# Altair 8800 Simulator

# Highlights

- Power supply must be center-positive 7V-12V DC (typical usage 200-500mA, 1A max)
- Runs at about the same speed as the original
- Emulated memory size (RAM) is 64KB
- ALTAIR extended BASIC ROM (16k) can be mapped to addresses 0xC000-0xFFFF
- Emulates one ALTAIR 88-SIO, 88-ACR and 88-2SIO board. Each device can be mapped to the Arduino's serial interface (on the Due, they can be mapped to either Serial or Serial1). Data sent to each device can be captured and replayed.
- The ACR device also supports using the CSAVE/CLOAD commands in extended BASIC. When invoking CSAVE, the program will automatically be saved to a file specified by the file name in the CSAVE command. For CLOAD, all programs saved with CSAVE will automatically be played back until the program specified by the file name is found (or not).
- By default, both the 88-SIO and 88-2SIO boards are mapped to the Arduino's main serial interface which is configured to 115200 baud 8n1. That interface be accessed via pins 0/1 or the Arduino's USB cable (on the Due make sure to connect the USB cable to the programming USB port, not the native port).
- Processes input/output on serial devices to deal with 7/8 bit output, upper-case input and backspace.
- Emulates 4 (can be configured to up to 16) Altair 88-DCDD disk drives
- Emulates the 88-RTC-VI board which makes it possible to run ALTAIR Time Sharing BASIC.
- Many settings can be modified via a configuration editor (invoke by holding STOP and raising AUX1)
- Above specs apply when running on an Arduino Due. The simulator can also work when running on an Arduino Mega 2560. In that case, it runs at about 25% original speed and has 6k emulated RAM. Disk drive emulation is not supported on the Mega.

# Front Panel Elements

**Lights:**

| | |
|---|---|
| A15-A0 | Shows the current address bus state (i.e. PC during normal operation) |
| D7-D0 | Shows the current data bus state |

**Switches:**

| | |
|---|---|
| SW15-SW0 | Address/Data entry switches |
| RUN | Execute instructions starting at current PC location |
| STOP | Stop program execution |
| SINGLE STEP | Execute single instruction at current PC location and increment PC |
| EXAMINE | Set PC to address from SW15-0 and show content of that address on D7-0 |
| EXAMINE NEXT | Increment PC and show content of that address on D7-0 |
| DEPOSIT | Store value of D7-0 at current PC address |
| DEPOSIT NEXT | Increase PC by one and store value of D7-0 at that address |
| CLR | Stop serial capture/replay activated by AUX2 (see below)<br>Holding CLR down during power-up will initialize memory and CPU registers to 0 |
| RESET | Reset processor (set PC to 0) |
| PROTECT | Mark current memory page as write-protected (cannot be written to) |
| UNPROTECT | Remove write-protect status of current page |
| AUX1/AUX2 | See detailed information below |

# Auxiliary Switch Functions

**AUX1 down:**

Function depends on current setting of SW7-0:

0…0000: Print this list to serial interface

0…0001: Calculator (David Hansel, 2015)

- Flipping SW15 (on->off or off->on) executes operation selected by SW14-13 between operand currently showing on A15-8 lights and operand selected by SW12-8 switches. Result is shown on A15-8 lights.
- Operations (SW14-13): 00=Add, 01=Subtract, 10=Multiply, 11=Divide

0…0010: Kill-the-bit (Dean McDaniel, 1975)

- Kill the rotating bit. If you miss the lit bit, another bit turns on leaving two bits to destroy.
- Quickly toggle the switch, don't leave the switch in the up position.
- Before starting, make sure all the switches are in the down position.

0…0011: Pong game using front panel (http://altairclone.com/downloads/pong.pdf)

- Left player quickly toggles SW15 to hit the "ball."
- Right player toggles SW8. Score is kept in memory locations 0x80 and 0x81 (left and right).
- Score is missed balls, so the lower number wins.

0…0100: Pong game using serial terminal (David Hansel, 2015)

- Needs terminal connected to serial interface. Terminal must understand escape sequences for cursor movement ("ESC-[")
- Left player uses A/Z keys (paddle up/down), right player uses K/M keys (paddle up/down)

0…0101: 4k Basic (Bill Gates, Paul Allen, Monte Davidoff 1975)

- SW11 down: I/O to SIO device, SW11 up: I/O to 2SIO device
  (either setting will work in default simulator configuration)
- Answering N to questions about SIN/RND/SQR slightly increases available BASIC memory

0…0110: MITS 16k ROM Basic (see AUX1 UP section below)

- On Arduinoe Due, maps ROM extended BASIC to addresses 0xC000-0xFFFF until next RESET.
  (On Arduino Mega, ROM extended BASIC is always mapped to that range).
- Sets PC to 0xC000 and starts execution (i.e. starts BASIC)
- Before activating, set SW15-12 switches to
  0000: I/O goes to 2SIO device
  0010: I/O goes to SIO device
  (wither setting will work in default simulator configuration)
- When asked MEMORY SIZE, just press enter.
- When asked LINEPRINTER, enter capital O and press enter
- Available memory for BASIC programs is 48101 bytes (~3000 bytes on Arduino Mega)
- CSAVE and CLOAD commands can be used to save/load programs to/from internal storage

0…0111: MITS Programming System II (Due only)

- SW11 down: I/O to SIO device, SW11 up: I/O to 2SIO device
  (either setting will work in default simulator configuration)
- Editor, Assembler and Debugger
- See intro at the end of this document, google for full documentation

0…1000: Disk Drive Boot ROM (Due only)

- See Disk Drive Support section below

0…1001: ALTAIR Turnkey Monitor (Due only)

- Uses 2SIO device for I/O

0…1010: Music (“Daisy, Daisy…”, Due only) (Steve Dompier, 1975)

- In configuration menu, set throttle delay to 5 before running (automatic throttle introduces noise due to the throttle-adjustment code that runs 40 times per second)
- An AM radio held on top of Simulator, close to D0-D7 lights will pick up the song
- See: http://www.digibarn.com/collections/weirdstuff/altair-sheetmusic/

0…1011: 8080 CPU Diagnostic (Microcosm Associates, 1980)

- Basic test, takes about a second to finish
- Outputs to serial interface (“CPU IS OPERATIONAL”)

0…1100: 8080 CPU Exerciser (Frank D. Cringle 1994, Ian Bartholomew 2009)

- Very thorough test that generates a CRC code for each group of tests.
- Outputs to serial interface.
- Full test takes about 4 hours. The "aluop <b,c,d,e,h,l,m,a>" section takes especially long

11xxxxxx: Save the 256-byte memory page currently selected on the SW15-8 switches to file #xxxxxx

10xxxxxx: Load the 256-byte memory page currently selected on the SW15-8 switches from file #xxxxxx

**AUX1 up:**

If STOP is held up while AUX1 is raised, then invoke the configuration editor (see Configuration menu below). Otherwise, run the program configured via the corresponding setting in the configuration menu (default is 16k ROM BASIC).

**AUX2 down:**

If SW12 is up, then mount disk in emulated disk drive (see *Disk Drive Support* section below).

Otherwise, play back captured data or example programs. SW15-13 select the device to which data is played back and SW8-0 select what data is being played back:

- SW15 down: Use the serial device which is mapped to the host serial output (primary) and has last seen input/output activity. In most cases this will automatically select the intended device.
- SW15 up: Use serial device selected on SW14-13:
  00: 88-SIO (port 0x00/0x01)
  01: 88-ACR (port 0x06/0x07) (audio cassette interface)
  10: 88-2SIO, serial 1 (port 0x10/0x11)
  11: 88-2SIO, serial 2 (port 0x12/0x13)
- SW8 down: Play back basic/assembly example # selected on switches SW7-0 (see below)
- SW8 up: Play back captured data in file # selected on switches SW7-0 (see below)

Loading BASIC/assemly examples:

- SW7 up: BASIC example, SW7 down assembly example
- If SW6-0 are all 0 then a list of available examples will be transmitted
- Set SW6-0 to the example number in the list and push AUX2 DOWN to transmit example
- Playback can be stopped by pushing CLR or by pushing AUX2 DOWN again

Playing back captured data:

- Play back data previously captured via AUX2 up
- The file number to be played back must be selected via SW7-0
- Playback can be stopped by pushing CLR or by pushing AUX2 DOWN again

**AUX2 up:**

If SW12 is up, then unmount disk from disk drive (see *Disk Drive Support* section below).

Otherwise, capture data. SW15-13 select the device from which data is captured (same as SW15-13 settings in *AUX2 down* section above). SW7-0 specify the file number under which the captured data will be saved. Capturing continues until AUX2 is again pressed UP.

