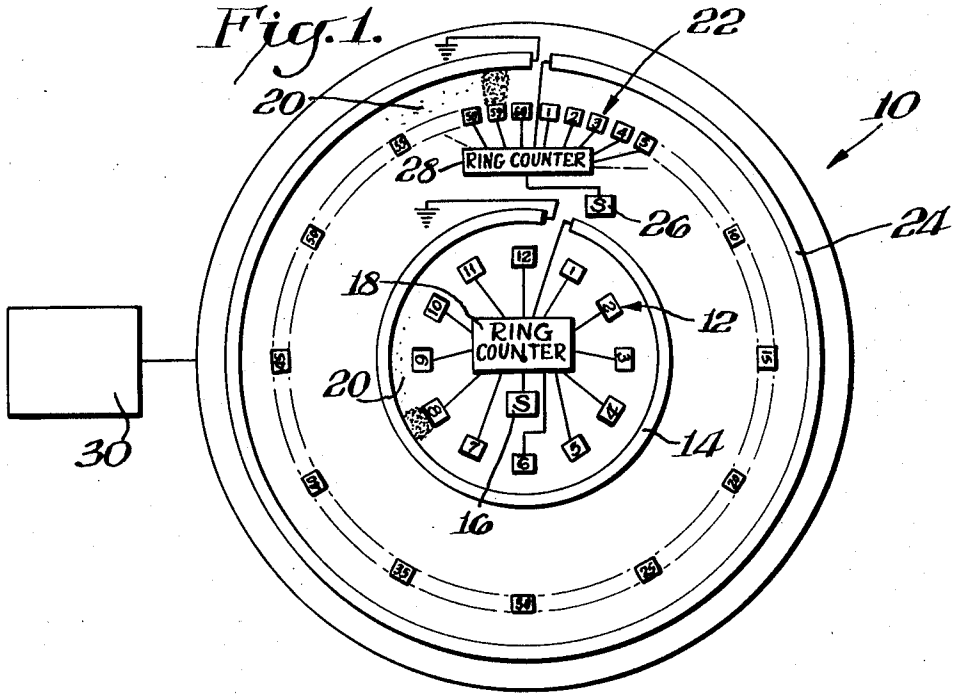
June 23, 1970 K. LEHOVEC 3,516,242

VISUAL DISPLAY OF TIME VARIABLE ELECTRIC INFORMATION

Filed Feb. 23, 1968 2 Sheets-Sheet 1

Fig. 1.



