buffer and subroutine WRREC to write the record from the buffer to the output device. Each subroutine must transfer the record one character at a time because the only I/O instructions available are RD and WD. The buffer is necessary because the I/O rates for the two devices, such as a disk and a slow printing terminal, may be very different. (In Chapter 6, we see how to use channel programs and operating system calls on a SIC/XE system to accomplish the same functions.) The end of each record is marked with a null character (hexadecimal 00). If a record is longer than the length of the buffer (4096 bytes), only the first 4096 bytes are copied. (For simplicity, the program does not deal with error recovery when a record containing 4096 bytes or more is read.) The end of the file to be copied is indicated by a zero-length record. When the end of file is detected, the program writes EOF on the output device and terminates by executing an RSUB instruction. We assume that this program was called by the operating system using a JSUB instruction; thus, the RSUB will return control to the operating system.

## 2.1.1 A Simple SIC Assembler

Figure 2.2 shows the same program as in Fig. 2.1, with the generated object code for each statement. The column headed Loc gives the machine address (in hexadecimal) for each part of the assembled program. We have assumed that the program starts at address 1000. (In an actual assembler listing, of course, the comments would be retained; they have been eliminated here to save space.)

The translation of source program to object code requires us to accomplish the following functions (not necessarily in the order given):

- 1. Convert mnemonic operation codes to their machine language equivalents—e.g., translate STL to 14 (line 10).
- 2. Convert symbolic operands to their equivalent machine addresses e.g., translate RETADR to 1033 (line 10).
- 3. Build the machine instructions in the proper format.
- 4. Convert the data constants specified in the source program into their internal machine representations—e.g., translate EOF to 454F46 (line 80).
- 5. Write the object program and the assembly listing.

All of these functions except number 2 can easily be accomplished by sequent tial processing of the source program, one line at a time. The translation of addresses, however, presents a problem. Consider the statement

aress	25, 11011	22 02 <b>*</b>		RETADR	141033
	1000	FIRST	STL	RETADIO	

Line	Loc	Sou	rce staten	nent	Object code
	1000		1	1000	
5	1000	COPY	START	1000	1.11.000
10	1000	FIRST	STL	RETADR	141033
15	1003	CLOOP	JSUB	RDREC	482039
20	1006		LDA	LENGTH	001036
25	1009		COMP	ZERO	281030
30	100C		JEQ	ENDFIL	301015
35	100F		JSUB	WRREC	482061
40	1012		J	CLOOP	3C1003
45	1015	ENDFIL	LDA	EOF	00102A
50	1018		STA	BUFFER	0C1039
	101B		LDA	THREE	00102D
55	101E		STA	LENGTH	0C1036
60			JSUB	WRREC	482061
65	1021				
70	1024		LDL	RETADR	081033
75	1027		RSUB		4C0000
80	102A	EOF	BYTE	C'EOF'	454F46
85	102D	THREE	WORD	3	000003
90	1030	ZERO	WORD	0	000000
95	1033	RETADR	RESW	1	
100	1036	LENGTH	RESW	1	
105	1039	BUFFER	RESB	4096	
	1	Tak			
			SHEROH	TINE TO READ RE	ECORD INTO BUFFER
115			SUBROU'	TINE TO READ RE	ECORD INTO BUFFER
115 120	2020	PDREC			
115 120 125	2039	RDREC	LDX	ZERO	041030
120 125 130	203C		LDX LDA	ZERO ZERO	041030 001030
115 120 125 130 135	203C 203F	RDREC RLOOP	LDX LDA TD	ZERO ZERO INPUT	041030 001030 E0205D
115 120 125 130 135 140	203C 203F 2042		LDX LDA TD JEQ	ZERO ZERO INPUT RLOOP	041030 001030 E0205D 30203F
115 120 125 130 135	203C 203F 2042 2045		LDX LDA TD JEQ RD	ZERO ZERO INPUT RLOOP INPUT	041030 001030 E0205D 30203F D8205D
115 120 125 130 135 140	203C 203F 2042		LDX LDA TD JEQ RD COMP	ZERO ZERO INPUT RLOOP INPUT ZERO	041030 001030 E0205D 30203F D8205D 281030
115 120 125 130 135 140 145	203C 203F 2042 2045		LDX LDA TD JEQ RD	ZERO ZERO INPUT RLOOP INPUT	041030 001030 E0205D 30203F D8205D 281030 302057
115 120 125 130 135 140 145 150	203C 203F 2042 2045 2048		LDX LDA TD JEQ RD COMP	ZERO ZERO INPUT RLOOP INPUT ZERO	041030 001030 E0205D 30203F D8205D 281030
115 120 125 130 135 140 145 150 155	203C 203F 2042 2045 2048 204B		LDX LDA TD JEQ RD COMP JEQ	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT	041030 001030 E0205D 30203F D8205D 281030 302057
115 120 125 130 135 140 145 150 155 160	203C 203F 2042 2045 2048 204B 204E		LDX LDA TD JEQ RD COMP JEQ ,	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X	041030 001030 E0205D 30203F D8205D 281030 302057 549039
115 120 125 130 135 140 145 150 155 160 165	203C 203F 2042 2045 2048 204B 204E 2051		LDX LDA TD JEQ RD COMP JEQ, STCH	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E
115 120 125 130 135 140 145 150 155 160 165 170 175	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057	RLOOP	LDX LDA TD JEQ RD COMP JEQ, STCH TIX JLT STX	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F
115 120 125 130 135 140 145 150 165 170 175 180	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A	RLOOP	LDX LDA TD JEQ RD COMP JEQ , STCH TIX JLT STX RSUB	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D	RLOOP  EXIT INPUT	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A	RLOOP	LDX LDA TD JEQ RD COMP JEQ , STCH TIX JLT STX RSUB	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D	RLOOP  EXIT INPUT	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH X'F1' 4096	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000
115 120 125 130 135 140 145 150 165 170 175 180 185 190 195 200	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D	RLOOP  EXIT INPUT	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH X'F1' 4096	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN  .	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER
115 120 125 130 135 140 145 150 155 160 175 180 485 190 195 200 205 210	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD SUBROUT	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 200 200 210 215	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN  .	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD SUBROUT LDX TD	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 200 205 210 215 220	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD SUBROU	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER,X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079 302064
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 225	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD SUBROUT LDX TD	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 200 205 210 225 230	203C 203F 2042 2045 2048 204B 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD SUBROU	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER,X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079 302064
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 200 205 210 215 220 225 230 235	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ , STCH TIX JLT STX RSUB BYTE WORD  SUBROU  LDX TD JEQ LDCH	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER,X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079 302064 509039
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 200 205 210 225 230 235 240	203C 203F 2042 2045 2048 204B 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ STCH TIX JLT STX RSUB BYTE WORD  LDX TD JEQ LDCH WD	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER,X MAXLEN RLOOP LENGTH X'F1' 4096 TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079 302064 509039 DC2079
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 200 210 215 220 225 235 240 245	203C 203F 2042 2045 2048 204B 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ, STCH TIX JLT STX RSUB BYTE WORD  LDX TD JEQ LDCH WD TIX JLT	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH  X'F1' 4096  TINE TO WRITE I	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079 302064 509039 DC2079 2C1036 382064
115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 200 205 210 225 230 235 240	203C 203F 2042 2045 2048 204B 204E 2051 2054 2057 205A 205D 205E	RLOOP  EXIT  INPUT  MAXLEN   WRREC	LDX LDA TD JEQ RD COMP JEQ, STCH TIX JLT STX RSUB BYTE WORD  LDX TD JEQ LDCH WD TIX	ZERO ZERO INPUT RLOOP INPUT ZERO EXIT BUFFER, X MAXLEN RLOOP LENGTH  X'F1' 4096  TINE TO WRITE I  ZERO OUTPUT WLOOP BUFFER, X OUTPUT LENGTH WLOOP	041030 001030 E0205D 30203F D8205D 281030 302057 549039 2C205E 38203F 101036 4C0000 F1 001000 RECORD FROM BUFFER 041030 E02079 302064 509039 DC2079 2C1036

Figure 2.2 Program from Fig. 2.1 with object code