A Digital Meter for Measuring the Rate of Heat Transferred Through Walls

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Abstract: ***Heat transfers through a wall are one of the most important parameters that must be considered in designing systems for heating or cooling building. In this paper a digital meter for measuring the rate of heat transferred through Walls have been designed to measure Time rate of heat transfer through the wall which gives an indication of the amount of energy lost through this path.***

Keywords: ***transfers, Heat, measure, Walls, systems for heating,***

I. INTRODUCTION

One important source of loses in energy required for heating or cooling a building is due to the heat transferred through the walls between the inner and outer sides of the building. In order to determine the total amount of heat transferred through a wall, it is necessary to know in forehand the time rate of heat transfer through the wall. This gives an indication of the amount of energy lost through this path. However, this coefficient is a function of the room and ambient temperatures during day and night. Conduction is the only heat transfer mode in opaque solid media [1]. When a temperature gradient exists in such a body, heat will be transferred from the higher to the lower temperature region. The rate at which heat is transferred by conduction, q, is proportional to the temperature gradient dT/dx times the area A through which heat is transferred as in fig 1.

$$q = -KA\frac{dT}{dx} \qquad \text{………………..(1)}$$

Where K is the thermal conductivity of the solid media of the wall. When both surfaces of the wall are at uniform temperature, the heat flow will be in one direction, perpendicular to the wall surface.

For many materials, the thermal conductivity is a linear function of temperature,

$$K(T) = K_o(1 + BT) \qquad \text{…………….(2)}$$

Where K_o and B are the constant depending on the wall material. However , B is a small number which in some approximations is neglected. Integration of (1) gives the time rate of heat transfer per unit area as,

$$\frac{q}{A} = \frac{K_o}{W}(T_1 - T_2) + \frac{B}{2}(T_1^2 - T_2^2) \qquad \text{………………….(3)}$$

Where,

q → time- rate of heat transferred through the wall

A → total area of the wall surface, through which heat is transferred,

W → thickness of the wall,

T_1 → the higher temperature (usually of inner wall surface)

T_2 →the lower temperature (usually of outer wall surface)

The following section describes the design and theory of digital meter for measuring the time rate of heat transferred through a wall per wall unit area.

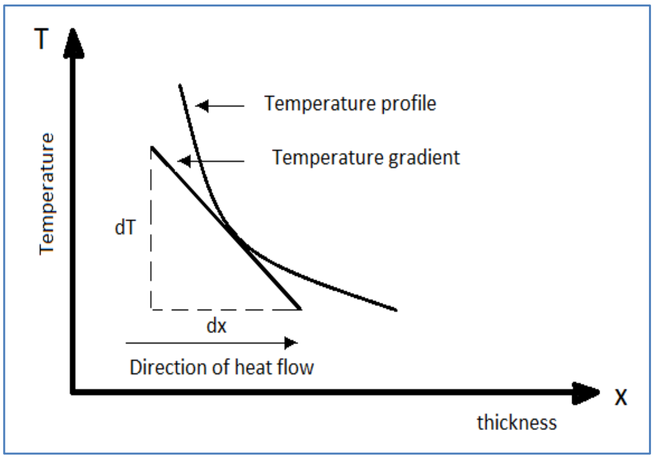

Figure (1) : Temperature gradient and direction of heat conduction in a solid.

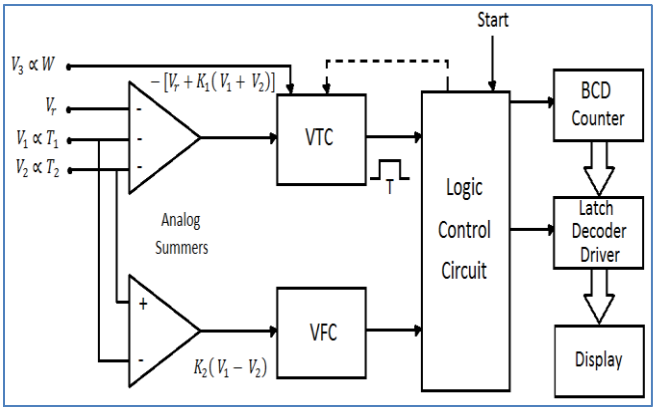

Figure (2): block diagram of the heat transfer meter

II. THEORY OF OPERATION

Three voltages are assessed V_1, V_2 and V_3 representative of T_1, T_2 and W, respectively. V_1 and V_2 are developed via two thermocouples attached to the inner and outer wall surfaces, respectively. V_3 is obtained via a thumb wheel or a dial potentiometer, adjusted to the value of W.

Fig (2) shows a block diagram of the meter that measures the time rate of heat transfer through a wall.