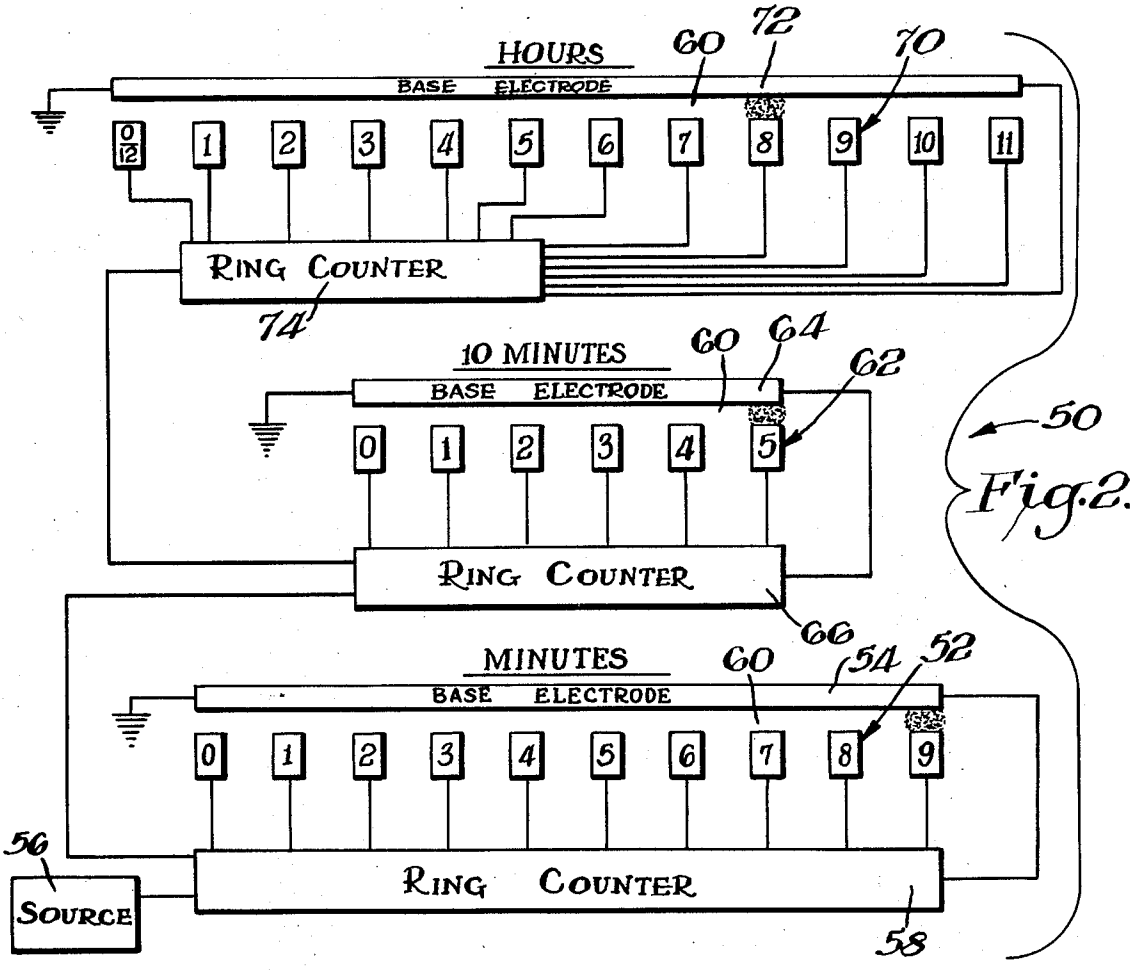


Fig. 2.

June 23, 1970 K. LEHOVEC 3,516,242

VISUAL DISPLAY OF TIME VARIABLE ELECTRIC INFORMATION

Filed Feb. 23, 1968 2 Sheets-Sheet 2

Fig. 3.

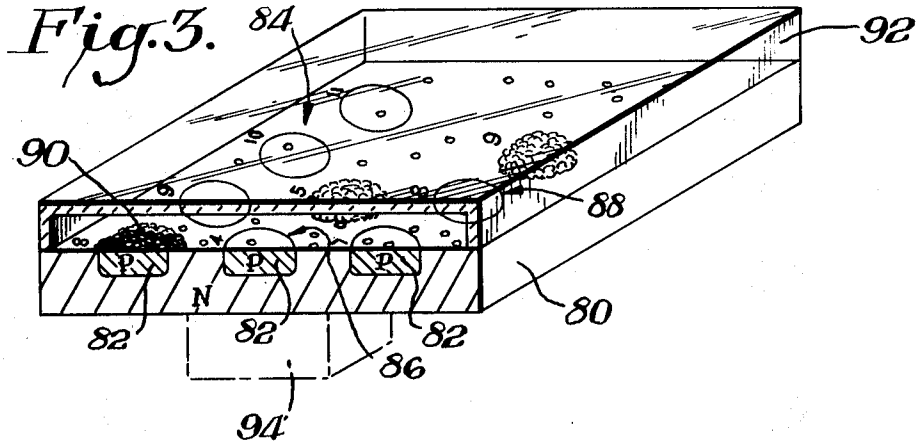


Fig. 4.

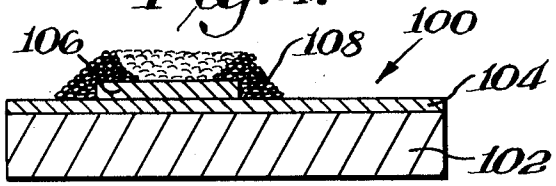


Fig. 5.

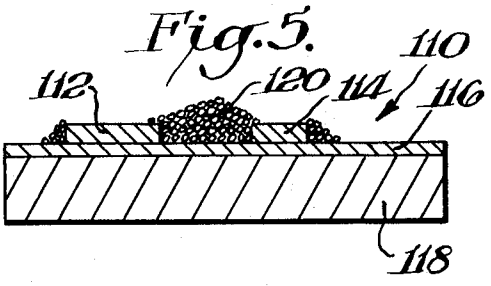


Fig. 6.

