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[56]

References Cited

UNITED STATES PATENTS

2,668,190	2/1954	Sziklai.....	313/67X
2,775,719	12/1956	Hansen.....	313/65X
2,899,580	8/1959	Dranetz et al.	313/89
2,903,617	9/1959	Turner	313/68X
2,957,340	10/1960	Rocha	313/65X
3,213,675	10/1965	Goldman.....	73/67.5

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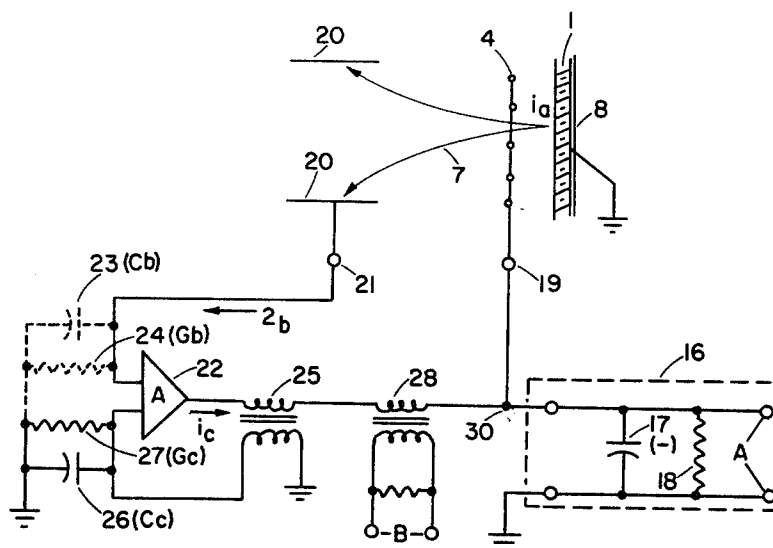
[54] **SYSTEM USING A MODIFIED ULTRASONIC IMAGING TUBE**
2 Claims, 5 Drawing Figs.

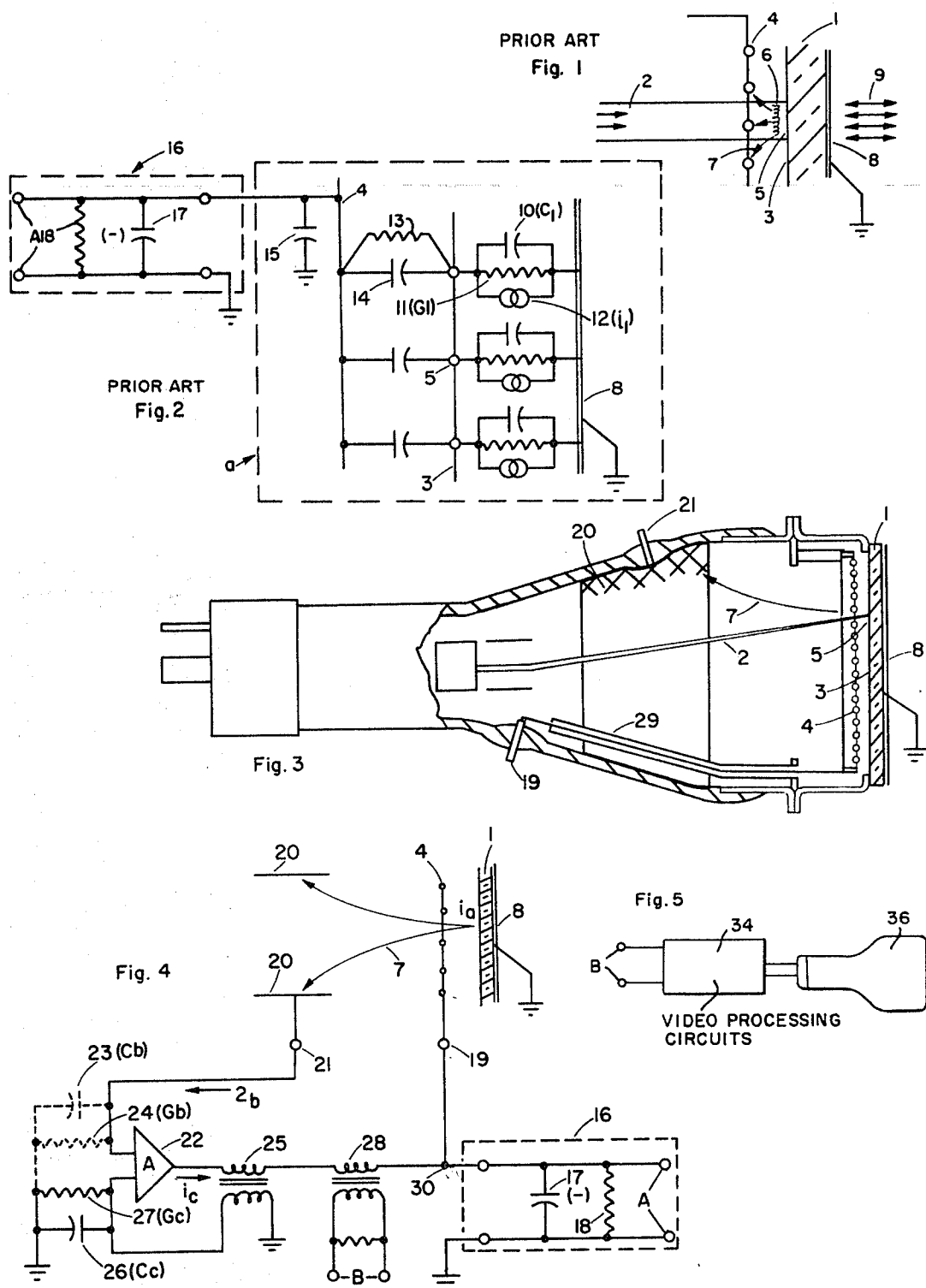
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 (Inquired); 315/9, 11; 313/65, 65 (A), 66, 67, 68;
 73/67.5, 67.6

