Digital and Analog Electronics
for the Hobbyist

Electrofrolics
Shaastra 2010

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Signal processing systems

Sensor(s) → Digital Processing → Actuator(s)

DSP

...0100011011...

Interface Electronics
(Signal Conditioning)
(A-D and D-A Conversion)

Continuous-time
Continuous-amplitude

Discrete-time
Discrete-amplitude

Continuous-time
Continuous-amplitude
Why digital?
Why digital?

• Digital levels less corrupted by noise
• Convenient storage
• Convenient signal processing
Why analog?
Why analog?

• Interface with the natural world
• Higher maximum speed of operation
• Analog to digital conversion
• Digital to analog conversion
Digital
Digital logic circuits

• Simple logic gates
• Complex logic gates
  – Encoders
  – Adders
• Storage elements
  – Latches
  – Flip flops
• Input and output interfaces
Digital logic-basic gates

- 7404 Inverter
- 7400(NAND), 7402(NOR)
- 7408(AND), 7432(OR)
- 7486: XOR gate
Digital logic-more complex blocks

- 74147: 10-Line to 4-Line Priority Encoder
- 74154: 4-Line to 16-Line Decoder
- 74273: 8 bit register with reset
- 7483: 4 bit full adder
- 7447 BCD to 7 segment decoder
Digital logic-encoder

Figure reproduced from manufacturer’s datasheet
Digital logic-adder (7483)

Figure reproduced from manufacturer’s datasheet
Digital logic-storage

Figure reproduced from manufacturer’s datasheet
Human interface-input

- Ideal input: 5V, 0V
- Actual input: 5V, 0V with "bounce"

Push button switch

RC > bounce period

Schmitt trigger

PRESS SWITCH
Human interface-input

```
<table>
<thead>
<tr>
<th>Ideal</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>5V</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>&quot;bounce&quot;</td>
</tr>
</tbody>
</table>
```

- Push button switch
- Press switch
- Needs to be reset before next key press
Human interface-output (display)

- Display type: LED: bright / LCD: low power
- Interface type: 7 segment / dot matrix / anything else
Driving an LED

- Switch + current limiting resistor
- Current source drive
- Gate switching
- Source switching
Driving a 7 segment display

- Simple
- \(7 \times N\) pins, drivers for \(N\) displays
Driving a 7 segment display: Multiplexing
Driving a 7 segment display: Multiplexing

- Cycle through N displays at a high rate (~ few kHz) to result in a persistent display
- N+7 pins, drivers for N displays
- Display blanking to avoid wrong digit flickering. Enable only when digit input is stable
- Larger peak current (~sqrt(N)) to preserve brightness
- Dot matrix displays: multiplexed row/column drivers
Analog
Analog circuit components

- Opamp
- CMOS inverter
- Transistors
- Diodes
Opamp

- Provides a high gain
- Used to provide negative feedback
- $v_d = 0$ in negative feedback
Opamp

\[ V_s \]

\[ V_d \]

\[ V_o \]

- \( \frac{V_o}{V_d} \): very large @ dc
- In negative feedback: \( V_d \approx 0 \)

\[ V_s : \ 6 - 20V \]

for typical opamps
Opamp: LM741

- Single opamp in a package
- 1MHz gain bandwidth product
- 1V/μs slew rate

Figure reproduced from manufacturer’s datasheet
Opamp: LM324

- 4 opamps in a package
- 1MHz gain bandwidth product
- 0.5V/μs slew rate

Figure reproduced from manufacturer’s datasheet
Opamp: LF347

- 4 opamps in a package
- 4MHz gain bandwidth product
- 13V/μs slew rate
- OUR CHOICE!

