

# 2FSK Modem Based on the Microcontroller AT89C51

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**Abstract**—In order to simplify the device of modulation and demodulation of 2FSK, a 2FSK modem based on the microcontroller AT89C51 was designed. This modem is mainly composed of an AT89C51 microcontroller, a simple two order passive low-pass filter, and a shaping circuit. Modulation is achieved on the basis of the principle of pulse width modulation (PWM). By executing PWM signal generating program, a digital base band signal is converted into the corresponding PWM signal after it is input into an I/O port of the microcontroller. Then the PWM signal is outputted from another I/O port and sent into the two order passive low-pass filter. On the output side of the filter, the 2FSK signal can be obtained. For demodulation, the 2FSK signal shaped by the shaping circuit is input into microcontroller from its I/O port. Then the widths of positive and negative half-waves are measured by the microcontroller internal timer. By comparing the value of each width with the appropriate threshold value, the binary digital signal is gotten and outputted from another I/O port of microcontroller. This modem makes full use of the resources of the microcontroller. As a result, it is simple, easy to use, economical and reliable. Furthermore, it can generate and demodulate the 2FSK signal with high good accuracy.

**Index Terms**—Modem; 2FSK; Modulation; Demodulation; PWM; Microcontroller

## I. INTRODUCTION

In the communication system, many original signals are not suitable for direct transmission in many channels due to the low frequency spectral components. Therefore, the modulation process at the transmitting end and the demodulation process at the receiving end are usually required in communication systems. The so-called modulation is the process to change some parameters of the carrier according to the variation of the modulated signal (baseband signal). The carriers can be divided into two categories: a sinusoidal signal, and a series of pulses or a digital signal. In most communication systems, the sine wave signal is selected as a carrier because that the form of a sinusoidal signal is simple, easy to generate and receive. Typically, the modulation can be divided into analog (continuous) modulation and digital modulation. In analog modulation, the value of the modulation signal is continuous; while the value of the modulation signal is discrete in digital modulation.

There are three kinds of digital modulation mode, amplitude modulation, frequency modulation and phase modulation.

The digital frequency modulation, is also known as frequency shift keying (FSK). The binary frequency shift keying is recorded as 2FSK. The digital frequency shift keying transmits digital messages with the carrier frequency. That is, the frequency of carrier is controlled by the transmitted digital message.

In principle, the digital frequency modulation can be achieved by the analog FM method, but also available keying method [1]. With the analog FM method, the frequency of the carrier is modulated by a rectangular pulse train. This method is used in early implementations of digital frequency modulation. With the keying method, the switch circuit controlled by the rectangular pulse sequence strobe the different independent frequency sources, respectively.

The keying method is characterized by fast switching speed, good waveform, and high stability and easy to implement, but the phase of the waveform is not continuous. By contrast, if the analog FM method is used, the phase of waveform created is continuous, but the switching speed is slow and stability is not high.

At the same time, it is a more difficult problem to demodulate the 2FSK signal. If traditional methods are used, very complicated circuit is required.

In many remote sensing and controlling equipments, 2FSK modulation and demodulation are very necessary parts. If the analog FM method is adopted and some dedicated modem interface chips are used, the disadvantages described above cannot be avoided. On the other hand, these dedicated chips will increase the cost of the equipment [2] [3]. At the same time, the chip qualities will directly affect the performance of the monitoring and controlling equipment. However, the keying method is not imperfect due to the discontinuous phase. Then if a DSP chip is used for completing modulation and demodulation, it is surely overkill for a device, which only requires a modem, without the need for other software radio or data computing functions [4]. For the above reasons, a 2FSK modem based on microcontroller AT89C51 is used for completing 2FSK modulation and demodulation. With this modem, the phase of modulated waveform is continuous, and the device will become simply, reducing or eliminating the need for special modem interface chips and complex DSP systems [5]. So,

we can greatly reduce the variety and number of components in the device to greatly improve the stability and reliability of the equipment.

