MICRO-PROCESSOR BASED TEMPERATURE CONTROLLER ON POWER TRANSISTORS

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Abstract

Radio frequency (RF) signal amplification was considered to solve the power transistor's problems caused by temperature. The goal is to minimize power losses and maximize signal area of coverage. The problems are drift, gain loss and failures in power transistors. This is mainly caused by temperatures exceeding preset design limit. These problems lead to low radio frequency power output and white noise in output signal. Micro-Processor based temperature controller was designed to solve the problem. Experiment was carried out to determine the required air flow rate at a certain ambient temperature and power transistor temperature. Intercooled stata 8.0 software was used and gave characteristic depicting power loss and the regression coefficient (r^2) for the independent and dependent variables. Through the research, design and testing an intelligent temperature controller monitoring both ambient air and power transistors temperature hence realizing the required ambient air flow rate was achieved. This enhanced RF power transistors to increase the power of carrier signals, increase the range of radio waves and suppress noise in the wanted signals.

Keywords: Power loss, Temperature, Drift, Gain Loss, White Noise.

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1. INTRODUCTION

During signal transmission, heat is generated, which leads to an increase in power transistors temperature. This makes the power transistors to be pushed to the saturation point. At high temperatures transistors normally draw more current. This makes them to operate beyond cut off region causing drift, low radio frequency (RF) output power and subjecting the required signals to white/thermal noise.

The research investigated temperature effects on power transistors and tried to enhance better temperature regulation hence power losses minimized and noise signals suppresed.

1.1 Proportional Integral Differential (PID) Control

This controller combines proportional control with two additional adjustments which helps the unit to compensate for the changes. These adjustments, integral and derivative are expressed in time based unit. The proportional, integral and derivative terms must be individually adjusted in a system using trial and error method. The PID controllers perform poorly in some applications and do not in general provide optimal control. The   fundamental difficulty with PID control is that, it is a feedback system, with constant parameters and no direct knowledge of the process. Thus the overall performance is reactive and compromise [1 − 2].

1.2 Heat Sink Temperature Control

A peltier cooling system for solid state operational amplifier reduces the bias current [3]. The sense output which is proportional to the absolute temperature of the amplifier is fed to the temperature control circuitry. The control circuit compares the sensor current with the temperature set point current and the difference is used for the control. However amplifier drift remains a problem to be solved since temperature gradient exists between a semiconductor substrate and the peltier junction [4].

1.3 Broadcast electronics (BE) Transmitter Temperature Control

It's an air cooled suction blowers running at a constant speed. It acts by reducing the RF power output to stabilize the temperature [5].

2. RESEARCH METHOD.

2.1 Design of Temperature Control System

This section dealt with the actual design of the temperature control system. The section was divided into two main parts, namely:

- Hardware development
- Microcontroller software development

The hardware system was important because it did the actual implementation of the desired control. However, the software is what enabled the hardware to do what was required.

2.2 Hardware Development

The hardware development consisted of the design of six blocks of the temperature control system. These parts included:

- The power supply
- The temperature detection system
- The man-to-machine communication interface
- The machine-to-man communication interface
- The cooling system's actuation and control mechanism
- The system control unit

Each of the blocks performed a specific function that contributed to making the entire system work as shown in Figure 2.1.

2.3 System Control Unit

To achieve the entire functional temperature control system, ATmega32 microcontroller, two LM35 precision centigrade temperature sensors, matrix keypad, LCD and LEDs for display and motor were used. The microcontroller is an 8-bit powerful general purpose processor with integrated peripheral features. It minimizes the need to have additional interfaces to get a fully functional control system. For example, the microcontroller comes with an inbuilt 8-channel ADC with a 10-bit resolution. It also has an inbuilt noise canceller making it very immune to noise signals. With the ability to be clocked up to 16MHz, the chip is fast enough and hence allows for temperature control.

