X10 RF Receiver

Please review the "X10 RF Transmission Theory.htm" document for a complete discussion of the X10 RF Transmission Theory.

The X-10 RF frequency can be one of three possible frequencies:
1. 310 MHz - "A" - North America
2. 418 MHz - "U" - Britain and Europe
3. 433.92 MHz - "E" - Europe

Except for the difference in carrier frequencies, the RF protocol that X-10 uses for standard (i.e. non-security) X-10 RF devices is identical to the original NEC IR protocol which is widely used for IR remote controls. The data envelope for a typical NEC code is pictured below.
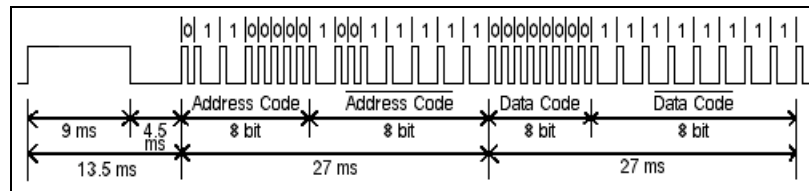

Figure 1: NEC IR

Each code starts with a 9 msec burst of carrier followed by a 4.5 msec silence. This leader is necessary to set the ACG in the RF receivers which dynamically adapt to signal strength. After the leader, there are 32 bits with binary 1 represented by 2.25 msec between rising edges and binary 0 represented by 1.125 msec between rising edges. The rising edge of the 33rd and final pulse marks the end of the last bit and is followed by a silence of approximately 40 msec. Most X-10 RF transmitters send a minimum of five copies of the code separated by 40 msec silences although some can send single bursts.

Instead of address and data bytes, X-10 sends two bytes of data with each byte followed immediately by its bitwise complement for error checking. Within each byte, bit7 is received first and bit0 last. In the pictured code above, in the order received, the first byte is 0110-0000, the second is 1001-1111, the third is 0000-0000, and the fourth is 1111-1111. After testing for bitwise complementarity, the two data bytes are 0110-0000 and 0000-0000 or 0x60 and 0x00. Since the illustration was taken from an explanation of IR codes, these represent a device and button for an IR code. If these were X-10 RF codes the bytes would be two data bytes as detailed in the CM17A protocol (see below) and would represent "A1 ON".

The overall time to send one code, including the approximate 40 msec silence, is about 108 msec. Timings will vary from one transmitter to another but are repeatable for a specific transmitter. It appears, from articles on the 'net, that other people have seen a range from 95 msec to 116 msec for various transmitters and that standard X-10 transceivers can tolerate timing variations of 30-35% from nominal.

So much for the specification. It's now time to start verifying the data. Figure 2 below shows that the X-10 RF Transmitter HR12A transmits six groups of the command code separated by 40

msec of silence. I'm not sure what the last 'burst' represents and I haven't been able to find out any thing about it.
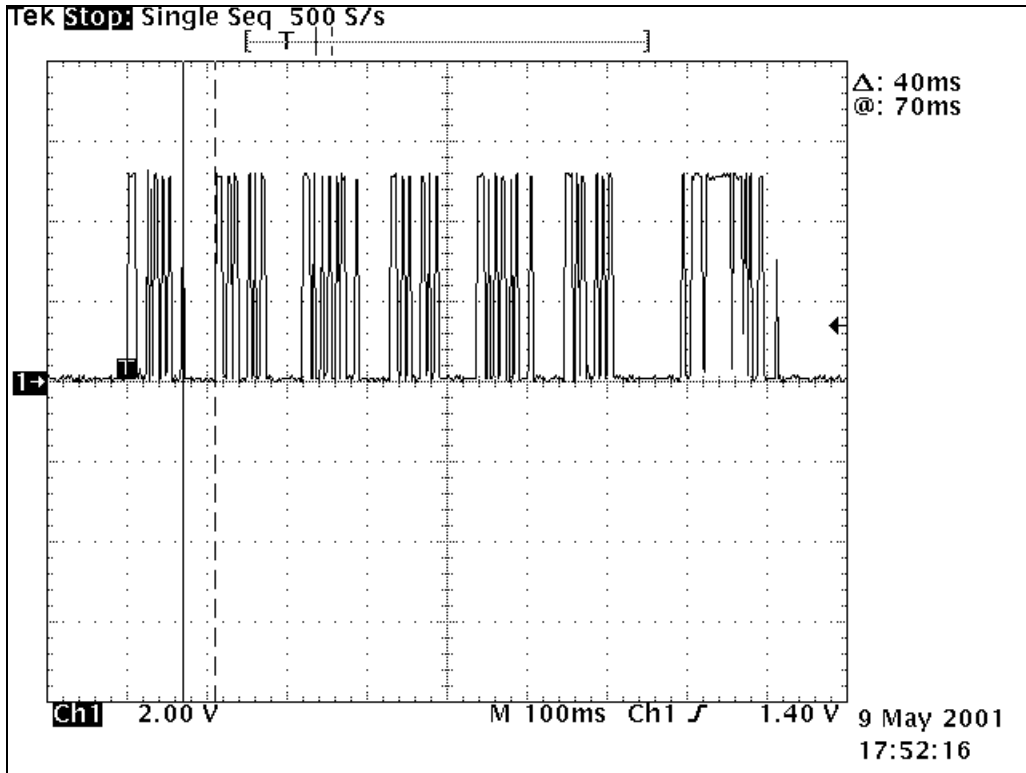
Figure 2: A1ON 6 Copies

Figure 3 shows a single X-10 command code. This is the same command code shown in Figure 2. The length of the command code is approximately 68 msec which correlates with the specification value of $9.0 + 4.5 + 27 + 27 = 67.5$ msec.
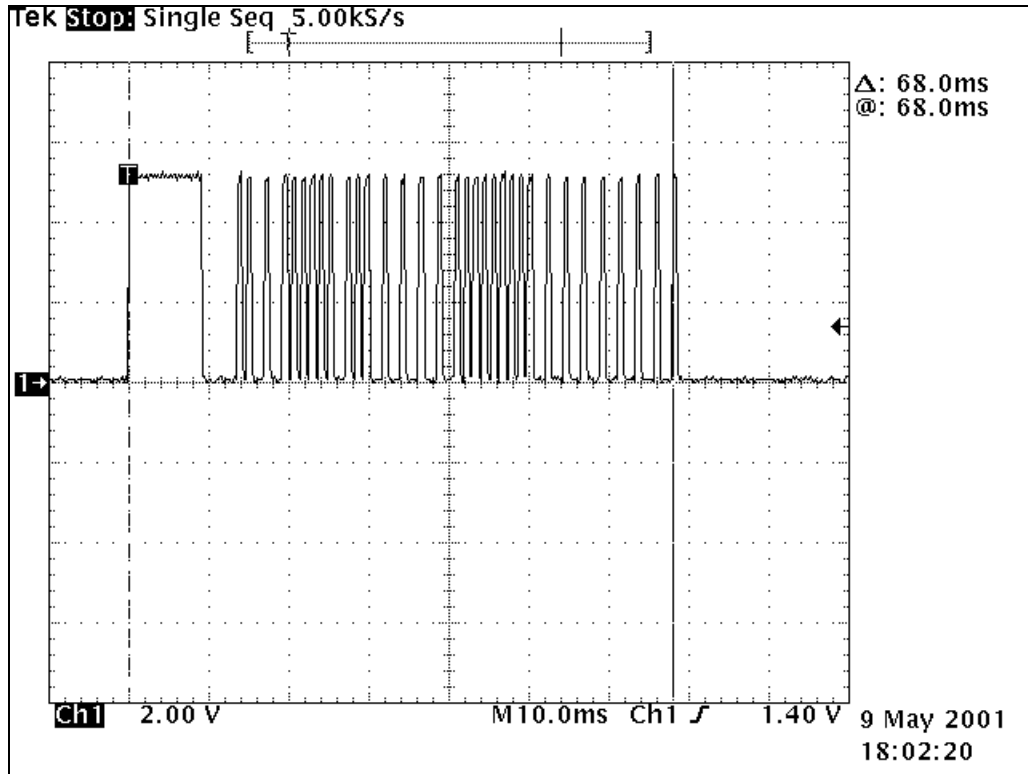
Figure 3: A1ON Total Time

Expanding the X-10 command code even further to see the leader, Figure 4, again confirms that the leader consists of a 9 msec carrier followed by 4.5 msec of silence before the first data bit appears.

Figure 4: A1ON Leader

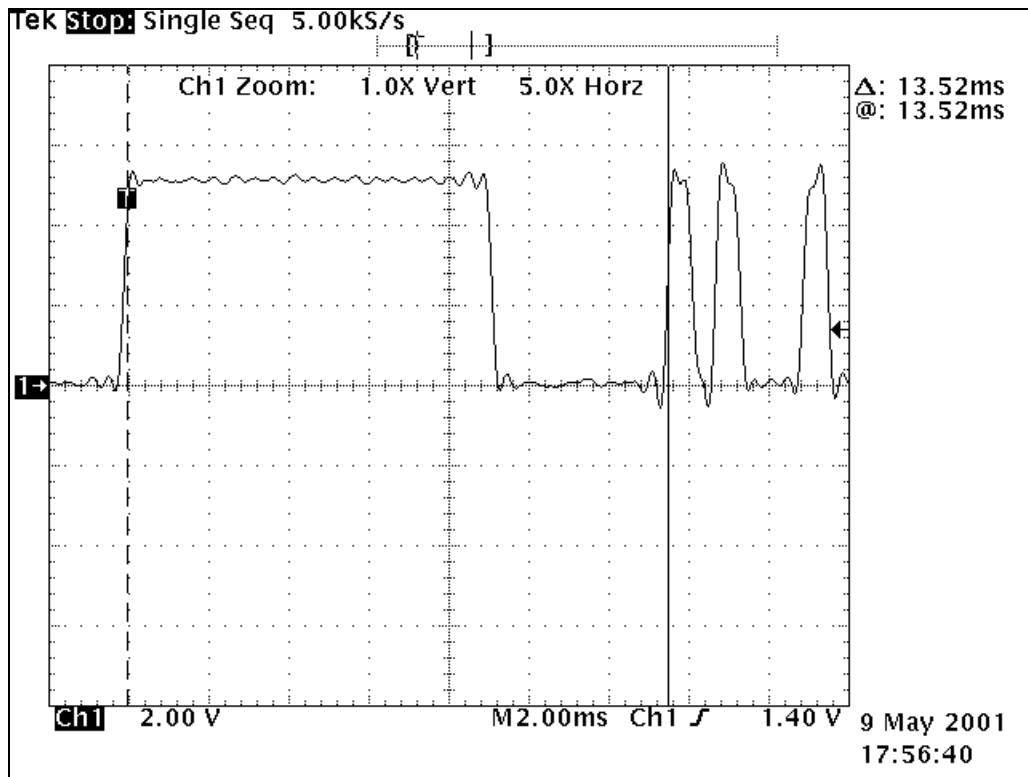Continuing on, Figures 5 and 6 show that the time values for a 0 bit (1.16 msec) and 1 bit (2.24 msec) also match the specification.
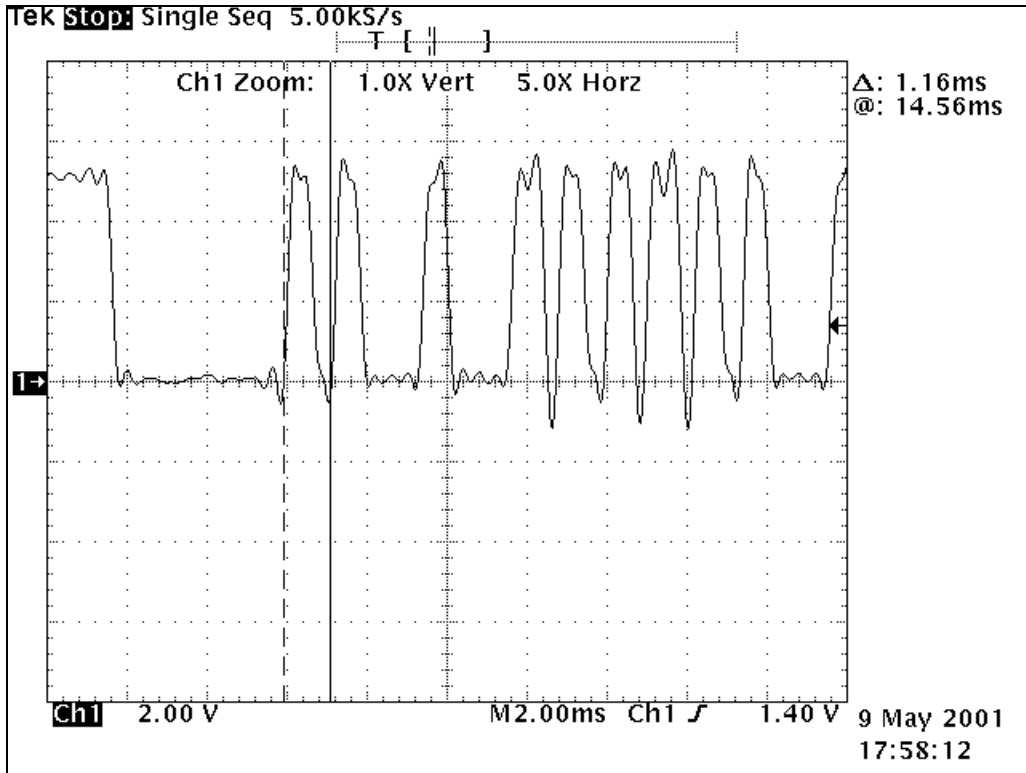

Figure 5: A1ON First Bit
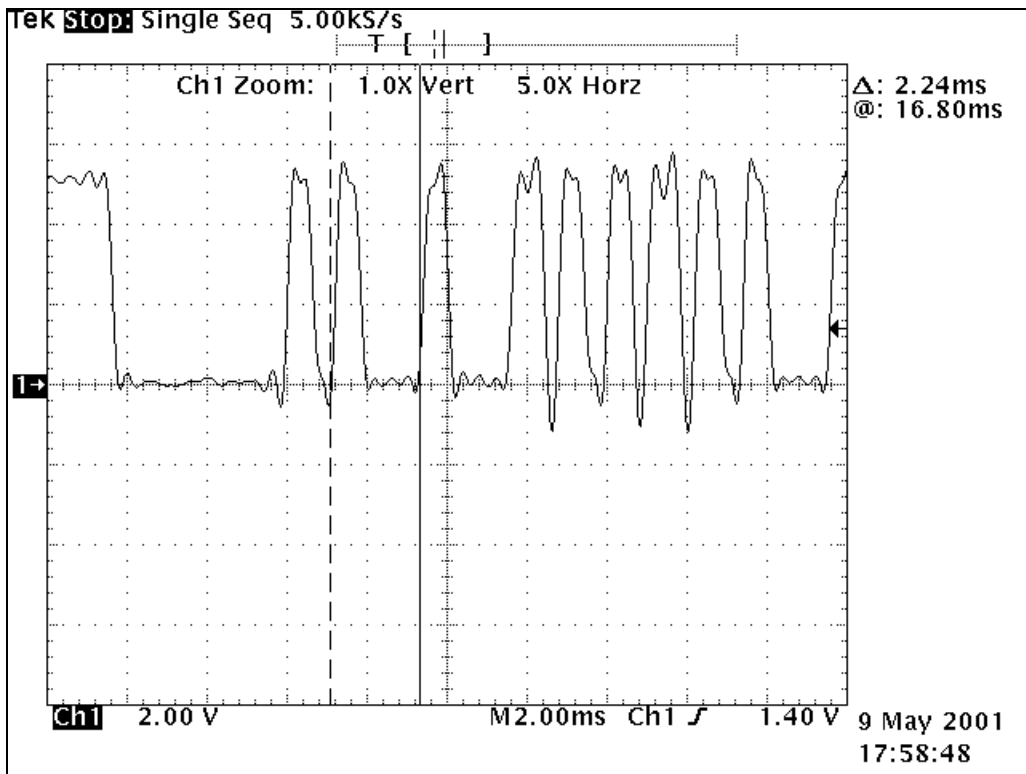
Figure 6: A1ON Second Bit

To decode the RF input, I'll use an interrupt and a 16-bit timer. One of the requirements that I'm hoping for is to read the timer value on each interrupt and then restart the timer.

The timer increments every instruction cycle (Fosc / 4). Assume a clock frequency of 4 MHz. When divided by 4, this gives a working frequency of 1 MHz. Each bit of a 16-bit timer represents 1 usec. This gives a maximum count of 65356 usec or 65.356 msec. Since the largest time I need to detect is >= 40 msec this should work OK.

There are four times that need to be detected:
1. 40 msec gap between commands.   40,000 ticks
2. 13.5 msec header.   13,500 ticks
3. 1.125 msec for a 'zero' bit.   1,125 ticks
4. 2.25 msec for a 'one' bit.   2,250 ticks

When you add in a fudge factor or +/- 30% to the timing, the values become:
1. 40,000 +/- 30%   28,000 to 52,000 ticks
2. 13,500 +/- 30%   9,450 to 17,550 ticks
3. 1,125 +/- 30%   787 to 1,463 ticks
4. 2,250 +/- 30%   1,575 to 2,925 ticks

As a note, for the 40 msec time I only need to compare to the bottom limit (28,000) or to see if a rollover occurred.

CM17A Protocol

Bright and Dim transmissions.

To brighten or dim a lamp, it is necessary to send consecutive signals (each equivalent to a 5% dim or brighten) until the desired level is attained.

Data Table

X-10 Command	Bit 76543210	Bit 76543210	X-10 Command	Bit 76543210	Bit 76543210
A1 ON	01100000	00000000	B1 ON	01110000	00000000
A1 OFF	01100000	00100000	B1 OFF	01110000	00100000
A2 ON	01100000	00010000	B2 ON	01110000	00010000
A2 OFF	01100000	00110000	B2 OFF	01110000	00110000
A3 ON	01100000	00001000	B3 ON	01110000	00001000
A3 OFF	01100000	00101000	B3 OFF	01110000	00101000
A4 ON	01100000	00011000	B4 ON	01110000	00011000
A4 OFF	01100000	00111000	B4 OFF	01110000	00111000
A5 ON	01100000	01000000	B5 ON	01110000	01000000
A5 OFF	01100000	01100000	B5 OFF	01110000	01100000
A6 ON	01100000	01010000	B6 ON	01110000	01010000
A6 OFF	01100000	01110000	B6 OFF	01110000	01110000
A7 ON	01100000	01001000	B7 ON	01110000	01001000
A7 OFF	01100000	01101000	B7 OFF	01110000	01101000
A8 ON	01100000	01011000	B8 ON	01110000	01011000
A8 OFF	01100000	01111000	B8 OFF	01110000	01111000
A9 ON	01100100	00000000	B9 ON	01110100	00000000
A9 OFF	01100100	00100000	B9 OFF	01110100	00100000
A10 ON	01100100	00010000	B10 ON	01110100	00010000
A10 OFF	01100100	00110000	B10 OFF	01110100	00110000
A11 ON	01100100	00001000	B11 ON	01110100	00001000
A11 OFF	01100100	00101000	B11 OFF	01110100	00101000
A12 ON	01100100	00011000	B12 ON	01110100	00011000
A12 OFF	01100100	00111000	B12 OFF	01110100	00111000
A13 ON	01100100	01000000	B13 ON	01110100	01000000
A13 OFF	01100100	01100000	B13 OFF	01110100	01100000
A14 ON	01100100	01010000	B14 ON	01110100	01010000
A14 OFF	01100100	01110000	B14 OFF	01110100	01110000
A15 ON	01100100	01001000	B15 ON	01110100	01001000
A15 OFF	01100100	01101000	B15 OFF	01110100	01101000
A16 ON	01100100	01011000	B16 ON	01110100	01011000
A16 OFF	01100100	01111000	B16 OFF	01110100	01111000
A BRIGHT 005	01100000	10001000	B BRIGHT 005	01110000	10001000
A DIM 005	01100000	10011000	B DIM 005	01110000	10011000
C1 ON	01000000	00000000	D1 ON	01010000	00000000
C1 OFF	01000000	00100000	D1 OFF	01010000	00100000
C2 ON	01000000	00010000	D2 ON	01010000	00010000
C2 OFF	01000000	00110000	D2 OFF	01010000	00110000
C3 ON	01000000	00001000	D3 ON	01010000	00001000
C3 OFF	01000000	00101000	D3 OFF	01010000	00101000
C4 ON	01000000	00011000	D4 ON	01010000	00011000
C4 OFF	01000000	00111000	D4 OFF	01010000	00111000

X-10 Command	Bit 76543210	Bit 76543210	X-10 Command	Bit 76543210	Bit 76543210
C5 ON	01000000	01000000	D5 ON	01010000	01000000
C5 OFF	01000000	01100000	D5 OFF	01010000	01100000
C6 ON	01000000	01010000	D6 ON	01010000	01010000
C6 OFF	01000000	01110000	D6 OFF	01010000	01110000
C7 ON	01000000	01001000	D7 ON	01010000	01001000
C7 OFF	01000000	01101000	D7 OFF	01010000	01101000
C8 ON	01000000	01011000	D8 ON	01010000	01011000
C8 OFF	01000000	01111000	D8 OFF	01010000	01111000
C9 ON	01000100	00000000	D9 ON	01010100	00000000
C9 OFF	01000100	00100000	D9 OFF	01010100	00100000
C10 ON	01000100	00010000	D10 ON	01010100	00010000
C10 OFF	01000100	00110000	D10 OFF	01010100	00110000
C11 ON	01000100	00001000	D11 ON	01010100	00001000
C11 OFF	01000100	00101000	D11 OFF	01010100	00101000
C12 ON	01000100	00011000	D12 ON	01010100	00011000
C12 OFF	01000100	00111000	D12 OFF	01010100	00111000
C13 ON	01000100	01000000	D13 ON	01010100	01000000
C13 OFF	01000100	01100000	D13 OFF	01010100	01100000
C14 ON	01000100	01010000	D14 ON	01010100	01010000
C14 OFF	01000100	01110000	D14 OFF	01010100	01110000
C15 ON	01000100	01001000	D15 ON	01010100	01001000
C15 OFF	01000100	01101000	D15 OFF	01010100	01101000
C16 ON	01000100	01011000	D16 ON	01010100	01011000
C16 OFF	01000100	01111000	D16 OFF	01010100	01111000
C BRIGHT 005	01000000	10001000	D BRIGHT 005	01010000	10001000
C DIM 005	01000000	10011000	D DIM 005	01010000	10011000
E1 ON	10000000	00000000	F1 ON	10010000	00000000
E1 OFF	10000000	00100000	F1 OFF	10010000	00100000
E2 ON	10000000	00010000	F2 ON	10010000	00010000
E2 OFF	10000000	00110000	F2 OFF	10010000	00110000
E3 ON	10000000	00001000	F3 ON	10010000	00001000
E3 OFF	10000000	00101000	F3 OFF	10010000	00101000
E4 ON	10000000	00011000	F4 ON	10010000	00011000
E4 OFF	10000000	00111000	F4 OFF	10010000	00111000
E5 ON	10000000	01000000	F5 ON	10010000	01000000
E5 OFF	10000000	01100000	F5 OFF	10010000	01100000
E6 ON	10000000	01010000	F6 ON	10010000	01010000
E6 OFF	10000000	01110000	F6 OFF	10010000	01110000
E7 ON	10000000	01001000	F7 ON	10010000	01001000
E7 OFF	10000000	01101000	F7 OFF	10010000	01101000
E8 ON	10000000	01011000	F8 ON	10010000	01011000
E8 OFF	10000000	01111000	F8 OFF	10010000	01111000
E9 ON	10000100	00000000	F9 ON	10010100	00000000
E9 OFF	10000100	00100000	F9 OFF	10010100	00100000
E10 ON	10000100	00010000	F10 ON	10010100	00010000
E10 OFF	10000100	00110000	F10 OFF	10010100	00110000
E11 ON	10000100	00001000	F11 ON	10010100	00001000
E11 OFF	10000100	00101000	F11 OFF	10010100	00101000
E12 ON	10000100	00011000	F12 ON	10010100	00011000
E12 OFF	10000100	00111000	F12 OFF	10010100	00111000
E13 ON	10000100	01000000	F13 ON	10010100	01000000
E13 OFF	10000100	01100000	F13 OFF	10010100	01100000
E14 ON	10000100	01010000	F14 ON	10010100	01010000

X-10 Command	Bit 76543210	Bit 76543210	X-10 Command	Bit 76543210	Bit 76543210
E14 OFF	10000100	01110000	F14 OFF	10010100	01110000
E15 ON	10000100	01001000	F15 ON	10010100	01001000
E15 OFF	10000100	01101000	F15 OFF	10010100	01101000
E16 ON	10000100	01011000	F16 ON	10010100	01011000
E16 OFF	10000100	01111000	F16 OFF	10010100	01111000
E BRIGHT 005	10000000	10001000	F BRIGHT 005	10010000	10001000
E DIM 005	10000000	10011000	F DIM 005	10010000	10011000
G1 ON	10100000	00000000	H1 ON	10110000	00000000
G1 OFF	10100000	00100000	H1 OFF	10110000	00100000
G2 ON	10100000	00010000	H2 ON	10110000	00010000
G2 OFF	10100000	00110000	H2 OFF	10110000	00110000
G3 ON	10100000	00001000	H3 ON	10110000	00001000
G3 OFF	10100000	00101000	H3 OFF	10110000	00101000
G4 ON	10100000	00011000	H4 ON	10110000	00011000
G4 OFF	10100000	00111000	H4 OFF	10110000	00111000
G5 ON	10100000	01000000	H5 ON	10110000	01000000
G5 OFF	10100000	01100000	H5 OFF	10110000	01100000
G6 ON	10100000	01010000	H6 ON	10110000	01010000
G6 OFF	10100000	01110000	H6 OFF	10110000	01110000
G7 ON	10100000	01001000	H7 ON	10110000	01001000
G7 OFF	10100000	01101000	H7 OFF	10110000	01101000
G8 ON	10100000	01011000	H8 ON	10110000	01011000
G8 OFF	10100000	01111000	H8 OFF	10110000	01111000
G9 ON	10100100	00000000	H9 ON	10110100	00000000
G9 OFF	10100100	00100000	H9 OFF	10110100	00100000
G10 ON	10100100	00010000	H10 ON	10110100	00010000
G10 OFF	10100100	00110000	H10 OFF	10110100	00110000
G11 ON	10100100	00001000	H11 ON	10110100	00001000
G11 OFF	10100100	00101000	H11 OFF	10110100	00101000
G12 ON	10100100	00011000	H12 ON	10110100	00011000
G12 OFF	10100100	00111000	H12 OFF	10110100	00111000
G13 ON	10100100	01000000	H13 ON	10110100	01000000
G13 OFF	10100100	01100000	H13 OFF	10110100	01100000
G14 ON	10100100	01010000	H14 ON	10110100	01010000
G14 OFF	10100100	01110000	H14 OFF	10110100	01110000
G15 ON	10100100	01001000	H15 ON	10110100	01001000
G15 OFF	10100100	01101000	H15 OFF	10110100	01101000
G16 ON	10100100	01011000	H16 ON	10110100	01011000
G16 OFF	10100100	01111000	H16 OFF	10110100	01111000
G BRIGHT 005	10100000	10001000	H BRIGHT 005	10110000	10001000
G DIM 005	10100000	10011000	H DIM 005	10110000	10011000
I1 ON	11100000	00000000	J1 ON	11110000	00000000
I1 OFF	11100000	00100000	J1 OFF	11110000	00100000
I2 ON	11100000	00010000	J2 ON	11110000	00010000
I2 OFF	11100000	00110000	J2 OFF	11110000	00110000
I3 ON	11100000	00001000	J3 ON	11110000	00001000
I3 OFF	11100000	00101000	J3 OFF	11110000	00101000
I4 ON	11100000	00011000	J4 ON	11110000	00011000
I4 OFF	11100000	00111000	J4 OFF	11110000	00111000
I5 ON	11100000	01000000	J5 ON	11110000	01000000
I5 OFF	11100000	01100000	J5 OFF	11110000	01100000
I6 ON	11100000	01010000	J6 ON	11110000	01010000
I6 OFF	11100000	01110000	J6 OFF	11110000	01110000

X-10 Command	Bit 76543210	Bit 76543210	X-10 Command	Bit 76543210	Bit 76543210
I7 ON	11100000	01001000	J7 ON	11110000	01001000
I7 OFF	11100000	01101000	J7 OFF	11110000	01101000
I8 ON	11100000	01011000	J8 ON	11110000	01011000
I8 OFF	11100000	01111000	J8 OFF	11110000	01111000
I9 ON	11100100	00000000	J9 ON	11110100	00000000
I9 OFF	11100100	00100000	J9 OFF	11110100	00100000
I10 ON	11100100	00010000	J10 ON	11110100	00010000
I10 OFF	11100100	00110000	J10 OFF	11110100	00110000
I11 ON	11100100	00001000	J11 ON	11110100	00001000
I11 OFF	11100100	00101000	J11 OFF	11110100	00101000
I12 ON	11100100	00011000	J12 ON	11110100	00011000
I12 OFF	11100100	00111000	J12 OFF	11110100	00111000
I13 ON	11100100	01000000	J13 ON	11110100	01000000
I13 OFF	11100100	01100000	J13 OFF	11110100	01100000
I14 ON	11100100	01010000	J14 ON	11110100	01010000
I14 OFF	11100100	01110000	J14 OFF	11110100	01110000
I15 ON	11100100	01001000	J15 ON	11110100	01001000
I15 OFF	11100100	01101000	J15 OFF	11110100	01101000
I16 ON	11100100	01011000	J16 ON	11110100	01011000
I16 OFF	11100100	01111000	J16 OFF	11110100	01111000
I BRIGHT 005	11100000	10001000	J BRIGHT 005	11110000	10001000
I DIM 005	11100000	10011000	J DIM 005	11110000	10011000
K1 ON	11000000	00000000	L1 ON	11010000	00000000
K1 OFF	11000000	00100000	L1 OFF	11010000	00100000
K2 ON	11000000	00010000	L2 ON	11010000	00010000
K2 OFF	11000000	00110000	L2 OFF	11010000	00110000
K3 ON	11000000	00001000	L3 ON	11010000	00001000
K3 OFF	11000000	00101000	L3 OFF	11010000	00101000
K4 ON	11000000	00011000	L4 ON	11010000	00011000
K4 OFF	11000000	00111000	L4 OFF	11010000	00111000
K5 ON	11000000	01000000	L5 ON	11010000	01000000
K5 OFF	11000000	01100000	L5 OFF	11010000	01100000
K6 ON	11000000	01010000	L6 ON	11010000	01010000
K6 OFF	11000000	01110000	L6 OFF	11010000	01110000
K7 ON	11000000	01001000	L7 ON	11010000	01001000
K7 OFF	11000000	01101000	L7 OFF	11010000	01101000
K8 ON	11000000	01011000	L8 ON	11010000	01011000
K8 OFF	11000000	01111000	L8 OFF	11010000	01111000
K9 ON	11000100	00000000	L9 ON	11010100	00000000
K9 OFF	11000100	00100000	L9 OFF	11010100	00100000
K10 ON	11000100	00010000	L10 ON	11010100	00010000
K10 OFF	11000100	00110000	L10 OFF	11010100	00110000
K11 ON	11000100	00001000	L11 ON	11010100	00001000
K11 OFF	11000100	00101000	L11 OFF	11010100	00101000
K12 ON	11000100	00011000	L12 ON	11010100	00011000
K12 OFF	11000100	00111000	L12 OFF	11010100	00111000
K13 ON	11000100	01000000	L13 ON	11010100	01000000
K13 OFF	11000100	01100000	L13 OFF	11010100	01100000
K14 ON	11000100	01010000	L14 ON	11010100	01010000
K14 OFF	11000100	01110000	L14 OFF	11010100	01110000
K15 ON	11000100	01001000	L15 ON	11010100	01001000
K15 OFF	11000100	01101000	L15 OFF	11010100	01101000
K16 ON	11000100	01011000	L16 ON	11010100	01011000

X-10 Command	Bit 76543210	Bit 76543210	X-10 Command	Bit 76543210	Bit 76543210
K16 OFF	11000100	01111000	L16 OFF	11010100	01111000
K BRIGHT 005	11000000	10001000	L BRIGHT 005	11010000	10001000
K DIM 005	11000000	10011000	L DIM 005	11010000	10011000
M1 ON	00000000	00000000	N1 ON	00010000	00000000
M1 OFF	00000000	00100000	N1 OFF	00010000	00100000
M2 ON	00000000	00010000	N2 ON	00010000	00010000
M2 OFF	00000000	00110000	N2 OFF	00010000	00110000
M3 ON	00000000	00001000	N3 ON	00010000	00001000
M3 OFF	00000000	00101000	N3 OFF	00010000	00101000
M4 ON	00000000	00011000	N4 ON	00010000	00011000
M4 OFF	00000000	00111000	N4 OFF	00010000	00111000
M5 ON	00000000	01000000	N5 ON	00010000	01000000
M5 OFF	00000000	01100000	N5 OFF	00010000	01100000
M6 ON	00000000	01010000	N6 ON	00010000	01010000
M6 OFF	00000000	01110000	N6 OFF	00010000	01110000
M7 ON	00000000	01001000	N7 ON	00010000	01001000
M7 OFF	00000000	01101000	N7 OFF	00010000	01101000
M8 ON	00000000	01011000	N8 ON	00010000	01011000
M8 OFF	00000000	01111000	N8 OFF	00010000	01111000
M9 ON	00000100	00000000	N9 ON	00010100	00000000
M9 OFF	00000100	00100000	N9 OFF	00010100	00100000
M10 ON	00000100	00010000	N10 ON	00010100	00010000
M10 OFF	00000100	00110000	N10 OFF	00010100	00110000
M11 ON	00000100	00001000	N11 ON	00010100	00001000
M11 OFF	00000100	00101000	N11 OFF	00010100	00101000
M12 ON	00000100	00011000	N12 ON	00010100	00011000
M12 OFF	00000100	00111000	N12 OFF	00010100	00111000
M13 ON	00000100	01000000	N13 ON	00010100	01000000
M13 OFF	00000100	01100000	N13 OFF	00010100	01100000
M14 ON	00000100	01010000	N14 ON	00010100	01010000
M14 OFF	00000100	01110000	N14 OFF	00010100	01110000
M15 ON	00000100	01001000	N15 ON	00010100	01001000
M15 OFF	00000100	01101000	N15 OFF	00010100	01101000
M16 ON	00000100	01011000	N16 ON	00010100	01011000
M16 OFF	00000100	01111000	N16 OFF	00010100	01111000
M BRIGHT 005	00000000	10001000	N BRIGHT 005	00010000	10001000
M DIM 005	00000000	10011000	N DIM 005	00010000	10011000
O1 ON	00100000	00000000	P1 ON	00110000	00000000
O1 OFF	00100000	00100000	P1 OFF	00110000	00100000
O2 ON	00100000	00010000	P2 ON	00110000	00010000
O2 OFF	00100000	00110000	P2 OFF	00110000	00110000
O3 ON	00100000	00001000	P3 ON	00110000	00001000
O3 OFF	00100000	00101000	P3 OFF	00110000	00101000
O4 ON	00100000	00011000	P4 ON	00110000	00011000
O4 OFF	00100000	00111000	P4 OFF	00110000	00111000
O5 ON	00100000	01000000	P5 ON	00110000	01000000
O5 OFF	00100000	01100000	P5 OFF	00110000	01100000
O6 ON	00100000	01010000	P6 ON	00110000	01010000
O6 OFF	00100000	01110000	P6 OFF	00110000	01110000
O7 ON	00100000	01001000	P7 ON	00110000	01001000
O7 OFF	00100000	01101000	P7 OFF	00110000	01101000
O8 ON	00100000	01011000	P8 ON	00110000	01011000
O8 OFF	00100000	01111000	P8 OFF	00110000	01111000

X-10 Command	Bit 76543210	Bit 76543210	X-10 Command	Bit 76543210	Bit 76543210
O9 ON	00100100	00000000	P9 ON	00110100	00000000
O9 OFF	00100100	00100000	P9 OFF	00110100	00100000
O10 ON	00100100	00010000	P10 ON	00110100	00010000
O10 OFF	00100100	00110000	P10 OFF	00110100	00110000
O11 ON	00100100	00001000	P11 ON	00110100	00001000
O11 OFF	00100100	00101000	P11 OFF	00110100	00101000
O12 ON	00100100	00011000	P12 ON	00110100	00011000
O12 OFF	00100100	00111000	P12 OFF	00110100	00111000
O13 ON	00100100	01000000	P13 ON	00110100	01000000
O13 OFF	00100100	01100000	P13 OFF	00110100	01100000
O14 ON	00100100	01010000	P14 ON	00110100	01010000
O14 OFF	00100100	01110000	P14 OFF	00110100	01110000
O15 ON	00100100	01001000	P15 ON	00110100	01001000
O15 OFF	00100100	01101000	P15 OFF	00110100	01101000
O16 ON	00100100	01011000	P16 ON	00110100	01011000
O16 OFF	00100100	01111000	P16 OFF	00110100	01111000
O BRIGHT 005	00100000	10001000	P BRIGHT 005	00110000	10001000
O DIM 005	00100000	10011000	P DIM 005	00110000	10011000