A High Performance Industrial Weighing System

National Semiconductor
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The continuing emphasis on efficiency and waste control in the industrial environment has opened new applications areas for electronic measurement and control systems. Standard electronic techniques can be used to solve many of these application problems. In some areas, however, the measurement requirements are so demanding that novel and unusual circuit architectures must be employed to achieve the desired result. In particular, very high precision transducer-based measurements can be achieved by combining microprocessor and analog techniques. The performance achievable can surpass the best levels obtainable with conventional approaches.

An example of a requirement involves high resolution weighing of 2000 pound rolls of plastic material. In this application, the rolls must be weighed before they are fed into machinery which utilizes the plastic in a coating process. Because the plastic material is relatively expensive, and the number of rolls used over time quite large, it is desirable to keep close tabs on the amount of material actually used in production. This involves weighing the roll before it is used and then weighing the amount of material left on the roll core after it has unwound. In this fashion, the losses accumulated over hundreds of rolls can be tracked and appropriate action taken if the losses are unacceptable. *Figure 1* shows the way the rolls are handled and fed into the coating machinery. The desired weighing system performance specifications also appear in the figure. *Figure 2* shows the specifications for a typical high quality strain gauge load cell transducer. From this information, it can be seen that the electronic error budget is vanishingly small. The 3 mV/V specification on the load cell means that only 30 mV of full-scale is available for a typical 10V transducer excitation. The desired 0.01% resolution means that only $3\mu V$ referred-to-input error is allowable. In addition, the gain slope tolerance and temperature coefficients of the load cells, while small, seem to preclude meeting the required specifications. The 0.1% gain slope tolerance also appears to mandate the need for manual system recalibration whenever load cells must be replaced in the field. Finally, assuming these specifications can be met, an A/D converter which will hold near 15-bit stability over the required temperature range is required.

The key to achieving the desired performance is in the realization that the system must be designed as an *integrated* function instead of a group of interconnected signal conditioning blocks. Traditional approaches which rely on "brute force" high stability amplifiers and data converters cannot be successfully used to meet the required specifications.

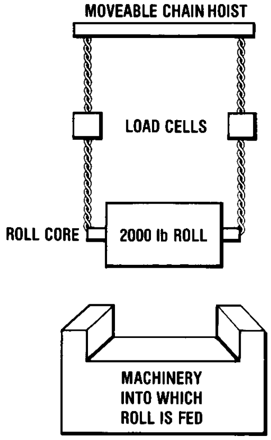

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FIGURE 1

Desired System Specifications

Accuracy, 0.03%
Stable Resolution, 0.01%
Operating Temperature Range, 10°C to 45°C
Full Load Cell Field Interchangeability
20,000 Count Display