The microcontroller also has 14 PWM modes, giving the designer a choice of PWM generation to use. In addition to the PWM channels, there is a multiplexed Input Capture Pin (ICP) which allows the system to capture signals from a tachometer directly and hence enable the system to be able to detect rate of motion of a motor or other devices. Due to availability of 32 multiplexed bidirectional input/output pins, inbuilt EEPROM memory, a large flash memory, internal and external interrupt control channels and inbuilt serial communication channels, ATmega32 was ideal as a single controller of multiple hardware systems, hence the choice [6 – 8].

The complete circuit diagram is shown in Figure 2.1. Figure 2.2 on the other hand shows the assembled unit of the micro-processor based temperature controller.
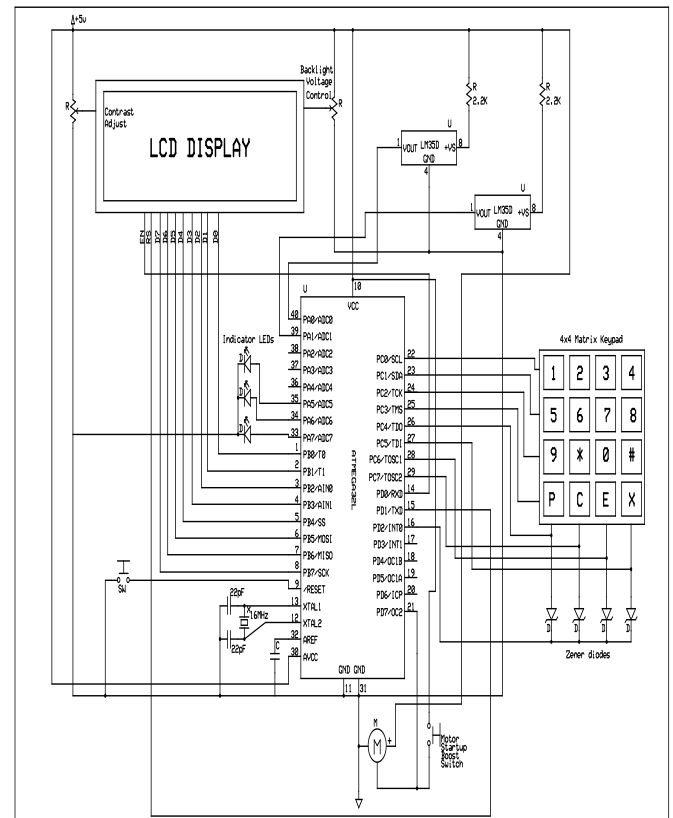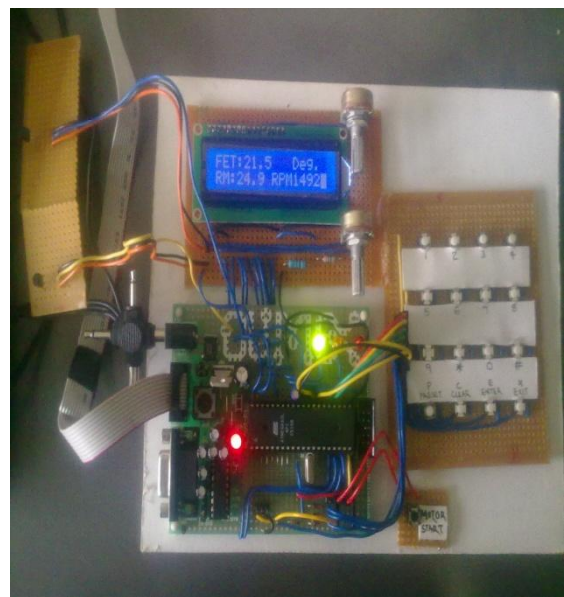

Figure 2.1 Full Circuit Diagram

Fig 2.2 Assembled Microprocessor temperature controller

2.4 Software Development

The temperature control system required control software to run. This was developed using AVRStudio designed for Atmel's microcontrollers. The AVRStudio uses assembly and C programming languages for software development. Hence the software was mainly developed in C but some low-level functionality were developed using Assembly programming language.

