2-19-92
E6851

NASA Technical Memorandum 105541

Using Silicon Diodes for Detecting the Liquid-Vapor Interface in Hydrogen

Paula J. Dempsey and Richard H. Fabik
Lewis Research Center
Cleveland, Ohio

Prepared for the
38th International Instrumentation Symposium
sponsored by the Instrument Society of America
Las Vegas, Nevada, April 26–30, 1992

NASA

USING SILICON DIODES FOR DETECTING THE LIQUID-VAPOR INTERFACE IN HYDROGEN

Paula J. Dempsey and Richard H. Fabik
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

KEY WORDS

Cryogenic Liquid Level Sensors

ABSTRACT

Tests were performed using commercially available silicon diode temperature sensors to detect the location of the liquid-vapor interface in hydrogen during ground test programs. Results show that by increasing the current into the sensor, silicon diodes can be used as liquid level point sensors. After cycling the sensors from liquid to vapor several times, it was found that with a 30 mA (milliamps) input current the sensors respond within 2 seconds by measuring a large voltage difference when transitioning from liquid to vapor across the interface. Nearly instantaneous response resulted during a transition from vapor to liquid. This paper details test procedures, experimental results, and guidelines for applying this information to other ground test facilities.

INTRODUCTION

The Cryogenic Fluids Technology Office (CFTO) at the NASA Lewis Research Center is responsible for developing methods for handling cryogens in space. Several ground test programs are underway within this office to aid in simulating key cryogenic fluid management technologies. These fluid management tests demonstrate techniques for storage, transfer, and supply of liquid hydrogen. Experiments are conducted on various LH_2 (liquid hydrogen) processes such as tank pressure control, tank pressurization and expulsion, and nonvented tank fill. Tests are performed in several ground test facilities using a supply dewar and receiver tank. One of the first tests performed in a facility at the start-up of a test program is determining baseline instrumentation measurements so the accuracy of the sensors can be recorded for post-processing analysis. One of these measurements important to all researchers is the locations of the liquid level.

There are various techniques available for measuring liquid level, but, like in most large-scale test facilities, there are many constraints when choosing the proper method for a given application. The measuring device used must be able to function in a test tank with elaborate internal instrumentation, with limited wire paths. The type of sensor employed must be able to operate when the operational environment changes. For example, depending on the test performed, pressures, temperatures, flowrates, and liquid level may be constantly changing.

In early tests, a capacitance liquid level probe was used to continuously measure liquid level, and hot wire point sensors were used to measure level at discrete points. Many problems were encountered when using these point sensors including high cost, large size, large heat dissipation, lack of stability, and high excitation current. Due to the high current required to operate the hot wire point sensors, the signal conditioning had to be located near the sensor making it impossible for adjustments during a test (the test facility is 500' from the control building). A capacitance probe, on the other hand, depends on the dielectric constant of the fluid to determine liquid level (Reference 1). The dielectric constant is sensitive to temperature changes of the LH_2 and/or pressure in the tank. These changes in the dielectric constant may cause erroneous measurements of liquid level. A method of measuring level independent of changes in the thermodynamic environment is required. Silicon diodes were tested to verify that they could measure the liquid-vapor interface at select points in the receiver tank. The silicon diodes could then be used to calibrate the capacitance probes by accurately locating silicon diodes at selected locations inside each test tank. Calibration of the capacitance probe using silicon diodes consists of first chilling down the test tank. Then, while controlling tank pressure, the tank is slowly filled from the bottom. As the silicon diodes sense liquid, they provide accurate level measurements which can be used to calibrate each capacitance probe. By keeping the pressure controlled, the liquid dielectric constant should remain constant. During subsequent testing the silicon diodes can also be used to provide discrete liquid level indications to verify the liquid level measurements provided by each capacitance probe.

BACKGROUND

In the past, many different types of sensors have been used to detect liquid level in cryogenic test tanks. These methods include observation, hydrostatic level gages, float gages, weight gages, radiation level detection, sonar level detection, optical, electrical resistance, and superconductors. These sensors and their operation are detailed in Reference 2. All of the sensors mentioned can be used as liquid level point sensors in a specific application. The problem with many of these gages is that the operation is dependent on the facility and tankage. In most real-life applications, the instrumentation supports the research package, the research package is not designed around the instrumentation. Most of these methods can be eliminated due to the system constraints. Of the methods mentioned, the most practical method of level measurement would be electrical resistance. This type of sensor includes hot wire point sensors(3), thermopiles(4), carbon resistors(1), thermistors(5), and germanium diodes(6). The goal of the instrumentation engineer is to find a sensor to measure the liquid level in a variety of applications. In order to establish that the sensor will have general utility, it should meet the following criteria: (1) The sensor should have minimal effect on the experimental data. Therefore, heat dissipation into the bulk liquid should be kept to a minimum. (2) The sensor should be easy to operate and calibrate. (3) Test conditions such as changes in tank pressure, flowrates, and temperature, should have minimal effect on the sensor accuracy.

Silicon diode temperature sensors, tested as liquid level sensors, met most of these goals. Early tests using diodes required an additional heat source, because the diode could not withstand the high currents required to measure changes in level. Silicon diode temperature sensors are used by applying a constant specified signal current, and measuring the voltage drop across the diode. The National Institute of Standards and Technology, NIST, performed some preliminary tests using silicon diodes to detect the liquid-vapor interface. They examined fast-response level sensors (<0.5 seconds) to detect liquid motion experienced during low gravity slosh dynamics experimentation (Reference 7). The point sensor they selected as being appropriate for the desired application is not commercially available. For ground tests, the response does not have to be less than one second, therefore, commercially available silicon diode temperature sensors are candidates to be used. Since the voltage drop across the diode is a strong function of temperature, it is possible to relate the measured voltage drop to temperature. A typical response curve for a silicon diode temperature sensor with a 10 μA (microamps) signal current is shown on Figure 1-1. For the liquid level sensor application, the 10 μA current used for silicon diode temperature sensors was increased several orders of magnitude to provide self-heating of the diode. Self-heating of the silicon diode was important for several reasons. If the tank is at steady state conditions, both the liquid and vapor will reach saturation temperature at the interface, and no change will be observed in the silicon diode output when in liquid or vapor. By increasing the current, the self-heating should be sufficient to produce a significantly higher diode temperature in vapor than in liquid due to the differing heat dissipation rates. By sensing this temperature difference, the silicon diodes can be used as a liquid-vapor interface sensor. Also, sufficient self-heating of the silicon diode temperature sensor must be present to vaporize any liquid remaining on the sensor when going from liquid to vapor.

