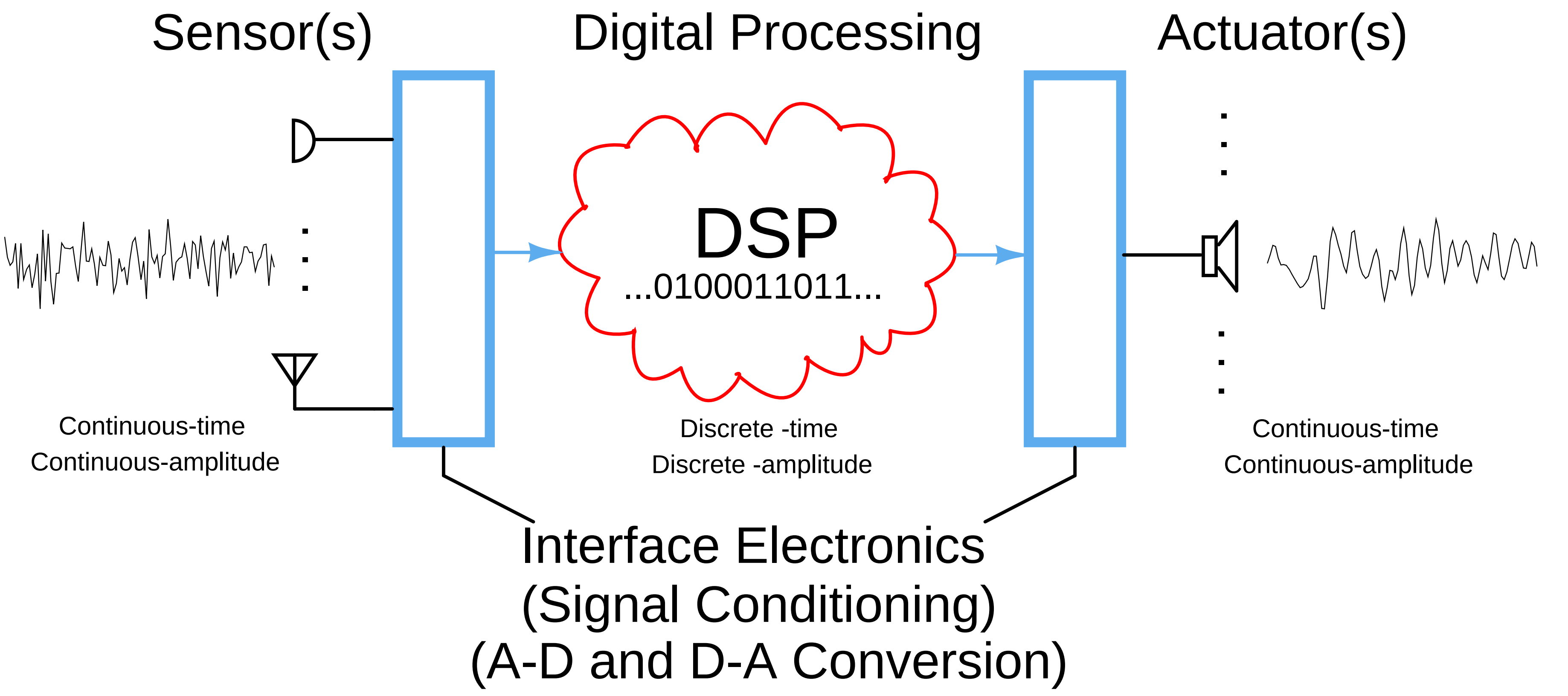
Digital and Analog Electronics for the Hobbyist