The software was developed in a modular manner and consisted of the following main modules

- System initialization code
- ADC control code for sampling temperature readings and calculating the current temperature values
- The keypad logic control code for executing commands based on keypad entries
- The LCD control code for controlling the display, in conjunction with the indicator LED software

The cooling system ON/OFF control system, speed regulation and variation of the ambient air flow rate
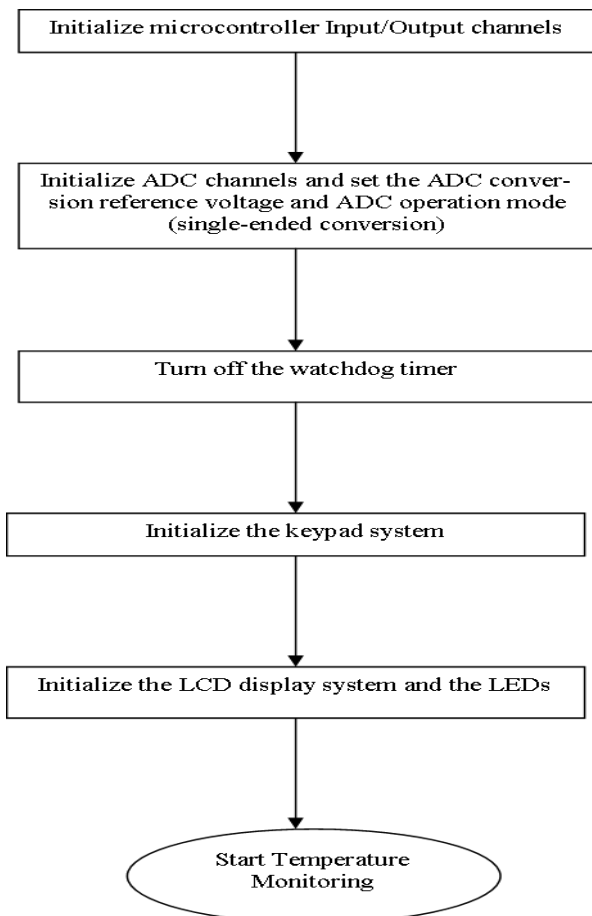To achieve this it was as in the flow charts shown in figures 2.3 to 2.6.
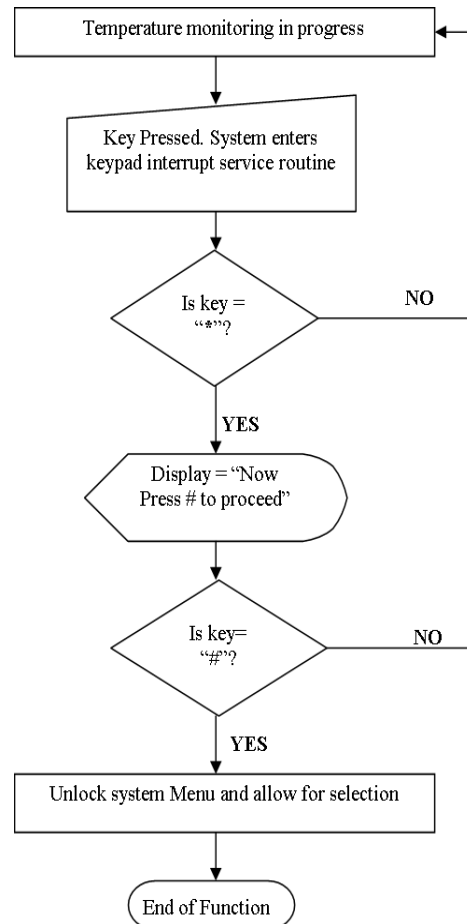