EXPERIMENTAL APPARATUS

HARDWARE

Tests were performed at The NASA Lewis Research Center in the Liquid Transfer Cryogenic Test Facility at CCL7 (Reference 4). A photo of the rig and a simplified piping schematic are shown in Figures 1-2 and 1-3, respectively. The test tank, or receiver dewar, is a vacuum jacketed stainless steel tank. Multilayer insulation is located within the vacuum annulus. The tank main body is cylindrical in shape, with a mating lid assembly. The internal tank height is 28 inches (71.1 cm), and inside diameter is 22 inches (55.9 cm).

INSTRUMENTATION

Two silicon diodes, designated SD54 and SD55, were mounted on an instrumentation rake at the same elevation inside the test tank. A capacitance liquid level probe, which was used to determine the rate of change in the liquid level, was also located inside the tank. A simplified schematic of their location is shown on Figure 1-3. Tank pressure was measured with a strain gage pressure transducer. The silicon diodes were mounted by the leads to minimize the effects of the mounting fixture which can delay the sensor response time. The physical dimensions of the silicon diodes are detailed on Figure 1-4.

DATA ACQUISITION

During the test, data is transmitted from the silicon diode sensors to a multiplexer in the remotely located control room. Data is recorded in millivolts, and then converted to engineering units using a microcomputer. Real time data was also displayed on the microcomputer CRT. Data was recorded once every 2 seconds. In addition to the silicon diode output in millivolts, the following parameters were measured and recorded: rate of liquid level change in inches, tank pressure in psia, and time in seconds.

PROCEDURE

The receiver tank, as shown in Figure 1-3, was chilled down prior to the beginning of the test, then the tank was filled to a level above the fixed location of the silicon diodes. The current to the silicon diodes was increased to a test current setting. The liquid level at the silicon diodes was then varied slightly above the sensor and slightly below the sensor a minimum of three times using pressurized expulsion and nonvented fill of the receiver tank.

Voltage response of the silicon diode was recorded using four current sources: 10 mA(milliamps), 20, 30, and 40 mA. Voltage response was also checked at the 10 µA current level after completion of the test to verify the temperature sensing ability of the silicon diodes was not affected by tests at the increased current levels. The average fill/drain rate was 3 inches per minute (7.6 cm/min). Pressure fluctuated from 20 psia (137.9 kPa) to 27 psia (186.2 kPa) during this fill-drain procedure.

RESULTS

Millivolt output for silicon diode SD55 and the change in liquid level versus time is plotted for four current settings (Figures 1-5 to 1-8). The 0.0 on the "change in liquid level" axis represents the silicon diodes location. If the data is above the 0.0 point, the silicon diode is in liquid, if below the 0.0 point, the silicon diode is in vapor. This change in liquid level was determined by the capacitance probe. Millivolts and level versus time is also plotted for the 10 µA current settings on Figure 1-9 showing that the normal temperature measurement current is inadequate for the liquid level sensing function. The output of SD55 was approximately 70 mV higher in liquid, and 50 mV higher in vapor than SD54, which is insignificant compared to the large voltage change at the interface (greater than 2 times this difference). The manufacturer supplied interchangeability specifications for these two sensors suggest that a 10 mV difference between these two diodes at the normal operating current of 10 µA can be expected. The increase in current employed for the liquid/vapor detection tests, or wiring techniques may have increased this difference. When used in future tests they will be wired in series as detailed in Figure 1-10. The average millivolt output in the liquid and the average millivolt output in the vapor is listed in the Table 1-1 for both sensors. The change in millivolt output of the silicon diodes is the difference in average voltage output between the sensor in liquid and the sensor in vapor. This change is greater than the characteristic difference between the two sensors. The mean is the average millivolt output between each sensor in liquid and in vapor. The mean for both sensors was then averaged. This average value was used as a millivolt switch point to determine if the silicon diode is in liquid or vapor. For example, if the millivolt output of the silicon diode is greater than the millivolt switch point, liquid is detected. If the millivolt output of the silicon diode is less than or equal to the millivolt switch point, vapor is detected. This detection logic can be programmed into a data acquisition system. The millivolt switch points are listed in Table 1-1, and can be easily adjusted in the data system during a test run.

The silicon diodes responded within 2 seconds based on the change in level measured by the capacitance level probe at all of the four test current levels. The repeatability of the sensor response was also verified by cycling the liquid level at the different test current settings. Of the four current settings, a 30 mA current was chosen to be used with the silicon diodes during the next ground test program. The heat introduced into the test volume by a silicon diode at 30 mA was limited to 52.5 mW (milliwatts). This heat input is less than 0.5% of the parasitic heat leak for this test tank. This current setting was also within intrinsic safety limits for hydrogen.