Electrofrolics
Shaastra 2010

Nagendra Krishnapura
Dept. of EE, IIT Madras
30th September 2010

Signal processing systems



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

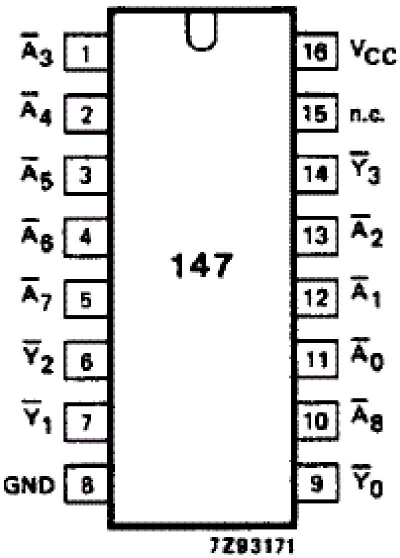
Digital logic-basic gates

- 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



FUNCTION TABLE

INPUTS									OUTPUTS			
$\overline{A}_0$	$\overline{A}_1$	$\overline{A}_2$	$\overline{A}_3$	$\overline{A}_4$	$\overline{A}_5$	$\overline{A}_6$	$\overline{A}_7$	$\overline{A}_8$	$\overline{Y}_3$	$\overline{Y}_2$	$\overline{Y}_1$	$\overline{Y}_0$
H	H	H	H	H	H	H	H	H	H	H	H	H
X	X	X	X	X	X	X	X	L	L	H	H	L
X	X	X	X	X	X	X	L	H	L	H	H	H
X	X	X	X	X	X	L	H	H	H	L	L	L
X	X	X	X	X	L	H	H	H	H	L	L	H
X	X	X	X	L	H	H	H	H	H	L	H	L
X	X	X	L	H	H	H	H	H	H	L	H	H
X	X	L	H	H	H	H	H	H	H	H	L	L
X	L	H	H	H	H	H	H	H	H	H	L	H
L	H	H	H	H	H	H	H	H	H	H	H	L

Notes

1. H = HIGH voltage level
   L = LOW voltage level
   X = don't care

Figure reproduced from manufacturer's datasheet

Digital logic-adder (7483)