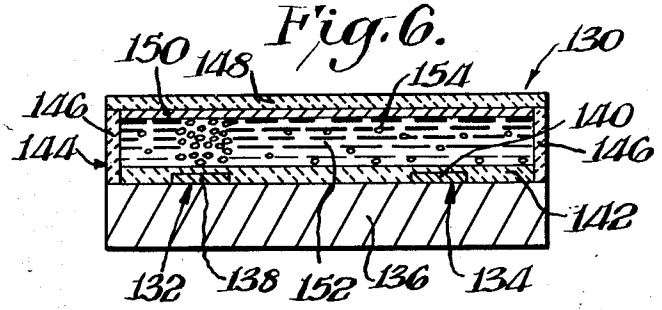
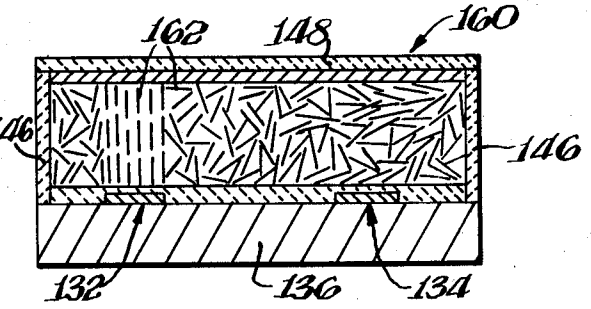


Fig. 7.



United States Patent Office 3,516,242 Patented June 23, 1970

3,516,242

VISUAL DISPLAY OF TIME VARIABLE ELECTRIC INFORMATION

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Int. Cl. G04c 3/00
U.S. Cl. 58—23 10 Claims

ABSTRACT OF THE DISCLOSURE

A visual display of time variable electric information comprising a source of information in the form of electric signals and a series of spacially arranged electrodes forming a plurality of electrode pairs. Circuitry is constructed and arranged to transmit the signals from the source to the electrode pairs in sequence so that a sequential pattern of electric fields is produced. A mass of randomly disposed particles adjacent the electrode pairs is adapted to accumulate in the electric fields thus produced whereby a visual display corresponding to the sequential pattern of electric fields is provided.

BACKGROUND OF THE INVENTION

The present invention relates to a visual display, and more particularly to a visual display of information, which information is available in the form of electric signals.

Presently, electric data processing of information is widely applied in such fields as television, time pieces, copying machines and calculators. Miniaturization of electric circuitry by semiconductor microcircuit techniques has drastically reduced the size of the electric systems used in these fields. However, it is of prime importance that the results of the data processing system be displayed in a manner compatible with the human senses, which in almost all instances, results in a visual or audio display of the information. In the past, such displays have been achieved either mechanically, by using gears and the hands of a clock or typewriters, for example, or electrically, through the use of bulky electronic devices, such as television picture tubes.

Additionally, simple displays of light have been produced through the orientation of particles within electric fields. Such a system is disclosed in Marks Pat. 3,257,903, granted June 28, 1966.

Accordingly, it is an object of the present invention to provide a compact, simple and highly reliable visual display of time variable electric information.

SUMMARY OF THE INVENTION

In accordance with the present invention a visual display of time variable electric information is provided comprising a source of information in the form of electric signals and a series of spacially arranged electrodes forming a plurality of electrode pairs. Circuitry is constructed and arranged to transmit the signals from the source to the electrode pairs in sequence so that a sequential pattern of electric fields is produced. A mass of randomly disposed particles adjacent the electrode pairs is adapted to accumulate in the electric fields thus produced to thereby provide a visual display corresponding to the sequential pattern of electric fields.

Moreover, the particular sequential pattern of electric fields produced can be such that only one electric field is produced at a time, and upon transmission of the next electric signal only the next field of the sequence is produced. Thus, the particles only accumulate in the field across one electrode pair at any one time. Alternatively,

the particular sequential pattern of electric fields produced can be such that all of the electric fields are produced except one, for example, all the fields except the field across the first pair of electrodes. Transmission of the next electric signal would then produce electric fields across every electrode pair except the second pair. The visual display thus produced would be one which was evident from the absence of particle accumulation adjacent one of the electrode pairs.

