Apparent Thermal Conductivity Digital Meter in Trains as an Energy – Conserving Measure

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Abstract: Energy conserving measure is one of important factors that must be measured in constructions of building, an energy conserving measure leads to the practical thickness of the proper used insolent, the function of both the temperatures of the bounding surfaces and the thickness of the air layer are considered the apparent thermal conductivity of the air layer due to the combined modes of conduction and radiation which increases with the thickness. This paper introduces the design and implementation of an electronic digital meter suitable for the measurement of the apparent thermal conductivity and has been tested in eight departments of institute of technology/ Baghdad in four labs.

Keywords: Energy, constructions, implementation, temperatures.

I. INTRODUCTION

The insulation value in the train which is the energy conserving measure leads to the practical thickness of the proper used insolent. The heat transfers in low density porous insulation occur through a combination of several modes acting simultaneously. These would include conductions through the solid and gaseous phases, heat transmission by natural or forced convection in open pore systems, such as that fibers used in trains, and heat exchanges by radiation. Reduction of train carriages energy demands have led to increases in their insulation thickness of roof spaces. The apparent thermal conductivity of each material used generally it has been assumed that has been a constant and equal to value obtained in a testing laboratory under different conditions.

A simplified understanding of thermal insolent thickness effect which is partly due to radiation may be obtained from following analysis:

A layer of still air enclosed between two infinite parallel planes, 1 and 2, composed of materials of emissivity, ε_1 and ε_2 , at absolute temperature of T_1 and T_2 respectively would have a net radiant heat flux exchange rate described by :

$$\dot{q_R} = \frac{\sigma\, \varepsilon_1\, \varepsilon_2}{(\varepsilon_1 + \varepsilon_2) - \varepsilon_1\, \varepsilon_2}(T_1^4 - T_2^4) \text{ ....(1)}$$

I.e. the radiation heat flux does not depend upon the distance between the plates.

The rate of conduction through the air between the two plates is described by the expression:

$$\dot{q_C} = \frac{K_m(T_1 - T_2)}{\delta} \text{ ....(2)}$$

Where

K_m → is the true thermal conductivity of the air enclosed by the two plates.

δ → is the separation between the plates.

The total steady state heat flux, $\dot{q_r}$ due to both radiation and conduction, would therefore be:

$$\dot{q_r} = \dot{q_R} + \dot{q_C} = \frac{\sigma\, \varepsilon_1\, \varepsilon_2}{(\varepsilon_1 + \varepsilon_2) - \varepsilon_1\, \varepsilon_2}(T_1^4 - T_2^4) + \frac{K_m}{\delta}(T_1 - T_2) \text{ ....(3)}$$

The apparent thermal conductivity, K, of the air layer is defied by:

$$k = \frac{\dot{q_r}\delta}{(T_1 - T_2)}$$

Therefore, from this and (3):

$$k = K_m + \sigma \frac{(T_1+T_2)(T_1^2+T_2^2)}{\left(\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}\right)-1} \text{ ....(4)}$$

As ε_1 and ε_2 are both equal to, or, more probably, less than, unity.

The second term on the right-hand side of eq.(4) is essentially positive. Therefore, under the stated conditions, $K>K_m$.

the apparent thermal conductivity of the air layer due to the combined modes of conduction and radiation from eq. (4) that is a function of both the temperatures of the bounding surfaces and the thickness of the air layer, and increases with the thickness. This paper introduces the design and implementation of an electronic digital meter suitable for the measurement of the apparent thermal conductivity (k) defines by eq. (4).

II. THEORY OF OPERATION

The electronic system is required to solve digitally the apparent thermal conductivity K of eq.(4). This may be simplified to the following form:

$$k = k_m + k_n(T_1 + T_2)(T_1^2 + T_2^2) \text{ ....(5)}$$

Where

$$k_n = \frac{\sigma\delta}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2}\right) - 1}$$

The above variables and constant are already defined in the introduction. The

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temperature T_1 and T_2 are measured via appropriate thermal transducer to develop voltage V_a and V_b respectively.

Eq. (5) may be expressed in term of voltage V_a and V_b as follows:

$$k = k_m + k_n(V_a + V_b)(V_a^2 + V_b^2)\text{..............}(6)$$

By referring to the timing diagram of fig (1), at t= t_0 the analog voltage (- V_a) is applied to the reset integrator circuit to develop the voltage V_1:

$$V_1 = \frac{-1}{RC}\int_{t_0}^{t_1} -V_a dt \quad \text{.....................}(7)$$

Hence,

$$V_1 = \frac{V_a}{RC}(t_1 - t_0) \text{ ....}(8)$$

And *(t_1-t_0) =T_1*

During the period (T_1), the counter is allowed to pass pulses of duration (τ_1) to count up to half the full scale capacity of the counter ($2^n/2$) where n is the number of bits of the counter.

Therefore,

$$T_1 = \frac{2^n}{2}\tau_1$$

Hence,

$$V_1 = \frac{2^n V_A}{2RC}\tau_1 \text{ ....}(9)$$

At t= t_1 (fig 1.a), the second voltage (- V_b) is applied to the integrator circuit and the counter is allowed to count pulses of duration (τ_2) during the period (t_1-t_2) up to full scale (2^n) capacity of the counter.

At t = t_2 the integrator voltage is:

$$V_2 = V_1 - \frac{1}{RC}\int_{t_1}^{t_2} -V_b dt\text{.................................}(10)$$

Hence,

$$V_2 = V_1 + \frac{V_b}{RC}\ (t_2 - t_1) \text{ ....}(11)$$

But

t_1-t_2 =T_2

where

$$T_2 = \frac{2^n}{2}\tau_2$$

Hence,

$$V_2 = V_1 + \frac{2^n V_b}{2RC}\tau_2 \text{ ....}(12)$$

From eq. (9) to eq. (11)

$$V_2 = \frac{2^n V_a}{2RC}\tau_1 + \frac{2^n V_b}{2RC}\tau_2 \text{ ....}(13)$$

At t = t_2, the reference voltage V_r is switched in the integrator circuit. The integrator output voltage (V_2) during the period T_3 ramps down till it crosses zero axis at t=t_3. This voltage V_3may be expressed by the following equation:

$$V_3 = V_2 - \frac{1}{RC}\int_{t_2}^{t_3} V_r\, dt \text{ ....}(14)$$

By substituting V_2 from eq. (13) into eq. (14):

$$V_3 = \frac{2^n V_a}{2RC}\tau_1 + \frac{2^n V_b}{2RC}\tau_2 - \frac{V_r}{RC}\ (t_3 - t_2) \text{ ....}(15)$$

Where t_3-t_2=T_3

During the period (T_3) the counter starts from zero count at t= t_2 and progress counting up to (N) count and terminates at t=t_3 at which time the count is stopped and the digital number (N) may be expressed in the following way:

$$N = \frac{T_3}{\tau_3} \text{ ....}(17)$$

Hence,

$$t_3 - t_2 = N\tau_3\text{................................}(18)$$

By combining eqs. (15) and (18),

$$V_3 = \frac{2^n V_a}{2RC}\tau_1 + \frac{2^n V_b}{2RC}\tau_2 - \frac{V_r}{RC}\ N\tau_3\text{..................}(19)$$

But at t=t_3, V_3=0

Therefore , eq. (19) becomes

$$0 = \frac{2^n V_a}{2RC}\tau_1 + \frac{2^n V_b}{2RC}\tau_2 - \frac{V_r}{RC}\ N\tau_3 \text{ ....}(20)$$

Therefore,

$$N = \frac{2^n}{2\tau_3 V_r}(V_a\tau_1 + V_b\tau_2)\text{..................................}(21)$$

Or

$$N = \frac{2^n V_a}{2\tau_3 V_r}\tau_1 + \frac{2^n V_b}{2\tau_3 V_r}\tau_2 \text{ ....}(22)$$

Compering the term of eq. (22) with that modified of eq. (6) which may be rewritten in the following form:

$$k = k_m + k_n(V_a + V_b)N_a^2 + k_n(V_a + V_b)V_b^2 \text{ ....}(23)$$

By noting from eq. (22) and (23) that $1/\tau_3$ and $(V_a + V_b)$ are common terms, one can express $1/\tau_3$ proportional to $(V_a + V_b)$ by mean of (VFC) circuit.

Also by making the duration τ_1 and τ_2 proportional to their respective voltage V_a and V_b by means of two voltage to time convertor (τ_1 proportional to V_a and τ_2 proportional to

V_b), then the term K_n is given by the following equation:

$$k_n = \frac{2^n k_3 k_1}{2V_r} \quad \text{..............................(24)}$$

Where K_3 is the conversion constant of the VFC in Hz/V. K_1 is the conversion constant of the VTC in sec/V. the term K_m may be obtained by loading its digital equivalent into the counter N at the proper time where $t=t_2$.

III. CIRCUIT DESCRIPTION AND OPERATION

The circuit operation may be described by referring to the circuit diagram of fig (2) and the timing diagram of fig (1).

At t= t_0 the reset pulse fig (1-b) is applied to reset the counter N, Q_1 and Q_2 and analog switch S_3 of the integrator.

The switches S_1 and S_2 are so organized that logic "1" will make them in the upper position and logic "2" for lower position.

The analog voltage "-V_a" is now applied at $t=t_0$ through S_1 to the integrator circuit and clocking of period "τ_1" is allowed only to pass through "AND gate 1" to start the counting by the digital counter "N".

The time digital counter is half-way from full capacity "2^n" the MSB will change from low to high level at $t=t^2$. This change will clock the data of Q_1 such that Q_1=1 at $t=t_2$.

The "NOR-1" output becomes low making S_1 in the down position to allow the integrator to receive the second analog voltage "-V_b" .

The counter continues now to the full capacity by clocking it through "AND -2" to allow Pulses of duration "τ_2" to pass through the counter.

At $t=t_2$ the MSB changes " fig 1-d" from high to low , this change makes Q_2 equal to 1 fig (2-g). Thus NOR-2 output SQ_2 equal to 0 at $t=t_2$, the integrator circuit receives at $t=t_3$ the reference voltage "+V_r".

The integrator circuit output V_{int} ramps down towards zero.

The clocking of the counter during period "T_3" is made by means of clock pulses of duration "τ_3".

At $t=t_3$ the comparator (CO-output "fig 2-c") goes low and the number N is read to represent the apparent thermal conductivity.

IV. MEASURING RESULTS

Table (1) illustrate measuring results of comparison of divided bar thermal conductivity measurements which have been tested in 8 building departments in institute of technology / Baghdad, in each building 4 laboratories have been measured the heating conductivity using the proposed digital meter. Where the mean thermal Conductivity in table (1-1) are calculated theoretically and compered with the practical results in four labs belongs to eight buildings.

Building Number	Mean Thermal Conductivity ($Wm^{-1}k$-1)	% Deviation from the mean			
		Lab 1	Lab 2	Lab 3	Lab 4
1	1.75	+0.3	+5.4	-6.0	+0.3
2	1.91	+2.5	-3.8	+0.4	+0.9
3	2.36	0.0		+2.8	-2.7
4	2.78	+1.7		-1.2	-0.5
5	2.78	+1.4	-2.2	+1.1	-0.4
6	2.91	+0.3	+4.1	-3.4	-1.0
7	3.44	-4.2		+6.0	-1.8
8	3.75	+0.9	-1.8	+2.5	-1.5
mean deviation from the mean(%)		+0.4	+0.3	+0.3	-0.8
rms deviation from the mean (%)		1.9	3.7	3.5	1.4

V. CONCLUSION

This paper introduced the theory and circuit operation of proposed method and device suitable for measurement of apparent thermal conductivity utilizing digital techniques. It employs linear analog and digital logic counting and control circuits. This digital meter is a useful tool in the assessment of energy conserving measure such as in trains for example by allowing suitable means in finding the apparent thermal conductivity.

