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Design and Realization of SPI Interface in Lithium-ion Battery Voltage Measuring System

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Abstract—**This paper presents a voltage measuring system, which based on the AVR microcontroller AT90CAN32 and one or more multicell battery monitoring integrate circuits LTC6802 used in BMS(battery management system). Gives the hardware design and the software design for serial peripheral interface(SPI) communication. The use of iCoupler technology realizes the high-speed SPI communication and its reliable isolation. The off-line test shows that the system is compact in structure, ease to expand and meet the requirements of stabilization and reliability**

Keywords—**Serial Peripheral Interface; LTC-6802; AT90CAN32; iCoupler**

I. Introduction

Nowadays Lithium-ion batteries have boomed the energy storage market. Compared to NiMH and other batteries, lithium-ion batteries have higher cell voltage, superior energy density, lower self-discharge rate, and with no memory effect, which has become the first choice for the power battery of electric vehicle(EV)[1,2]. However, the voltage in each cell has to be between 2. 5 V and 4.25 V, if the voltage beyonds the range, the lithium-ion battery would be driven into deep discharge or overcharge, which may cause the battery to swell or even explode and catch fire. Therefore, it is important to development a battery management system(BMS) to monitor the cell voltage and to avoid the above accidents [3,4].

The LTC6802 is a complete battery monitoring integrated circuit (IC), which includes a 12-bit Analog-to-Digital Converter (ADC), a high voltage input multiplexer, a precision voltage reference and a serial peripheral interface. Each LTC6802 has the ability of measuring up to 12 series connected battery cells, and it can management the input voltage up to 60V. In addition, multiple LTC6802 devices can be connected in series to measure the voltage of each battery in a long battery string. The unique level-shifting serial interface allows multiple LTC6802 devices to be daisy-chained without optocouplers or isolators[5,6].

In a BMS based on LTC6802, SPI communication is an import factor or a bottleneck in the design process, for the reasons listed as following.

1. All digital data are transferred by this bus, including the control commands of LTC6802, battery voltages, temperatures, battery conditions and GPIOs, and so on.

2. The LTC6802 can measures the voltage of each cell in a long battery string, but the problem of floating ground, which exists in the charge and discharge circuit, will affect the process of measuring and balancing.

3. The clock for SPI communication in a BMS is above 1MHz in common, but general optocouplers are not competent for such application.

4. LTC6802 links the battery main circuit and BMS together, the main circuit works on strong power conditions while the BMS works on feebleness electricity conditions, so it’s essential to isolate the two circuits on both sides.

Considering the requirement of the accurate and rapid measuring of each cell voltage, this paper presents a voltage

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measuring system based on the AVR microcontroller AT90CAN32, which could read back the real time battery voltage from LTC6802, and using one or more multicell battery monitoring integrate circuits of LTC6802 as sub-cpu In the SPI communication AT90CAN32 acts as host controller while LTC6802 acts as sub controller, there also gives an implement design in hardware and software. A type test is done and give an verification for test analysis.

II. Hardware Design

Multiple LTC6802 devices can be daisy-chained without optocouplers or isolators in the design of normal BMS. Figure1 shows a SPI communication based on daisy-chain topology, where 3 LTC6802 ICs daisy-linked in a string to monitor a battery.

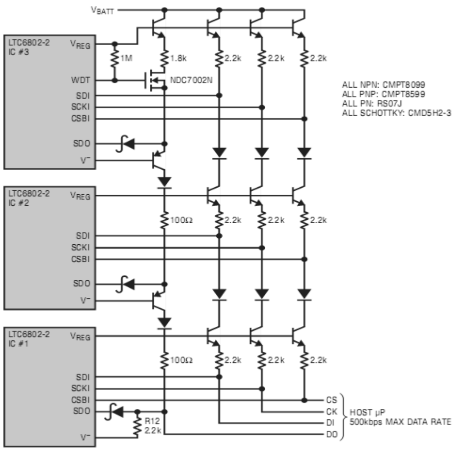

Figure 1. A SPI communication based on daisy-chain topology

This kind of daisy-chain topology has the limitation as following:

1. Compared to other topologies , the cost of managing the network is high in the daisy-chain. In case one component in the daisy-chain system breaks down, the entire network will down, so the topology will not be suitable for expansion and implement.

