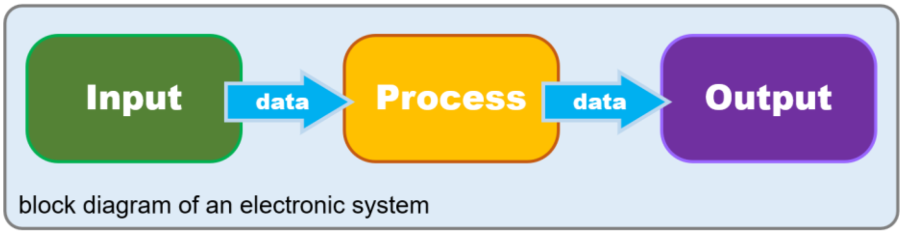
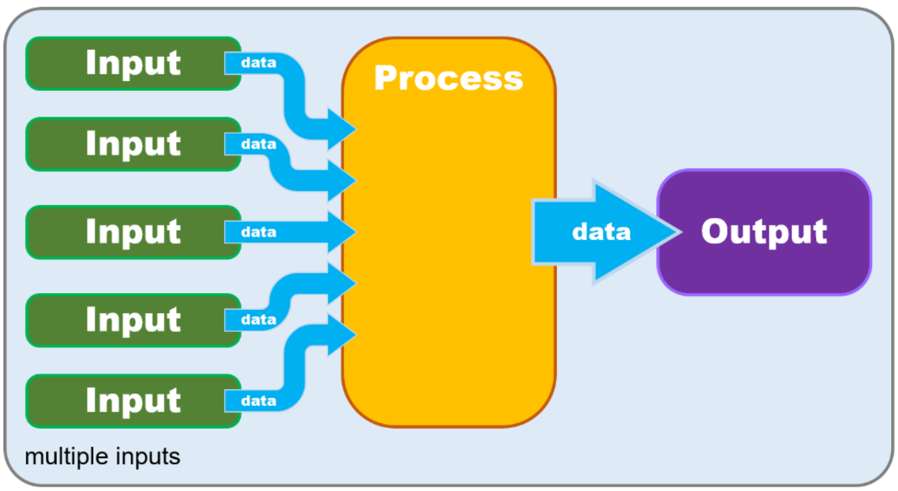
Synth Design System
Microcontroller Addressable MUX

Introduction
Most electronic systems can be explained using this diagram.



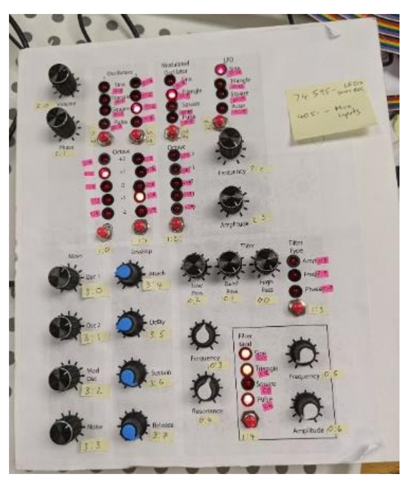
Systems consist of inputs that connect to the outside world, some form of processing or control and outputs to interact with the outside world.

If the system needs multiple inputs (buttons, potentiometers, sensors), you either run out of pins to connect to or you expand your circuit, making it more complex.



This is especially true if you are using a microcontroller (µC) as the process section of the system. As you add more inputs both your circuitry and your code become more complex. Plus, there will be a limited number of IO pins.

I started to think about this project after building a few synthesizers using a Teensy microcontroller. I would lose track of what pin was connected to each input. Plus, I had to totally rebuild the circuit each time I wanted to try something new.



As my designs started to become more complex, I wanted to add multiple potentiometers, buttons, and LEDs. More IO than the Teensy has pins.

Here is one example that I struggled to work with after I had taken a break from the project for a while.

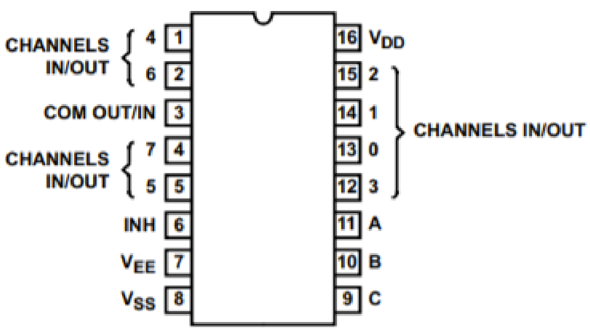
Not Enough Pins

As with most microcontroller projects you can quickly run out of pins. Especially analog inputs. A common technique to solve this is to use a multiplexer/demultiplexer. There are analog and digital versions. A common chip that is used is the 4051.

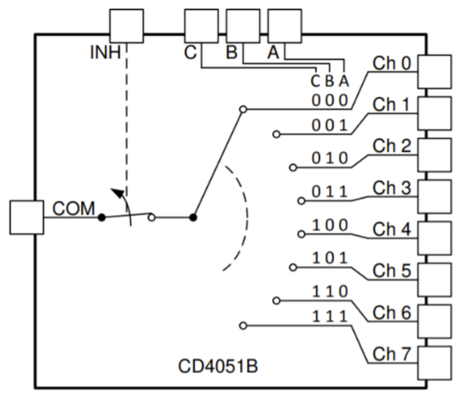
The following is from the Texas Instruments Data Sheet - CD405xB CMOS Single 8-Channel Analog Multiplexer/Demultiplexer with Logic-Level Conversion

"The CD4051B, CD4052B, and CD4053B analog multiplexers are digitally-controlled analog switches having low ON impedance and very low OFF leakage current."

"The CD4051B device is a single 8-channel multiplexer having three binary control inputs, A, B, and C, and an inhibit input. The three binary signals select 1 of 8 channels to be turned on and connect one of the 8 inputs to the output"

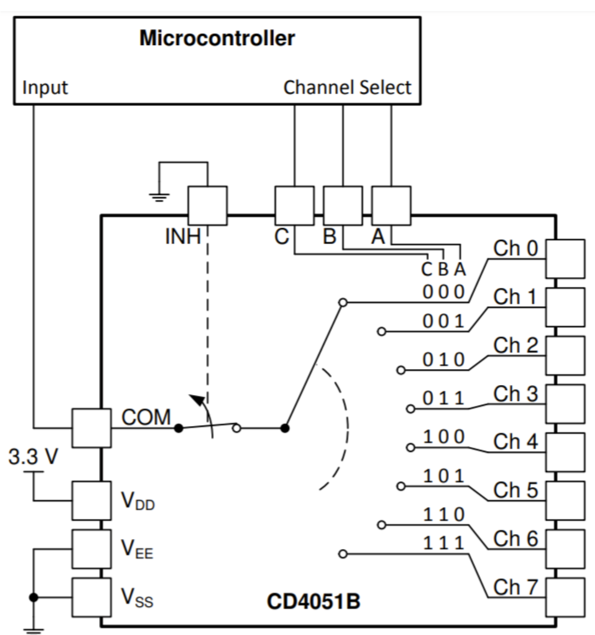


Pinout



Functional Diagram

Here is an example using a microcontroller.

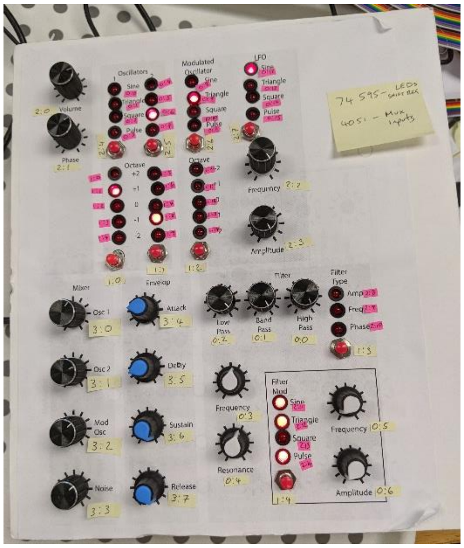


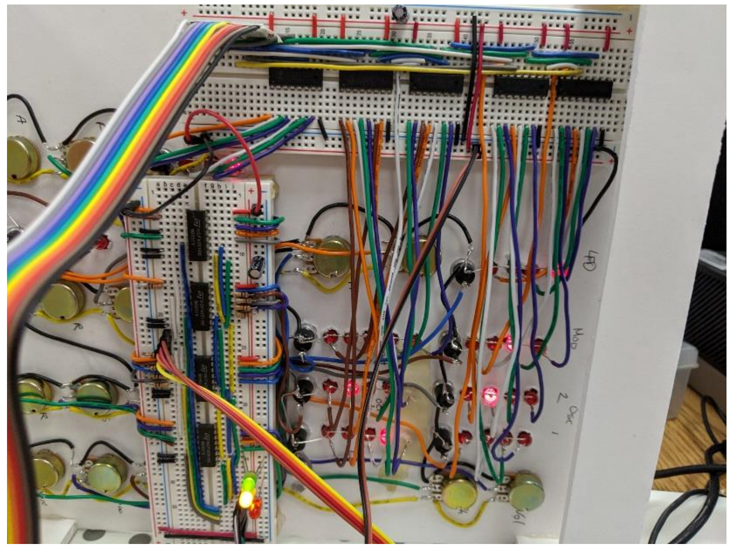
The microcontroller sends the channel select signals to the 4051. The corresponding channel is then connected to the common pin.

NOTE in this example the 4051 is being used to connect multiple inputs to one pin but the 4051 will work in either direction.

Although I have used 4051 MUX in previous projects, I found that similar problems would occur with each new system I created. I would lose track of what pin on the 4051 mux was connected to the pins on the microcontroller. Each mux needed a set of control pins (C, B, A) and analog input, so I would quickly run out of pins. Plus, I had to totally rebuild the circuit each time I wanted to try something new.

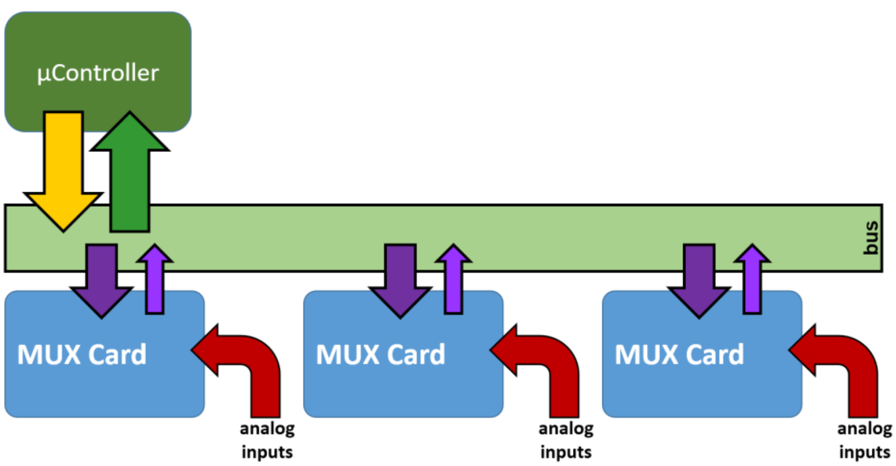
Here is my example synth project again. It worked ok but when I started to work on it again after a few weeks break I struggled to continue with its development due to the circuit's complexity.