## II. PRINCIPLE

### A. 2FSK Waveform

2FSK signal is the modulated waveform which has two different carrier frequencies,  $f_1$  corresponding to "1" symbols, and  $f_2$  corresponding to "0" symbol. The change of the waveform frequency is done instantaneously. In Fig. 1,  $s(t)$  is the binary rectangular pulse sequence,  $e_0(t)$  is the corresponding 2FSK signal.

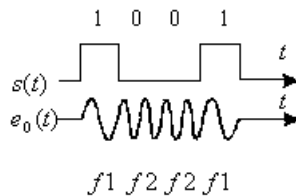


Figure 1. Waveform of 2FSK signal

According to the principle of the 2FSK signal, modulated signal can be expressed mathematically:

$$e_0(t) = \sum_n a_n g(t - nT_s) \cos(\omega_1 t + \phi_n) + \sum_n \bar{a}_n g(t - nT_s) \cos(\omega_2 t + \theta_n) \quad (1)$$

where  $a_n$  is equal to 1 (with probability  $P$ ) or 0 (with probability  $1 - P$ ),  $\bar{a}_n$  is the anti-code of  $a_n$ ,  $g(t)$  is a single rectangular pulse,  $T_s$  is the width of the single rectangular pulse,  $\omega_1$  and  $\omega_2$  are the angular frequencies of the two different carrier,  $\phi_n$  and  $\theta_n$  are the start-up phases of the  $n$ -th signal element [6] [7].

### B. Modulation

AT89C51 microcontroller output interface cannot produce a continuous voltage change, it can only output two level-"0" and "1". In order to obtain the 2FSK signal, a PWM signal is output from the microcontroller and sent to a low-pass filter circuit. After low-pass filtering, the 2FSK signal is generated.

The pulse width modulation (PWM) is a modulation technology used for encoding the analog signals. By modulating the width of the pulses, it can convert the voltage signal changed continuously into the signal with only the varying of 0, "1" two level maintenance time [8].

For digitally processing the continuous curve, the ladder diagram is often used for representing the curve by dividing time into many equal segments [9]. If the ladder step or the time segment is small enough, the representing is considered to be accurate. According to the ladder diagram of the curve, a PWM signal can be obtained. Fig. 2 shows the continuous curve, ladder diagram, and corresponding PWM signal. In each time segment, the shaded area of PWM signal is equal to that of the ladder

diagram, so the maintenance time of 0, "1" two level in the PWM signal can be calculated.

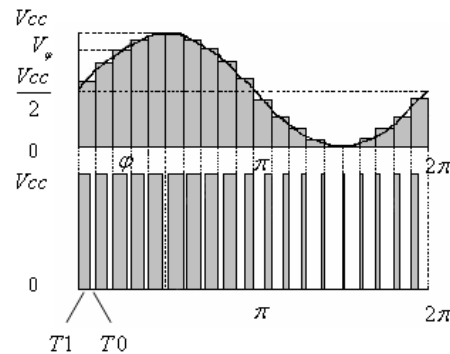


Figure 2. Pulse width modulation of sine wave

When the PWM is done for sine wave, the number of the time segments must be even, since the sine waveform is a symmetric.

A periodic function can be represented by Fourier series as follows:

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx) \quad (2)$$

In the Fourier series of the PWM signal, which is generated from the sine signal, Fourier coefficient  $a_n$  is 0, and  $b_n$  is also 0 if  $n$  is even. Therefore, the PWM signal can be expressed by the Fourier series as follows:

$$f(x) = \frac{a_0}{2} + b_1 \sin x + b_3 \sin 3x + b_5 \sin 5x + b_7 \sin 7x + \dots \quad (3)$$

Without the DC component being considered in the series, the harmonic coefficients are listed in Table I.

