*Proceedings of the 14th*
**KACC, Octorber 1999**

# Oven Temperature Control by Integral – Cycle Binary Rate Modulation Technique

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**Abstract**

This paper proposes controlling of temperature in an oven by using 4 bits Integral – Cycle Binary Rate Modulation (IBRM) method and ac line with frequency 50 Hz. Microcontroller MCS-51 controls IBRM according to Proportional Integral controller (PI) function . Discrete signals are used in the system modeled by using Ziegler Nichols principle for analyzing the stability before designing the system. This procedure makes it easy to investigate system response. The system is implemented by 4 bits digital circuit which gives 320 patterns of ac signal for controlling the generation of energy for 3,000 watts thermal coil every 20 ms of each cycle. We divide scan time ($Ts_n$) in to 20 intervals, 1 ms interval is selected to generate 16 patterns IBRM. Because of this method gives the ripple lower than 2% it generates less noise for system. Moreover, we can consider whole system from the time model of control procedure and IBRM algorithm at 40-200 $^{o}$C with ± 1 $^{o}$C error in the 1 cubic meter oven.

## 1. Introduction

Generally, an electric ovens are used in both household as well as in industries. The temperature used differs in different purposes, but the control of temperature usually use ON and OFF switch or atmost, phase control. If temperature required is accurate with high resolution, and fast response, it can be replaced by Binary Rate combination [1], Thus there will be 2 variables i.e., $K_c$ and $T_i$ for constant temperature adjustment and accurate control. It is seen that when $T/T_P$ is used, the ripple is ≤ 2%. If number of bit are increased more than 4, the resolution of temperature will be high as well as time response improving while $Ts_n$ is kept constant.

## 2. Structure and Theory

### 2.1 Principle of IBRM Signal mixing

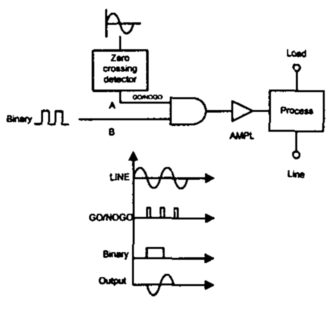



Fig .1. Block diagram of Binary Rate and alternating voltage mixing.

Fig.1 shows that input a receives AC signal when the AC crosses Zero point, the GO pulse permits AC to modulate with binary fed from terminal B of AND gate with the timing that gives output one cycle. After mixing, the waveform of $f_1$ , $f_2$ , $f_3$ , $f_4$ appeared [2], these four independent waveform are linear combined to give the different waveform patterns as in Fig. 2 and equation (1) shows frequency combination

$$f_{2^a} = \sum_{b=0}^{2^a-1}\left[u\left(t-\left(\frac{2^n}{2^{a+1}}-1+b\frac{2^n}{2^a}\right)T\right)-u\left(t-\left(\frac{2^n}{2^{a+1}}+b\frac{2^n}{2^a}\right)T\right)\right]\sin\omega t \qquad (1)$$

u(t) = Unit Step Function
ω = frequency
a = binary bit weight (0 , 1 ,.... N – 1)

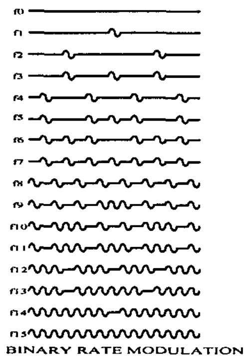



Fig . 2. Binary Rate Modulate on patterns.

The waveform in Fig. 2 are formed from Fig.1, each continuous AC waveform can be represented by equation (2)

$$f = d_3 2^3 + d_2 2^2 + d_1 2^1 + d_0 2^0 \qquad (2)$$

d = binary bit of IBRM pattern

Pulse input energy in each cycle with open time aT and close time bT depends on time constant. The output ripple at temperature stable state can be written as equation (3)

$$\text{Ripple} = K_p \frac{(1-e^{-aT/T_P})(1-e^{-bT/T_P})}{1-e^{-(a+b)\frac{T}{T_P}}} \qquad (3)$$

Where $K_P$ is the dc gain of the plant and $T_P$ the time constant.

## 2.2 Structure of control system

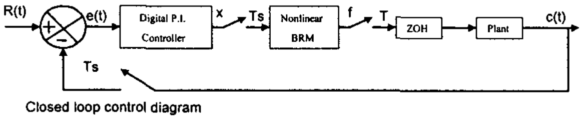



Fig. 3. Block diagram of close loop control.

