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[54] **IONOGRAPHY IMAGING CHAMBER FOR VARIABLE DISTANCE X-RAY SOURCE**

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[52] **U.S. Cl.** **250/315;** 250/336

[51] **Int. Cl.** **G03b 41/16**

[58] **Field of Search** 250/315, 324

[56] **References Cited**

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[57] **ABSTRACT**

An imaging chamber for an X-ray system using a dielectric or other suitable receptor of a latent electrostatic image in the gap between electrodes. A chamber with planar electrodes of finite conductivity and having the conductivity per unit area varying from a central zone to the edge of each electrode to produce electrostatic potentials at the gap surfaces the same as the electrostatic potentials of concentric spherical metal electrodes, and having a variable resistance connected in parallel with one or both of the electrodes to compensate for movement of the X-ray source relative to the imaging chamber.

9 Claims, 3 Drawing Figures

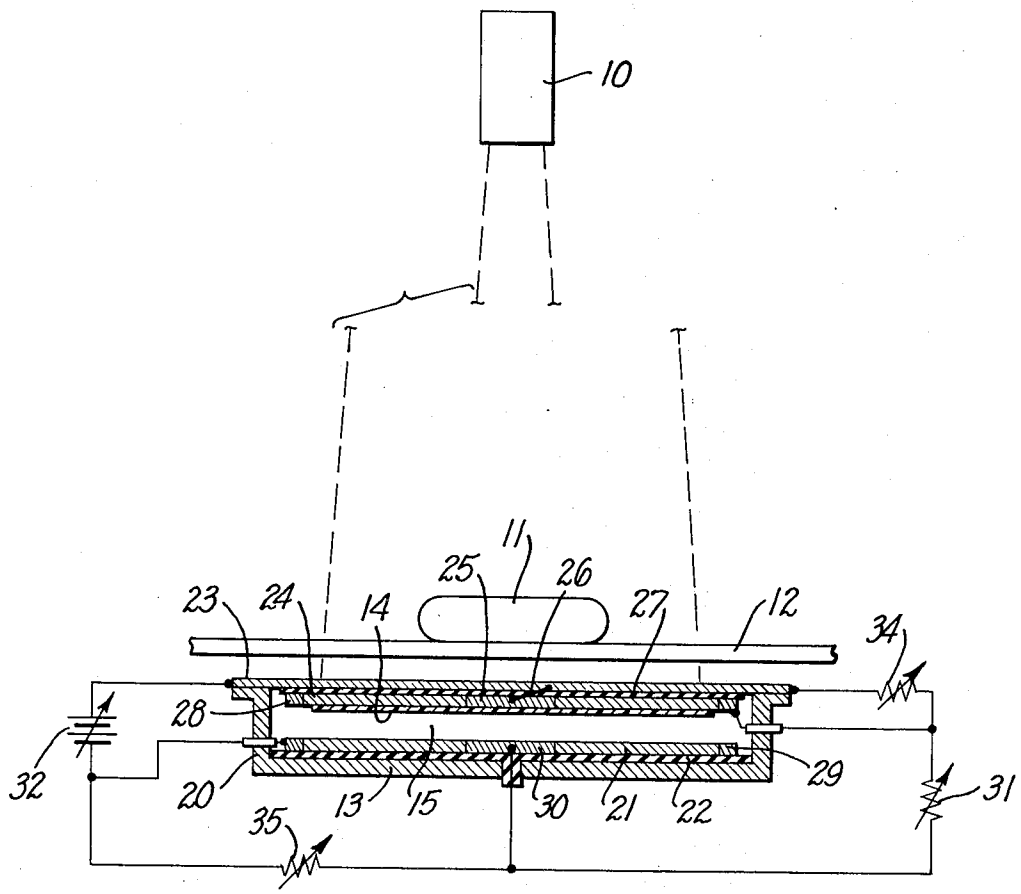


FIG. 1.