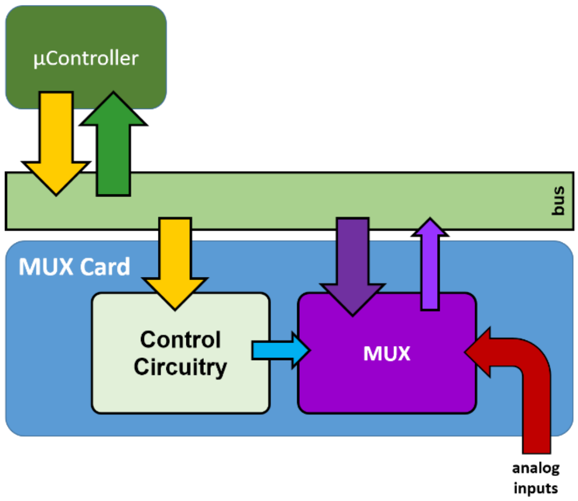
Initial Idea

I had the idea of designing a system that would allow me to add as many MUX circuits as needed without the need to modify the code too much. I could use a bus to carry the signals to and from each MUX card circuit.



The microcontroller connects to each card via the bus(es)

My idea was to make each card have a unique address that the microcontroller could use to enable each card independently.



Each card would require control circuitry to read the address from the microcontroller and enable that cards MUX.

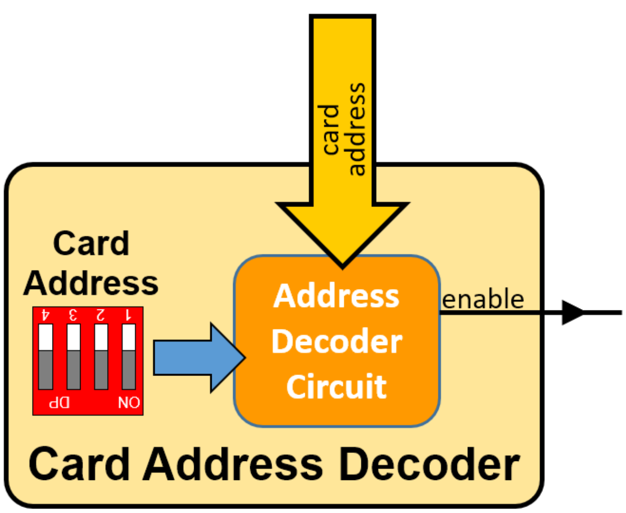
Control Circuitry

Initially I planned to use just three address lines from the microcontroller. This would give me 8 possible addresses for the MUX cards. Each MUX can have 8 inputs so 8 cards x 8 inputs = 64 possible inputs.

> NOTE
> The system is designed to allow me to add another address line later if needed. 4 address lines = 16 addresses. 16 cards x 8 inputs = 128 inputs.
> Also if needed it is possible to put multiple MUX chips at each address giving more inputs or you could use a 16 channel MUX. e.g. a 74HC4067.

The MUX card needs to control the enable pin of the MUX. To do this it reads the address from the microcontroller. If the address is identical to the cards address, then enable the MUX. If not, then disable the MUX.

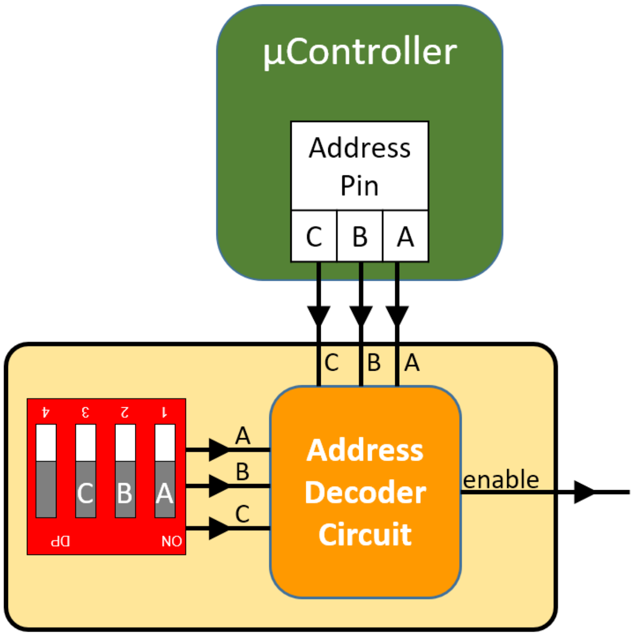
The 4051 MUX control pin is called INH (pin 6). A high signal disables the MUX. Therefore, the control circuit needs an output that goes low when the correct address is read.



Here is a block diagram of the address decoder.

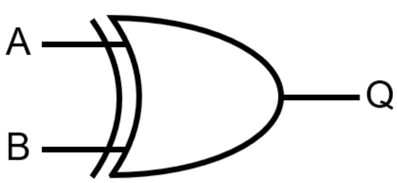
I will use a DIP switch x 4 to set the address of the card.
NOTE – the switch is shown upside down as I plan to use pull up resistors.

Designing the Control Circuitry



The enable needs to go low when:
- microcontroller address pin A = DIP Switch A
- microcontroller address pin B = DIP Switch B
- microcontroller address pin C = DIP Switch C

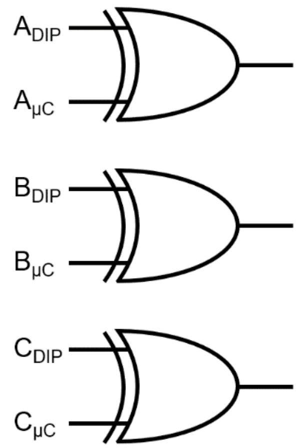
There are several techniques to design a logic system to do this but…
Looking at an exclusive OR gate you can see that when its two inputs are the same you get a logic 0.



B	A	Q
0	0	0
0	1	1
1	0	1
1	1	0

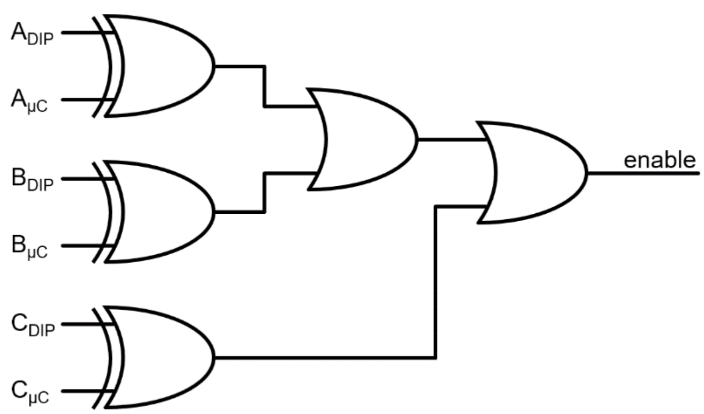
When A = B
Q is 0

Therefore, each address line from the microcontroller and each line from the DIP switch need to be XOR'd.



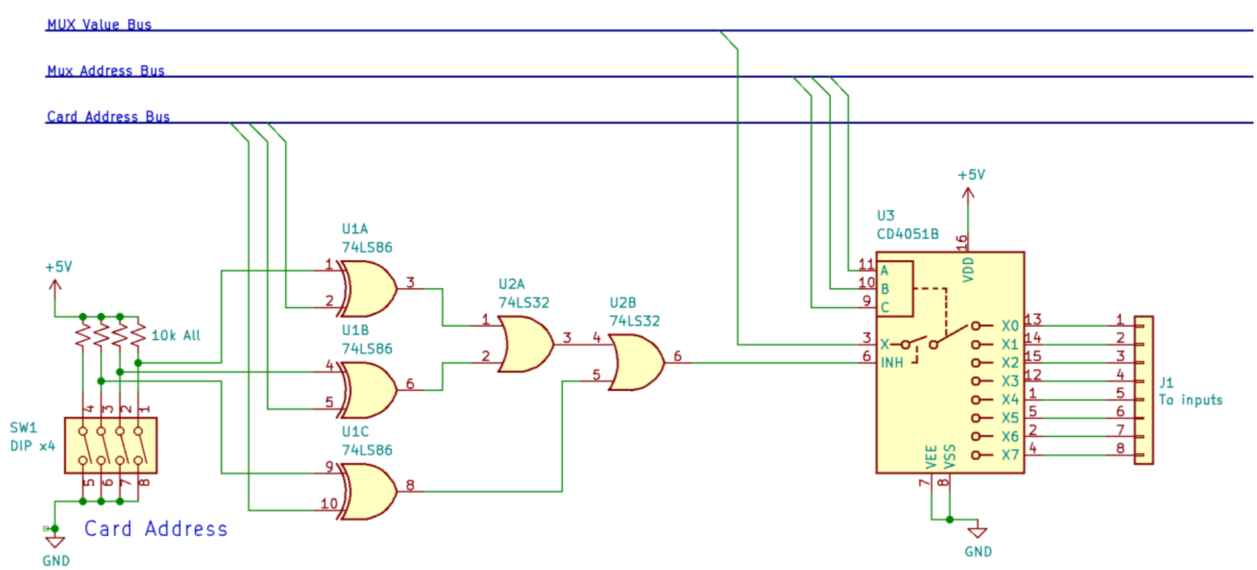
These then need to be combined in a way that will pass the 0 or 1 to the output.

OR gates will do this – the only way to get a zero is if all outputs from the XORs are zero.



This circuit will give a low enable when the address from the microcontroller is the same as the DIP switch.

Here is the full circuit for the address decoder and the MUX.