TABLE I. HARMONIC COEFFICIENTS OF PWM SIGNAL

K	$b_n=1$	$b_n=3$	$b_n=5$	$b_n=7$	$b_n=9$	$b_n=11$	$b_n=13$	$b_n=15$	$b_n=17$	$b_n=19$
2	1.273	0.424	0.255	0.182	0.141	0.116	0.098	0.085	0.075	0.067
6	0.807	0	0.603	0.430	0	0.073	0.062	0	0.177	0.159
12	0.967	0	0.012	0.167	0	0.369	0.186	0	0.174	0.105
20	0.975	0.013	0.034	0.003	0.003	0.024	0.061	0.206	0.033	0.333
36	0.984	0.010	0.024	0.009	0.010	0.004	0.004	0.001	0	0.003
52	0.988	0.007	0.018	0.007	0.008	0.004	0.005	0.003	0.003	0.001

Without the DC component being considered in the series, the harmonic coefficients are listed in Table I.

In Table I,  $K$  is the number of the time segments in a period of sine waveform. From this table, we can find that  $b_n$  varies with the changes of  $n$  and  $K$ . Initially,  $b_n$  decreases gradually with the increase of  $n$ . When  $n = K - 1$ ,  $b_n$  suddenly increases, and then it decreases gradually again with the increase of  $n$ . But overall, the rate of sudden increase will be getting smaller and smaller with the increase of  $K$ . On the other hand, the sudden increase moved to the higher-order harmonics and the coefficients of the harmonics near the fundamental harmonic are also decreased, with  $K$  increasing. So if more time segments are split, the portion of fundamental harmonic in the Fourier series will be larger and the PWM signal will be more accurate [10].

### C. Demodulation

At first, the 2FSK signal need to be demodulated is shaped by a shaping circuit. After shaping, the signal is input into microcontroller. With the microcontroller internal timer, the widths of positive and negative half-waves are measured. By comparing the value of each width with the appropriate threshold value, the binary digital signal is gotten [11].

The threshold value is provided by the formula

$$N_0 = (N_1 + N_2) / 2 \quad (4)$$

$N_1$  is defined as:

$$N_1 = (f_{osc} \times 10^6) / (2 \times f_1 \times 12) \quad (5)$$

$N_2$  is defined as:

$$N_2 = (f_{osc} \times 10^6) / (2 \times f_2 \times 12) \quad (6)$$

where  $f_{osc}$  is the frequency of crystal oscillator,  $f_1$  and  $f_2$  are the two different carrier frequencies,  $f_1$  corresponding to "1" symbols, and  $f_2$  corresponding to "0" symbol [12] [13].

If the width of half-wave is less than  $N_0$ , the corresponding binary symbol is "0". If the width of half-wave is greater than  $N_0$ , the corresponding binary symbol is "1". The principle of demodulation is shown in Fig. 3.  $t_1$  and  $t_2$  are the widths of half-wave. From Fig. 3, we can get the relationship of the 2FK signal and the demodulated signal.

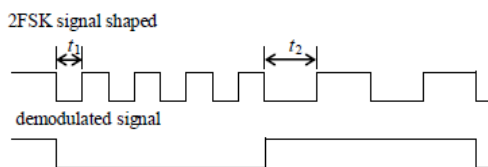


Figure 3. The principle of demodulation

By this way, every half-wave is detected, and every binary symbol can be gotten. So, the binary digital signal can be generated and outputted from the I/O port of microcontroller.

## III. CIRCUIT

### A. Modulation Circuit

With simple low pass filter circuit, the PWM signal outputted from the microcontroller can be converted into smooth 2FSK signal. The circuit is shown in Fig. 4. P1.3 is used for inputting the digital baseband signal, and P1.0 is used for outputting PWM signal. The frequency of the crystal is 12MHz.

As CMOS inverter, 74HC04 plays a buffer-driven role. Since the P1 port of the AT89C51 Microcontroller is quasi-bidirectional, output current of "1" is much smaller than the absorption current of "0" when P1 used for output port. With the Symmetric Complementary Structure of P-channel and N-channel MOS transistor in the 74HC04, the output signal "0" and "1" has the same switching characteristics [14] [15]. As a result, output

current of "1" is at the same level as the absorption current of "0" when PWM signal is outputted from the P1 port.