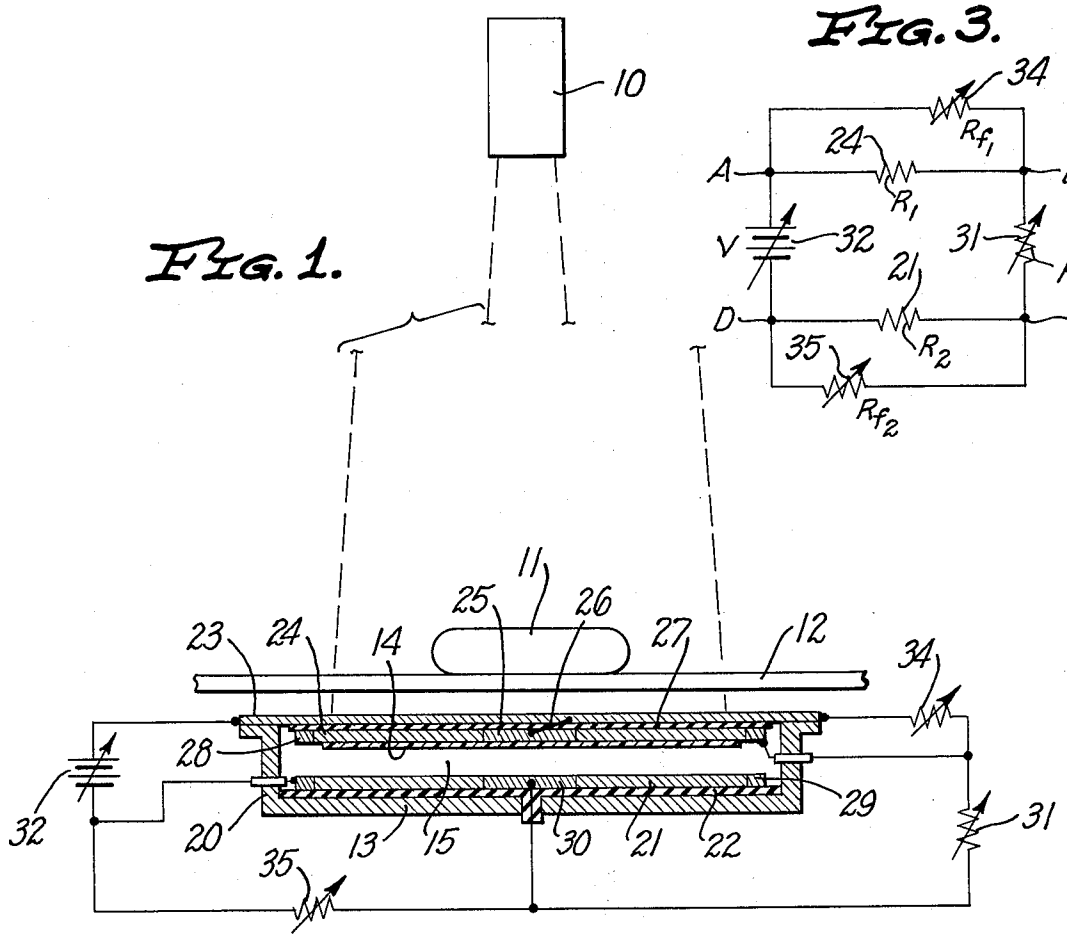
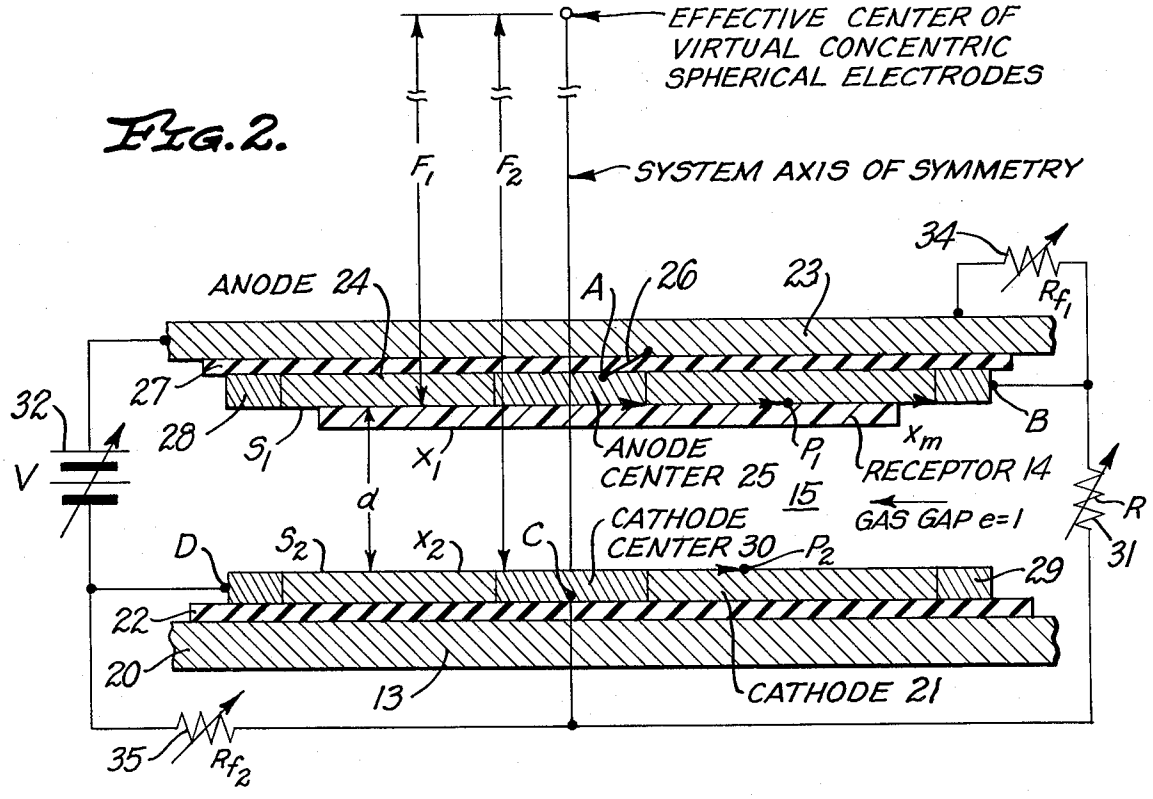


