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A design and Implementation of Portable Spectrum Analyzer

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Abstract

With the progress of society signal measurement and analysis have more widely range of applications, but the spectrum analyzer was generally expensive to make it difficult for popularization and application. In this paper, a design methodology of low cost, stable reliable spectrum analyzer based on the idea of Software Defined Radio (SDR) is presented, which consists of three functional units. The STM32 is the core of spectrum analyzer and is the key base to signal acquisition and analysis of the system. This paper designs the detailed hardware circuit and the software and optimizes the display program to obtain a higher refresh rate. Through testing the design is stable and reliable, simple and practical, and suitable for use in scientific research and industry production.

Keyword: *Software Defined Radio; STM32; FFT; DMA; FSMC*

1. Introduction

Spectrum analysis is the signal analysis technique by translating the signal from time domain to frequency domain, which has a wide range of application in the field of life, production, scientific research. Especially for some signal whose characteristics of the time-domain are not significant spectrum analysis is very necessary. In order to observe the spectrum directly a spectrum analyzer is usually used. The spectrum analyzer has numerous type and mature technology, but the main products are monopolized by several foreign large company and had expensive price, such as R&S, Agilent, *etc.* [1].

With the acceleration of industrialization and information process there are more and more measuring and testing which are not just in theoretical research but also in the real experiment. Therefore the demand for the spectrum analyzer is also growing. In recent years, the rapid development of microelectronic technology and modern signal processing technology provide the conditions for design and implementation of spectrum analyzer which is portable and has the advantage of low-cost, high-performance [2].

This paper presents a design methodology of digital spectrum analyzer which based on the idea of Software Defined Radio (SDR) and explained its software and hardware explicitly.

2. System Structure and Principle

The idea of the Software Defined Radio is put forward in 1990s. The key of SDR is to build a common, standardized, modular hardware platform, then to implement the various functions of radio by software programming. Thus the electronic design is getting present the characteristics of "software defined hardware", and greatly reduces the cost of electronic design and development [3].

This paper brings forward the design schemes of the hardware platform using stm32 as the core, in the light of its richness of peripherals devices. The design is divided into three parts as shown in Figure 1: signal input module, signal processing module and signal output module. Firstly, the input signal is modulated by signal conditioning circuits,

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then converted into digital signal by A/D converter. After the data is sampling by STM32, the data is transform processing by FFT and then transferred to the TFT-LCD display or send to computer for further processing. Its performance is mainly affected by CPU speed, ADC speed, output speed, *etc.* [3], and its key performance indicators as follows:

(1) Signal amplitude: 0-3.3V

(2) Bandwidth: 1- 20 kHz

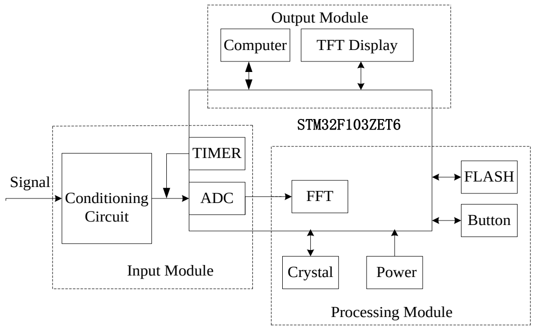

Figure 1. System Structure Diagram

There are two main methods to adjust the accuracy which is influenced by the conversion speed of A/D converter. One is automatic conversion that is performed in scanning mode. Sample rate is controlled by defining different sample time. This design method is simple, but there are only 8 different options, and have great deficiency in flexibility.

The other is performed in single-shot conversion which is triggered by an external event that generated by the TIMER, and can realize any conversion speed. This design method is flexible and has wide measuring range, but there are some shortages such as complicated design *etc.* Both methods are used in this design to adapt different situations.

3. System Hardware Design

3.1. STM32 Introduction

The STM32F103ZET6 is the latest 32-bit RISC Flash microcontrollers based on the ARM® Cortex®-M3 processor which is developed by ST Microelectronics [4], and has the advantage of high performance and low cost which is suitable for embedded system design. The chip's operating frequency can reach 72MHz. High-speed embedded memories which include 512K bytes of flash memory and 64K bytes of SRAM are satisfy the storage requirements of program and data.

