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Chen

[11] 3,846,800
[45] Nov. 5, 1974

[54] INK JET RECORDING METHOD AND APPARATUS

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[52] **U.S. Cl.** **346/1**, 346/75
[51] **Int. Cl.** **G01d 15/18**
[58] **Field of Search** 346/1, 75

[56] **References Cited**

UNITED STATES PATENTS

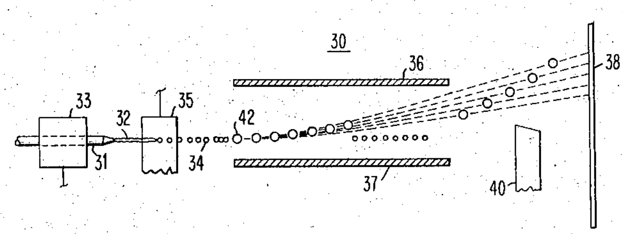
3,562,761 2/1971 Stone et al. 346/75
3,786,517 1/1974 Krause 346/75

Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—Francis V. Giolma

[57] ABSTRACT

A base voltage of one polarity and signal voltages of the opposite polarity are applied to the charging electrode of an ink jet printer in selected sequences, so that two or more oppositely charged drops merge in flight to produce larger drops, thus controlling not only the placing of the drops on a document but the density of the printing also.