CONCLUDING REMARKS

Silicon diodes temperature sensors can be used to measure the liquid-vapor interface in hydrogen. These silicon diode temperature sensors met the criteria required for a point sensor to operate in most applications. The heat dissipation in the tank caused by the silicon diodes was limited to 52.5 mW per silicon diode at 30 µA. The silicon diode is easy to operate and calibrate. By filling and draining the tank, and measuring the voltage output of the silicon diodes at a specific location, the millivolt switch point can be determined for all tests. Pressure and temperature changes in the test tank have minimal effect on the data. Additional advantages of using silicon diodes for this application include simple signal conditioning, good stability, and low cost compared to other cryogenic point sensors. Also, connector requirements can be reduced by wiring these sensors in series, as long as the constant current power supply voltage is larger than the voltage drop across all of the diodes (Figure 1-10). In addition, these sensors can again be used as temperature sensors by changing the current setting back to 10 μA. These sensors will be used in future test programs to calibrate the capacitance liquid level probe by accurately establishing the discrete locations of the silicon diode point sensors, and adjusting the capacitance probe to reflect these locations when the level is changed. In some applications, a capacitance probe may no longer be required.

Although minimal, several other parameters may affect silicon diode response. These parameters include the location of the sensor in the tank, flowrate during fill and drain, tank pressure, thermal cycling, and initial tank temperature. More development work is planned to quantify the impact of these effects.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the data reduction efforts of Matt Moran, and the test operations support of Ted Nyland.

REFERENCES

1. McCarty, R.D., "Hydrogen Technological Survey-Thermophysical Properties," NASA SP-3089, 1975.

2. Hoenig, M.O., "Cryogenic Liquid Level Detection and Control-A Survey," ISA Paper 73-552, Instrument Society of America, International Conference, Houston, TX, Oct. 15-18, 1973.

3. Olsen, W.A., "An Integrated Hot Wire Stillwell Liquid Level Sensor System For Liquid Hydrogen And Other Cryogenic Fluids," NASA TN D-2074, Nov. 1963.

4. DeWitt, R.L., and Stochl, R.J., "Temperature and Liquid Level Sensor for Liquid Hydrogen Pressurization and Expulsion Studies," NASA TN D-4339, Feb. 1968.

5. Moran, M.E., Nyland, T.W., and Papell, S.S., "Liquid Transfer Cryogenic Test Facility: Initial Hydrogen and Nitrogen No-Vent Fill Data," NASA TM-102572, Mar. 1990.

6. Hyman, L.G., Sheppard, J.F., and Spinka, H., "An Improved Liquid Level Sensor," ANL-7243, Argonne National Laboratory, Argonne, Ill, July 1966.

7. Siegwarth, J.D., Voth, R.O., and Snyder, S.M, "Liquid-Vapor Surface Sensors For Liquid Nitrogen and Hydrogen," Presented at the Space Cryogenics Workshop, NASA Lewis Research Center, Cleveland, Ohio, June 18-20, 1991.

Table 1-1: Summary of Silicon Diode Test Data

Sensor Designation	Current, Milliamps	Millivolt Output, Liquid	Millivolt Output, Vapor	Change in Millivolt Output	Millivolt Switch Point, Mean
SD54	40	1719	1420	299	1589
SD55	40	1791	1459	332	
SD54	30	1683	1410	273	1580
SD55	30	1759	1477	282	
SD54	20	1628	1432	196	1559
SD55	20	1695	1490	205	
SD54	10	1544	1435	109	1517
SD55	10	1609	1490	119	

Data system software logic:
If sensor millivolt output is greater than millivolt switch, then liquid is detected.
If sensor millivolt output is less than or equal to mV switch, then vapor is detected.

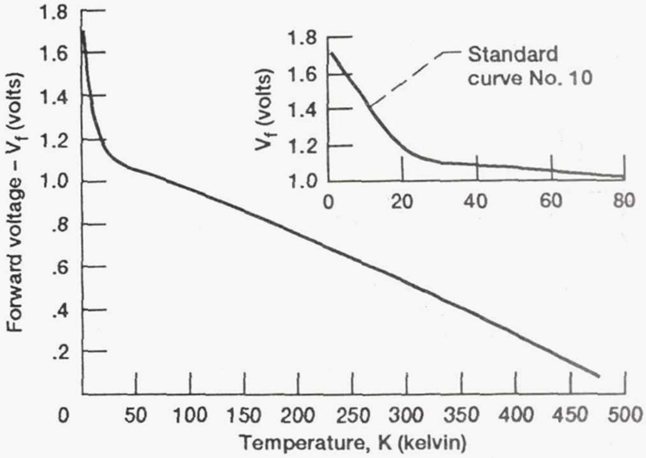


Figure 1-1.—Typical response curve for a silicon diode temperature sensor at 10 μA. Reprint with written permission of Lake Shore Cryotronics, Inc.