The circuitry for transmitting the signals to the electrode pairs in sequence may be a ring counter. Moreover, an agitator may be provided for vibrating the mass of particles so that the random disposition of the particles is maintained except in the vicinity of the electric fields where there is an accumulation of particles. The series of electrode pairs may be provided in the form of a microcircuit in a substrate of semiconducting material with the electrodes on the face of the substrate. Alternatively, the electrode pairs can be provided on top of an insulating layer covering the face of a semiconducting substrate containing a microcircuit for feeding the electrical signals in sequence to the electrode pairs.

In one form of the present invention, the mass of randomly disposed particles are located in a non-conducting liquid medium. In this embodiment, the particles migrate to the electric fields to provide a pronounced accumulation of particles at positions indicative of the electric information transmitted to the electrode pairs.

Numerous combinations of electrode pairs, circuitry and sources of electric information are within the scope of the present invention. A clock can be produced that indicates time in hour and minute intervals, hour and ten minute intervals or hour, minute and second intervals. In the case of a time piece that indicates hours and minutes, a first series of twelve electrode pairs is provided, with a source of electric signals that are interrupted every hour. The circuitry transmits the signals to the electrode pairs in sequence whereby after the lapse of one hour the signal is transmitted to the next electrode pair in the series. A second series of sixty electrode pairs is provided as well as a second source of electric signals interrupted every minute. The circuitry transmits the electric signal from one of the pairs to the next pair in the series after the lapse of one minute. Accordingly, a pronounced accumulation of particles occurs adjacent the electrode pairs to which the signals are transmitted which accumulation is indicative of the time in hours and minutes.

Further, the particular orientation of non-spherical particles can be utilized to produce the visual display. In this regard, electric fields change the degree of orientation of the particles within the field to thereby provide a visual display corresponding to the sequential pattern of electric fields produced.

BRIEF DESCRIPTION OF THE DRAWING

Novel features and advantages of the present invention in addition to those mentioned above will become apparent to one skilled in the art from a reading of the following detailed description in conjunction with the accompanying drawing wherein similar reference characters refer to similar parts and in which:

FIG. 1 is a diagrammatic view of a visual display according to the present invention;

FIG. 2 is a diagrammatic view of another visual display according to the present invention;

FIG. 3 is a perspective view of a portion of a visual display according to the present invention;

FIG. 4 is a sectional view of an electrode pair configuration of a visual display according to the present invention;

FIG. 5 is a sectional view of another electrode pair configuration of a visual display according to the present invention;

FIG. 6 is a sectional view of still another visual display according to the present invention; and

FIG. 7 is a sectional view of another visual display according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring in more particularity to the drawing, FIG. 1 illustrates a visual display of time variable information in the form of a clock **10** arranged to indicate time in hours and minutes. A first series of twelve spacially arranged electrodes **12** are provided on an insulating substrate and each electrode carries a number from 1 to 12. A base electrode **14** is located adjacent the electrodes **12**, and together, these electrodes form a plurality of twelve electrode pairs, with the base electrode acting as one of the electrodes of each pair. An electric signal applied to one of the electrodes **12** and the base electrode **14** produces an electric field across that particular electrode pair. In this regard, a source of electric signals **16** is connected to the electrodes **12** and the base electrode **14** by circuitry in the form of a ring counter **18**. As is well known, a ring counter is a re-entrant multi-stable circuit in which any number of stages are arranged so that a unique condition exists in one stage and each pulse or electric signal at the input causes this condition to transfer one unit at a time. A suitable ring counter is described, for example, by Palmer in Electronic Engineering (Great Britain), August 1964, pp. 519–23. The ring counter **18** functions to transmit in sequence the signals from the source **16** to the electrode pairs. The source is arranged so that the signal is interrupted each hour and the ring counter transmits the signal to the next electrode pair each time the signal is interrupted.