7 Claims, 8 Drawing Figures



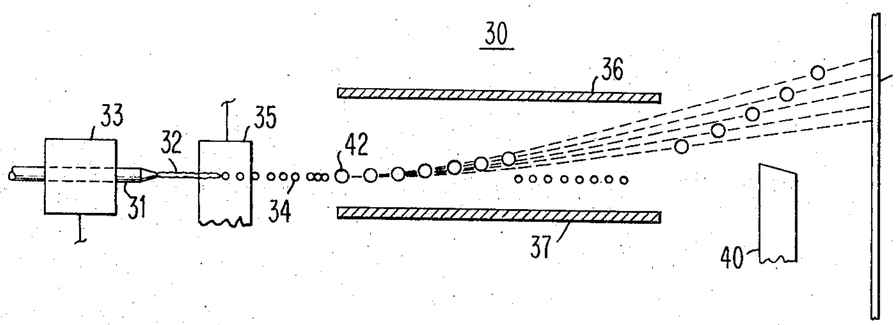


FIG. 1

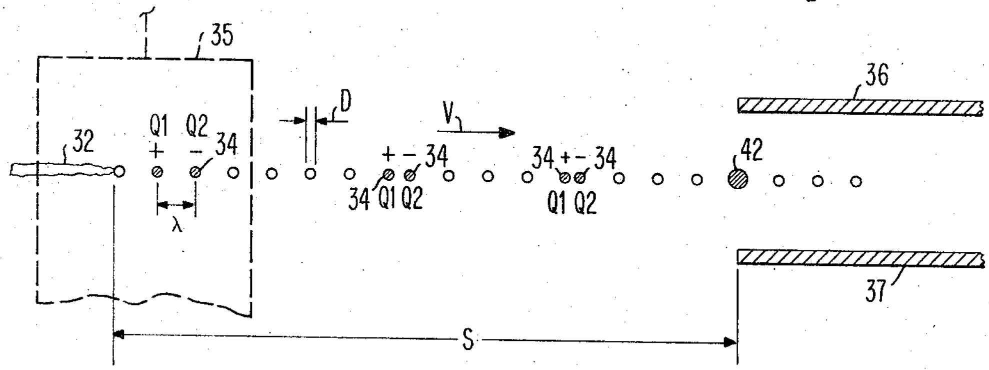


FIG. 2

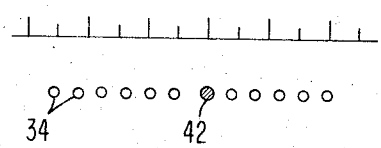


FIG. 3

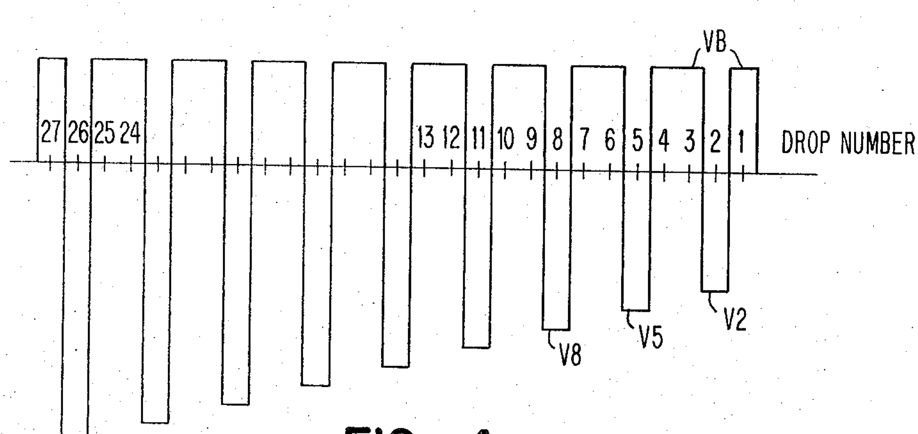


FIG. 4

FIG. 5

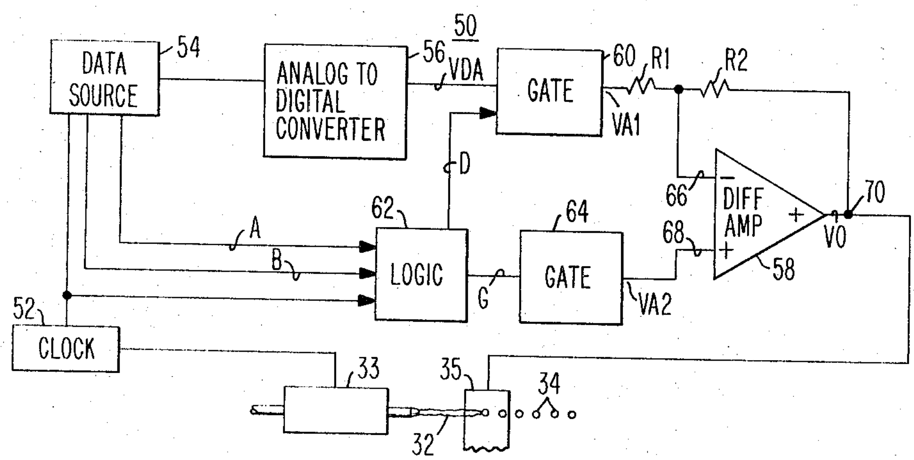


FIG. 6

A	B	G	D	V1	V2	V3	GRAY SCALE
0	0	0	0	0	0	0	0 (NO DROP)
0	1	0	1	0	1	0	1 (1 DROP)
1	0	1	1	1	1	0	2 (2 DROPS)
1	1	1	1	1	1	1	3 (3 DROPS)