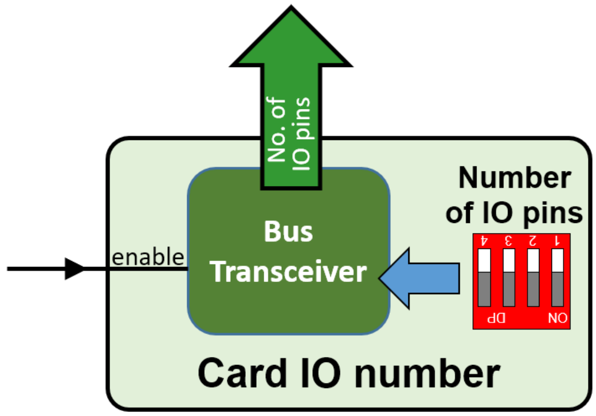


Number of Inputs

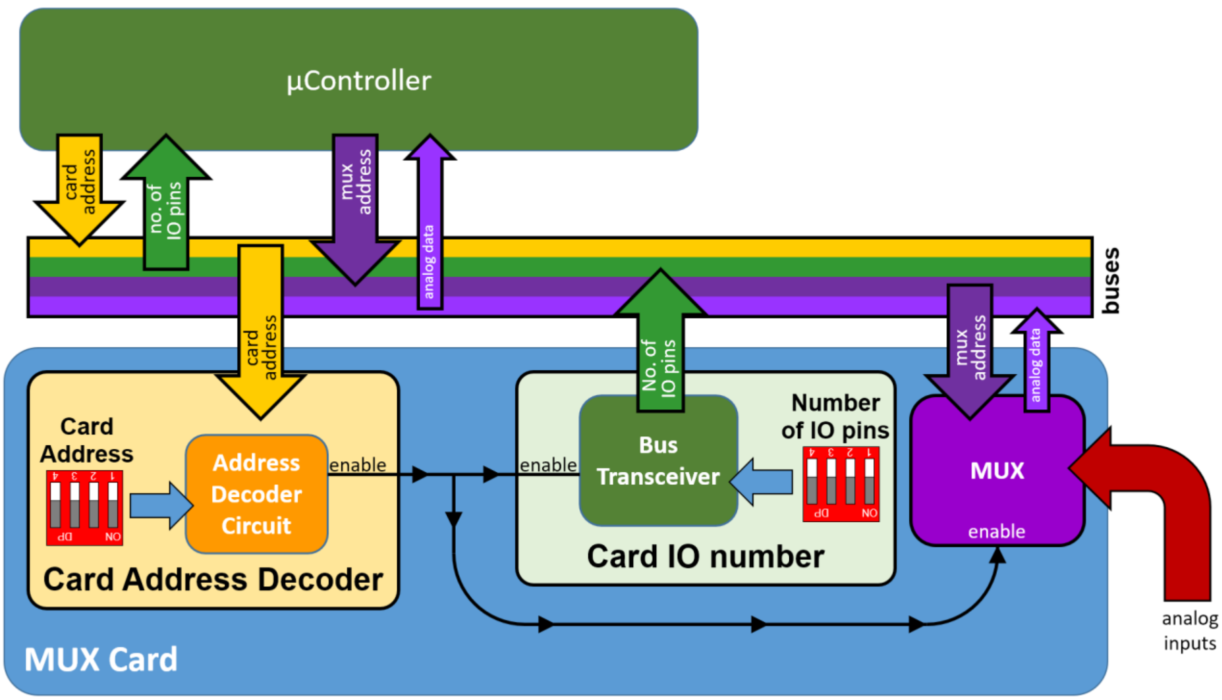
At this point I realised that I may not want to use all 8 inputs on every MUX. Any unused inputs being checked by the microcontroller will slow down the system.

I added another DIP switch and a bus transceiver to each card. The second DIP switch allows the card to send the number of IO pins to read to the microcontroller. A bus transceiver is used so that each card will only send the value when that card is selected. (plus, these were the chips I had)

Here is the block diagram.

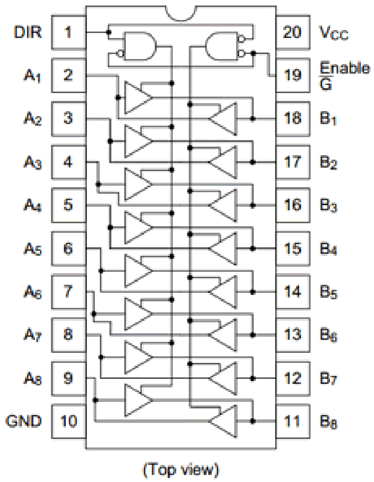


Here is the full block diagram for a single card.



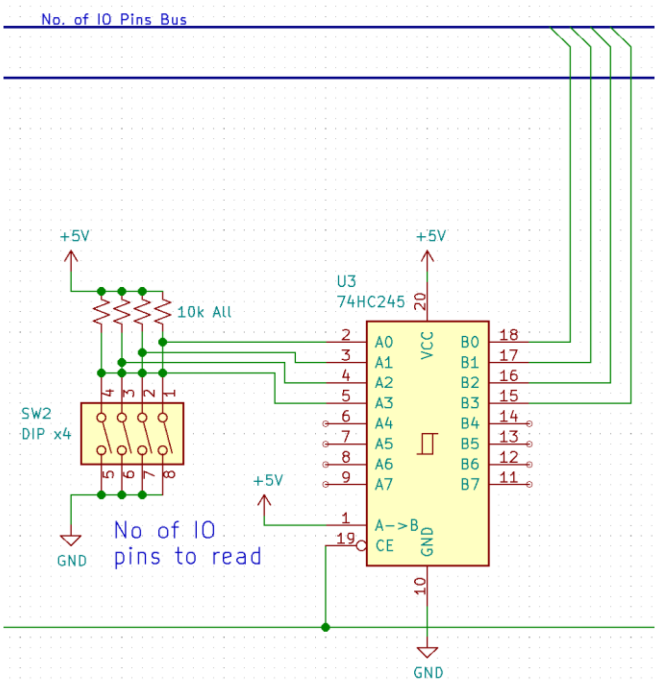
Bus Transceiver

I used a [74HC245 Octal Bus Transceiver] to link to the bus.



The enable (CE) pin also needs a low signal so I can use the same signal as the MUX enable.
The only other connection on the transceiver is a direction pin, set to 5v for the direction I used – A to B.

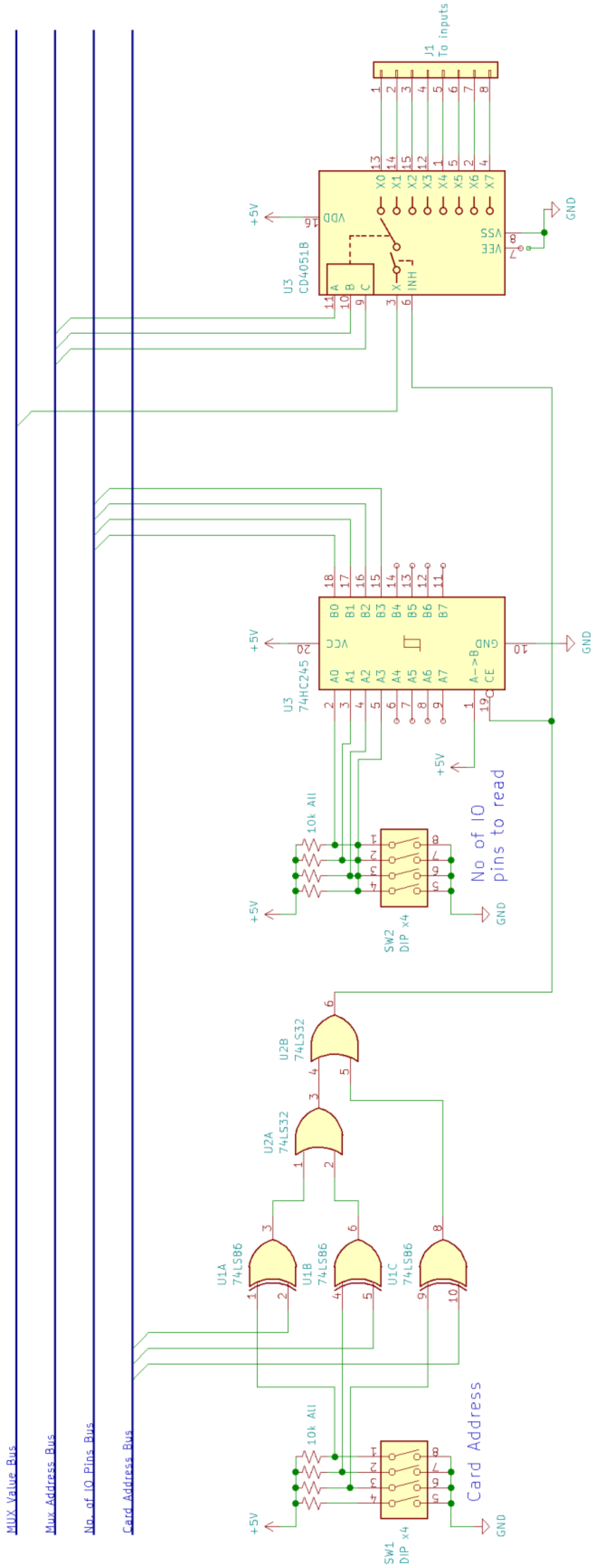
Again, I used pull-up resistors on the DIP switch.



When the enable (CE) is pulled low the transceiver connects its input (A0 – A7) pins to its output pins (B0 – B7).

When enable (CE) is high the output pins are not connected to anything.

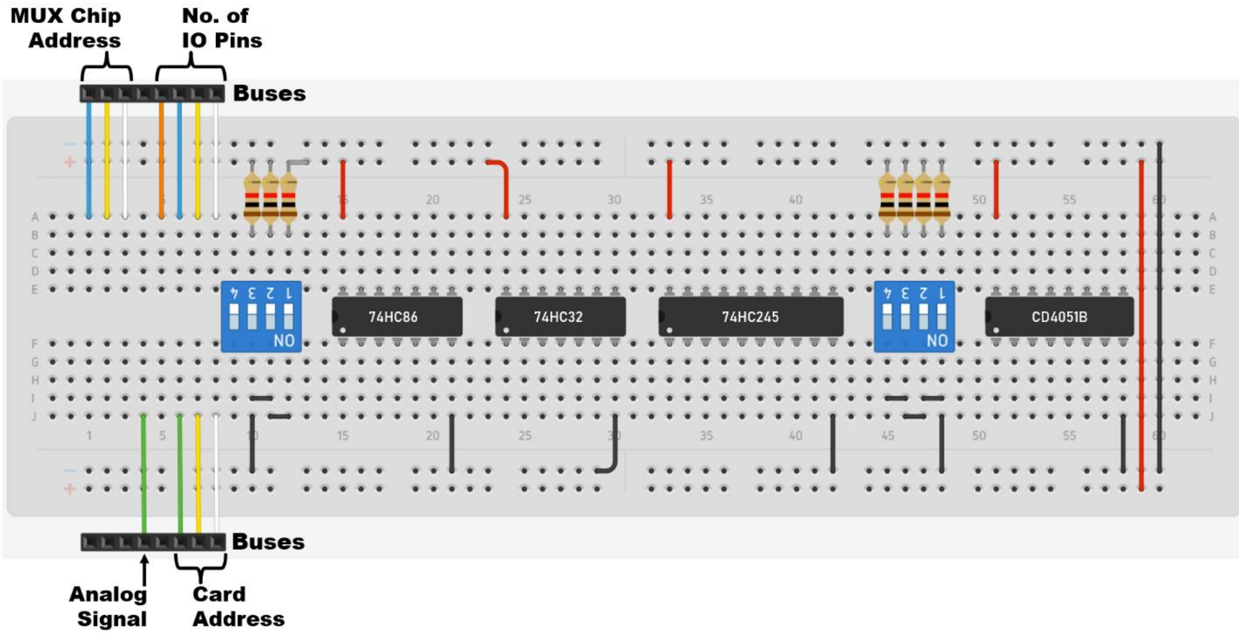
The complete circuit diagram can be seen below.