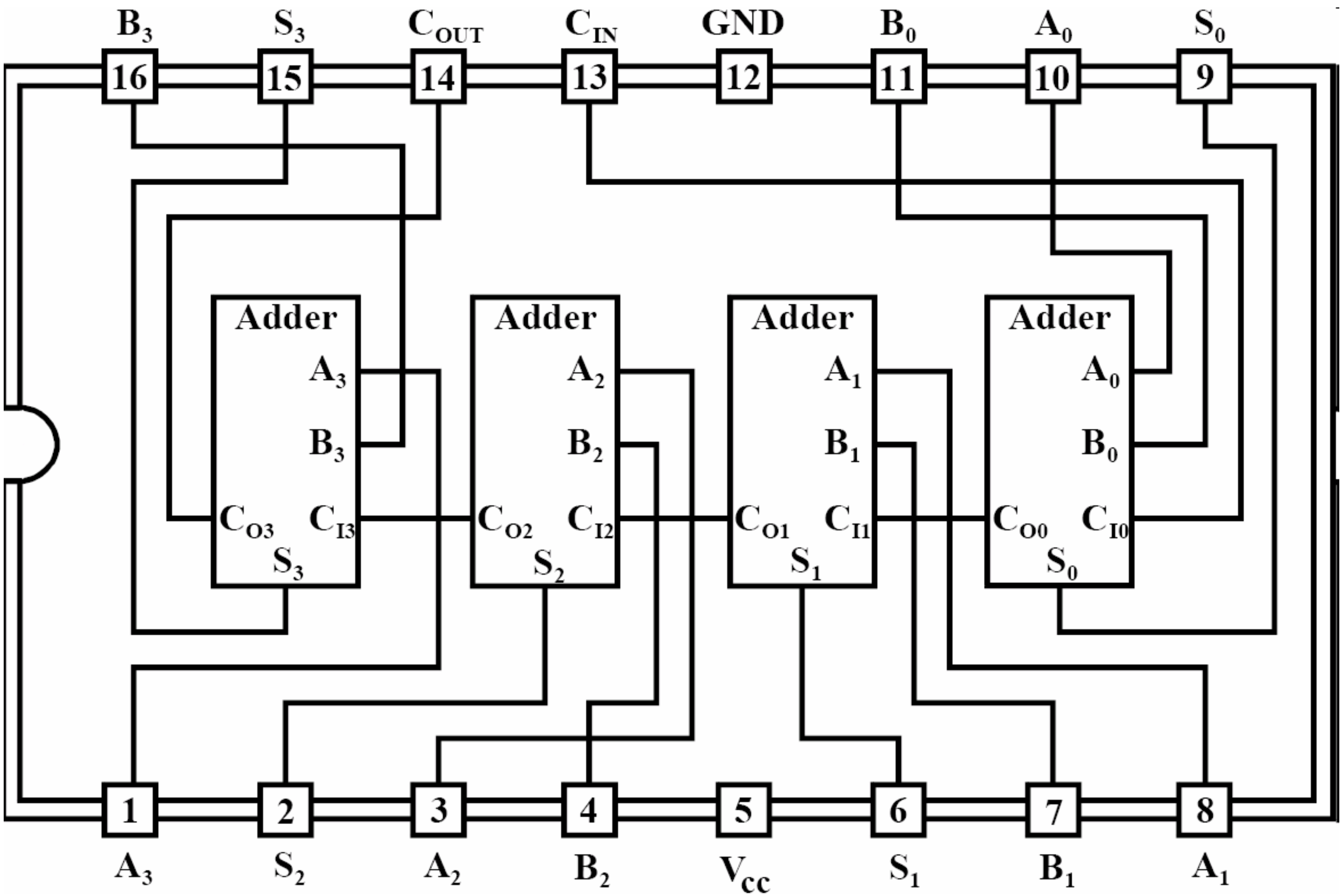
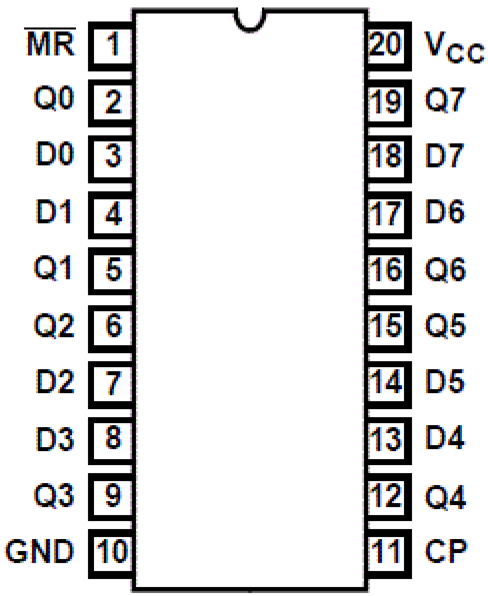