Capturing serial data can be used to save a BASIC program in BASIC (note that in extended BASIC the CSAVE/CLOAD commands provide an easier way of doing this):

1. Set SW7-0 to the desired storage file number
2. Set SW15-13 to 000 (to automatically select capture device)
3. type "list" (but **not** ENTER)
4. activate AUX2 up to start capture
5. press ENTER
6. wait until listing is finished
7. activate AUX2 up again to finish capture

To later restore a program:

1. Set SW7-0 to a storage file number under which serial data has been captured before
2. Set SW15-13 to 000 (to automatically select replay device)
3. type "new" to clear the current program
4. activate "AUX2 down" to start replaying the captured data
5. Ignore the "SYNTAX ERROR" at the end
   (reported because the final "ok" of the "list" function was also captured)

Capturing cassette data can be used to save BASIC variable contents in Extended BASIC or saving programs from MITS Programming System II

1. Set SW7-0 to the desired storage file number
2. Set SW15-13 to 101 (to capture from ACR device on I/O address 6/7)
3. activate AUX2 up to start capture
4. enter CSAVE*v [where v is the variable name that is supposed to be saved]
5. Repeat the previous step if more variables need to be saved
6. wait until listing is finished
7. activate AUX2 up again to finish capture

To later load the data:

1. Set SW7-0 to a storage file number under which cassette data has been captured before
2. Set SW15-13 to 101 (to replay to ACR device on I/O address 6/7)
3. Set SW8 to 1 (to select file replay, not BASIC example)
4. activate AUX2 down to start replaying the captured cassette data
5. enter CLOAD*v [where v is the variable name that is to be loaded]
6. Repeat the previous step if more variables need to be loaded
7. Activate AUX2 down to stop replay

# Disk Drive Support

Disk drive support is optional and requires a SD card attached to the Arduino Due's SPI header (the 2-row, 6-pin header marked "SPI"). See the *Wiring SD card to Arduino DUE* section at the end of this document about how to physically hook up the card.

Disk drive support is **not** available in the Arduino Mega build, mainly for two reasons: 1. The SPI pins on the Mega are directly connected to some general I/O pins which are already used for the front panel and 2. The Mega only provides 6k of emulated RAM. Most disk based programs require more than that.

If you do not want to connect a SD card to the Due then you may want to change the `NUM_DRIVES` setting in `config.h` to 0. If `NUM_DRIVES` is greater than 0 then the Due spends about 1-2 seconds during startup looking fort the SD card (it will continue normally but without drive support if no card is found).

If an SD card is detected, the following files are expected to be found in the root directory of the (FAT format) card (the `disks` subdirectory in the source archive contains several disks including CP/M and Altair DOS):

- **DISKxx.DSK** (where xx is a 2-digit hexadecimal number): Disk images that the simulator can mount.
- **DISKDIR.TXT**: A text file whose contents will be sent to the serial connection (i.e. shown to the user) if front panel switches are set to 0001xxxx00000000 and the AUX2 switch is pressed down. This should contain information about each of the DISKxx.DSK files

To mount disks in the drive, use the AUX2 down switch:

- Set SW15-0 to: 0001nnnnDDDDDDDD where nnnn is a 4-bit number selecting the drive (i.e. drive 0-15) and DDDDDDDD is an 8-bit number selecting the disk number and press AUX2 down.
- The 8-bit disk number corresponds to the xx in the DISKxx.DSK files on the SD card.
- For example, setting SW15-0 to 0001 0010 0000101 and pressing AUX2 down will mount disk number 5 in drive 2.
- Selecting disk number 0 is a special case. If disk 0 is selected for mounting, it will not be mounted but instead the contents of the DISKDIR.TXT file will be sent to the serial output (i.e. shown to the user). Note that that means a file named DISK00.DSK can not be mounted.
- If a disk is already mounted in the drive the mounted disk will be unmounted before mounting the new disk
- If the disk file does not exist, it is like inserting an empty disk in the drive. If the operating system writes to the disk, the selected disk file will be created. So inserting a non-existent disk and then formatting that disk via the operating system (e.g. CP/M) will create a new empty disk.
- It is possible to mount the same disk in multiple drives. The simulator has no problem with that but the running operating system may get confused.

To unmount a disk from a drive, use the AUX2 up switch:

- Set SW15-0 to: 0001nnnnxxxxxxxx where nnnn is a 4-bit number selecting the drive (i.e. drive 0-15) and press AUX2 up.
- It is not necessary to unmount disks before turning off the computer. Each write operation to a disk gets flushed to the SD card immediately so turning the computer off with disks mounted will not lose data.

To run a bootable disk image, first mount the disk and then start the Disk Boot ROM:

- Set SW0-7 to 00001000 (to select Disk Boot ROM)
- Press AUX1 down
- This will install the Disk Boot ROM at 0xFF00 and immediately start it. If a bootable disk has been mounted it should automatically start now

# Configuration Menu

The simulator configuration menu can be entered by holding STOP up and raising AUX1.
The following settings/actions are available:

- *Enable profiling*
  If enabled and the simulator is running (i.e. not in STOP mode) a message showing the current performance of the simulator is written to the (primary) serial output.
- *Set throttle delay* (Arduino Due only)
  Allows to throttle simulator performance. Throttling is done by busy-waiting, i.e. an empty loop counting down from the value selected here to zero. If set to “auto adjust”, the simulator evaluates performance about 40x a second and automatically adjusts the throttle delay to get as close to 100% of the original (i.e. 2MHz clock frequency) as possible. If profiling is enabled too then the effect of changes in the throttle delay can easily be observed.
- *Enable serial panel*
  Shows a simple representation of the front panel lights and switches on the (primary) serial output. Mostly useful when STANDALONE mode is enabled.
- *Enable serial input*
  When stopped, the simulator processes the inputs described in the “Debugging capabilities” section below.
- *Enable serial debug*
  Print processor status and disassembled opcode during single stepping
- *Clear memory on powerup*
  If enabled, the simulated memory will be cleared (set to 0) when the simulator starts up. Otherwise, memory content is random (as with the original).
- *Aux1 shortcut program*
  Sets the program to be run when the AUX1 switch is raised. This can be any if the built-in programs available via AUX1 down or a disk. If a disk is selected, pushing up AUX1 will mount the disk and then install and run the disk boot loader.
- *Configure Interrupts*
  See “Interrupts configuration” section below.
- *Host Serial baud rate*
  Sets the baud rate for the Serial interface (pins 0/1 and USB serial on the Arduino)
- *Host Serial1 baud rate* (Arduino Due only)
  Sets the baud rate for the Serial1 interface (pins 18/19) on the Arduino
- *Primary host serial* (Arduino Due only)
  Selects which serial interface (Serial/Serial1) is used as the primary interface. All simulator related output (such as the configuration menu) is sent to the primary serial interface. Also, when auto-detecting the serial device for capturing/replaying data, only devices mapped to the primary serial interface are considered.
- *Configure SIO/ACR/2SIO port 1/2SIO port 2*
  See “Serial device configuration” section below
- *Manage Filesystem*
  Starts file system manager (see File System Manager section below).
- *Apply host serial settings*
  When making changes to the host serial settings (baud rate, primary interface), those are not applied immediately. Select this option to apply the modified settings.
- *Clear memory*
  Clear the memory of the simulator (set all to 0)

- *Save configuration*
  Saves the configuration. Up to 256 different configurations can be saved.
  Configuration #0 is automatically loaded when the simulator starts.
- *Load configuration*
  Loads a saved configuration
- *Reset to defaults*
  Resets all settings to their default values. This can also be done by holding RESET up during power-up of the Simulator.

## Interrupt configuration

The simulator can emulate a 88-RTC-VI board which provides a real-time clock and vector interrupt capability (both are necessary to run Altair Timesharing Basic). The following settings can be configured:

- *Real Time Clock*
  Can be either disabled or set to produce an interrupt at one of the following frequencies:
  0.06, 0.6, 6, 10, 60, 100, 1000 or 10000Hz
  Note that (despite the name) the frequency is based on simulated time, not real time.
- *Vector Interrupt Board*
  If set to "Interrupts connected directly to CPU" then the Vector Interrupt functionality is disabled.
  In that case, the device interrupt settings below can only be changed between "connected" or "not connected". Note that the simulator (unlike the original) allows to connect multiple devices to the CPU's interrupt line
  If this is set to "Use Vector Interrupt Board" then each device interrupt can be assigned a level/priority according to the 88-RTC-VI board's functionality. Consult the 88-RTC-VI board's user manual for more information about the interrupt levels.
- *[Device] interrupt*
  This configures the connection of the interrupt line for each of the listed devices. If the VI board is disabled, then an interrupt line can either be connected or not connected to the CPU. If the VI board is enabled, then the interrupt can be connected to a specific level on the VI board.

