April 2, 1940. H. E. HOLLMANN 2,195,455

ELECTRONIC SYSTEM

Filed Feb. 24, 1937

Fig. 1

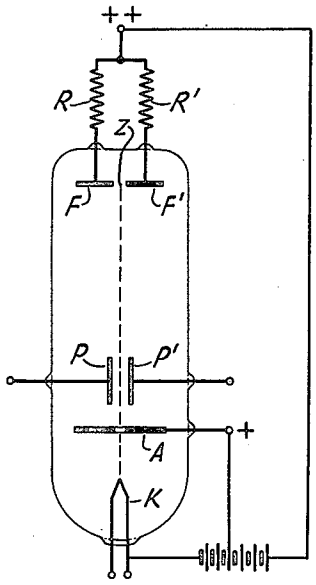


Fig. 2

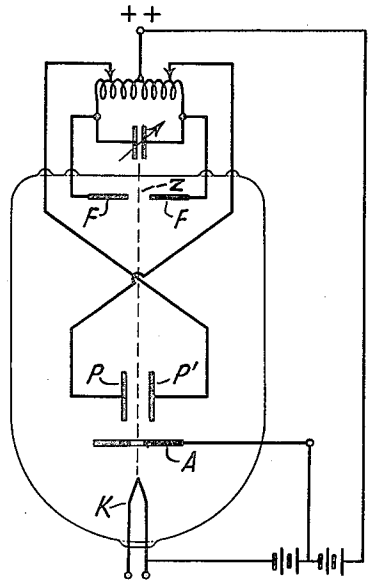


Fig. 5

Fig. 3

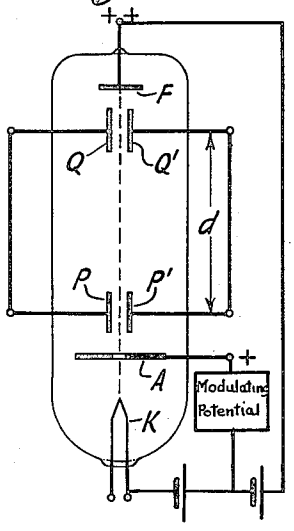
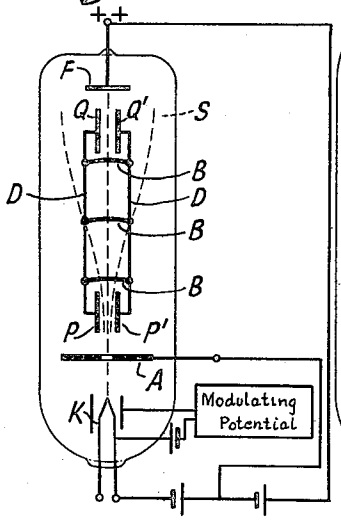
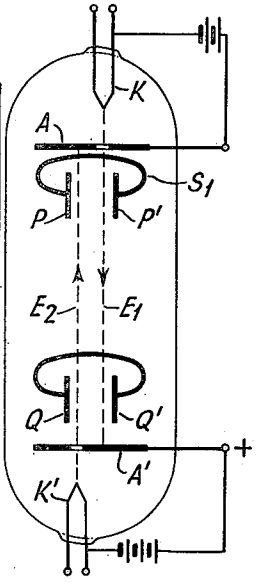


Fig. 4





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ELECTRONIC SYSTEM

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16 Claims. (Cl. 250—36)

The invention is concerned with means adapted to amplify and generate undamped electrical oscillations (c. w.) by the aid of a novel form of electron tube. The invention distinguishes itself from the standard amplifier and transmitter tube predicated for their operation upon space-charge control action in that, instead of longitudinal control of the electronic discharge by the agency of a grid or by what may be called a non-material electrode in the shape of a magnetic field, a concentrated or focused pencil, jet or beam of electrons of filamentary, thread-like or band-shaped form is deflected by an electric or magnetic transversal or cross-field in a way well known from the art of cathode-ray oscillograph tubes in a transverse direction, and that the said beam or pencil is caused to release or yield its transversal oscillation energy in amplified form and measure to another transverse or cross-field until it is finally made to impinge upon an electrode which bears no direct relationship to the oscillation process. The basic merit and advantage of this new cross-control type of tube resides in the fact that all such actions and factors as tend to impose a limitation upon the effect of longitudinal space-charge control in the direction of high frequencies are fundamentally precluded, with the result that this novel tube is capable of operating, basically speaking, at all frequencies no matter how high, that is, under conditions where all other methods have been found to fail utterly. In order that these properties of the new tube may be properly understood, it may be necessary to say a few explanatory words regarding the reasons and causes tending, in a gradual way, to lead to a failure of the standard space-charge control type of tubes as the frequency is raised.