FIG. 7

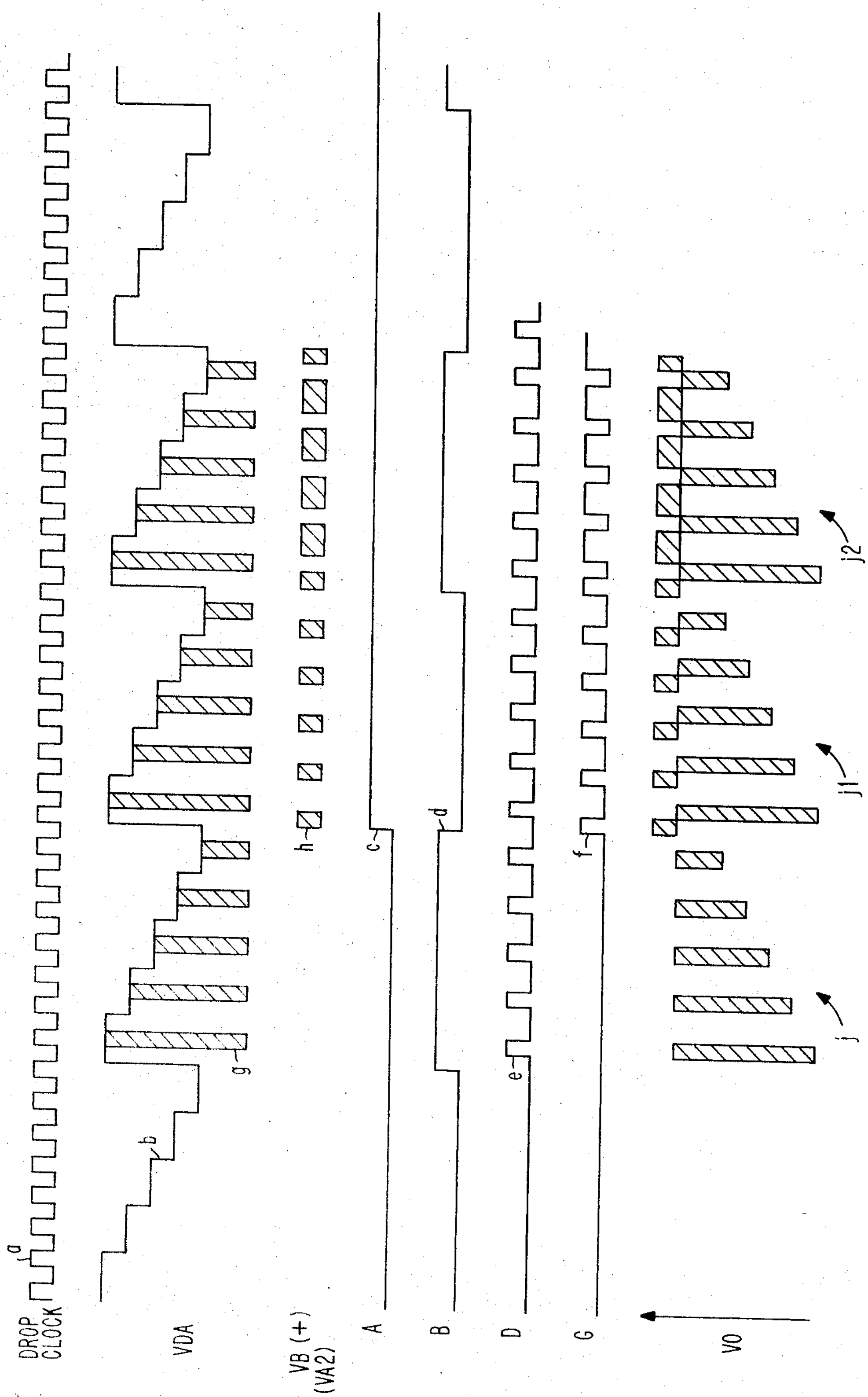


FIG. 8

INK JET RECORDING METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to ink jet printing methods and apparatus, and it has reference in particular to drop size and print density control in ink jet printing.

2. Description of the Prior Art

U.S. Pat. No. 3,465,351 which issued on Sept. 2, 1969 to R. I. Keur, et al., entitled "Ink Drop Writing Apparatus" describes a phase correction system in which a 33KHz test signal is applied to drops formed at a 66KHz rate so that only every other drop is charged, and charged and uncharged drops combine and are detected by a target to check for proper phasing of drop formation and charging signal. ink jet printer.

U.S. Pat. NO. 3,596,276, which issued on July, 27, 1971 to Lovelady, et al., entitled "Ink Jet Printer with Droplet Phase Control Means" discloses the application of a negative sawtooth test signal during non-printing intervals for the purposes of detecting and correcting phase errors between the drop formation and the drop charging in an

U.S. Pat. No. 3,604,846 which issued on Sept. 14, 1971 to D. Behane, et al., discloses gray scale printing by assigning from zero to nine separate drops of ink to a unit area in accordance with the darkness of a surface being copied, in order to vary the density of printing.

OBJECTS AND SUMMARY OF THE INVENTION

Generally stated, it is an object of this invention to provide an improved method of ink jet printing.

Another object of the invention is to provide a simple and effective ink jet printer for gray scale printing.

It is an important object of the invention to provide for so charging successive drops in an ink jet printer that they attract each other and merge into larger drops in flight.