FIG. 3.

FIG. 2.



IONOGRAPHY IMAGING CHAMBER FOR VARIABLE DISTANCE X-RAY SOURCE

This invention relates to electronradiography and in particular, to a new and improved imaging chamber. In electronradiography or ionography, and X-ray opaque gas is used between two electrodes in an imaging chamber to produce a photoelectric current within the chamber, which current is collected on a dielectric sheet placed on one or the other of the electrodes, resulting in a latent electrostatic image. The latent image is then made visible by xerographic techniques.

An X-ray source is used to create primary photoelectrons in a gas in the gap between the electrodes of the imaging chamber. Typical imaging chambers have planar or cylindrical electrodes and the oblique incidence of the incoming X-ray produces geometric unsharpness in the resultant image. One solution of this problem is set out in the copending application Ser. No. 319,999, filed Jan. 2, 1973, entitled Ionography Imaging Chamber and in the continuation-in-part application of the same title filed concurrently with this application, Ser. No. 388,212, now U.S. Pat. No. 3,859,529 both copending applications being assigned to the same assignee as the present invention. In the imaging chamber of the copending applications, the electrodes are constructed in such a manner that the potential variations at the electrode surfaces correspond to that of concentric spherical equipotential in the imaging gap. In the preferred embodiment, a layer of finite and variable conductivity material is used for each electrode, with the potential applied between the center and periphery of the electrodes. Reference may be had to the copending applications for a complete discussion of the problem and the solution.

However the imaging chamber of the aforementioned copending application is designed for use with a single fixed distance between the X-ray source and the imaging chamber. In many instances, the person making the X-ray picture wishes to change the position of the X-ray source, and accordingly it is an object of the present invention to provide a new and improved imaging chamber having the potential variation at the electrode surfaces corresponding to concentric spherical equal potentials in the imaging gap for various distances between the X-ray source and the imaging gap. This additional advantageous characteristic is achieved in the imaging chamber of the present invention by incorporating a resistor in parallel with one or both of the electrodes, the resistors preferably having a variable or adjustable resistance, so as to obtain different currents in the two electrodes. Other objects, advantages, features and results of the invention will more fully appear in the course of the following description.