## Serial device configuration

The simulator emulates four serial devices connected to the Altair:

- 88-SIO card at port 0x00/0x01
- 88-ACR audio cassette interface at port 0x06/0x07
- 88-2SIO, card with serial 1 at port 0x10/0x11 and serial 2 at port 0x12/0x13

For each of these devices the following settings can be configured in the configuration menu:

- *Map to host interface*
  Select to which host interface input/output of device gets directed.
  When using Arduino Mega, there is only one host interface (Serial). When using the Due, there is the primary and secondary interface. The physical interface (Serial/Serial1) that the primary interface maps to can be picked on the main setup screen. The other one becomes the secondary interface.

- *Simulated baud rate*
  If receive interrupts are disabled for a serial device and “Force baud rate” is off, the simulator just makes a new byte available for playback whenever the running program requests one. That way, playback runs as maximum speed without the program missing any characters. If receive interrupts are enabled however, the characters must be sent at a rate that gives the running program a chance to keep up. Similarly, if transmit interrupts are enabled, the program expects some time to pass between sending characters.
  This setting selects the baud rate at which input/output is processed. Note that the timing is based on simulated time, not real time. That means that on the Mega (since it is running at 25% original speed) a rate of 110 baud may actually look more like 25 baud in real time.
- *Force baud rate*
  If this option is on then the simulator will always use the given baud rate for receive and transmit, even if interrupts are disabled. This can be used to get more realistic timing for code that is not using interrupts.
- *Example playback NULs*
  When playing back data to the running program (e.g. the AM2 assembler), the program may need some extra processing time after a carriage return to process the previous line. This is done (as it would have been on the original) by sending a number of NUL (0) bytes after a carriage return. Note that this setting only affects the case when playing back examples stored in the simulator, not for captured data being played back. For captured data, make sure to set the program from which you are capturing to produce the proper number of NULs.
- *Use 7 bits*
  Some Altair programs (e.g. 4k BASIC) use the 8$^{th}$ bit of a character to signal end-of-string, assuming that the output device only uses 7 bits. If this is the case, then the last character of any string will appear mangled in the output. If this option is enabled, the simulator will always clear the 8$^{th}$ bit before sending it to the serial output.
  If the option is set to “autodetect”, the s will detect (for some known programs) based on the memory location of the “OUT” instruction whether the bit needs to be cleared or not.
- *Serial input uppercase*
  Some Altair programs (e.g. 4k BASIC) only display uppercase characters and expect all input to be uppercase characters. If this option is enabled, the simulator will translate any incoming lower-case character to upper-case.
  If the option is set to “autodetect”, the simulator will detect (for some known programs) based on the memory location of the “IN” instruction whether the translation is required.
- *Translate backspace to*
  Allows to map the backspace character to other characters expected by different ALTAIR programs:
  *off* – backspace is sent as backspace (ASCII 8)
  *underscore* – backspace is sent to the simulated program as an underscore ‘_’ (ASCII 95) and an underscore sent by the simulated program is interpreted as backspace. This is usefule for 4k BASIC and ROM BASIC.
  *rubout* – backspace sent to the simulated program as a rubout (ASCII 127) character. Time-sharing BASIC expects this
  *autodetect* – the simulator attempts to automatically determine which conversion is necessary by the memory location of IN/OUT opcode.
- *Enable CLOAD/CSAVE traps* (for ACR device only)
  If this option is enabled then the simulator will catch BASIC CLOAD/CSAVE calls and automatically save/load to the internal simulator storage, avoiding the need to manually start cassette capture/replay.

# File System Manager

The emulator includes a very simple mini file system to store the different types of data that can be saved/captured. The file system manager can be invoked by selecting (M) in the configuration menu.

The file system manager supports the following commands:

- **F**: Format file system (erases all files)
- **d**: Delete a file from the file system
- **r**: Read a file and show contents on screen

# Debugging Capabilities

When simulation is stopped (i.e. the WAIT LED is on) and the "Serial debug" option is enabled in the configuration menu, the following keys have a function:

| | |
|---|---|
| 0-9,a-f | Toggle SW0-15 (only if stand-alone mode enabled in setup.h) |
| / | Prompt for value to set SW0-15 (only if stand-alone mode enabled in setup.h) |
| r | Run |
| o | Stop |
| t | Step |
| R | Reset |
| ! | Hard reset (STOP+RESET) |
| X/x | Examine/examine next |
| P/p | Deposit/deposit next |
| U | AUX1 up |
| u | AUX1 down |
| s | AUX2 up |
| l | AUX2 down |
| Q | Protect |
| q | Unprotect |
| B | Add breakpoint (only if breakpoints enabled in setup.h) |
| V | Delete last breakpoint |
| D | Disassemble (will prompt for start address, space bar continues, any other key exits) |
| M | Dump memory (will prompt for start address, space bar continues, any other key exits) |
| n | change number system (hexadecimal/octal/decimal) |
| C | Enter configuration menu |
| L | Load a program from serial<br>First value is start address, second value is length, followed by data bytes<br>(all values separated by spaces). Can be used to load a program via the terminal. |

# Example program: Kill-the-bit game

To enter the kill-the-bit game below into the ALTAIR:

1. Activate RESET
2. Set SW7-0 to first byte of program (041 octal, 00 100 001 binary)
3. Activate DEPOSIT
4. Set SW7-0 to next byte of program
5. Activate DEPOSIT NEXT
6. Repeat steps 4-5 until all bytes have been entered
7. If running the simulator on an Arduino MEGA, the game runs slow.
   To compensate, change the content of memory location 006 from 016 to 056 (all octal).

To run the game:

1. Activate RESET
2. Set SW15-8 switches to 0
3. Activate RUN

To save the game to Arduino storage:

1. Set SW15-8 to 0 (selects memory page 0)
2. Set SW7 to 1 (selects memory page operation)
3. Set SW6 to 1 (selects memory page save)
4. Set SW5-0 to 0 (selects file number 0)
5. Activate AUX1 down

To load the game from Arduino storage:

1. Set SW15-0 as above, except SW6 to 0 (selects memory page load)
2. Activate AUX1 down

```
                  ; Kill the Bit game by Dean McDaniel, May 15, 1975
                  ;
                  ; Object: Kill the rotating bit. If you miss the lit bit, another
                  ;         bit turns on leaving two bits to destroy. Quickly
                  ;         toggle the switch, don't leave the switch in the up
                  ;         position. Before starting, make sure all the switches
                  ;         are in the down position.
                  ;
0000                           org   0
0000 210000                    lxi   h,0     ; initialize counter
0003 1680                      mvi   d,080h  ; set up initial display bit
0005 010E00                    lxi   b,0eh   ; higher value = faster
0008 1A           beg:         ldax  d       ; display bit pattern on
0009 1A                        ldax  d       ; ...upper 8 address lights
000A 1A                        ldax  d
000B 1A                        ldax  d
000C 09                        dad   b       ; increment display counter
000D D20800                    jnc   beg
0010 DBFF                      in    0ffh    ; input data from sense switches
0012 AA                        xra   d       ; exclusive or with A
0013 0F                        rrc           ; rotate display right one bit
0014 57                        mov   d,a     ; move data to display reg
0015 C30800                    jmp   beg     ; repeat sequence
0018                           end

Here is the program in octal for easier entry into the Altair:
000: 041 000 000 026 200 001 016 000
010: 032 032 032 032 011 322 010 000
020: 333 377 252 017 127 303 010 000
```

# Loading 4k BASIC the old-school way

The simulator provides a quick and easy way to load 4k BASIC by setting SW0-7 to 00000101 and pressing AUX1 down (see “Aux1 down” section above).

However, it is also possible to load 4k BASIC the original (slow) way via a boot loader.

Here’s how to load BASIC as if it came from a paper tape reader:

- Start the configuration editor and select (1) to configure the SIO device
- Make sure the device is mapped to the host serial port to which your terminal is connected
- Set the “Use 7 bits”, “Serial input uppercase” and “Translate Backspace to” settings to “autodetect”
- Set the simulated baud rate to 110 baud. Obvioulsy you can choose other baud rates here but 110 baud is the speed at which a typical TeleType tape reader operated. **Note**: the baud rate is based on simulated time (not real time), so when running on the Arduino Mega, 110 baud will be closer to 25 baud. All time estimates given below will be about 4x longer. I suggest using 600 baud in that case.
- Enable the “Force baud rate” option
- Exit the configuration editor
- Key in the SIO bootloader (same procedure as entering kill-the-bit above):
  ```
  000: 041 256 017 061 022 000 333 000
  010: 017 330 333 001 275 310 055 167
  020: 300 351 003 000
  ```
- You may want to save the bootloader to a file so you can reuse it later (same procedure as for the kill-the-bit example above)
- Activate RESET (to reset program counter to 0, the start of the boot loader)
- Activate RUN. The boot loader is now running. You should see LEDs A0-A4 on, A5-A15 should be off.
- Set all switches to 0, then raise SW15, SW7 and SW6. Tthis selects example 0xC0 (SW7-0=0xC0) which is the 4k BASIC tape image to be played back to the SIO device (SW15-13=100)
- Activate AUX2 down. The HLDA LED will come on indicating that data replay has started.
- Immediately switch A15 down (otherwise the second stage boot loader will attempt to load from ACR instead of SIO).
- For the first 17 seconds (while the first-stage boot loader is running) the pattern on the A15-A0 LEDs should not change.
- After about 17 seconds the second stage (checksum) boot loader should start running.
  At that point, LEDs 15-12 should be off, A11-A7, A5, A2, A1, A0 should be on and A6, A4 and A3 should be very faintly flashing (about 10x per second, one flash per byte received).
- The second stage boot loader takes about 6 ½ minutes. Once it is done, the LED pattern should change to A9-A7 and A3-A0 on, all others off and your termial should show the “MEMORY SIZE?” prompt.
- After you answer the usual startup questions, BASIC should be up and running.
- To load a BASIC example program, set SW0-7 to the program number (e.g. 00011011 for a simple prime number computation) and activate AUX2 down.