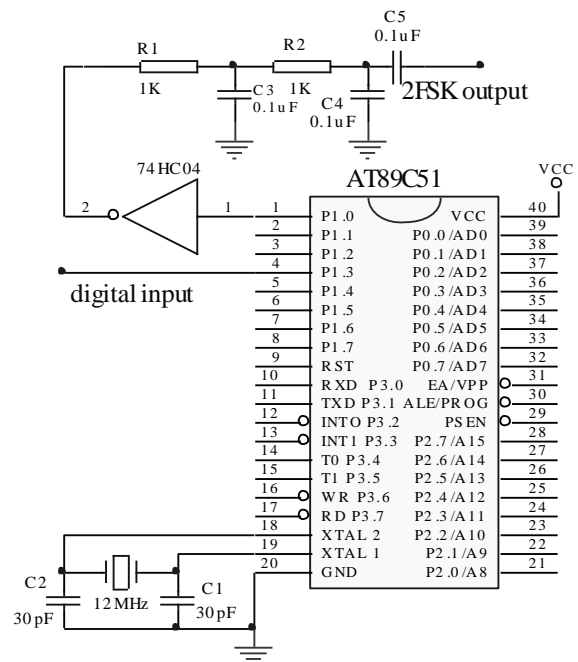


Figure 4. Circuit of the 2FSK modulation

The two resistors R1, R2, and two capacitors C3, C4, constitute the two order passive low-pass filter. The basic components of a one order passive low-pass filter are shown in Fig. 5.

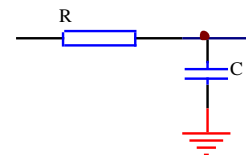


Figure 5. Circuit of the passive low-pass filter

For a passive low-pass filter, the capacitance tends to infinity when the signal frequency tends to zero, so the pass-band magnification is

$$\dot{A}_{up} = \frac{\dot{U}_o}{\dot{U}_i} = 1 \quad (7)$$

When frequency changes from zero to infinity, the voltage amplification factor can be expressed as:

$$\dot{A}_u = \frac{\dot{U}_o}{\dot{U}_i} = \frac{1}{j\omega C} \cdot \frac{1}{R + \frac{1}{j\omega C}} = \frac{1}{1 + j\omega RC} \quad (8)$$

If we assume that

$$f_p = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC} \quad (9)$$

We obtain the voltage amplification factor

$$\dot{A}_u = \frac{1}{1 + j \frac{f}{f_p}} = \frac{\dot{A}_{up}}{1 + j \frac{f}{f_p}} \quad (10)$$

The modulus of the voltage amplification factor is

$$|\dot{A}_u| = \frac{|\dot{A}_{up}|}{\sqrt{1 + \left(\frac{f}{f_p}\right)^2}} \quad (11)$$

If  $f = f_p$ , we obtain the expression

$$|\dot{A}_u| = \frac{|\dot{A}_{up}|}{2} \approx 0.707 |\dot{A}_{up}| \quad (12)$$

If  $f$  is far greater than  $f_p$ , we obtain the expression

$$|\dot{A}_u| \approx \frac{f_p}{f} |\dot{A}_{up}| \quad (13)$$

When the frequency is increased by 10 times,  $|\dot{A}_u|$  downs 10 times, that is, the slope of the transition zone is -20dB [15].

Therefore, the PWM signal can be transformed into 2FSK signal with two order low-pass filter.

#### B. Demodulation Circuit

In traditional ways, the demodulation of 2FSK signal usually requires band-pass filter, frequency multipliers, and phase locked loop [16]. Therefore, the circuit is very complex. However, the demodulation circuit based on microcontroller is greatly simplified and mainly composed with two chips: AT89C51 and LM324, as shown in Fig. 6.

The LM324 is a low-cost, quad operational amplifier with true differential inputs. It is used for shading the 2FSK signal need to be demodulated,

After shading, the signal is input into the microcontroller AT89C51 from the I/O port P1.4. Then the binary digital signal is output from the I/O port P0.2.