A sequential pattern of electric fields is produced across the electrode pairs. After the lapse of one hour the signal is transmitted to the next electrode in the series and the base electrode **14**. A visual display of the sequential pattern of electric fields is produced by providing a mass of randomly disposed visual particles **20** adjacent the electrode pairs comprising the series **12** and the base electrode **14**. These particles are attracted to the electric fields and accumulate preferentially in the electric field between the electrode pair to which a signal is transmitted. Thus, the particles accumulate adjacent a particular electric field to provide a visual indication of the sequential pattern of electric fields similar to the familiar case of iron filings accumulating preferentially in a magnetic field. With the arrangement diagrammatically illustrated in FIG. 1, hours of time are visually displayed, and the hour indicated is eight.

The arrangement **10** shown in FIG. 1 also includes a second series of sixty electrodes **22** numbered from 1 to 60 and arranged adjacent a base electrode **24**. The base electrode cooperates with the series of electrodes **22** to provide sixty electrode pairs. A source of electric signals **26** interrupted every minute is connected to the electrode pairs comprising the electrodes **22** and the base electrode **24** by a ring counter **28**. The ring counter functions in the same manner as the ring counter **18** and supplies electric signals in sequence to the electrode pairs. The ring counter **28** transfers the signal to an adjacent electrode pair after the lapse of one minute. The sequential pattern of electric fields produced between the electrodes **22** and the base electrode **24** attracts the randomly disposed particles so that the particles accumulate in the electric field between the electrode pair to which a signal is transmitted. In FIG. 1, the electric signal from the source **26** is applied to the fifty-ninth electrode in the series **22** and the base electrode **24**. Thus, an electric field is produced between that electrode and the base electrode which is rendered visible by the accumulation of particles attracted to the electric field.

Accordingly, a time piece is produced that indicates time in hours and minutes. As explained above, the mass of randomly disposed particles **20** is located adjacent all the electrode pairs in the arrangement **10**. Moreover, an agitator **30** can be provided to slightly vibrate the particles so that the random disposition is maintained except in the vicinity of an electric field. In the case of a wristwatch a vibrator is not necessary because the motion of the wrist will generate sufficient agitation to maintain the random distribution of the particles except in the vicinity of an electric field. Loss of particles can be prevented by a transparent cover.

FIG. 2 illustrates another embodiment **50** of the invention wherein the particular elements are arranged to indicate time in hours and minutes. A series of ten electrodes **52** numbered 0 to 9 is provided and each electrode cooperates with a base electrode **54** to provide a plurality of ten electrode pairs. A source of electric signals **56** is connected to the electrodes **52** and the base electrode **54** by a ring counter **58**. The signals are interrupted every minute and the ring counter transmits the signals in sequence to the ten electrode pairs. Randomly disposed visual particles **60** are provided adjacent the electrode pairs and these particles are attracted to and accumulate in the electric field between the electrode pair to which a signal is transmitted. In the case of the embodiment illustrated in FIG. 2, an electric signal is transmitted to the number nine electrode of the series **52** and the base electrode **54**. Thus, the particles **60** accumulate in the electric field produced across that electrode pair to indicate the minute is nine.

Time piece **50** also includes a series of six electrodes **62**, a second base electrode **64** and a second ring counter **66**. The electrodes **62** are numbered 0 to 5 and cooperate with the base electrode to provide a plurality of six electrode pairs. Signals from one stage of the ring counter **58** are transmitted to the second ring counter **66**. These signals are interrupted every ten minutes so that a signal is transmitted in sequence from one electrode pair to an adjacent pair every ten minutes. The particles **60** migrate to the electric field produced across the electrode pair to which a signal is transmitted. In FIG. 2, the signal is transmitted to the fifth electrode in the series and the base electrode **64**.

Additionally, time piece **50** includes a series of twelve electrodes **70**, a third base electrode **72** and a third ring counter **74**. The electrodes **70** are numbered 1 to 12 and cooperate with the base electrode to provide a plurality of twelve electrode pairs. Signals from one stage of the second ring counter **66** are transmitted to the third ring counter **74**. These signals are interrupted every hour so that they shift along the series of electrodes **70** to provide a sequential pattern of electric fields indicative of hours of time. Particles **60** accumulate adjacent the electrode pair to which a signal is transmited to thereby visually display the particular hour of time. Accordingly, in FIG. 2 the time indicated is 8:59.

