the direction of droplet flow are designed so that droplet deflections will correspond with printing positions on the record member. A source of charge voltage is provided for the pins and to selectively apply this voltage each pin is connected to an associated electronic switch and shift register. All of the shift registers are connected to a computer or source of input data to be printed. The pins will be charged in accordance with the input data and when a droplet comes in contact with a charged pin, the droplet will become charged and will be deflected by the constant high voltage electric field until it strikes the record member. Since the droplets are charged from a single source of constant charge voltage, all droplets will be charged to the same constant value and the amount each charged droplet is deflected is dependent upon the distance between its charge pin and the record member.

To compensate for possible variations in the formation of the droplets, the present system is provided with a synchronization scheme which makes use of phase maintenance logic circuitry. When a droplet is charged, a current pulse is developed. There will be a current pulse for each droplet since the gutter pin will charge those droplets which are not used for printing. These current pulses are fed into the phase maintenance logic along with a phase sample pulse and suitable clock pulses and the logic output is fed back to the charge pin shift registers whereby the droplet charging voltage is phased with respect to the time the droplets arrive at the charge pins.

The present system arrangement wherein charge pins are used to give all the droplets a constant charge of equal value offers a number of advantages which result in better printing and more efficient and reliable system operation. For example, the charges carried by the preceding droplets do not affect the final charge on the droplet being charged. Also, the presence of satellite droplets will not affect the printing. The charge and synchronization scheme allows the use of every droplet. In addition, the ink resistivity tolerance range is high and lower deflection voltages are permitted.

It is, then, a primary object of the present invention to provide a novel and improved printing system which writes on a record medium by projecting a stream of writing fluid in the form of a succession of uniformly spaced droplets.

A further object of the present invention is to provide a printing system which writes on a record medium by projecting a stream of writing fluid in the form of a succession of uniformly spaced droplets and which includes means for imparting equal charges to droplets to be used for printing and means for deflecting these droplets to printing positions on the record medium.

A still further object of the present invention is to provide a printing system which writes on a record medium by projecting a stream of writing fluid in the form of a succession of uniformly spaced droplets which are charged and then deflected and wherein previously charged droplets have no effect on the droplet being charged.

Another object of the present invention is to provide a printing system which writes on a record medium by projecting a stream of writing fluid in the form of a succession of uniformly spaced droplets and wherein the presence of satellite droplets will not affect the printing. A further object of the present invention is to provide a fluid droplet printer wherein selected ones of a succession of uniformly spaced writing fluid droplets are given equal charges by a row of spaced apart charging pins and electrostatic means is provided which deflects the charged droplets an amount depending upon the distance they travel between the time they are charged and the time they reach a record medium for deposition thereon.

Another object of the present invention is to provide a fluid droplet printer wherein selected ones of a flowing succession of uniformly spaced writing fluid droplets are given equal voltage charges by contacting a row of spaced apart charging pins and synchronization means is provided whereby the drolet charging voltage can be phased with respect to the time the droplets arrive at the charging pins.

A still further object of the present invention is to provide a printing system which writes on a record medium by projecting a stream of writing fluid in the form of a succession of uniformly spaced droplets which are charged and then deflected and which includes charging means and synchronization means which allow the use of every droplet.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of apparatus embodying and illustrating the present invention.

FIG. **2** is a schematic diagram representing a fluid droplet printing system constructed in accordance with the present invention.

FIG. **3** is a block diagram showing the phase maintenance system for synchronizing the printing system shown in FIG. **2.**

FIG. **4** shows the pulse trains for the system shown in FIG. **3.**

FIG. **5** is a schematic diagram illustrating typical design values for apparatus constructed in accord-ance with the present invention.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring to FIG. **1,** there is shown apparatus which illustrates the inventive concept of the present invention. This apparatus includes a record receiving member **10,** such as a strip of record paper, which is arranged to be driven in a vertical direction by suitable means such as the pin feed roller **11** or by pin feed tractors commonly used in printing machines. Record writing fluid or ink **12** under a hydrostatic pressure head of between 40 and 100 lbs. per square inch is supplied to the system through a nozzle **13** and an electrically grounded tubular shield member **14.** The ink issues from the nozzle **13** in a jet which may be on the order of 1/1000 of an inch in diameter and issuing from the nozzle in this fashion, the jet has a natural tendency, due at least in part to surface tension of the fluid, to break up into a succession of tiny droplets. In order to assure that the droplets Will be substantially uniform in dimension and frequency, means are provided for introducing regularly spaced varicosities in the issuing jet. These varicosities, or undulations in the cross-sectional dimension of the issuing jet stream, are made to occur at a pre-selected frequency. This frequency may typically be on the order of 100,000 cycles per second. In the structure shown in FIG. **1**, the varicosities are introduced into the issuing jet stream by vibrating the nozzle **13** at the desired frequency. This is accomplished by attaching the nozzle to a piezoelectric transducer **15** which is excited by a suitable sinusoidal oscillator **16.** As the individual droplets form, they pass through the grounded shield member **14** which functions to prevent the droplets from picking up any stray inductive charges which may exist as a result of electrical components in the system.