2. Limited by manufacturing technology, the daisy-chained electric devices will share the battery voltage in an unbalanced mode, that means some devices may share too high voltage to break down, even cause a short-circuit failure.

3. The BMS would be destroyed when the high terminal voltage(between VBATT and V-) pours into the SPI communication circuit directly.

These issues are mainly caused by the floating ground, for the power supply of LTC6802 is taken from the upper and lower voltages of the cells connected in series, but the micro-controller is powered by the low drop voltage regulator, the respective ground of these two module are different, so isolators are needed. For the clock of SPI communication between the AT90CAN32 and the LTC6802 is above 1MHz, an general optocouplers are not competent for the application, where ADUM1411 device is used to isolate the both sides of SPI communication. The ADuM1411 device is a four-channel digital isolator based on iCoupler technology with no need of external interface circuitry for logic interface. Combining monolithic air core transformer and high speed CMOS technologies, the isolation component provides outstanding performance characteristics superior to optocoupler and other isolator devices . Meanwhile, the data rates of AduM1411 up to 10 Mbps, with which speed the device is competent for the application. Figure2 shows the typical isolation circuit for SPI communication based on ADUM1411,this circuit provides totally galvanic isolation between the batteries and the LTC6802, when the ltc6802s are stacked in a chain, the communication circuit is same.

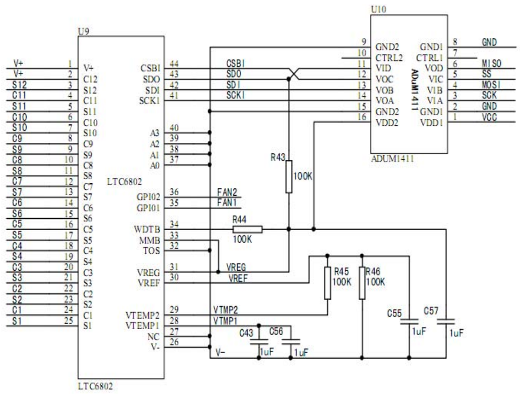

Figure 2. A typical isolation circuit for SPI communication based on ADUM1411

In this design of the SPI communication, The logic electrical level of LTC6802 is depended on the two pins (VREG and V-), which represent the logic high level and logic low level respectively. The pins of A0,A1,A2,A3 are the address inputs, the pins are tied to VREG or V-. The state of the address pin(VREG=1,V-=0) determines the LTC6802 address, and the multiple devices are uniquely identified by the address determined by the A0 to A3, Where, the address of LTC6802 is set to 0x80 , so address pins are all tied to V- pin. On the LTC6802, four pins comprise the serial interface: CSBI, SCKI, SDO and SDI, which are corresponding to SS, SCLK,MISO, MOSI pins in AT90CAN32. Based on the above settings and planning we carried on the software design.