There is a rich set of peripherals, communication interfaces which are embedded in STM32F103ZET6 such as 12-bit ADC, 16-bit timer, PWM, USART, and FSMC. The peripherals and communication interfaces make the chip easy to embedded development and design, and make it get a rapidly application in consumer electronics, smart devices, home security, *etc.* [5].

This paper develops the hardware platform using STM32F103ZET6 as core controller with a conditioning circuitry, buttons and large-scale TFT-LCD display circuit. Due to making full use of its rich peripherals and communication interfaces, the design is simple, reliable, easy to expand.

The STM32 chip is working at the voltage (VDD) for 2.0~ 3.6 V for I/Os, which provided externally through VDD pins. The voltage of ADC also is 2.0~ 3.6 V through VDDA and VSSA pins respectively. The power supply circuit design is as shown in

Figure 2, where the input VCC5V dc voltage after 3.3 V dc stability of linear 3.3 V voltage VCC3V3 though AMS1117.

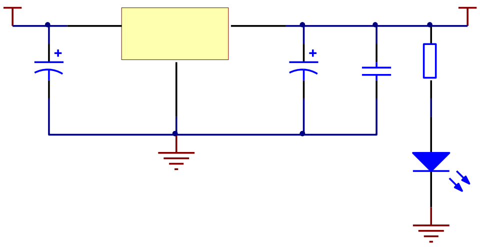

Figure 2. The Power Conversion Circuit

3.2. Signal Input Module Design

There are three 12-bit analog-to-digital converters (ADC) embedded into STM32F103ZET6, and each maximum sampling rate can reach 1Msps with ADCCLK at 14 MHz which satisfied the demand of most signal analysis. The ADC input ranges from 0V to 3.3V, when VREF- is 0V and VREF+ is 3.3V, and compatibles with most of the chip IO port voltage which bring convenience to the design [6].

Single conversion mode can be triggered by different ways such as setting software collocation and external trigger. In this paper, the input module is composed by PA1 port and PA8 port. PA1 port is configured to ADC1_IN1 and PA8 port is configured to TIM1_CH1. There is a zener diode in ADC port to constitute a voltage limiting protection circuit, and the circuit design shown in Figure 3.

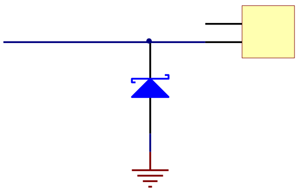

Figure 3. The Input Circuit Diagram

3.3. Output Module Design

There is a 7-inch resistive touch TFT LCD screen-MD070SD as the main display modes in the pape. The careen has advantages of accurate color reproduction, clear display signal details, with superior anti-interference ability, work stability, and is widely used in home security, industrial control, instrumentation, and other fields. The MD070SD has a resolution of 800 × 480. The output module can display waveform, spectrum and other information on the screen.

MD070SD uses a 16bit Parallel Bus Interface, and the transmission timing is 8080 series which has RD, WR, RS and CS control lines. The FSMC signals that are typically used to interface SRAM are WE, OE, CS and address bus. The difference between them is that the RS, but address bus are on MD070SD and FSMC are on the contrary [7]. The RS on MD070SD which is used to swap data and command can be tied to an address pin on FSMC through writing the address to choose data or command. The circuit design is shown as Figure 4, where FSMC_D15-D0 is connected to DB15 - DB0, and PB0, PB5, PD4, PD5, PG0, PG12 connected to LED_A, REST, RD, WR, RS, CS to achieve the functions of backlight control, reset, chip select, *etc.*

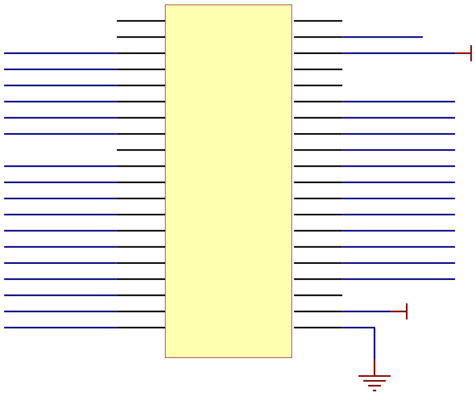

Figure 4. TFT Circuit Design Diagram

4. Software Design

The performance of the system will directly be affected by the function of the system software and the performance. The STM32F10x_StdPeriph_Lib and STM32F10x_DSP_Lib which are provided by the ST Company are used to design the software system in this paper. STM32 firmware library is a firmware package provided by ST Company including programs, data structures and macros, and covers all the performance characteristics of STM32 peripherals [8]. The firmware library allows any device to be used without directly operate on registers which make the development faster and easier, and reduce the difficulty of software design, save the time which spend on coding, improve the design efficiency and convenient to use.

