A. PRELAB

1. Binary (base 2) numbers

All digital technologies use “bits” as their basic unit of information. A bit is a single piece of information which is in one of two states. These states are called on and off (lights), yes and no (logic), high and low (voltage), or 1 and 0 (base 2 numbers). Base 2 numbers are just like ordinary numbers except that there are only two symbols, 0 and 1. Here is base 2 counting from 0 to 111 (7 in base 10):

000 001 010 011 100 101 110 111

Use four digits to count in base 2 from 1000 to 1111. What numbers would these be in base 10?

Try adding some binary numbers, then check your answer in base 10. Remember that when you add a 1 and a 1 you get a 0 AND YOU MUST CARRY A 1 TO THE NEXT PLACE.

Example: 0101 
+0110 
1011 

Base 10 equivalent: 5 
+6 
11 

1001 
+0010 
0111 
+0010 
0111 
+0010 

B. Digital to Analog Converter

In this week’s lab you will make a Digital to Analog Converter, a circuit which turns a binary number into a voltage. The circuit is:

![Circuit Diagram]

Notice that this circuit is like the inverting amplifier you have studied before, except that this one has four inputs. Since the inputs have different resistance, the signals coming in are amplified by different amounts.

Each input corresponds to one binary digit. The input signals are either 0 (a low or zero voltage) or 1 (a high voltage).

How it works: an inverting amplifier with several inputs acts as a summing amplifier. With the non-inverting input grounded, the inverting input becomes a "virtual ground." When you apply a positive voltage, $V_{in}$, to one or more of the inputs, current will flow through the corresponding input resistor(s) towards the inverting input of the op-amp (for example, if $V_{in}$ is applied to input a, current $V_{in}/R_a$ will flow through input resistor a. Note that for a given $V_{in}$ the most current will flow through the smallest input resistor, the least will flow through the largest. The total current, $I$, is the sum of the currents through each input resistor. All this current cannot flow into the op-amp's input, instead, almost all of it flows through the feedback resistor, $RF$. The result is that the other side of the feedback resistor, which is also the output of the op-amp (pin 6), will be at a voltage $-I*RF$ with respect to virtual ground. Therefore, the output voltage is proportional to the total current flowing through the feedback resistors.
QUESTIONS:

1. In a number, the digit on the left is called the Most Significant Digit, because it’s size affects the number more than any other digit. **Which input of this circuit (a, b, c, or d) corresponds to the most significant digit? (i.e., which will affect the voltage output the most?)**

2. Let input a be on, b be off, c on, and d on. **What binary number does this represent?**

3. Assume for a minute that the input signals are either 0 or 1 Volt. **What voltage comes out of the DAC?**

C. **DIGITIZATION**

The next two labs are a very basic introduction to digital recording and playback. There are three parts to digital recording:

1. Converting a voltage (derived from a sound source) into a series of numbers.
2. Storing the numbers in a computer or on a CD or digital tape (possibly with compression).
3. Converting those numbers back into a voltage (which drives a speaker to make sound).

You will do the first and third of these.

**1. Analog to Digital Converter (ADC)**

The first step is to convert a voltage into a number. This is done by an analog to digital Converter, also called an A/D converter or just an ADC. An audio ADC is basically a very fast digital voltmeter (it records the voltage signal from a transducer many times per second). You will use an **ECG 2053** chip, an **8 bit ADC** of which you will use only the four “most significant bits”.

**Build your ADC** on the bottom half of the board of your breadboard. Keep the top half free for the Digital to Analog Converter, which you will build later.
Hook up this circuit, following the instructions given after the diagram.

First ground pins 1, 2, 7, 8, and 10. With a small wire connect pins 3 and 5. Connect pin 4 to pin 19 with a 10 k ohm resistor and connect a 1000 ohm resistor from the input pin (6) to some free place on the board. Run all inputs through this resistor.

Hook pins 11, 12, 13, and 14 to the four indicator lights on your breadboard. Pin 11 is the “most significant” digit, so to get an output that looks like a normal binary number it should go to the light which is farthest to the left.

Now connect pin 20 to the +5 volt power supply on your breadboard box and turn on the power.

Since no voltage is hooked to the input, the lights should remain off.

As an input we will use a 1000 ohm potentiometer hooked to the +5 V power supply. A potentiometer is usually called a “pot” and is really just a variable resistor with a “center tap”. It looks like this:

Hook the $a$ wire to ground, the $b$ wire to the input of the ADC (through the 1000 ohm resistor) and the $c$ wire to +5 V. Turn the knob back and forth and watch the lights count up and down in binary.
Use one of the BNC in/out terminals to look at the input voltage on the scope. **What is the smallest voltage that light each of the different combinations of lights?**

<table>
<thead>
<tr>
<th>Light Combination</th>
<th>Minimum Input Voltage [V]</th>
<th>Light Combination</th>
<th>Minimum Input Voltage [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>1000</td>
<td>0001</td>
<td>1001</td>
</tr>
<tr>
<td>0010</td>
<td>1010</td>
<td>0011</td>
<td>1011</td>
</tr>
<tr>
<td>0100</td>
<td>1100</td>
<td>0101</td>
<td>1101</td>
</tr>
<tr>
<td>0110</td>
<td>1110</td>
<td>0111</td>
<td>1111</td>
</tr>
</tbody>
</table>

Now use your 2002 function generator to provide a constantly changing sine voltage. You will need to adjust the DC offset on the generator so that the signal is always positive. Set the frequency to be so slow that you can easily watch the lights count up and down. **What frequency is just high enough to make the lights a blur?**
2. **Digital to Analog Converter**

Rather than store the numbers from your ADC, in this lab you will convert them directly back into voltage using a DAC. First, however, it will be necessary to build the DAC. Do this now on the top half of your board. The input circuit is the one from the prelab (see page 2).

Don't forget to bring in +15 V and -15 V to power the op amp. (+15 V to pin 7 and -15 V to pin 4.) Because resistors are not available in factors of two, it will be necessary to use identical resistors in series and parallel to get the same effect. **Use all 10 k ohm resistors** hooked up as shown:

![Diagram of input circuit]

Turn on the breadboard power supply. Connect four of the +5 V logic switches (above the breadboard) to the DAC inputs and display the output on the scope. Use Channel 2 because it allows you to invert the signal by pulling out the positional knob. This will correct for the fact that it is an inverting amplifier.

Using the logic switches as binary digits, count up from zero to fifteen and watch the output voltage on the scope increase by steps and record them. If it doesn’t, you have the switches hooked up incorrectly to the inputs.
3. There and back again

Now it is time to hook the ADC and DAC together. Move the wires that connect the DAC inputs from the logic switches over to the outputs of the ADC. Be sure to get them hooked up in the right order.

Use the function generator as an input to the ADC, making a 100 Hz sine voltage. Look at the DAC output on the scope (CH2 inverted). With the scope in DC mode, note the effects of adjusting the DC offset and amplitude on the function generator. Look at the ADC input signal on CH1. **What is the largest peak-to-peak amplitude that can be used without clipping?**

**What is the smallest input signal which will assure you of getting an oscillating signal out?** (Be sure to try varying the DC offset before answering this.)

**LEAVE YOUR CONVERTERS SET UP FOR NEXT LAB!!!