Figure reproduced from manufacturer’s datasheet
Opamp: Amplifiers

Non-inverting amplifier

Inverting amplifier

\[ R \approx kR \rightarrow \text{tens of } kR \]
Opamp: Adders

\[ V_1, \frac{R}{a_1}, V_2, \frac{R}{a_2}, V_3, \frac{R}{a_3} \]

\[ V_s, R \]

\[ a_1V_1 + a_2V_2 + a_3V_3 \]

\[ -V_s \]
Opamp: Negative feedback

\[ \frac{V_d}{V_o} = -\frac{1}{k} \text{ (negative)} \]
Opamp: Negative feedback

Any complicated circuit
Opamp: Negative feedback

\[ \frac{V_d}{V_o} \text{ should be negative at dc with the opamp removed} \]

Any complicated circuit!
Opamp: Integrator??

![Circuit Diagram]

$$\frac{V_d}{V_o} = 0 \text{ at } dc$$
Opamp: Integrator??

\[ \frac{V_d}{V_o} = \frac{-R}{R + R_{\text{LARGE}}} \quad \text{at} \quad dc \]
Opamp: Filters

\[ \frac{V_o}{V_i} = \frac{1}{(SCR)^2 + SCR(3-k) + 1} \]

\[ 3-k = \sqrt{2} \]

\[ \Rightarrow \text{Maximally flat response} \]

\[ f_{\text{Hz}} = \frac{1}{2\pi RC} \]
Opamp: Filters
Opamp: Logarithmic amplifiers

**Diode**

\[ l_d \approx I_s \exp \left( \frac{V_D}{V_T} \right) \]

\[ V_D \approx V_T \ln \left( \frac{l_d}{I_s} \right) \]

**Bipolar transistor**

\[ l_c \approx I_s \exp \left( \frac{V_{BE}}{V_T} \right) \]

\[ V_{BE} \approx V_T \ln \left( \frac{l_c}{I_s} \right) \]

\[ V_T = \frac{kT}{q} \approx 25.9 \text{mV} \text{ @ } \text{R.T.} \]
Opamp: Logarithmic amplifiers

\[ V_0 = V_t \ln \left( \frac{V_i}{R_1 s} \right) \]
Opamp: Digital to analog converter

Digital input: $D_{in} = b_3 b_2 b_1 b_0$

Analog output: $V_{out} = \left( \frac{b_3}{2} + \frac{b_2}{4} + \frac{b_1}{8} + \frac{b_0}{16} \right) V_{ref}$

$V_{ref}$: Full scale voltage

From logic gates

- $b_3$
- $b_2$
- $b_1$
- $b_0$

$2R$, $4R$, $8R$, $16R$

$R$

[Diagram of an opamp circuit with resistors and logic gate inputs]
Opamp: Digital to analog converter

Digital input: $D_{in} = b_3 b_2 b_1 b_0$

Analog output: $V_{out} = \left( \frac{b_3}{2} + \frac{b_2}{4} + \frac{b_1}{8} + \frac{b_0}{16} \right) V_{ref}$

$V_{ref}$: Full scale voltage

Diagram of the Opamp circuit

From logic gates
Opamp: Schmitt trigger

Inverting Schmitt trigger

Non inverting Schmitt trigger

Positive Feedback: $V_d \neq 0$
Opamp: Schmitt trigger
Comparator

Dual-In-Line Package

Top View
Order Number LM111J-8, LM111J-8/883 (Note 21),
LM311M, LM311MX or LM311N
See NS Package Number J08A, M08A or N08E

TTL Interface with High Level Logic

Figure reproduced from manufacturer’s datasheet
CMOS inverter for analog
CMOS inverter for analog

\[ \frac{v_o}{v_i} \approx -g_m \cdot r_{ds} \]

\[ \frac{v_0}{v_i} \approx - \frac{R_2}{R_1} \]

[Small values of \( \frac{R_2}{R_1} \)]

Many other circuits at
http://www.ee.iitm.ac.in/vlsi/courses/ec330-2010/start
Oscillator circuits

\[ f_{osc} = \frac{2N}{t_d} \]

\[ t_d: \text{ inverter delay} \]

\[ \frac{R_2}{R_1} = 2; \text{ Try slightly more than 2 if it doesn't oscillate} \]
Oscillator circuits
Audio power amplifier-LM386