The driver source code is developed in 'Strict ANSI-C'. It has a very strong compatibility, and can be used in different development environments, so there are many development tools, and everyone can use their familiar development environment to develop. In this paper the software development are based on Keil uVision4.

According to different functions the system software is divided into following modules: A/D convert, TFT-LCD display and FFT transform, *etc.* ADC adopted single-shot conversion mode, and the sampling rate is set up by TIMER where ADC1_IN1 sampling is triggered by the TIMER1. Then a set of the sampled data is brought into the memory by DMA. STM32 carries on the DIT4-FFT (Radix 4 Decimation in Time, DIT4-FFT) and send the results to TFT LCD driving by FSMC to display. The whole flow chart is shown in Figure 5.

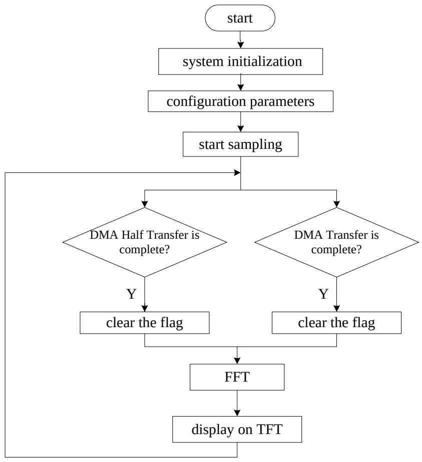

Figure 5. Program Flow Chart

4.1. FFT Transform

FFT is a spectrum analysis and measure technology by dividing the signal into some frequency component independently [9], using convert information from the time domain into the frequency domain or vice versa, with no information is gained or lost in transforming from one domain to the other. It is one of the conventional algorithms and is a kind of fast computation method of Discrete Fourier Transform (DFT). The basic principle is decomposed the long input sequence into successively shorter sequences and then calculated, the transform size may be any power of 2, *i.e*. 8, 16, 32, and 2048 *etc*.. This operation is often known as butterfly computation. Compared with DFT, FFT can effectively reduce number of calculation and is widely applied in spectral analysis.

The length of FFT is the number of sampling points, and the frequency of the signal is calculated as follows:

$Fn=(n-1)*Fs/N$, （$1 \le n \le N$）.

Where, Fs is sampling frequency, Fn is the frequency of the signal, N is the number of sampling points. The amplitude of DC value plus the n-1 frequency points are determined by the module of complex.

Hence, frequency resolution is Fs/N, under the condition of sampling frequency, the number of sampling points will increase if improving resolution. On the premise of making comprehensive consideration for the DMA, and CPU, a length of 1024 DIT4-FFT is used in this paper, which is supplied by STM32F10x_DSP_Lib that is compiled by assembly language with fast speed and high efficiency.

4.2. ADC Sampling

The total conversion time is calculated as follows:

Tconv = Sampling time + 12.5 cycles

Where, Tconv is the total conversion time, and there were eight kinds of sampling time period to choose the range from 1.5 cycles to 239.5 cycles [10]. The code set the sampling time is as follows.

ADC_RegularChannelConfig(ADC1, ADC_Channel_1, 1, ADC_SampleTime_239Cycles5);

Due to the maximum sampling rate is affected by the minimum conversion time of A/D conversion, the sampling rate in automatic conversion determined by the conversion time, and in single-shot conversion determined by the TIMER in the chip.

The STM32F103ZET6 including two advanced control timers, four general-purpose timers, that are based on a 16-bit auto-reload up/down counter, and a 16-bit prescaler, can achieve any dividing ratio and any sampling rate. The main code proposed to set the TIMER to trigger is as follows.

```
TIM_OCInitStructure.TIM_OCMode = TIM_OCMode_Toggle;
TIM_OCInitStructure.TIM_OutputState = TIM_OutputState_Enable;
TIM_OCInitStructure.TIM_Pulse = 99;
TIM_OCInitStructure.TIM_OCPolarity = TIM_OCPolarity_Low;
```

4.3. DMA Transfer

Direct memory access (DMA) is are widely used in digital processor chip in order to provide high-speed data transfer between peripherals and memory as well as memory to memory, where data can be quickly moved by DMA without any CPU actions. The DMA on the STM32 chip has two DMA controllers and supports circular buffer management to fulfill the continuous transmission of data.