In the drawing:

FIG. **1** is a diagrammatic illustration of an X-ray system with an imaging chamber incorporating the presently preferred embodiment of the invention;

FIG. **2** is an enlarged view of the imaging chamber of FIG. **1**; and

FIG. **3** is a schematic of the equivalent circuit of the imaging chamber of FIG. **2.**

The system as illustrated in FIG. **1** includes an X-ray source **10** positioned for directing radiation to an object **11** which may rest on a table **12.** An imaging chamber **13** carrying the sheet receptor **14** may be positioned below the table, with X-rays from the source

passing through the object **11** and into the gas filled gap **15** of the imaging chamber **13.** The design of the imaging chamber itself is not a feature of the present invention and various of the presently known imaging chambers may be utilized.

The imaging chamber may comprise a housing **20** with a high resistance cathode **21** carried therein on an insulating sheet **22.** The housing cover **23** may serve as the electrical ground, with the center **25** of the high resistance anode **24** connected to the cover through a fine conducting (e.g., aluminum) wire or thin strip **26.** The anode is otherwise attached to the housing cover by a thin adhesive insulator **27,** so that it is in electrical contact with the cover only through the strip or wire **26.** Conductive strips **28** and **29** are attached to the outer edges of the anode and the cathode, respectively, so as to make good electrical contract all around the edges of the electrodes. The outer edge of the anode is electrically connected via the strip **28** to the center **30** of the cathode through a variable resistance **31.** The outer edge of the cathode is connected via the strip **29** to a power supply **32.** The other terminal of the power supply **32** is grounded or equivalently connected to the housing cover **23.** The concentric ring electrode construction disclosed in the aforesaid copending applications may be used if desired.

The imaging chamber described in the preceding paragraph corresponds to the imaging chamber of the aforesaid copending applications. Additionally, a variable resistor **34** is connected in parallel with the anode **24,** as by being connected between the center **25** and strip **28.** Another variable resistor **35** is connected in parallel with the cathode **21,** as by being connected between the center **30** and the strip **29.** As will be evident from the discussion herein, only one of the resistors **34,** 35 is necessary. Also, the resistor in parallel with the electrode may have a fixed value for a particular source distance and be switched in and out as desired. The electrical circuit formed by the above arrangement is shown schematically in FIG. **3.** As described in said copending applications, the electrodes have a variation in thickness and/or conductivity to obtain the desired results.

Referring to FIG. **2,** the potential variations required along the two electrodes can be written as (equations *1a* and *1b* correspond to equations 1 and 2 of said copending applications):

$$\phi_1(x_1) = V_g \frac{F_1}{d} \left(1 + \frac{x_1^2}{F_1^2}\right)^{-1/2} \qquad (1a)$$

$$\phi_2(x_2) = V_g \frac{F_2}{d} \left(1 + \frac{x_2^2}{F_2^2}\right)^{-1/2} \qquad (1b)$$

In the above equations ϕ_1 is the potential on the 'upper' electrode (nearest the X-ray source) and ϕ_2 is the potential on the 'lower' (furthest) electrode, as functions of the distances x_1 and x_2 respectively from the centers of the upper and lower electrodes, i.e., the intersections of the electrode surfaces with the normal to the electrodes passing through the X-ray source.

V_g is the gap potential,

F_1 is the 'focal length,' i.e., the normal distance from the upper electrode to the virtual center of the concentric set of spherical equipotentials in the imaging gap,

d is the imaging gap width, and

$F_2 = F_1 + d$

The potential variations ϕ_1 and ϕ_2 are so chosen as to make the 'virtual' center of the set of equipotentials in the gap, coincide with the X-ray source (regarded as a point).