Another important object of the invention is to provide for selectively charging alternate drops in a stream of ink drops with opposite polarities so that they merge in predetermined arrangements.

Yet another object of the invention is to provide for selectively charging different drops in an ink jet printer as they form in accordance with data signals and a base signal of a different polarity so that they combine in flight according to different predetermined patterns.

By charging the drops of successive pairs of drops, one with a base voltage of one polarity and the other with a signal voltage of the opposite polarity, the two drops of each pair may be made to combine in flight and form larger drops prior to being deflected onto the document for printing.

Print density may be controlled in an ink jet printer by selectively charging alternate drops of ink with a base voltage of one polarity and signal voltages of the opposite polarity to cause different numbers of the drops to combine and form larger drops which produce a more dense printout.

Yet another object of the invention is to provide for gating character signals and base voltage signals to a differential amplifier supplying the charging voltage to the charging electrode in an ink jet printer so as to cause selective groups of ink drops to merge and control the density of printing.

It is also an important object of the invention to provide for using logic circuits to selectively gate data signals and base voltage signals to the charging electrode of an ink jet printer through a differential amplifier so as to effect selective merging of two or more charged ink drops before being deflected to print on a document.

The foregoing and other objects, features and advantages of the invention will be apparent to those skilled in the art from the following more detailed description of a preferred embodiment of the invention as illustrated in the accompanying drawing.

DESCRIPTION OF THE DRAWING

In the drawing

FIG. **1** is a schematic view in side elevation of an ink jet printer structure showing the general arrangement of the nozzle, transducer, charging electrode, deflection plates and document;

FIG. **2** is a partial schematic diagram of a portion of the system of FIG. **1** showing the relations between oppositely charged adjacent drops as they travel from the charging electrode to the deflection electrodes;

FIG. **3** is a reproduction of a photograph of the ink jet drop stream showing an enlarged drop formed by merged ink drops;

FIG. **4** is a showing of a typical charging electrode waveform for forming merged ink drops from three adjacent drops in the stream.

FIG. **5** is a reproduction of print samples made from merged ink drops using a charging electrode waveform as shown in FIG. **4.**

FIG. **6** is a schematic block diagram of an ink jet control system for printing with merged ink drops;

FIG. **7** is a truth table illustrating the logic conditions for the logic in FIG. **6** for different ink drop charging conditions for producing different ink drop densities, and

FIG. **8** shows typical waveforms for the system of FIG. **6** for different drop charging conditions.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to FIG. **1** the reference numeral **30** denotes generally a schematic representation of an ink jet printer in which a nozzle **31** is connected to a source of ink under pressure for producing a stream of ink **32.** A transducer **33** is connected to the nozzle **31** and energized from a suitable periodic source of electrical energy for causing the stream play to break into drops of ink **34.** The drops **34** are suitably charged by means of a charging electrode **35** and then passed between deflection plates **36** and **37** which are raised to a suitable potential to provide a fixed field therebetween for deflecting charge drops onto a document **38** for printing or into a gutter **40** for return to the ink source. According to the invention the drops **34** are so charged that adjacent drops attract each other and merge into larger drops **42** during flight. These merged drops then pass between the deflection plates **36** and **37** and are deflected corresponding to the amount of charges they carry to predetermined positions on the document **38.** Uncharged drops **34** are not deflected when they pass between the deflection plates **36** and **37,** and are collected by the gutter **40.**

A unique way of charging and combining droplets **34** into larger droplets **42** for printing is based on a phenomena observed in experiments. It has been discovered that when a succession of droplets in flight carry alternate signs of charges, such as the charges Q_1 and Q_2 on adjacent drops **34** as shown in FIG. 2 where Q_1 is a positive charge and Q_2 is a negative charge, they attract each other by electrostatic force and result in merging as shown at **42** before they reach the deflection plates if the following condition is satisfied:

$$S > (8\pi\epsilon_o m/9Q_1 Q_2)^{1/2} (\lambda - D)^{3/2} v \quad \text{(Eq. 1)}$$

where

S	=	Distance between drop formation point and deflection plates.
v	=	velocity of droplets
m	=	mass of droplet
Q_1, Q_2	=	Charges of two adjacent drops (Q_1 & Q_2 are opposite in sign)
λ	=	Wave length
D	=	Drop diameter
ϵ_0	=	permittivity of free space

For instance, when $S = .400$, $v = 450$/sec., V_1 (base voltage) = −30V, V_2 (signal voltage) = +140V, $\lambda = .010$, $D = .004$, ink resistivity = 200 ohm cm, the merging of droplets takes place as shown schematically in FIG. 2 and in the reproduction of an actual printing operation in FIG. 3.

