# **BCD** Arithmetic

## Implementing the Decimal Adjust Command in WIMP51 CpE-213 Sp 2014 Project 1

#### 3/17/2014

Abstract: The 8051 Microcontroller "decimal adjust" (DA) command was to be implemented for WIMP51. This function was to be programmed so that it could be called by the standard 8051 instruction byte. Moreover, the successful implementation would leave all other functionality of the processor unaffected.

## Table of Contents

- 2 Introduction
- 2 Description of Work
- 6 Conclusion
- 7 Appendix A—Test Program

#### Introduction

The 8051 microcontroller has several functions not available in the WIMP51. One such function is "decimal adjust", which converts single byte hexadecimal numbers to binary-coded decimal (BCD) and allows for decimal arithmetic to be performed on what are in fact binary numbers. The assembly level command for 8051's decimal adjust is DA; and the machine code is D4H. For convenience, the 8051 instruction was retained in the WIMP51 implementation.

#### **Description of Work**

The majority of modifications to the WIMP51 affects	ed only the arithmetic logic unit (ALU).
The sole	least significant two bits
of the in	conflicts between DA and
SETB, si	ur bits. (Time was not
taken to	during troubleshooting,
the extr	rces of malfunction.)
The algo	ere added, the result was
checked	for the least significant
nibble (	n 9H, then 6H was added
to that r	(CY) or the auxiliary
carry bi	LSN, respectively.
The mai	between the inputs from
the auxi	ipple adder (B_n). The
aux regi	prresponding MUX, these
two inp	K was connected directly
to grour	cc) in the following
pattern:	pnnected to logic
designe	ed D4H (1101 0100).

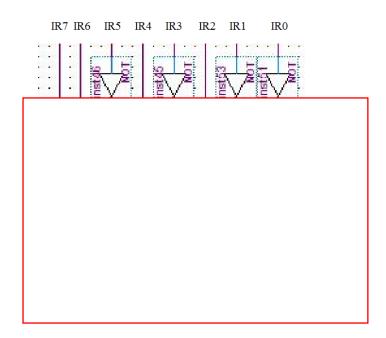
And inputs S\_1 corresponding to the MSN and the LSN of the auxiliary register were made to be '1' whenever the carry bit and the auxiliary carry bit were '1', respectively.

With this configuration, the following five outputs were possible:

#### Figure 1—BCD MUX Inputs and Outputs

S <sub>1</sub> (MSN)	S <sub>1</sub> (LSN)	S <sub>0</sub>	MUX Outputs
Y			<u> </u>
Q			
Q			
1			
1			

The logic circuit designed to control the S\_0 inputs was simply an eight-input AND gate with four NOT gates complimenting the values of IR<sub>5</sub>, IR<sub>3</sub>, IR<sub>1</sub> and IR<sub>0</sub>, as shown in Figure 2, below. Thus the state of S\_0 was '1' only for the D4H instruction, as mentioned before.



**Figure 2—DA Instruction Decoding** 

The auxiliary carry used to control the state of the S 1's in the LSN did	<u>not a</u> lready exist in
the WIMP51	ed. This was
done simply	er in the ripple
adder, as sh	would be
latched duri	p-flop circuit
that was alr	In both cases,
the state of	ed from the IR.

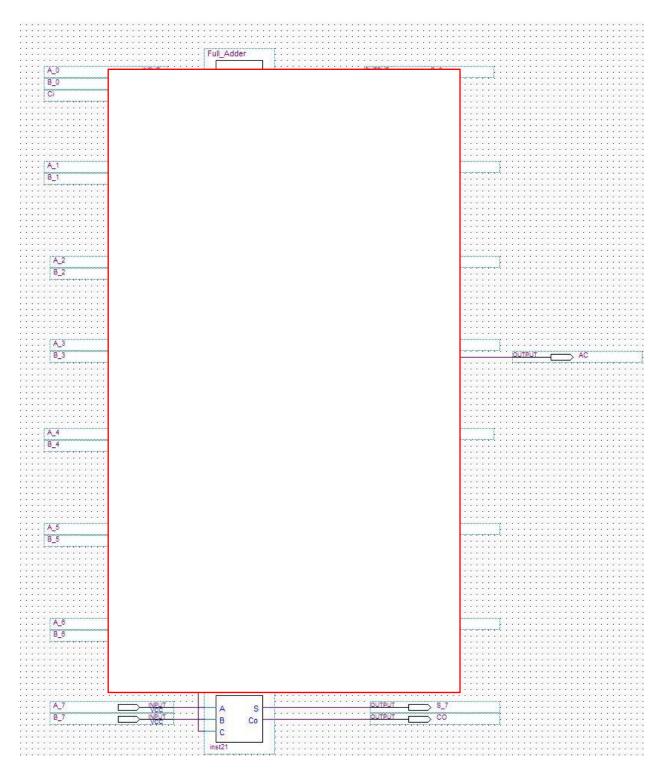
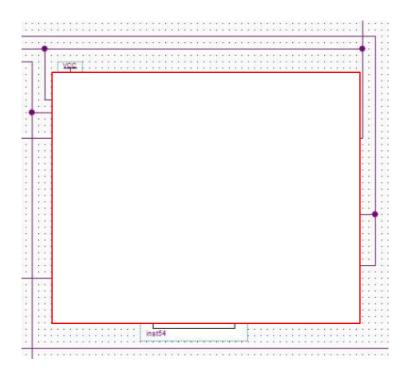