The electrode pairs of the visual display of the present invention form read-out capacitors which can be conveniently constructed in several different manners. In FIG. 3, a silicon substrate **80** of the n-type has a plurality of p-islands **82** at one of its surfaces. The p-n junction between each p-island and the n-bulk act as a capacitor. FIG. 3 also illustrates a convenient arrangement for constructing the system diagrammatically illustrated in FIG. 2. Three lines of p-islands are provided with the first line **84** having twelve p-islands, the second line **86** having six p-islands, and the third line **88** having ten p-islands. The p-islands in the first line **84** can be connected to a ring counter similar to **74**, and the p-islands in the second line **86** can be connected to a ring counter, such as **66**. The p-islands in the third line **88** are connected to a source, such as **56**, and a ring counter, such as **58**. The field across a particular p-n junction can be increased by applying a signal thereto with the p-region being negative and the n-region being positive.

The various connections of the ring counters to the p-islands can be made in one of the manners well known in microcircuit technology. Accordingly, signals applied in sequence to the various lines of p-islands produce a desired pattern of electric fields corresponding to the signals transmitted. The fields attract a mass of randomly disposed visual particles **90** located adjacent the p-islands, in the same manner described above. An enclosure **92** can be provided to hold the particles. Like the time piece **50** shown in FIG. 2, the time indicated by the arrangement of FIG. 3 is 8:59. Moreover, an agitator **94** can be connected to the substrate **80** to maintain the random distribution of the particles except in the vicinity of the electric field produced. Additionally, in the structure of FIG. 3, the read-out p-n junction capacitors can be covered by a thin oxide layer whose thickness may range from 100 to 10,000 angstroms. The electric fields at the particular junctions penetrate the oxide layer to thereby cause an accumulation of the particles adjacent the p-n junction capacitors to which the electric signals are transmitted.

FIG. 4 illustrates another read-out capacitor **100** for use in a visual display according to the present invention. The capacitor consists of an M-O-S structure which is well known in semiconductor circuitry. A silicon substrate **102** has an oxide film **104** grown on one of its surfaces with a metal electrode **106** on top of the oxide film. When an electric potential is applied between the electrode **106** and the silicon substrate **102**, a mass of visual particles **108** randomly disposed adjacent the electrode are attracted by the electric field thus produced and accumulate as shown in FIG. 4. The connection of the M-O-S capacitor illustrated in FIG. 4 to the remainder of the microcircuit is well known and further discussion is not considered necessary.

FIG. 5 illustrates still another version of a read-out capacitor **110** for use in conjunction with a visual display according to the present invention. Capacitor **110** comprises two metal electrodes **112** and **114** spaced close to one another on top of an insulating layer **116** that overlays a silicon substrate **118**. An electric signal applied across the metal electrodes produces a field which attracts randomly disposed visual particles **120**, as illustrated in FIG. 5. The particles accumulate in the space between the electrodes and to a lesser extent outside of the electrodes as indicated in this figure. The silicon substrate **118** may contain the electric circuitry feeding the electric signal to the electrodes **112** and **114** through openings in the layer **116**.

Another visual display **130** is illustrated in FIG. 6 of the drawing and two read-out capacitors **132, 134** are shown. A silicon substrate **136** has electrodes **138, 140** formed on one of its surfaces and an oxide coating **142** covers the electrodes. A fluid-tight transparent enclosure **144** is formed above the oxide coating by vertical walls **146** and a horizontal wall **148**. Wall **148** is coated on its underside with a transparent conducting layer, such as tin oxide, to form an electrode **150**. Isolating non-conducting liquid **152** is disposed within the enclosure **144** and a mass of particles **154** are suspended in the liquid. Read-out capacitor **132** is formed by the electrodes **138** and **150** while read-out capacitor **134** is formed by the electrodes **140** and **150**. In FIG. 6, an electric signal is applied to the read-out capacitor **132** and the particles **154** are attracted to the electric field thus produced. The accumulation of visual particles in the vicinity of the electric field provides a visual indication of the electric field which in turn is representative of the information to be displayed.