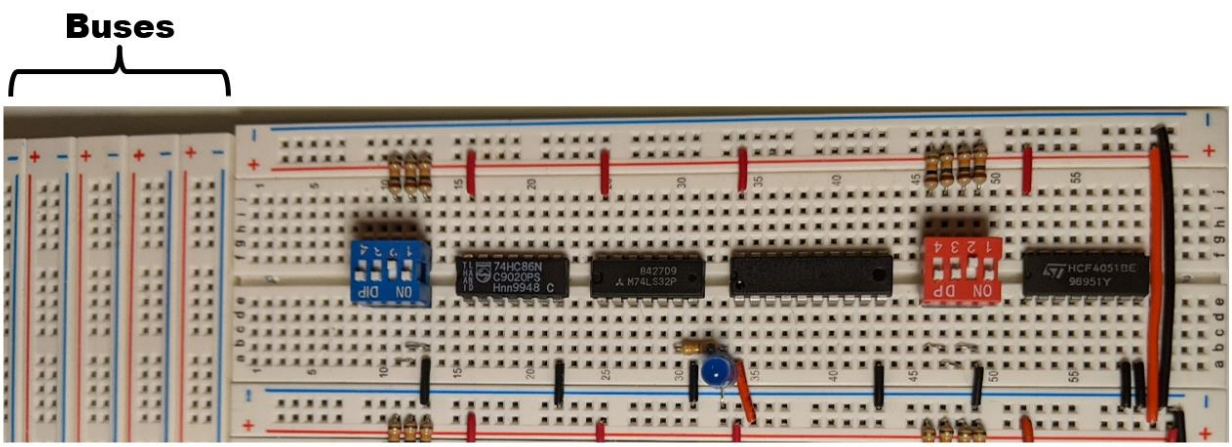


Building the circuit

Step 1

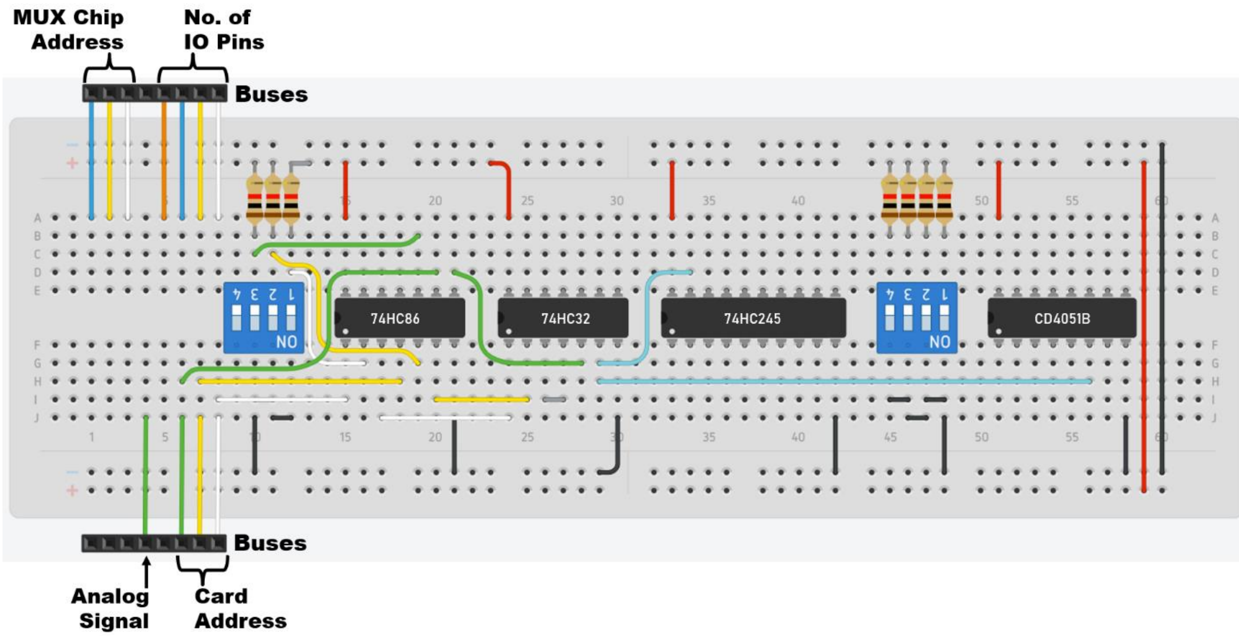
Place the DIP switches, resistors, chips and power lines.

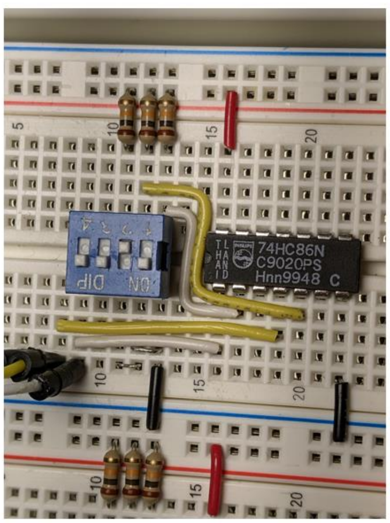


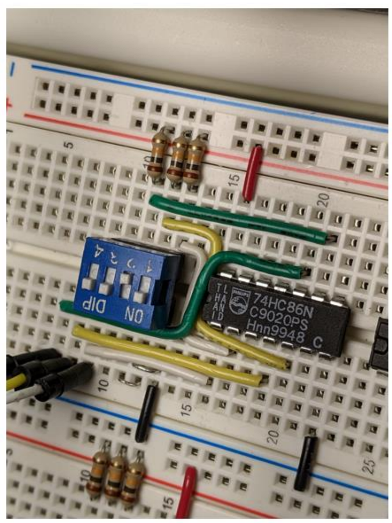


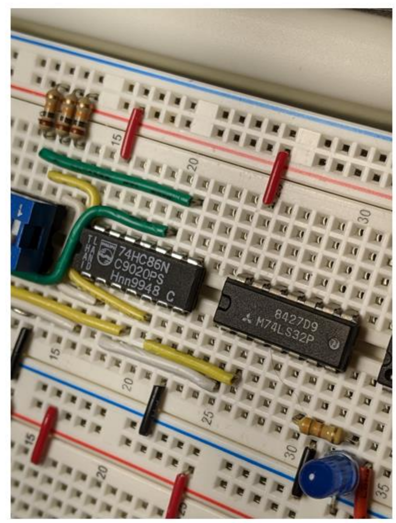
Step 2

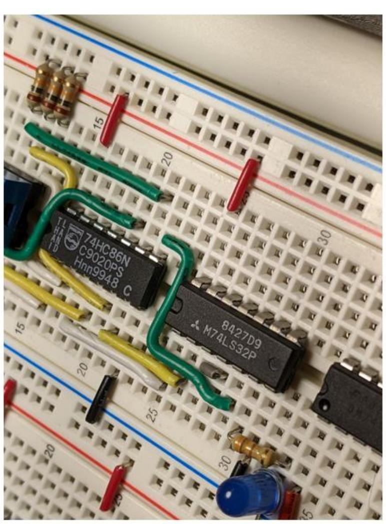
Wire up the address decoder circuit.

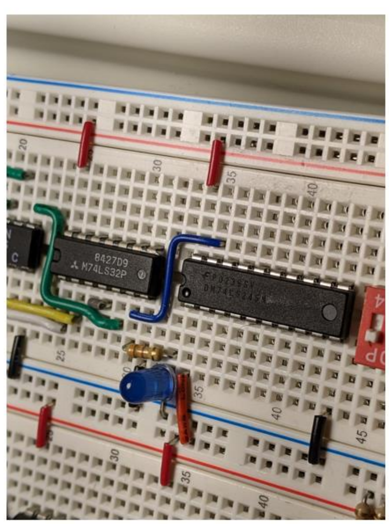






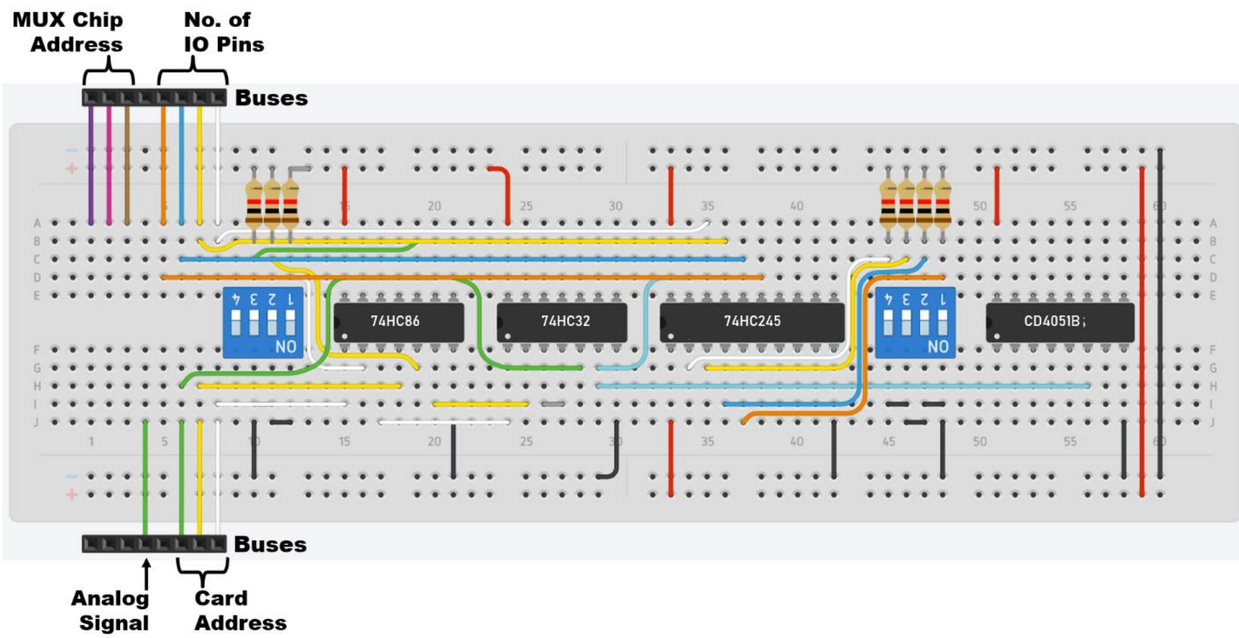


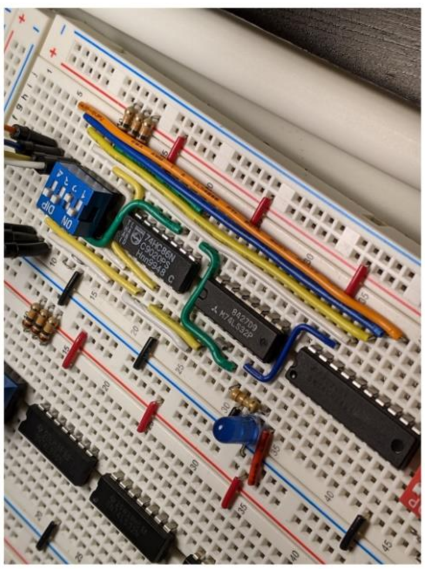


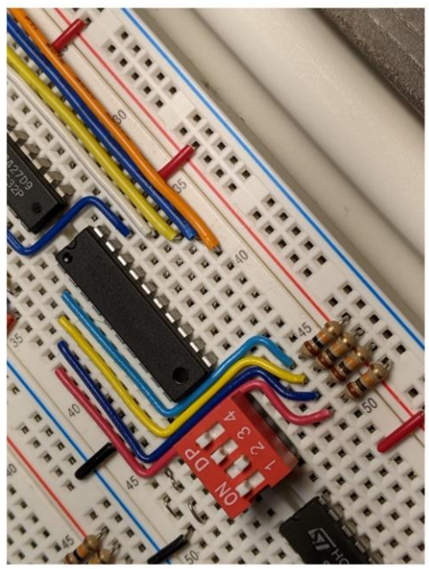


Step 3

Wire up the IO pins circuit.