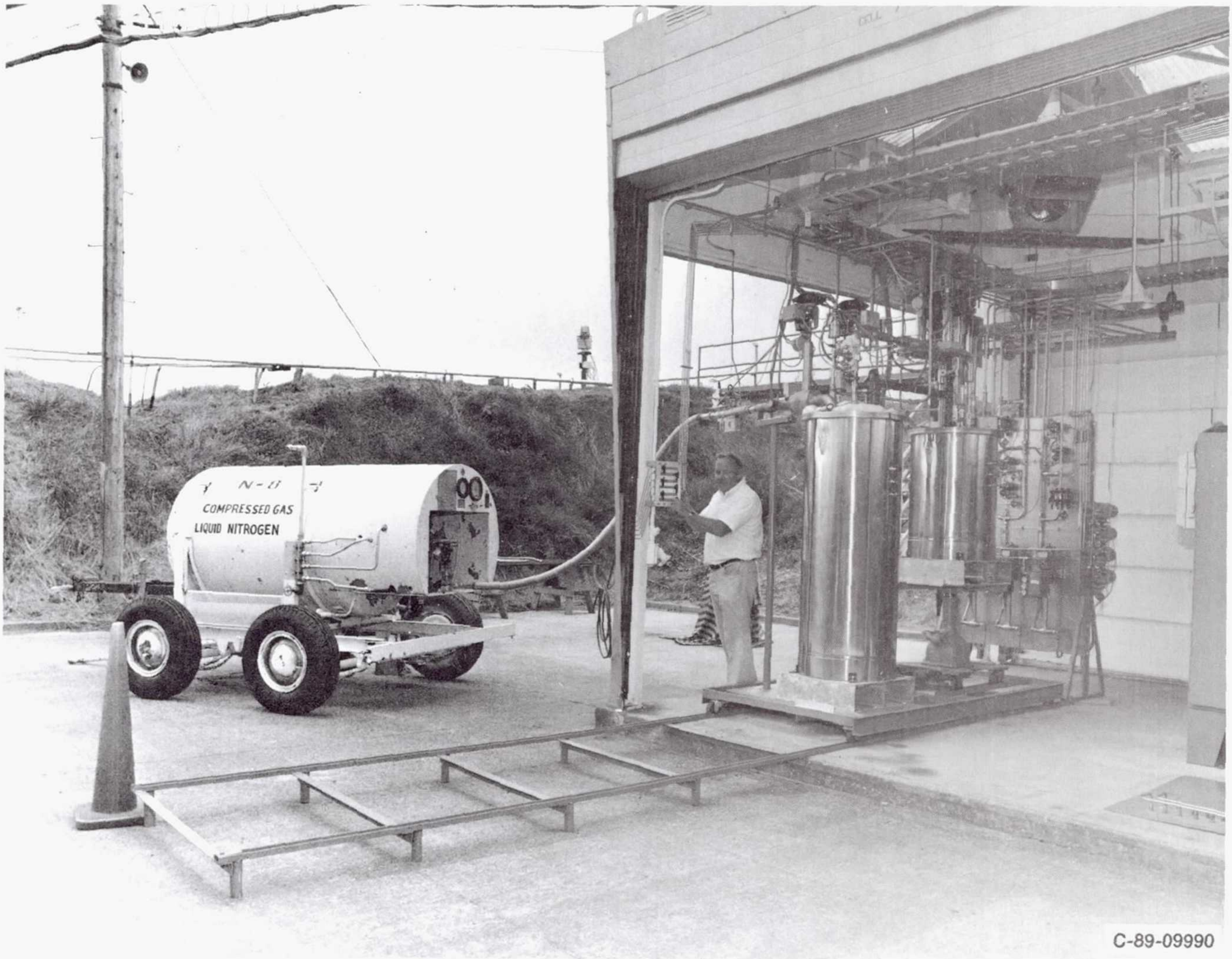


Figure 1-2.—Photograph of the liquid transfer cryogenic test facility at CCL7.

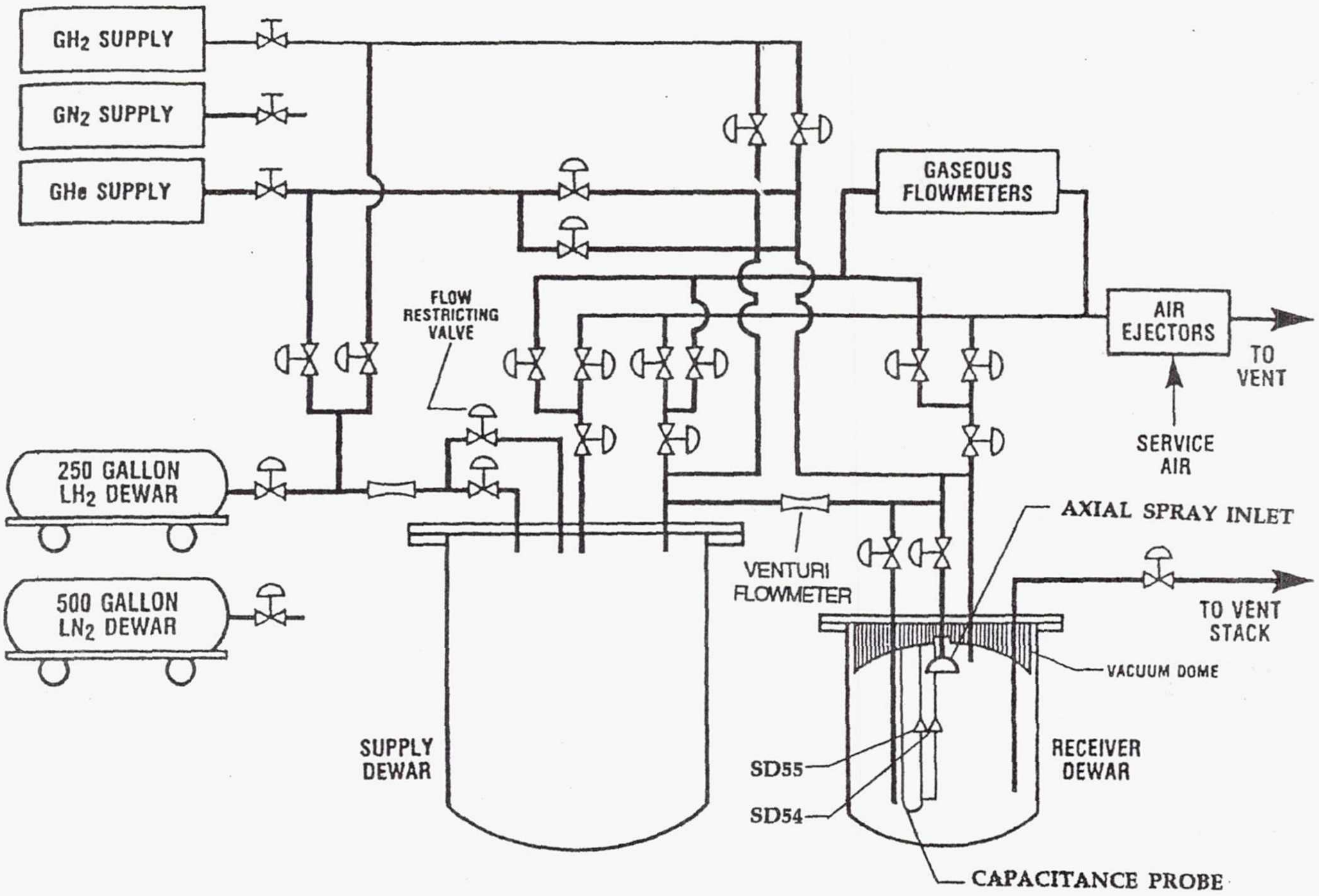
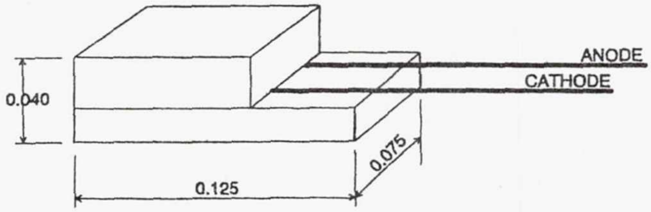