These droplets, substantially free of any electrical charge, are directed at relatively high velocity toward the surface of the record receiving paper **11,** and on their way they pass between a pair of electrostatic deflecting electrodes or plates **17** and **18.** These plates are oppositely charged to a constant voltage. For example, the deflecting plate **17** might be charged to a positive 250 volts through the lead **19** and deflecting plate **18** might be charged to a negative 750 volts through the lead **20.** The voltages applied to these plates are held at a constant level, therefore, a fixed electrical field and a virtual electrical ground plane exists between them. The jet nozzle **3** is aimed such that the uncharged droplet path is coincident with the virtual electrical ground.

In carrying out the inventive concept constituting the present invention, a row of charge pins **21** is positioned between the deflection plates and along the droplet path. The number of charge pins would be the same as the number of the required droplet deflection positions or Printing positions on the recerd plus a gutter pin. For normal printing applications, there may be from 10 to 15 pins plus a gutter pin while for plotting and graphic applications there may be as many as 30 pins. The charge pins **21** are aligned parallel to the deflection plates and extend in a direction perpendicular to the droplet path such that an uncharged droplet will come in contact with all pins and the pins function to impart a constant and equal voltage charge to those droplets which are to be used for printing on the record member.

It has been found that an uncharged droplet can maintain a constant path in the presence of minute variations in gravity, pressure, and voltage source. With regard to gravity, the droplet velocity is in the order of 700–1000 inches/sec. and the flight distance inside the deflection plates is in the order of one to two inches. Therefore, the maximum deviation of the droplet from a perfect straight path due to gravity will be less than 0.001 inches. However, this deviation is predictable and can be mechanically adjusted if necessary.

Aerodynamic forces and pressure variations will change the droplet velocity in the same direction as the droplet path. Their effects on the droplet path are primarily related to the gravitational forces which operate over a variable flight time and thereby causes deflection errors in the order of 10^{-6} inches and can be neglected.

With regard to the voltage source, a shift in the deflection plate voltage source will effect the position of virtual ground unless both plate voltages changed proportionally. A nominally uncharged droplet then may be charged slightly due to the voltage source variation and this depends upon the voltage regulation. A voltage regulation of 0.02 percent will result in giving a maximum path deviation in the order of 10^{-5} inches which may be considered insignificant.

As will be more fully described, selected pins will be given a constant equal charge voltage under control of the input data to be printed. When an uncharged droplet comes in contact with a charged pin, the droplet will become charged and as such it will now be deflected from its normal path under the influence of the fixed electrical field between the deflection plates. As shown in FIG. 1, the charged droplets are deflected laterally across the vertically moving paper 10 to produce the desired printing. All droplets are charged to the same constant value and the amount each charged droplet is deflected is dependent upon the distance the droplet travels between the time it is charged by a pin and the time it strikes the paper. Those droplets which are not charged for printing will be charged by the last pin in the row, which is the gutter pin, and these droplets will be deflected into a suitable gutter pipe 22 to be returned back to the ink reservoir.

Referring now to FIG. 2, there is shown a schematic representation of a complete printer system constructed in accordance with the present invention. A pressure source 23 is provided for establishing and maintaining a desired predetermined pressure head on an ink reservoir 24. The ink in the reservoir is fed through any suitable pipe means to the jet nozzle 25. The pressure on the ink supplied to the nozzle causes the ink to be projected from the nozzle through a tubular electrically grounded shield member 26 and on toward a record receiving member or paper 27. Suitable feeding means would be provided to feed the paper at a predetermined velocity in a direction away from the viewer when looking at FIG. 2. It will be understood that any suitable mechanical valve means may be employed to start and stop the flow of ink from the reservoir.

In order to vibrate the nozzle 25, to introduce the varicosities previously mentioned, there is provided a piezoelectric transducer 28 which is mechanically attached to the nozzle. A sinusoidal oscillator 29 provides an oscillatory signal which, when amplified by a power amplifier 30, is applied as a driving signal for the transducer 28. Thus, if the desired rate of occurrence of the ink droplets is 100,000 per second, the oscillatory signal produced by the oscillator is also 100,000 cycles per second.