Fig 2.3 System Initialization flow chart

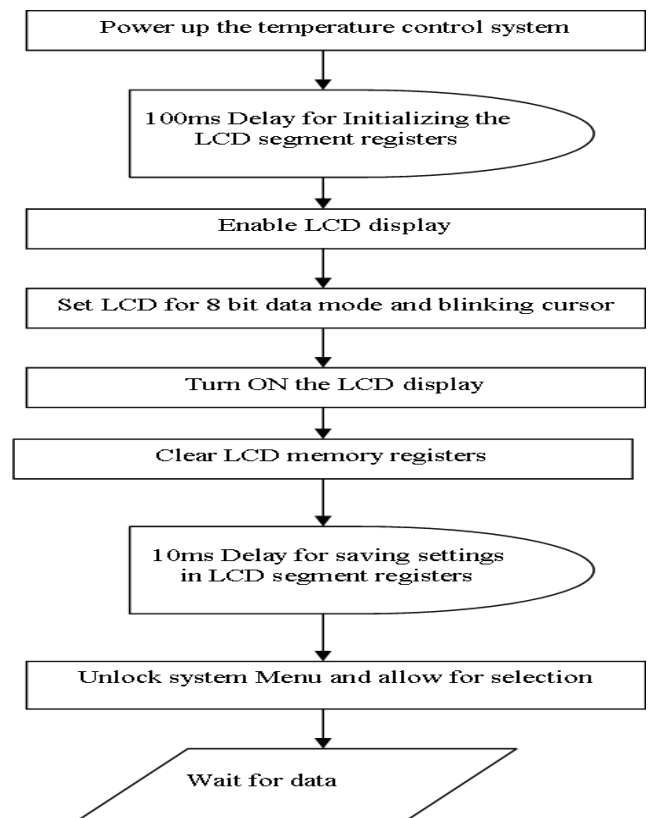**Fig 2.4** Keypad control logic flow chart

Fig 2.5 LCD display control logic flow chart

2.3 Data Presentation

Experiments were carried out and data collected after every half an hour at various power transistors (FET) randomly as shown in the table 2.0.
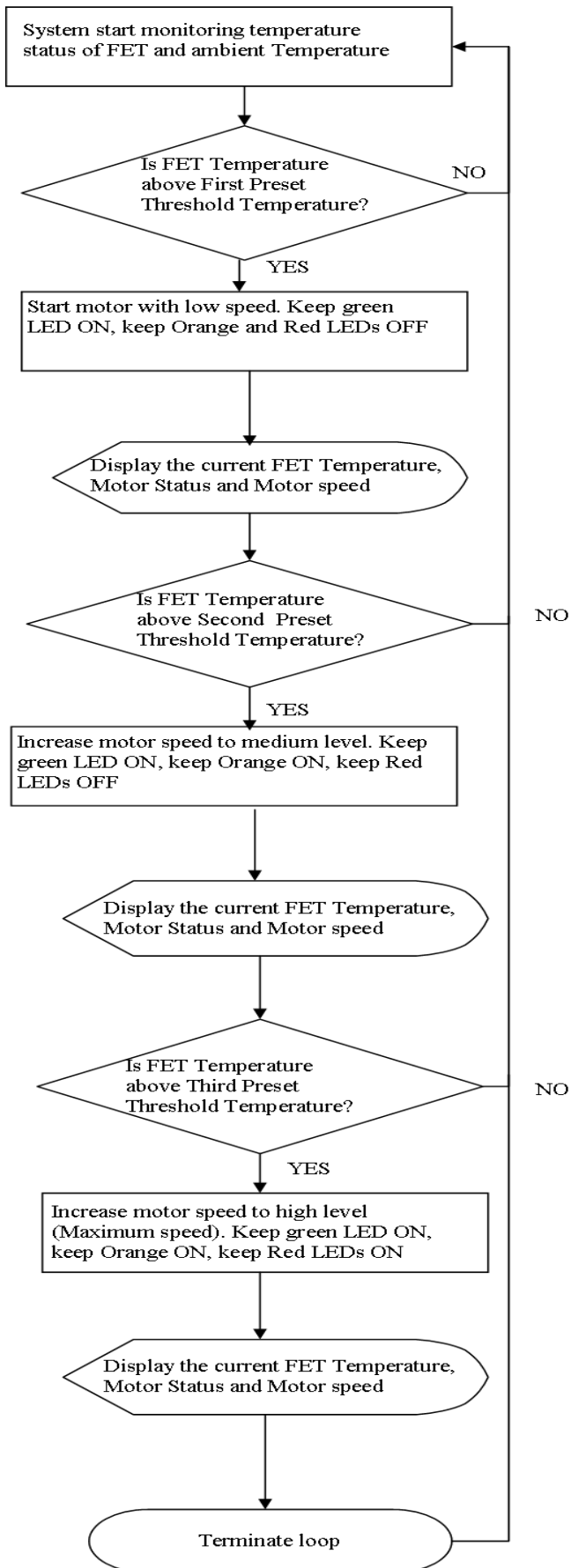
Fig 2.6 Motor speed control flow chart

