CONSIDERATIONS IN THE HIGH-VOLUME PRODUCTION
OF HYBRID PRESSURE SENSOR MODULES
FOR AUTOMOTIVE APPLICATIONS

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I. INTRODUCTION

This paper will present some of the methods and requirements for taking a pressure sensor module from the laboratory to a point where it is a commercially practical product using existing technology. The specific market addressed is the automotive market in which volumes of 6 to 8 million units per year are common.

II. TECHNOLOGY DESCRIPTION

The technology used at Delco Electronics Corporation to build the module consists of a piezo-resistive pressure sensing cell with resistors in a bridge configuration. The cell is formed by using an anisotropic etch resulting in a diaphragm 1 mil thick (Fig. 1). The temperature correction thermistors for the cell and the functional adjust resistors are printed on an alumina substrate. Also on the substrate are two EMC (electromagnetic compatibility) capacitors and an integrated circuit operational amplifier which is attached to the substrate by automated pattern recognition integrated circuit flip chip mounting equipment. Welded wires are used to connect the cell housing to the substrate and to connect the substrate to the package which contains the electrical connector (Fig. 2). The functional adjust and temperature compensation are accomplished by computer-controlled laser abrade of the printed resistors (Fig. 3). The module is then passivated, covered, and tested. Both differential and absolute units are available (Fig. 4).

III. REQUIREMENTS

The module must operate in the harsh underhood environment. Temperature extremes of -40° to $+125^{\circ}\text{C}$ are encountered along with many different fluids and vapors including intake manifold gases. This harsh environment requires stringent product assurance tests before even low-volume production can be considered. Some examples of environmental conditions and product assurance tests required, and some general requirements are (Fig. 5):

1. Analog output voltage proportional to pressure over a 90 kPa range.
2. Operate from $5.1\text{ V} \pm .36\text{ V}$ dc supply.
3. Output voltage ratiometric to supply voltage.
4. Accuracy = 1.5% of full scale pressure.
5. Sensor output must stabilize in less than 12 milliseconds in response to pressure change with output noise level less than 10 millivolts.
6. The design must meet all requirements over a temperature range of 0 to $+125^{\circ}\text{C}$, relative humidity of 0 to 100%, and over all the electrical and environmental conditions encountered over the complete pressure range.

7. The module must be unaffected by automotive vapors at temperatures of 150°C , shall not leak or expose any electrical connection to manifold gases for an operable life of 6 years or 120,000 miles.

8. The design shall meet the following tests with no degradation allowed in the electrical or mechanical specification:

- * 1,000 cycles of -40° to $+125^{\circ}\text{C}$.
- * 2,000,000 cycles of 15 kPa to atmosphere.
- * 1,000 combined cycles of above temperature and pressure.
- * 500 hours each of biased and unbiased 85°C and 85% relative humidity.
- * 3 mechanical shocks of 50 G for 11 ms in 3 axes.
- * Low- and high-frequency vibration in 3 axes.
- * Automotive fluid compatibility for 30 min. at 100°C (dip test).
- * Extended exposure to NOx and humidity combination.
- * Drop test of one meter.
- * Unbiased 5% salt fog for 48 hours with contacts and port sealed.
- * Autoclave at 121°C and 15 psig for 96 hours.
- * 100,000 cycles of 2 times operating pressure.
- * EMI exposure of 100 V/m in automobile.
- * 5 hours exposure to "Arizona dust" (with agitation).

The above requirements must be met while also meeting demands for ever-tightening specifications covering such items as: wider temperature ranges, tighter transfer function error bands, and higher level EMI protection.

IV. TIMING

The traditional approach to new product development and production was to do the development work without involving manufacturing engineering till late in the design stage. This serial approach to designing and producing a product did not work well and cannot be used today for several reasons.

The first reason that serial design-production engineering cannot be used today is the need of manufacturing engineering to know if new technologies will be required to produce a product. New processes may need to be developed along with the product development.

The second reason that a serial design-production engineering approach will not work today is the time required to obtain equipment for manufacturing the new product. Because a majority of the equipment required will be custom designed and built, it is not uncommon to have delivery times approach, and sometimes exceed, a full year (Figs. 6, 7, 8). Manufacturability must be considered before committing the design to paper. Therefore, the above design audit tests should be satisfied before equipment can be committed. An example of timing required for a 1989 MY program follows (Fig. 9):

Working Backwards to Arrive at a Start Date

Start of production	1989 MY
Equipment in place and running	March 1988
Equipment ordered (1 yr. lead time)	March 1987
Equipment spec., quotes, and vendor selection	Oct. 1986
Engineering qualification complete (Engineering and proto samples designed, built, and passed all Product Assurance tests)	Aug. 1986

In an effort to eliminate time from program schedules, design engineering and production engineering must work on the programs in a cooperative design approach from the initial product concepting stages.

A third reason that a parallel engineering approach must be used is to meet Total Quality System requirements, a small part of which is shown in Fig. 10. An assessment of the criteria leading to a quality product must be made in the design phase. By recognizing areas where quality may be sacrificed, all options to eliminate the quality problem can be evaluated early in the design and the best solution used.

V. CONCLUSIONS

The final pressure sensor module which evolves, must not only be producible in high volume, meet the specification, pass product assurance testing, meet continuing quality requirements, work in the application, and be very reliable, but must also be in a price range that is attractive compared to competitive products. This can only be achieved by involving the necessary disciplines in the design effort, establishing rigid accelerated product assurance tests which correlate to the real world, using statistical process control "in house" and at the vendor level, anticipating potential problems when introducing changes in design and solving the potential problems before they become crises by establishing effective product engineering support groups.

PRESSURE SENSOR CHIP

Figure 1

ASSEMBLY

Figure 2

LASER TRIM

Figure 3

ABSOLUTE MODULE

Figure 4

REQUIREMENTS

1. Analog output voltage proportional to pressure over a 90 Kpa range.
2. Operate from 5.1v +/- .36v D.C. supply.
3. Output voltage ratiometric to supply voltage.
4. Accuracy = 1.5% of full scale pressure.
5. Sensor output must stabilize in less than 12 milliseconds in response to pressure change with output noise level less than 10 millivolts.
6. The design must meet all requirements over a temperature range of 0 to +125 degrees centigrade, relative humidity of 0 to 100%, and over all the electrical and environmental conditions encountered over the complete pressure range.
7. The module must be unaffected by automotive vapors at temperatures of 150 degrees centigrade, shall not leak or expose any electrical connection to manifold gases for an operable life of 6 years or 120,000 miles.
8. The design shall meet the following tests with no degradation allowed in the electrical or mechanical specification:
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GENERAL REQUIREMENTS

Figure 5

SUBSTRATE ASSEMBLY

Figure 6

HOUSING BACKPLATE ASSEMBLY

Figure 7

FILL AND COVER

Figure 8

SCHEDULE

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Equipment spec., quotes, & vendor selection	Oct. 1986
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TIMING FOR '89 MY PROGRAM

Figure 9

QC EXAMPLE

Figure 10