The ink, which is at ground potential, issues from the shield member 26 in the form of a Succession of uniformly spaced uncharged droplets 31 and on their way toward the recording paper these droplets pass between a Pair of parallel electrostatic deflection plates 32 and 33. Deflection plate 32 has applied thereto a positive voltage V_{p1} and deflection plate 33 has applied to it a negative voltage V_{p2}. These voltages are held at a constant level and, therefore, a fixed electrical field and a virtual electrical ground plane exists between the deflection plates. The jet nozzle 25 is aimed such that the uncharged droplet path 34 is coincident with the virtual electrical ground.

Also included in the charge-deflection unit of the present printer system is a row of spaced apart charge pins 35. Although only four pins are shown in FIG. 2 for illustrative purposes, as was previously mentioned, the number of pins actually employed will depend upon the particular printing application being carried out. The pins 35 when given a constant and equal charge voltage function to charge the ink droplets 31 so that they will be deflected to the desired printing positions on the paper 27. The number of charge pins matches that of the droplet deflection positions plus a gutter deflection pin which is the last pin in the row. The pins are aligned along the path 34 such that an uncharged droplet will come in contact with all pins. Their locations in the direction of the jet flow with respect to the leading edge of the deflection plates are computed from the following equation:

$$l_i = a + b \sqrt{b^2 - \Delta_i/\delta}$$

where

$\delta = 0.113\ E\ \epsilon\ /2mu^2$

E = electric field intensity between plates (volts/inch)

ϵ = charge carried by the droplet (coulomb)

u = longitudinal speed of the droplet (inches/sec.)

m = mass of the droplet (lb.-sec²/in.)

a = length of deflection plates (inches)

b = distance between trailing edge of deflection plates and record paper (inches)

Δ_i = amount of droplet deflection to a printing position on the paper (inches)

l_i = distance charge pin must be located from leading edge of deflection plates to cause the droplet deflection Δ_i (inches) When the charge pins 35 are implemented according to the above equation, then as illustrated in FIG. 2, the droplet charged by the first pin located at a distance l_1 from the leading edge of the plates will be deviated from its original course by an amount Δ_1 when it reaches the paper and it will strike the paper in printing position 1. The droplets charged by the second and third pins from the leading edge of the plates will be deviated or deflected by amounts Δ_2 and Δ_3, respectively, and will strike the paper at printing positions 2 and 3. As shown, the ink droplets are deflected from their normal path laterally toward the negative deflection plate 33 and, hence, printing is carried out in horizontal fashion across the vertically moving paper 27.

A constant and equal charge voltage is applied to the charging pins 35 which are selected to charge a droplet and this is accomplished by providing a constant positive voltage source $+V_1$ which is applied to selected pins under the control of electronic switches which in turn are controlled by the input data to be printed. As shown in FIG. 2, the charging circuit for the first or number 1 pin in the row comprises an NPN transistor T1 having its collector electrode 36 connected to the first charging pin and its emitter electrode 37 connected to a source of ground potential 38. The ground potential source 38 establishes the virtual electrical ground plane, previously mentioned. This source 38 may have a value other than ground and the plane would have a corresponding value. The collector electrode 36 is also connected by way of a resistor R1 to a current sensor 39 which in turn is connected to the $+V_1$ charging voltage source. This charging voltage might have a value, for example, of a positive 250 volts. It can be seen that the charging circuits for the second and third pins are identical to the one just described with the circuit for the second pin comprising the NPN transistor T2 and resistor R2 and the circuit for the third pin comprising the NPN transistor T3 and resistor R3. All of the transistors have their emitter electrodes connected to the source of ground potential **38** and their collector electrodes connected by way of the collector resistors to the current sensor **39** and the charging voltage $+V_1$. The charging circuit for the last or gutter pin is different from the circuit for the other pins in that it does not include an electronic switch. The gutter pin is connected directly by way of a resistor R to the current sensor **39** and the charging voltage $+V_1$. The switching of the transistors to effect charging of the pins is controlled by shift registers and, as shown, a position **1** shift register **40** is connected to the base electrode of transistor T1, a position **2** shift register **41** is connected to the base electrode of transistor T2, and a position **3** shift register **42** is connected to the base electrode of transistor T3. Input data to be printed, from a computer or the like, is fed into the shift registers via the leads **43, 44** and **45.** The position **1** shift register **40** is a one bit register, position **2** shift register **41** is a two bit register, and position **3** shift register **42** is a third bit register to provide the required outputs to the transistors.

