

Signal Digitization Using Voltage To Frequency Conversion For Wireless Sensor Node

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Abstract: In future reactors, WSN is going to take a major role in the monitoring and control instrumentation. Diversity and redundancy are the prime requirements of nuclear domain. To provide diversity in the data acquisition method of WSN, instead of using legacy ADCs, an alternate method of digitization can be introduced. This paper proposes a method of digitizing using the concept of Voltage to Frequency Conversion (VFC). But there exists a serious constraint on resources like energy, memory and bandwidth for a deployment based on wireless sensor nodes. Key idea explained in this paper is about the selection of components, which consumes minimum energy, to develop a signal conditioning board that performs signal digitization utilising VFC. This paper also explains the establishment of a typical network that utilizes VFC.

Keywords: Wireless Sensor Network, Voltage to Frequency Conversion, VFC, Signal digitization, Data acquisition.

I. INTRODUCTION

Wireless Sensor Network (WSN) is a network of many sensor nodes which are employed for sensing various physical parameters. These sensed data are transmitted wirelessly to the receiving end; generally called as base station. Wireless sensor node consists of many blocks such as power supply block, microcontroller, transceiver, sensors, signal conditioning board and Analog to Digital Converter (ADC) as shown in Fig. 1.

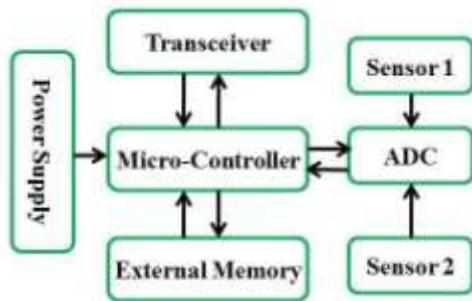


Fig.1 Wireless Sensor Node Architecture

Power Supply block is the main source that provides power to the WSN node. It is designed to meet the power requirement of the node. Power consumption is more during the sensing of process parameters, processing of sensed data and during the transmission of the processed data. Reduction of energy consumption is an important task to be followed because these sensor nodes are deployed in sites where availability of power source is limited. Microcontroller is used for processing the sensed data and to handle the RF protocol stack. Processed data is transmitted via a transceiver utilizing radio frequency to the base station where the data can be viewed.

Sensors are used to sense the environmental/ process parameters like temperature, pressure, vibration, humidity, etc. and to produce a measurable electrical response. Signal conditioning is the modification of the signal in a way that prepares the signal for next stages of processing. Most analog signals require some form of conditioning before they can be digitized. For example, the thermocouple signals are in millivolt level that must be amplified before they can be properly digitized, while other sensors like thermistors, strain gauges, accelerometers require excitation to operate. Thus signal conditioning includes process like amplification, filtering, level translation, range matching and isolation to make the sensor output suitable for processing.

The conditioned signal is then digitized by an ADC. Sample & hold circuitry of ADC samples the input and converts an analog signal to a discrete time and discrete amplitude digital signal. ADC generates a digital number proportional to the magnitude of the input analog voltage. This conversion involves quantization of the input so that, only a small amount of error is introduced.

In general ADCs are the primary mode of digitization. In order to have a better resolution, dynamic ranging than the available traditional ADCs and to have an alternate method of digitizing, concept of Voltage to Frequency Conversion (VFC) is presented in this paper. A typical application of acquiring slow varying signal like thermocouple is also explained.

II. VOLTAGE TO FREQUENCY CONVERTER

VFC generates a stream of pulses with frequency proportional to the input voltage. VFC works on the principle of current integration and comparison with input voltage as shown in Fig.2 [3]. In the first stage of VFC, input voltage is passed through an integrator that produces a ramp signal and this signal is compared with a comparator that produces a negative or positive voltage. The output voltage from the comparator is again given as a feed-back to integrator which gives a triangular wave as output. Slope of the triangular wave and ramp signal is proportional to the input voltage. Integrator output is compared with a reference signal in the comparator to produce a pulse signal.