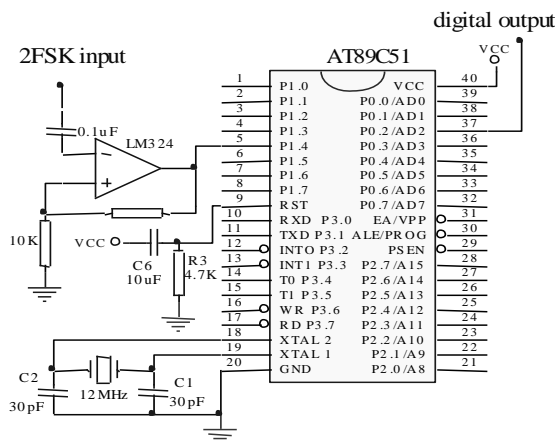


Figure 6. Circuit of the 2FSK demodulation

## IV. SOFTWARE

### A. Microcontroller Internal Timer/Counter

The microcontroller internal timer/counter is used to time the widths of pulses for modulation and measure the widths of pulses for demodulation. Internal timer/counter has the following characteristics:

- 1) Timer/Counters have a variety of ways of working.
- 2) The modulus values of the two counter are variable, the maximum count is dependent on the number of bits of the counter.
- 3) Timer/Counters can send an interrupt requests when the regular time or count terminate. So the timing or counting control can be achieved.

AT89C51 microcontroller has two 16-bit timer/counters: Timer 0 and Timer1. Each timer/counter occupied two special function registers. Timer 0 is composed of TL0 and TH0, and Timer 1 is composed of TL1 and TH1 [17]. For each timer/counter, there are four ways of working, as shown in the Table II.

TABLE II. THE WORKING WAYS OF TIMER/COUNTER

M1	M0	Mode	Function
0	0	0	13-bit timer
0	1	1	16-bit timer
1	0	2	8-bit Auto reload
1	1	3	One 8-bit counter

### B. Modulation Program

We assume that 2FSK frequencies are 980Hz for “1” and 1180Hz for “0”, and divide a period into 20 equal time segment.

Since the frequency of crystal is 12MHz, the number of microcontroller machine cycles in each period is  $(12 \times 10^6) / (12 \times 980)$  (i.e. 1020) for the sine wave of 980Hz, and is  $(12 \times 10^6) / (12 \times 1180)$  (i.e. 847) for that of 1180Hz. So the number of microcontroller machine cycles in each time segment for 980Hz is 1020/20, i.e. 51. However, 847/20 is equal to 42 with remainder 7. If the remainder 7 is discarded, there will be a big error in the frequency of the signal. We interpolate the remainder into seven different time segments of 1180Hz, respectively, in other words, the number of microcontroller machine cycles is 42 in each of 13 time segments and 43 in each of remaining 7 time segments.

From Fig. 2, we can get the following formula:

$$T1 = \frac{T}{2} (1 + \sin \phi) \quad (14)$$

$$T0 = T - T1 \quad (15)$$

where  $\phi$  is the current phase,  $T$  is the number of machine cycles in the corresponding segment,  $T1$  is the number of machine cycles occupied by “1” level and  $T0$  is the number of machine cycles occupied by “0” level in the segment. According to equation (14) and (15), we can get  $T1$  and  $T0$  in each time segment, as shown in Table III, where  $ts$  is the sequence number of the time segments.

TABLE III. THE NUMBER OF MACHINE CYCLES IN EACH TIME SEGMENT

	$t_s$	1	2	3	4	5	6	7	8	9	10
$f$ (Hz)	$\phi$	$\frac{\pi}{10}$	$\frac{\pi}{5}$	$\frac{3\pi}{10}$	$\frac{2\pi}{5}$	$\frac{\pi}{2}$	$\frac{3\pi}{5}$	$\frac{7\pi}{10}$	$\frac{4\pi}{5}$	$\frac{9\pi}{10}$	$\pi$
980	$T1$	33	40	46	50	51	50	46	40	33	26
	$T0$	18	11	5	1	0	1	5	11	18	25
1180	$T1$	27	33	38	41	42	41	38	33	27	21
	$T0$	15	9	4	1	0	1	4	9	15	21
$f$ (Hz)	$t_s$	11	12	13	14	15	16	17	18	19	20
$\phi$		$\frac{11\pi}{10}$	$\frac{6\pi}{5}$	$\frac{13\pi}{10}$	$\frac{7\pi}{5}$	$\frac{3\pi}{2}$	$\frac{8\pi}{5}$	$\frac{17\pi}{10}$	$\frac{9\pi}{5}$	$\frac{19\pi}{10}$	$2\pi$
980	$T1$	18	10	5	1	0	1	5	10	18	25
	$T0$	33	41	46	50	51	50	46	41	33	26
1180	$T1$	14	9	4	1	0	1	4	9	15	21
	$T0$	28	33	38	42	43	42	39	34	28	22