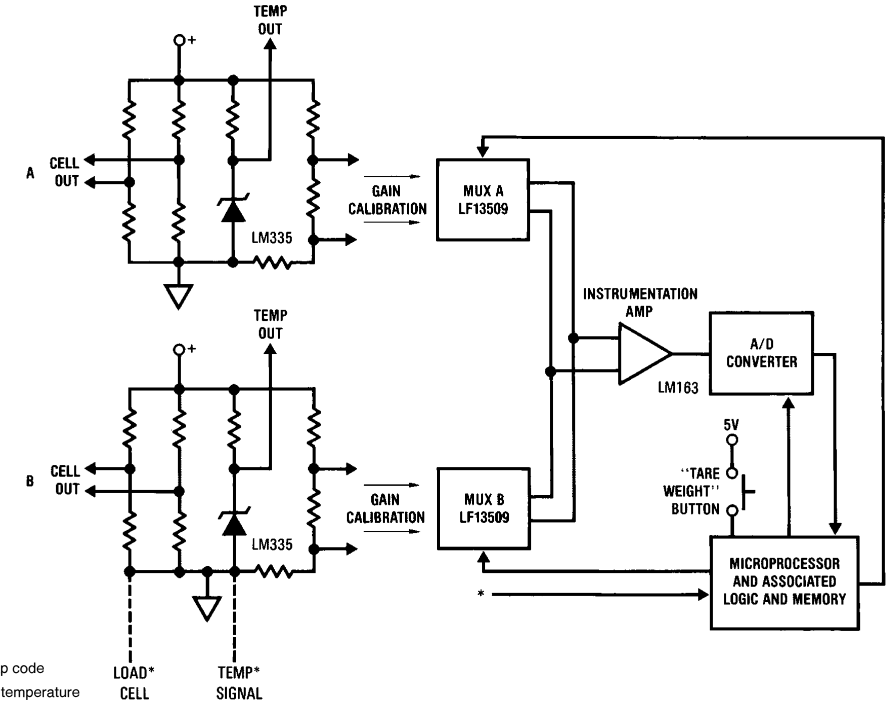
FIGURE 2

Typical Load Cell Specifications

Gain Slope—3 mV/V Excitation ±0.1%
Recommended Excitation—10V
Gain Tempco—±0.0008%/°F
Zero Tempco—±0.0015/°F

The approach utilized is diagrammed in *Figure 3*. In this arrangement a microprocessor is used to effectively close an analog loop around the load cells with an instrumentation amplifier and an A/D converter. In this system, four discrete measurements are continuously performed on each load cell to determine its error corrected output. Corrections are made for zero and gain drift and a first-order temperature error correction is also made. The actual load cell output voltage is read to complete the measurement cycle. The start of a measurement cycle is initiated by the microprocessor commanding the LF13509 differential input multiplexer A to position 1 (See *Figure 4*). In this position, the amplifier inputs are connected to one side of the transducer bridge. This determines the electrical zero in the system at the common-mode output voltage of the bridge. Physical zero information (e.g., "tare weight") is fed to the microprocessor via a pushbutton which is depressed when no load is in the chain hoist. This operation need only be carried out when the system is first turned on. The multiplexer is then switched to position 2.

In this position, the LM163 inputs are connected across the middle resistor in a string of resistors. The voltage across this resistor represents the precise full-scale output voltage of the load cell transducer. Although the transducers are specified for only 0.1% interchangeability, the precise value of gain slope is furnished with each individual device. This information allows the system to determine the gain slope of the transducer. In practice, the middle resistor in the string is physically located within the load cell connector. When any such equipped load cell is plugged into the system, the value of this resistor allows immediate and precise gain slope compensation and eliminates the usual manual calibration requirements. When this measurement is completed, the multiplexer is switched to position 3. In this position the output of strain gage bridge A is connected to the LM163 instrumentation amplifier. This signal, which represents the transducer output, is amplified by the LM163, converted by the A/D and stored in memory. The fourth multiplexer operation is used to read the temperature of the load cell. In this position, the output of the LM335 temperature sensor, which is located inside the load cell transducer, is determined and stored in memory. The relatively high level LM335 output is resistively divided by 100 so the LM163 does not saturate. Two separate temperature terms, zero and gain TC, affect the load cell. Although the LM335 provides the absolute cell temperature, the sign of each temperature term in any individual cell will vary. Thus, not only the cell's temperature but the sign for both zero and gain terms must be furnished. This is accomplished by a pin strapping code inside the load cell's connector. This sequence of operations is also performed by multiplexer B for load cell B. When all the information for both transducers has been collected, the microprocessor can determine the actual weight of the roll. The temperature information provides a first-order correction for the relatively small effect of ambient temperature on the load cell's gain and zero terms.