ABSTRACT: An improved ultrasonic to visual signal conversion system utilizing a cathode ray tube, said tube having a piezoelectric face plate or conversion plate, a controlling screen adjacent thereto and a collector electrode back of the screen for receiving current generated by the conversion plate. The collector current is utilized to control a video tube synchronized with the first tube, and is shunted in feedback fashion to the screen to control terminal admittance thereof and thereby increase the signal to noise ratio of the system as well as to raise the effective signal level.





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SYSTEM USING A MODIFIED ULTRASONIC IMAGING TUBE

This invention pertains to an improved ultrasonic to video conversion system utilizing two cathode-ray tubes, one of which is equipped with a piezoelectric face plate or conversion capable of converting ultrasonic to electric signals and vice versa, and a second cathode ray, video tube which serves to display the signal picked up by the first tube.

Heretofore, the signal current output from the high-conductance ultrasonic converter tube has been obtained directly from a screen closely spaced to the conversion plate. This screen when swept by cathode-ray beam, establishes the electrical field at the conversion plate surface necessary for the high conductance path between the electron beam landing point and the screen. However, the capacitance of the screen to ground sets a lower limit on the termination admittance, and hence, the signal level, achievable for a given bandwidth; the capacitance between the conversion plate surface and the screen introduces an extraneous signal current that must be removed by signal processing; and the small percentage of the primary electron beam intercepted by the screen produces a significant amount of tube noise.

The present invention avoids the defects of prior devices by the use of high-transparency screen and separate collector electrode which draws the signal current therethrough. The electrode is so positioned at a distance from the screen that the capacity coupled signal and primary noise are eliminated. Moreover, the signal of the collector electrode is amplified in a circuit that balances out electrode capacitance and is then applied to the screen in feedback fashion to produce a potential which increases the electric field at the conversion plate. The effective termination admittance is thus reduced by the factor of current multiplication, increasing the degree of conversion plate element control and raising the output signal level.

Although the invention herein might be applied to various types of ultrasonic-electronic converters, optimum performance would be attained by utilizing it in the high-conductance-type converter disclosed in prior U.S. patent to W. R. Turner, U.S. Pat. No. 2,903,617 of Sept. 8, 1959, or in the article entitled "Ultrasonic Imaging" by W. R. Turner published in *Ultrasonics* for Oct.—Dec. 1965, pp. 182—187. Also, it could be readily adapted to the "Transceiver Ultrasonic Image System" disclosed in the inventor's copending U.S. Pat. application Ser. No. 718,024 filed Apr. 1, 1968, with beneficial effects accruing in its operation in reciprocal modes.

The principal object of the invention is to provide an improved ultrasonic-electronic video system having a higher signal conversion efficiency and reduced noise factor.

A further object of the invention is to provide an imaging tube equipped with a collector electrode in addition to the customary screen.

A still further object is to make an output connection from the aforesaid collector electrode to an amplifier, to feed said amplifier signal to the video phase of the system, and to shunt said signal to the screen to lower the admittance margin of the imaging tube.

Still another object of the invention is to modify the geometry of an image tube so as to permit the use of a separate collector electrode independently of the screen adjoining the piezoelectric face of the tube, in receiving mode of its operation.