Figure reproduced from manufacturer’s datasheet

Digital logic-storage



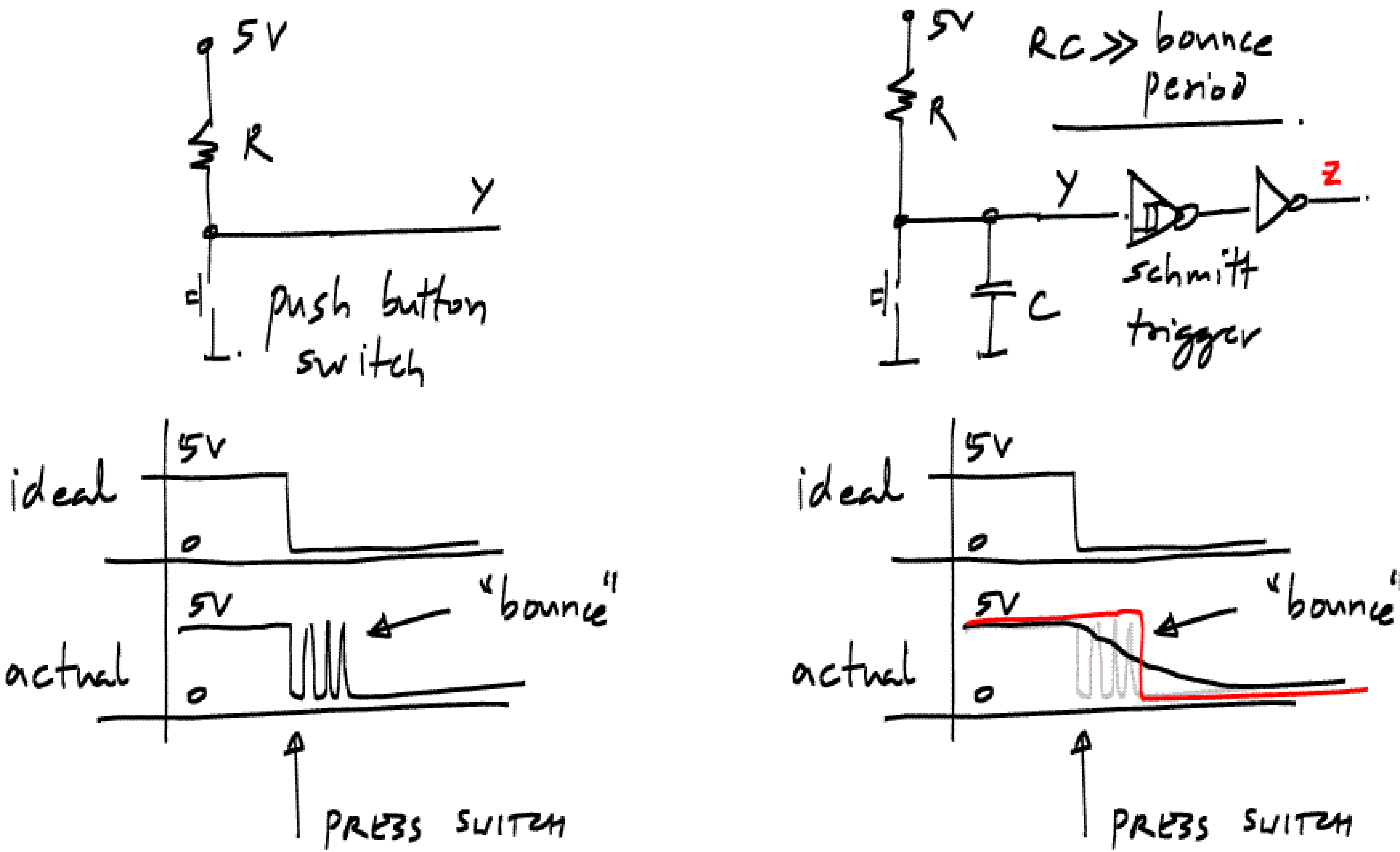
TRUTH TABLE

INPUTS			OUTPUT
RESET ($\overline{MR}$)	CLOCK CP	DATA D_n	Q
L	X	X	L
H	↑	H	H
H	↑	L	L
H	L	X	Q_0