The liner voltage to time convertor VTC produces a time period T proportional to its input voltage starting at time t = t_0

Revised Version Manuscript Received on September 24, 2016.

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$T = \frac{K_T}{V_3}\,(V_r + K_1(V_1 + V_2))$ ……………..(4)

Where:

K_T/V_3 represent the proportionality factor of the VTC
K_T is a constant
V_r is a reference voltage of a positive polarity
K_1 is the gain of analogue summer
The voltage to frequency convertor (VFC) produces a sequence pulses with frequency f_0 proportional to its input voltage.

$$f_0 = K_f V_{in}$$

$$= K_f K_2 (V_1 - V_2)$$

Where :

K_f is the proportionality constant of the VFC

K_2 is the gain of the analogue summer.

At $t = t_0$, the digital counter start counting the clock pulses throughout the time interval T. At the end of the time interval T, namely at $= t_1$, the digital number N_{t1} present on the counter is proportional to the time rate of the heat transferred through the wall per unit area.

$$N_{t1} = T\,f_0$$

$$= K_T[V_r + K_1(V_1 + V_2)]\,K_f K_2 (V_1 - V_2)$$

$$= \frac{K_T\,K_f K_2 V_r}{V_3}\,[(V_1 - V_2) + \frac{K_1}{V_r}(V_1^2 - V_2^2)]$$

$$= \frac{K_3}{V_3}\,[(V_1 + V_2) + K_4(V_1^2 - V_2^2)]$$

………………..(6)

Where:

N_{t1}= the final number on the counter at $t = t_1$

f_0= the output frequency of VFC

K_3= $K_T\,K_f K_2 V_r$ constant $\propto K_0$

$K_4 = \frac{K_1}{V_r}$ Constant $\propto \frac{B}{2}$

By a proper adjustment of the constant meeting the properties of the wall material, the number N_{t1} is proportional to q/A.

III. CIRCUIT OPERATION

Figure 3 shows completes circuit diagram of the conduction heat transfer meter.

At $t = t_0$ the negative going start command signal, reset the counter and also closes S momentarily, thus discharging the capacitor C. just after $t = t_0$ the integrator starts integrating the voltage V_3applied to its input.

$$V_o = \frac{-1}{R_c}\int_{t_o}^{t} V_3 dt$$

$$= \frac{-V_3}{R_c}(t - t_0) \quad …………………. (7)$$

Where

V_3 is the proportional to the wall thickness.

V_o is a ramo-up voltage.

The BCD counter counts the clock pulses generated by the VFC.

At $t = t_1$, V_o becomes equal to $V_r + K_1(V_1 + V_2)$ so the comparator output goes low and counting is ceased.

$$V_o(t_1) = -[V_r + K_1(V_1 + V_2)] = -\frac{V_3}{R_c}(t_1 - t_0)$$

$$\therefore\ t_1 - t_0 = \frac{R_c}{V_3}[V_r + K_1(V_1 + V_2)]$$

$$= \frac{R_c V_r}{V_3}\,[1 + \frac{K_1}{V_r}(V_1 + V_2)] \quad ………………. (8)$$

Where

V_r = a positive reference voltage

K_1 = gain of the summer

V_1 = voltage proportional to T_1

V_2 = voltage proportional to T_2

$$N_{t1} = (t_1 - t_0)f_0$$

$$= \frac{RC\,K_f V_r}{V_3}\,[(V_1 - V_2) + \frac{K_1}{V_r}(V_1^2 - V_2^2)]$$

$$= \frac{K_3}{V_3}\,[(V_1 + V_2) + K_4(V_1^2 - V_2^2)] \quad ....(9)$$

Where :

N_{t1}= the final number on the counter at $t = t_1$

K_3= $K_f RCV_r$ constant $\propto K_0$

$K_4 = \frac{K_1}{V_r}$ Constant $\propto \frac{B}{2}$

$f_0 = K_f(V_1 - V_2)$ output frequency of the VFC

K_f= conversion constant of VFC.

It's obvious thatN_{t1} is proportional to q/A . Figure 4 shows the timing diagram of the previously described meter.