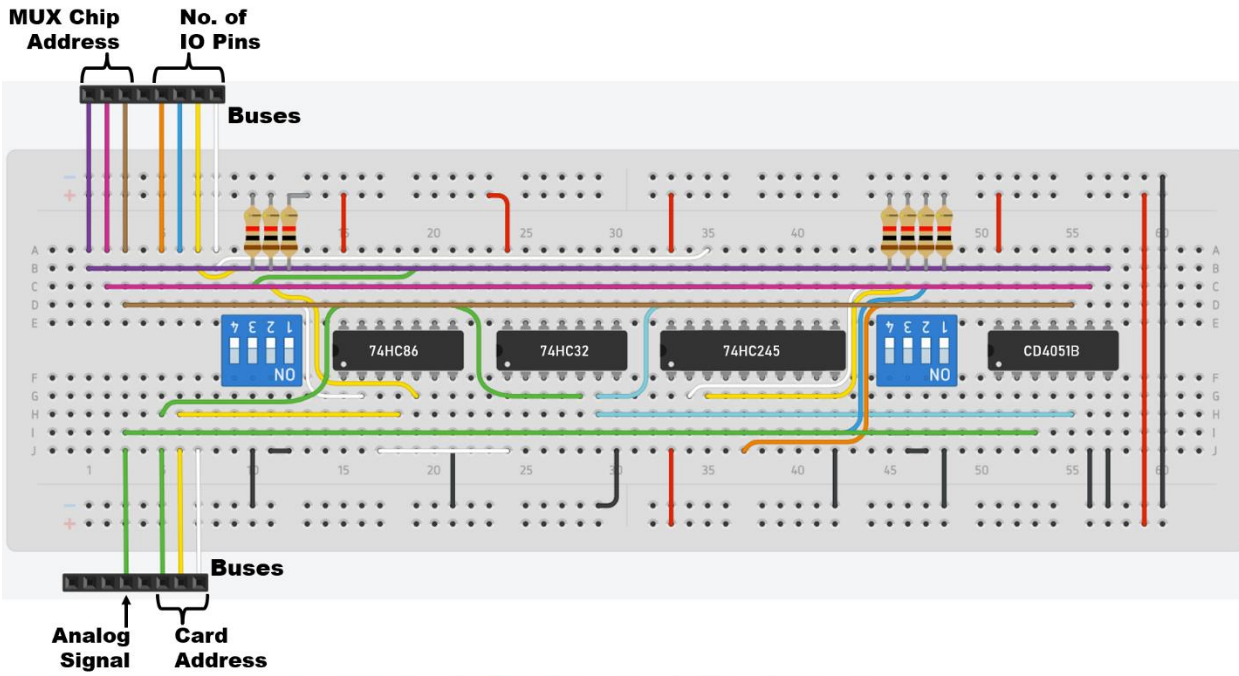


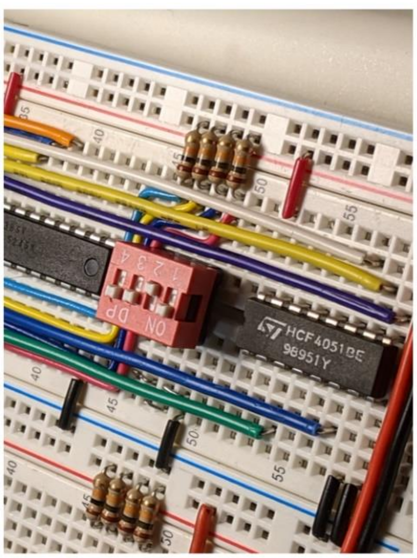


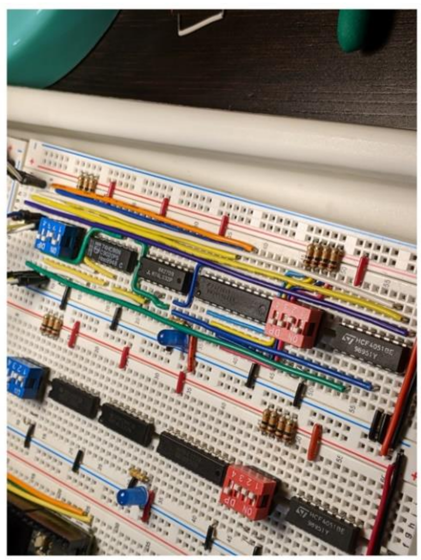


Step 4

Wire up the MUX address and the MUX common (analog signal).

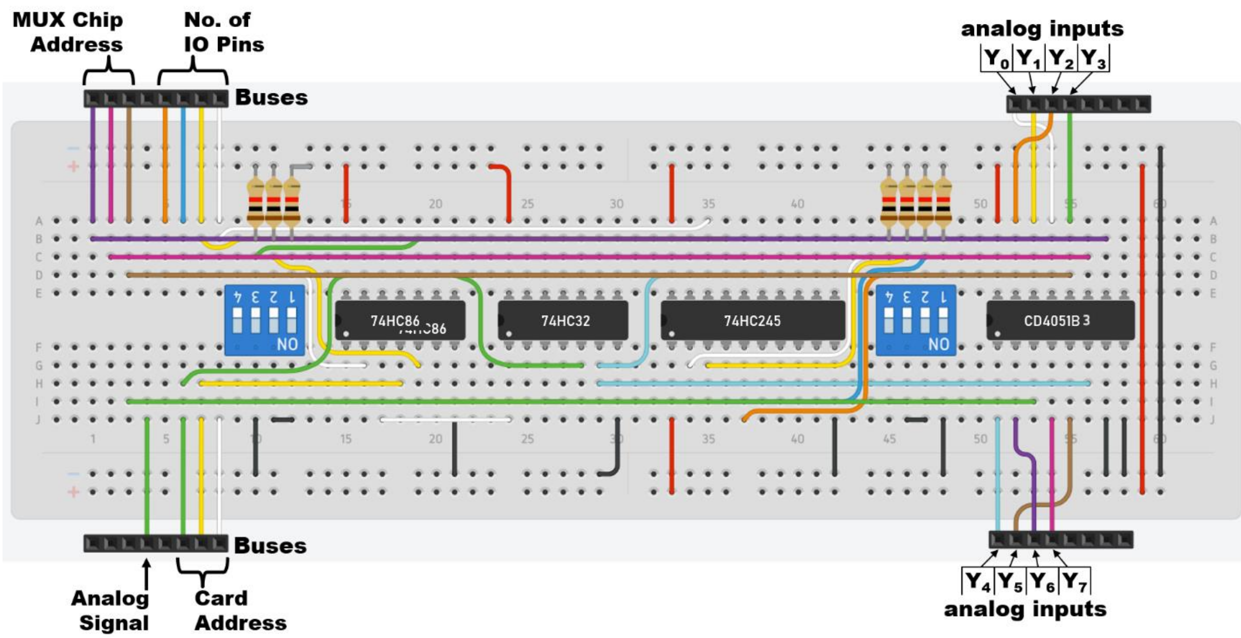


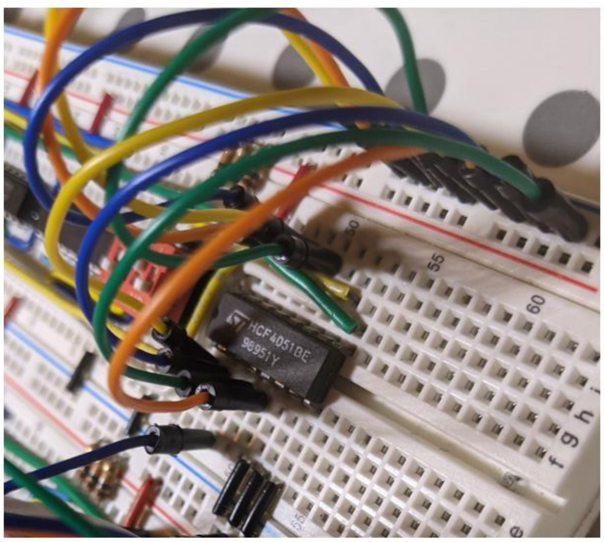




Step 5

Wire up the MUX inputs Y0 to Y7.





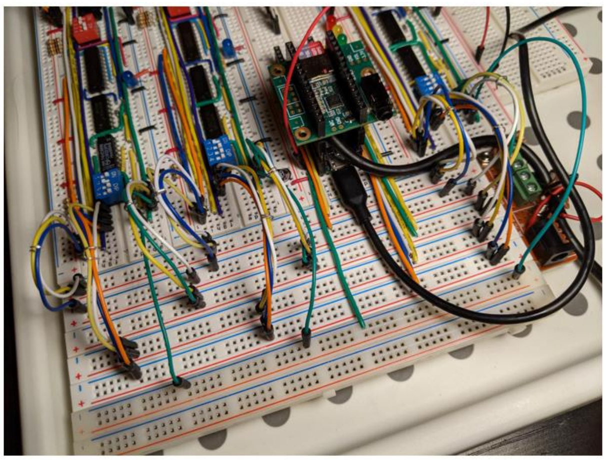
Step 6

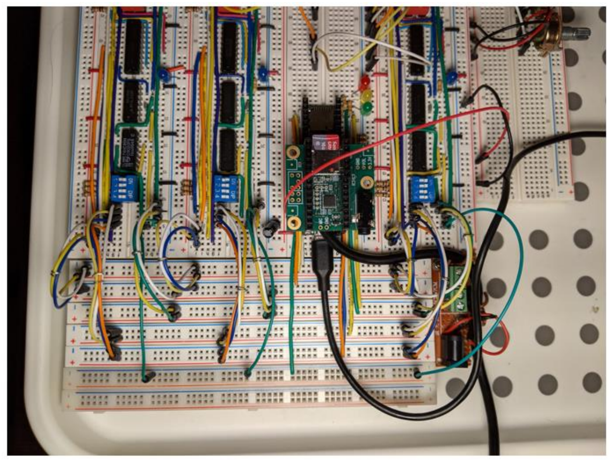
Now the microcontroller needs to connect to each bus.