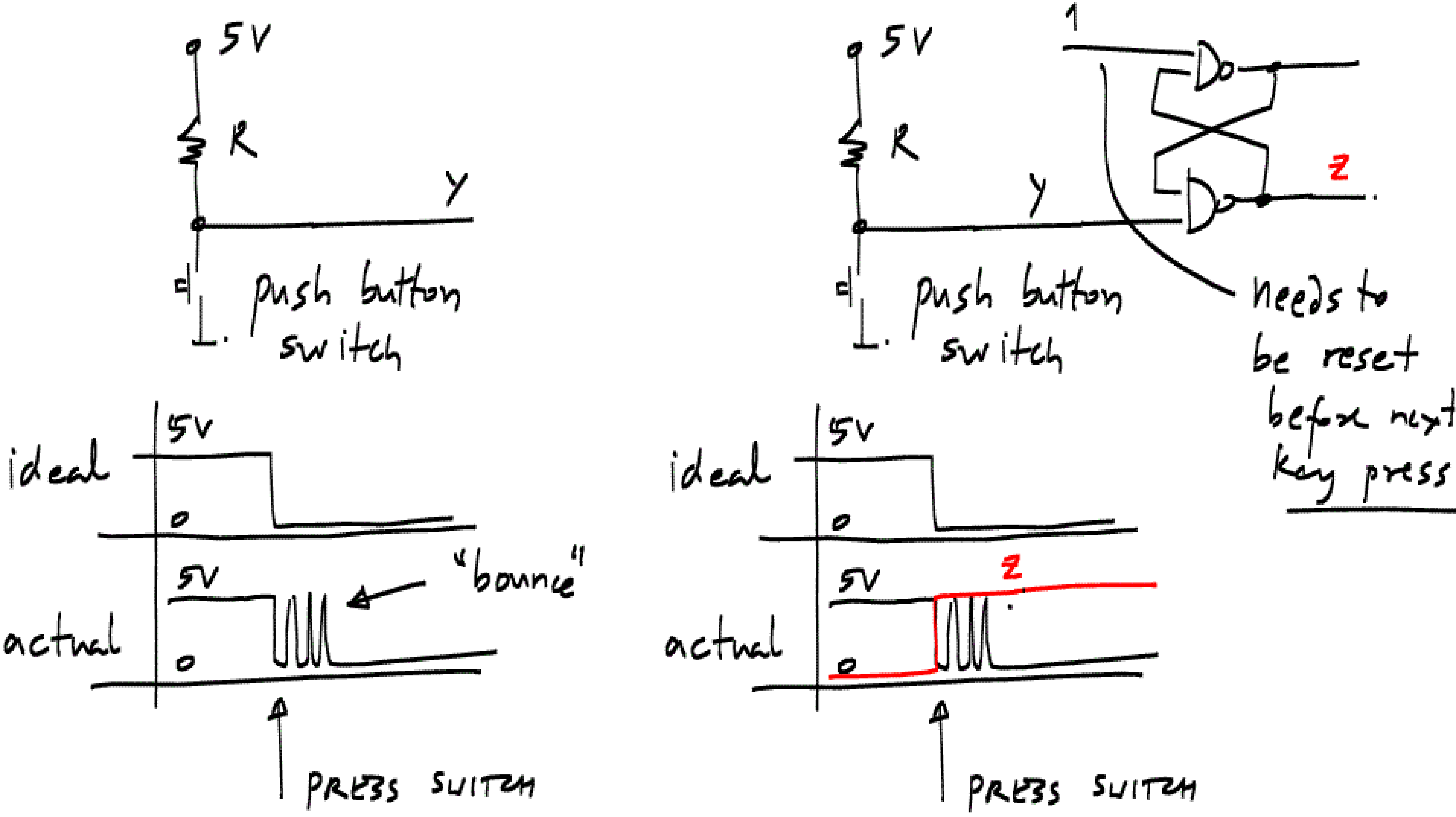
NOTE: H = High Voltage Level, L = Low Voltage Level, X = Don't Care, ↑ = Transition from Low to High Level, Q_0 = Level Before the Indicated Steady-State Input Conditions Were Established.