In charging the ink droplets **31,** the net charge Q on the droplet at any time within the constant field is given by the following equation:

$$Q = C_{dl}\,(V_d - 0\,V_1) + C_{d2}\,(V_d + \mathrm{dl/d}\;V)$$

where

V_d = the voltage to which the droplet is charged at the time of interest

V_1 = the charging voltage

V = the voltage across the deflection plates

C_{d1} = the capacitance existing between the droplet and the positive deflection plate

C_{d2} = the capacitance existing between the droplet and the negative deflection plate

d_1 = the distance between the droplet and the positive deflection plate

d = the distance between both deflection plates. collector transistor

The transistors T1, T2 and T3 will normally be conducting when no printing is desired and looking at transistor T1, for example, when it is conducting current flows from the charging voltage source $+V_1$, through the current sensor **39,** resistor **R1,** transistor T1, and to the ground **38.** As a result the associated number **1** charging pin is essentially at ground potential. Referring to the above charge equation, V_d is zero and the remaining charge components in the equation are equal and the opposite resulting in a net droplet charge of zero and no deflection occurs. If the position **1** shift register **40** produces an output calling for a printing operation, transistor T1 is rendered non-conducting and, since its c'llector electrode **36** does not require any current, the charging voltage $+V_1$ is reflected on the first charge pin **35** through resistor R1. Now when a droplet makes contact with the first charge pin and transisto T1 is off, a small current will flow to charge the capacitors C_{d1} and C_{d2} from the charging voltage source $+V_1$, through the current sensor **39** and resistor R1 to the ink droplet to establish the potential of the ink droplet to that of the charge pin which is $+V_1$. The charge pin and ink droplet form the common electrode of capacitors C_{d1} and C_{d2} thereby completing the circuit through the deflection plate voltage sources $+V_{p1}$ and $-V_{p2}$, respectively. From the charge equation given above, when $V_d = V_1$ it is evident that the charge on the droplet is $Q_d = C_{d1}\,(d/d_1,)\,V_1$. This almost instantaneous change of charge from zero to Q_d coulombs is the current sensed for phase maintenance. If T1 is conducting, there is no change in voltage of the ink at the point of contact of the charge pin. Therefore, there is no change in charge and the current is zero.

As shown in FIG. **2,** the droplet charged by the first pin will now be deflected from its normal path by the fixed electrical field and will move along a position **1** deflection path until it strikes the record paper **27** at which point it will have been deflected an amount Δ_1. All droplets which come in contact with a pin that has been charged for printing purposes will be charged and deflected as just described with the amount of deflection being determined by the distance the charged droplet travels before striking the record player.

The formation of the ink droplets **31** depends upon the operation of the oscillator **29** and the pressure source **23** and if, for example, the pressure should vary a small amount the droplet formation will very likely vary. It is desirable to know when each droplet arrives at each charge pin so that the transistors can be switched at the proper time to charge the pins. With data input every 10 microseconds, it is desirable to have the droplet charging interval, which is in the order of four microseconds, arrive in the center of the data interval. As was described, when a droplet makes contact with a charged pin a small current, for approximately 250 nanoseconds, will flow in the collector resistor of the associated transistor. This current can be sensed with a common amplifier and converted to a logic output to synchronize the charging of the droplets with the time the droplets contact the pins. As shown in FIG. **2,** the current is sensed by the current sensor **39** which provides an input to a sense amplifier **46** having a logic output. The logic "0" state indicates no charging while the positive transmission to the "1" state indicates the time of pin contact when charging a droplet. All droplets are charged because the last or gutter pin will give necessary synchronization information for those droplets not actually used in printing. Droplets charged by the last pin are deflected into a gutter pipe **47** for return back to the ink reservoir **24.**

The current pulse can be used in the following two ways to control the synchronization:

1. The phase of the crystal driver output can be varied with respect to the memory clock to accomplish synchronization.
2. The crystal driver output can be held constant and the droplet charging voltage can be phased with respect to the time the droplets arrive at the charge pins.

A synchronization scheme can be contrived by those skilled in the art for the first method. An error voltage can be developed and used in a conventional feedback loop to control the time when the droplet contacts the pin. This scheme offers all the advantages associated with feedback systems; however, it can only be implemented in systems of one nozzle per crystal or where each nozzle of a multiple nozzle drive adequately tracks the others. The present system preferably makes use of the second method and, as shown in FIG. **2,** the logic output from sense amplifier **46** is fed to a phase maintenance system **47** along with phase sample pulses and pulses from a drop formation clock. The phase sample pulses would be taken from a computer and could be, for example, one pulse for each line printed. The drop formation clock is made up of the senusoidal oscillator **29** and a comparator **48** which is used to compare the oscillator pulses against a reference V_{ref} to obtain a series of square wave pulses. The output from the phase maintenance system **47** is fed back and applied to the shift registers **40, 41** and **42** by way of the single shots **49, 50** and **51**, respectively, and as will be further described, this results in either delaying or advancing the time that the input data is applied to the charge pins.

