

Lecture 11 objectives

- DAC review
- sound amplifier
- real time systems

11.4. Digital to Analog Converters

11.4.1. DAC Converter Parameters

The DAC *precision* is the number of distinguishable DAC outputs (e.g., 4096 alternatives, 12 bits).

The DAC *range* is the maximum and minimum DAC output (0 to 5V).

The DAC *resolution* is the smallest distinguishable change in output. ($5V/4096 = 0.0012V$)

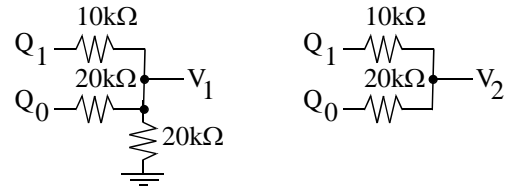
$$\text{Range(volts)} = \text{Precision(alternatives)} \cdot \text{Resolution(volts)}$$

The DAC *accuracy* is (Actual - Ideal) / Ideal

If you do not have a SPI-based DAC chip, like the Max539, you will need to build one using summing voltage summing resistors. A 74HC595 serial-in parallel-out shift register should be interfaced to the SPI port.

For example, if we were to build a 2-bit DAC
Assume V_{OH} of the 74HC595 is 5, and its V_{OL} is 0

N	Q1	Q0	V1(V)	V2(V)
0	0	0	0.00	0.00
1	0	5	1.25	1.67
2	5	0	2.50	3.33
3	5	5	3.75	5.00



You can realistically build a 4- or 5-bit DAC using this method.

$$V_{out} = (Q5/2 + Q4/4 + Q3/8 + Q2/16 + Q1/32 + Q0/64)$$

Assume V_{OH} of the 74HC595 is 5, and its V_{OL} is 0

N	Q5	Q4	Q3	Q2	Q1	Q0	V _{out} (V)	V _{out} (V)
0	0	0	0	0	0	0	0.00	0.00
1	0	0	0	0	0	5	0.08	0.08
2	0	0	0	0	5	0	0.16	0.16
32	5	0	0	0	0	0	2.50	2.54
63	5	5	5	5	5	5	4.92	5.00

Need an audio amp to connect DAC output to 32Ω speaker

Be careful to limit voltage and power to speaker

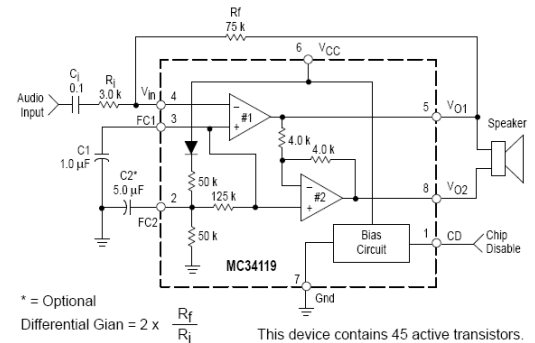
$$0 < V < 5$$

$$< 200 \text{ mW}$$

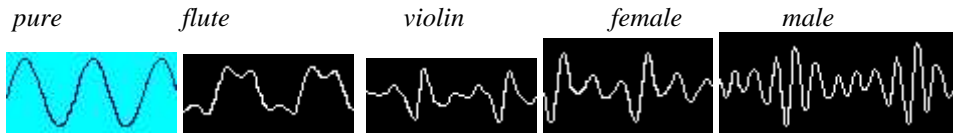
show scope and spectrum analysis of my Lab5 solution

Need software to create sounds. Frequency is the pitch

- Humans can hear from about 25 to 20,000 Hz.
- Middle A is 440 Hz
- Other notes on a keyboard are determined
 - $440 * 2^{N/12}$
 - "N" is number of notes up or down from middle A.
- Middle C is 261.6 Hz.
- music contains multiple harmonics



* = Optional
Differential Gain = $2 \times \frac{R_f}{R_i}$
This device contains 45 active transistors.



Let's generate a 440 Hz sound (assume TCNT = 1 μ s)

Interrupt period is $1000000/32/440 = 71\mu$ s

```
unsigned short I;
// 12-bit 32-element sine wave
const unsigned short wave[32]= {
```

```
2048,2438,2813,3159,3462,3711,3896,4010,4048,4010,3896,
3711,3462,3159,2813,2438,2048,1658,1283,937,634,385,
200,86,48,86,200,385,634,937,1283,1658};
```

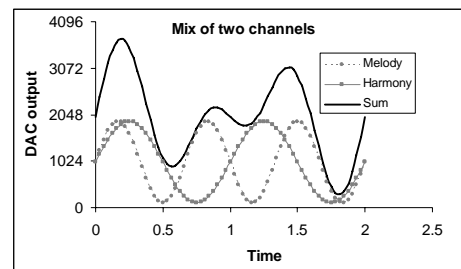
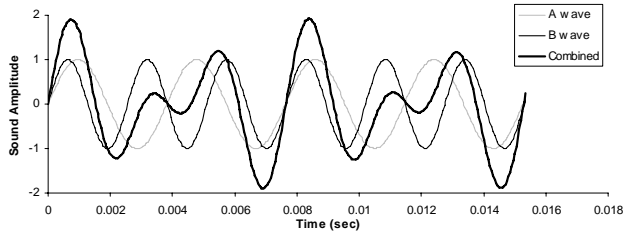
Program 11.4. Simple data structure for the waveform.

```
interrupt 11 void TC3hand(void){
    TC3 = TC3+71;        // 71us
    TFLG1 = 0x08;       // ack
    I = (I+1)&0x1F;     // 0 to 31
    DACout(wave[I]);
}
```

Program 11.5. Periodic interrupt used to create the analog output waveform.

How to mix two waves

- 1) Reduce range of each to 0 to 2047
- 2) Generate two output compare interrupts, one for each wave
- 3) Maintain two indices I0 and I1
- 4) Add the waveforms together



```
unsigned short I1,I0;
unsigned short Period1,Period0;
unsigned char Out1,Out0;
interrupt 8 void TC0handler(void){
    PTT ^= 0x01;        // debugging
    TFLG1 = 0x01;       // acknowledge C0F
    if(Period0){        // 0 means quiet
        TC0 = TC0+Period0; // sound frequency
        I0 = (I0+1)&0x1F; // 0 to 31
        Out0 = wave[I0];
        DAC_Out(Out0+Out1);
    } else{
        TC0 = TC0+500; // quiet
    }
}
```

```

}
interrupt 9 void TC1handler(void){
  PTT ^= 0x02;          // debugging
  TFLG1 = 0x02;        // acknowledge C1F
  if(Period1){
    TC1 = TC1+Period1;  // sound frequency
    I1 = (I1+1)&0x1F;    // 0 to 31
    Out1 = wave[I1];
    DAC_Out(Out0+Out1);
  } else{
    TC1 = TC1+500;      // quiet
  }
}

```

Real time systems

Bounded latency

Input interface:

input interface latency RDRF -> Read SCIDRL

Output interface:

output interface latency TDRE -> Write SCIDRL

Periodic process (DAC output, ADC input):

software activity occurs at a periodic rate, Δt

let t_n be the n th time the process executes

goal to make $t_n - t_{n-1} = \Delta t$

$\delta t = \text{jitter}$ $\Delta t - \delta t < t_i - t_{i-1} < \Delta t + \delta t$ for all I

Run Lab 5 solution

Discuss possibilities for the data structures

How to vary pitch?

How to mix multiple channels?

Analog

Digital

View analog signals

Verify real time