I am using a Teensy 3.6.

Here are the pins I used for each bus.

Card Address Bus	Card MUX Address Bus	IO Pin Number Bus
A – pin 30 **B – pin 31** **C – pin 32**	**A – pin 33** **B – pin 34** **C – pin 35** **Analog Input – pin 36 (A17)**	**A – pin 24** **B – pin 25** **C – pin 26** **D – pin 27**





I decided to use powerlines to create the buses. Above you can see how the microcontroller and each card connects to the buses.

The hardware side of this project is now complete.

Code

As mentioned, one of the reasons for developing this system is that I do not want to rewrite code every time I start a new synth project.

The idea with this project is that when initialised the microcontroller will poll each possible card address and read back the number of IO pins being used.
The system will then know how many cards are connected plus their addresses and how many pins need to be read for each card.

Polling Cards for number of IO pins

With three address lines there is a maximum of 8 cards 0 to 7.

The microcontroller needs to send the following Addresses.

C	B	A	Card No.
0	0	0	**0**
0	0	1	**1**
0	1	0	**2**
0	1	1	**3**
1	0	0	**4**
1	0	1	**5**
1	1	0	**6**
1	1	1	**7**

This could be done in via nested loops.

```
// nested Loops for address control
for (int C = 0; C < 2; C++){
    for (int B = 0; B < 2; B++){
            for (int A = 0; A < 2; A++){
                    Serial.print (C);     // this would give you the
                    Serial.print (B);     //  correct values of C, B  & A
                    Serial.println (A);
            }
    }
}
```

But I found a [MUX library]() that will do this for you.

```
#include "Mux.h"                    // add mux library to easily controll multiplexer chips
using namespace admux;              // admux is a register to use ADC

// create new muxCard object, to control Card Address bus
//  note: I am using the mux object to just control the bus (C, B, A)
//       there is no data to read.  This could be done with a set of nested for loops instead
//  so set to pin A18, type - INPUT, Analog, Address ABC pins 30,31,32)
Mux muxCard(Pin(A18, INPUT, PinType::Analog), Pinset(30, 31, 32));

    // look at each possible address of the cards using loop 0 to <8
    for (int i = 0; i < 8; i++) {
          muxCard.read(i);          // use muxCard.read to set muxCard Address i
          delay(20);                // pause to allow data to settle
    }
```

Now for each polled address, the IO pin number bus must be read.

The easiest way to do this is with a loop and bitWrite.

Here is the code to read the number of IO pins for each card.

```
// array to store the number of IO pins on each card MUX - 9 means card not found
//  you cannot change the size of an array in Arduino – therefore I have to setup this array fully
int cardRead[] = {9, 9, 9, 9, 9, 9, 9, 9};

int dipPins[] = {27, 26, 25, 24};              // an array for the Card IO Bus pins on the Teensy
```

```
int pinNum = sizeof(dipPins) / 4;            // divide the size of the array by 4 to get the number of slots
                                             //  I used a variable in case I need to change the number of pins


//-------------------------------------------------------------------------------
// Find what cards are connected, their address and how many pins are used by each card
//  Check each card address to see if a card is connected
//  If a card is connected
//   read the number of IO pins and store in cardRead[]
//   the number of IO pins will be on the following Teenay inputs
//   A = p24, B = p25, C = p26, D = p27
//-------------------------------------------------------------------------------
void readCards() {
  // look at each possible address of the cards using loop 0 to <8
  for (int i = 0; i < 8; i++) {
    muxCard.read(i);                // use muxCard.read to set muxCard Address i
    delay(20);                      // pause to allow data to settle

    // use loop to read each wire of the card IO bus
    for (int j = 0; j < pinNum; j++) {
      // add the read value to the correct bit of the number in cardRead[i]
      bitWrite(cardRead[i], j,  digitalRead(dipPins[j]));
    }
    if (cardRead[i] == 0)           //  check to see if the read value is 0
    {                               //   this means no pins used
      cardRead[i] = 9;              //   so store 9 instead to show no IO pins to read on this card
    }
  }
}
```

To check the read values, I created this

```
//-------------------------------------------------------------------------------
// Print out all 8 possible cards and their IO pin number values
// It will look like this
//   "cardRead index 0 = (4)"
//-------------------------------------------------------------------------------
void printCardRead() {
  for (int i = 0; i < 8; i++) {
    Serial.print("cardRead index ");
    Serial.print(i);
    Serial.print(" = (");
    Serial.print(cardRead[i]);
    Serial.println(")");
  }
}
```

This is an example output

COM3 (Teensy) Serial

```
cardRead index 0 = (7)
cardRead index 1 = (5)
cardRead index 2 = (1)
cardRead index 3 = (9)
cardRead index 4 = (9)
cardRead index 5 = (9)
cardRead index 6 = (9)
cardRead index 7 = (9)
```

You can see that in my system I have three cards with addresses 0, 1 & 2. The other cards still have a value of 9 showing that a card is not available at that address.

Next, I created code to calculate how many elements are needed to store all the read values from the MUX's and how many cards are available).

```
//--------------------------------------------------------------------------------
//  Calculate the
//    number of elements needed to store data from MUX's
//    number of cards found
//--------------------------------------------------------------------------------
void calcDataMuxSize() {
 //  again 0 - 7 possible cards
 for (int i = 0; i < 8; i++) {
  // only values less than 9 are valid
  if (cardRead[i] < 9) {                    // if card found
   noCards++;                               //   add 1 to noCards
   muxSize = muxSize + cardRead[i];         //   add no. of IO pins to mux Size
  }
 }
}

//--------------------------------------------------------------------------------
// Print out the card setup values
// It will look like this
//  "number of cards 2"
//  "cardRead index 0 = (4) : pins 0 to 3"
//  "cardRead index 2 = (3) : pins 4 to 6"
//  "muxSize = 7 values in store 0 to 6"
//--------------------------------------------------------------------------------
void printCards() {
 Serial.print("number of cards ");
 Serial.println(noCards);                   // no. of cards found
 int indexCount = 0;
 for (int i = 0; i < 8; i++) {              // use loop to print out no. of IO pins on each card

  if (cardRead[i] < 9) {                    // only values less than 9 are valid
   Serial.print("cardRead index ");         // The following code prints outb the current card
   Serial.print(i);                         //  index,
```

```
    Serial.print(" = (");
    Serial.print(cardRead[i]);              //  no. of IO inputs expected
    Serial.print(") : pins ");
    Serial.print(indexCount);               //  start index in array
    indexCount += cardRead[i];
    Serial.print(" to ");
    Serial.println(indexCount - 1);         //  end index  in array
   }
  }
  Serial.print("muxSize = ");               // Then print how many values are to be stored
  Serial.print(muxSize);
  Serial.print(" values in store 0 to ");
  Serial.println(muxSize - 1);
  Serial.println("");
}
```

Here is an example printout

```
number of cards 3
cardRead index 0 = (7) : 0 to 6 in muxData[i]
cardRead index 1 = (5) : 7 to 11 in muxData[i]
cardRead index 2 = (1) : 12 to 12 in muxData[i]
muxSize = 13 values in store 0 to 12
```

Now that the code has worked out how many cards and IO pins are to be read on each card, we can use this information to read the data coming into the MUX pins.

```
// create new muxRead object to control mux and read data on each card
//  analog in pin A17, type - INPUT, Analog, Address ABC pins 33,34,35)
Mux muxRead(Pin(A17, INPUT, PinType::Analog), Pinset(33, 34, 35));

//--------------------------------------------------------------------------------
//  Setup Global Variables to work with mux
//   note - because you MUST setup arrays when code is compiled for Arduino
//   the arrays to store the mux values have to have 64 slots available (just in case)
//   8 cards x 8 inputs = 64 slots
//--------------------------------------------------------------------------------
int muxData[64];                // main array storing read mux values from inputs
int muxOld[64];                 // store previous value
int noCards;                    // store the number of cards found
int muxSize;                    // store number of spaces used in muxData
int muxChanged;                 // store if mux value has changed

//--------------------------------------------------------------------------------
// Find what cards are connected, their address and how many pins are used by each card
//  Check each card address to see if a card is connected
//  If a card is connected
//   read the number of IO pins and store in cardRead[]
//   the number of IO pins will be on the following Teenay inputs
//   A = p24, B = p25, C = p26, D = p27
//--------------------------------------------------------------------------------
void readCards() {
  // look at each possible address of the cards using loop 0 to <8
```