An electrical configuration to achieve the desired potential variation is described in said copending application and corresponds to FIG. **3** with resistances **34** and **35** omitted. l

The top and bottom electrodes **24** and **21** are represented electrically as resistance R_1 and R_2, respectively. A variable resistance R and a variable applied voltage V are used to insure that the desired gap potential V_g between the electrode centers is achieved.

For the case of planar electrodes, the variation of conductivity of the electrodes, assumed of (variable or constant) thickness t, required to produce the desired potential variation $\phi(x)$(where t, ϕ x are meant to represent either t_1, ϕ_1 and x_1, or t_2,ϕ_2 and x_2) is given by:

$$2\pi x t(x)\,\sigma(x)\left(\frac{-d\phi}{dx}\right)=I \qquad (2)$$

where I is the current that flows through the circuit of FIG. **3** and σ is the electrode conductivity. Combining Eqs. (1) and (2), and choosing for simplicity the case in which the conductor thickness t is a constant, we find:

$$2\pi x t\sigma(x)V_g\,\frac{F}{d}\,\frac{x}{F^2}\left(1+\frac{x^2}{F^2}\right)^{-3/2}=I \qquad (3)$$

To a sufficient approximation, since $(x/F)<<1$, we may rewrite the above as

$$2\pi x^2 t\,\pi(x)\,\frac{1}{Fd}=I \qquad (4)$$

Restoring the subscripts 1 and 2, we have, for the upper and lower electrodes respectively:

$$2\pi x_1^2 t_1\sigma_1(x_1)V_g\,\frac{1}{F_1 d}=I \qquad (5a)$$

$$2\pi x_2^2 t_2\sigma_2(x_2)V_g\,\frac{1}{F_2 d}=I \qquad (5b)$$

Defining for the sake of convenience $\sigma_1(x_m)=\sigma_{m1}$,$\sigma_2(x_m)=\sigma_{m2}$ where x_m is the maximum value of the electrode radius, we may rewrite Eqs. (5a) and (5b) as:

$$x_1^2 t_1\sigma_1(x_1)=x_m^2 t_1\sigma_{m1}=\frac{IF_1 d}{2\pi V_g} \qquad (6a)$$

$$x_2^2 t_2\sigma_2(x_2)=x_m^2 t_2\sigma_{m2}=\frac{IF_2 d}{2\pi V_g} \qquad (6b)$$

The value of the current I in the above expressions can be chosen essentially arbitrarily (by proper choice of R_1, R_2, R and V) within the twin constraints that on the one hand not too much power be required from the power supply not dissipated in the electrodes, and on the other hand that the current I be large compared to the current flowing between the electrodes during X-ray exposure, so that the latter current will not significantly affect the equipotentials during exposure. Consider now the following situation:

Suppose that electrodes have been selected with the proper variation of conductivity to insure that the proper potential variations are achieved so that the concentric equipotential spherical surfaces are centered at the X-ray source, a specified distance F from the upper electrode for a given selected value of the image gap d and accelerating gap voltage V_g. Suppose now that the X-ray source is moved up or down so that it is now a new distance F from the upper electrode: the virtual electrodes now still provide concentric spherical equipotentials, but the virtual center of those equipotentials no longer coincides with the X-ray source. As a consequence, the creation path of the electrons created by the incident X-rays in the imaging gap no longer coincides with the electric field lines in the gap, and geometric image unsharpness reappears. Thus, in the virtual electrode system of said copending application, geometrical unsharpness is obviated only for one position of the X-ray source with respect to the imaging chamber, that position being determined once the electrode materials have been chosen (as we shall see below).

In ordinary X-ray practice, it is not uncommon to vary the so called film to focus distance F by as much as 10 or 20 inches up or down from the most frequently used distance of 40 inches. With the prior system it is not possible to 'refocus' the imaging chamber, for a given set of electrodes by using 'electrical' means such as adjustment of the values of the resistance R or the voltage V. Adjustment of the gap width d, while permitting as we shall show 'refocussing' of the chamber, is not a practical approach since gap width is set by the quantum efficiency requirements.