The PWM waveform of each phase is programmed, respectively in order to ensure that the phase of the waveform is continuous. A part of program flow chart is shown in Fig. 7, which is used for outputting the waveform of the first phase.

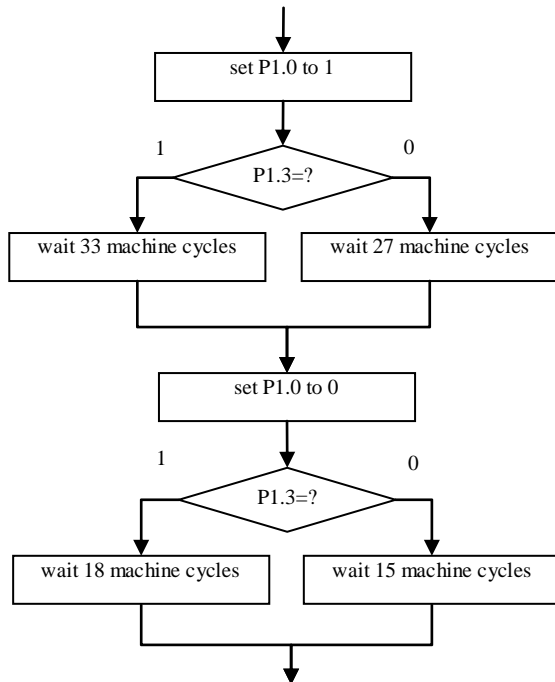


Figure 7. Program flow chart of the first phase

Except for the number of the machine cycles, the programs of the phases from  $2\pi/5$  to  $\pi$  are same as that of the first phase. However, the programs of the phases from  $11\pi/10$  to  $2\pi$  are very different. In these programs, the output of P1 port is changed not from "1" to "0", but from "0" to "1".

After the program of the first phase is executed, the program of the second phase follows. In this way, the programs of all the phases run one by one in the order of phase shown in Table 2. The program of each phase is designed, respectively. If the input of P1.3 port begins to change from "1" to "0" or "0" to "1", the output maintenance time of P1.0 port will be changed. However, the program of each phase is executed in the same order

as previously. So, the two sine waves of the different frequencies will be connected together with a same phase [18]. In other words, the phases of 2FSK signal are continuous.

Time delay control is achieved by the use of the timer 0 working in the Mode 1. The initial values of the timer 0 can be calculated according to the number of machine cycles in each time segment. They are expressed with hexadecimal number and shown in Table IV.

For each phase, program execution follows the same process. Firstly, the P1.0 port is set to "1" corresponding with the phases from  $2\pi/5$  to  $\pi$  or "0" corresponding with the phases from  $11\pi/10$  to  $2\pi$ . Secondly, the timer 0 is loaded with corresponding initial value shown in Table IV according to the input value of P1.3. Then timer 0 starts to time. When the timer overflows and expires, P1.0 port is set to the value opposite with the previous one. Then the timer 0 is loaded with corresponding initial value and starts to time again. When the timer overflows and expires, the similar program of the next phase follows.

### C. Demodulation Program

We assume that 2FSK frequencies are 980Hz for "1" and 1180Hz for "0". According to equation (4), (5) and (6), we can obtain that  $N_1=510$ ,  $N_2=423$ ,  $N_0=466$ . By comparing the width of every half-wave with 466, the demodulated signal can be generated.