Table 2: Data Presentation

Ref.	Time of the day	Ambient Temperature		FET Temperature Fan speed Constant	FWD Power (KW) Fan speed Constant	RFL Power (W)	Microprocessor-controlled FET Temperature	Microprocessor-controlled RPM	Microprocessor-controlled Q (m³/s)	FWD power (KW) with microprocessor-controlled FET temperature	RFL power with microprocessor-controlled temperature (KWx10⁻³)
		Thermometer Reading	LM35 Sensor Reading								
1	7.00am	20	20.4	21.2	2.0	2	21.1	1440	55.1232	2.2	2
2	7.30am	22	22.2	25.5	2.0	2	25.4	1700	65.076	2.2	2
3	8.00am	22	22.5	26.4	2.0	2	26.3	1752	67.06656	2.2	2
4	8.30am	22.5	22.8	28.4	2.0	2	27.3	1804	69.05712	2.2	2
5	9.00am	23	23.4	29.5	2.0	2	28.7	1856	71.04768	2.2	2
6	9.30am	23.5	23.8	31.4	2.0	2	30.1	1960	75.0288	2.2	2
7	10.00am	24	24.3	33.6	1.9	2	32.5	2064	79.00992	2.2	2
8	10.30am	25	25.3	36.1	1.85	2	34.9	2168	82.99104	2.2	2
9	11.00am	27	27.4	40.2	1.8	2	37.8	2324	88.96272	2.1	2
10	11.30am	27	27.3	42.3	1.7	2	39.7	2436	93.25008	2.1	2
11	12.00pm	27	27.4	45.6	1.65	2	41.6	2532	96.92496	2.0	2
12	12.30pm	26.5	26.8	46.4	1.60	2	43.1	2636	100.90608	2.0	2
13	1.00pm	25	25.3	44.6	1.65	2	42.1	2584	98.91552	2.0	2
14	1.30pm	25	25.3	44	1.65	2	41.6	2532	96.92496	2.0	2
15	2.00pm	24.5	24.9	42.8	1.7	2	39.2	2428	92.94384	2.1	2
16	2.30pm	24.5	24.8	39.9	1.75	2	37.3	2324	88.96272	2.1	2
17	3.00pm	24.5	24.8	38.9	1.75	2	35.9	2220	84.9816	2.1	2
18	3.30pm	24	24.4	36.5	1.8	2	34.9	2168	82.99104	2.1	2
19	4.00pm	24	24.3	33.2	1.8	2	32.1	2064	79.00992	2.2	2
20	4.30pm	24	24.3	31.7	1.85	2	30.6	1960	75.0288	2.2	2
21	5.00pm	23.5	23.7	30.2	1.85	2	29.7	1908	73.03824	2.2	2
22	5.30pm	23	23.4	28.8	1.9	2	28.2	1856	71.04768	2.2	2
23	6.00pm	22.5	22.9	27.3	1.9	2	26.8	1752	67.06656	2.2	2
24	6.30pm	22.5	22.8	26.1	2.0	2	25.8	1700	65.076	2.2	2
25	7.00pm	22	22.4	25.3	2.0	2	24.9	1648	63.08544	2.2	2
26	7.30pm	21.5	21.8	23.8	2.0	2	23.4	1596	61.09488	2.2	2