In this paper the ADC is served by the DMA controller and the converted data will be sent to the memory using DMA transfer. The size of the transfer data are depended on the depth of the DMA buffer. The number of sampling points are 1024 in the design, thus the number of data to be transferred also is 1024, and set up the DMA buffer depth refer to 2048. The main code proposed to set the DMA is as follows.

```
DMA_InitStructure.DMA_PeripheralBaseAddr =&ADC1->DR;
DMA_InitStructure.DMA_MemoryBaseAddr = ADC_ConvertedData_Buffer;
DMA_InitStructure.DMA_DIR = DMA_DIR_PeripheralSRC;
DMA_InitStructure.DMA_BufferSize = 2048;
DMA_InitStructure.DMA_PeripheralInc = DMA_PeripheralInc_Disable;
DMA_InitStructure.DMA_MemoryInc = DMA_MemoryInc_Enable;
DMA_InitStructure.DMA_Mode = DMA_Mode_Circular;
DMA_InitStructure.DMA_M2M = DMA_M2M_Disable;
```

4.4. Display Design and Optimization

The program driving TFT LCD is similar to SRAM extensions by FSMC. In order to realize the function of RS operation on two contiguous addresses of FSMC because of the RS is connected to the address pin. A common approach is cast the address into a structure, to achieve the function of RS. The main code of structure as follows:

```
typedef struct
{
        u16 LCD_REG;
        u16 LCD_RAM;
} LCD_TypeDef;
```

Large scale TFT LCD screen can display more details about each image, and improve observational results. With the increase of the screen size and the increase of resolution, the screen pixels is also sharply increase and richer detail at the expense of data transmission. The STM32 chip not only conducted an FFT transformation, but also sent the result to TFT-LCD screen. With the increase of the sampling rate, the time spent on sending the result will less, and need ensure the screen refresh rate. In order to ensure the refresh rate, it is very necessary to improve data transmission efficiency, and reduce the amount of data transmission, because of the transmission at a constant speed of FSMC, according to the timing requirement of writing data timing on datasheet as shown in Figure6.

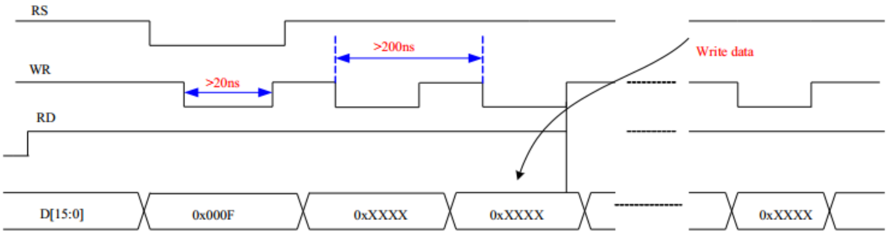

Figure 6. The Writing Data Timing Diagram

There is a function of address auto-increment on each screen, which means that the address pointer can automatically increase in one direction, and the color sequence filling, to avoid setting one after another address and filling color.

The scanning direction register in MD070SD are presented in Table 1, where the default direction is the row and will be on the loop to the beginning if met at the end of the line.

Table 1. Register List

CS	RS	DATA[15:0]	WR	RD	function
0	0	0x000D	0	×	The scanning direction register
0	1	0x0000	0	×	auto-increment on row
0	1	0x0001	0	×	auto-increment on column

It can effectively reduce the operations of setting pixel coordinates by using the function of the address auto-increment, when need to write one or more rows consecutively. In this paper, there is the great need for drawing spectrum image, and drawing the vertical line and the horizontal line will be the main operation.

No matter what kind of graphics, the graphics functions are achieved by drawing point. The drawing point function LCD_DrawPoint is the basis for all graphics functions, and is also the most important function. The code of point function is as follows.

```
void LCD_DrawPoint(u16 Xpos, u16 Ypos)
{
        Address_set(Xpos, Ypos,Xpos, Ypos);
        LCD_Write(Color);
}
```

All the graphics such as drawing lines and color filling are achieved by continuous drawing point. That means all of these functions are constantly set the coordinate position of a point through the cycle, fill the color to complete. Through the rational design of these functions, the operations will reduced greatly, and decrease data transmission, thus ensure refresh rate.

The coordinate setting function (Address_set (Xpos, Ypos, Xpos, Ypos))of MD070SD need a pair of start, end coordinate, while drawing a straight line, color filling usually also need a start, end coordinate. It can reduce the amount of the address setting operation and data transfer, using the similarity to set the address of the line or region

The code drawing line is as follows.

```
for(t=0;t<=distance+1;t++ )
{
        LCD_DrawPoint(uRow,uCol);
        uRow+=incx;
```

```
            uCol+=incy;
    }
```

Drawing a horizontal line need Length times the operation of Address_set and LCD_Write. It only need to Address_set once by using the line coordinate replace the point coordinate, and can reduce Length-1 times Address_set, and operations will greatly reduced, thus greatly decrease data transmission. The optimized code is as follows.

```
Void LCD_DrawHline(u16 Xpos, u16 Ypos, u16 Length)
{
        Address_set(Xpos,Ypos,Xpos+Length,Ypos)
        for(i = 0; i < Length; i++)
            {
                LCD_Write(Color);
            }
}
```

5. System Debugging and Testing

The display interface of the system is mainly composed of two parts:

(1) The display area of Time-domain waveform: Time;
(2) The display area of Spectrum waveform: Freq;

The ATF20B Function Generator of the NANJING GLARUN-ATTEN TECHNOLOGY CO. LTD which uses Direct Digital Synthesis (DDS) technology is used as a testing platform. Through changing some parameters such as frequency, amplitude, offset, the ATF20B Function Generator can generate sine wave, triangle wave, square wave, sawtooth wave and other standard signal.

The performance was tested on different frequencies including 0.1HZ and 10HZ of two waves-sine wave, square wave, while setting the amplitude lower than 3V. According to the results shown in Figure 7 and Figure 8, the design has perfect function, displays clear and smooth, and achieves the expectant results.

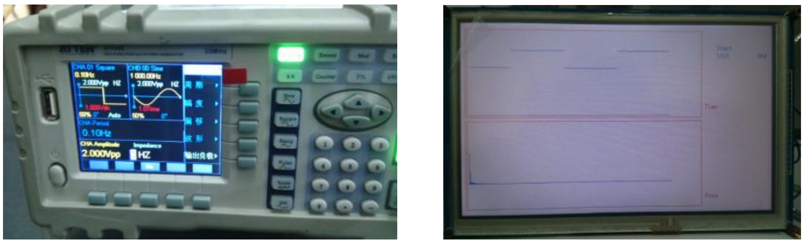

Figure 7. The Results of Square Wave

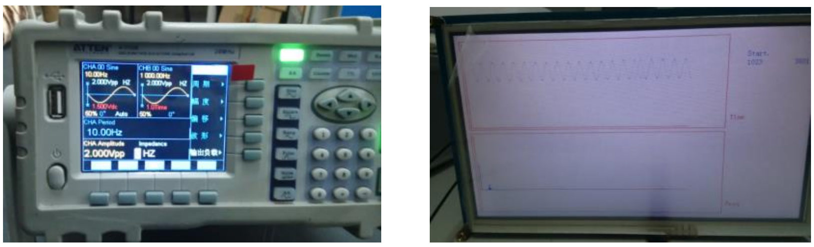

Figure 8. The Results of Sine Wave

6. Conclusion

With the increasing demand of signal measurement in scientific research and other areas, it is necessary to develop and design a Spectrum Analyzer which is cheap, effective, and suitable for the low frequency signals. This paper brings forward a design and implementation of Spectrum Analyzer using stm32 as core, designs the hardware and software, analysis the crucial technologies such as DMA, TIMER, ADC and FSMC.

For the sampling rate increases with the addition of the screen size, the display function is reduce the amount of the address setting operation and data transfer based on the function of address auto-increment. According to test, the design is stable, reliable, simple, economical, and easy to upgrade, expansion, has high value and a wide range of application.

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