TABLE IV. THE INITIAL VALUES OF TIMER 0

	$t_s$	1	2	3	4	5	6	7	8	9	10
$f$ (Hz)	$\phi$	$\frac{\pi}{10}$	$\frac{\pi}{5}$	$\frac{3\pi}{10}$	$\frac{2\pi}{5}$	$\frac{\pi}{2}$	$\frac{3\pi}{5}$	$\frac{7\pi}{10}$	$\frac{4\pi}{5}$	$\frac{9\pi}{10}$	$\pi$
980	$T1$	FF DF	FF D8	FF D2	FF CE	FF CD	FF CE	FF D2	FF D8	FF DF	FF E6
	$T0$	FF EE	FF F5	FF FB	FF FF	—	FF FF	FF FB	FF F5	FF EE	FF E7
1180	$T1$	FF E5	FF DF	FF DA	FF D7	FF D6	FF D7	FF DA	FF DF	FF E5	FF EB
	$T0$	FF F1	FF F7	FF FC	FF FF	—	FF FF	FF FC	FF F7	FF F1	FF EB
$f$ (Hz)	$t_s$	11	12	13	14	15	16	17	18	19	20
$\phi$		$\frac{11\pi}{10}$	$\frac{6\pi}{5}$	$\frac{13\pi}{10}$	$\frac{7\pi}{5}$	$\frac{3\pi}{2}$	$\frac{8\pi}{5}$	$\frac{17\pi}{10}$	$\frac{9\pi}{5}$	$\frac{19\pi}{10}$	$2\pi$
980	$T1$	FF EE	FF F6	FF FB	FF FF	—	FF FF	FF FB	FF F6	FF EE	FF E7
	$T0$	FF DF	FF D7	FF D2	FF CE	FF CD	FF CE	FF D2	FF D7	FF DF	FF E6
1180	$T1$	FF F2	FF F7	FF FC	FF FF	—	FF FF	FF FC	FF F7	FF F2	FF EB
	$T0$	FF E4	FF DF	FF DA	FF D6	FF D5	FF D6	FF D9	FF DE	FF E4	FF EA

However, error rate may be very large in practical use if we give a judgment on the binary symbol according to comparing the current width of half-wave with 466. The reason is that the actual width of the signal shaped is changed due to many kinds of noises and interferences existing in the circuit. Therefore, the method of data window average is used, and the average width of several half-waves in the data window is used to compare with 466. With this method, the average width cannot beyond the threshold value even if there are noises and

interferences in the circuit [19] [20]. So, the method can greatly reduce the impact of noises and interferences.

When a data window is set up, the number of data is definite. It depends on the symbol rate  $f_H$  and the average carrier frequency  $(f_1 + f_2)/2$  [21]. The relationship is

$$M \leq (f_1 + f_2)/f_B \quad (16)$$

where  $M$  is the number of data in the data window. So, the average width of several half-waves in the data window is expressed mathematically

$$T_{b0} = (\sum T_{bi})/M \quad (17)$$

where  $T_{bi}$  is the width of  $i$ -th half-wave. Substituting  $T_{bi}$ ,  $T_{b0}$  is used for comparing and judging.