FIG. 7 illustrates still another version **160** of the present invention. In many respects the display **160** of variable electric information is similar to the embodiment of the invention illustrated in FIG. 6, and similar portions are identified by similar reference numerals. The basic difference resides in the type of particles, and in display **160** the particles **162** comprise a mass of non-spherical particles, such as platelets or needles. The orientation of these particles is controlled by the electric fields across the electrode pairs in the manner illustrated in FIG. 7. The concept of reorientation of non-spherical particles within an electric field can also be used without non-conducting liquid.

Although the above described embodiments include the accumulation of particles at one electrode pair, and none at the others, the sequential pattern of electric fields can be such that the particles accumulate at all electrode pairs except one, namely, that one to which no field is applied. A display is then evident from the absence of particle accumulation at one electrode pair.

In most instances of the present invention, the source of electric signals comprises an electric circuit that provides a sequence of voltage pulses at a repetitious rate which is an integer fraction of the frequency of a frequency stabilizer. The frequency stabilizer can be a tuning fork or else a quartz crystal interacting with the electric circuit to provide a constant frequency. In the case of time pieces, the generated voltage pulses can be provided at an interval equal to our customary units of time, such as second, minute or hour intervals. As described above, several signal sources can be utilized in the production of a time piece, with one of the sources providing pulses at hour intervals and another source providing pulses at minute intervals, for example.

Moreover, in the displays according to the present invention, the mass of particles adjacent the electrode pairs can be made of any one of a large number of materials. For example, dielectric particles can be used as well as other types. In general there are three types of phenomena which cause a redistribution of particles in an electric field. An electric field $\vec{E}$ of a strength varying with position exerts a force on particles having an electric dipole moment $\vec{P}$. The electric dipole can be induced by the electric field itself, in which case

$$\vec{P}=\alpha\cdot\vec{E}$$

The latter case occurs with all insulating or conducting particles. For insulating spherical particles of radius r and dielectric constant ϵ_1,

$$\alpha=r^3\frac{\epsilon_1-\epsilon_2}{\epsilon_1+2\epsilon_2}$$

where ϵ_2 is the dielectric constant of the ambient. In air $\epsilon_2=1$. For metallic particles $\alpha=r^3$ (metals behave like dielectric particles of $\epsilon=\infty$). The force acting on a spherical particle with such an induced dipole moment is

$$F=\frac{\alpha}{2}\operatorname{grad}(E^2)$$

The dipole moment induced in insulating (dielectric) particles arises instaneously for all frequencies used in electric communication. Particles of a dielectric constant larger than that of the ambient are drawn to positions of highest electric field strength, for example, to the rim of the read-out capacitor shown in FIG. 4, if an electric potential is applied to the electrode **106**. The effect is independent of the polarity of the potential, and also occurs for A.C. potentials. The dipole moment induced in metal particles arises by conduction of charges through the metal particles. In the case of A.C. fields this conduction causes electric losses in the read-out capacitor. Some particles, such as ferro-electrics, e.g., barium titanate powder contain permanent dipole moments in addition to the induced dipole moments just discussed.

An electric field can also be used to affect the orientation of non-spherical particles, as described above in conjunction with FIG. 7. For example, platelets of a dielectric constant larger than that of the ambient will line up in an electric field so that their major dimension, such as the base plane, lies in the field direction. Platelets are the natural particle shape of many materials

crystallizing in the hexagonal mode. Examples are graphite and molybdenum disulfide.

A preferred orientation of particles in an electric field may also arise from the fact that the dielectric constant differs in different directions in non-isotropic materials. Changes from a random to a preferred orientation of such particles are visually perceptable.

Another class of particles which are of interest in the context of the present invention is found among the liquid crystals. These are swarms of rod-like molecules arranged parallel to each other which can slide along each other, but not change orientation with respect to each other. However, the orientation of the entire swarm can be changed similar to that of a domain in a ferro-electric, when an electric field is applied. Since the orientation affects the optical properties, the presence of an electric field can be detected visually. An example for a material showing this effect is p-azoxyanisole at 125° C. in a field of about 2500 v./cm.

