EE 319K
Introduction to Embedded Systems

Lecture 10: Digital-to-analog conversion (DAC), Sound on 9S12

Announcements

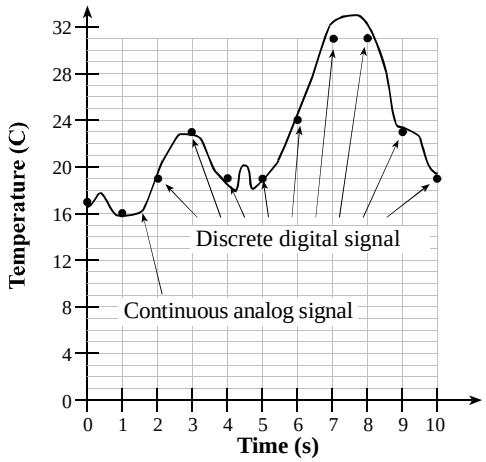
- Homework 8, next Monday
  - Metrowerks programming
    - Lessons/Videos 1-5 from Jon's website
    - Assembly/C interface, parameter passing, simulating
- Lab 7, next week
  - Digital/analog (D/A) conversion
    - Digital piano: sound & music
- Plagiarism checks are being performed!

Agenda

- Recap
  - Interrupts
  - Output compare interrupts on the 9S12
  - Metrowerks C programming
- Outline
  - Digital-to-analog conversion (DAC)
  - Analog signal generation
    - Sound and music

A/D and D/A Conversion Basics

Digitization:Amplitude and time quantizing

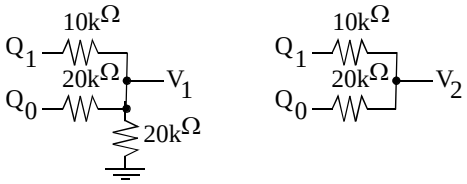


Digital to Analog Conversion

- Examples
  - Signal generation (sound, image, touch…)
  - Output to affect external devices (power, flow, heat…)
- The DAC *precision* is the number of distinguishable DAC outputs
  - (e.g., 16 alternatives, 4 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/16 =0.31V)
- Range(volts) = Precision(alternatives) * Resolution(volts)
- The DAC *accuracy* is (Actual - Ideal) / Ideal

2-bit DAC - Two Designs

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

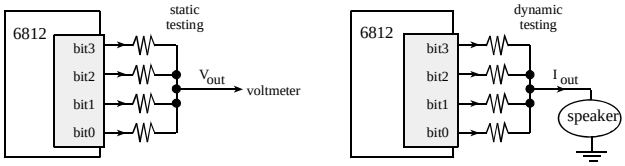


*Assume V_{OH} of the 9S12 is 5V and V_{OL} is 0V

4-bit DAC

N	Q3	Q2	Q1	Q0	theory	Vout(V)
0	0	0	0	0	5*0/15	0.00
1	0	0	0	5	5*1/15	0.33
2	0	0	5	0	5*2/15	0.67
8	5	0	0	0	5*8/15	2.67
15	5	5	5	5	5*15/15	5.00

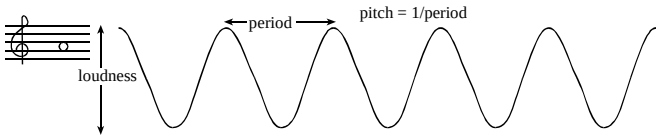
$V_{out} = (8*Q_3 + 4*Q_2 + 2*Q_1 + Q_0)/15$
where Q_n is 5V or 0V



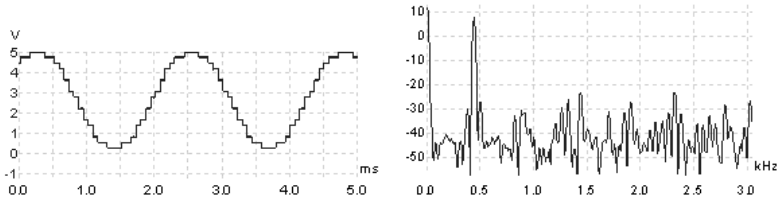
Sound Basics

- 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

Sound

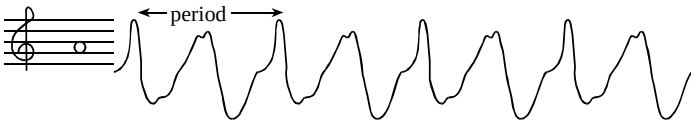


The loudness and pitch are controller by the amplitude and frequency.



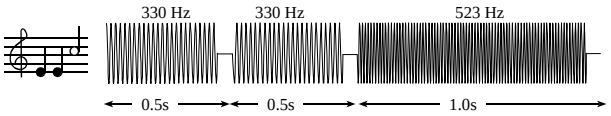
A 440Hz sine wave generated with a 4-bit DAC. The plot on the right is the Fourier Transform(frequency spectrum dB versus kHz) of the data plotted on the left.

Music

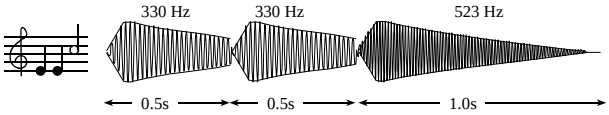


A waveform shape that generates a trumpet sound.

...Music

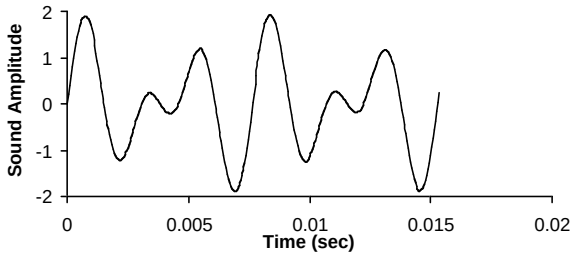


You can control the amplitude, frequency and duration of each note (not drawn to scale).



The amplitude of a plucked string drops exponentially in time

...Music



A simple chord mixing the notes C and G

Song

How much memory does it take to store a song?

- 3 minutes
- Stereo Channels
- 44 kHz
- 12-bit per channel

How many bus cycles does it take to output one value?

- Fetch data from memory
- Decompress
- Filter/amplify/mix/envelope
- DAC speed

Lab 7: Sound

- Debugging: Use a DC motor to test the voltages being output to the analog out
  - Connect the PH3-0 lines to power a DC motor
  - Connect a scope to view this voltage as a function of time
- Once you are sure your DAC_Out is doing what it is supposed to, then go ahead and implement the piano keys

Sine Wave with period T

- Periodic Interrupt every T/32
- Output next entry in below table on interrupt

```
SinTab  fcb  8,9,11,12,13,14,14,15,15,15,14
        fcb  14,13,12,11,9,8,7,5,4,3,2
        fcb  2,1,1,1,2,2,3,4,5,7
```