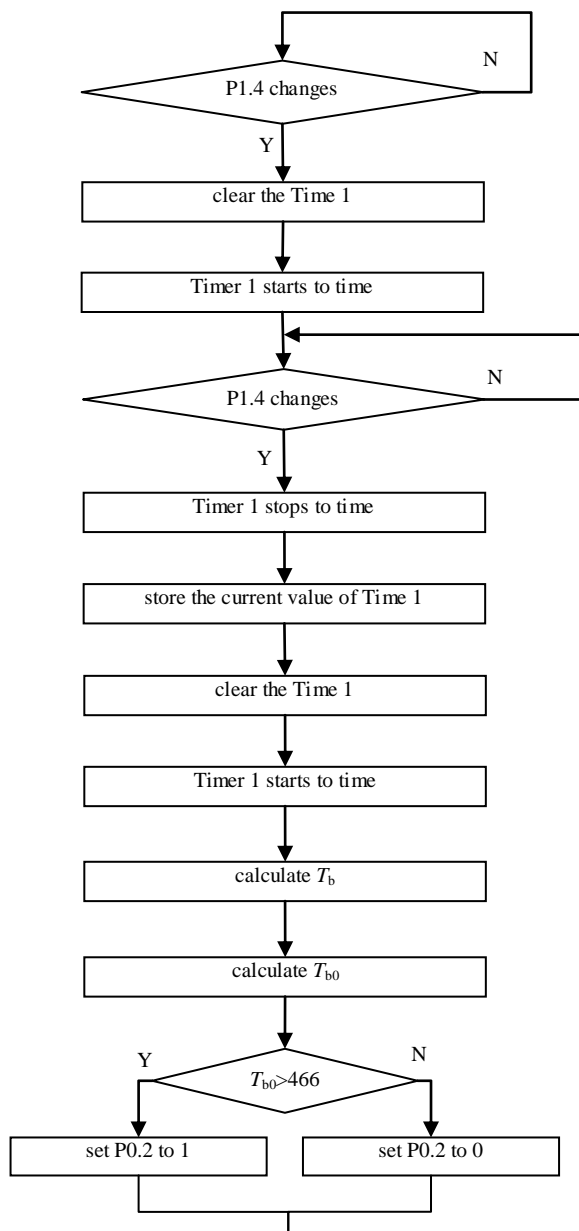


Figure 8. Program flow chart of demodulation.

Data in the data window move sequentially. Each time a new data enters into the data window, the oldest data

will be lost. There is no data aging. The number of data represents the carrier information of a symbol width.

Comparing with the modulation code, the demodulation code delays half a symbol width. However, Accuracy of the judgments of follow-up code isn't affected.

With this method of data window average, there is a problem about initialization [22] [23]. If the initial value is wrong, the start information of data frame will be missed.

Because the serial communication of a data is characterized by that the beginning bit is "0" and the stop bit is "1", initial data can be set to the value of  $N_2$  (see formula 6) corresponding with symbol "1". By this way, the start symbol of each data frame is not loss. In order to ensure synchronization the start bit of the data frame, initializing must be done after all data of each frame are collected.

For acquiring the width of every half-wave, Timer 1 is used to time. When a rising or falling edge is detected from P1.4 port, Timer 1 starts to time. When next rising or falling edge is detected, Timer 1 stop to time. According to the two values of Timer 1 at the beginning and the end of timing, the width of every half-wave can be acquired. The program flow chart of demodulation is shown in Fig. 8.

Timer 1 is set to operate in non-interrupt manner. So the interrupt enable bit of Timer 1 must be cleared. Every time the rising or falling edge of P1.4 port is detected except the first time, the Timer 1 stop to time and the current value of the Timer 1 is stored for calculating the width of the previous half-wave. Then the Timer 1 is cleared and starts to time again. It will keeping to timing continuously until the next rising or falling edge of P1.4 port is detected again.

In this manner, every width of half-wave in the data window is calculated. So the  $T_{b0}$  can be obtained according to the formula 16. Then the  $T_{b0}$  is compared with 466. If it is less than 466, "0" is recorded as the corresponding binary symbol and input from P0.2 port of the microcontroller. If it is greater than 466, "1" is recorded as the corresponding binary symbol and input from P0.2 port.

The program of demodulation is a part of the main program of the AT89C51 microcontroller. In the main program, some initialization tasks are implemented firstly. Then the program of demodulation is followed. The process of modulation is mainly implemented in the interrupt service program of the Timer 0 except the first setting the P1.0 and detecting the P1.3 port.

## V. SUMMARY

With the 2FSK modem, the 2FSK signal can be generated with good accuracy, since the pulse width modulation (PWM) technology is used. Taking full advantage of the resources of the microcontroller AT89C51 and saving many components, the modem is miniaturized and integrated. The modulation and demodulation is mainly achieved by executing program in the modem. Thus some kinds of digital modulation and

demodulation different from that we discussed above can be done without hardware upgrade.

#### ACKNOWLEDGMENT

The authors wish to thank Jiang Xiahan for assistance with the figures and Su Zhen for enlightening discussions.

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