3. RESULTS AND DISCUSSION

The experiment was done on different combinations in regard to the forward power. Measurements were carried out and gave the characteristics as shown in figures 3.0 to 3.2
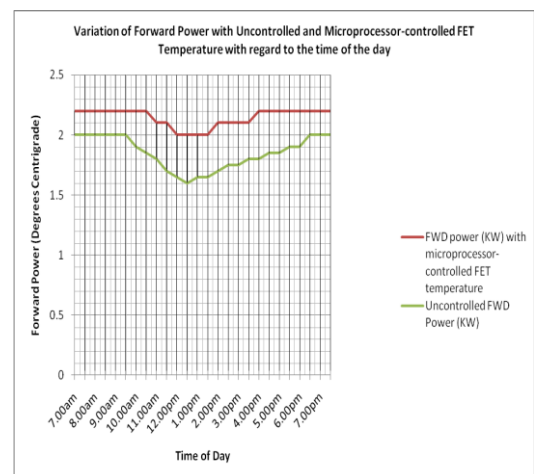

Fig 3.0: Variation of forward power with uncontrolled and microprocessor-controlled FET temperature with regard to the time of the day

It is clear from Figure 3.0 that the microprocessor-controlled FET temperature has a lower recovery time and higher forward power compared to when the FET temperature is controlled unintelligently.

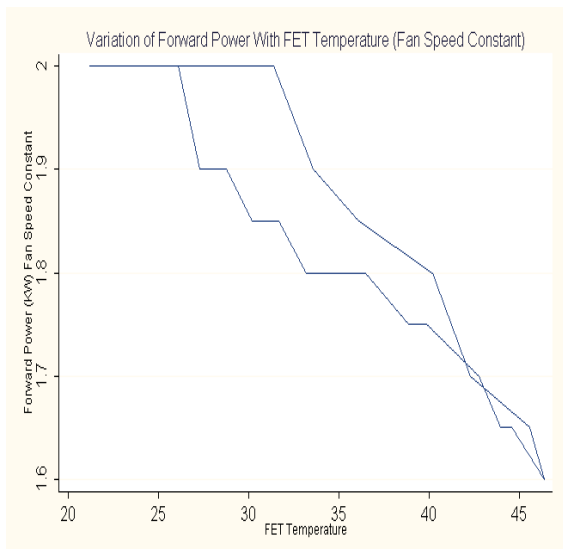Using Intercooled STATA 8.0, the characteristics depicting the power loss were as shown in Figure 3.1and 3.2 [9].

Fig 3.1: Variation of forward power with FET temperature (Fan speed constant)

The calculated total area of the Figure 3.1 is 13.32775 cm^2. Relating the power loss to the area of the Figure 3.1 in regard to temperature change,

$$P_1 = \frac{Area}{Q_2 - Q_1}$$

Where P_1 is power, Q_1 is the lower temperature, and Q_2 is the upper (maximum) temperature measured.

Hence

$$P_1 = \frac{13.32775}{46.4 - 21.2}$$
$$P_1 = 0.5289 \, cm^2 / °C$$

Hence percentage loss of power is 52.89% (in this part, note that the Y axis has units in kW so that $P_1 = 0.5289$ KW/ °C)
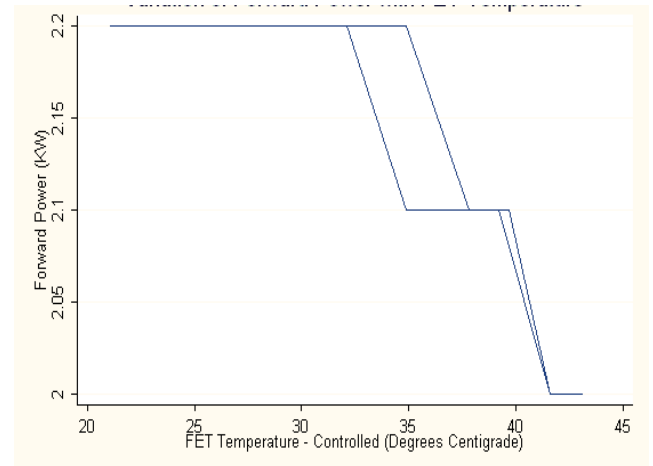