III. SOFTWARE DESIGN

A. Initialization of the SPI communication

In the SPI communication case, a AT90CAN32 acts as a master, and the LTC6802 acts as a slave. Both of them prepare the data to be sent in their respective shift registers, and the AT90CAN32 generates the required clock pulses on the SCK line to interchange data. Data is shifted from the AT90CAN32 to the LTC6802 on the MOSI (Master out- Slave in) line, and from LTC6802 to AT90CAN32 on the MISO(Master in-Slave out) line. After each data packed, the AT90CAN32 will synchronize the LYC6802 by pulling the CSBI (Salve Select) line. The registers of SPCR(SPI Control Register), SPSR (SPI Status Register) and SPDR (SPI Data Register) have direct relation with SPI communication. When exchanging data, the MSB(Most Significant Bit) of the data word is transferred first. Where the external oscillator is used as the system clock input, its clock is $f_{cklio} = 8\ MH_Z$, so there setting SPR1 = 0, SPR0 = 1, SPI2X = 1, then $f_{sck} = f_{cklio}/8 = 1\ MHz$. The PB pins is set for SPI communication. The pieces of codes as following.

```
void port_init()
   {
 //Set the MISO pin as input pin, all others as output pin//
     DDRB=0X07;
     PORTB=0XFF;
         }
void spi_init(void)
   {
     SPCR=0XDD;
     SPSR=0X01;  //Double SPI speed//
         }
void spi_write(unsigned char data)
   {
     SPDR=data;
     while (!(SPSR&(1<<SPIF)));
   }
int  spi_read()
   {
     while (!(SPSR&(1<<SPIF)));
     return SPDR;
     }
```

B. Main program

The main program mainly accomplishes the initialization of the entire system, including the initialization of the AT90CAN32 and the LTC6802. The address pins of LTC6802 are tied to V-,so the address of LTC6802 is 0X80, and the command of start cell voltage A/D conversions (STCVAD) must be send first before sending the command of read voltage(RDCV). A whole process of SPI communication is as following.

(1) Pull CSBI low.

(2) Send Address (In the case the address is 0X80).

(3) Send the command.

(4) Pull CSBI high.

Where, Flg_Read_Vol is the flag of reading voltage which is used in the interrupt program.

```
int  main (void)
  {
     cli();
     port_init();
     spi_init();
     ltc6802_init();
     sei();
     while(1)
         {
            PORTB&=0XFE;
            spi_write(0x80);
             spi_write(STCVAD);
             PORTB|=0X01;
             PORTB&=0XFE;
             spi_write(0x80);
            Flg_Read_Vol=1;
             spi_write(RDCV);
            PORTB|=0X01;
           }
     }
```

C. Read Cell Voltage

The AT90CAN32 uses SPDR(Ring-Shift- Register) for receiving data in a SPI communication process. When receiving data, the received data must be read from the SPI Data Register before the next data has been completely shifted in, otherwise, the first byte will lost. However, the LTC6802 can not generate the clock pulses for the AT90CAN32 in this case. So the AT90CAN32 must generates the clock pulses before receiving cell voltages from LTC6802. The receiving data, including 18 bytes of cell voltages for 12 batteries and a byte of PEC code, are placed in the registers from CVR00 to CVR18.

```
void Read_volitage (void)
   {
     int j=0;
     for (j=0;j<19;j++)
          {
             spi_write(0X00);
//Generate the clock pulses for receiving data//
             RCV[j]=spi_read();
          }
     }
```

D. Interrupt Service Routine

This subroutine accomplishes the mission of receiving the data from LTC6802.

```
SIGNAL(SIG_SPI)
  {
        cli();
        if (FLG_Read_Vol==1)
          {
          Read_volitage ();
          Flg_Read_Vol&=0;
          }
        else
          {
            ;
          }
       sei();
  }
```

E. CRC Calculation

The PEC(Packet Error Code) byte is a CRC value, which is calculated for all of the bits in the register group in the order they are read, the characteristic polynomial is as following：

$$G(x) = X^8 + X^2 + X + 1$$

When a reading command, after sending the last byte of the register group, the device may shift out the calculated PEC, MSB first. The CRC107 is the subroutine for Cyclic Redundancy Check (CRC).

```
unsigned char  CRC107(unsigned char *buff, int len)
{
    int   ByteC, BitC;
    int   CRC;
    int  i;
    CRC = 0;
    ByteC = 0;
    BitC = 0;
    while(ByteC < len)
    {
       if(buff[ByteC] & (0x80>> BitC))
           CRC |= 0x01;
       if(crc >= 0x100)
           CRC ^= 0x107;
       CRC <<= 1;
       BitC++;
       if(BitC== 8)
       {
           BitC= 0;
           ByteC++;
       }
    }
    for(i=0; i<8; i++)
    {
       if(CRC >= 0x100)
           CRC ^= 0x107;
       CRC <<= 1;
    }
    CRC >>= 1;
       return (char)CRC;
}
```

F. Test and Analysis

Selecting a lithium-ion battery group that consists of 12 batteries with nominal voltage. In the off-line condition, use the battery voltage measuring system to measure the signal battery voltage.