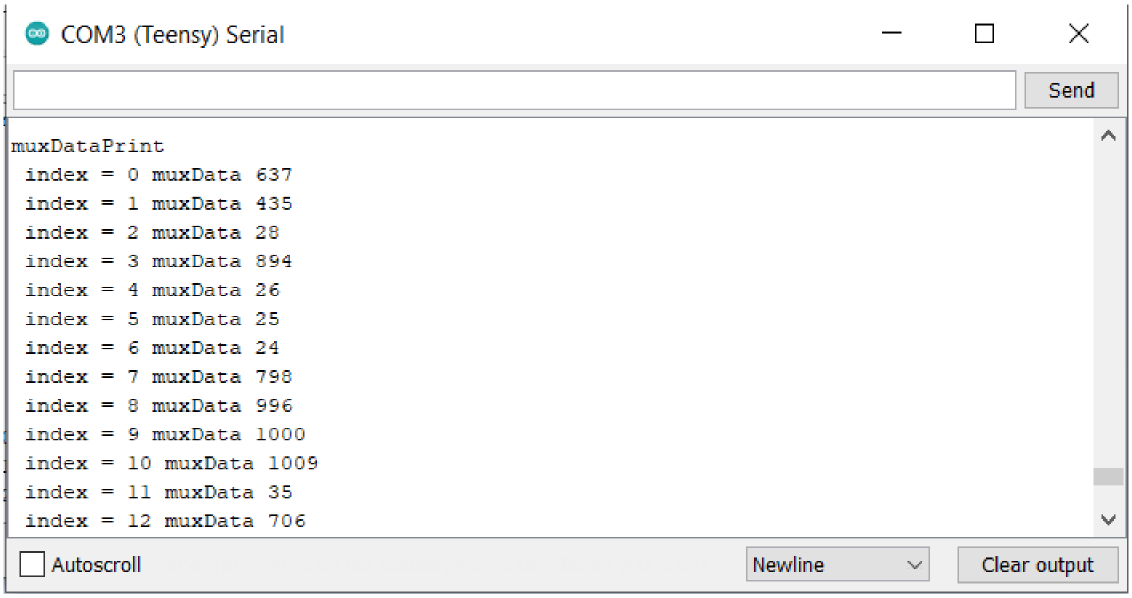
```
  for (int i = 0; i < 8; i++) {
    muxCard.read(i);                    // use muxCard.read to set muxCard Address i
    delay(20);                          // pause to allow data to settle

    // use loop to read each wire of the card IO bus
    for (int j = 0; j < pinNum; j++) {
      // add the read value to the correct bit of the number in cardRead[i]
      bitWrite(cardRead[i], j,  digitalRead(dipPins[j]));
    }
    if (cardRead[i] == 0)               //  check to see if the read value is 0
    {                                   //   this means no pins used on this card
      cardRead[i] = 9;                  //   so store 9 instead to show card not used
    }
  }
}

//--------------------------------------------------------------------------------
// To see if the Teensy needs to be updated with values
// Two functions
//  1. Store previous values of muxData in muxOld
//  2. Check if new values are different to previous values - 0 = no 1 = yes
//  used to only update teensy if changes have occured
//--------------------------------------------------------------------------------
void storePrevious() {
  // loop through the muxData array upto the number of slots in muxData
  for (int j = 0; j < muxSize; j++) {
    muxOld[j] =  muxData[j];            // store current value in muxOld
  }
}
void muxValueChanged() {
  muxChanged = 0;                       //reset the muxChanged flag

  // loop through the muxData array upto the number of slots in muxData
  for (int j = 0; j < muxSize; j++) {
    //check to see if new data is not the same as old data
    if ( muxData[j] != muxOld[j]) {
      muxChanged = 1;                   // if data has changed muxChanged = 1
    }                                   //  and Teensy needs to be updated
  }
}
```

Finally, I created this code to print out the values read from the MUX's

```
//--------------------------------------------------------------------------------
// print the values in muxData
//--------------------------------------------------------------------------------
void muxDataPrint() {
  Serial.println("muxDataPrint");
  // loop through the muxData array upto the number of slots in muxData
  for (int i = 0; i < muxSize; i++) {
    Serial.print(" index = ");
    Serial.print(i);                    // print out the data and text
    Serial.print(" muxData ");
    Serial.println(muxData[i]);
```

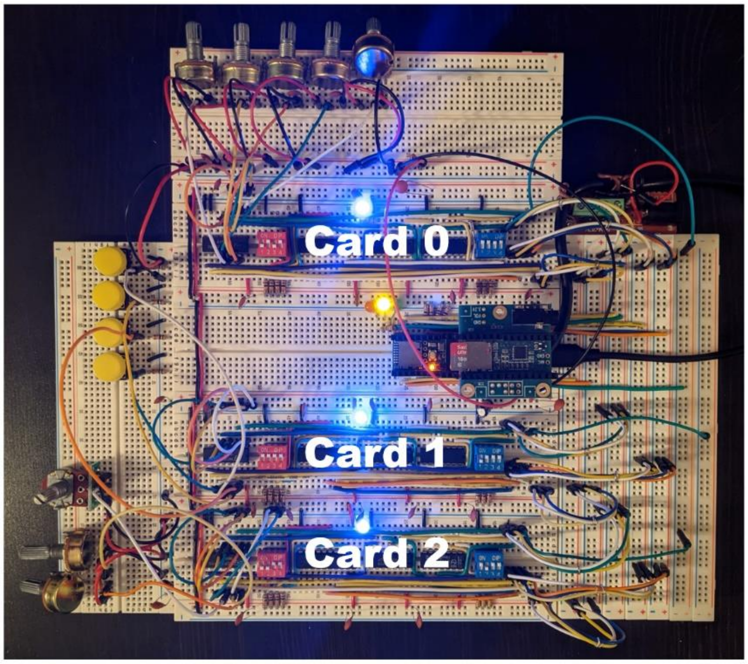
```
 }
 Serial.println("");
}
```

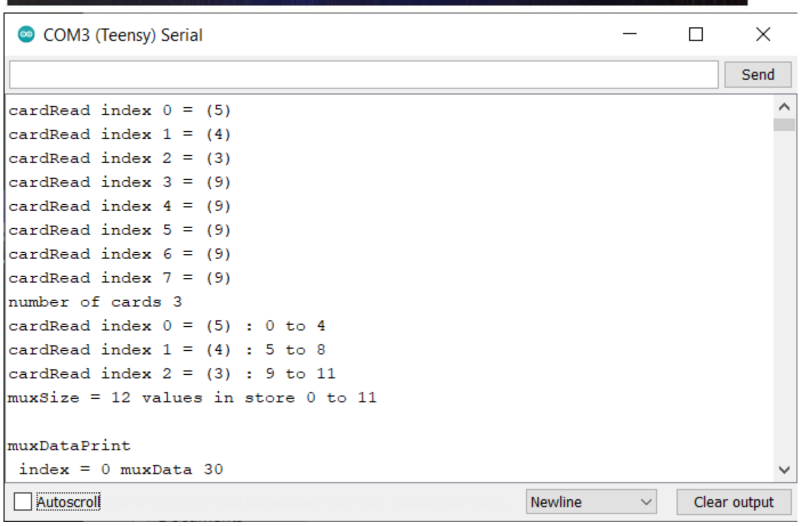
Here is an example printout.



Now I can use the values in muxData[i] to control my synthesizers.

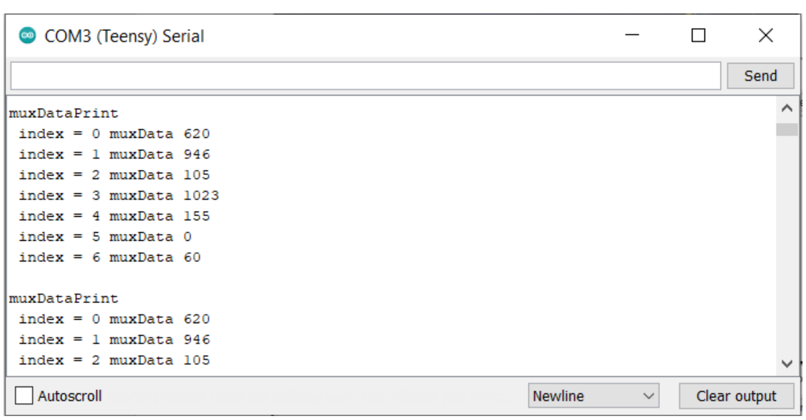
There are three cards.
Card [0] has 4 IO pins connected to potentiometers.
Card [1] has **0** IO pins connected to buttons – this is to show that the card will be ignored
Card [2] has 3 IO pins connected to potentiometers.





SerialPrint of the cards and IO pin numbers.

This printout is useful to see what parts of the muxData array holds the data from each card.

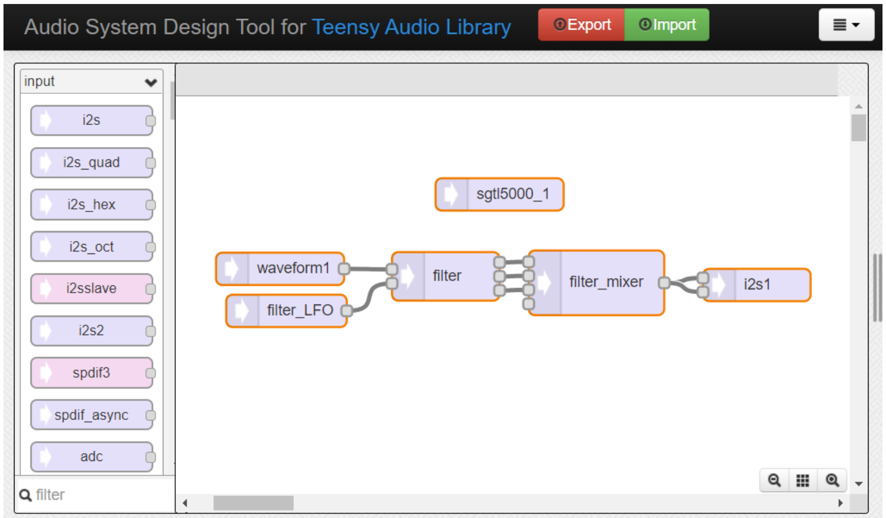


SerialPrint of values read into the microcontroller.

Now I can use these values to control the inputs of any synth I design using the Teensy 3.6.

There are lots of tutorials to explain how to use the Teensy to make a synth. I will give a brief overview.

Here is the Audio System Design Tool for Teensy Audio Library



When exported the following code is created.

```
// GUItool: begin automatically generated code
AudioSynthWaveform       waveform1;                   //xy=482.5555953979492,232.6666784286499
AudioSynthWaveform       filter_LFO;         //xy=488.8889617919922,271.66662979125977
AudioFilterStateVariable filter;                      //xy=636.5555458068848,239.00004768371582
AudioMixer4              filter_mixer;                //xy=776.38916015625,245.16670608520508
AudioOutputI2S           i2s1;                        //xy=925.0556049346924,247.0000514984131
AudioConnection          patchCord1(waveform1, 0, filter, 0);
AudioConnection          patchCord2(filter_LFO, 0, filter, 1);
AudioConnection          patchCord3(filter, 0, filter_mixer, 0);
AudioConnection          patchCord4(filter, 1, filter_mixer, 1);
AudioConnection          patchCord5(filter, 2, filter_mixer, 2);
AudioConnection          patchCord6(filter_mixer, 0, i2s1, 0);
AudioConnection          patchCord7(filter_mixer, 0, i2s1, 1);
AudioControlSGTL5000     sgtl5000_1;                  //xy=686.4365005493164,163.16664505004883
// GUItool: end automatically generated code
```

I split the code up into three by putting the MUX code and the Teensy settings in library files.