# Altair Time Sharing BASIC

The simulator allows to run Altair Time Sharing BASIC with two users, one on a terminal connected to the Arduino Due's main serial port (either use pins 0 and 1 or the USB connection), the other using the Due's Serial1 port at pins 18 and 19.

To set up the simulator, enter the Configuration Editor and make sure both the Serial and Serial1 baud rates are set properly for your two terminals. The primary host serial port can be either one, whichever is more convenient.

Next configure the emulated devices. Time Sharing BASIC only supports 2SIO cards, so set the SIO and ACR cards to "Not mapped". Configure the the two ports of the 2SIO card as follows:

- One mapped to primary, the other mapped to the secondary host interface
- Simulated baud rate: 2400 (anything higher can cause problems when trying to play back examples)
- Example playback NULs: 0
- Use 7 bits: on
- Serial input uppercase: on
- Translate backspace to: rubout

Time Sharing BASIC relies on interrupts to give each user their proper time slice and uses the 88-RTC-VI (Real-Time Clock and Vector Interrupt board) to do so. Therefore, both the Real-Time Clock and Vector Interrupts must be set up properly in the simulator. Select "Configure Interrupts" sub-menu:

- Enable the Real-Time Clock and set it to 60Hz or 100Hz
- Enable the Vector Interrupt board (Use Vector Interrupt Board)
- Set the Disk drive interrupt to VI0
- Set the Real-Time Clock interrupt to VI1
- Set the 88-2SIO port 1 interrupt to VI2
- Set the 88-2SIO port 2 interrupt to VI2
- Set the 88-SIO and 88-ACR interrupts to "Not Connected"

For convenience, you may want to configure the "Aux1 shortcut program" setting to the Time Sharing Basic v1.1 disk. After everything is set, you may want to save the configuration so you can later just load it.

Ready to run Time-Sharing BASIC!

First, connect your two terminals to the Serial and Serial1 connection on the Arduino. Make sure the terminal settings match the **host** interface baud rates set above (NOT the simulated baud rates).
Next, either press AUX1 UP (if you have configured it) or mount the Time-Sharing BASIC disk and run the disk boot loader (see the Disk Drive Support section for more information). After a few seconds, the ALTAIR T/S DISK BASIC V1.1 prompt should appear. Answer the configuration questions as follows:

- RECONFIGURE? N (you may say L and verify that LEVEL1 is set to TIMER and LEVEL2 is set to 2 – 16, 18)
- MEMORY SIZE? [just press ENTER]
- NUMBER OF USERS? 2
- TERMINAL ADDRESS? 16
- REGION SIZE? 20000
- TERMINAL ADDRESS? 18
- REGION SIZE? 20000
- MOUNT PASSWORD? [pick a password and press ENTER]

After the last prompt, a BASIC startup message (ALTAIR T/S DISK BASIC V1.1) should show up on both terminals. Both terminals can be used independently to interact with BASIC and load and run programs. Refer to the ALTAIR Time Sharing BASIC manual (can be found online) on how mount disks and load programs.

# MITS Programming System II

[adapted from instructions at altairclone.com]

The MITS Programming System II allows development of 8080 assembly language applications on the Altair 8800 using just paper tape or cassette for mass storage. The package consists of an editor, assembler, debugger and a monitor that allows execution of these programs as well as the programs you may develop.

To use the programming package, the monitor program is loaded from paper tape or cassette in the same manner as loading BASIC. Once loaded, the monitor is then used to load the editor, assembler, debugger or user programs.

The monitor loads from paper tape or cassette using the same bootstrap loader as would be used for BASIC version 3.2. Sense switch settings are the same with the addition of A9 functionality:

A9 up – the monitor does NOT use serial input interrupts

A9 down – the monitor uses serial input interrupts

## Loading the Monitor, Editor and Assembler

1) Raise A9 if you want to disable interrupts. If interrupts are enabled, serial replay is slower (because it must run at a specific baud rate). On the other hand, enabling interrupts enables the use of Ctrl-C.
2) Set A7-A0 to 00000110 and then push AUX2 down to load the monitor.
3) The monitor prompt is two spaces and "?"
4) STOP! Do not type any commands to see "what happens." If what is typed is not a command, the monitor tries loading a program of that name from the cassette and hangs there until you provide that program. If the ABS device has been set to audio-cassette (AC), then Ctrl-C will return to the monitor prompt if interrupts were enabled during the boot process. Otherwise, follow the instructions below to restart the monitor from the front panel.
5) Assign the program load device to the cassette, type: "OPN ABS,AC<cr>"
6) Load the editor, type: "EDT<cr>" and then send the editor .bin file through the cassette port. When loaded, the editor's prompt "*" is displayed. Type "E<cr>" to return the monitor.
7) Move the editor's buffer location into high memory so the assembler can reside in memory at the same time as the editor. For larger programs, more than the default 2K of buffer space will probably be needed as well. Here are settings for an 8K buffer:

    Type "DEP 5124<cr>" and enter "0<cr>" then "100<cr>" then ctrl-z.
    This specifies the 16-bit octal address 40000 (0x4000) for buffer start.
    Type "DEP 5530<cr>" and enter "0<cr>" then "140<cr>" then ctrl-z.
    This specifies the 16-bit octal address 60000 (0x6000) for buffer end.
8) Load the assembler, type: "AM2<cr>" and the send the assembler version 2 .bin file through the cassette port. When loaded, the assembler prompt is "*ASM*<cr>". Type "EOA<cr>" (end of assembly) to return to the monitor.
9) DBG, EDT and ASM share the same memory space (see Memory Allocation section below). If two of them are loaded sequentially, the system will just start the second one loaded, even if invoking the first. For example, if EDT is loaded first and then ASM, the monitor will invoke ASM if EDT is typed as a command. To force reloading of a component, use CLR to remove it from the program table, i.e. in the situation mentioned before, typing CLR EDT and then EDT will invoke the editor.

The computer is now ready to iteratively edit, assemble and run/test a program.

## Using the Editor and Assembler

1. To start the editor, type: “EDT<cr>” This starts the editor and clears the edit buffer. To subsequently re-edit a program, type “EDT(R)<cr>” This leaves the existing source code in memory. If the “(R)” is left off, the program source will be erased.
2. At the editor prompt type “I” for insert. Ctrl-Z exits the insert mode. “P” prints (displays) the file with line numbers. “W” displays the file without line numbers. “D line[,line]” deletes line(s). “R line” replaces a line. “I line” inserts after the specified line. “I” by itself inserts before the first line. “E” exits the editor and returns control to the monitor.
3. End programs with:
   - BEG start label
   - END program name
   - EOA

   Where “start label” is the program entry point, “program name” is a three character program name. “EOA” means end of assembly.
4. Assign source file input to come from the edit buffer instead of a device and declare file type of ASCII (text file): Type, “OPN FIL,EB,A<cr>” This only has to be done once during a session (or if the FIL device was subsequently assigned to a different device during the session).
5. Run the assembler: Type “AM2<cr>”
6. Tell the assembler to take input from a file: Type “FILE<cr>” The assembler will run and show errors and undefined symbols. Note: The “Undefined Symbols” heading is displayed even when there are no undefined symbols. Control is returned to the monitor.
7. Run the program by jumping to the starting address: Type “JMP xxxxxx” where xxxxxx is the program starting address in octal.
8. You can enter the program into the monitor’s program table as follows: After a successful assembly, re-enter the assembler and preserve symbols: Type “AM2(P)<cr>”
9. Type “RUN name<cr>” where name is the three character name for the program. The program will run. From here on, the program can be run by typing the “name” specified at the monitor prompt. This step does not have to be repeated after subsequent assemblies if the entry address has not changed.