Figure 1-3.—Simplified piping schematic of the liquid transfer cryogentic test facility.



DIMENSIONS ARE IN INCHES

Figure 1-4.—Typical silicon diode temperature sensor.

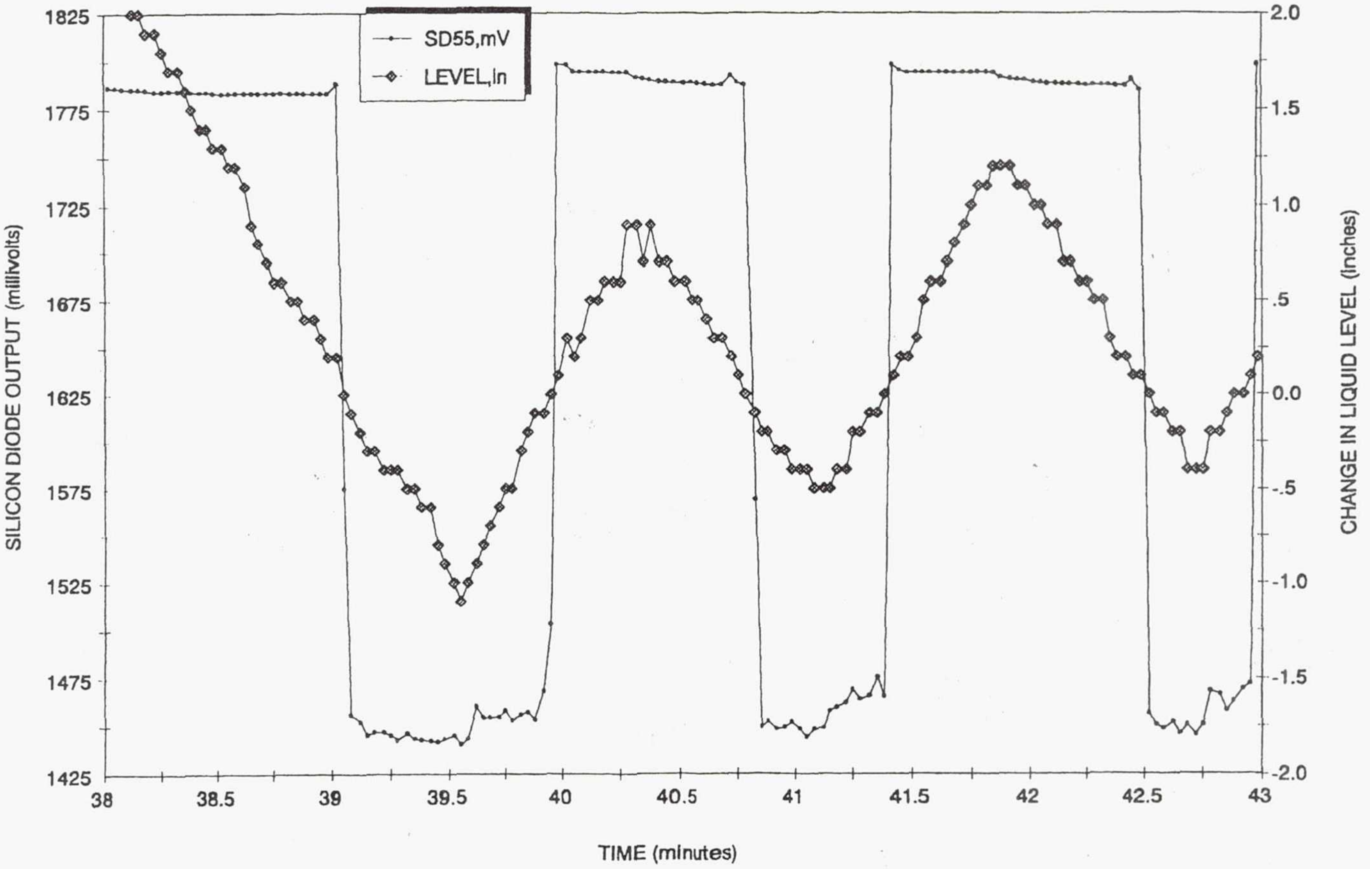


Figure 1-5.—Silicon diode response at 40 mA.