For the present printing scheme, a typical charging voltage pattern is composed of a base voltage and signal voltages. They are opposite in sign and are pulsed alternatively as shown in FIG. 4 where drops **1, 3, 4, 6, 7, 9, 10,** etc. are charged by a base voltage V_B and drops **2, 5, 8, 11,** etc. are charged by signal voltages V_2, V_5, V_8, V_{11}, etc. The signal voltages V_2, V_5, V_8, determine the amount of deflection of the associated drops.

The parameters of the printing system Sv, λ, D_m, V_B, and V are arranged to satisfy the requirements of equation **1** so that the merging effect will take place. Thus drops **1, 2** and **3** with charges Q_B, Q_2, and Q_B induced by the voltages V_B, V_2 and V_B merge into a single drop. The deflection of this merged drop on paper is: (Deflection of drops **1, 2, 3**) =

$$K (2 Q_B - Q_2/3m) (E/v^2) (L_1 L_2 + L_1^2/2)$$

where

K	=	constant
E	=	Electric Field
L_1	=	Length of Deflection plates
L_2	=	Distance between Deflection plates and paper

By controlling the signal voltages it is possible to deflect all the merged drops onto predetermined positions on the paper to form matrix printing. For instance the charging voltage pattern of FIG. 4 will make a printing of a vertical bar composed of 9 dots such as shown in FIG. **5** which is a reproduction of an actual print sample, each of the dots comprising three merged ink drops. Another print sample is shown in FIG. **5** which is a condensed 7 × 9 matrix block. Note that each dot on the paper is made of **3** droplets issued by the nozzle **31.**

Referring to FIG. **6** the referenced numeral **50** designates generally a logic control system for an ink jet printer embodying the features of the invention. As shown, the transducer **33** is energized from a clock or oscillator **52** which provides the desired varicosity effects for separating the ink stream **32** into droplets **34** which are charged by means of a charging electrode **35.** A data source **54** provides data signal voltages to a digital to analog converter **56.** Instead of connecting the digital to analog converter **56** directly to the charging electrode **35,** it is connected to the charging electrode through a differential amplifier **58** and an analog gate **60.** A logic circuit **62** is provided which is connected to the differential amplifier **58** through an analog gate **64.** The logic circuit **62** provides gating signals to the analog gates **60** and **62** for gating output signals from the digital to analog converter **56** to one terminal **66** of the differential amplifier **55,** and to the analog gate **64** for gating a base voltage signal V_B to the other input terminal **68** of the differential amplifier. Resistors R1 and R2 determine the ratio of the effects of the inputs at the terminals **66** and **68** on the output voltage V_o at the terminal **70** of the differential amplifier, which is connected to the charging electrode **35.** The logic circuit **62** is designed to operate in accordance with the truth table shown in FIG. **7.** Clock signals are provided by the oscillator **52** to the logic circuit **62** as well as to the data source **54.** The data source also provides tone or gray scale control signals A and B to the logic for determining the output voltage at V_O in accordance with the input signals at the terminals **66** and **68.**