The values in the array RCV[j] are:

38 ,F9, 9E ,58, EA, 96 ,64 ,8A ,9A ,BD ,38, 8B ,41 ,DA, 94 ,8F, E9, 8A, 27

And the last data ”27” is the PEC, the former eighteen data are corresponding to the values of CVR00 to CVR17, and the actual Hex code for the voltage of 12 cells are sliced from the registers:

938， 9EF， A58， 96E， A63， 9A8， 8DB， 8B3， A41，94D，98F，8AE

Here, the cell voltages is calculated by these data multiply 1.5mv. The acquired voltage datum are accurate and reliable. An universal meter is also used to measure the voltages for the cells as reference. The result is shown in the Table 1 below.

TABLE I. THE DATA MEASURED BY LTC6802 COMPARED WITH THAT FROM A DIGITAL UNIVERSAL METER.

NO.	Measure data(v)	Detected data(v)	Error(V)
1	3.54	3.52	+0.02
2	3.81	3.80	+0.01
3	3.97	3.94	+0.03
4	3.62	3.60	+0.02
5	3.99	3.98	+0.01
6	3.56	3.56	0
7	3.34	3.32	+0.02
8	3.39	3.46	+0.03
9	3.94	3.91	+0.03
10	3.57	3.56	+0.01
11	3.67	3.70	-0.03
12	3.33	3.32	+0.01

CONCLUSION

Based on the analysis on the character of lithium-ion battery and SPI communication, this paper presents a voltage monitoring system to monitor the voltages of cells in a string uses the LTC6802 device and AT90CAN32 micro-controller. The iCoupler technology is used to guarantee the validity and accuracy of the SPI communication. Meanwhile cooperated with the AT90CAN32, the work also helps the smart control of voltage balancing for lithium-ion battery. The design is part functionality of a BMS, and the future work will focus to the issues of electro-magnetic interference and system power consumption .

References

[1] Dai Yongnian, Yang Bin, Ma Wenhui, The Development of Li-ion Battery and Light-EV[J]. Advanced Materials Industry,2006.(9):16-18.

[2] Huang Xuejie. Li-ion Battery and its Key Materials[J].Materials China, 2010,(8):46-51.

[3] Sun Bei,Wei Xuezhe, Design of voltage monitoring module of stacked lithium-ion cells in series[J].Applied Mechanics and Materials Vos.29-32(2010)1888-1893.

[4] Michael Kultgen, Jon Munson. Battery stack monitor extends life of Li-Ion batteries in hybrid electric vehicles[J]. Linear Technology, 2009 , 19(1):1-2.

[5] Linear Technology Corporation,Datasheets of Multicell Addresssable Battery Stack Monitor LTC6802

[6] Greg Zimmer, Design of battery management for high power li-ion battery stack management [J]. Electronic Products,2009,(2):61-62.

[7] Liang Dejian,Liu Yuqiong, Remote transmission of SPI bus data[J].Electronic Test,2009.0(1):72-74.

[8] Hang Qiu, Ding Wei-cheng,Fang Fang; The Interface Circuit Design Between FLASH ROM with SPI Interfaces and C8051F340[J].Techniques of Automation and Applications, 2010,29(4): 99-102.

[9] Xiao Qingliang;Yang Dewei;Zhang Chaoyang, Noise Analysis of Optic-Electrical Signal Conditioning Circuit in Acquisition System[J]. Journal of Data Acquision and Processing, 2009,10(24):206-209.