From Fig.3 given sampling rate of controller $T_s = (2^n - 1)\,T$ and zero order hold (ZOH), an integral part of the plant . To give proper controlling and reduce error, PI is selected from transfer function as shown.

$$\text{Digital PI} \;=\; K_c\left\{\frac{1+(T_s/T_i)-z^{-1}}{1-z^{-1}}\right\} \qquad (4)$$

In Z – domain $K_c$ is a gain , $T_i$ is a reset time. When we consider plant and ZOH, the transfer function of both are

$$G(z) = K_p\,\frac{\left(1-e^{T_s/T_p}\right)}{\left(Z-e^{-T_s/T_p}\right)} \qquad (5)$$

$$\frac{C(z)}{R(z)} = \frac{K_cK_dK_p\{1+T_s/T_i-Z^{-1}\}\frac{(1-e^{-T_s/T_p})}{(Z-e^{-T_s/T_p})}}{1+K_cK_dK_p\left\{\frac{1+T_s/T_i-Z^{-1}}{1-Z^{-1}}\right\}\left(\frac{1-e^{-T_s/T_p}}{Z-e^{-T_s/T_p}}\right)} \qquad (6)$$

$$(z-1)(z-a)+K\,\{z\,(1+T_s/T_i)\}-1 = 0 \qquad (7)$$

Equation (7), R changes step input in order to determine the response that related to transfer function on Z – domain while C (t) and R are equal. To investigate the starting condition we consider equation (7) by given a $=e^{-T_s/T_i}$ and $K = K_c\,K_d\,K_p\,(1-a)$ , and T , $T_p$, $K_p$ $K_d$ are determined from $T_i$. From open loop control the IBRM as in Fig. 2 are obtained. With high gain, the noise reduction and fast response are resulted.

## 2.3 Energy supplied to heater

Heater received the IBRM through drive circuit [3], thus increases in controllable temperature, accurate, fast and stable . It can be considered from Fig.4.

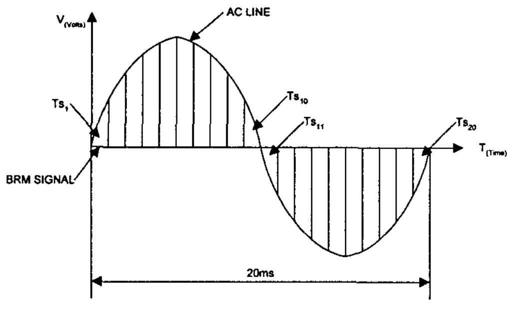
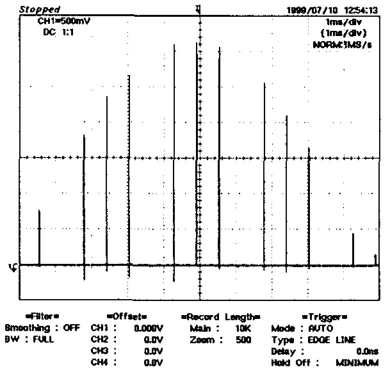
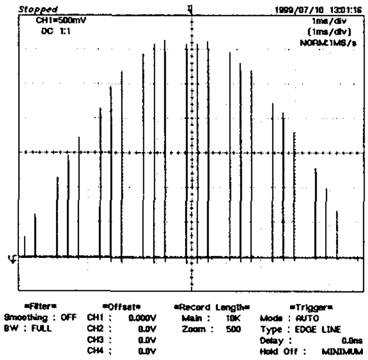



Fig. 4. Energy distribution in one cycle.

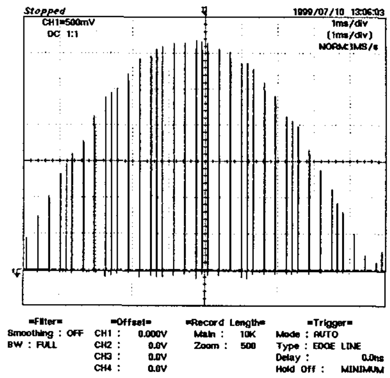
From Fig. 4, one cycle of sine wave is divided into 20 parts, each part is equivalent to 20 millisecond called scan time ($Ts_n$). Part of each waveform that occupied $Ts_n$ is converted into 16 binary bit waveform, Starting from $f_0$ - $f_{15}$. If more energy is required to supply to oven, the energy during $T_{s1}$-$T_{s20}$ is fed to heater accordingly. If 100 percent energy supplied is required it has to supply with $f_{15}$ bit waveform.



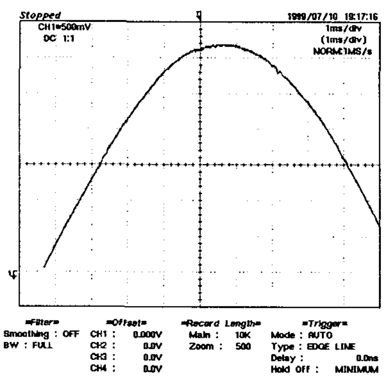
(a) $f_1$ waveform



(b) $f_5$ waveform



(c) $f_{10}$ waveform



(d) $f_{15}$ waveform

Fig. 5. IBRM pattern supplied to oven

In Fig. 5 It is shown only amplitude of positive half – cycle.