Fig 3.2: Variation of forward power with auto-controlled FET temperature

The calculated total area of the Figure 3.2 is 5.58cm^2. Relating the power loss to the area of the Figure 3.2 in regard to temperature change

$$P_1 = \frac{Area}{Q_2 - Q_1}$$

Where P_1 is power, Q_1 is the lower temperature, and Q_2 is the upper (maximum) temperature measured.
Hence

$$P_1 = \frac{5.58}{43.1 - 21.1}$$
$$P_1 = 0.2536 \, cm^2 / °C$$

Hence percentage loss of power is 25.36%, giving a loss of 0. 254 KW/ °C of temperature rise. From the analysis above, it is clearly shown that the microprocessor-controlled FET temperature contributed much in maintaining the output power of the transmitter as compared to the unintelligent controlled FET temperature. The ratio between P_1 and P_2 is 2.08. Hence the microprocessor controlled temperature was a factor of 2 better in stabilizing output power than the fan alone. It's also clearly shown that the power recovery time is less.

3.1 Validity of the System

Validity test was conducted to ascertain the significance of the collected data in regard to the dependent and independent variables in maintaining the RF output power and signal quality.

This involved:
  i. The validity of monitoring ambient air temperature and power transistors temperature.
  ii. The ability of auto varying the motor speed hence varying the ambient flow rate according to the prevailing temperature.

iii. The ability of the system to record data within 5 seconds and display it on the LCD in a readable form.

Hence regression analysis was done on the variables using the Least Square method to get the best fit straight line with the data from Table 3.0[10].

Table 3.0 regression analysis

Microprocessor-controlled FET Temperature (x)	Squared value of Microprocessor-controlled FET Temperature (x^2)	Microprocessor-controlled Q (m³/s) (y)	Squared value of Microprocessor-controlled Q (y^2)	xy
21.1	445.21	55.1232	3038.5672	1163.0995
25.4	645.16	65.076	4234.8858	1652.9304
26.3	691.69	67.06656	4497.9235	1763.8505
27.3	745.29	69.05712	4768.8858	1885.2594
28.7	823.69	71.04768	5047.7728	2039.0684
30.1	906.01	75.0288	5629.3208	2258.3669
32.5	1056.25	79.00992	6242.5675	2567.8224
34.9	1218.01	82.99104	6887.5127	2896.3873
37.8	1428.84	88.96272	7914.3656	3362.7908
39.7	1576.09	93.25008	8695.5774	3702.0282
41.6	1730.56	96.92496	9394.4479	4032.0783
43.1	1857.61	100.90608	10182.037	4349.0521
42.1	1772.41	98.91552	9784.2801	4164.3434
41.6	1730.56	96.92496	9394.4479	4032.0783
39.2	1536.64	92.94384	8638.5574	3643.3985

$\sum x = 511.4$	$\sum x^2 = 18164.02$	$\sum y = 1233.2285$	$\sum y^2 = 104351.1493$	$\sum xy = 43512.5545$

The regression equation is $y = a_0 + a_1 x$

Evaluating for the regression equation

$$S_{xx} = \sum x^2 - \frac{\left(\sum x\right)^2}{n} = 18164.02 - \frac{(511.4)^2}{15}$$
$$= 728.6893$$

$$S_{yy} = \sum y^2 - \frac{\left(\sum y\right)^2}{n} = 104351.1493 - \frac{(1233.2285)^2}{15}$$
$$= 2960.9837$$

$$S_{xy} = \sum xy - \frac{\sum x \sum y}{n} = 43512.5545 - \frac{511.4 \times 1233.2285}{15}$$
$$= 1467.6848$$

$$a_1 = \frac{S_{xy}}{S_{xx}} = \frac{1467.6848}{728.6893} = 2.0141$$

$$\bar{y} = \frac{1233.2285}{15} = 82.2152$$

$$\bar{x} = \frac{511.4}{15} = 34.0933$$

$$a_0 = \bar{y} - a_1 \bar{x}$$
$$= 82.2152 - (2.0141 \times 34.0933)$$
$$= 13.5479$$
$$= 13.55$$