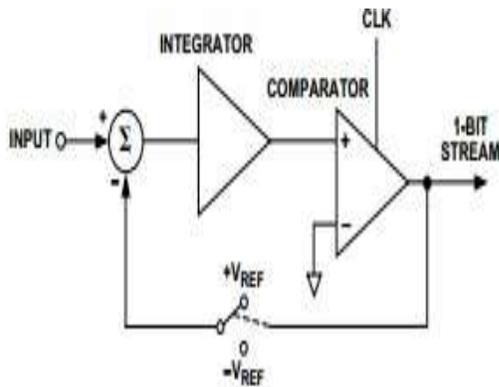


Fig.2 VFC Converter

Designing of voltage to frequency converter using discrete components increases the overall power consumption. Since, discrete components individually contributes to increase in overall power consumption, a single VFC IC provides a better solution to this problem.

TABLE 1: Comparison of VFC converters based on specifications

Parameters	ADVFC32 [4]	VFC32 [5]	AD7741 [6]
Voltage	10 V	22 V	5V
Input current	10mA	6 mA	8 mA
Internal Non-linearity	0.2% (at 500 KHz)	0.01% (at 10KHz)	0.012% (at 1.35MHz)
Max output frequency	500 KHz	500 KHz	2.76MHz

The VFC is selected based on comparison among different vendors as shown in Table 1. It has single channel converter which consumes typically 6 mA current and also has a power down feature that reduces the current consumption to less than 35 μ A. Moreover it has very less gain error, thus AD7741 is chosen to perform VFC.

III. TYPICAL APPLICATION

In this paper a typical application of acquiring a slow varying signal from thermocouple is used as input. Design has been made with a provision to connect eight thermocouple signals.

A. Hardware Development

Signal conditioning board to acquire eight thermocouple inputs consists of blocks as shown in Fig.3. Thermocouple leads are connected to an 8x1 multiplexer since the VFC chosen is for a single channel. Selected input will be fed to an instrumentation amplifier which conditions the signal to get digitized using the VFC IC. The frequency output is given to a counter to count the pulses. Final count corresponding to the input voltage is read by the microcontroller. The host microcontroller in the main board is connected to a pre-configured RF233 based zigbee module which transmits the thermocouple data to the base station where data corresponding to individual channel can be viewed in a Graphical User Interface (GUI).

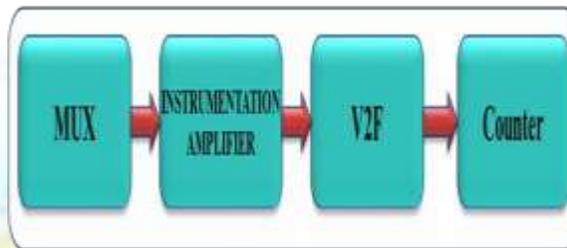


Fig. 3 Block diagram of proposed model

B. Component Selection

Multiplexer: Multiplexer is termed as a data selector due to the fact that it selects one of many analog or digital inputs. The selected input is then forwarded onto a single channel thus facilitating many signals to share a single common medium.

Different multiplexers are compared as shown in Table 2. Based on the specification of minimum current consumption and operating voltage, ADG707 has been selected. This analog multiplexer is capable of handling 16 single channels or eight differential channels.

The ADG707 Multiplexer switches between one of eight differential pairs of thermocouple input. The selected signal is then forwarded to a common differential output as determined by the 3-bit binary address lines. Address lines A0, A1, and A2 are connected to the GPIO pins of the microcontroller. An EN pin is used to enable or disable the multiplexer.

TABLE 2: Comparison of multiplexers based on specifications

Parameters	74HC151 [7]	74HC153 [8]	ADG707 [9]
Voltage	7V	7 V	5.5 V
Power Consumption	500mW	500mW	<0.01 μ W
Leakage current	$\pm 0.1\mu$ A (25°C)	$\pm 0.1\mu$ A (25°C)	± 0.2 nA (25°C)

Differential channels	8x1	4x1	8x1
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Instrumentation Amplifier: Instrumentation amplifier has high input impedance due to which it does not load the input system. Hence this amplifier is aptly suitable for use in industrial data acquisition. Instrumentation amplifiers provide better accuracy and stability.

AD8237 is chosen as the instrumentation amplifier because it provides very less gain error and very high input impedance. Moreover it operates right from 1.8V and current consumption is far less than other amplifiers. Gain is set by using two external resistors and it creates low gain drift at all gains.

TABLE 3: Comparison of Instrumentation Amplifiers based on specifications

Parameters	AD623 [10]	AD620 [11]	AD622 [12]	AD8237 [13]
Gain error(1-1000)	0.03-0.35%	0.03-0.7%	0.05-0.5%	0.005%
Input Impedance Differential mode Common mode	2 2 GΩ pF 2 2 GΩ pF	10 2 GΩ pF 10 2 GΩ pF	10 2 GΩ pF 10 2 GΩ pF	100 5 MΩ PF 800 10 MΩ pF
Operating Range	±2.5-±6 V	±2.3 - ±18 V	±2.6 - ±18 V	1.8 to 5.5 V
Quiescent current	375-550 mA	0.9 - 1.8 mA	0.9 - 1.3 mA	115 to 130 μA

Counters: Counters are used to count the number of pulses from the VFC. Upon comparison of various counters, SN74LV8154 is a 32-bit counter which can also be used as a dual 16-bit counter is chosen. It provides 8 bit data lines where individual lines are configured as 3 state logic output. To map a 32-bit storage register on the 8 bit output bus, four bus reads are required. The GAL, GAU,

GBL, GBU inputs are used to select the byte that needs to be output at Y0–Y7. These select lines are configured as GPIO output while data bus lines are set as input in microcontroller.

TABLE 4: Comparison of Counters based on specifications

Parameters	HEF4516B [14]	74HC193 [15]	MC14516B [16]	SN74LV8154 [17]
Voltage	18 V	7 V	8 V	7 V
Supply Current	50 mA	50mA	10mA	20μA
Power Dissipation	100 mA	500 mW	500 mW	56 mW

After careful selection of individual components, signal conditioning board which does digitizing using the concept of VFC, is designed and fabricated. Fabricated VFC board is shown in Fig.4 and Fig.5



Fig. 4 Top view of fabricated VFC board



Fig.5 Fabricated VFC board connected to main board

C. Embedded Program Development

Embedded program involves usage of primitive APIs and development of drivers to interface GPIOs and SPI. GPIO pins are used to control the select lines of multiplexer and counter. SPI is used to interface pre-configured RF233 based zigbee module. APIs are used for communicating with the transceiver.

1) General Purpose Input/Output (GPIO)

GPIO is an interface available on microcontrollers to provide an ease of access to the device internal properties. GPIO pins on a single microcontroller can be programmed as input or Output and can be pulled-up or pulled-down. Address lines A0, A1 and A2 of multiplexer are connected to GPIO pins that are configured as output in the microcontroller. Similarly, data lines Y0-Y7 of counter are interfaced with input pins and the control address lines are interfaced with output pins, by configuring the GPIO pins of the host microcontroller.

2) Serial Peripheral Interface (SPI)

SPI is a synchronous data bus that uses separate lines for data and clock. The clock signal is an oscillating signal that acts as a reference to the receiver to indicate exactly when to sample the bits on the data line. This could be the rising (low to

high) or falling (high to low) edge of the clock signal. When the receiver detects that corresponding edge, it will immediately read the data line. Flowchart of SPI communication is explained in Fig. 6.

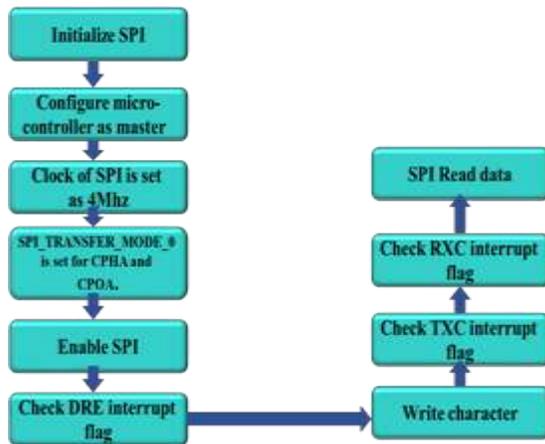


Fig. 6 Flowchart for SPI driver

Sensor node is interfaced with pre-configured RF233 based transceiver module using SPI. Transceiver is programmed with a minimalistic Zigbee RF stack. APIs are used for communication between transceiver module and the microcontroller of sensor node. Data transfer between sensor node and base station is shown in Fig. 7.

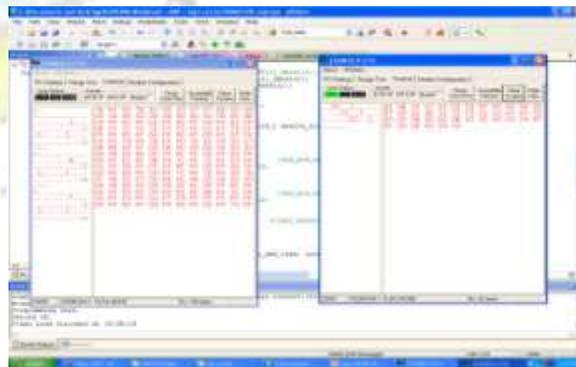
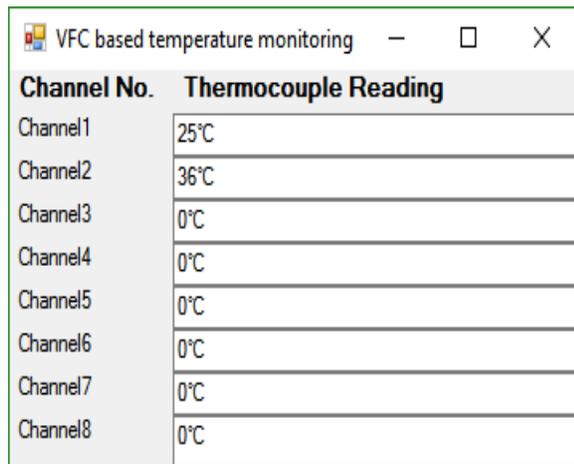


Fig. 7 Data transfer between sensor node and base station

D. Standalone Desktop Application

A standalone desktop application based on Visual Basic platform has been developed. The application utilizes COM port component of the platform and communicates with the base station that has RF233 based transceiver. The application then parses the content of the frame being received through the COM port and displays the readings of the sensor node in its corresponding textbox. Database connectivity using MS Access has been provided to log the temperature readings.

In a typical application, 2 numbers of thermocouple signals have been connected to the node. One thermocouple measures the lab temperature and other measures the ambient temperature of environment. Other inputs are made short. Snapshot of the readings transmitted by the sensor node is shown in Fig. 8.



Channel No.	Thermocouple Reading
Channel1	25°C
Channel2	36°C
Channel3	0°C
Channel4	0°C
Channel5	0°C
Channel6	0°C
Channel7	0°C
Channel8	0°C

Fig.8 Display of Thermocouple readings at base station

IV. CONCLUSIONS

Generally all the sensor nodes will be using ADCs to digitize the real world analog data. But in a field where diverse and alternate mode of digitizing is required, solution based on Voltage to Frequency can be utilized. To check the functionality based on this digitization, a typical application has been identified to connect 8 thermocouples and a suitable VFC hardware has been designed. In this paper, the flow involved in the development of digitization, circuit fabrication, embedded program development to read the process parameter and finally displaying the thermocouple readings in a standalone application are explained.

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