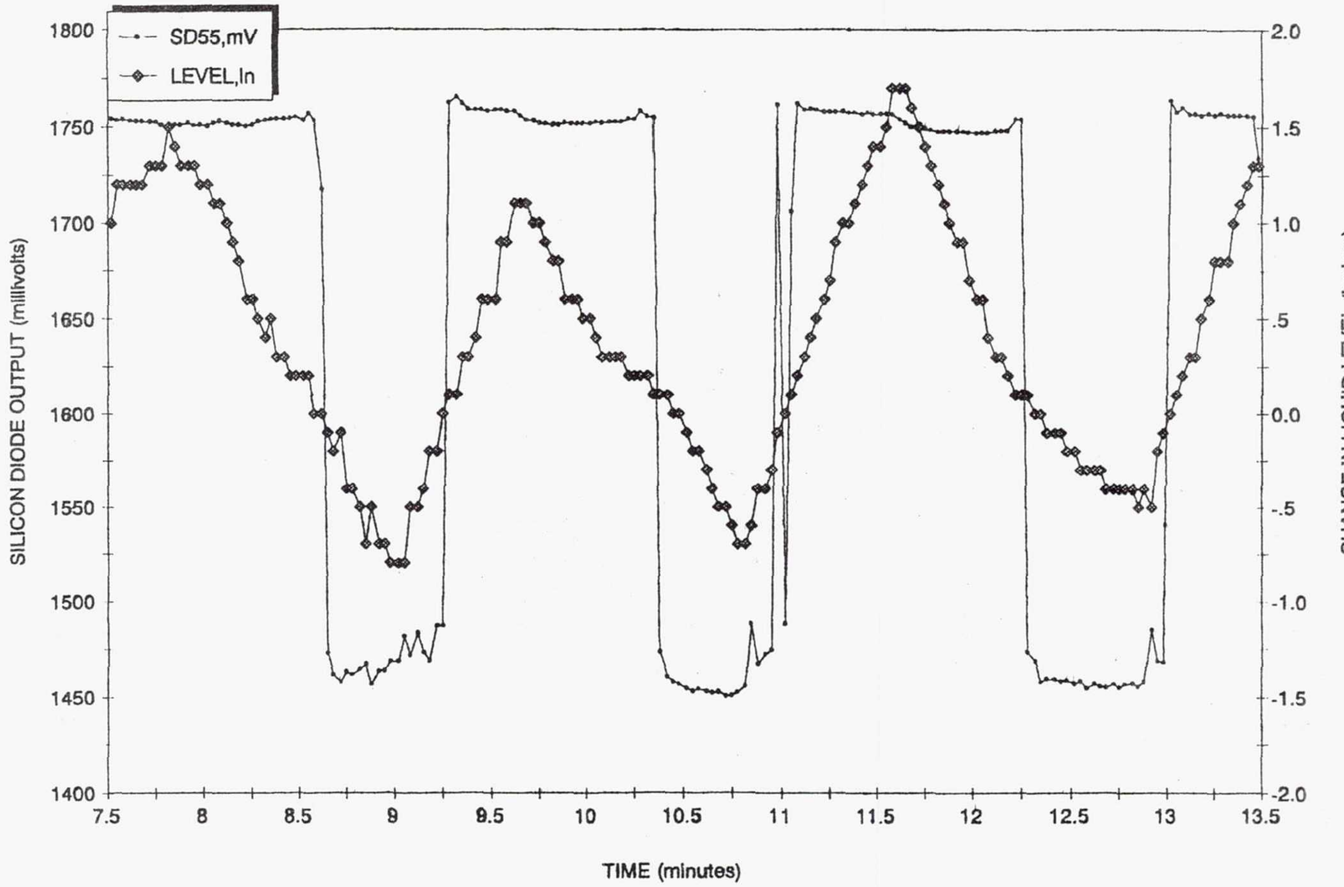


Figure 1-6.—Silicon diode response at 30 mA.