### 3. Structure and Design

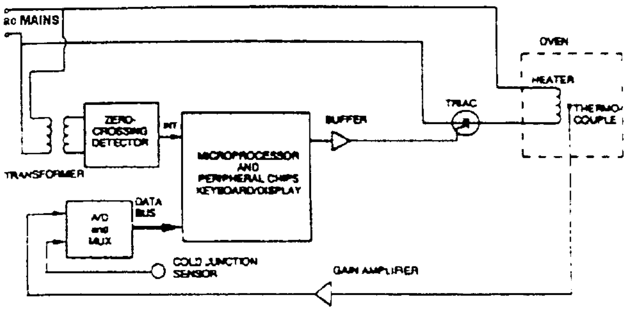



Fig. 6. Hardware System.

From Fig. 6 Hardware consisted of different units, such as microcontroller MCS-51 functions as IBRM bit generator to supply proper bit for heater by PI Algorithm. A/D and Mux circuits convert incoming signal to digital signal and feedback to preset reference. Zero crossing detector transmit to interrupt signal at the trailing edge of the pulse to microcontroller to start generating the IBRM pulse train in each cycle. Driver circuit supplies energy in the form of bit to heater [4]. It is seen that the whole process continues to supply proper and accurate energy to the heater .

### 4. Testing results of open and close loop of oven at 100 °C

The experiment is performed on an oven of the size of width 1 meter, length 1 meter, heater wire 3000 watts, room temperature 25 $^{0}$ C. The draft circulation in an oven keeps temperature at different position equal, by open loop testing, set output at 55% as the results shown in Fig.7 Calculate parameters $K_c$ and $T_i$ by Ziegler Nichols, using $T_1$ = 6.875 minutes ( 2.75 time slot, each equivalent to 2.5 minute) and $L_1$ = 0.625 minute (0.25 time slot ) will give $K_c$ = 9.9 and $T_i$ = 125 seconds .With set point at 100 $^{0}$C, $K_c$ is slightly reduced and $T_i$ slightly increased, finally it comes to balance point which give response time of 15 minutes and percentage over shoot less than 5%. Different parameters given are gain $K_c$ = 9, Integral time ($T_i$ ) = 200 seconds , Delay time (DT ) = 150 seconds. Fig. 8 show the response at set point 100 °C, chart speed 240 mm/hr. (Horizontal axis , each scale = 2.5 minutes ) input from 0 to 5 volts , output from 0 to 200 °C (0 to 100%).

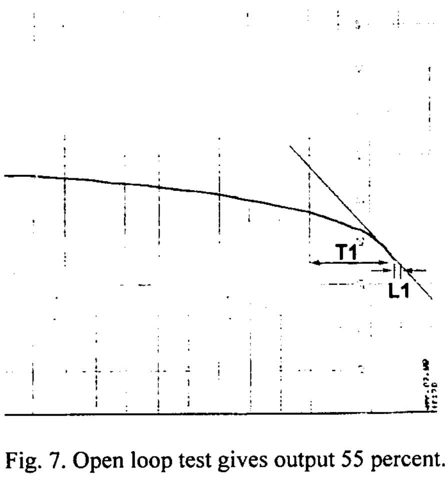



Fig. 7. Open loop test gives output 55 percent.

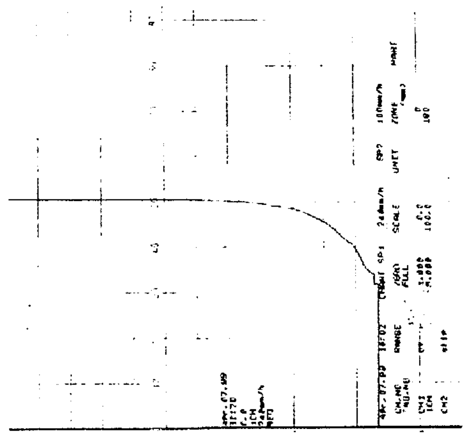


Fig. 8. Close loop test with set point 100 °C (50 percent).

### 5. Conclusions

By mixing ac signal with IBRM to control temperature ranging from 40 °C - 200 °C is very efficient to keep temperature constant. Temperature controlling by means of PI can be able to fix the percentage ripple by keeping the ratio of $T/T_p \leq 1$ . If bit number N is more than 4, high resolution can be obtained including faster response. while $Ts_n$ mainsnchange.This technique concentrates on IBRM , which is considered to be linear and equal heat energy distribution i.e., 187.5 W/bit. The IBRM bit dictates the energy content, which depends on number of bit and clock rate. If we require fast response and energy saving. The energy supplied to heater has to be compared to gain $K_d$ which controlled by PI at that monent such that it can satisfy the required condition.

### References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