Referring to FIG. **8,** it will be seen that the clock **52** provides clock pulse signals as shown at *a*. The digital to analog converter **56** provides a step or staircase waveform V_{DA} as shown at *b*. The A and B signals are shown at *c* and *d* respectively while the output signals of the logic circuit **62,** D and G, are shown at *e* and *f*, respectively. The output voltages V_{A1} and V_{A2} of the gates **60** and **64** are shown at g and h, respectively. Combinations of these signals result in an output voltage V_O as shown by the curve *j* at the bottom of the page. For example, referring to the truth table in FIG. **7** when the input signals to the logic circuit **62** are not A and not B ($\bar{A}$ and $\bar{B}$) the output signals G and D are equal to zero and the output voltages V_O are zero for successive drops **1, 2** and **3.** When the input signal to the logic circuit **62** is not A and B ($\bar{A}$ and B) then the output signal G will be zero but the output signal D will be up and the voltage on drop **2** will correspond to the voltage V_{A1} as shown by *j* in FIG. **8.** When the input to the logic circuit **62** is A and not B (A and $\bar{B}$) then the output signals G and D will both be up and the output voltages V_1 and V_2 will be up while the voltage V_3 will be zero as shown as j**1.** Accordingly, **2** drops will combine to form a single drop giving printing of double the density of a single drop. Where the condition when A and B signals are both applied to the logic circuit **62** then the outputs G and D are both up and voltages V_1, V_2 and V_3 are all up as shown at *j2* so that the base voltage V_B is applied to drops **2** and **3** of each sequence, and drops **1, 2** and **3** combine to provide a single drop **42** three times the size of a single original drop **34,** thus increasing the density of the printing.

From the above description and the accompanying drawing it will be apparent that the invention provides a simple and effective way of controlling the density of printing. By selectively applying control voltages to the logic circuit **62,** ink drops may be caused to merge to provide single drops of one, two, three or more times the size of a normal drop and printing of different densities may be thereby effected.

While the invention has been 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. In a method of printing on a document wherein ink is supplied to a nozzle under pressure and varicosities are produced in the ink stream to cause the stream to break up into uniformly sized and spaced drops in the region of a charging electrode which is energized to charge selected ones of said drops for causing them to deflect while passing through an electric field, the improvement which comprises;

energizing said charging electrode with signal voltages of one polarity at spaced time intervals to charge spaced ink drops to deflect them onto said document in a predetermined pattern, and energizing said charging electrode at intervening time intervals with a base voltage of the opposite polarity and sufficient value to cause selected ones of said signal voltage charged drops to merge in flight before being deflected to print on said document.

2. The invention as defined in claim **1** characterized by every other ink drop being charged by a signal voltage and the intervening drops being charged by a uniform base voltage so that pairs of adjacent drops merge in flight to form larger drops with a resultant increase in the density of the printing.

3. The invention as defined in claim **1** characterized by every fourth drop being charged by a signal voltage, and the two drops on either side of each such fourth drop being charged with a base voltage of the opposite polarity so that three successive ink drops combine in flight and form a larger drop with a resultant increase in print density.

4. In an ink drop printer having a nozzle for producing a stream of ink drops,

transducer means associated with said nozzle for producing varicosities in the ink stream to insure uniform drop formation,

clock means for applying timed pulses to said transducer means,

a charging electrode positioned in predetermined spaced relation with said nozzle for charging selected ones of said ink drops,

deflection means providing a field beyond said charging electrode to deflect said charged ink drops,

and means connecting said charging electrode to a source of data signals,

the improvement comprising circuit means connected between said charging electrode and said source of data signals and said clock means for selectively charging selected spaced ink drops with predetermined data signals of one polarity and intervening drops with a uniform base voltage of the opposite polarity to cause selected ones of said data signal charged ink drops and said base voltage charged ink drops and said base voltage charged ink drops to combine in flight before being deflected by said deflecting field.

5. The invention as defined in claim **4** characterized by said circuit means including logic means and a differential amplifier connected between the charging electrode and the data source and said clock means operable to selectively gate inputs to said differential amplifier from said data source and said clock means.

6. The invention as defined in claim **5** characterized by said circuit means including gating means connecting said data source and a source of base voltage to said differential amplifier.

7. The invention as defined in claim **6** characterized by said logic means functioning in accordance with the following truth table:

A	B	G	D	V1	V2	V3		Gray Scale
0	0	0	0	0	0	0	0	(No Drop)
0	1	0	1	0	1	0	1	(1 Drop)
1	0	1	1	1	1	0	2	(2 Drops)
1	1	1	1	1	1	1	3	(3 Drops)

where A and B are gray scale binary signals from the datas source, G and D are the gating signals for data source and base voltage signals respectively, and V1, V2 and V3 are the charging voltages applied to drops **1**, **2** and **3** respectively.

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