So now

Synth_USB_Modular_MUX.ino

Calls the libraries

MUXController.h

TeensyAudioDesignTool.h

The above code was put into the TeensyAudioDesignTool.h file

The main program has the following sections.

```
//------------------------------------------------------------------------------
// libraries to load
//------------------------------------------------------------------------------
#include "USBHost_t36.h"                // USB host library to allow use of USB devices
#include <Audio.h>                      // Teensy Audio Library
#include <Wire.h>                       // Library to communicate with I2C / TWI devices
#include <SPI.h>                        // Library to communicate with SPI devices
#include <SD.h>                         // Library to allow SD cards to be used
#include <SerialFlash.h>                // Library to allow access to SPI Flash memory

#include "Mux.h"                        // add mux library to easily controll multiplexer chips
using namespace admux;                  // admux is a register to use ADC

#include "TeensyAudioDesignTool.h"      // Library containing Teensy Design Tool settings
#include "MUXController.h"              // Library containing addressable MUX code


//------------------------------------------------------------------------------
// Setup Global Objects
//------------------------------------------------------------------------------
USBHost myusb;            // create new USBHost
USBHub hub1(myusb);       // create three hubs
USBHub hub2(myusb);
USBHub hub3(myusb);
MIDIDevice midi1(myusb);  // create new midi device object

//------------------------------------------------------------------------------
// Setup Global Variables
//------------------------------------------------------------------------------
// array of note frequencies to use when notes are received from midi device
const float noteFreqs[128] = {8.176, 8.662, 9.177, 9.723, 10.301, 10.913, 11.562, 12.25, 12.978, 13.75,
14.568, 15.434, 16.352, 17.324, 18.354, 19.445, 20.602, 21.827, 23.125, 24.5, 25.957, 27.5, 29.135,
30.868, 32.703, 34.648, 36.708, 38.891, 41.203, 43.654, 46.249, 48.999, 51.913, 55, 58.27, 61.735,
65.406, 69.296, 73.416, 77.782, 82.407, 87.307, 92.499, 97.999, 103.826, 110, 116.541, 123.471,
130.813, 138.591, 146.832, 155.563, 164.814, 174.614, 184.997, 195.998, 207.652, 220, 233.082,
246.942, 261.626, 277.183, 293.665, 311.127, 329.628, 349.228, 369.994, 391.995, 415.305, 440,
466.164, 493.883, 523.251, 554.365, 587.33, 622.254, 659.255, 698.456, 739.989, 783.991, 830.609,
880, 932.328, 987.767, 1046.502, 1108.731, 1174.659, 1244.508, 1318.51, 1396.913, 1479.978,
1567.982, 1661.219, 1760, 1864.655, 1975.533, 2093.005, 2217.461, 2349.318, 2489.016, 2637.02,
2793.826, 2959.955, 3135.963, 3322.438, 3520, 3729.31, 3951.066, 4186.009, 4434.922, 4698.636,
4978.032, 5274.041, 5587.652, 5919.911, 6271.927, 6644.875, 7040, 7458.62, 7902.133, 8372.018,
8869.844, 9397.273, 9956.063, 10548.08, 11175.3, 11839.82, 12543.85};

// the following two constants are used to convert input data to a percentage
const float DIV127 = (1.0 / 127.0);           // some midi data is between 0 and 127
const float DIV1024 = (1.0 / 1024.0);         // analog inputs are between 0 and 1024
unsigned long oldtime;                        // store the time since last mux checkup
```

```
//-----------------------------------------------------------------------------------
// Setup Function
//-----------------------------------------------------------------------------------
void setup() {
  // initial setup of Teensy Audio
  AudioMemory(20);                 // amount of memory to put aside for Teensy Audio
  Serial.begin(9600);              // setup and start serial comunication
  myusb.begin();                   // start usb object - used by Teensy for 2nd USB port
  delay(200);                      // let serial communication  initialise/settle

  // setup input pins for card address
  for (int i = 0; i < pinNum; i++) {
    pinMode(dipPins[i], INPUT);
  }

  // Run Addressable Mux setup
  readCards();             // check how many cards there are and how many IO pins for each card
  printCardRead();         // print out the cards and IO pins for each card
  calcDataMuxSize();       // calculate how many locations are needed to store data from Main MUX
  printCards();            // print number of cards found, IO pins for each card, number of values stored


  //***********************************************************
  // Teensy Synth setup
  //   this section will change depending upon the system designed with the Audio Design Tool
  //***********************************************************
  // link actions of midi1 to functions to allow control via a midi keyboard connected via USB
  midi1.setHandleNoteOff(OnNoteOff);                      // when key is released
  midi1.setHandleNoteOn(OnNoteOn);                        // when key is pressed
  midi1.setHandleControlChange(OnControlChange);          // when a control signal changes

  // Teensy Initial Sound Settings
  sgtl5000_1.enable();             // enable Teensy sound output
  sgtl5000_1.volume(0.7);          // set master volume

  // waveform1 settings – Sawtooth waveform, amplitude 0, frequency 82.41Hz, pulse width 0.15
  waveform1.begin(WAVEFORM_SAWTOOTH);
  waveform1.amplitude(0.0);
  waveform1.frequency(82.41);
  waveform1.pulseWidth(0.15);

  // filter LFO settings – Sine waveform, amplitude 0, frequency 20Hz, pulse width 0.15
  filter_LFO.begin(WAVEFORM_SINE);
  filter_LFO.amplitude(0.0);
  filter_LFO.frequency(20);
  filter_LFO.pulseWidth(0.15);

  // filter mixer settings – each input set to 0.25 gain
  filter_mixer.gain(0, 0.25);
  filter_mixer.gain(1, 0.25);
  filter_mixer.gain(2, 0.25);

}
```

```
//--------------------------------------------------------------------------------
// Main Loop Program
//--------------------------------------------------------------------------------
void loop()
{
  myusb.Task();              // poll connected usb devices for updates to their status
  midi1.read();              // read USB midi signals

  // using millis to only check the IO via mux every so often
  if ( (millis() - oldtime) > 100) {  // if 100ms has passed do the following
    oldtime = millis();      // store current time
    storePrevious();         // run storePrevious function to store muxData values
    readmuxRead();           // run readmuxRead function to get new IO values
    muxDataPrint();          // run muxDataPrint to print out the current muxData values
    muxValueChanged();  // run muxValueCheck to see if muxData values have changed since last read

    // check if muxData values values have changed since last time read
    if (muxChanged = 1) {
      updateControls();      // run updateControls to update the Teensy control values
    }
  }
}

//******************************************************************************
//Edit following section to use the muxData values to control the Teensy settings
//******************************************************************************
// Help
//   frequency 20Hz - 20KHz
//   LFO freq below 20Hz  around 10Hz
//   mixer values 0 - 1 - 3 (above 1 amplifies)
//   filter outputs
//    0 - low pass
//    1 - band pass
//    2 - high pass
//   filter resonance 0.7 - 5.0
//   amplitudes 0 - 1
//
//******************************************************************************
//--------------------------------------------------------------------------------
// update the teensy control settings with the latest values from the IO
//--------------------------------------------------------------------------------
void updateControls() {
  // filter settings
  filter.frequency(10000 * muxData[2] * DIV1024);          // filter frequency - 0 - 10000 is a good range
  filter.resonance((4.3 * muxData[3] *DIV1024) + 0.7);     // resonance value needs to be between 0.7
                                                           //   and 5.0
  // filter LFO settings
  filter_LFO.frequency(20 * muxData[0] * DIV1024);         // LFO frequency 0 - 20Hz is a good range
  filter_LFO.amplitude(muxData[1] * DIV1024);              // LFO amplitude 0 - 1

  // filter mixer settings - each input of the mixer connects to three filter outputs
  filter_mixer.gain(0, muxData[4] * DIV1024);              //  filter: Low Pass
  filter_mixer.gain(1, muxData[5] * DIV1024);              //  Filter: Band Pass
  filter_mixer.gain(2, muxData[6] * DIV1024);              //  Filter: High Pass
```

```
}

//------------------------------------------------------------------------------
// code to control note when note on is recieved
//------------------------------------------------------------------------------
void OnNoteOn(byte channel, byte note, byte velocity)
{
  // check note is between sensible values
  if ( note > 23 && note < 108 ) {

    float velo = (velocity * DIV127);                    // calculate new velocity value
    waveform1.frequency(noteFreqs[note]);         // use key pressed to grab note from array
    waveform1.amplitude(velo);                         // set amplitude using new velocity value
  }
}

//------------------------------------------------------------------------------
// code to control note when note off is recieved
//------------------------------------------------------------------------------
void OnNoteOff(byte channel, byte note, byte velocity)
{
  // check if note is a sensible value
  if ( note > 23 && note < 108 ) {
    waveform1.amplitude(0);                             // set amplitude to zero as key is released
  }
}

//------------------------------------------------------------------------------
// use this function if midi conrols are to be used
//------------------------------------------------------------------------------
void OnControlChange(byte channel, byte control, byte value)
{
        //empty on purpose as midi controls not being used
}
```

Testing

I connected an Arturia BeatStep to the Teensy's second USB port and downloaded the code to the Teensy.

Here is a video showing the system working.

Final Evaluation

When I want to start work on a new synth, follow these steps:

- set the number of IO pins on each card via the dip switch x4.
- change the potentiometers and buttons on each card to what is needed.
- edit the Audio System Design Tool and import the new code into TeensyAudioDesignTool.h.
- update the Teensy synth setup in the setup function.
- modify the midi control functions.
- look at the new muxData array to modify the "updateControls()" function.

I do not have to worry about the mux circuits or the mux program. The busses and control circuitry on each card allow the mux code to automatically read just the inputs that are connected. By looking at the array muxData[] I can use the collected signals from the inputs to help me control new synths and synth code.

I am really pleased with how the system works. So far it is doing exactly what I had hoped for. As I build new projects, I will update this page to show what I have created.

If you spot any mistakes or issues, please point them out. I am self taught in Arduino and Teensy so have probably made errors in the way I coded the project. Or if you can think of improvements, please let me know. I have a few ideas of how I would like to develop the system in the future but for now I plan to use it to mess around with Teensy Synth designs.

Future Plans

Just a quick list of possible improvements

- Make the address bus 4 line to allow the system to control up to 16 cards.
- Add the option to make the mux circuits outputs as well as the current inputs. This would allow me to control lots of LEDs and other outputs.
- Make a PCB of the mux card circuitry. I would like to make something that looks a bit like a Eurorack. Each card would have a front panel with whatever inputs/outputs are needed. The cards would plug into a bus connected to the teensy.

Resources

The following resources were a huge help.

A good place to start when you get a Teensy. Getting started tutorials and lots of information.
It is also where you can buy a Teensy and the audio adapter.
PJRC, "Teensy USB Development Board"
https://www.pjrc.com/teensy/

Within the PJRC website the Teensy audio section in Libraries is also useful.
PJRC, "Teensy Audio Library"
https://www.pjrc.com/teensy/td_libs_Audio.html

I followed this set of tutorials when I first started to use the Teensy to design synths. The videos and resources are awesome.
Nuts and Volts, "TEENSY-Synth PART 1 – 11"
https://www.notesandvolts.com/2018/05/teensy-synth-part-1.html

I used the following datasheets to help me design the address decoder circuitry.
Texas Instruments, "High speed CMOS logic analog multiplexers/demultiplexers," 74HC4051 datasheet,
https://www.ti.com/lit/ds/symlink/cd4051b.pdf

Texas Instruments, “SNx4HC245 Octal Bus Transceivers With 3-State Outputs” 74HC245 datasheet,
https://www.ti.com/lit/ds/symlink/cd4051b.pdf