*Pin strap code for cell temperature signs (both A and B)

FIGURE 3

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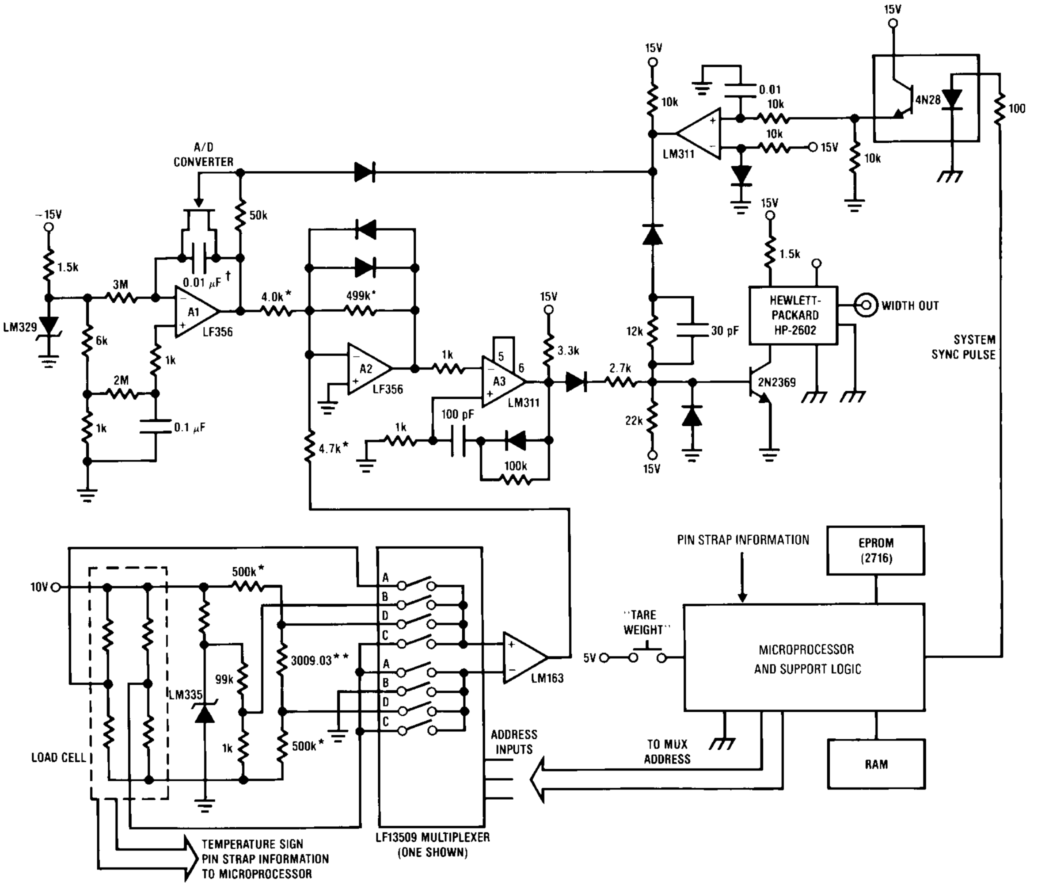
The gain calibration resistor string inside the load cell allows complete field interchangeability with no manual field calibration required. In practice, the load cell connector heads are modified by the addition of the resistor string, temperature sensor and temperature sign pin strapping after the cells have been purchased from the manufacturer. Connector types with the appropriate extra number of pins are substituted for the originals and the completed modified transducer is furnished as a unit to the end user. The stability of this approach is entirely dependent on the resistors in the gain calibration string. The voltage drive to the bridge need not be stable because it is common to the gain calibration string and ratiometrically cancels. Low pass filtering of electrical and mechanical noise is achieved by displaying the digitally-averaged value of a number of measurement cycles. It is worth noting that zero and gain drifts in the instrumentation amplifier and the A/D converter are continuously compensated for by the closed loop action of the microprocessor. The sole requirement for these components is that they be linear and have noise limits within the required measurement precision. In this manner, the zero and gain drifts of all active electronic components in the system are eliminated, which considerably simplifies the selection and design of these components.