## Memory Allocation

- The monitor is about 2.5K in length and uses RAM up through 0x0A3F
- The editor is about 2K in length and resides just above the monitor at 0xA40 – 0x11B1, followed by the default 2K edit buffer space from 0x11B2 – 0x19B1.
- Two versions of the assembler are available. Each are about 3K in length. ASM (assembler version 1) loads at the same address as the editor (0xA40). This is inconvenient for the iterative cycle of edit, assemble and test. As an alternative, AM2 (assembler version 2) loads just above the editor at 0x1350 – 0x1D78. The assembler’s symbol table grows up from 0x1D78. Note that the default location of the edit buffer conflicts with the load address of AM2 as the edit buffer grows. Before using the editor for longer programs, the location of the edit buffer should moved to a free area in memory by using the monitor DEP command to patch the buffer start address into octal locations 5124-5125 and the buffer end address+1 into octal locations 5530-5531.
- When using the AM2 assembler, a program loaded at 0x2000 leaves about 650 bytes of symbol table space (0x1D78 – 0x1FFF). This is enough for small demo programs of 100 lines or less. Otherwise, a higher starting address should be used for the target program
- The debugger is is about 2K in length and overlays the editor at 0xA40 – 0x133F. The debugger and AM2 assembler can both reside in memory at the same time. This makes it easy to patch programs with the assembler while debugging the program.

## Loading and Saving Files

1. Assign the FIL device to the audio cassette and specify ASCII files:
   Type “OPN FIL,AC,A<cr>”
2. In the editor, type “L<cr>” to load a source file. Type “S<cr>” to save a source file.
3. After loading a source file into the editor, you can re-assign FIL to the edit buffer for use as the assembler input: Type “OPN FIL,EB,A<cr>”
4. When you want to save an edited file after the edit and assemble process, be sure to set the FIL device back to AC before using the “S” command from within the editor.
5. Optionally, you can take assembler source file input from the audio cassette. After assigning FIL to the AC (see step 2), in the assembler, type “FILE name<cr>” where “name” is the three character source file name for the assembler to read. The source file is then read directly from the audio cassette instead of the edit buffer.

## Additional Notes

- When using the edit buffer as the source for the assembler, the source file must be “rewound” by editing the source file in between successive assemblies.
- To restart the monitor, stop the machine, set all switches off except A6 (i.e., set address of octal 100). Raise examine, set front panel switches back the way they were at load time, then depress run.
- When sending large amounts of text (e.g. pasting source code into the serial terminal), it may come out corrupted because if the serial interface speed is greater than 1200 baud because the editor/assembler cannot process the arriving characters at that speed, so some get lost. You may need to drop the host serial interface speed to 1200 baud (via the configuration editor).

## Example usage #1: assemble directly from input

| | | |
|---|---|---|
| 1) | Make sure simulator is configured to send SIO output and SIO2 port 1 output to your terminal | |
| 2) | *[STOP]+[RESET]* | reset Altair |
| 3) | *[A15-A3 down, A2, A1, A0 up]* | select program #7 (PS2 monitor) using SIO card with interrupts |
| 4) | *[AUX1 down]* | load and run PS2 monitor and mount PS2 cassette tape |
| 5) | OPN ABS,AC | assign ACR to ABS device (to load editor/assembler) |
| 6) | AM2 | start assembler (to load it into memory) |
| 7) | *[CLR]* | un-mount the PS2 tape |
| 8) | *[A7 up, A2 down, A1 up]* | select ASM example #2 (“dump” example from PS2 documentation) |
| 9) | *[AUX2 down]* | start ASM source code example replay |
| 10) | RUN DUMP | runs DMP example directly from assembler |

## Example usage #2: insert into edit buffer, then assemble

| | | |
|---|---|---|
| 1) | Make sure simulator is configured to send SIO output and SIO2 port 1 output to your terminal | |
| 2) | *[STOP]+[RESET]* | reset Altair |
| 3) | *[A15-A3 down, A2, A1, A0 up]* | select program #7 (PS2 monitor) using SIO card with interrupts |
| 4) | *[AUX1 down]* | load and run PS2 monitor and mount PS2 cassette tape |
| 5) | OPN ABS,AC | assign ACR to ABS device (to load editor/assembler) |
| 6) | EDT | start editor (to load it into memory) |
| 7) | E | end editor |
| 8) | AM2 | start assembler (to load it into memory) |
| 9) | EOA | exit assembler |
| 10) | DEP 5124 | move edit buffer to 0x4000-0x6000 = 8K length |
| 11) | 0 | start address 100-000 = 40000 octal = 0x4000 |
| 12) | 100 | |
| 13) | *[CTRL-Z]* | end of input |
| 14) | DEP 5530 | |
| 15) | 0 | end address 140-000 = 60000 octal = 0x6000 |

| | |
|---|---|
| 16) 140 | |
| 17) *[CTRL-Z]* | end of input |
| 18) EDT | start editor again (with new buffer) |
| 19) I | enter "insert" mode |
| 20) *[CLR]* | un-mount the PS2 tape |
| 21) *[A7 up, A2 down, A1 down, A0 up]* | select ASM example #1 (PONG) |
| *or [A7 up, A2 down, A1 up]* | select ASM example #2 (DUMP) |
| 22) *[AUX2 down]* | start ASM source code example replay |
| 23) *[CTRL-Z]* | exit "insert" mode after example is loaded |
| 24) E | exit editor |
| 25) OPN FIL,EB,A | select edit buffer as input device |
| 26) AM2(S) | go into assembler (S parameter to print symbol table at end) |
| 27) FILE | load input file (from edit buffer) |
| 28) EOA | return to monitor |
| 29) JMP 20000 | run program |

## Example usage #3: insert into edit buffer, assemble, write to file, run file

1) Make sure simulator is configured to send SIO output and SIO2 port 1 output to your terminal

| | |
|---|---|
| 2) *[STOP]+[RESET]* | reset Altair |
| 3) *[A15-A3 down, A2, A1, A0 up]* | select program #7 (PS2 monitor) using SIO card with interrupts |
| 4) *[AUX1 down]* | load and run PS2 monitor and mount PS2 cassette tape |
| 5) OPN ABS,AC | assign ACR to ABS device (to load editor/assembler) |
| 6) EDT | start editor (to load it into memory) |
| 7) E | end editor |
| 8) AM2 | start assembler (to load it into memory) |
| 9) EOA | exit assembler |
| 10) DEP 5124 | move edit buffer to 0x4000-0x6000 = 8K length |
| 11) 0 | start address 100-000 = 40000 octal = 0x4000 |
| 12) 100 | |
| 13) *[CTRL-Z]* | end of input |
| 14) DEP 5530 | |
| 15) 0 | end address 140-000 = 60000 octal = 0x6000 |
| 16) 140 | |
| 17) *[CTRL-Z]* | end of input |
| 18) EDT | start editor again (with new buffer) |
| 19) I | enter "insert" mode |
| 20) *[CLR]* | un-mount the PS2 tape from ACR |
| 21) *[A7 up, A2 down, A1 down, A0 up]* | select ASM example #1 (PONG) |
| 22) *[AUX2 down]* | start ASM source code example replay |
| 23) *[CTRL-Z]* | exit "insert" mode after example is loaded |
| 24) E | exit editor |
| 25) OPN FIL,EB,A | select edit buffer as input device |
| 26) AM2(S,A) | go into assembler (S parameter to print symbol table at end, A to dump output binary to file) |
| 27) *[A15, A13, A8 up, A7 down]* | Prepare to capture file #1 from ACR device |
| 28) FILE | load input file (from edit buffer) |
| *[wait for "SENSE SW 15 FOR DUMP" message]* | |
| 29) *[AUX2 up]* | start capturing |
| 30) *[A15 down, A15 up]* | tells AM2 to start writing |
| *[wait for "?" prompt from PS2 monitor]* | |
| 31) *[AUX2 up]* | finish capturing |
| 32) *[AUX2 down]* | start replay |
| 33) PONG | load and run PONG |

