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SHORT COMMUNICATION
An Inexpensive Diffusion Furnace

M.R. HASKARD and J. BANNIGAN
School of Electronic Engineering, South Australian Institute of Technology

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The paper describes the design of a low cost diffusion furnace suitable for monolythic circuit manufacture in educational and other establishments, where throughput is small. Features include maximum temperature of 1300° C, direct reading set temperature dial, flat zone 55 mm and an idle temperature of 420° C when the furnace is not in use.

Four such furnaces have been in operation at the School of Electronic Engineering, South Australian Institute of Technology, each for a twelve month period and have given trouble free operation.

1. INTRODUCTION

An essential item in the practical teaching of monolythic integrated circuit manufacture is the diffusion surface. Since a number are required (for example N doping, P doping, oxidisation and alloying), teaching institutions cannot always afford the larger three zone furnaces manufactured for the industry.

The School of Electronic Engineering at the South Australian Institute of Technology undertook to design and produce a bank of four diffusion furnaces for their Microelectronic Laboratory. This paper summarises the design and results in characterising these furnaces. It is presented in four main sections namely, furnace selection, electronic controller, final construction and performance.

2. FURNACE SELECTION

In view of our previous successful experience in constructing a belt furnace for thick film production,[1] it was decided to construct our own diffusion furnace using a commercial furnace tube. Several types are available enabling a choice to be made based on the following considerations.

a) Single or three zone furnace. Since only a few wafers would be processed at any time the small flat zone provided by a single zone furnace would be adequate. Further, three zone furnaces cost more and require additional control hardware.

b) Mains or low voltage operation. Experience gained in the operation of furnaces indicated that at elevated temperatures the life of a mains operated heating element was shorter than the more robust lower voltage element. For this reason a low voltage unit was selected even though there was the additional cost of a step down transformer.

c) Temperature range. For processing silicon wafers temperatures in the range of 500 to 1250°C are necessary. The minimum requirement for the furnace was one that could operate to 1300°C.

d) Tube diameter. Processing in the Microelectronics Laboratory is based on using quarters of 50 mm diameter wafers. Thus the furnace must accommodate these quarter wafers standing in a quartz boat. An inner diameter quartz tube of 50 mm would be adequate so an inner furnace tube diameter of 60 mm or so is necessary.

The furnace selected was a Heraus RoK/F7/60. Details of this furnace are given in Table I.

3. ELECTRONIC CONTROLLER

Specifications drawn up for the overall system are shown in Table II while Figure 1 gives in block diagram form the final system. The controller consists of three sections; thermocouple amplifier, controller and associated SCR^S, and power supply.

The thermocouple amplifier (Figure 2) includes a cold junction compensating diode and voltage to

TABLE I
Heraus RoK/F7/60 furnace details

Rated temperature	1300° C
Internal diameter tube	70 mm
Heated length	500 mm
Rated voltage of furnace	48 volt
Rated power	2.10 kW
Net weight	25 kgrams

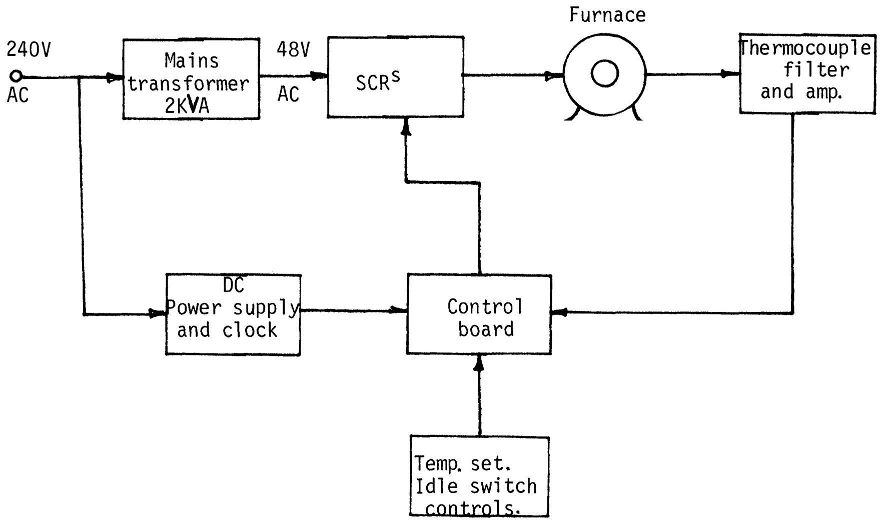

FIGURE 1 Diffusion furnace system.

TABLE II
Systems specification

Temperature range 400 to 1250°C
Accuracy at thermocouple point ± 1°C cycling error
Single control to preset temperature, presetable to within 5°C
Minimum time to heat up and stabilize, preferably less than 2 hrs
Idle temperature setting facilities
System to be simple, self contained and operable by students

current converter having zero and span adjustments. A considerable amount of filtering had to be included on the amplifier (input, output and internal filtering pin), for at elevated temperatures it was found that a 50 Hz induced common mode signal upset the operation. The thermocouple amplifier is mounted close to the furnace thermocouple as it requires only two wires to connect it to the control section. This is a useful characteristic of the integrated circuit, type LH0045CG, employed.

The control circuit shown in Figure 3 consists of a stable reference voltage (type LM399), ten turn temperature setting potentiometer, zero crossover triac control integrated circuit and instead of a triac two silicon controlled rectifiers back to back. For large temperature errors the control unit functions in an on/off mode thereby giving the maximum rate of heat up. For small temperature errors it operates in a proportional mode to reduce overshoot; the combined effect is to minimize the time for the furnace to heat up and stabilize at the set temperature. The proportional control is achieved by superimposing on the reference a one second period sawtooth waveform.

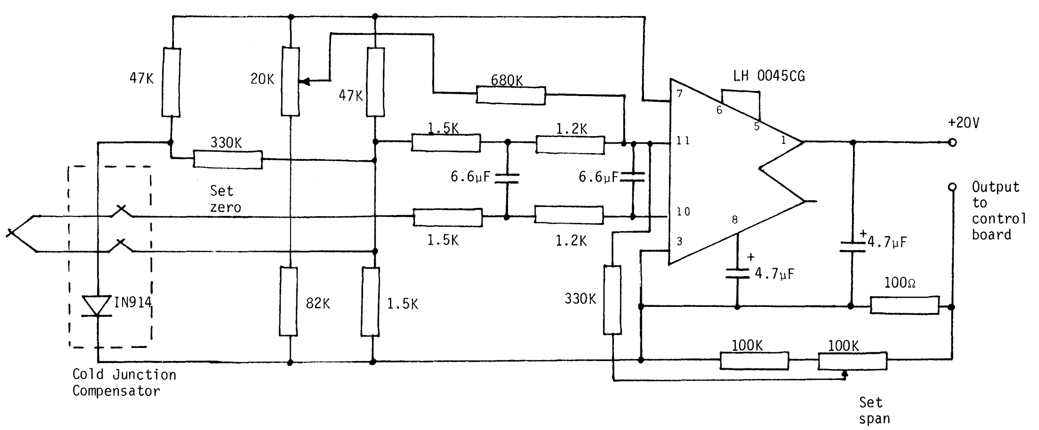

FIGURE 2 Thermocouple amplifier

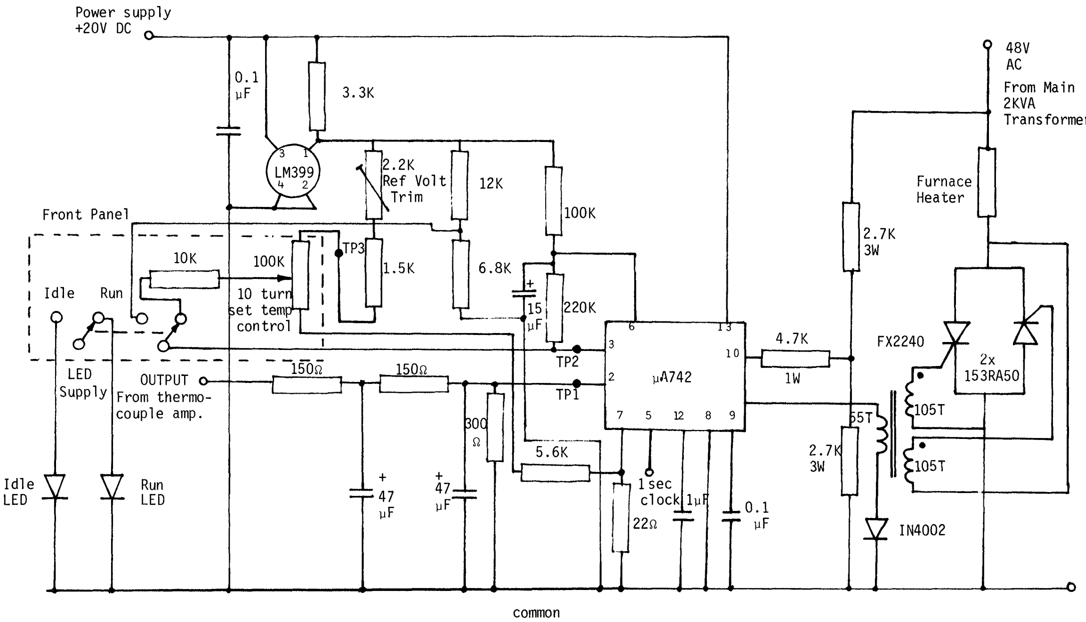

FIGURE 3 Control board and SCRs.

Initially the silicon controlled rectifiers were connected on the earth side of the transformer secondary with the furnace winding connected to the 48 volts AC active line. This resulted in a 50 Hz signal being capacity coupled into the thermocouple when the silicon controlled rectifiers were off, causing the rectifiers to fire erroneously. Reversing the position of the furnace winding and silicon controlled rectifiers overcame this problem, but resulted in an increased inductive pick up signal in the thermocouple wire when the silicon controlled rectifiers conducted. This pick up, as already mentioned, increased with increasing temperature and became troublesome at temperatures in excess of 1000°C. Hence the heavy filtering.

All of the trim potentiometers, reference voltage preset, zero and span, must be of high quality and be multiturn types. The set temperature potentiometer has a standard 10 turn dial offset so that it reads from 300 to 1300 thereby giving a direct temperature reading in degrees Celsius.

Literature[2,3] suggests that with quartz tubes there is a temperature below which the tubes recrystallize and eventually fracture. This process is speeded up if dopants are present. Since the furnaces would be used

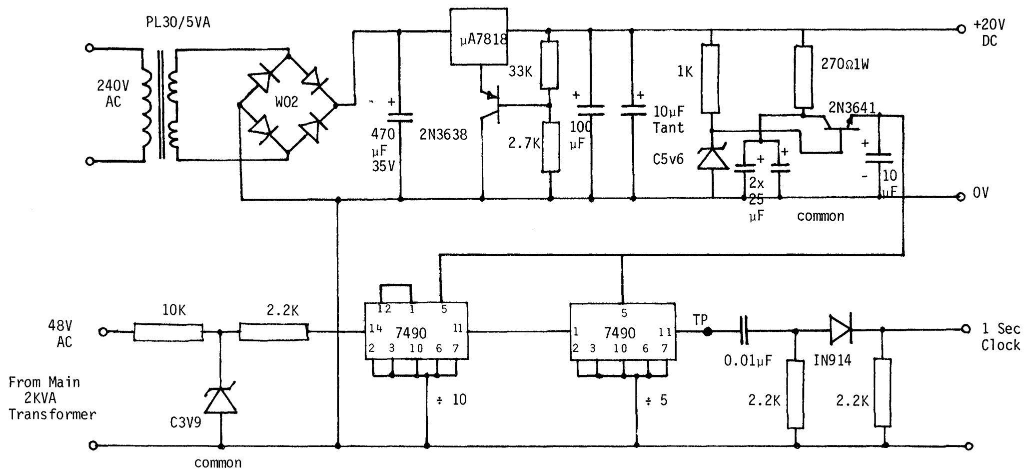

FIGURE 4 Power supply and clock.

only for short durations, depending on class times, a switch was incorporated so that the furnace could be switched to a safe idle temperature of approximately 420°C when not in use.

The final circuit (Figure 4) consists of a regulated power supply and timing chain to produce a one second trigger pulse for the μA742 internal triac saw-tooth generator.

To calibrate the unit both zero and span controls must be correctly adjusted. Details of this procedure are given in Appendix A.

4. CONSTRUCTION

The four furnaces were mounted in a single frame with gas flow meters, gas filters and bubblers all accommodated at one end. The unit is connected to

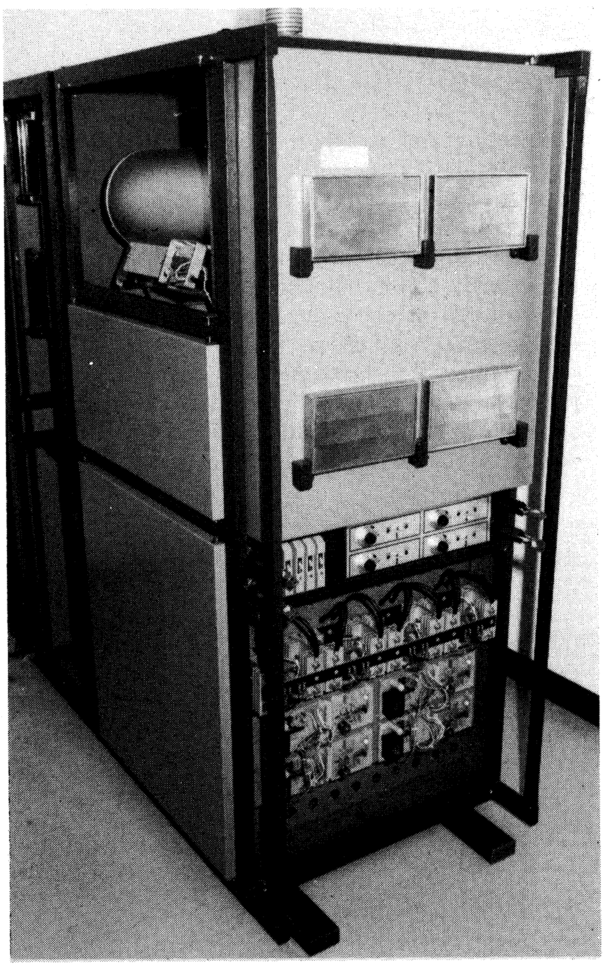

FIGURE 5 Furnace construction.

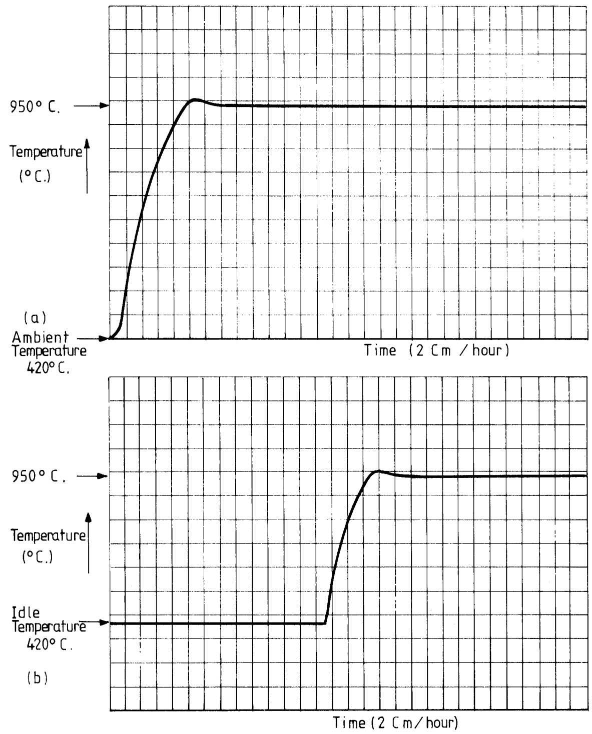

FIGURE 6 Furnace response.

an exhaust system so that gases emerging from the open end of the quartz diffusion tubes are swept away. The bulky 2KVA transformers for each furnace are mounted below the furnaces. All metal side panels can be removed for easy access while the bubbler area at the end is accessible through clear perspex doors. Figure 5 shows a photo of the completed unit.

5. PERFORMANCE

Furnaces have been calibrated, checked and left running (both on preset temperatures and the idle state) for long periods. The heat up time from ambient to the set temperature is typically 1½ hours. However to achieve a temperature cycling of less than 2°C, 3 hours should be allowed. Preset tests, where the furnace was set to a temperature on several different days and its actual temperature recorded indicate that it will stabilize to within 1°C after 6 hours. Figure 6 shows a chart recording for the furnace set to 950°C and (a) heating from ambient and (b) heating from the idle position.

The thermal profile of a furnace at 830°C is shown in Figure 7. For a 1°C temperature change the flat

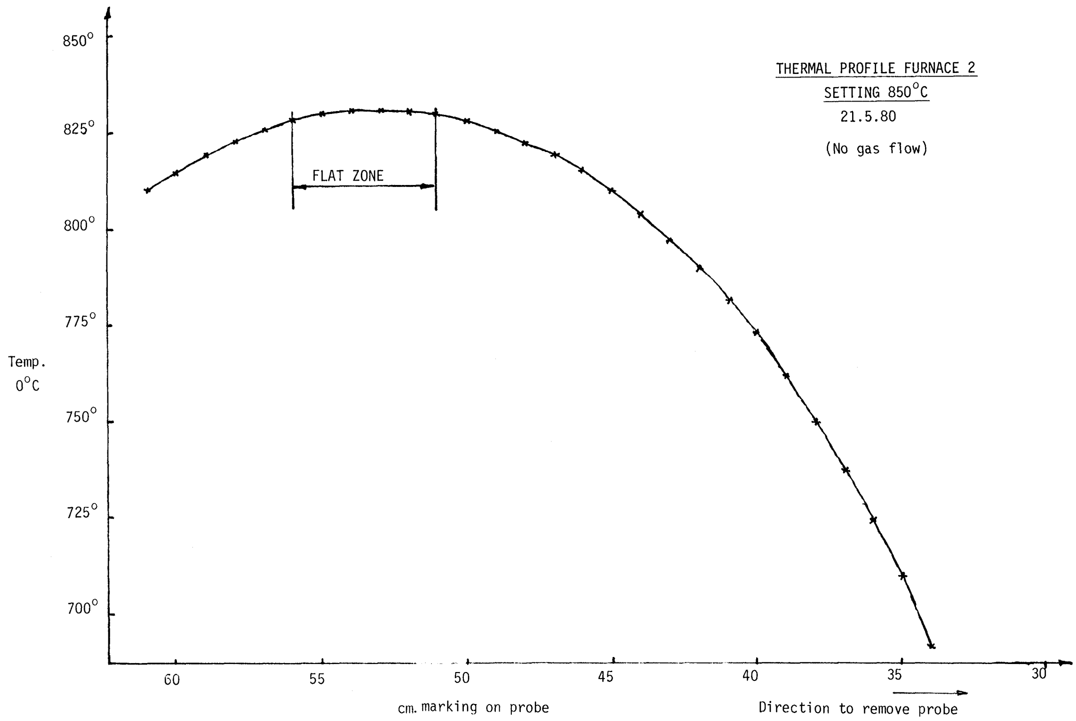

FIGURE 7 Furnace profile.

zone is 35 mm, a 2°C change 55 mm and for a 5°C change 80 mm.

6. CONCLUSIONS

The furnaces selected and controller designed have been in operation for more than 12 months and have proved to be satisfactory. They are currently being used in the teaching of microelectronics courses both to final year students in our Bachelor of Engineering in Electronics Degree and Graduate Diploma students.

ACKNOWLEDGEMENTS

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2. Quartz Glass for the Semiconductor Technology, *Heraeus Report, Q-B3/112E.*
3. Hanau transparent and opaque fused silica, *Heraeus Report Q-A1/111.*

Appendix

CALIBRATION PROCEDURES

Calibration of the system is undertaken as follows:

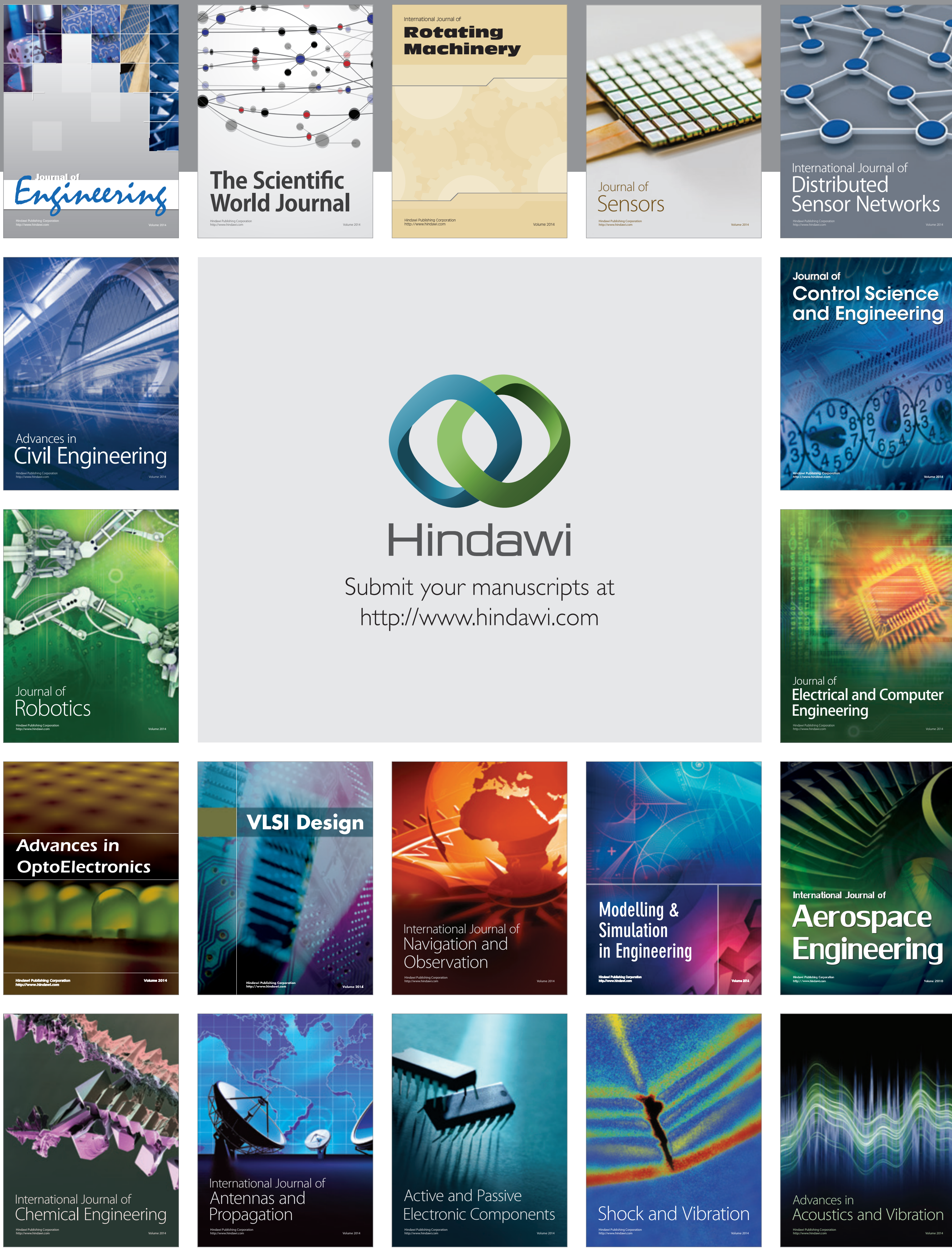
a) Set the voltage at test point 3 to 6.000 volts (a digital voltmeter should be used for the whole calibration procedure) using the reference voltage trim potentiometer (Figure 3). Make sure that when the temperature setting potentiometer is on 1300 the 6 volts also appears on the wiper output. We discovered that with some potentiometers this may not always occur.

b) With the thermocouple shorted, adjust the set zero potentiometer (Figure 2) for the voltage at test point 1 to be 1.273 volts (Figure 3).

c) Remove one lead of the thermocouple and apply a DC signal equal to that from the furnace thermocouple of 1300°C. In our case for a Platinum-Platinum + 13% Rhodium thermocouple this is

14.563 m Volts. Adjust the span potentiometer (Figure 2) for 6.000 volts at test point 1 (Figure 3).

d) Repeat (b) and (c) until the span and zero are correct. Note that the circuit has a long time constant and therefore should be given adequate time to stabilize. Furthermore if the thermocouple input to the amplifier is left disconnected so that the amplifier input is open circuit the amplifier will overload. Shorting the input will eventually allow the amplifier to recover.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