With the above and related objects in view, the invention is described below in conjunction with the drawings, in which:

FIG. 1 is a partial diagrammatic showing of a high-conductance image tube preceding this invention.

FIG. 2 is a partial analog circuit depicting properties of the tube in terms of electrical components, and including a coupling network utilized to balance out capacitive components thereof.

FIG. 3 is a partial cross section of the image tube of this invention.

FIG. 4 is a diagrammatic circuit showing the several components and novel coupling employed in the output phase of the subject invention.

FIG. 5 is a diagrammatic representation of a video projection system to display the signal from the output of the invention.

Referring to fragmentary enlargement FIG. 1, the high-conductance image tube disclosed in applicant's copending application referred to above consists of an envelope, cathode-ray gun and sweep deflecting plates (as in FIG. 3) and employs a piezoelectric face plate or conversion plate 1 sealed to the envelope. The plate is covered by a grounded, thin, protective membrane generally designated 8 which is in contact with a suitable ultrasonic transmitting medium—such as water. The other side of the plate 1 (Within the envelope) carries an insulated target surface 3 which has a high secondary emission yield (greater than unity). Mounted in proximity of target surface 3, is a closely spaced but highly transparent wire capture screen 4. While the conversion plate 1 is continuous physically, it functions in cooperation with screen 4 and cathode ray beam 2 as though it was composed of a plurality of discrete-transducer elements, the area 5 of which is determined by the area of the impinging beam.

The impact of cathode-ray beam 2 upon target surface 3, landing area 5, gives rise to space charge 6 which serves as a coupling medium between landing area 5 and screen 4. When the space charge is in equilibrium, the electrons therein are at zero velocity and are free to move either to landing area 5 or toward screen 4 acting as capture electrode. The direction of electron motion may be determined by minute changes of electric field in the vicinity of zero velocity position and random fluctuation in emission velocity. If an alternating potential should appear on land area 5 due to piezoelectric action of plate 1, in response to ultrasonic signal 9, the space charge equilibrium will be disturbed and an alternating electron flow 7 therefrom will be driven to the screen; if, on the other hand, an alternating potential from a suitable external source (not shown) is applied to screen 4, the equilibrium of the space charge will be disturbed in the opposite direction, driving an alternative electron flow to landing space 5 and generating ultrasonic vibration on plate 1. The above describes the effective, alternative operations of an imaging tube in receiving and transmitting modes, respectively, thus the electron beam 2 sweeping over target surface 3 forms a conductive (or resistive) link from the beam landing area 5 to the screen 4, which provides for alternating current flow between them in opposite directions depending on operational mode.

FIG. 2 depicts, in dotted rectangle *a*, an analog of the three discrete transducer elements (landing areas 5 of plate 1, which may be impinged by CR beam 2 in predetermined, desired sequence. Each such transducer comprises the following equivalent electrical components: a capacitance 10 (C_1) being the electrical capacitance of the element; a conductance 11 (G_1) being the radiation conductance of the element when the front face of the conversion plate is coupled to an ultrasonic transmission medium 9 such as water; and a current generator 12 (i_1) being the electrical analog of ultrasonic energy entering the element through the transmission medium. The result of such excitation is an alternating potential on the landing point. Alternatively, a internal excitation of the element by an alternating current impressed upon the landing point will cause current to flow into the radiation admittance, and hence a conversion into ultrasonic energy that is projected into the transmission medium.

The relation between the equilibrium electron current and the potentials defining the electrical field in front of the emission surface is given by,

$$I_{eq} = \frac{A}{(L-L_e)^2} (V_0 - V_s + V_e)^{3/2} \times 2.325 \times 10^{-6} \text{ ampere} \quad (1)$$

where A is the space charge area, L the spacing from the emission surface to the capture electrode, L_e the distance from the emission surface to the plane of minimum electron velocity,

V_c , the capture electrode potential, V_s , the emission surface potential, and V_e , the average secondary emission velocity in electron volts.

Alternately the relation between the current and the potential difference from the beam landing point to the capture electrode can be defined as a small signal conductance,

$$G_x = I_{eq}^{1/3} \left(\frac{\sqrt{A}}{L} \right)^{4/3} 2.64 \times 10^{-4} \text{ ohms} \quad (2)$$

in this expression, L_e , being ignored in relation to L .

Thus, the action of the electron beam can be represented as a conductive (or resistive) link from the beam landing point to the screen. This provides a bilateral path for alternating current flow between the beam landing point and the screen.