# 8080 Instruction Set

```
Conventions in instruction source:
    D   = Destination register (8 bit)
    S   = Source register (8 bit)
    RP  = Register pair (16 bit)
    #   = 8 or 16 bit immediate operand
    a   = 16 bit Memory address
    p   = 8 bit port address
    ccc = Conditional

Conventions in instruction encoding:
    db  = Data byte (8 bit)
    lb  = Low byte of 16 bit value
    hb  = High byte of 16 bit value
    pa  = Port address (8 bit)

Dest and Source reg fields:
    111=A   (Accumulator)
    000=B
    001=C
    010=D
    011=E
    100=H
    101=L
    110=M   (Memory reference through address in H:L)

Register pair 'RP' fields:
    00=BC   (B:C as 16 bit register)
    01=DE   (D:E as 16 bit register)
    10=HL   (H:L as 16 bit register)
    11=SP   (Stack pointer, refers to PSW (FLAGS:A) for PUSH/POP)

Condition code 'CCC' fields: (FLAGS: S Z x A x P x C)
    000=NZ  (Zero flag not set)
    001=Z   (Zero flag set)
    010=NC  (Carry flag not set)
    011=C   (Carry flag set)
    100=PO  (Parity flag not set - ODD)
    101=PE  (Parity flag set - EVEN)
    110=P   (Sign flag not set - POSITIVE)
    111=M   (Sign flag set - MINUS)
```

| Inst | Encoding | Flags | Description |
|---|---|---|---|
| ACI # | 11001110 db | ZSCPA | Add immediate to A with carry* |
| ADC S | 10001SSS | ZSCPA | Add register to A with carry |
| ADD S | 10000SSS | ZSPCA | Add register to A |
| ADI # | 11000110 db | ZSCPA | Add immediate to A |
| ANA S | 10100SSS | ZSCPA | AND register with A |
| ANI # | 11100110 db | ZSPCA | AND immediate with A |
| CALL a | 11001101 lb hb | - | Unconditional subroutine call |
| Cccc a | 11CCC100 lb hb | - | Conditional subroutine call |
| CMA | 00101111 | - | Complement A |
| CMC | 00111111 | C | Complement Carry flag |
| CMP S | 10111SSS | ZSPCA | Compare register with A |
| CPI # | 11111110 | ZSPCA | Compare immediate with A |
| DAA | 00100111 | ZSPCA | Decimal Adjust accumulator |
| DAD RP | 00RP1001 | C | Add register pair to HL (16 bit add)* |
| DCR D | 00DDD101 | ZSPA | Decrement register* |
| DCX RP | 00RP1011 | - | Decrement register pair |
| DI | 11110011 | - | Disable interrupts |
| EI | 11111011 | - | Enable interrupts |
| HLT | 01110110 | - | Halt processor |
| IN p | 11011011 pa | - | Read input port into A |
| INR D | 00DDD100 | ZSPA | Increment register |
| INX RP | 00RP0011 | - | Increment register pair |
| Jccc a | 11CCC010 lb hb | - | Conditional jump* |
| JMP a | 11000011 lb hb | - | Unconditional jump* |
| LDA a | 00111010 lb hb | - | Load A from memory |
| LDAX RP | 00RP1010 *1 | - | Load indirect through BC or DE |
| LHLD a | 00101010 lb hb | - | Load H:L from memory* |
| LXI RP,# | 00RP0001 lb hb | - | Load register pair immediate* |
| MOV D,S | 01DDDSSS | - | Move register to register* |
| MVI D,# | 00DDD110 db | - | Move immediate to register* |
| NOP | 00000000 | - | No operation |
| ORA S | 10110SSS | ZSPCA | OR register with A |
| ORI # | 11110110 | ZSPCA | OR immediate with A |
| OUT p | 11010011 pa | - | Write A to output port |
| PCHL | 11101001 | - | Jump to address in H:L |
| POP RP | 11RP0001 *2 | *2 | Pop register pair from the stack |
| PUSH RP | 11RP0101 *2 | - | Push register pair on the stack |
| RAL | 00010111 | C | Rotate A left through carry* |
| RAR | 00011111 | C | Rotate A right through carry |
| Rccc | 11CCC000 | - | Conditional return from subroutine |
| RET | 11001001 | - | Unconditional return from subroutine |
| RLC | 00000111 | C | Rotate A left |
| RRC | 00001111 | C | Rotate A right |
| RST n | 11NNN111 | - | Restart (Call n*8) |
| SBB S | 10011SSS | ZSCPA | Subtract register from A with borrow |
| SBI # | 11011110 db | ZSCPA | Subtract immediate from A with borrow |
| SHLD a | 00100010 lb hb | - | Store H:L to memory* |
| SPHL | 11111001 | - | Set SP to content of H:L |
| STA a | 00110010 lb hb | - | Store A to memory |
| STAX RP | 00RP0010 *1 | - | Store indirect through BC or DE |
| STC | 00110111 | C | Set Carry flag |
| SUB S | 10010SSS | ZSCPA | Subtract register from A |
| SUI # | 11010110 db | ZSCPA | Subtract immediate from A |
| XCHG | 11101011 | - | Exchange DE and HL content |
| XRA S | 10101SSS | ZSPCA | Exclusive OR register with A |
| XRI # | 11101110 db | ZSPCA | Exclusive OR immediate with A |
| XTHL | 11100011 | - | Swap H:L with top word on stack |

*1 = Only RP=00(BC) and 01(DE) are allowed for LDAX/STAX
*2 = RP=11 refers to PSW for PUSH/POP (cannot push/pop SP).
When PSW is POP'd, ALL flags are affected.

| Encoding | Inst | Flags | Description |
|---|---|---|---|
| 00000000 | NOP | - | No operation |
| 00000111 | RLC | C | Rotate A left |
| 00001111 | RRC | C | Rotate A right |
| 00010111 | RAL | C | Rotate A left through carry* |
| 00011111 | RAR | C | Rotate A right through carry |
| 00100010 lb hb | SHLD a | - | Store H:L to memory* |
| 00100111 | DAA | ZSPCA | Decimal Adjust accumulator |
| 00101010 lb hb | LHLD a | - | Load H:L from memory* |
| 00101111 | CMA | - | Complement A |
| 00110010 lb hb | STA a | - | Store A to memory |
| 00110111 | STC | C | Set Carry flag |
| 00111010 lb hb | LDA a | - | Load A from memory |
| 00111111 | CMC | C | Complement Carry flag |
| 00DDD100 | INR D | ZSPA | Increment register |
| 00DDD101 | DCR D | ZSPA | Decrement register* |
| 00DDD110 db | MVI D,# | - | Move immediate to register* |
| 00RP0001 lb hb | LXI RP,# | - | Load register pair immediate* |
| 00RP0010 *1 | STAX RP | - | Store indirect through BC or DE |
| 00RP0011 | INX RP | - | Increment register pair |
| 00RP1001 | DAD RP | C | Add register pair to HL (16 bit add)* |
| 00RP1010 *1 | LDAX RP | - | Load indirect through BC or DE |
| 00RP1011 | DCX RP | - | Decrement register pair |
| 01110110 | HLT | - | Halt processor |
| 01DDDSSS | MOV D,S | - | Move register to register* |
| 10000SSS | ADD S | ZSPCA | Add register to A |
| 10001SSS | ADC S | ZSCPA | Add register to A with carry |
| 10010SSS | SUB S | ZSCPA | Subtract register from A |
| 10011SSS | SBB S | ZSCPA | Subtract register from A with borrow |
| 10100SSS | ANA S | ZSCPA | AND register with A |
| 10101SSS | XRA S | ZSPCA | Exclusive OR register with A |
| 10110SSS | ORA S | ZSPCA | OR register with A |
| 10111SSS | CMP S | ZSPCA | Compare register with A |
| 11000011 lb hb | JMP a | - | Unconditional jump* |
| 11000110 db | ADI # | ZSCPA | Add immediate to A |
| 11001001 | RET | - | Unconditional return from subroutine |
| 11001101 lb hb | CALL a | - | Unconditional subroutine call |
| 11001110 db | ACI # | ZSCPA | Add immediate to A with carry* |
| 11010011 pa | OUT p | - | Write A to output port |
| 11010110 db | SUI # | ZSCPA | Subtract immediate from A |
| 11011011 pa | IN p | - | Read input port into A |
| 11011110 db | SBI # | ZSCPA | Subtract immediate from A with borrow |
| 11100011 | XTHL | - | Swap H:L with top word on stack |
| 11100110 db | ANI # | ZSPCA | AND immediate with A |
| 11101001 | PCHL | - | Jump to address in H:L |
| 11101011 | XCHG | - | Exchange DE and HL content |
| 11101110 db | XRI # | ZSPCA | Exclusive OR immediate with A |
| 11110011 | DI | - | Disable interrupts |
| 11110110 | ORI # | ZSPCA | OR immediate with A |
| 11111001 | SPHL | - | Set SP to content of H:L |
| 11111011 | EI | - | Enable interrupts |
| 11111110 | CPI # | ZSPCA | Compare immediate with A |
| 11CCC000 | Rccc | - | Conditional return from subroutine |
| 11CCC010 lb hb | Jccc a | - | Conditional jump* |
| 11CCC100 lb hb | Cccc a | - | Conditional subroutine call |
| 11NNN111 | RST n | - | Restart (Call n*8) |
| 11RP0001 *2 | POP RP | *2 | Pop register pair from the stack |
| 11RP0101 *2 | PUSH RP | - | Push register pair on the stack |

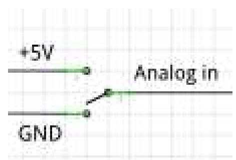
*1 = Only RP=00(BC) and 01(DE) are allowed for LDAX/STAX
*2 = RP=11 refers to PSW for PUSH/POP (cannot push/pop SP).
When PSW is POP'd, ALL flags are affected.