Referring now to FIGS. **3** and **4**, there is shown the phase maintenance system and its related pulse trains. In this system, the drop formation clock **52** produces a pulse D for every 10 microseconds or every time a droplet is formed. These pulses are fed to a high frequency clock **53** synchronized with and at a multiple integer **10** of the droplet formation clock frequency. This 10 times clock is used to derive 10 discrete one microsecond phase increment pulses A for every drop formation pulse. The **10** times clock pulses A are fed into a logic box **54** along with the drop charging current pulses B and the phase sample pulses C. The logic box has a truth table as indicated in FIG. **3** and the phase sample pulses periodically allows the system to correct when the data is changed such that the output phase Q is changed as follows:

1 With no phase sample pulse, the output phase remains unchanged.
2. With the phase sample pulse present and no current pulse, the output phase is delayed by t which is equal to 1/10 times the droplet formation period.
3. With the phase sample pulse and the current pulse present, the output phase is advanced by t.

The output pulses Q from logic box **54** are fed into a 10 bit ring counter **55** which provides **1** output pulse E for every 10 pulses it receives. The output pulse E width has the same period as the input pulse A. The output pulses E from the ring counter are fed back to the single shots **49, 50** and **51** to clock the shift registers **40, 41** and **42.** For condition (1) where there is no phase sample pulse, the output phase remains unchanged and the Q out pulse train will be the same as that of the 10 times clock. After **10** Q out pulses, the ring counter delivers the output pulse E to the single shots and they in turn deliver an output pulse to the shift registers which is delayed such that the data to be charged will arrive when the ink droplet arrives at the charge pin. This delay is fixed and is predetermined by the speed of the droplet flow and the location of the charge pins. The delay can be adjusted to compensate for tolerances between the charge pins.

For condition (2) where there is a phase sample pulse but no current pulse, it is desirable to delay the output phase by t or 1/10 times the droplet formation period. This is accomplished by deleting one pulse in the Q out pulse train, as indicated by the gap X in the train in FIG. **4.** As a result, the feedback from the ring counter **55** to the single shots **49, 50** and **51** now delays the input data being applied to the charge pins by the one pulse time or one microsecond. This condition occurs until both a current pulse and a phase sample pulse are present.

To illustrate condition (3) where a phase sample pulse and a current pulse are both present, there is shown in FIG. **4** a dotted current pulse B_1 occurring with the phase sample pulse C. When this happens, logic box **54** will transmit two rapid pulses, shown by the dotted pulses Q_1 and Q_2, in one microsecond which is the time interval of the missing clock pulse. The positive edge of pulses Q_1 and Q_2 advances the ring counter **55** an extra position which results in an earlier output pulse, as illustrated by the dotted pulse E_1. The feedback of this pulse to the single shots results in the input data being applied to the charge pins 1 microsecond sooner.

It can be seen, then, that when the system is first started the output phase is delayed in discrete t increments until the current pulse occurs simultaneously with the phase sample pulse and then the output phase is advanced by t. Therefore, the phase will oscillate $\pm t$ about the correct charging time, thus, following any variations in the time the droplets arrive at the pin.

The present phase maintenance system can be used for either single or multiple nozzle drive systems. One is required for each nozzle. The data is presented to the shift registers of all positions to be printed. The output phase can be used to advance the position shift registers for the pertinent nozzle. Because charged droplets may occasionally contact succeeding pins, the successive electronic switches must be set to charge the droplet as it contacts those pins or the charge will be lost. The data must be translated for the greatest number of pins that a charged droplet can contact before sufficient deflection has occurred. The length of the position shift registers is equal to the time required for the droplet to move from the position P, shown in FIG. **2,** to the pin associated with that shift register.

Referring now to FIG. **5,** there is illustrated typical design values for a workable system of the present invention. As shown, these values may be as follows:

ink pressure = 60 p.s.i.
nozzle diameter = 0.002 inch
dimension of deflection plates = 1.5 inches × 0.5 inch
positive plate charge voltage = +250 V
negative plate charge voltage = −750 V
spacing between charge pins ≈0.01 inch
pin charge voltage = +250 V
space between pin and positive plate = 1/32 inch
space between pin and negative plate = 3/32 inch
space between the leading edge of plate and nozzle = ¼ inch
space between the trailing edge of plate and paper = ½ inch
charge pin diameter = 0.004 inch base → fine tip

It will be understood that the above values are illustrated and that a workable design of the present system would not be restricted to these values.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A fluid droplet printer comprising:

means for projecting a stream of writing fluid in the form of a succession of spaced discrete droplets along a path toward the surface of a record member;

means for effecting relative movement between the record member and said projecting means;

means for establishing an electric field through which the succession of droplets pass during their flow along said path from the projecting means to said record member;

charging means for depositing a constant equal charge on said droplets at spaced locations along their path of travel through said electric field; and

means controlled by input data to be printed for rendering said charging means effective to charge at least some of said droplets, said electric field being effective to deflect charged droplets from their path by an amount dependent upon the distance a droplet travels from the time it is charged until it strikes said record member whereby the charged droplets are deposited on said record member to produce a record representing the input data to be printed.