- LM386 audio amplifier IC ~ Rs. 12/-
- Works without fuss with a minimum number of external components
- Gain of 20 or 200
- Can be used for any of your projects
- Data sheet has several example circuits
Audio power amplifier-LM386

Typical Applications

Amplifier with Gain = 20
Minimum Parts

Amplifier with Gain = 200

Figure reproduced from manufacturer’s datasheet
Other analog chips

- Analog multiplier
- MC1496 balanced modulator
- CXA1619BM/BS AM/FM radio chip
- LM565 Phase locked loop
- LM566 Voltage controlled oscillator
- ... and many more
More advanced circuit blocks

- Microcontrollers: PIC, 8051
- Microcontrollers with ADC/DAC
- Cypress PSoC
  - Programmable analog and digital blocks
Suggestions for projects
Calculator

• Optimization
  – Minimize the number of chips
  – Combine the adder/subtractor

• Multiplier
  – Shift and add
Analog to digital converter

- ADC using DAC and binary search

Digital code should result in a DAC output of $V_i$
Class D audio amplifier

Note: triangular wave and signal inputs to the comparator must be around the same bias point
Spectrum analyzer

Input (0.1-5kHz) → Lowpass filter → Image rejection 5kHz cutoff → Mixer → Bandpass filter → 10kHz → Envelope detector

Ramp → V_{cl} → Local oscillator 10-15kHz → f_{out} linear with V_{cl}

http://www.ee.iitm.ac.in/vlsi/courses/ec330_2010/start
Hobby of the era: Robotics

• Control systems
• Electrical, mechanical engg.
• Digital and analog electronics

• Lots of college level participation
• International level events like Robocon
Radio projects

- See “Radios for the hobbyist” Shaastra 2007 presentation

http://www.ee.iitm.ac.in/~nagendra/misc/20071006iitm_shaastra.pdf
Assembling circuits
Assembling circuits

• Breadboard
  – Quick assembly
  – Low frequency/low precision circuits
  – Not very robust

• PCBs
  – Takes time for assembly
  – High frequency/high precision circuits
  – Very robust
A Neat Board : Guaranteed 😊 ...
Guaranteed 😊: Not to work! …
Spaghetti is good stuff, but not on your board
What can happen with messy wiring
Both channels connected to the same signal!
What can happen with messy wiring
A Neatly Wired Breadboard
Another one...
Good practices

Colour: Red for Vdd, Black for ground
Good practices

Colour: Neatly placed components
PCBs

• **Homebrewing**
  – Copper clad board
  – Pattern transfer (from photocopies)
  – Ferric chloride etching

• **Commercial (2 layer boards)**
  – 3 medium sized boards for Rs. 500/- to 1000/-
  – ~ 1 week for fabrication
  – Many vendors in major cities
From hobby to profession
Theory and practice

• Not separate entities, go hand in hand
• All the stuff from digital and analog circuits classes are used in practical circuits
• Need theory to push circuits’ performance
• Need practice to be finally useful
  – Takes a lot more time than solving textbook problems!

• BE METICULOUS, NOT SLOPPY!
Links
The internet

- Circuit schematics
- Data sheets
- Troubleshooting information
- Many sites dedicated to hobbyists
- Many sites dedicated to robotics, many colleges have active robotics groups
My pages

• http://www.ee.iitm.ac.in/nagendra/E4332/2005/courseinfo.html
  – E4332: VLSI design laboratory
  – Design of an AM radio and a digital clock on an integrated circuit
• http://www.ee.iitm.ac.in/nagendra/E4332/2005/handouts/amradio-trf.pdf
  – AM radio on a chip
  – Theory of Tuned frequency radios
  – Receiver block and schematic diagrams (more suitable for IC designs)
  – Has information on crystal oscillators
• http://www.ee.iitm.ac.in/vlsi/courses/ec330_2010/start
  – Many experiments using CMOS inverters as amplifiers
• http://www.ee.iitm.ac.in/~nagendra/misc/20071006iitm_shaastra.pdf
  – Radios for the hobbyist