# Hardware setup for Arduino Mega 2560

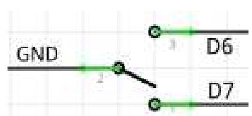
What makes the Arduino Mega 2560 perfect for this project is that it has exactly the right number of I/O pins to connect all the Altair's input/output elements:

| | | |
|---|---|---|
| Altair: | 12 | Status LEDs (INT,WO,STACK,HLTA,OUT,M1,INP,MEMR,PROT,INTE,WAIT,HLDA) |
| | 8 | Data bus LEDs (D0-D7) |
| | 16 | Address bus LEDs (A0-A15) |
| | 16 | Input switches (SW0-15) |
| | 16 | Function switches (RUN,STOP,EXAMINE,EXAMINE NEXT,DEPOSIT,DEPOSIT NEXT,RESET,CLR,PROTECT,UNPROTECT,AUX1 UP/DOWN,AUX2 UP/DOWN) |
| | 2 | Connections for serial RX/TX |
| | **70** | **(digital) inputs/outputs required** |
| Arduino Mega 2560: | 54 | Digital I/O pins |
| | 16 | Analog input pins (can be used for digital input) |
| | **70** | **I/O lines available** |

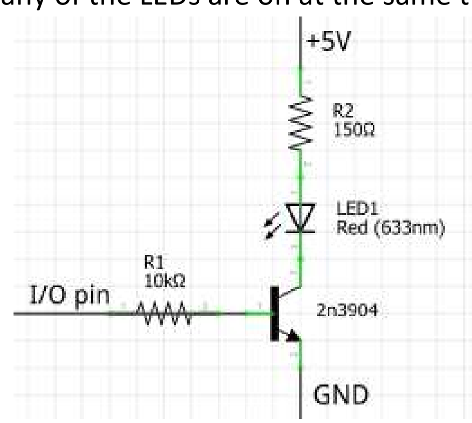
For simplicity, we connect the Altair's 16 input switches (SW0-15) to the Arduino's 16 analog inputs. These are SPDT On-On switches that alternate between two settings:




For the function switches we use the Arduino's internal pull-up resistors and just switch GND to the appropriate digital input. These are momentary SPDT (On)-Off-(On) switches. For example, the EXAMINE/EXAMINE NEXT switch is connected like this:




To drive the output LEDs we just use a simple transistor switch circuit for each LED (to prevent overload on the Arduino if too many of the LEDs are on at the same time):




See the following page for a mapping of exactly which front panel element maps to which Arduino I/O pin.

# Pin Mapping for Arduino Mega 2560

Mapping Arduino pin to Altair element

| Arduino Pin | Altair Element | Direction | Arduino Pin | Altair Element | Direction |
|---|---|---|---|---|---|
| **D0** | Serial RX | in | **D35** | A10 | out |
| **D1** | Serial TX | out | **D36** | A9 | out |
| **D2** | AUX1 UP | in | **D37** | A8 | out |
| **D3** | AUX1 DOWN | in | **D38** | INTE | out |
| **D4** | STEP | in | **D39** | PROT | out |
| **D5** | SLOW | in | **D40** | WAIT | out |
| **D6** | EXAMINE | in | **D41** | HLDA | out |
| **D7** | EXAMINE NEXT | in | **D42** | D7 | out |
| **D8** | DEPOSIT | in | **D43** | D6 | out |
| **D9** | DEPOSIT NEXT | in | **D44** | D5 | out |
| **D10** | OUT | out | **D45** | D4 | out |
| **D11** | M1 | out | **D46** | D3 | out |
| **D12** | INP | out | **D47** | D2 | out |
| **D13** | MEMR | out | **D48** | D1 | out |
| **D14** | AUX1 UP | in | **D49** | D0 | out |
| **D15** | AUX1 DOWN | in | **D50** | HLTA | out |
| **D16** | PROTECT | in | **D51** | STACK | out |
| **D17** | UNPROTECT | in | **D52** | WO | out |
| **D18** | RESET | in | **D53** | INT | out |
| **D19** | CLR | in | **A0** | SW0 | in |
| **D20** | RUN | in | **A1** | SW1 | in |
| **D21** | STOP | in | **A2** | SW2 | in |
| **D22** | A0 | out | **A3** | SW3 | in |
| **D23** | A1 | out | **A4** | SW4 | in |
| **D24** | A2 | out | **A5** | SW5 | in |
| **D25** | A3 | out | **A6** | SW6 | in |
| **D26** | A4 | out | **A7** | SW7 | In |
| **D27** | A5 | out | **A8** | SW8 | In |
| **D28** | A6 | out | **A9** | SW9 | In |
| **D29** | A7 | out | **A10** | SW10 | In |
| **D30** | A15 | out | **A11** | SW11 | In |
| **D31** | A14 | out | **A12** | SW12 | In |
| **D32** | A13 | out | **A13** | SW13 | In |
| **D33** | A12 | out | **A14** | SW14 | In |
| **D34** | A11 | out | **A15** | SW15 | In |

Mapping Altair element to Arduino pin

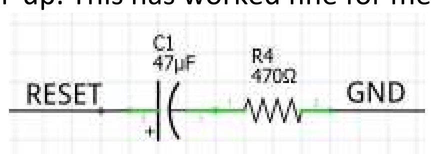
| Altair Element | Arduino Pin | Direction | Altair Element | Arduino Pin | Direction |
|---|---|---|---|---|---|
| **SW0** | A0 | in | **A0** | D22 | out |
| **SW1** | A1 | in | **A1** | D23 | out |
| **SW2** | A2 | in | **A2** | D24 | out |
| **SW3** | A3 | in | **A3** | D25 | out |
| **SW4** | A4 | in | **A4** | D26 | out |
| **SW5** | A5 | in | **A5** | D27 | out |
| **SW6** | A6 | in | **A6** | D28 | out |
| **SW7** | A7 | In | **A7** | D29 | out |
| **SW8** | A8 | in | **A8** | D37 | out |
| **SW9** | A9 | in | **A9** | D36 | out |
| **SW10** | A10 | in | **A10** | D35 | out |
| **SW11** | A11 | in | **A11** | D34 | out |
| **SW12** | A12 | in | **A12** | D33 | out |
| **SW13** | A13 | in | **A13** | D32 | out |
| **SW14** | A14 | in | **A14** | D31 | out |
| **SW15** | A15 | in | **A15** | D30 | out |
| **STOP** | D21 | in | **D0** | D49 | out |
| **RUN** | D20 | in | **D1** | D48 | out |
| **SINGLE STEP** | D4 | in | **D2** | D47 | out |
| **SLOW** | D5 | in | **D3** | D46 | out |
| **EXAMINE** | D6 | in | **D4** | D45 | out |
| **EXAMINE NEXT** | D7 | in | **D5** | D44 | out |
| **DEPOSIT** | D8 | in | **D6** | D43 | out |
| **DEPOSIT NEXT** | D9 | in | **D7** | D42 | out |
| **RESET** | D18 | in | **INT** | D53 | out |
| **CLR** | D19 | in | **WO** | D52 | out |
| **PROTECT** | D16 | in | **STACK** | D51 | out |
| **UNPROTECT** | D17 | in | **HLTA** | D50 | out |
| **AUX1 UP** | D14 | in | **OUT** | D10 | out |
| **AUX1 DOWN** | D15 | in | **M1** | D11 | out |
| **AUX2 UP** | D2 | in | **INP** | D12 | out |
| **AUX2 DOWN** | D3 | in | **MEMR** | D13 | out |
| **Serial RX** | D0 | in | **PROT** | D39 | out |
| **Serial TX** | D1 | out | **INTE** | D38 | out |
| | | | **WAIT** | D40 | out |
| | | | **HLDA** | D41 | out |

## Hardware setup for Arduino Due

The setup for the Arduino Due is similar to the Arduino Mega (see above), just the pins are different (because the simulator accesses some of the pins directly by their processor register to increase efficiency). See the next page for the Arduino Due connections.

- LED drivers: Same as for the Arduino Mega. Note that the LED driver still uses +5V even though the Due runs at 3.3V (because the voltage is only used for lighting the LEDs).
- Function switches: Same as for the Arduino Mega (only different pins)
- Address switches: On the Due we can access the analog input pins just like digital inputs, including the ability to switch on an internal pullup resistor. That slightly simplifies the setup for the SW0-SW15 switches as we do not have to connect Vcc to the switches, only GND:


- The reset circuit on (some) Due boards is not very reliable at power-up (this seems to be a common problem), leaving the Due sometimes in a blocked state after power-up. If you experience this, a simple workaround is to add a capacitor and resistor to keep the RESET line low for a bit longer at power-up. This has worked fine for me and not caused any side effects.