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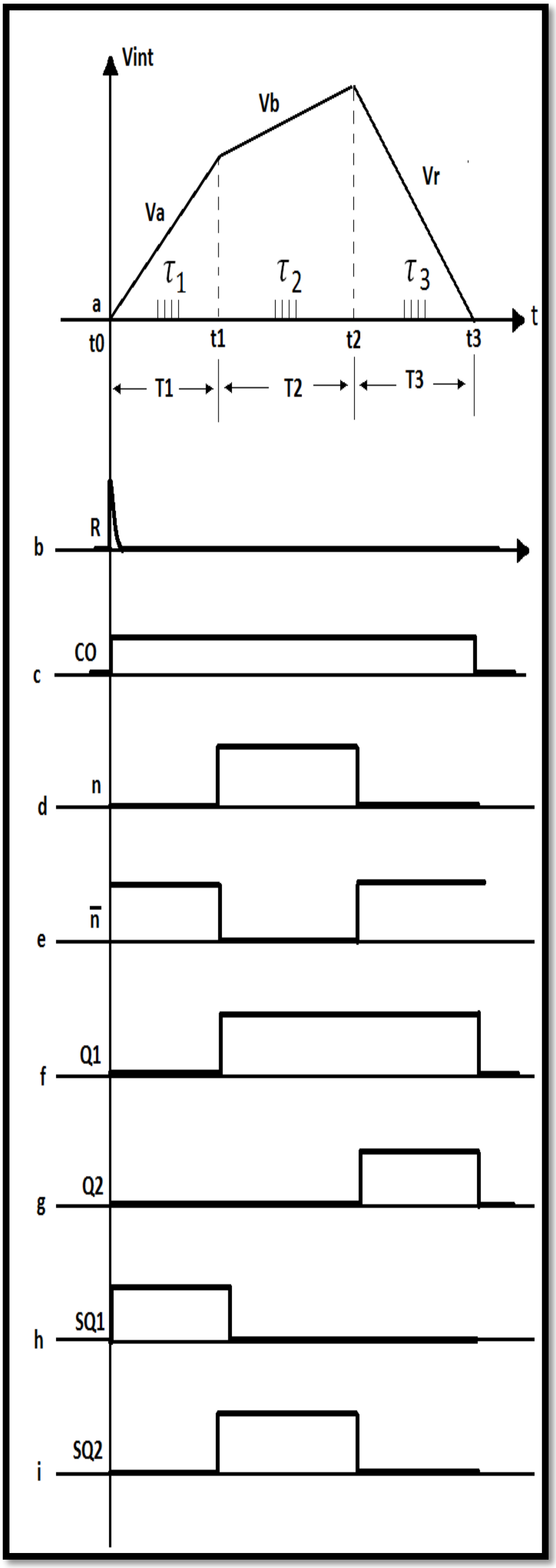

Figure (1) Timing Diagram

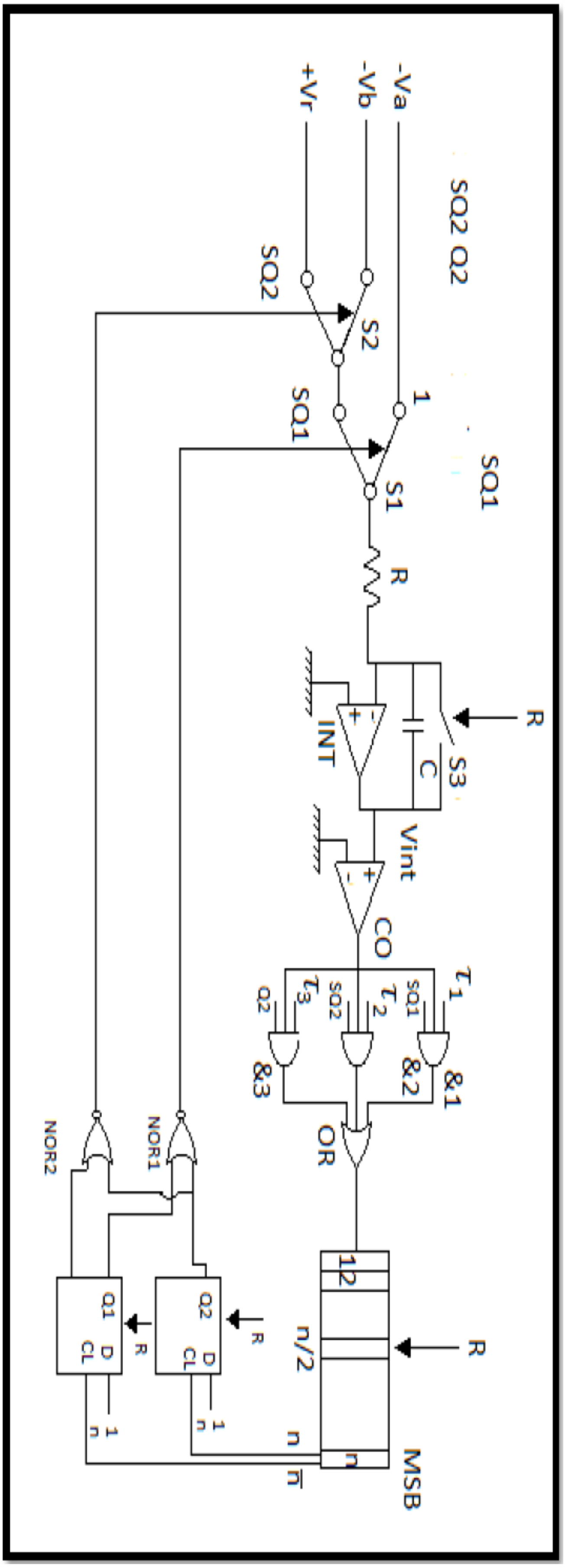

Figure (2): Circuit of the Apparent Thermal Conductivity Meter.