Thus the regression coefficient r^2 is as shown

$$r^2 = \frac{S_{xy}^2}{S_{xx} \times S_{yy}} = \frac{1467.6848^2}{728.6893 \times 2960.9837}$$
$$= 0.998360$$

Hence, evaluating the value of y using the equation

$$y = a_0 + a_1 x$$

$$y_1 = 13.55 + (2.01 \times 21.1) = 55.96 = 56$$

Using the formula for y, the rest are;

y_1=56	y_9=90
y_2=65	y_{10}=93
$y3$=66	y_{11}=97
y_4=68	y_{12}=100
y_5=71	y_{13}=98
y_6=74	y_{14}=97
y_7=79	y_{15}=92
y_8=84	

Evaluating for the regression equation yields a regression coefficient of r^2=0.998360

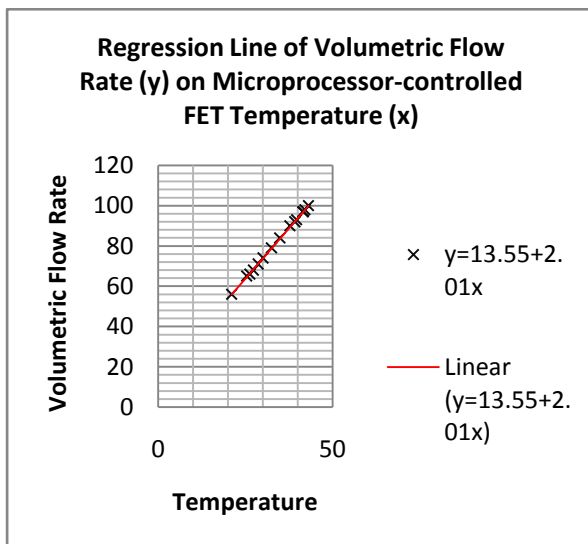Figure 3.3 shows the regression line depicting the FET temperature and flow rate relationship.

Fig 3.3: Regression Line of Volumetric Flow Rate (Y) on Microprocessor-controlled FET temperature (x)

From the graph (Figure 3.3), a change in Temperature produces a change in volumetric flow rate i.e., increased flow rate, showing that the microprocessor responded positively to increase in temperature.

3.2 Discussion

From the analysis, it is clearly shown that, the microprocessor controlled power transistors (field effect transistors – FET) temperature, contributed much in maintaining the radio frequency output power as compared to the unintelligent power transistor temperature controller. The ratio between P_1 and P_2 referring to figures 3.1 and 3.2 is 2.08. Hence the microprocessor controlled temperature was by a factor of 2 better in stabilizing the RF output power than the fan running at a constant speed. This meant high strength of the carrier frequency. Thus improved signal to noise ratio was achieved, leading to a high quality signal.

Referring to figure 3.0, the microprocessor controller minimised the RF output power fluctuations as compared to the fan running at constant speed.. This led to maintaining the range of radio waves thus better signal coverage.

Temperature being fully controlled indicates that, power transistors are not pushed to conduct at the saturation region or beyond the cut off region. This means an increased lifespan of the power transistors, hence minimal cost of running a transmitter.

Using the least square method analysis, gave a regression coefficient (r^2) of 0.99836. This showed the positive relationship between the FET temperature and ambient air flow rate. Thus much of the variation in temperature can be controlled by the volumetric flow rate as it caters for 99% of the variations.

4. CONCLUSIONS

The FET microprocessor temperature controller increased the effectiveness of the transmitter by stabilizing the Forward Power. This is because there is minimal reduction of radio frequency power and smaller recovery time in response to temperature changes. This indicates that by use of the microcontroller-based temperature controller, there is increased signal coverage and better quality signal is achieved since signal amplitude is well maintained and noise suppressed.

Energy saving is also achieved, since the intelligent temperature controller reduces power consumption at low temperatures and increases consumption at high temperatures to enhance temperature regulation.

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