Figure 3—Auxiliary Carry





Two additional modifications were found to be necessary before DA would function

properly. First, the MS	<ol> <li>had to be added as a condition</li> </ol>
for accumulator write-	(see Figure 5). And second, the
carry bit being held in	blocked from the ripple adder
carry-in during the DA	ause one of the conditions for DA
adding 0110 to the MS	to the adder carry-in in this case,
then 0111 would be ac	7' instead of '6'. Figure 6 shows
the 2:1 MUX inserted i	ck it during DA.

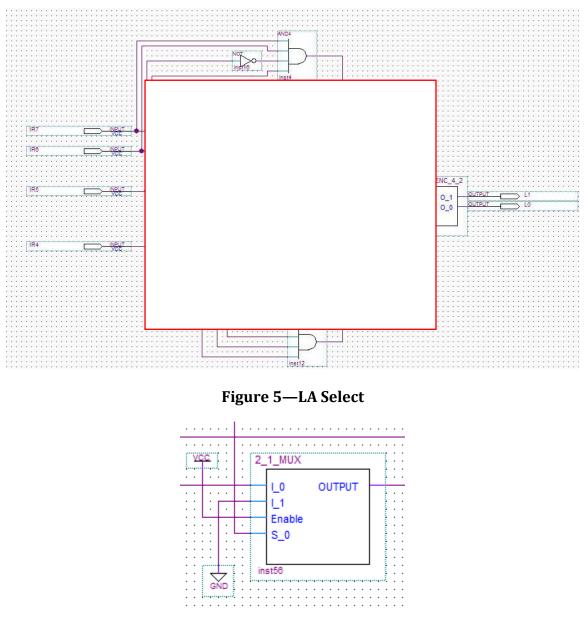


Figure 6—Block Carry-in for DA

Finally, the DA instruction, as well as the entire standard WIMP51 instruction set, was tested to ensure that everything was working properly. The test code used can be found in Appendix A. Lines 00-1B of this program demonstrate the functionality of the DA instruction, and line 1B-38 make us of all of the other instructions.

#### Conclusion

As mentioned above, the problem seemed simple enough—the problem of how to implement BCD arithmetic in WIMP51. Still, some trial and error proved necessary before a fully functioning solution was found. However, such unforeseen difficulties cannot help but further the learning process.

### Appendix A—Test Program

00         CLR C         C3H         00H           01         MOV A, #00H         74H         00H           02         00H         00H         00H           03         ADDC A, #0AH         34H         00H           04         0AH         00H         00H           05         DA A         D4H         0AH         USN>9           06         ADDC A, #F0H         34H         10H         C=1           07         F0H         10H         C=1         0           08         DA A         D4H         00H         C=1           09         CLR C         C3H         60H         0           08         AA         D4H         CH         MSN>9           01         CLR C         C3H         20H         MSN>9           02         CLR C         C3H         17H         AC=1           10         OFH         02H         0         0         0           01         DA A         D4H         11H         AC=1         0           12         CLR C         C3H         17H         0         0           13         ADDC A, #44         34H         <		Code		Accumulator	Notes
02       00H       00H       00H         03       ADDC A, #0AH       34H       00H         04       0AH       00H         05       DA A       D4H       0AH       LSN>9         06       ADDC A, #F0H       34H       10H       0H       0H         07       F0H       10H       0H       C=1         08       DA A       D4H       00H       C=1         09       CLR C       C3H       60H       60H         08       ADDC A, #60       34H       60H       60H         08       MA A       D4H       C0H       MSN>9         010       CLR C       C3H       20H       MSN>9         02       SWAP A       C4H       20H       0H         04       OF       ADDC A, #0F       34H       02H       0H         05       ADDC A, #0F       34H       11H       AC=1       11         14       DA A       D4H       11H       AC=1       11         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       7H       14         19       DA A       <	00	CLR C	СЗН	00H	
03       ADDC A, #0AH       34H       00H         04       0AH       00H         05       DA A       D4H       0AH         06       ADDC A, #F0H       34H       10H         07       F0H       10H         08       DA A       D4H       00H         08       DA A       D4H       00H         09       CLR C       C3H       60H         08       ADDC A, #60       34H       60H         09       CLR C       C3H       60H         00       CLR C       C3H       20H         01       CLR C       C3H       20H         02       SWAP A       C4H       20H         04       ADDC A, #0F       34H       02H         11       DA A       D4H       11H       AC=1         12       CLR C       C3H       7H       11         13       ADDC A, #FB       34H       7H       14         14       FBH       17H       14       17H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H       14H         <	01	MOV A, #00H	74H	OOH	
04       0AH       00H         05       DA A       D4H       0AH       LSN>9         06       ADDC A, #F0H       34H       10H       0H         08       DA A       D4H       00H       C=1         09       CLR C       C3H       60H       0H         04       ADDC A, #60       34H       60H       0H         05       DA A       D4H       C0H       MSN>9         06       CLR C       C3H       60H       0H         06       OA       ADDC A, #60       34H       C0H       MSN>9         00       CLR C       C3H       20H       MSN>9       0D         05       SWAP A       C4H       20H       0H       0F         06F       ADDC A, #0F       34H       02H       0E       SWAP       0FH       02H         11       DA A       D4H       11H       AC=1       12       CLR C       C3H       7H         13       ADDC A, #FB       34H       17H       13H       12H       C=AC=1       14H         14       FBH       17H       2H       MSN, LSN>9       14H       2H       14H       7H	02		ООН	OOH	
05       DA A       D4H       OAH       LSN>9         06       ADDC A, #F0H       34H       10H         07       F0H       10H         08       DA A       D4H       00H       C=1         09       CLR C       C3H       60H       60H         0A       ADDC A, #60       34H       60H       60H         0C       DA A       D4H       C0H       MSN>9         0D       CLR C       C3H       20H       60H         0C       DA A       D4H       C0H       MSN>9         0D       CLR C       C3H       20H       60H         0E       SWAP A       C4H       20H       60H         0F       ADDC A, #0F       34H       11H       AC=1         12       CLR C       C3H       17H       11H         14       FBH       17H       17H       14H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H       17H         17       ADDC A, #05H       74H       22H       MSN, LSN>9         1A       CLR C       C3H       22H       MSN,	03	ADDC A, #OAH	34H	OOH	
06         ADDC A, #FOH         34H         10H           07         FOH         10H           08         DA A         D4H         00H         C=1           09         CLR C         C3H         60H         60H           0A         ADDC A, #60         34H         60H         60H           0B         60H         60H         60H         60H           0C         DA A         D4H         C0H         MSN>9           0DE         CLR C         C3H         20H         60H         60H           0E         SWAP A         C4H         20H         60H         60H         60H           0F         ADDC A, #0F         34H         02H         60H         60H         60H           0F         ADDC A, #0F         34H         11H         AC=1         60H         60H           11         DA A         D4H         11H         AC=1         60H         60H         60H           12         CLR C         C3H         7H         7H         7H         7H         7H         7H         7H           14         FBH         17H         ADDC A, #144         34H         78H	04		0AH	OOH	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	05	DA A	D4H	OAH	LSN>9
08       DA A       D4H       00H       C=1         09       CLR C       C3H       60H       60H         0A       ADDC A, #60       34H       60H       60H         0C       DA A       D4H       C0H       MSN>9         0D       CLR C       C3H       20H       MSN>9         0D       SWAP A       C4H       20H	06	ADDC A, #FOH	34H	10H	
09       CLR C       C3H       60H         0A       ADDC A, #60       34H       60H         0B       60H       60H         0C       DA A       D4H       C0H       MSN>9         0D       CLR C       C3H       20H       0H         0E       SWAP A       C4H       20H       0H         0F       ADDC A, #0F       34H       02H       0H         10       0FH       02H       0E       1H         11       DA A       D4H       11H       AC=1         12       CLR C       C3H       17H       0E         13       ADDC A, #FB       34H       17H       0E         14       FBH       17H       0E       0E         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H       0E         17       ADDC A, #44       34H       78H       0E         18       0A A       D4H       BCH       MSN, LSN>9         14       CHR C       C3H       22H       MSN, LSN<9, C=AC=0	07		FOH	10H	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	08	DA A	D4H	OOH	C=1
0B $60H$ $60H$ $MSN > 9$ $0C$ $DA$ A $D4H$ $C0H$ $MSN > 9$ $0D$ $CLR$ C $C3H$ $20H$ $0H$ $0E$ $SWAP$ A $C4H$ $20H$ $0FH$ $02H$ $0F$ $ADDC$ A, #0F $34H$ $02H$ $AC=1$ $10$ $0FH$ $02H$ $AC=1$ $11$ $DA$ A $D4H$ $11H$ $AC=1$ $12$ $CLR$ C $C3H$ $17H$ $AC=1$ $13$ $ADDC$ A, #FB $34H$ $17H$ $AC=1$ $14$ $FBH$ $17H$ $C=AC=1$ $66$ $15$ $DA$ A $D4H$ $12H$ $C=AC=1$ $16$ $CLR$ C $C3H$ $78H$ $78H$ $17$ $ADDC$ A, #44 $34H$ $78H$ $78H$ $18$ $DA$ A $D4H$ $22H$ $MSN, LSN > 9, C=AC=0$ $1C$ $MOV$ A, #05H $74H$ $22H$ $SESH$ $SESH$ $10$ $OSH$ $CH$ $SH$ $SH$ <td>09</td> <td>CLR C</td> <td>СЗН</td> <td>60H</td> <td></td>	09	CLR C	СЗН	60H	
0C       DA A       D4H       C0H       MSN>9         0D       CLR C       C3H       20H         0E       SWAP A       C4H       20H         0F       ADDC A, #0F       34H       02H         10       0FH       02H         11       DA A       D4H       11H       AC=1         12       CLR C       C3H       17H       13         13       ADDC A, #FB       34H       17H       14         14       FBH       17H       14       6=AC=1         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H       17         17       ADDC A, #44       34H       78H       18         18       DA A       D4H       22H       MSN, LSN>9         14       05H       22H       11       11         15       DA A       D4H       22H       MSN, LSN<9, C=AC=0	0A	ADDC A, #60	34H	60H	
0D       CLR C       C3H       20H         0E       SWAP A       C4H       20H         0F       ADDC A, #0F       34H       02H         10       0FH       02H         11       DA A       D4H       11H       AC=1         12       CLR C       C3H       17H       13         13       ADDC A, #FB       34H       17H       14         14       FBH       17H       14       C=AC=1         16       CLR C       C3H       78H       14         17       ADDC A, #44       34H       78H       18         18       04 A       12H       C=AC=1       16         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       18         19       DA A       D4H       22H       MSN, LSN<9, C=AC=0	0B		60H	60H	
0E       SWAP A       C4H       20H         0F       ADDC A, #0F       34H       02H         10       0FH       02H         11       DA A       D4H       11H       AC=1         12       CLR C       C3H       17H         13       ADDC A, #FB       34H       17H         14       FBH       17H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H       78H         17       ADDC A, #44       34H       78H       78H         18       04A       D4H       8CH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	0C	DA A	D4H	СОН	MSN>9
0F       ADDC A, #0F       34H       02H         10       0FH       02H         11       DA A       04H       11H       AC=1         12       CLR C       C3H       17H         13       ADDC A, #FB       34H       17H         14       FBH       17H       FC=AC=1         16       CLR C       C3H       78H         17       ADDC A, #44       34H       78H         18       44H       78H         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	0 D	CLR C	СЗН	20H	
10       0FH       02H         11       DA A       D4H       11H       AC=1         12       CLR C       C3H       17H         13       ADDC A, #FB       34H       17H         14       FBH       17H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H         17       ADDC A, #44       34H       78H         18       44H       78H         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	ΟE	SWAP A	C4H	20H	
11       DA A       D4H       11H       AC=1         12       CLR C       C3H       17H         13       ADDC A, #FB       34H       17H         14       FBH       17H         14       FBH       17H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H	ΟF	ADDC A, #OF	34H	02H	
12       CLR C       C3H       17H         13       ADDC A, #FB       34H       17H         14       FBH       17H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H       17         17       ADDC A, #44       34H       78H       18         18       A4H       78H       18       17         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	10		OFH	02H	
12       CLR C       C3H       17H         13       ADDC A, #FB       34H       17H         14       FBH       17H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H       17         17       ADDC A, #44       34H       78H       17         18       A4H       78H       18       17         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	11	DA A	D4H	11H	AC=1
14       FBH       17H         15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H         17       ADDC A, #44       34H       78H         18       44H       78H         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	12	CLR C	СЗН	17H	
15       DA A       D4H       12H       C=AC=1         16       CLR C       C3H       78H         17       ADDC A, #44       34H       78H         18       44H       78H         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	13	ADDC A, #FB	34H	17H	
16       CLR C       C3H       78H         17       ADDC A, #44       34H       78H         18       44H       78H         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	14		FBH	17H	
16       CLR C       C3H       78H         17       ADDC A, #44       34H       78H         18       44H       78H         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H       MSN, LSN<9, C=AC=0	15	DA A	D4H	12H	C=AC=1
18       44H       78H         19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H         1B       DA A       D4H       22H       MSN, LSN<9, C=AC=0	16	CLR C	СЗН	78H	
19       DA A       D4H       BCH       MSN, LSN>9         1A       CLR C       C3H       22H         1B       DA A       D4H       22H         1C       MOV A, #05H       74H       22H         1D       05H       22H         1E       ADDC A, #07H       34H       05H         1F       07H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       3FH       0CH         26       SWAP A       C4H       0H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       OCH	17	ADDC A, #44	34H	78H	
1A       CLR C       C3H       22H         1B       DA A       D4H       22H         1C       MOV A, #05H       74H       22H         1D       05H       22H         1E       ADDC A, #07H       34H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       OCH	18		44H	78H	
1A       CLR C       C3H       22H         1B       DA A       D4H       22H         1C       MOV A, #05H       74H       22H         1D       05H       22H         1E       ADDC A, #07H       34H       05H         1F       07H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       3FH       0CH         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       OCH	19	DA A	D4H	BCH	MSN, LSN>9
1C       MOV A, #05H       74H       22H         1D       05H       22H         1E       ADDC A, #07H       34H       05H         1F       07H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       OCH	1A	CLR C	СЗН	22H	
1D       05H       22H         1E       ADDC A, #07H       34H       05H         1F       07H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       OCH	1B	DA A	D4H	22H	MSN, LSN<9, C=AC=0
1E       ADDC A, #07H       34H       05H         1F       07H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       CCH         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       OCH	1C	MOV A, #05H	74H	22H	
1F       07H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	1D		05H	22H	
1F       07H       05H         20       MOV R7, A       FFH       0CH         21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	1E	ADDC A, #07H	34H	05H	
21       ADDC A, R7       3FH       0CH         22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	1F		07H	05H	
22       SWAP A       C4H       18H         23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	20	MOV R7, A	FFH	OCH	
23       MOV A, R7       EFH       81H         24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	21	ADDC A, R7	ЗFН	OCH	
24       XRL A, R7       6FH       0CH         25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	22	SWAP A	C4H	18H	
25       ORL A, R7       4FH       00H         26       SWAP A       C4H       0CH         27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	23	MOV A, R7	EFH	81H	
26SWAP AC4H0CH27ADDC A, R73FHC0H28ANL A, R75FHCCH29SETB CD3H0CH	24	XRL A, R7	6FH	OCH	
27       ADDC A, R7       3FH       C0H         28       ANL A, R7       5FH       CCH         29       SETB C       D3H       0CH	25	ORL A, R7	4FH	ООН	
28     ANL A, R7     5FH     CCH       29     SETB C     D3H     0CH	26	SWAP A	C4H	OCH	
29 SETB C D3H OCH	27	ADDC A, R7	3FH	СОН	
	28	ANL A, R7	5FH	CCH	
2A CLR C C3H OCH	29	SETB C	D3H	OCH	
	2A	CLR C	СЗН	OCH	

2в		MOV A,	#04H	74H	OCH
C2				04H	OCH
2D	Х:	CLR C		СЗН	04H
2E		ADDC A,	#FFH	34H	04H
2F				FFH	04H
30		JZ Y		60H	03H,02H,01H,00H
31				02H	
32		SJMP X		80H	
33				F9H	
34	Υ:	SETB C		D3H	ООН
35		ADDC A,	#02H	34H	00H
36				02H	ООН
37	Z:	SJMP Z		80H	03H
38				FEH	03H