- In the mapping on the next pages you will see some Arduino pins shown with two labels, for example A0 (D54). In this case, A0 is the label on the board and D54 is the digital pin number that relates to that connection (i.e. Analog input 0 (A0) can be accessed as Digital input 54 (D54))

# Pin Mapping for Arduino Due

Mapping Arduino pin to Altair element

| Arduino Pin | Altair Element | Direction | Arduino Pin | Altair Element | Direction |
|---|---|---|---|---|---|
| **D0** | Unused | | **D36** | A2 | out |
| **D1** | Unused | | **D37** | A3 | out |
| **D2** | INT | out | **D38** | A4 | out |
| **D3** | WO | out | **D39** | A5 | out |
| **D4** | STACK | out | **D40** | A6 | out |
| **D5** | HLTA | out | **D41** | A7 | out |
| **D6** | OUT | out | **D42** | SW14 | in |
| **D7** | M1 | out | **D43** | SW15 | in |
| **D8** | INP | out | **D44** | A15 | out |
| **D9** | MEMR | out | **D45** | A14 | out |
| **D10** | WAIT | out | **D46** | A13 | out |
| **D11** | D7 | out | **D47** | A12 | out |
| **D12** | INTE | out | **D48** | A11 | out |
| **D13** | PROT | out | **D49** | A10 | out |
| **D14** | D4 | out | **D50** | A9 | out |
| **D15** | D5 | out | **D51** | A8 | out |
| **D16** | SW9 | in | **D52** | RESET | in |
| **D17** | SW8 | in | **D53** | CLR | in |
| **D18** | Serial TX | out | **A0 (D54)** | STEP | in |
| **D19** | Serial RX | in | **A1 (D55)** | SLOW | in |
| **D20** | RUN | in | **A2 (D56)** | EXAMINE | in |
| **D21** | STOP | in | **A3 (D57)** | EXAMINE NEXT | in |
| **D22** | HLDA | out | **A4 (D58)** | DEPOSIT | in |
| **D23** | SW10 | in | **A5 (D59)** | DEPOSIT NEXT | in |
| **D24** | SW11 | in | **A6 (D60)** | PROTECT | in |
| **D25** | D0 | out | **A7 (D61)** | UNPROTECT | in |
| **D26** | D1 | out | **A8 (D62)** | SW0 | in |
| **D27** | D2 | out | **A9 (D63)** | SW1 | in |
| **D28** | D3 | out | **A10 (D64)** | SW2 | in |
| **D29** | D6 | out | **A11 (D65)** | SW3 | in |
| **D30** | AUX1 UP | in | **DAC0 (D66)** | SW4 | in |
| **D31** | AUX1 DOWN | in | **DAC1 (D67)** | SW5 | in |
| **D32** | AUX2 UP | in | **CANRX (D68)** | SW6 | in |
| **D33** | AUX2 DOWN | in | **CANTX (D69)** | SW7 | in |
| **D34** | A0 | out | **SDA1 (D70)** | SW12 | in |
| **D35** | A1 | out | **SCL1 (D71)** | SW13 | in |

Mapping Altair element to Arduino pin

| Altair Element | Arduino Pin | Direction | Altair Element | Arduino Pin | Direction |
|---|---|---|---|---|---|
| **SW0** | A8 (D62) | in | **A0** | D34 | out |
| **SW1** | A9 (D63) | in | **A1** | D35 | out |
| **SW2** | A10 (D64) | in | **A2** | D36 | out |
| **SW3** | A11 (D65) | in | **A3** | D37 | out |
| **SW4** | DAC0 (D66) | in | **A4** | D38 | out |
| **SW5** | DAC1 (D67) | in | **A5** | D39 | out |
| **SW6** | CANRX (D68) | in | **A6** | D40 | out |
| **SW7** | CANTX (D69) | In | **A7** | D41 | out |
| **SW8** | D17 | in | **A8** | D51 | out |
| **SW9** | D16 | in | **A9** | D50 | out |
| **SW10** | D23 | in | **A10** | D49 | out |
| **SW11** | D24 | in | **A11** | D48 | out |
| **SW12** | SDA1 (D70) | in | **A12** | D47 | out |
| **SW13** | SCL1 (D71) | in | **A13** | D46 | out |
| **SW14** | D42 | in | **A14** | D45 | out |
| **SW15** | D43 | in | **A15** | D44 | out |
| **STOP** | D21 | in | **D0** | D25 | out |
| **RUN** | D20 | in | **D1** | D26 | out |
| **SINGLE STEP** | A0 (D54) | in | **D2** | D27 | out |
| **SLOW** | A1 (D55) | in | **D3** | D28 | out |
| **EXAMINE** | A2 (D56) | in | **D4** | D14 | out |
| **EXAMINE NEXT** | A3 (D57) | in | **D5** | D15 | out |
| **DEPOSIT** | A4 (D58) | in | **D6** | D29 | out |
| **DEPOSIT NEXT** | A5 (D59) | in | **D7** | D11 | out |
| **RESET** | D52 | in | **INT** | D2 | out |
| **CLR** | D53 | in | **WO** | D3 | out |
| **PROTECT** | A6 (D60) | in | **STACK** | D4 | out |
| **UNPROTECT** | A7 (D61) | in | **HLTA** | D5 | out |
| **AUX1 UP** | D30 | in | **OUT** | D6 | out |
| **AUX1 DOWN** | D31 | in | **M1** | D7 | out |
| **AUX2 UP** | D32 | in | **INP** | D8 | out |
| **AUX2 DOWN** | D33 | in | **MEMR** | D9 | out |
| **Serial RX** | D19 | in | **PROT** | D13 | out |
| **Serial TX** | D18 | out | **INTE** | D12 | out |
| | | | **WAIT** | D10 | out |
| | | | **HLDA** | D22 | out |

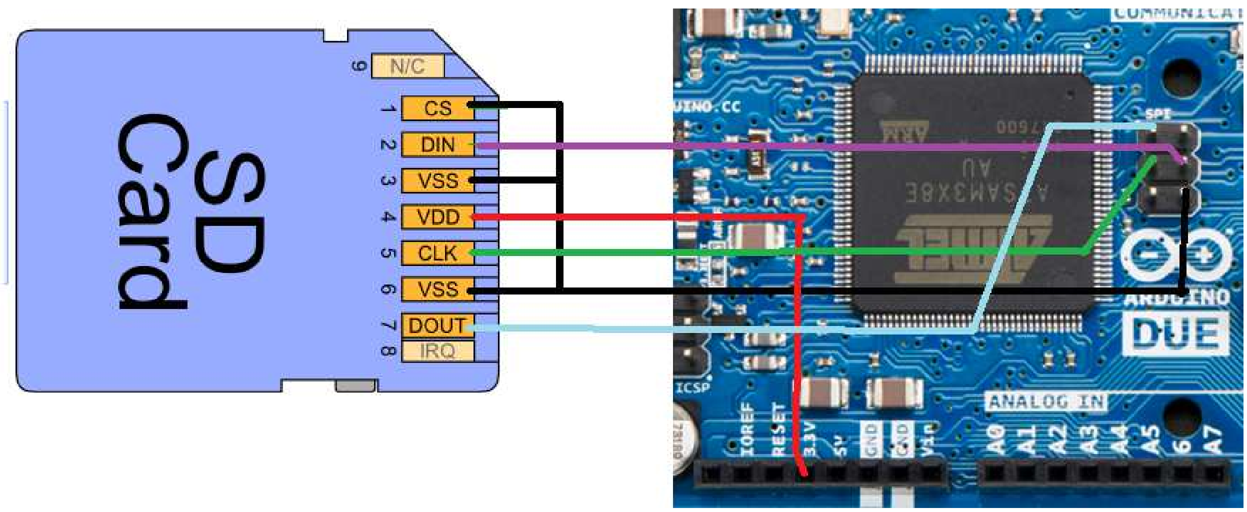
# Wiring an SD card to the Arduino Due

Standard Arduino SD card shields will not work with the Arduino Due because the SPI pins are not connected to the D13-D11 pins as in other Arduino board. That is a good thing because we're already using the D13-D11 pins for front panel elements.

On the DUE, the SPI pins are **only** available on the separate 2-row, 6-pin SPI header (labeled "SPI" on the board).

There are commercial products such as the SparkFun Level Shifting microSD Breakout board that provide an SD card slot. That board is certainly works but is overkill since the Arduino DUE (like the SD cards) operates on 3.3V so no level shifting is required.

In fact, an SD card can be wired directly (without any other required electronic elements) to the SPI header on the Due:




Unfortunately, there is no 3.3V pin on the SPI header on the Arduino Due so that wire must go to the (separate) 3.3V pin. Do not wire the 5V output from the SPI header to the card. Doing so could damage the SD card and/or the Due.

The CS (chip select) pin is wired directly to GND, so the SD card is always selected. That saves us from having to find another I/O pin on the Arduino to use for chip select. The SD library on the Arduino requires to specify a Chip Select output pin but the simulator software sets that to the HLDA light output pin which as a side effect gives a "sd card active" visual indicator.

I recommend getting a microSD card with a microSD-to-SD adapter. Take the microSD card out of the adapter and create a cable by soldering wires directly to the adapter's pins and connecting them to the SPI header using the wiring given above. The adapter now serves as the socket for the microSD card, which can be plugged in and taken out easily.