2. A fluid droplet printer comprising:

means for projecting a stream of writing fluid in the form of a succession of spaced discrete droplets along a path toward the surface of a record member;

means for effecting relative movement between the record member and said projecting means;

means for establishing an electric field through which the succession of droplets pass during their flow along said path from the projecting means to said record member;

a plurality of charging elements disposed at spaced locations along the path of droplet travel through said electric field for depositing a constant equal charge on said droplets; and

charging circuit means controlled by input data to be printed for rendering said charging elements effective to charge at least some of said droplets, said electric field being effective to deflect charged droplets from their path by an amount dependent upon the distance a droplet travels from the time it is charged until it strikes said record member whereby the charged droplets are deposited on said record member to produce a record representing the input data to be printed.

3. A fluid droplet printer as in claim **2** wherein said charging elements comprises a row of spaced apart charging pins which are contacted by uncharged droplets as they flow along said path.

4. A fluid droplet printer as in claim **3** and including synchronization means for synchronizing the charging of said pins with the arrival of the droplets at the pins.

5. A fluid droplet printer as in claim **3** including droplet collection means and wherein the last charging pin in said row charges all droplets which have not been deflected for printing, said electric field being effective to deflect the droplets charged by the last pin to said collection means.

6. A fluid droplet printer comprising:

means for projecting a stream of writing fluid in the form of a succession of spaced discrete droplets along a path toward the surface of a record member;

means for effecting relative movement between the record member and said projecting means;

means for establishing an electric field through which the succession of droplets pass during their flow along said path from the projecting means to said record member;

a plurality of charging elements disposed at spaced locations along the path of droplet travel through said electric field for depositing a constant equal charge on said droplets;

a source of constant charging voltage for said charging elements;

switching means for applying said charging voltage to said charging elements; and

means controlled by input data to be printed for operating said switching means whereby said charging elements are rendered effective to charge at least some of said droplets, said electric field being effective to deflect charged droplets from their path by an amount dependent upon the distance a droplet travels from the time it is charged until it strikes said record member whereby the charged droplets are deposited on said record member to produce a record representing the input data to be printed.

7. A fluid droplet printer comprising:

means for projecting a stream of writing fluid in the form of a succession of spaced discrete droplets along a path toward the surface of a record member;

means for effecting relative movement between the record member and said projecting means;

means for establishing an electric field through which the succession of droplets pass during their flow along said path from the projecting means to said record member;

a row of spaced apart charging pins located along the path of droplet travel through said electric field and which are contacted by uncharged droplets as they flow along said path;

a source of constant charging voltage for said charging pins;

electric switches associated with the charging pins and operable to effect application of said charging voltage to said pins; and

storage means associated with said electronic switches and responsive to input data to be printed, the outputs from said storage means operating the electronic switches whereby said charging pins are rendered effective to charge at least some of said droplets, said electric field being effective to deflect charged droplets from their path by an amount dependent upon the distance a droplet travels from the time it is charged until it strikes said record member whereby the charged droplets are deposited on said record member to produce a record representing the input data to be printed.

8. A fluid droplet printer as in claim **7** including gutter means and a gutter charging pin located at the end of said row and connected to said charging voltage source whereby it will charge all droplets which have not been deflected for printing, said electric field being effective to deflect the droplets charged by the gutter pins into said gutter means.

9. A fluid droplet printer as in claim **7** wherein said electric field is established by a pair of spaced apart electrostatic deflection plates between which said succession of droplets pass, said plates being connected to a constant high voltage charge which produces a constant high voltage electric field between the plates.

10 A fluid droplet printer as in claim **9** wherein a virtual electrical ground plane exists between said deflection plates and the flow path of uncharged droplets is coincident with said plane.

11. A fluid droplet printer as in claim 7 including a hollow electrically grounded shield member located between said projecting means and said electric field and through which the succession of droplets pass.