So far particles having no net charge have been considered. However, it is well known that particles suspended in a liquid assume a net charge due to the contact potential difference which usually exists between different media. The net charge may arise by transitions of electrons across the particle-liquid interface or else by preferential absorption or desorption of ions at the particle surface. An equal charge of opposite sign to that of the particles is located in the liquid. In conducting liquids much of this charge occurs in the so called diffuse double layer, whose extension is characterized by the Debye-length. For the present application, it is desirable to select insulating or nearly insulating liquids, usually organic or non-aqueous systems, whose Debye-length is large compared to the dimensions of a read-out capacitor. Thus the net charge of the particles is not compensated by its close surrounding and an electric field will move the particle to the appropriate electrode where they accumulate. This effect depends on the polarity of the field. Thus, A.C. fields are not effective. However, the polarity effect provides means for extinguishing the read-out by a brief reversal of polarity.

The effect of charging of particles in a liquid is common to metal particles as well as dielectric particles. The electrodes need not necessarily make contact with the liquid, but can be separated by an insulating layer, for example, the oxide film **142** of FIG. 6.

Particles of atomic dimensions (ions) have been considered for the purpose of providing contrast by simple electrolytic plating effects. However, the yield which is defined as "material deposited per unit charge" is limited by Faraday's law in the case of plating ions and is quite inferior to that achieved with particles containing many atoms with a net charge per particle of only a few electrons.

In all these cases particle size is of secondary importance. Clearly the particles should be smaller than the desired resolution limit. In practice particles varying from a fraction of a micron in diameter to several microns have been found adequate. The particles, can be colored, for example, to improve the optical contrast.

What is claimed is:

1. A visual display of time variable electric information comprising a timed source of information in the form of electric signals, a series of spacially arranged electrodes forming a plurality of electrode pairs which when electrically charged form an unhomogeneous electric field in the vicinity of said electrode pairs with strongest electric field strengths in the areas directly between the rims of said electrode pairs, circuitry constructed and arranged to transmit the signals from the timed source to the electrode pairs in sequence whereby a sequential pattern of electric field strengths is produced, and a mass of randomly disposed particles within said unhomogeneous electric field, said particles being drawn by the inherent forces of said unhomogeneous electric field towards the areas of strongest field strength thereby providing a visual display corresponding to the sequential pattern of electric field strengths.

2. A visual display as in claim **1** wherein the circuitry is a ring counter.

3. A visual display as in claim **1** including means for agitating the mass of particles whereby the random disposition of the particles is maintained except in the vicinity of the electric fields.

4. A visual display as in claim **1** wherein the series of electrode pairs are provided in the form of electrodes on the face of a semiconducting substrate with the electrodes connected to a microcircuit in the substrate.

5. A visual display as in claim **1** wherein the series of electrode pairs are provided on top of an insulating layer covering the face of a substrate of semiconducting material that contains a microcircuit for feeding the electric signals in sequence to the electrode pairs.

6. A visual display as in claim **1** including a non-conducting liquid in which the mass of randomly disposed particles are located.

7. A visual display as in claim **1** including a second source of electric information in the form of electric signals, a second series of electrodes adjacent the mass of randomly disposed particles forming a plurality of electrode pairs, a second circuit constructed and arranged to transmit the signals from the second source to the second series of electrode pairs in sequence whereby a second sequential pattern of electric fields is produced and a visual display corresponding to the second sequential pattern of electric fields is provided by the particulate material which accumulates in the second electric fields thus produced.

8. A visual display as in claim **7** wherein the first series of electrodes includes twelve electrode pairs and the electric signals from the first source are interrupted every hour, and wherein the second series of electrodes includes sixty electrode pairs and the electric signals from the second source are interrupted every minute whereby the visual display is a clock that indicates time in hours and minutes.

9. A visual display as in claim **8** wherein the first and second series of electrodes are provided on the face of a substrate of semiconducting material with the electrodes connected to a microcircuit in the substrate.

10. A visual display as in claim **7** wherein the first series of electrodes includes twelve electrode pairs and the electric signals from the first source are interrupted every hour, and wherein the second series of electrodes includes ten electrode pairs and the electric signals from the second source are interrupted every ten minutes whereby the visual display is a clock that indicates time in hour and ten minute intervals.

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RICHARD B. WILKINSON, Primary Examiner

E. C. SIMMONS, Assistant Examiner

U.S. Cl. X.R.

340—309.1