

# A Wireless Addressing Circuitry for Microthruster Array

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## Abstract

The microspacecraft is one of the applications of microsystems technology in space field. The micropropulsion system is indispensable in microspacecraft. The solid propellant microthruster is a new class of micropropulsion system, which presents many merits over other micropropulsion systems. The solid propellant microthruster array is necessary to produce the controlled, vectored thrust. Realization of addressing ability and wireless communication is the key to the development of the microthruster array. Therefore, a prototype wireless addressing circuitry is developed to realize the addressing of the microthruster array by multiplexing system, to measure the igniter temperature variation with time by measuring the igniter resistance change, and to achieve automatic control by RS232 and RF wireless communications. Operation principle, design, fabrication, and testing of the circuitry are presented. Measurement results using the circuitry both for the silicon solid propellant microthruster and the ceramic solid propellant microthruster are also included in this paper.

*Keywords: Wireless, Addressing, Circuitry, Microthruster, Array*

## 1 INTRODUCTION

The state-of-the-art microspacecraft is one of the applications of microsystems technology in space field. The versatile clusters of microspacecraft have more merits than a single large conventional spacecraft in fabrication, launch and operation. The micropropulsion system is indispensable in microspacecraft for attitude control, station keeping and orbit adjust. The solid propellant microthruster is a relatively new class of micropropulsion system, which is an active research field because it presents many advantages over other microthrusters such as reduced system complexity, no moving parts and very low propellant leakage possibility [1-6]. As stated in Refs. [1-6], a microthruster array is very important to partially compensate for the lack of restart ability of single solid propellant microthrusters, to produce the controlled, vectored thrust and impulse. Realization of addressing ability and wireless communication is the key to the development of a microthruster array. However, very little investigation on integrated wireless addressing circuitry is carried out for the microthruster array. In this paper, a prototype wireless addressing circuitry is developed for the microthruster arrays developed in Refs. [5-6] to realize addressing, ignition control, RS232 and RF wireless communications.

## 2 DESIGN OF THE CIRCUITRY

The main functions of the designed circuitry are as follows: to realize addressing of the microthruster array; to measure the transient temperature variation of the igniter so as to control the ignition process; and to control the microthruster system both via RS232 and RF wireless communications. The addressing is achieved by

multiplexing. The experimental temperature is obtained by measuring the electrical resistance change of the igniter. This has been shown to be an accurate method to obtain the transient temperature of micro-scale heaters [7]. The electrical resistance change is caused by the heating process when a voltage is applied. The experimental calibration law between the igniter electrical resistance and temperature is needed to extract the actual temperature of the igniter. A programmable voltage source is designed in the circuitry to analyze wide range of voltage values. The schematic of the circuitry is shown in Figure 1.

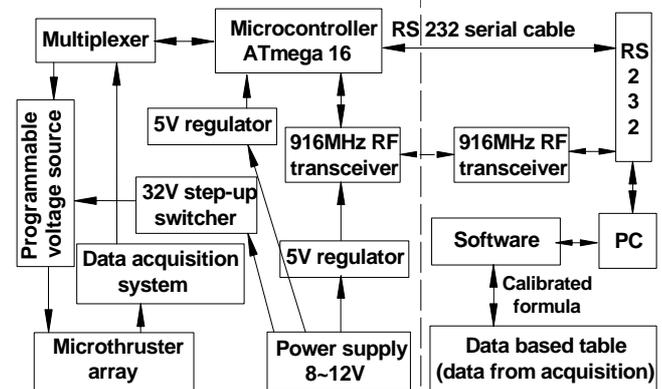


Figure 1. Schematic of the wireless addressing circuitry

Power supply is designed to accept 8-12 V DC (battery or adaptor). One part of the power supply is regulated to 5 V by a positive voltage regulator (LM7805) for the operation of microcontroller and other ICs. The other part is boosted to a maximum of 31.2 V by a boost switching converter (LM2577), supplying the collector of transistors and operational amplifier (Op-Amp) (LM124). Signals from serial RS232 are leveled to standard TTL 5V by a multi-channel RS232 driver/receiver (MAX232) for the

microcontroller. Communication of this signal is at TX/RX of 4800 bps.

The Atmel ATmega 16 microcontroller operates using the internal 1 MHz RC clock. Data received from the PC are fed to all DAC chips at the same time, thus enabling the addressing of the correct chip for ignition. When the data are converted into analog voltages, typically 0-2.2 V, Op-Amp and NPN transistor are employed to boost the voltage output so as to obtain sufficient power to drive the igniter. The power amplification principle is shown in Figure 2.

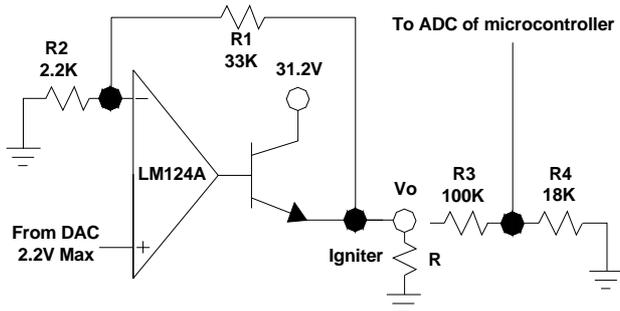


Figure 2. Principle of power amplification

ATmega 16 microcontroller comes with an 8 channel 10 bits ADC. Voltage is measured across a 0.5 ohm 1 % tolerance resistor in series with the igniter and is converted into digital data by ADC. It is used to calculate the current flow through the igniter. The current data information is sent back to PC for further manipulation. The change in the igniter resistance is calculated using  $R = V / I$ . The transient temperature of the igniter is then obtained using the formula derived from the calibration law. LINX SC-S 916 MHz transceivers are employed both on the circuit board and PC for wireless communication. They provide a transparent wireless serial data communication between two equipments up to 33.6 kbps. The system works on half duplex mode with wireless communication at current design.

### 3 FABRICATION OF THE CIRCUITRY

A double-side printed circuit board (PCB) for the circuitry is designed and fabricated. The electronic components including microcontroller, DAC chips, power supply connector, battery, RS232 ports, Op-Amp chips, step-up switcher, voltage regulators, RF transceiver chips, antennas, and microthrustor arrays are soldered manually onto the PCB. The fabricated electronic circuitry is shown in Figure 3. The silicon-based and ceramic-based microthrustor arrays developed in Refs. [5-6] are installed onto the circuitry for testing as shown in Figures 4 and 5, respectively.

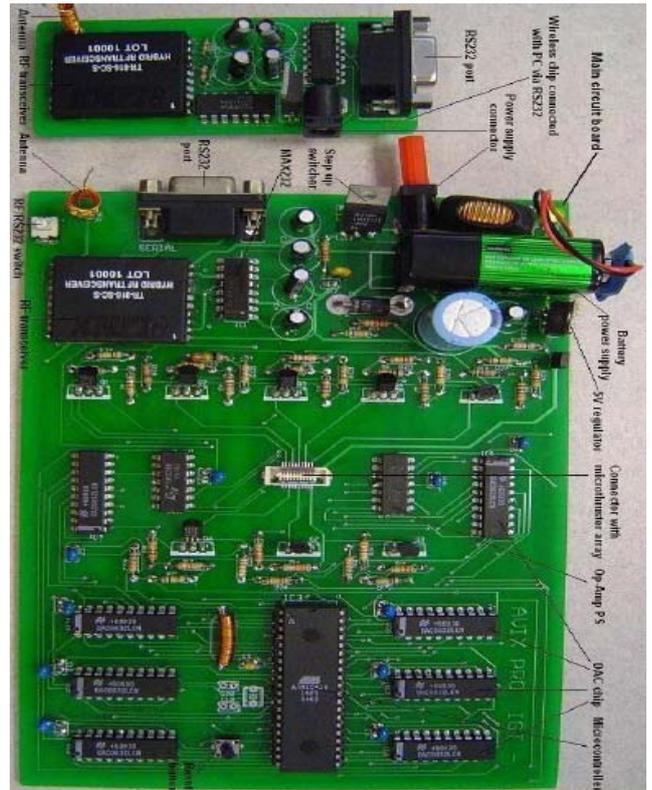


Figure 3. Fabricated wireless addressing circuitry

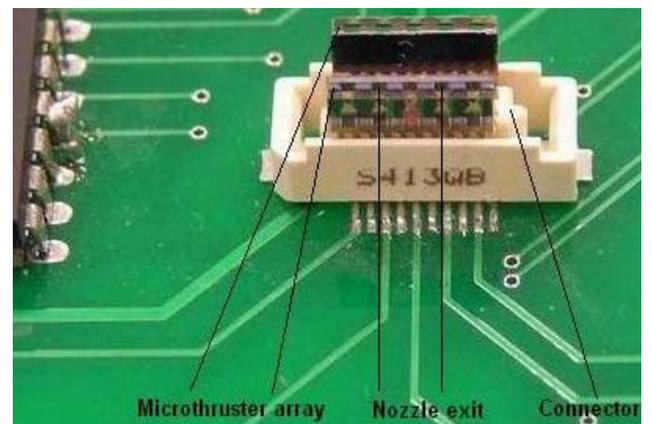


Figure 4. Silicon microthrustor array on the circuitry

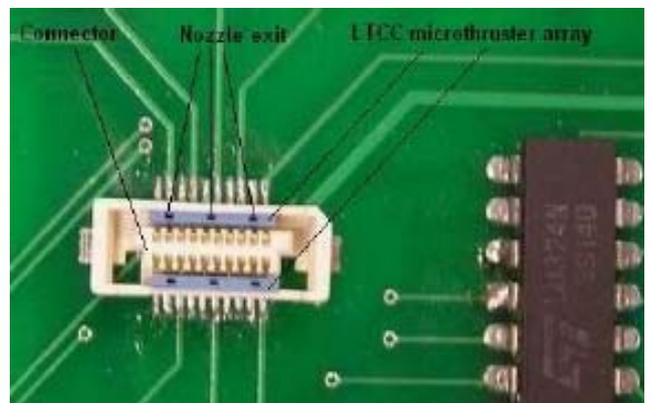


Figure 5. Ceramic microthrustor array on the circuitry

## 4 EXPERIMENTAL TESTING

### 4.1 Experimental Testing of the Au/Ti Igniter of the Silicon Microthruster

The circuitry is utilized here to measure experimentally the transient temperature of the Au/Ti igniter of the silicon-based microthruster developed in Ref. [5].

#### 4.1.1 Resistance vs. Temperature Calibration

A key issue for achieving meaningful temperature measurements is careful resistance vs. temperature calibration of the Au/Ti igniter. Because conventional printed circuit boards are not suitable for high temperature application, a silicon chip with a silicon dioxide insulation layer and Au contact pads is selected to hold the microthruster with Au/Ti igniter. The small Au contact pads of the microthruster are connected to the Au contact pads in the silicon layer using a thin Au wire by ultrasonic wire bonding. Then the Au contact pads in the silicon layer are attached to flexible wires using a high-temperature solder. The microthruster installed on the silicon chip is placed into a Carbolite 1200 burn-off furnace. The furnace temperature and the igniter resistance are simultaneously measured using an Agilent 34970A data acquisition unit. The furnace temperature is gradually increased and measured by taking the average readings of two type-K thermocouples mounted very close to the microthruster. The resistance of the igniter is measured using a four-wire technique to improve resistance measurement accuracy. The furnace temperature is increased in small steps and held at a constant level after each step until the temperature of the furnace and the resistance of the igniter are stabilized. The final calibration law of resistance vs. temperature deduced from the experiment is given by,

$$R = -0.0001T^2 + 0.1614T + 346.32$$

where  $T$  is the Au/Ti igniter average temperature and  $R$  is the resistance of the igniter.

#### 4.1.2 Igniter Temperature Variation with Time

For more accurate measurement and higher data acquisition rate, an Agilent 34970A data acquisition unit with a 34901A plug-in module is connected to the circuitry to measure the small current change with a scan rate of 3 ms. Because the internal resistance of the amperemeter in 34901A is very small (0.5 ohm) compared to the resistance of the thin film Au/Ti igniter (in the range of 300 ohm), the current measurement error caused by the series resistance can be neglected. The measurement is performed only for low voltage values to avoid the propellant combustion. The current change with a voltage input of 8 V is measured for the microthruster with Au/Ti igniter as shown in Figure 6. The calculated igniter resistance change is also shown in Figure 6.

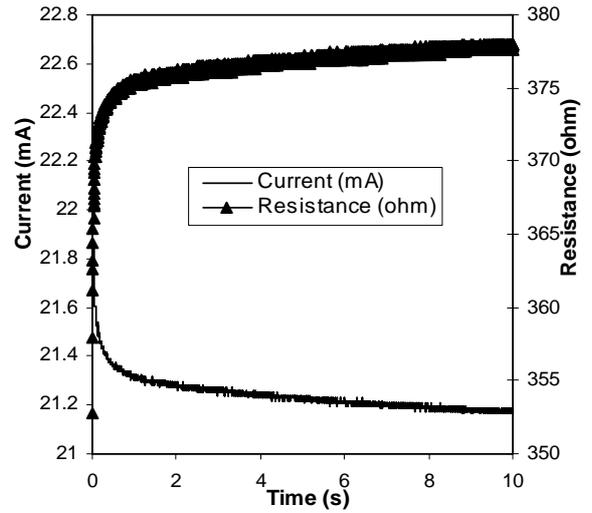


Figure 6. Current and resistance variations with time

Accordingly, the igniter average temperature variation with a voltage input of 8 V is deduced from the calibration law and is shown in Figure 7. The curve indicates that the average temperature increases quickly at the early stage of voltage supply but increases slowly after around 1 s. This is because of the equilibrium between heat generation by Joule effect and heat loss by conduction. As can be seen, the variation in temperature follows a logarithmic trend with a curve fit of  $T = 11.591Ln(t) + 197.89$ .

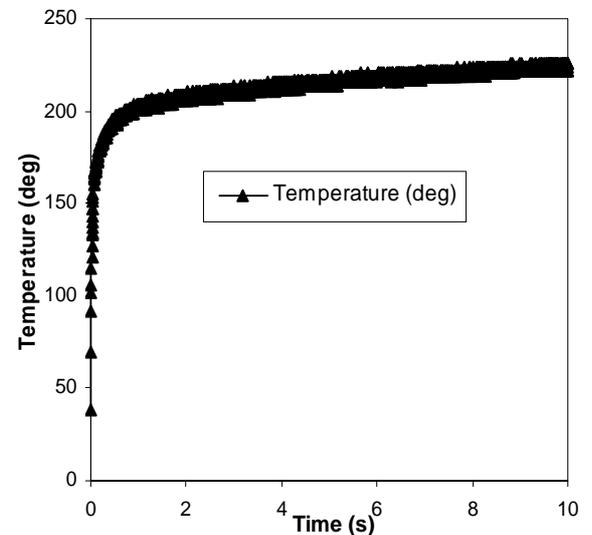


Figure 7. Au/Ti igniter temperature variation with time

### 4.2 Experimental Testing of the Ceramic Thin Film Igniter of the LTCC Microthruster

Employing the similar method described in Section 4.1, the temperature variation of the ceramic thin film igniter of the Low Temperature Co-fired Ceramic (LTCC) microthruster developed in Ref. [6] is measured experimentally. Figure 8 shows the measured current change at an input voltage of 30 V without the propellant. It also shows the calculated resistance versus time of the thin film igniter.

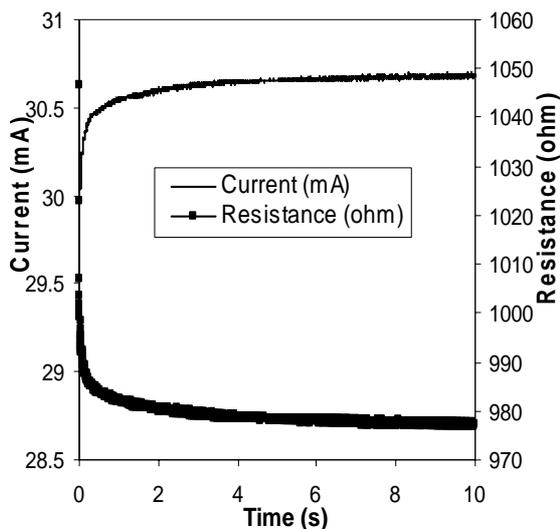


Figure 8. Current and resistance variations with time

Consequently, the ceramic igniter average temperature variation with a voltage input of 30 V without the propellant is deduced from its calibration law and is shown in Figure 9. The ceramic igniter temperature increases rapidly upon the application of the voltage and reaches a steady-state level after about 2 s. This is caused by the equilibrium of the heat generation by the Joule effect and the heat loss because of conduction.

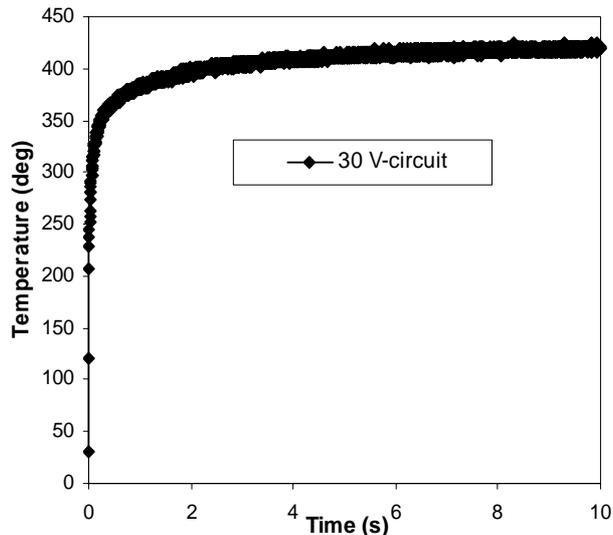


Figure 9. Ceramic igniter temperature variation with time

## 5 CONCLUSION

A prototype wireless addressing circuitry is designed and fabricated to realize the addressing of individual microthrusters in the microthruster array by multiplexing system, to measure the igniter temperature variation with time by measuring the igniter resistance change, and to achieve automatic control by RS232 and RF wireless communications. Using the programmable voltage source in the circuitry, the igniter temperature can be accurately controlled by 8 bit voltage levels (256 different levels).

The RF wireless communication and 9 V battery power supply enable the circuitry to be very suitable for mobility. The 10 bit ADC feedback loop circuitry can monitor real-time status of each igniter in the microthruster array and allows each igniter to be functionally controlled. Utilizing the circuitry, the temperature variations with time of the silicon-based microthruster Au/Ti igniter and the ceramic-based LTCC microthruster thin film igniter are measured experimentally.

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