A negative capacitance network 16 is employed with the above high-conductance conductance image tube to improve performance. This is a class of network described in detail by H. W. Bode in his book "Network Analysis and Feedback Amplifier Design." This network exhibits at its terminals a negative capacitance 17 (C_l) in parallel with a termination conductance 18 (G_l). The negative capacitance must be sustained over a frequency bandwidth sufficient to include the important sidebands of the electrical signal. It cancels the stray capacitances 14 and 15 terminating on the screen, and under certain circumstances can also act through the beam conductance 13 to cancel the capacitance 10 of the beam landing point element only.

A necessary condition for cancellation of the element capacitance is,

$$G_x \geq B_1 \left[\sqrt{\frac{2G_l}{B_1} + 1} + 1 \right] \quad (3)$$

where B_1 is the susceptance of the element capacitance 10 (C_l). Since B_1 is a small quantity G_l must also be limited in value if the required value of G_x is to be realizable. G_l however, is limited in minimum value by a network realizability relation derived by Bode and given approximately as,

$$G_l \approx C_s \cdot 4B \quad (4)$$

where C_s is the total shunt capacitance to be cancelled at the image tube terminal, and B is the bandwidth of the network.

As a consequence of these relationships, a number of compromises have been necessary in selecting the exact geometry for the high-conductance image tube of the prior art.

The beam conductance can be increased by reducing the spacing between the screen and the conversion plate surface. This, however, increases the capacitive coupling 14 between the conversion plate and the screen through which extraneous signal current flows from the remaining ultrasonically excited plate areas, and also increases the capacitance to ground for the screen, further limiting the minimum value of the termination conductance 13 (G_l). Alternately, the beam conductance can be increased by increasing the primary beam current 2. Higher beam currents result in an increased spreading of the electron beam through space charge repulsion, and hence a lessening of electronic resolution. More important, however, is the noise associated with the small proportion of primary beam current intercepted by the screen 4. Since this beam noise current is a significant component of total tube noise, as beam current is increased, this resulting noise source can cancel the effectiveness of any signal current improvement.

The invention herein discloses a method of signal extraction and feedback that significantly changes the limitations on tube geometry, termination network character, and operating parameters so that improved image tube performance is possible. The fundamental departure from my prior imaging systems resides in the use of separate collector electrode for signal current collection.

As will be seen in FIG. 3, the new imaging tube employs the usual conversion plate 1, having a grounded membrane 8 for contact with an ultrasonic conductive medium, and a secondary emission surface 3 impacted by CR beam 2. The construc-

tion of the capture screen 4 is essentially unchanged from the prior high conductivity tube, except that its spacing from the conversion plate surface may be decreased. The current output or collector electrode 20 is located behind the screen. The electrode 20 is generally annular in configuration and therefore may be formed as a conductive coating on the sidewall of the image tube.

Signal current diversion to the electrode 20 is possible because the secondarily emitted electrons approach the capture screen 4 with a velocity corresponding to the potential difference between the landing point 5 and the screen 4. Thus, the high transparency of screen 4 directly captures only those electrons incident upon screen wires and a large fraction of the electrons are propelled beyond the screen and are returned to it only because the screen is set at a high bias potential with respect to all nearby grounded surfaces.

The change in electrostatic fields within the image tube to effect signal current diversion to the new electrode 20 is effected by reducing the DC bias potential on screen 4 to an intermediate value, and applying a higher potential to the electrode 20. The potential of screen 4 need only be sufficiently high with respect to grounded sections of the tube wall to assure that all secondarily emitted electrons 7 will pass through the screen rather than terminate upon grounded area adjacent to the emission surface. The bias potential on the electrode 20 must then be sufficient to divert the electrons to electrode 20 before axial velocity has carried the electrons beyond the electrode 20 to other portions of the tube.

It should be noted that the diversion of signal current from the screen to a separate output electrode has no effect on the screen's control of emission at the space charge layer. Current released from the space charge region is wholly controlled by the potential difference between landing point 5 and screen 4. This will not be affected by bias changes on the screen because the insulated surface of the conversion plate will automatically adjust itself with reference to the screen to the potential difference given by,

$$V_c - V_s = I_{eq}^{2/3} \left(\frac{L}{\sqrt{A}} \right)^{4/3} \times 5.68 \times 10^3 - V_e \text{ volts} \quad (5)$$

which is the inverse of Eq. (1), ignoring L_e .

Referring to FIG. 4, the output electrode 20 will also have shunt capacitance and conductance to ground (shown in dotted lines), which while significantly less than that of screen 4, nevertheless would affect feedback performance if not satisfactorily compensated. The block diagram shows a circuit for current amplification with capacitance compensation, and includes the feedback connection described next below.

Current multiplication with capacitance compensation is obtained using a differential voltage amplifier 22. The terminal 21 of collector electrode 20 of the image tube is connected directly to one terminal of the amplifier, with precautions to limit wiring capacitance. Capacitance 23 (C_b) is the total capacitance associated with the electrode, and conductance 24 (G_b) is the total conductance. The amplifier is selected for high input impedance, low shunt input capacitance, and low equivalent input noise. Its output is fed back to screen 4 from junction 30 via terminal 19.

The signal for the inverse phase to the amplifier would be a voltage derived from a current transformer 15 shunted by capacitance 26 (C_c) and conductance 27 (G_c). Assuming a unity ratio transformer, the ratio of current is given by the equation,

$$\frac{i_c}{i_b} = \frac{\frac{1}{G_b + j\omega C_b}}{\frac{1}{Y_t A} + \frac{1}{G_c + j\omega C_c}} \approx \frac{G_c + j\omega C_c}{G_b + j\omega C_b} \quad (6)$$

where Y_t is the total termination admittance at the screen terminal 19 and A is amplifier gain. The second expression results if the product $Y_t A$ is made large compared to $(G_c + j\omega C_c)$.

A further simplification is possible if the ratio $G_c/\omega C_c$ is made equal to $G_b/\omega C_b$,

$$\frac{i_c}{i_b} \approx \frac{C_o}{C_b} = K \quad (6a)$$

Thus, the current i_b is multiplied by K, and this multiplication factor is set by a capacitance ratio, one of the capacitances being the termination capacitance for the electrode.

For state-of-the-art operational amplifiers suitable for this application, the shunt conductance at the electrode terminal will be small compared to the shunt capacitance. The effect of this conductance, however, can also be compensated by the adjustment of the G_c .

Two signal outputs A and B are indicated in the block diagram. Output A is through the negative capacitance network 16 connected to the junction 30. An output signal at this point would contain capacitively coupled signal and primary beam noise but these would be reduced in their effect by the signal current multiplication. The second output B is from tap 28 on the feedback line.

The signal from output B can be displayed by passing the output through appropriate video processing circuits 34 for display on a video tube 36, as shown in FIG. 5.

The subject of feedback system stability has been treated extensively in the literature. A potential source of instability for this application is capacitive coupling between screen 4 and the output electrode 20. A electrostatic shield 29 (FIG. 3) for the lead from screen 4 to terminal 19 is shown as being indicative of methods by which this coupling can be reduced. Other forms of electrostatic shielding or neutralization techniques might be used.

The alternating potential applied to the screen is given by,

$$e_a = KK' i_a / Y_t$$

where K' is the fraction of the original secondary signal current passing through the screen and becoming i_b . The effective termination admittance at the screen is,

$$Y_a = \frac{i_a}{e_a} = \frac{Y_t}{KK'} \quad (8)$$

Thus, the effective termination is the actual admittance of the screen to ground including stray capacitance and the effect of the termination network, divided by the net current multiplication. The small fraction of i_a terminating on the screen is ignored in this analysis as being insignificant in relation to i_c . Similarly, the current arising from capacitive coupling to the screen, and the noise current intercepted from the primary beam are regarded as insignificant in comparison to i_c if a large value is used for G_t and A.

New limits, of course, will exist on how large K can be made, how large G_t can become, and how small C_b can be made, etc. Nevertheless, within these limits a major signal-to-noise improvement will be possible.

I claim:

1. An ultrasonic imaging system comprising:

a high-conductance ultrasonic conversion tube, a video projection system, a conversion plate forming the face of the conversion tube, a grounded membrane on one side of the plate contacting an ultrasonic medium, a high secondary emission coating on the other side of said plate, a transparent control screen parallel to and in close proximity to the other side of the plate, a collector electrode located in spaced relation from said screen, a cathode ray beam generating and sweeping means, the beam forming a space charge between the screen and the secondary emission coating of the plate, at its point of impact means including a discrete portion of the plate at point of cathode ray beam impact to generate an electrical potential in response to ultrasonic signal reception to accelerate electrons from the space charge, through the screen and to the collector electrode to form a signal current thereon, amplifier means, means for coupling said collector signal current to the input of the amplifier, and means for transmitting the output of the amplifier to the video projection system and in shunt therewith to the screen of the conversion tube as a feedback.

2. A device according to claim 1, further including a negative capacitance-conductance network connected in shunt with the feedback and output to video circuits.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,577,171 Dated May 4, 1971

Inventor(s) WILLIAM R. TURNER

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

Claim 1, line 5, after "ultrasonic" insert --conducting--.

Claim 1, line 12, delete the comma (,) after "plate" and insert a comma (,) after "impact".

Signed and sealed this 3rd day of August 1971.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents