Using Low Power Schottky (74LS) Logic for the EDUC–8 Microcomputer

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Abstract

The original Electronics Australia EDUC–8 microcomputer from 1974 was designed using standard 74 series TTL logic. This article describes the changes that are needed when using 74LS series logic, which uses 80% less power, has twice the loading capability and is about 85% faster.

Introduction

The main changes that are required when using 74LS series logic are the pullup resistor values used on open collector (OC) outputs, mostly due to the lower I_{OL} (output low current), I_{IL} (input low current) and I_{IH} (input high current) values . Typically, the resistor values for 74LS are about twice that for standard 74 series TTL. For inputs that are tied high via a resistor, these should be connected directly to V_{CC} for 74LS, since they have diode inputs. However, some Fairchild 74LS logic uses the standard emitter type input (typically gates with open collector outputs, some flip–flops and the clock inputs of ripple counters). These inputs will need to use a resistor.

Summary of recommended changes

To reduce power consumption and meet loading requirements, these resistor values can be used for 74 series TTL. The values for 74LS must always be used. A detailed explanation for the changes is given in the following sections.

E8/F	Rowe	74/96L	74LS/96LS
SR0–SR7	10K	10K	10K
SR0–SR7	10K	3.3K	5.6K (with EDUC–8ME)
SR0–SR7	10K	1.5K	3.3K (with EDUC–8ME, paper tape reader and boot ROM)*
LA2 R_{x1}	10K	16K	9.1K (For 96L02 and 96LS02)
LA2 C_{x1}	100pF	56pF	100pF
$\overline{RC}$ R_{x2}	10K	18K	16K ($\overline{RC}$ = $\overline{\text{RUN COMMAND}}$)
$\overline{RC}$ C_{x2}	1nF	470pF	470pF

*For 74 series TTL, 7438 OC buffers must be used.
Replace 7405 with 74LS06 or 74LS16 and 7417 with 74LS07 or 74LS17.

E8/C	Rowe	74	74LS
BUS–A	470R	1.5K	3.3K
BUS–B	470R	1.0K	2.2K
BUS–C	680R	1.0K	1.8K
BUS–D	680R	3.9K	3.9K

E8/CE	Rowe	74	74LS
BUS–A	470R	1.2K	2.7K
BUS–B	470R	1.0K	2.2K
BUS–C	680R	1.0K	1.8K
BUS–D	680R	3.3K	6.8K

E8/T (UL)	Rowe	74	74LS
7420 (3)	2.2K	10K	0R (two resistors)
7473 (2)	2.2K	10K	0R
74161 (3)	2.2K	10K	0R

E8/D (UL)	Rowe	74	74LS
7400 (1)	2.2K	10K	0R
74259 (1)	2.2K	10K	0R

E8/A	Rowe	74	74LS
7401/7405	2.2K	3.9K	8.2K (three resistors)
AC=0	820R	680R	1.5K

E8/P (UL)	Rowe	74
7480 (0.8)	2.2K	10K
9001 (9)	2.2K	3.3K

E8/M	Rowe	74	74LS
7493	820R	3.9K	8.2K
MB=0	820R	680R	1.5K

7405 used for $\overline{\text{PC7}}$ and $\overline{\text{MA7}}$ replaced with 74LS06 or 74LS16

Page Zero	SSP	74	74LS
$\overline{\text{MB5}}$	820R	3.9K	8.2K
$\overline{\text{MB4}}$+MB5	820R	3.9K	8.2K
$\overline{\text{E}}$	820R	1.8K	3.3K
P14/MB3	2 Input	10K	0K (change from 2 input to 1 input with other input tied high)

E8/IOT	Rowe	74	74LS
4O/2I	1K	1.2K	2.7K
1O/2I	1K	3.9K	8.2K
1O/1I	1K	3.9K	8.2K
$\overline{\text{IOT\_SKP}}$	1K	3.9K	8.2K

E8/KI	Rowe	9602	96L02	96LS02
3I	1K	6.8K	10K	0R (4.5 UL for 9602, 1.5 UL for 96L02)
R_{x1}	10K		16K	9.1K
C_{x1}	100pF		56pF	100pF
R_{x2}	33K		36K	30K
C_{x2}	1nF		820pF	820pF

If driving LEDs, replace 7405 with 74LS06 or 74LS16.

E8/S (UL)	Rowe	74	74LS
7413 (3)	1K	10K	0R

Front Panel SR Pullup Resistor Values

The maximum resistor value is

$$R_{\text{max}} = \frac{V_{\text{CC,min}} - V_{\text{OH}}}{0.04U_{\text{IH}}} \qquad (1)$$

where for 74 series TTL we have

$V_{\text{CC,min}}$ = minimum power supply voltage (4.75 V)
V_{OH} = output high voltage level (2.4 V for 74, 2.7 V for 74LS)
U_{IH} = summation of input high unit loads being driven (typically 1 for 74 and 0.5 for 74LS)

Each SR switch drives one input. This gives R_{max} = 58.75/1 = 58.75 kΩ. EDUC–8 uses 10 kΩ, which is OK. For 74LS we have R_{max} 51.25/0.5 = 102.5 kΩ. So using 10K pullups is fine with 7400 or 74LS.

However, the situation changes with EDUC–8ME. In this case, there are up to eight additional inputs to the E8M/D decoder, one for each EDUC–8ME. This gives R_{max} = 58.75/9 = 6.528 kΩ for 74 and 102.5/9 = 11.389 kΩ for 74LS. Since switches are used to drive the signal we let the average resistance $R_{av} = R_{max}/2$ = 3.264 kΩ for 74 and 5.694 kΩ for 74LS. This implies the input voltage will be halfway between V_{CC} and V_{OH}. Choosing the closest recommended values gives 3.3K for 74 and 5.6K for 74LS.

Note that if a boot ROM and paper tape reader are used, we can have up nine inputs and two OC outputs. We have

$$R_{min} = \frac{V_{CC,max} - V_{OL}}{I_{OL} - 1.6U_{IL}} \qquad R_{max} = \frac{V_{CC,min} - V_{OH}}{N_O I_{OH} + 0.04U_{IH}} \tag{2}$$

where

$V_{CC,max}$ = maximum power supply voltage (5.25 V)
V_{OL} = output low voltage level (0.4 V for 74, 0.5 V for 74LS)
I_{OL} = output low open collector current (16 mA for 7401, 8 mA for 74LS01)
I_{OH} = output high open collector current (0.25 mA for 7401, 0.1 mA for 74LS01)
U_{IL} = summation of input low unit loads being driven (typically 1 for 74 and 0.25 for 74LS)
N_O = number of open collector outputs connected together

We thus have for 74 series TTL

$$R_{min} = \frac{4.85}{16 - 1.6N_{IL}} \qquad R_{max} = \frac{2.35}{0.25N_O + 0.04N_{IH}} \tag{3}$$

where N_{IL} and N_{IH} is the number of standard 1.6 mA input low and 0.04 mA input high units, respectively. For 74LS series TTL we have

$$R_{LS,min} = \frac{4.75}{8 - 0.4N_{IL}} \qquad R_{LS,max} = \frac{2.05}{0.1N_O + 0.02N_{IH}} \tag{4}$$

where N_{IL} and N_{IH} is the number of standard 1.6×0.25 = 0.4 mA input low and 0.04×0.5 = 0.02 mA input high units, respectively.

In this case, we have N_I = 9 and N_O = 2 which gives R_{min} = 3031 Ω and R_{max} = 2733 Ω, implying that the circuit won't work with any pullup value. This can be be fixed by using a 7438 2–input NAND OC buffer with U_{OL} = 30. This gives R_{min} = 144 Ω, R_{max} = 2733 Ω, R_{av} = 1438 Ω and R_{rec} = 1.5K. For 74LS01 we have R_{min} = 1080 Ω, R_{max} = 5395 Ω, R_{av} = 3237 Ω and R_{rec} = 3.3K.

Front Panel LED Resistors

The 5 mm Z0800 Red LEDs from Altronics have a forward current of 15 mA and forward voltage of 2.3 V. The pullup resistor is 180 Ω. Using the I_f versus V_f graph from the LED data sheet [1], V_{OL} = 0.4 V, V_{CC} = 5.25 V and R = 171 Ω (–5%), this gives I_f = 15.8 mA. As $I_{OL} = 10U_{OL}$ = 16 mA, this is just within specification for the 7405 OC inverters. The 7417 OC buffers have the same specification.

As the 74LS05 [2] has a standard output of only $I_{OL} = 5U_{OL}$ = 8 mA, this means a higher resistor value will be needed. With 74LS05 we have V_{OL} = 0.5 V. At I_f = 8 mA, this gives V_f = 2.03 V and R_{min} = (5.25–0.5–2.03)/0.008 = 340 Ω. Thus, you will need to use a 390 Ω resistor, but the LEDs are at 2.7 mcd, compared to 5 mcd with 7400.

However, the 74LS06/74LS16 OC inverters [3] and 74LS07/74LS17 OC buffers [4] all have I_{OL} = 16 mA at V_{OL} = 0.4 V. This means you will need to replace the 7405 either with a 74LS06 or 74LS16 and the 7417 either with a 74LS07 or 74LS17.

Front Panel 9602

The front panel uses a 9602 dual multivibrator. For signal LA2 R_{x1} = 10K and C_{x1} = 100 pF gives a pulse width of t_{w1} = 0.46 μs. For the 96L02 the graph from the data sheet gives R_{x1} = 20K and C_{x1} = 45 pF. This has a time constant of $T_1 = R_{x1}C_{x1}$ = 0.9 µs. By choosing standard component values of R_{x1} = 16K and C_{x1} = 56 pF, we have $R_{x1}C_{x1}$ = 0.896 µs, close to the desired value. The table below shows how the other values were calculated.

Rowe (9602)			Device	Graph			Recommended		
R_x (kΩ)	C_x (pF)	t_w (µs)		R_x (kΩ)	C_x (pF)	T (µs)	R_x (kΩ)	C_x (pF)	T (µs)
10	100	0.46	L02–1	20	45	0.90	16	56	0.896
			LS02–1	10	92	0.92	9.1	100	0.910
10	1000	3.3	L02–2	20	430	8.60	18	470	8.460
			LS02–2	10	750	7.50	16	470	7.520

Bus Pullups

Examining the schematics, the busses have the following UL for 74. The 7480 has an unusual 0.4 U_{IH}. For 74LS, U_{IH} is multiplied by 0.5 and U_{IL} by 0.25, except for the 7480 inputs in E8/P, since the 74LS80 is not available (a Texas Instruments 74LS80 is shown on eBay from China, but this is likely a fake part). For the D–bus, we use V_{OL} = 0.45 V, I_{OH} = 0.1 mA and U_{OL} = 10 for the 93415/D2115 static RAM OC outputs.

Board	A–BUS			B–BUS			C–BUS			D–BUS		
	N_O	U_{IH}	U_{IL}	N_O	U_{IH}	U_{IL}	N_O	U_{IH}	U_{IL}	N_O	U_{IH}	U_{IL}
E8/A	1	1	1	3	–	–	1	–	–	–	1	1
E8/P	1	2	2	1	0.4	1	2	0.4	1	–	–	–
E8/M	–	–	–	1	–	–	3	2	2	2	2	2
E8/IOT	1	–	–	–	–	–	–	–	–	–	–	–
Total 74	3	3	3	5	0.4	1	6	2.4	3	2	3	3
Total LS	3	1.5	0.75	5	0.4	1	6	1.4	1.5	2	1.5	0.75

The minimum, maximum, actual and recommended values for the pullup resistors that are on the E8/C board for 74 and 74LS are

Signal	74 series TTL					74LS series TTL			
	R_{rowe}	R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}	R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}
A–BUS	470R	433	2701	1567	1.5K	699	5694	3126	3.3K
B–BUS	470R	337	1856	1097	1.0K	742	3973	2358	2.2K
C–BUS	680R	433	1472	953	1.0K	848	3125	1987	1.8K
D–BUS	680R	429	7344	3886	3.9K	324	7885	4104	3.9K

We can see that for 74 series TTL, the original values are all within range, but are quite close to the minimum values. Higher values can be used, with a small reduction in power. For 74LS we can see that except for D–BUS, higher pullup values will need to be used. With EDUC–8ME, the A–bus has one extra driver from E8/B. The two RAMs for D–BUS are replaced by a single standard OC output from E8/B. For 7400 and 74LS we thus have

Signal	N_O	74 series TTL				74LS series TTL			
		R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}	R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}
A–BUS	4	433	2098	1266	1.2K	699	4457	2578	2.7K
D–BUS 7401	1	433	6351	3392	3.3K	699	12812	6756	6.8K
D–BUS 93415	1	429	10682	5555	3.3K	324	12812	6568	6.8K

As we need to use one 93415 RAM to adjust the $\overline{\text{WE}}$ width, we need to make sure the recommended value for the D–BUS will work. We can see that the 3.3K value for 74 and 6.8K for 74LS are within the minimum and maximum resistor range and thus can be used with both the 7401 from E8/B or one 93415.

E8/T Timing Board

Four 2.2K pullup resistors are used. Two 7420 dual 4–input NAND gates have one gate each (one for the clock and one for the master reset) with three inputs tied high. This gives R_{max} = 58.75/3 = 19.583 kΩ, R_{av} = 9.792 kΩ and R_{rec} = 10K. The 9316/74161 counter has two inputs tied high, but with three ULs, giving R_{rec} = 10K. Finally, the 7473 dual JK FF used for Execute and Defer Control has two inputs tied high. This gives R_{max} = 58.75/2 = 29.375 kΩ and R_{av} = 14.688 kΩ. Since this exceeds the 10K recommended maximum, we let R_{rec} = 10K. Thus, all the 2.2K pullups can be replaced with 10K pullups. For 74LS, the pullups should be replaced with wired links.

E8/D Decoder Board

Two 2.2K pullup resistors are used. One resistor is used to tie one input of the 9334/74259 decoder high. The other resistor ties one input of a 7400 quad 2–input NAND gate high. Thus, both these resistors can be replaced with 10K pullups.

E8/A Board

There are two spare 7401 quad 2–input NAND OC and one spare 7405 hex inverter OC gates with one output and one input. Two 7405 OC hex inverters are used with eight outputs tied together to generate the AC=0 signal. This signal goes to one input on E8/P. This gives

Signal	N_O	N_I	R_{rowe}	74 series TTL				74LS series TTL			
				R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}	R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}
Misc	1	1	2.2K	337	8103	4220	3.9K	625	17083	8854	8.2K
AC=0	8	1	820R	337	1152	744	680R	625	2500	1562	1.5K

Rowe uses 2.2K for the miscellaneous pullups, which will work fine for both 7400 and 74LS. However, 3.9K and 8.2K for 74 and 74LS, respectively, can also be used with a small reduction of power. For AC=0, Rowe used 820R for the pullup, which will also work with 74LS. A 680R resistor could be used for 74, which is closer to R_{av} than 820R. For 74LS, a 1.5K pullup can be used if desired.

E8/P Program Counter and Adder Board

Two 2.2K pullup resistors are used. One resistor is used to tie two inputs of the 7480 adder high. The other resistor ties five inputs of the 9001/74105 JK FF high. For the 7480, each input has U_{IH} = 0.4 for 0.8 UL total. Thus the pullup can be replaced with a 10K resistor if desired. For the 9001, four inputs have 1.5 UL while one input has 3 UL. This gives R_{max} = 58.75/(4×1.5+3) = 58.75/9 = 6.528 kΩ, R_{av} = 3.264 kΩ and R_{rec} = 3.3K.

E8/M Memory Board

Two 7405 OC hex inverters are also used on this board. Eight outputs are tied together to generate the MB=0 signal. This signal goes to one input on E8/P. One OC inverter drives two inputs of the 7493 strobe counter. We have

Signal	N_O	N_I	R_{rowe}	74 series TTL				74LS series TTL			
				R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}	R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}
7493	1	2	820R	379	7121	3750	3.9K	660	14643	7651	8.2K
MB=0	8	1	820R	337	1152	744	680R	625	2500	1562	1.5K

For the 7493 input, Rowe uses an 820R pullup which will also work with 74LS, although an 8.2K pullup can also be used if desired.

Two of the OC inverters are used to drive the MA7 and PC7 LEDs on the front panel. As for the front panel, the second 7405 will need to be replaced with a 74LS06 or 74LS16 in order to have sufficient drive for the LEDs.

Page Zero Modification

The page zero extension uses one of the 7405 OC inverters and a 7401 quad 2–input NAND OC. The inverter and one NAND have single outputs and inputs. We also have three outputs driving the the enable input of the 74157. The 74LS157 has a double load (U_{IH} = 1) for the $\overline{E}$ input. We have

Signal	N_O	N_I 74/LS	R_{SSP}	74 series TTL				74LS series TTL			
				R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}	R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}
Misc	1	1/1	820R	337	8103	4220	3.9K	625	17083	8854	8.2K
74157	3	1/2	820R	337	2975	1656	1.8K	660	6029	3345	3.3K

To decrease the load on the P14 and MB3 signals and reduce power, the two inputs to each NAND gate can be changed to a single input, with the other input tied high. A 10K pullup can be used for the two inputs tied high.

E8/IOT Interface Board

Two 7401 OC quad NANDs are used, all using 1K pullups. We have four outputs driving two inputs, one output driving one input, one output driving two inputs, and output IOT_SKP_ driving one input on E8/P. In summary

N_O	N_I	R_{rowe}	74 series TTL				74LS series TTL			
			R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}	R_{min} (Ω)	R_{max} (Ω)	R_{av} (Ω)	R_{rec}
4	2	1K	379	2176	1277	1.2K	660	4659	2659	2.7K
1	2	1K	379	7121	3750	3.9K	660	14643	7651	8.2K
1	1	1K	337	8103	4220	3.9K	625	17083	8854	8.2K

Thus, the 1K pullups can be used as is or the above values above can be used.

E8/KI Simple Input Keyboard

If driving LEDs, the 7405 needs to be replaced with either a 74LS06 or 74LS16. The 9602 dual multivibrator has one $\overline{I_0}$ and the two $\overline{C_D}$ inputs tied high. This has U_{IH} = 3×1.5 = 4.5 and thus R_{max} = 58.75/4.5 = 13.056 kΩ, R_{av} = 6.528 kΩ and R_{rec} = 6.8K (10K for 96L02 as U_{IH} = 1.5). The table below gives the values for R_x and C_x, where the formulas t_w = 0.31C_x(R_x+1), 0.33C_x(R_x+3) and 0.43$C_x R_x$ for 9602, 96L02 and 96LS02, respectively, were used for the second multivibrator.

Rowe (9602)			Device	Graph/Formula			Recommended		
R_x (kΩ)	C_x (pF)	t_w (μs)		R_x (kΩ)	C_x (pF)	T (μs)	R_x (kΩ)	C_x (pF)	T (μs)
10	100	0.46	L02–1	20	45	0.90	16	56	0.896
			LS02–1	10	92	0.92	9.1	100	0.910
33	1000	10.54	L02–2	28.9	1000	28.9	36	820	29.52
			LS02–2	24.5	1000	24.5	30	820	24.60

E8/S Octal Display

The 1713 dual 4–input NAND Schmitt trigger has three inputs tied high using a 1K resistor. This can be replaced with a 10K resistor if desired.

References

[1] Bright LED Electronics Corp., "5 mm bright red LED," BL–B5134, Dec. 2004. https://download.altronics.com.au/files/datasheets_Z0800.pdf

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[4] Texas Instruments, "74LS07 hex buffers/drivers with open–collector high–voltage outputs," SDLS021B, Jan. 2002. http://www.unicornelectronics.com/ftp/Data%20Sheets/74ls07.pdf