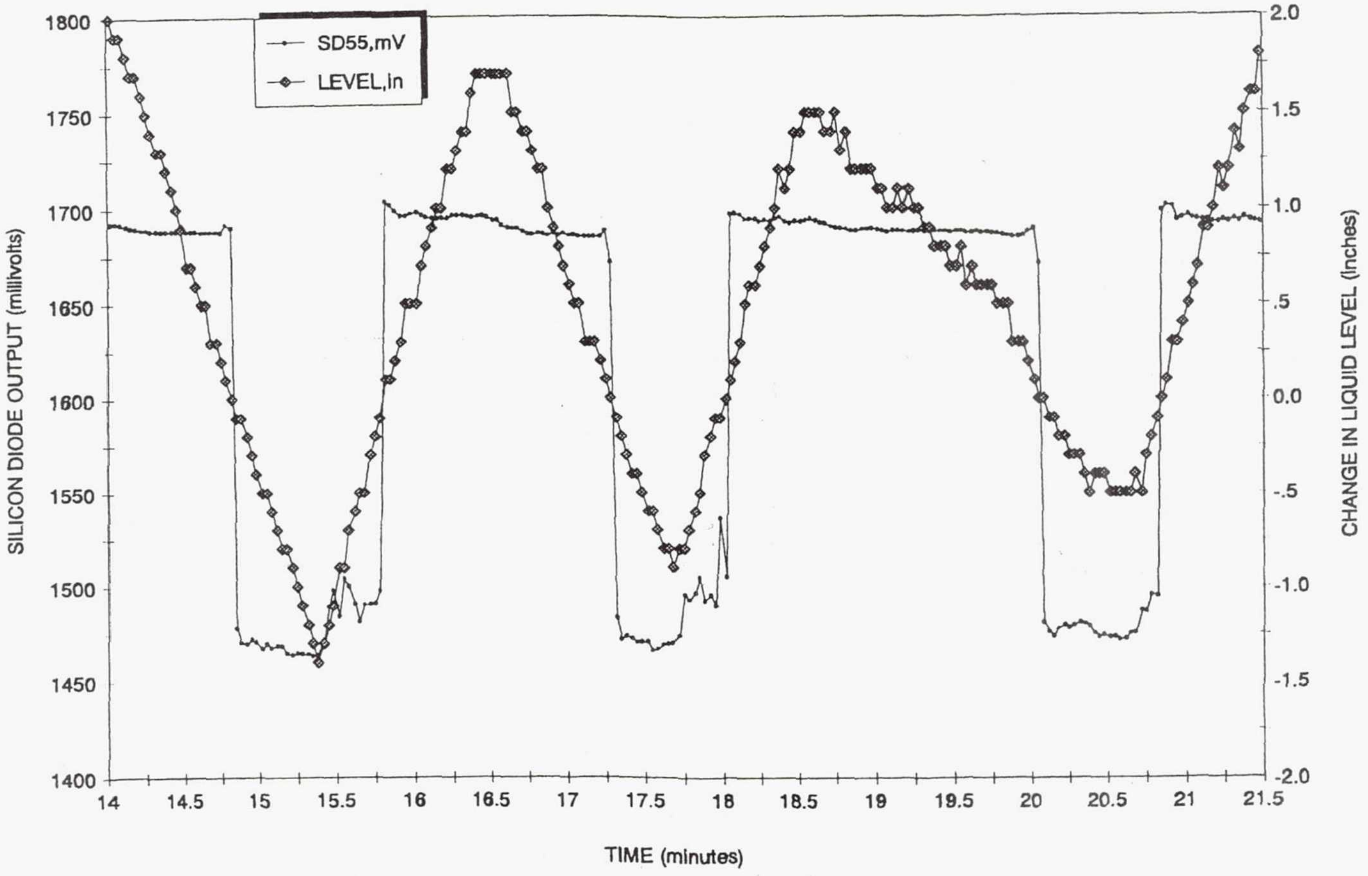


Figure 1-7.—Silicon diode response at 20 mA.

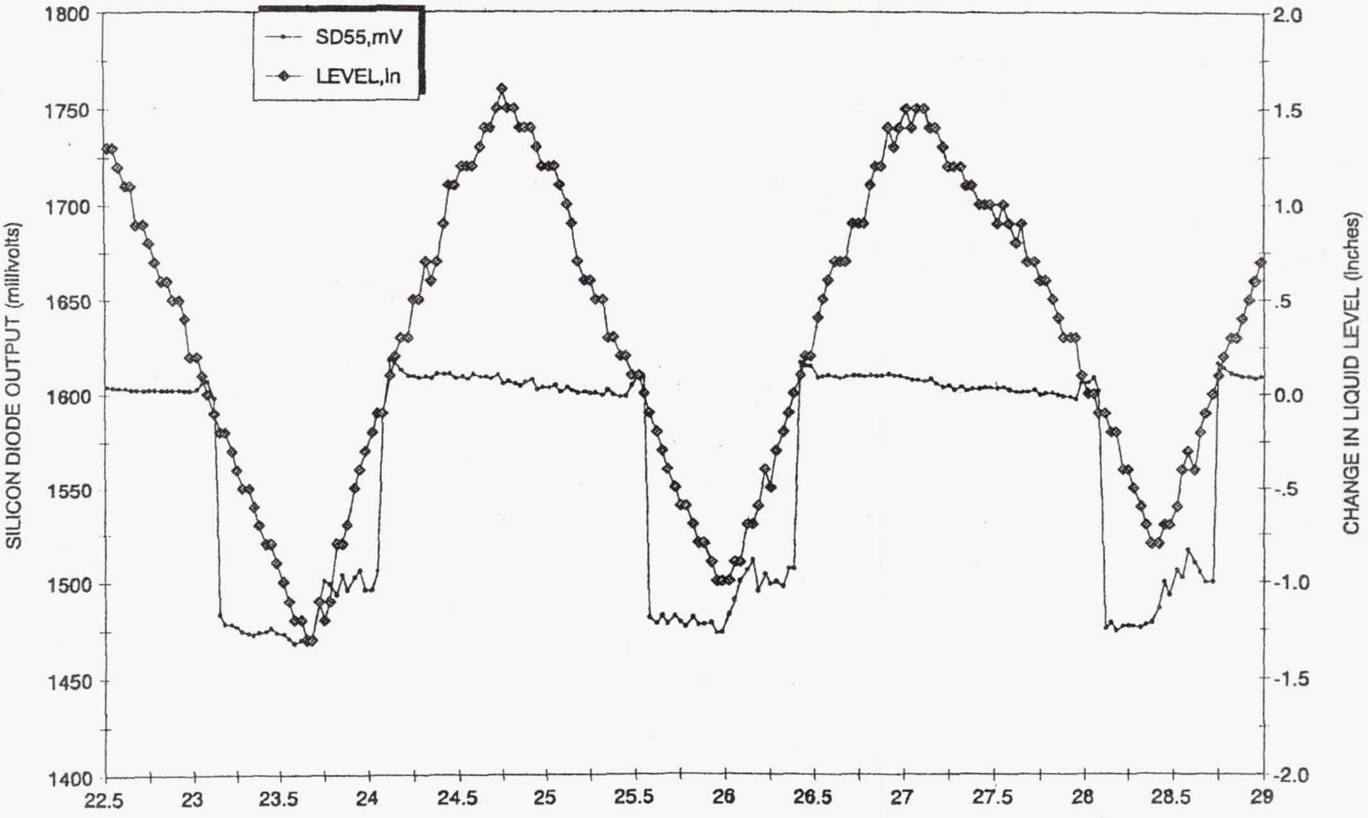


Figure 1-8.—Silicon diode response at 10 mA.

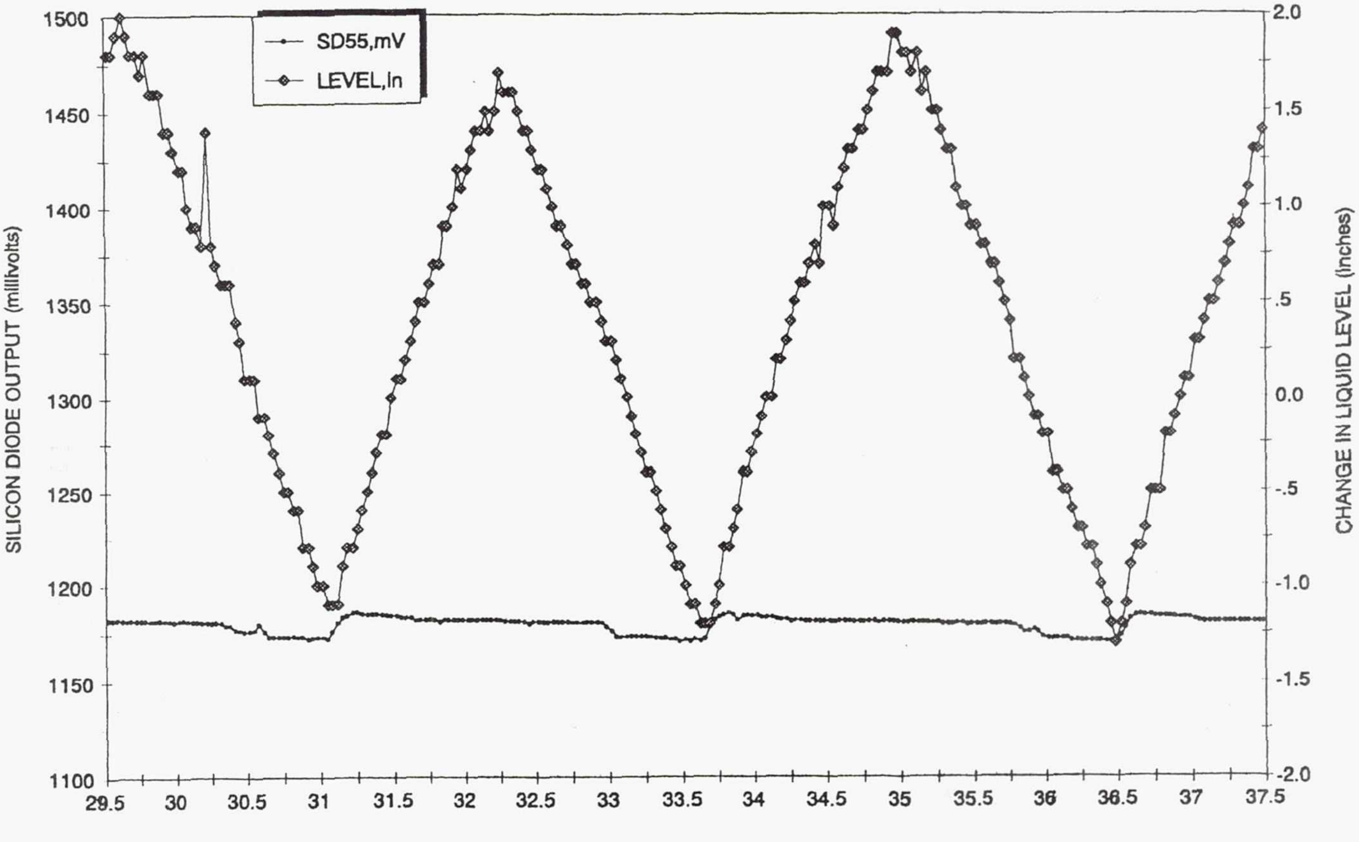


Figure 1-9.—Silicon diode response at 10 uA.

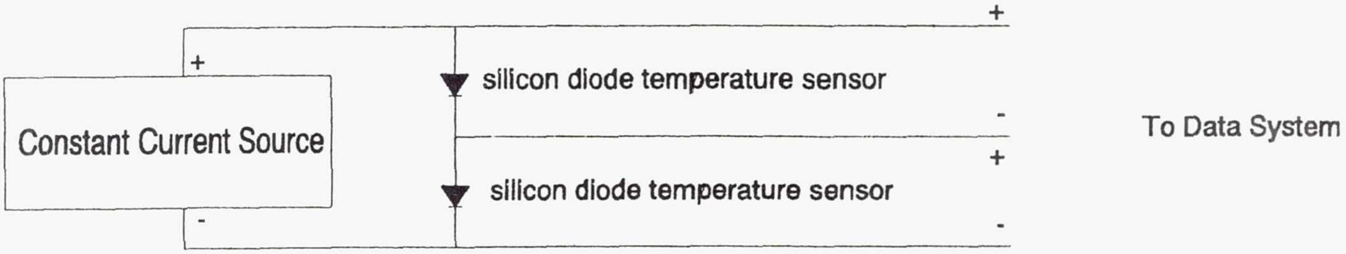


Figure 1-10.—Silicon diode schematic diagram.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** 1992	**3. REPORT TYPE AND DATES COVERED** Technical Memorandum

4. TITLE AND SUBTITLE

Using Silicon Diodes for Detecting the Liquid-Vapor Interface in Hydrogen

5. FUNDING NUMBERS

WU-593-21

6. AUTHOR(S)

Paula J. Dempsey and Richard H. Fabik

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E-6851

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-105541

11. SUPPLEMENTARY NOTES

Prepared for the 38th International Instrumentation Symposium sponsored by the Instrument Society of America, Las Vegas, Nevada, April 26-30, 1992. Responsible person, Paula J. Dempsey, (216) 433-6537.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories 14 and 35

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

Tests were performed using commercially available silicon diode temperature sensors to detect the location of the liquid-vapor interface in hydrogen during ground test programs. Results show that by increasing the current into the sensor, silicon diodes can be used as liquid level point sensors. After cycling the sensors from liquid to vapor several times, it was found that with a 30 mA (milliamps) input current the sensors respond within 2 seconds by measuring a large voltage difference when transitioning from liquid to vapor across the interface. Nearly instantaneous response resulted during a transition from vapor to liquid. This paper details test procedures, experimental results, and guidelines for applying this information to other ground test facilities.

14. SUBJECT TERMS

Cryogenic liquid level sensors

15. NUMBER OF PAGES

14

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT**

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102