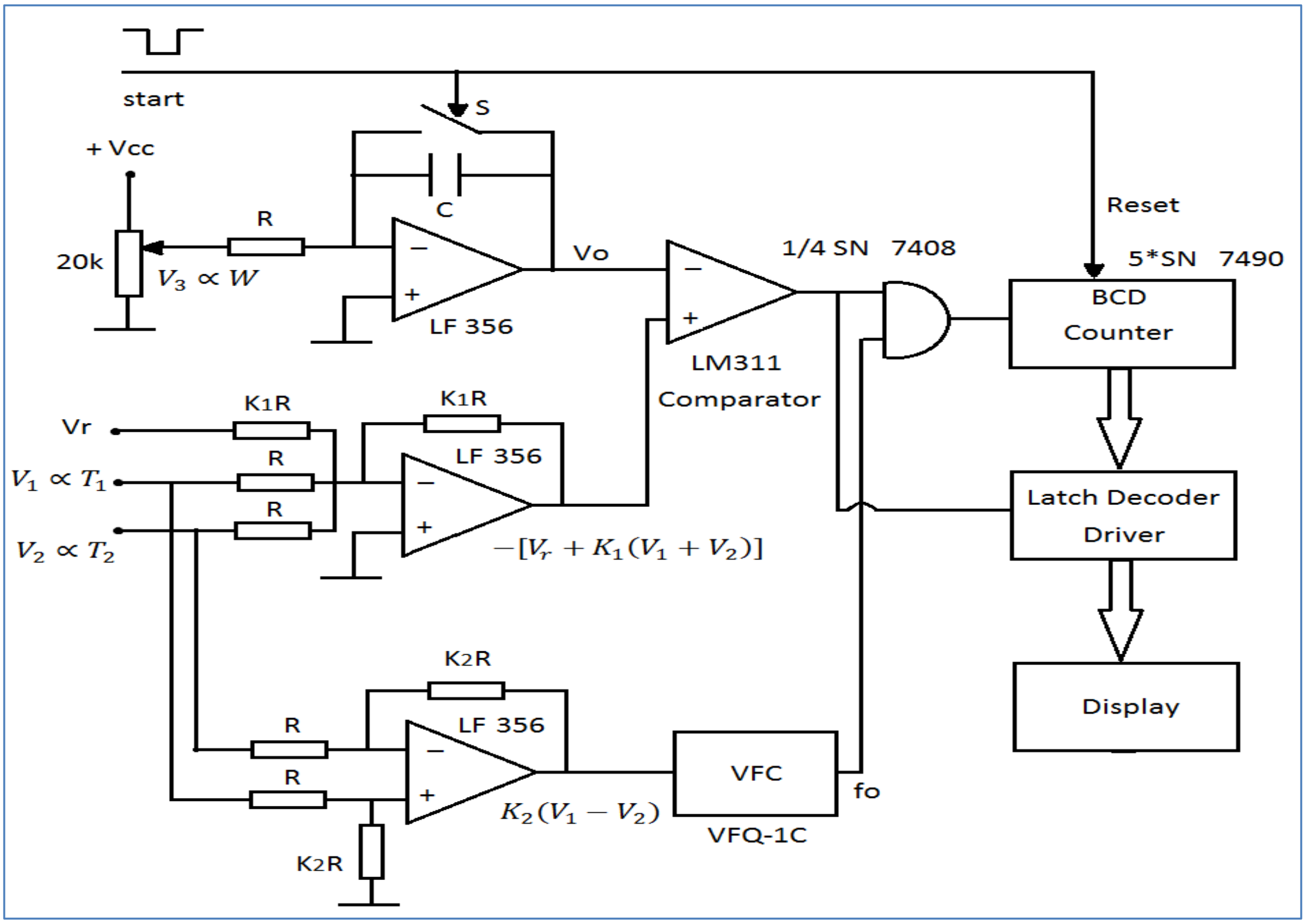

Figure 3: Complete circuit diagram of the heat transfer meter

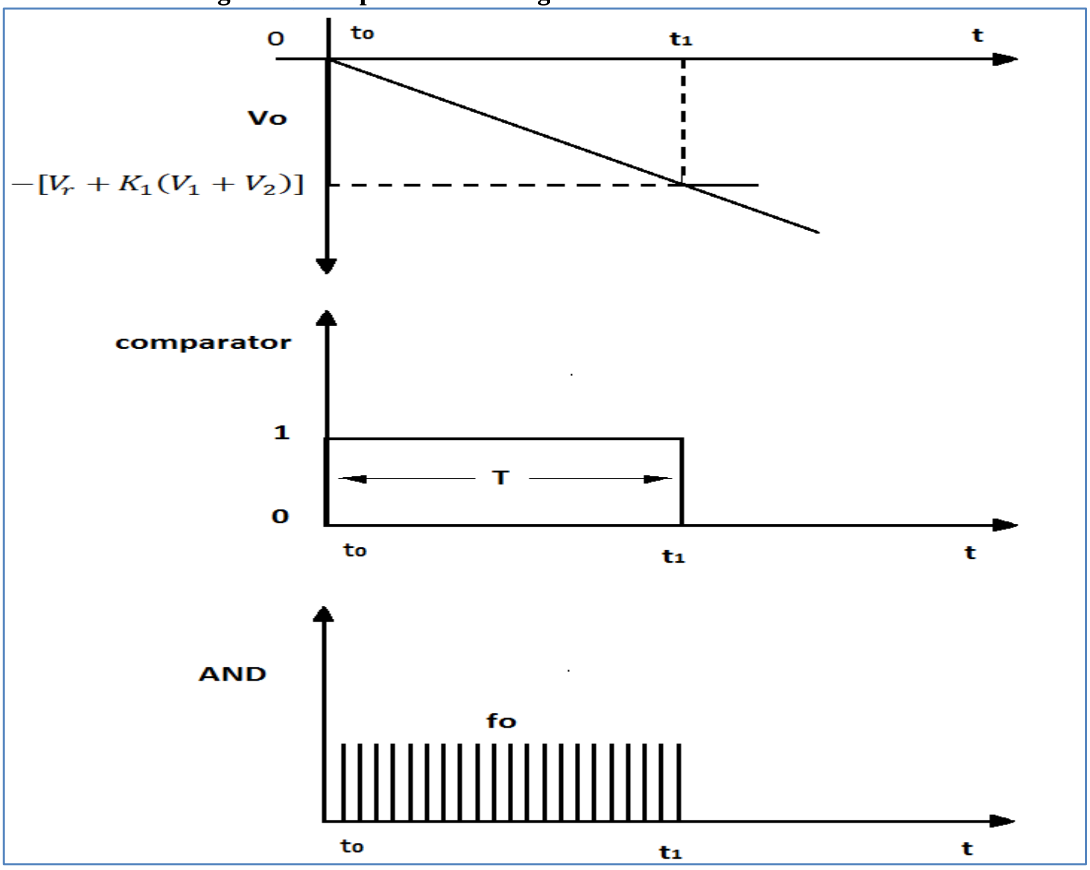

Figure4: timing diagram of the heat transfer meter

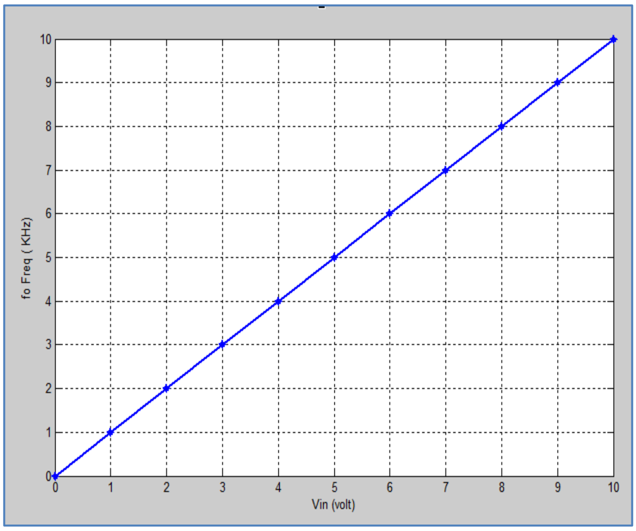

Figure 5: output frequency of the VFC a against input voltage

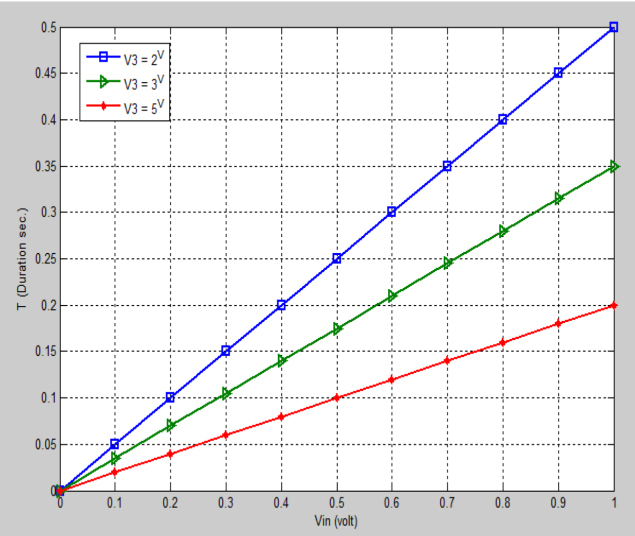

Figure 6: Output duration of VTC against input voltage

IV. RESULTS

Figure 5 shows the linearity of the VFC used in the circuit, while figure 6 shows the linearity of the VTC for some values of V_3. Experimental testes on the VTC produced an error of less than ± 0.15 % as compared to the theoretical values.

V. CONCLUSION

In this paper, was introduced the theory and design of a digital meter for measuring the rate of heat transfer through walls. Tests carried out on the circuit of fig.3 shows an overall error of less than ±0.2% as compared to theoretical investigation. This error is mainly affected by the integrators DC offset, the speed and threshold voltage of the comparators and tolerance of the passive components used.

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