Contradistinct from what has been formerly thought, these reasons do not reside in and are not ascribable to the finite flying speed of the electrons and the incidental phase shift between the control grid potential and the plate alternating current. For the said phase shift plays an actual part only in such arrangements in which the alternating potentials produced in the plate circuit, by virtue of intentional feed-back or regeneration, are brought into a definite relationship to the control potential, in other words, where they are fed back to the control electrode; but this condition is entirely absent in the case of cascade r-f amplification as long as no de-attenuating or neutralizing means are provided the effectiveness of which, where ultra-high frequencies are concerned, would anyway be quite questionable and unreliable for wiring or circuit reasons. As regards self excitation, in the light of the so-called "Inversion Theory" in Die Naturwissenschaften, 1932, volume 20, page 181 by Dr. Hollmann; and the Protocols of the Sessions at the Prussian Academy of Science, class VI, Physics and Mechanics for 1933, developments have been intentionally to include in the "phase balance" of any desired self-oscillatory scheme such inner phase shift as is inevitable in the oscillator tube; and this phase shift either is compensated by circuit or tuning means or else it is made so large that the phase angle results to be 360 degrees or a multiple thereof. Under this condition the phase balance again corresponds to the static characteristic of the tube and becomes positive with the result that oscillation is possible.

However, the finite speed of propagation of the space-charge density waves due to the grid alternating potentials has a far more unfavorable effect as regards the "amplitude balance". For if the grid potential reverses in less time than that required by the electrons for covering the distance from the control grid to the plate, there arise in the grid-plate space, at each instant, maxima or crests of space-charge in accordance with the positive alternations of the grid potential, and minimum values of space-charge according and corresponding to the negative grid voltage alternations. It is more to the point to consider the conditions from the viewpoint of static space-charge distribution, and to designate the excess of the space-charge peak as a positive space-charge wave (compression wave) and the valley or trough, dropping for negative grid potential below the static potential distribution, as a negative compression wave, both of which travel at the speed of the group or aggregate of electrons towards the anode or plate.

Now, it will be remembered that so far as the size of the instantaneous current flowing to the plate is concerned, the same is not a function, or not only a function, of the convention current, but rather the dielectric displacement current which is induced by the mobile charges located anteriorly of the plate, i. e., between grid and plate. Of course, this must embrace the entire charge which has accumulated between the electrodes by integrating throughout the whole distance between grid and plate, and it will be noted that the displacement current component originating from a positive space-charge density (compression) wave is diminished by the next negative compression wave.

The fact that from the outset no complete compensation down to zero occurs, in other words, the fact that the tube will not completely fail suddenly upon a certain critical frequency being reached, is ascribable to the circumstance that the equation determining the size of the displacement current according to well-known laws contains also the distance between the influencing charges and the plate as well as their instantaneous motional speed. The result of this situation is that the influence action of a compression wave which happens to be at close proximity to and anteriorly of the plate is greater than that of a similar wave being more remote therefrom, with the result that the displacement current component caused by the closer cloud of electrons will predominate. Hence, the influence of a positive compression alternation or half-wave will not be completely offset by the following negative alternation. By a logical prosecution of this qualitative consideration, the conclusion is compulsory and inescapable that in the presence of ultra-high frequencies the spacing between the positive and the negative compression waves must of necessity become less and less, and that, as a consequence, the influence actions of the positive and the negative displacement current components gradually must become more and more alike and must finally, that is, at infinitely high frequencies, entirely neutralize. In other words, in this case, no matter how high the alternating potentials at the grid, no plate alternating current can be secured any more, and this means that not only self-oscillation, but of course also amplification is prevented in a space-charge type of tube.

Another fact which generally complicates the use of standard electron tubes in connection with ultra-short waves resides in the unfavorable adaptation or matching conditions, seeing that the impedance of the plate circuit can no longer be matched to the inner impedance of the tube because of the minimum capacity inherent in the tube. Disregarding special arrangements such as the insertion of the tube electrodes in a concentric tubular line (co-axial arrangement), it will be seen that an increase of the impedance of the resonance circuits associated with the tube, or a reduction of internal tube capacitance is feasible solely by way of a reduction of the dimensions of the tube. But this, of necessity, is attended with a decrease in the tube power, while, on the other hand, the inner resistance grows again so that nothing is gained from the viewpoint of matching. It is a well known fact that all of the said reasons tend towards the common result that c. w. of say, a few decimeters' length, are producible in tubes predicated for their operation upon the space-charge control by virtue of the regeneration principle only with very low efficiency and that amplification is similarly handicapped.

Now, the accumulative effect of the space-charge compression waves which is a basic property of all grid-controlled electron tubes, is avoidable if the idea of using longitudinal control is entirely abandoned and if recourse is had to transversal or cross control. Such a cross-control type of tube results from any desired cathode-ray oscillograph tube by that the electron pencil or beam is made to impinge upon two suitable anodes or plates rather than upon a fluorescent screen, the said anodes being so positioned that the cathode-ray pencil, when in quiescent state, is made to impinge just between the two plate surfaces.

Turning now to the drawing, in which Figs. 1 and 2 show schematically a tube for explaining my invention; and Figs. 3, 4 and 5 show embodiments and modifications thereof, I will explain my invention in more detail.

Such a cross-control field is schematically shown in Fig. 1. The cathode K and the accelerator electrode A represent any suitable generator system for a thread-like or flat jet or pencil which passes between the deflector plates P and P' and impinges on one of the two anodes F and F' between which a narrow slit *z* is formed. It will be seen at once that when the pencil is deflected towards P or P', the electron stream will pass over either to F or to F', as the case may be, with the result that the effect of a cross-control tube would be equivalent to the action of a push-pull arrangement. Since with adequate cross dimension and high geometric ratio, i. e., considerable distance between P and F high deflectability (response) is obtainable it will be seen that the tube will insure complete utilization with small deflector potentials. Hence, the voltages available across the plate resistances R and R' are far higher than the potentials impressed upon the deflection plates.

To include the cross-control tube in a self-oscillatory circuit organization, recourse may be had to any desired feed-back scheme. Inasmuch as the conditions surrounding regeneration play a large part also in the new cross-control type of tube to be described in more detail further below, the same shall be explained briefly in what follows by reference to the simplest form involving conductive feedback as shown in Fig. 2.

It will be clear that the static characteristics of the cross-control tube described, in other words, the currents of each plate half as a function of the potential of the deflection plate located on the same side, are rising as is true also of the characteristics of space-charge control tubes seeing that the pencil is deflected towards the positive deflector plate and since the current in the corresponding anode rises. Hence, so far as regeneration is concerned, the same laws hold good as for standard push-pull arrangements. The control potentials derived from the plate circuit must be impressed upon the deflection plates in phase opposition, i. e., with crossing (transposition) of the connection wires. Distinct blocking means designed to preclude the plate potential from the deflection plates are, basically, unnecessary seeing that the pencil deflection is merely a function of the potential difference between P and P'. The same situation applies also to the cascaded or series arrangement of several cross-control tubes.

Inside the tube, of course, the same phase shift occurs, fundamentally speaking, between the control potential and the plate alternating current which is typical of all electronic tubes. Inasmuch as the distance between P and F for reasons of raising the response and sensitivity is generally relatively great, it follows that the phase shift will become even far greater than in space-charge control tube involving far smaller inter-electrode distances. However, since it has been shown before in what way internal phase shifts are eliminatable, difficulties will not arise, either in this case, so far as the stimulation and excitation of extremely high frequencies is concerned. What is far more important in this connection is the circumstance that in the cross

control principle in the present form, the problem of dielectric displacement current with all of its attendant phenomena no longer plays a part, indeed, that what is dealt with here is a convection current of practically pure form. And yet, this cross-control tube evidences a similar droop of the plate a. c. with growing frequency, although this is here not attributable to an accumulative effect of the space-charge waves (which, as will be noted, are here transversal), but rather to a "blurring" of the space-charge or of the electron pencil in the leakage field about the slit or joint *z* which, in turn, is associated with the generated oscillatory voltages at the plate halves F and F'. In other words these troublesome actions may be characterized also so that the dynamic "throughgrip" (controllance) of the dynamic reaction of the stray field is taken into consideration, which, as soon as the electron transit time across the stray field of the anode sheets plays a part becomes so large that self-excitation stops.