The impossibility of refocusing by variation of the free parameters V and R can most easily be seen by using equations (6a) and (6b) together with the defining equation

$$F_2=F_1+d \qquad (6c)$$

Thus, taking the ratio of Eq(s) (6b) to (6a), we find

$$\frac{F_2}{F_1}=\frac{t_2\sigma_{m2}}{t_1\sigma_{m1}},$$

or, when taking into accound (6c),

$$\left(1+\frac{d}{F_1}\right)=\frac{t_2\sigma_{m2}}{t_1\sigma_{m1}}=K \qquad (7)$$

The ratio $(t_1\sigma_{m1}/t_2\sigma_{m2})=K$ is a fixed constant for a given choice of finite conductivity electrodes, quite independent of the values of R and V (or alternatively of I and V_g).

Thus, for a fixed value of d, the value of F_1, that is the normal distance from the upper electrode to the virtual center of the spherical equipotentials, is fixed, and cannot be varied by adjustment of R or V.

Thus, the freedom to adjust the parameters R and V, and thereby I, do not provide a means of varying R_1, because the constraint (Eq(7)) that must be satisfied by F does not depend on I or V_g. The circuit of FIG. **3** (omitting R_{f1} and R_{f2}), because it requires the same

current flowing through R_1 and R_2, leads to a single fixed value of F_1 for a given set of electrodes.

This limitation of the virtual electrode system is shared by a scheme which uses physically curved concentric spherical electrodes, and is a significant drawback, since radiologists and radiology technicians will vary the film-to-focus distance for various examinations, and the resultant image will be degraded in resolution.

Accordingly, the present invention was developed to provide a means for 'focusing' of the virtual electrode system, i.e., for varying the position of the virtual electrode center, by adjusting the value of F_1 electrically by means of a modification of the prior system.

The basis of the new system is the recognition of the fact that in Eqs. (6*a*) and (6*b*) the current I which would at first signt appear to be an added parameter permitting readjustment of F_1 and F_2, is not such a parameter because it in effect 'drops out' of the ratio $(F_2/F_1$. In order to retain an adjustable parameter in that ratio, it is thus necessary to make the currents flowing in the top and bottom electrodes unequal and their ratio variable (this ratio providing the neeced degree of freedom). This can easily be achieved by adding the resistances **34, 35** in parallel to the resistances R_1 and R_2 of the electrodes, thus 'uncoupling' the current flowing through each of the latter from the potential difference required to produce a particular set of spherical equipotentials.

Thus the present invention provides for a variable source distance by variable 'focusing' resistances R_{f1} and R_{f2} in parallel with the electrode resistances R_1 and R_2, respectively. In the analysis that follows, only one resistance R_{f2}, added in parallel to R_2 is considered, as this is sufficient. Addition of a second resistance R_{f1}, parallel to R_1, provides more flexibility in the circuit but is not essential.

With the circuit of FIG. **3** (omitting R_{f1}) the current I, flowing through the resistance R_1 (i.e., the upper electrode) need no longer be equal to the current I_2 flowing through the resistance R_2 (i.e., the lower electrode). The current conservation equations determining the required radial variations of conductivity, corresponding to Eq. (4) of the previous case, now become

$$x_m^2 t_1 \sigma_{m1} = \frac{I_1 F_1 d}{2\pi V_a} \tag{8a}$$

$$x_m^2 t_2 \sigma_{m2} = \frac{I_2 F_2 d}{2\pi V_a} \tag{8b}$$

Note that the proper potential variations $\phi_1(x_1)$ and $\phi_2(x_2)$ are still achieved by satisfying Eqs. (8*a*) and (8*b*).

The equations corresponding to Eq. (7) for the circuit of the prior system now becomes, for the circuit of the present invention,

$$\left(1 + \frac{F_1}{d}\right) = K \frac{I_2}{I_1} \tag{9}$$

Now, since (I_2/I_1) can be varied simply by varying the value of R_{f2}, this added resistance does provide a means of changing the value of F_1, and thus of refocusing the chamber electrically even though the electrodes, and therefore the constant K, remain unchanged. The freedom to choose $I_1 \neq I_2$ is the key to the problem.