A schematic diagram of the system appears in *Figure 4*. For purposes of clarity only, one load cell and its associated multiplexer are shown. Details of the microprocessor are also not included. The LF11509 multiplexer feeds the LM163 instrumentation amplifier. The LM163's output is routed to the A/D converter section which is composed of a ramp generator (A1) and a precision comparator circuit (A2-A3). The output of the A/D is a pulse width which varies with the LM163's output amplitude. This pulse width is fed to the microprocessor which uses it to gate a high speed clock. A



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†Teflon

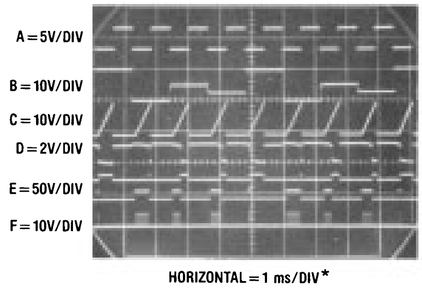
*Ultronix 104A ratio match 0.005%.

**Ultronix 104A, 0.01% value shown is ideal for precise 30 mV output load cell and must be selected at load cell test.

FIGURE 4

loop is completed by using the microprocessor to control the LF11509 multiplexer address inputs. Operation of the system is best understood by referring to *Figure 5*. Trace A is a system synchronizing pulse which is generated by the microprocessor. Trace B is the output of the LM163, which is connected to the multiplexer. Each time the synchronizing pulse goes low, the multiplexer advances one state. The leftmost multiplexer state in the photograph is the zero signal. The next state is the gain calibration, which is followed by the strain gage bridge output and then the temperature signal. The next 4 multiplexer states repeat this pattern for the other load cell. Each time the multiplexer changes state, the LM163 output is compared to the A1 ramp generator output (trace C) by the A2-A3 comparator. A2 acts as a preamplifier for the A3 comparator, insuring a low noise trip point. When the ramp is very close to balancing the current being pulled out of A2's summing junction by the LM163, A2 comes out of diode bound (trace D, *Figure 5*) and trips A3. The rapid slewing, high level signal from A2 allows A3 to have a noise free transition (trace E, *Figure 5*). This output is used to turn off a high speed clock (trace F, *Figure 5*) which was started at the beginning of the ramp (comparator-ramp-high speed clock detail shown in *Figure 6*). The waveforms show that the number of high speed pulses which occur at each multiplexer state varies with the LM163's output. Because the ramp is highly linear and the comparator very stable, a direct relationship between the number of high speed pulses and the LM163 output is assured. The final computed answer at which the microprocessor controlled loop arrives will nullify the effects of drift in the A/D converter and instrumentation amplifier.

In practice, this system has met specifications in the industrial environment for which it was designed. It furnishes a good example of the type of intelligence which is becoming typical in industrial measurement and control apparatus. The interlocking of analog and digital techniques to solve a difficult measurement problem will become even more common in future applications.



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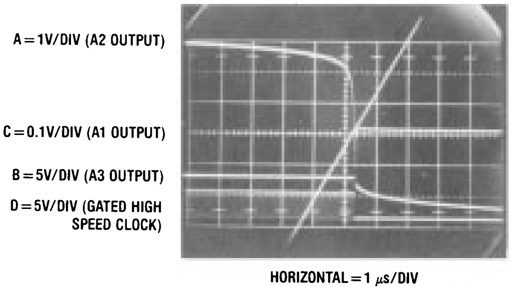
*System operation normally occurs at a 2 Hz rate but has been sped up for photographic convenience.

FIGURE 5



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Details of comparator-ramp-high speed clock interaction:

When A2's output comes out of bound (trace A), the A3 comparator responds with a clean, noise-free transition (trace B), causing the high speed clock burst to cease (trace D). Trace C shows the ramp, greatly expanded. A2-A3 trip point occurs just after the ramp passes center screen.

FIGURE 6

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