12. In a fluid droplet printer the combination of:

a nozzle for projecting a stream of writing fluid along a path toward the surface of a record member;

means for supplying writing fluid under pressure to said nozzle;

means for introducing regularly spaced varicosities in said stream of writing fluid to assure the formation of a succession of discrete droplets of uniform dimension and at a constant rate;

means for effecting relative movement between the record member and said nozzle;

a pair of spaced apart electrostatic deflection plates between which said succession of droplets pass along their path toward the record member;

means for applying a constant electrostatic charge to said deflection plates to produce a constant electric field therebetween;

a row of spaced apart charging elements located between said deflection plates and positioned along the path of droplet travel to make contact with said succession of droplets as they pass;

a source of constant charging voltage for said charging elements; and

means controlled by input data to be printed for applying said charging voltage to at least some of said charging elements whereby at least some of said droplets will receive a constant equal charge and said electric field will deflect said charged droplets from their path different amounts for deposition at different positions on said record member to produce a record representing said input data.

13. The invention as set forth in claim 12 wherein the location of each charging element along said droplet path is related to a printing position on said record member.

14. The invention as set forth in claim 12 wherein the amount a charged droplet is deflected is dependent upon the location of the charging element that charged the droplet.

15. The invention as set forth in claim 12 wherein means are provided to feed said record member in a vertical direction and said deflection plates are arranged to deflect the charged droplets horizontally for deposition across said record member.

16. The invention at set forth in claim 12 wherein said charging elements take the form of pins which are approximately equally spaced apart.

17. The invention as set forth in claim 12 and including a gutter pipe and a gutter charging element positioned at the end of said row and connected to said constant charging voltage source to charge all droplets which have not been deflected for printing, said electric field deflecting into said gutter pipe those droplets charged by said gutter element.

18. The invention as set forth in claim 12 and incuding phase maintenance means for phasing the droplet charging voltage with respect to the time the droplets arrive at the charging elements.

19. The invention as set forth in claim 12 wherein a virtual electrical ground plane exists between said deflection plates and said nozzle is aimed so that the flow path of uncharged droplets is coincident with said plane.

20. In a fluid droplet printer the combination of:

a nozzle for projecting a stream of writing fluid along a path toward the surface of a record member;

means for supplying writing fluid under pressure to said nozzle;

means for introducing regularly spaced varicosities in said stream of writing fluid to assure the formation of a succession of discrete droplets of uniform dimension and at a constant rate;

means for effecting relative movement between the record member and said nozzle;

a pair of spaced apart electrostatic deflection plates between which said succession of droplets pass along their path toward the record member;

means for applying an electrostatic charge to said deflection plates to produce an electric field therebetween;

a charging element located between said deflection plates and positioned in the path of droplet travel to make contact with said succession of droplets as they pass;

a source of charging voltage for said charging element; and

means controlled by input data to be printed for applying said charging voltage to said element whereby a droplet contacting the charged element will be charged and said electric field will deflect the charged droplet for deposition on said record member.

21. In a fluid droplet printer the combination of:

a nozzle for projecting a stream of writing fluid along a path toward the surface of a record member;

means for supplying wriring fluid under pressure to said nozzle;

means for introducing regularly spaced variscosities in said stream of writing fluid to assure the formation of a succession of discrete droplets of uniform dimension and at a constant rate;

means for effecting relative movement between the record member and said nozzle;

a pair of spaced apart electrostatic deflection plates between which said succession of droplets pass along their path toward the record member;

means for applying a constant electrostatic charge to said deflection plates to produce a constant electric field therebetween;

a row of spaced apart charging pins located between said deflection plates and positioned along the path of droplet travel to make contact with said succession of droplets as they pass;

a source of constant charging voltage for said charging pins;

electronic switches in circuit with said charging pins, each switch being operable to appy said charging voltage to an associated charging pin; and

a shift register associated with each said electronic switch for operating same, said shift registers being controlled by input data to be printed to provide outputs for operating their associated switches to apply said charging voltage to at least some of said charging pins whereby at least some fo said droplets will receive a constant equal charge and said electric field will deflect said charged droplets from their path different amounts for deposition at different positions on said record member to produce a record representing said input data.

22. The invention as set forth in claim 21 wherein each said shift register has a length which is related to the position of its associated charging pin along the pin row.

23. The invention as set forth in claim 21 and including logic circuit means controlled by the droplet formation rate and the charging of said pins to provide synchronizing pulses; and

feedback means for supplying said synchronizing pulses to said shift registers to either delay or advance the time that the input data is applied to the charge pins so that the droplet charging voltage is phased with respect to the time the droplets arrive at the charge pins.

24. The invention as set forth in claim 21 wherein the charging pins are located to enable said electric field to produce droplet deflection amounts which differ in accordance with the predetermined printing positions on the record member.