Another drawback is traceable to the third factor enumerated in the preamble, for the anodes F and F' can not be made of as small a size as might be desired if practically useful powers are to be handled by the jet. Also in this case the question of matching is extremely difficult because of the minimum capacity of the plates in the presence of ultra-high frequencies. It is particularly the plate edges which are extremely endangered as a result of heating, most particularly so when for reasons of maximum current intensity a flat jet of far greater cross-sectional area, instead of a filamentary jet, is used.

Now, all of these shortcomings are entirely obviated in the cross-control tube hereinafter to be disclosed and which forms the real object of the present invention. The principle of transversal deflection has been preserved also in the present new tube; all that is different is the ways and means resorted to in order to extract its radio frequency energy from the transversally oscillating cathode ray pencil with out "blurring" of the space-charge being occasioned and without the "anodes" being heated at all as a result of electron impacts.

The new cross-control tube of this invention is schematically illustrated in Fig. 3. The jet generator means K, A and the deflection plates P and P' are the same as in Figs. 1 and 2. However, the jet after its exit from the control field, P, P', is passed through another pair of plates Q and Q', and it is only then that the same is made to impinge upon a single collector electrode F, whence it is conducted away. Now, the plates Q and Q' represent and constitute the "anodes", in other words, the electrodes of the new tube which put out the oscillatory energy. The "anode currents" therefore are no longer convection currents, but rather displacement currents; and they are due to influence actions of the space-charge transversely oscillating between Q and Q'. So far as the said influence action is concerned, the co-existent longitudinal motion component of the electrons is immaterial. A closer theoretical examination of the displacement current results in this basic equation: $I=d\rho/dt$ where ρ is the space-charge between Q and Q'. On the basis of this starting equation it is found that the anode current has the following properties:

(*a*). The amplitude is proportional to the cyclic frequency ω, that is to say, the operation of the arrangement is static, it does not work at all at zero frequency, but starts to become operative only from a certain minimum frequency, and it becomes so much more effective, the higher the frequency. To be sure, this condition holds true only as long as the transit time of the electrons for the length of the cross fields P and Q remains negligible in contrast to the period of oscillation, a condition to be aimed at by proper choice of dimensions of the tube and of the working conditions, in the first place, of the pencil velocity, lest compensation of the positive and negative transversal waves of the space-charge located between the plates might occur also in this case. So far as the antecedents and the later events of the pencil during its motion from P to Q and thence to F are concerned, these are immaterial for the displacement current. Hence, the response or sensitiveness of the new arrangement is increasable practically in an unlimited manner by the choice of the geometric dimensions of the tube, without any disturbing actions having to be feared.

(*b*). The amplitude is moreover proportional to ρ, in other words, the pencil strength, and is inversely proportional to the pencil velocity. However, since the anodes carrying high frequency are not struck themselves by the jet and since they are not called upon to absorb any loss or dissipated power to be converted into heat, the problem of choosing their size is not complicated by thermal considerations, in fact, they may be chosen just so small that optimum pencil utilization is assured. Destruction of the kinetic electron energy is effected exclusively on the collector electrode F; however, the latter carries no RF energy so that the size thereof may be chosen regardless of capacity.

(*c*). The plate a. c. is shifted an angle of 90 degrees in reference to the oscillation amplitude of the space-charge in the cross field Q, a fact which must be taken into account also in fixing the optimum phase relations. The total phase displacement between the plate alternating current and the control potential, as will thus be seen, comprises two components, that is, the first mentioned 90 degree angle and secondly the time of lag of the electrons in Q compared to P. The resultant phase angle is calculated from the distance *d* between P and Q, the frequency ω, and the pencil speed *v*, namely,

$$\phi'=\frac{d}{v}$$

so that the entire internal phase angle of the new tube is

$$\phi=\frac{d.\omega}{v}-\pi/2$$

Hence, it is an easy matter to fix the inner phase shift, no matter what the frequency, by suitable choice of the pencil velocity in any given self-excitation organization. Hence, conditions are no longer predicated upon and tied up with a definite phase angle of the feedback potential, in fact, the two cross fields P and Q may be united, for instance, by non-transposed leads. In the case of ultra-short waves, moreover, special resonance circuits are dispensable, for the capacities of the cross-field plates and the inductances of the connecting wires which resemble a parallel wire structure, may be used, both in self-oscillatory schemes as well as in cascade radio frequency amplification, as construction elements of the circuits in which the waves are excited or of the coupling circuits, as shown, for instance, in Fig. 4 covering a case of conductive coupling for regeneration. In order

that the wire line D may not be excited at its fundamental wave to be chosen for adequate pencil deflection (voltage distribution curve *s*), certain harmonics of the system may be fixed by suitable wire bridges B. The parallel wires may be disposed inside the vacuous space of the tube. In choosing the dimensions for the cross-fields P and Q the laws which are known from the use of cathode-ray oscillographs for very high frequencies must be obeyed. In the light of these laws the deflectibility (deflection sensitiveness) attains a maximum value whenever the length of the cross plates is equal to the length of a half-wave in air less the ratio of pencil velocity v to speed of light c, in other words, equal to

$$\frac{\lambda v}{2c}$$

A similar situation, of course, holds good for the pickup cross-field Q. It is only this law which imposes a limitation upon the chance of handling extremely high frequencies seeing that if the cross fields are too shortened, the energy utilization of the electron pencil is more and more impaired.

Instead of returning the regenerative potential by way of wires from the pickup plates Q to the control plates P, regeneration is feasible also through the intermediary of another electron pencil traversing the cross fields in opposition to the first pencil. What thus results is the push-pull scheme schematically illustrated in Fig. 5. The arrangement comprises two assemblies for the generation of two distinct electron pencils, namely, K and A, and K′ and A′, respectively, which produce opposite cathode-ray pencils E1 and E2. In this scheme, one of the accelerator electrodes, that is, either A or A′, may act as a collector electrode for the other pencil. Both pencils traverse the two cross fields P and Q the plates of which are united with two inductance clips (loops) and which are tuned to the same frequency. If, for instance, by the switching-in surge alternating currents are set up in the oscillation circuit S1, these will be transferred in amplified measure through the pencil E1 and to S2, whence they are returned through pencil E_2 to S_1 and this closes the cyclic process. This twin or double push-pull scheme offers fundamentally this merit that the distance between the two cross fields may be chosen with proper consideration of the geometric translation of the transversal pencil oscillations. Operation is not impaired as a result of imedance or natural frequency oscillations of the feedback paths.

All of the cross-field transmitters may be modulated by means of intensity control of the cathode-ray pencil by the aid of methods known from the television arts. If desired, simple modulation of the pencil accelerator potential may suffice under certain circumstances. In this case the modulation voltage is superposed upon the positive potential impressed upon the electrode A. Modulation free from dissipation is made possible by interposing between K and A a negatively biased auxiliary electrode, say, a Wehnelt cylinder (shield), and if the modulation potential is impressed upon the latter. Another advantage of this last-named method consists in an invariable pencil velocity.

All of the exemplified embodiments hereinbefore described are predicated upon electrostatic pencil deflection by the aid of a cross field set up between the deflection plates P, P′, but it will be evident that a magnetic cross control action is adapted to insure the same results. In this instance, one or preferably two deflection coils placed symmetrically to the electron pencil traversed by the control current are mounted instead of the electrodes P and P′. The control circuit may again be a resonant circuit tuned to the frequency to be generated or to be amplified.

Having described my invention, what I claim is:

1. The method of producing oscillatory electrical currents which comprises the steps of producing a beam of electrons, deflecting the beam of electrons, producing displacement currents by the deflected beam of electrons, and utilizing a portion of the produced displacement currents to further deflect the produced beam of electrons.

2. The method of producing oscillatory electrical currents which comprises the steps of producing a beam of electrons, deflecting the beam of electrons, producing displacement currents by the deflected beam of electrons, and regeneratively further deflecting the beam of produced electrons by a portion of the produced displacement currents.

3. The method of producing oscillatory electrical currents which comprises the steps of producing a beam of electrons, electrostatically deflecting the beam of electrons, producing displacement currents by the deflected beam of electrons, and regeneratively further deflecting the beam of produced electrons by a portion of the produced displacement currents.

4. The method of producing oscillatory electrical currents which comprises the steps of producing a beam of electrons, electromagnetically deflecting the beam of electrons, producing displacement currents by the deflected beam of electrons, and regeneratively further deflecting the beam of produced electrons by a portion of the produced displacement currents.

5. The method of producing electrically oscillatory currents which comprises the steps of producing a beam of electrons, deflecting the produced beam of electrons, producing displacement currents by the deflected beam of electrons, and resonantly transferring a portion of the produced displacement currents to regeneratively further deflect the produced beam of electrons.

6. The method of producing electrically oscillatory currents which comprises the steps of producing a beam of electrons, electrostatically deflecting the produced beam of electrons, producing displacement currents by the deflected beam of electrons, and resonantly transferring a portion of the produced displacement currents to regeneratively further deflect the produced beam of electrons.

7. The method of amplifying electrical energy which comprises supplying a source of electrons, focusing and accelerating electrons from the source to produce a beam of electrons, deflecting the produced beam of electrons, producing displacement currents by the deflected beam of electrons, regeneratively further deflecting the beam of electrons by a portion of the produced displacement currents, and varying the acceleration of the electrons in accordance with energy to be amplified.

8. The method of amplifying electrical energy which comprises supplying a source of electrons, focusing and accelerating electrons from the source to produce a beam of electrons, deflecting the produced beam of electrons, producing dis-

placement currents by the deflected beam of electrons, regeneratively further deflecting the beam of electrons by a portion of the produced displacement currents, and varying the number of electrons from the source in accordance with the energy to be amplified.

9. The method of modulating electrical energy which comprises supplying a source of electrons, focusing and accelerating electrons from the source to produce a beam of electrons, deflecting the produced beam of electrons, producing displacement currents by the deflected beam of electrons, regeneratively further deflecting the beam of electrons by a portion of the produced displacement currents, supplying modulating energy, and varying the acceleration of electrons in accordance with the supplied modulating energy.

10. The method of modulating electrical energy which comprises supplying a source of electrons, focusing and accelerating electrons from the source to produce a beam of electrons, deflecting the produced beam of electrons, producing displacement currents by the deflected beam of electrons, regeneratively further deflecting the beam of electrons by a portion of the produced displacement currents, supplying modulating energy, and varying the number of electrons from the source in accordance with the modulating energy.

11. The method of generating electrical oscillations which comprises producing a first beam of electrons, direcing the first beam of electrons along a predetermined path, producing a second beam of electrons, directing the second produced beam of electrons along a path parallel to but in opposite direction of the predetermined path of the first beam of electrons, producing displacement currents by the first beam of electrons, utilizing the produced displacement currents to further deflect the second beam of electrons, producing displacement currents by the second beam of electrons, and utilizing the displacement currents produced by the second beam of electrons to further deflect the first beam of electrons.

12. An electronic system comprising means to produce a beam of electrons, means to deflect the beam of electrons, means to produce displacement currents from the produced beam of electrons, and means to feed back a portion of the produced displacement currents to the deflecting means.

13. An electronic system comprising means to produce a beam of electrons, means to deflect the beam of electrons, means to produce displacement currents from the produced beam of electrons, and transmission line means to feed back a portion of the produced displacement currents to the deflecting means.

14. An electronic system comprising means to produce a beam of electrons, means to deflect the beam of electrons, means to produce displacement currents from the produced beam of electrons, and resonant line means to feed back a portion of the produced displacement currents to the deflecting means.

15. An electronic system comprising means to produce a beam of electrons, means to deflect the beam of electrons, means to produce displacement currents from the produced beam of electrons, and short-circuited resonant line means to feed back a portion of the produced displacement currents to the deflecting means.

16. An electronic system comprising means for producing a first beam of electrons, means for directing the first beam of electrons along a predetermined path, means for producing a second beam of electrons, means for directing the second produced beam of electrons along a path parallel to but in opposite direction of the predetermined path of the first beam of electrons, means for producing displacement currents by the first beam of electrons, means for utilizing the produced displacement currents to further deflect the second beam of electrons, means for producing displacement currents by the second beam of electrons, and means for utilizing the displacement currents produced by the second beam of electrons to further deflect the first beam of electrons.

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