The gap voltage can still be maintained constant at whatever chosen value even though the value of R_{f2} is changed simply by adjusting V and/or R, since the gap volage is given by:

$$V_a = V \frac{R_1 + R}{R_1 + R_2 + R} \tag{10}$$

where $R_2' = \dfrac{R_2 R_{f2}}{R_2 + R_{f2}}$

is the equivalent resistance of the two parallel resistances R_2 and R_{f2}.

To obtain an estimate of the range of variability of F_1 by the above means, we may note that, since $d/F_1 << 1$, a large percentage change in F_1 will still result in a small change in the left hand side of Eq. (9), and therefore can be obtained with a small percentage change in the ratio (I_2/I_1). Note that (I_2/I_1) can be varied between 1 and 0.5 as the value of R_{f2} is varied from infinite (open circuit) to R_2. In practice, much smaller variations would be required to focus the system in the range of film-to-focus distances used by radiologists and radiology technicians.

The imaging chamber of the present application normally is used to produce a latent electrostatic image on a dielectric sheet placed at one or another electrode. However, the imaging chamber is not limited to the use of dielectric sheet receptors and the electron current produced in the chamber can be received on a receptor other than an ordinary dielectric. As an example, a photoconductor might be used, which would be in contact with a field sensitive material, such as a liquid crystal layer. The charge collected on the photoconductor would then create a field in the liquid crystal layer (sandwiched between the photoconductor and a suitable transparent electrode). This would alter the light scattering properties of the liquid crystal and could provide a means for reading or viewing the charge distribution on the photoconductor. The latter charge could then be erased from the photoconductor by exposure to light of the appropriate wavelength, and a new charge image be placed on the photoconductor. In this manner, a sequence of images could be viewed at a frame rate sufficient to provide real time X-ray movies. The significant point here is that the dielectric receptor is not an essential part of the functioning of the imaging chamber or of the present invention, but is merely a means of providing (by subsequent xerographic development) a permanent radiographic record.

I claim:

1. In an imaging chamber for an X-ray system having first and second substantially planar electrodes of low conductivity material,

means for mounting said electrodes in the chamber in spaced relation defining a gap therebetween for an imaging medium responsive to incoming radiation,

means for connecting a power supply to the center of said first electrode and to the periphery of said second electrode, and

a first resistance connected between the periphery of said first electrode and the center of said second electrode completing a current path across the

power supply to produce an electrostatic field in the gap,

with the conductivity per unit area of each of said electrodes varying from a central zone to said peripheries such that the electrostatic potential at the gap surfaces of the electrodes approximates the electrostatic potential for concentric spherical metal electrodes,

the improvement comprising a second resistance electrically connected in parallel between the center and periphery of one of said electrodes for producing different currents in said first and second electrodes and thereby compensate for movement of an X-ray source relative to said chamber.

2. An imaging chamber as defined in claim **1** including a third resistance electrically connected between the center and periphery of the other of said electrodes.

3. An imaging chamber as defined in claim **1** wherein said second resistance is a variable resistance.

4. An imaging chamber as defined in claim **1** wherein the variation in conductivity per unit area is obtained by varying the thickness of the electrode from the central zone to said periphery.

5. An imaging chamber as defined in claim **1** wherein the variation in conductivity per unit area is obtained by varying the conductivity of the material of the electrode from the central zone to said periphery.

6. An imaging chamber as defined in claim **1** wherein the variation in conductivity per unit area is obtained by varying both the thickness of the electrode and the conductivity of the material of the electrode from the central zone to said periphery.

7. An imaging chamber as defined in claim **1** wherein said electrodes have flat parallel gap surfaces and a central disk of high conductivity material.

8. An imaging chamber as defined in claim **1** wherein said electrodes have concentric cylindrical gap surfaces and a central arcuate strip of high conductivity material.

9. An imaging chamber as defined in claim **1** wherein the variation in conductivity per unit area of an electrode is obtained by a plurality of electrode sections each of different conductivity.

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