25. A method of printing on a record member by use of fluid droplets comprising the steps of:

supplying writing fluid under pressure to a nozzle to project a stream of writing fluid along a path toward said record member;

introducting regularly spaced varicosities in said stream of writing fluid to assure the formation of a succession of discrete droplets of uniform size and at a constant rate;

causing the succession of droplets to contact a row of spaced charging elements disposed along the path of droplet travel;

establishing a constant electrical field through which said droplets pass as they contact said charging elements;

causing relative movement between said record member and the nozzle; and

applying in response to input data a constant potential to at least some of said charging elements to deposit a constant equal charge on at least some of the droplets whereby the electric field will cause the charged droplets to deflect from their path with different trajectories for depostion on said record member.

26. A method as in claim 25 wherein the trajectory taken by a deflected charged droplet is dependent on when the droplet is charged as it passes along said row of charging elements.

27. A method as in claim 25 in which the application of the constant potential to the charging elements is synchronized with the arrival of the droplets at the elements.

28. A method as in claim 25 wherein all droplets not deflected for deposition on said record member are charged and deflected for collection.

29. A method of printing on a record member by use of fluid droplets comprising the steps of:

supplying writing fluid under pressure to a nozzle to project a stream of writing fluid along a path toward said record member;

introducing regularly spaced varicosities in said stream of writing fluid to assure the formation of a succession of discrete droplets of uniform size and at a constant rate;

causing the succession of droplets to contact a charging element positioned in the path of droplet travel;

establishing an electrical field through which said droplets pass as they contact said charging element;

causing relative movement between said record member and the nozzle; and

applying a charging voltage to said charging element to charge a droplet coming in contact therewith whereby the charged droplet will be deflected by said electrical field for deposition on said record member.

30. A fluid droplet printer as in claim 9 wherein a virtual electrical plane exists between said deflection plates which is coincident with the flow path of uncharged droplets and a voltage source is provided which establishes a potential on said plane.

* * * * *

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,769,624 Dated October 30, 1973

Inventor(s) Chen-Hsiung Lee et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the specification, Column 3, line 20, "drolet" should read --droplet--. Column 3, line 48, "accord-ance" should read --accordance--. Column 4, line 30, reference numeral "3" should read --13--. Column 4, line 37, "recerd" should read --record--. Column 4, line 64, "10-6" should read --10^{-6}--. Column 5, line 5, "10-5" should read --10^{-5}--. Column 7, line 29, that portion of the formula reading "(V_d -0 V_1)" should read --(V_d - V_1)--. Column 7, line 41, delete "col-" at the end of the line. Column 7, line 42, delete "lector transistor". Column 7, line 56, "c'llector" should read --collector--. Column 7, line 59, "transisto" should read --transistor--. Column 8, line 18, "player" should read --paper--. Column 9, line 3, "senusoidal" should read --sinusoidal--. Column 9, line 39, the reference character "A" should read --Q--.

In the claims, Column 12, line 57, "pins" should read --pin--. Column 13, line 49, "at" should read --as--. Column 14, line 34, "wriring" should read --writing--. Column 14, line 36, "variscosities" should read --varicosities--. Column 14, line 63, "fo" should read --of--. Column 15, line 25, "introducting" should read --introducing--.

Signed and sealed this 4th day of June 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,769,624 Dated October 30, 1973

Inventor(s) Chen-Hsiung Lee et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the specification, Column 3, line 20, "drolet" should read --droplet--. Column 3, line 48, "accord-ance" should read --accordance--. Column 4, line 30, reference numeral "3" should read --13--. Column 4, line 37, "recerd" should read --record--. Column 4, line 64, "10¯6" should read --10^{-6}--. Column 5, line 5, "10¯5" should read --10^{-5}--. Column 7, line 29, that portion of the formula reading "(V_d -0 V_1)" should read --(V_d - V_1)--. Column 7, line 41, delete "col-" at the end of the line. Column 7, line 42, delete "lector transistor". Column 7, line 56, "c'llector" should read --collector--. Column 7, line 59, "transisto" should read --transistor--. Column 8, line 18, "player" should read --paper--. Column 9, line 3, "senusoidal" should read --sinusoidal--. Column 9, line 39, the reference character "A" should read --Q--.

In the claims, Column 12, line 57, "pins" should read --pin--. Column 13, line 49, "at" should read --as--. Column 14, line 34, "wriring" should read --writing--. Column 14, line 36, "variscosities" should read --varicosities--. Column 14, line 63, "fo" should read --of--. Column 15, line 25, "introducting" should read --introducing--.

Signed and sealed this 4th day of June 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents