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INVENTION REPORT # 406

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Attachment (4)

SUBMITTED BY [redacted] DATE March 2 1960

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DESCRIPTIVE TITLE Electrical Analog for Radiation Heat Heat Transfer

Briefly, What Problem Were You Working On?

Design of Analog computer for Studying complex problems in heat transfer

How Does the Invention Work in Solving This Problem?

This device simulates heat transfer by the well known Radiation law

$$H = \frac{\epsilon_1 \epsilon_2}{\epsilon_1 + \epsilon_2 - \epsilon_1 \epsilon_2} \sigma \left(T_1^4 - T_2^4 \right)$$

where T is temperature, ϵ emissivity, σ is a constant, subscripts refer to walls #1 and #2

Circumstances Surrounding the Invention. (Notebooks for reference, other people contributing?)

Work Done under SPO 71696 and later 71945

Construction, Testing and use of Computer Done by [redacted]

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References: Report #5530 Appendix E (especially pp 45-50 and 56); Notebook #1034 p.7;

INTER-OFFICE CORRESPONDENCE

THE PERKIN-ELMER CORPORATION
NORWALK, CONN.

March 2, 19 60

SUBJECT: Invention Disclosure
FILE NO.: Ref: Docket #406

TO

FROM

Electrical Analog For Radiation Heat Transfer

When engineers learned that entirely different physical systems could be described mathematically by a common set of equations, they realized that one system could be used to simulate the other. Very often it is much easier to construct and test the simulated system instead of the real system of interest.

In problems of heat transfer, this technique has been quite helpful. By letting electrical voltage be the analog of temperature and electrical current be the analog of heat flux, one can construct an electrical system in which the flow of electricity simulates the flow of heat in the analogous physical system.

One serious limitation, however, has hindered the full utilization of this technique. The electrical systems which had been developed before now could simulate heat transfer by convection and by conduction but not by radiation.*

The device being disclosed here has been developed to fill this gap. It normally would be used as part of a larger analog system but could conceivably be used by itself or with others of its kind.

The heart of the simulator is a resistor which is made to conduct electrical current in a manner analogous to thermal radiation. The novel feature is the manner by which the conductivity of this resistor is controlled.

Principle of Operation

The net radiated heat flux between two bodies is:

$$H = k\,(T_1^{\,4} - T_2^{\,4}) \qquad (1$$

where k is a constant and T_1 and T_2 are the temperatures of bodies #1 and #2, respectively. The current flowing between two electrical points through a resistor R is:

$$I = \frac{1}{R}\,(V_1 - V_2) \qquad (2$$

* In special cases, radiation transfer could be approximated, but this had limited application.

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where V_1 and V_2 are the voltages at points #1 and #2, respectively. Equation (1 may be made to look like equation (2 by the identity

$$H = k(T_1^4 - T_2^4) \equiv k(T_1^2 + T_2^2)(T_1 + T_2)(T_1 - T_2) \qquad (3$$

which suggests that if

$$\frac{1}{R} = k(T_1^2 + T_2^2)(T_1 + T_2) \approx k4T^3_{avg} \qquad (4$$

then equation (2 would be completely analogous to equation (1, and we have an electrical analog for thermal radiation.

In this simulator, the resistor, R, is a photoconductive resistor element which is placed inside a light-tight box and is arranged so as to be illuminated by a small incandescent electric light. The lamp is powered by an amplifier which is, in turn, controlled by the voltage at points #1 and #2. This is illustrated in figure 1.

Consider first a simplified case. The voltage V_L at the lamp is the sum of $V_1 + V_2$. If the lamp filament has a constant resistance r_e, then power to the lamp (and hence from it) is

$$\frac{V_L^2}{r_e} = \frac{(V_1 + V_2)^2}{r_e} \qquad (5$$

The conduction of the photoconductive resistor is linearly proportional to the energy (in certain wave lengths) incident on it. Thus

$$\frac{1}{R} = \frac{k^1 (V_1 + V_2)^2}{r_e} = \frac{k_1 (V_1^2 + V_2^2 + 2V_1V_2)}{r_e} \qquad (6$$

where k^1 is a constant. Equation (6 shows a dependence on V_1 and V_2 which is similar to the dependence of 1/R upon T_1 and T_2 in equation (4.

Although equations (6 and (4 are not exactly of the same form, the observed dependence of 1/R upon V_1 and V_2 more nearly matches equation (4 instead of equation (6, and, thus, one obtains the desired effect. Many additional effects cause this to be so: At higher input voltages, the emission spectrum of the lamp moves more towards the region of the photoconductor spectral sensitivity, in which turn, makes the observed exponent in equation approximately 3 instead of 2 as was obtained by the simplified analysis.

Second, the lamp resistance increases at higher temperatures, but this effect is relatively small.

Third, by using an amplifier of the type shown in figure 2, the output voltage V_L can be made to be proportional to $\frac{V_1 + V_2}{2}$ when V_1 is nearly equal to V_2, but proportional to the larger of V_1 or V_2 when one is much less than the other.

These three effects make the photoconductor behave according to the relation

$$\frac{1}{R} = k(V_1^2 + V_2^2)(V_1 + V_2) \qquad (7$$

to a good approximation, and the analogy is complete.

Conclusions

The novel features of this device are:

1. Controlling current with a photoconducting resistor in order to simulate physical processes by analogy.
2. Controlling the photoconductor by varying both intensity and spectral distribution of incident light.
3. Using the nonlinear characteristics of the amplifier in figure 2 to improve ~~accuracy,~~ the accuracy of the lamp excitation system.

Two devices this form were constructed at Perkin-Elmer for use in a simulator used to study heat transfer problems involving heat transfer by radiation. They operated in an entirely satisfactory manner. In the particular problem studied, the coefficient k in equation (1. varied slightly with temperature, and we found that this effect could also be simulated by means of a scaling change in the analog.

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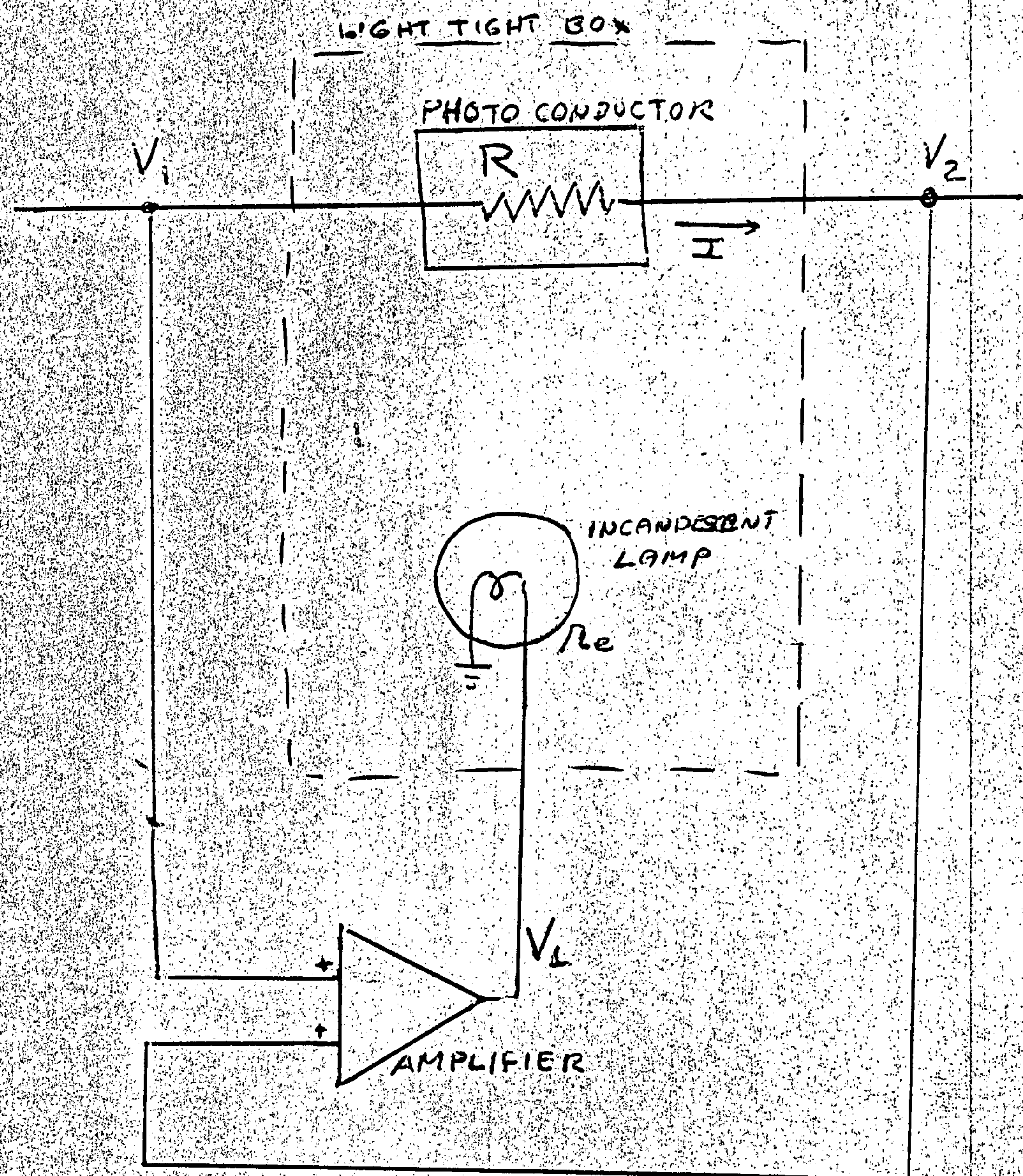

FIGURE 1

BASIC ELEMENTS IN ELECTRICAL ANALOG FOR RADIATION HEAT TRANSFER

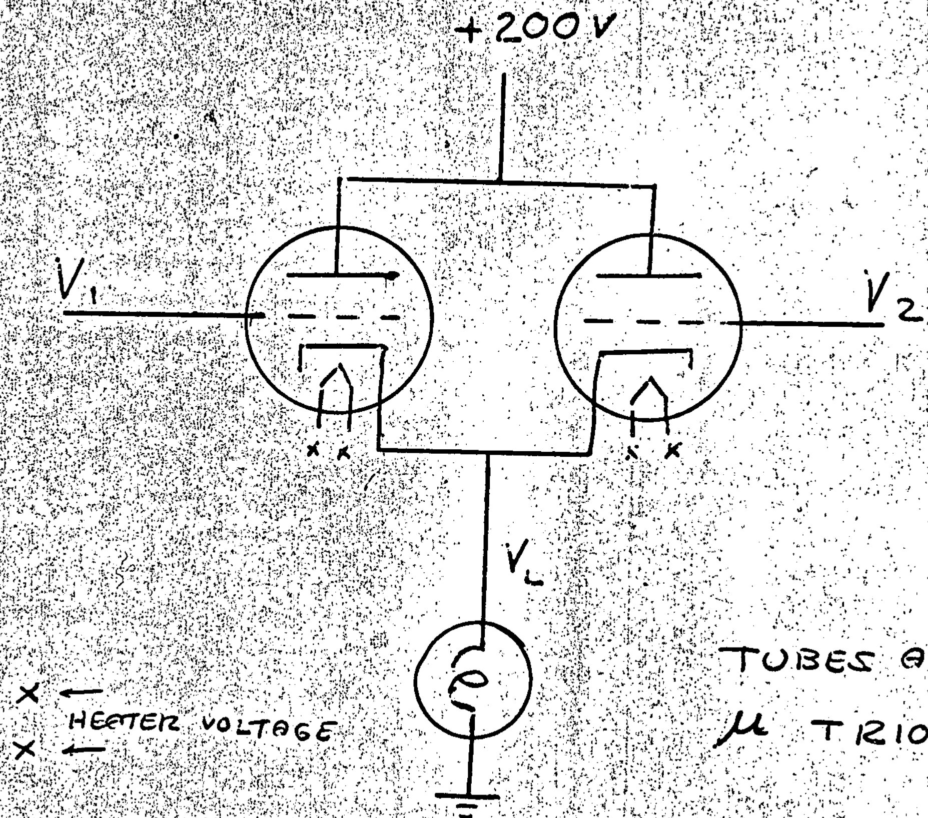

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FIGURE 2

NONLINEAR AMPLIFIER FOR USE IN ELECTRICAL ANALOG FOR RADIATION HEAT TRANSFER

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