Figure reproduced from manufacturer's datasheet

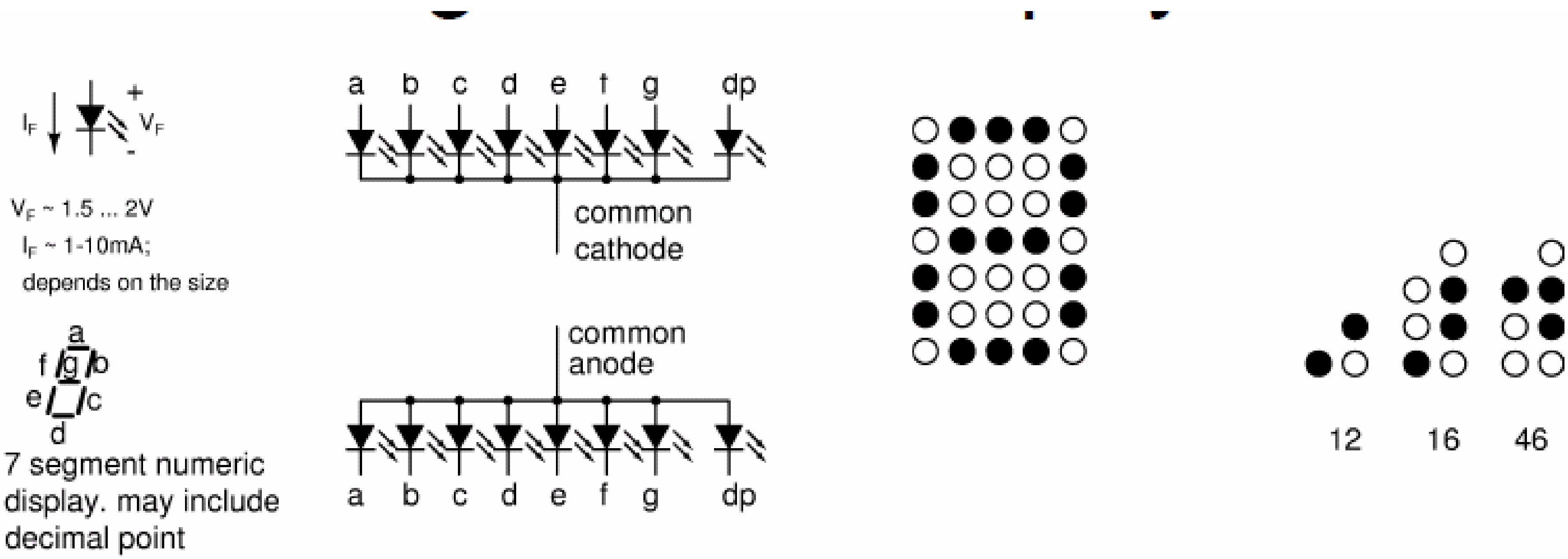
Human interface-input



Human interface-input



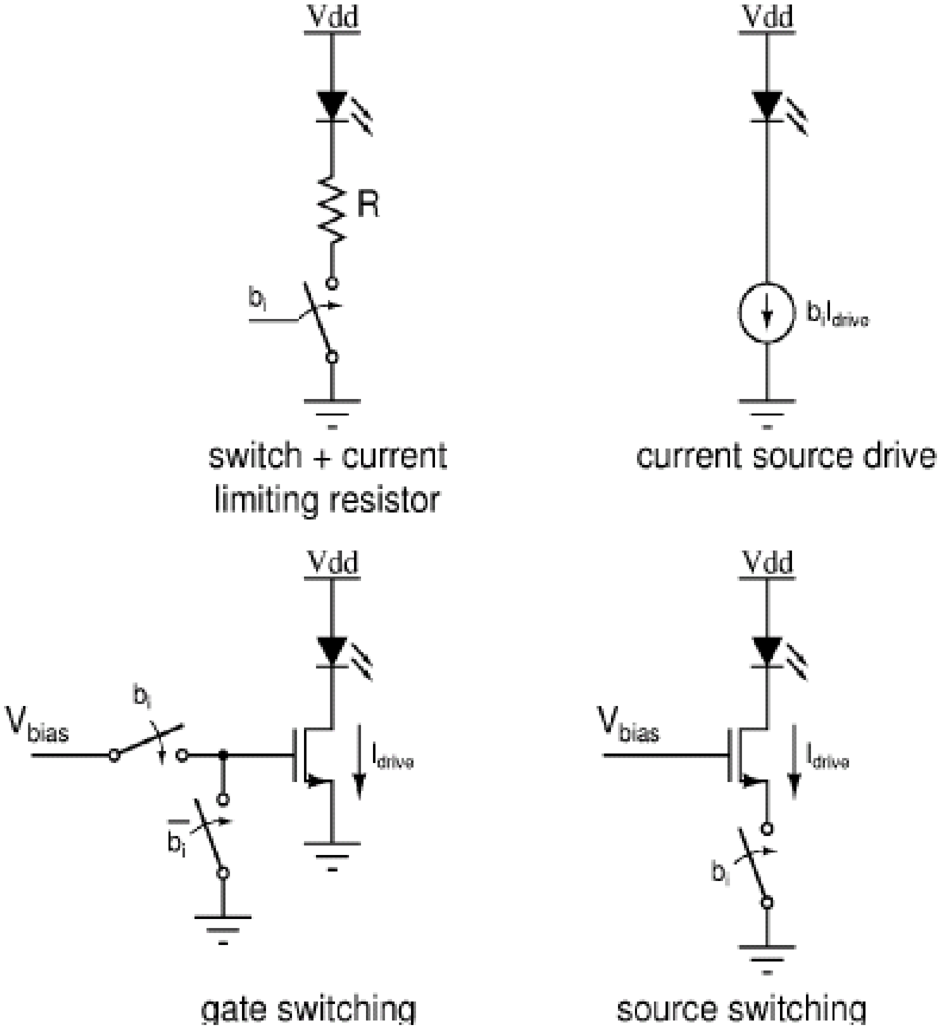
Human interface-output(display)



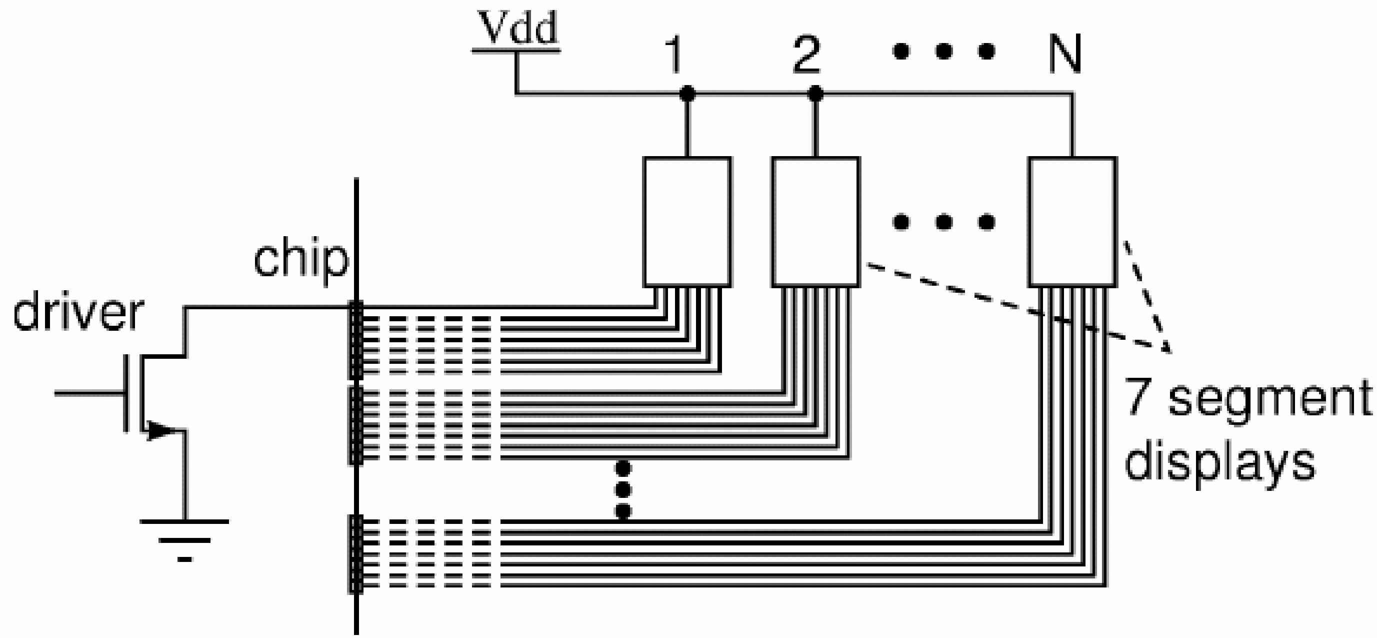
a) 7 segment display b) 5x7 array display c) bcd display

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

Driving an LED

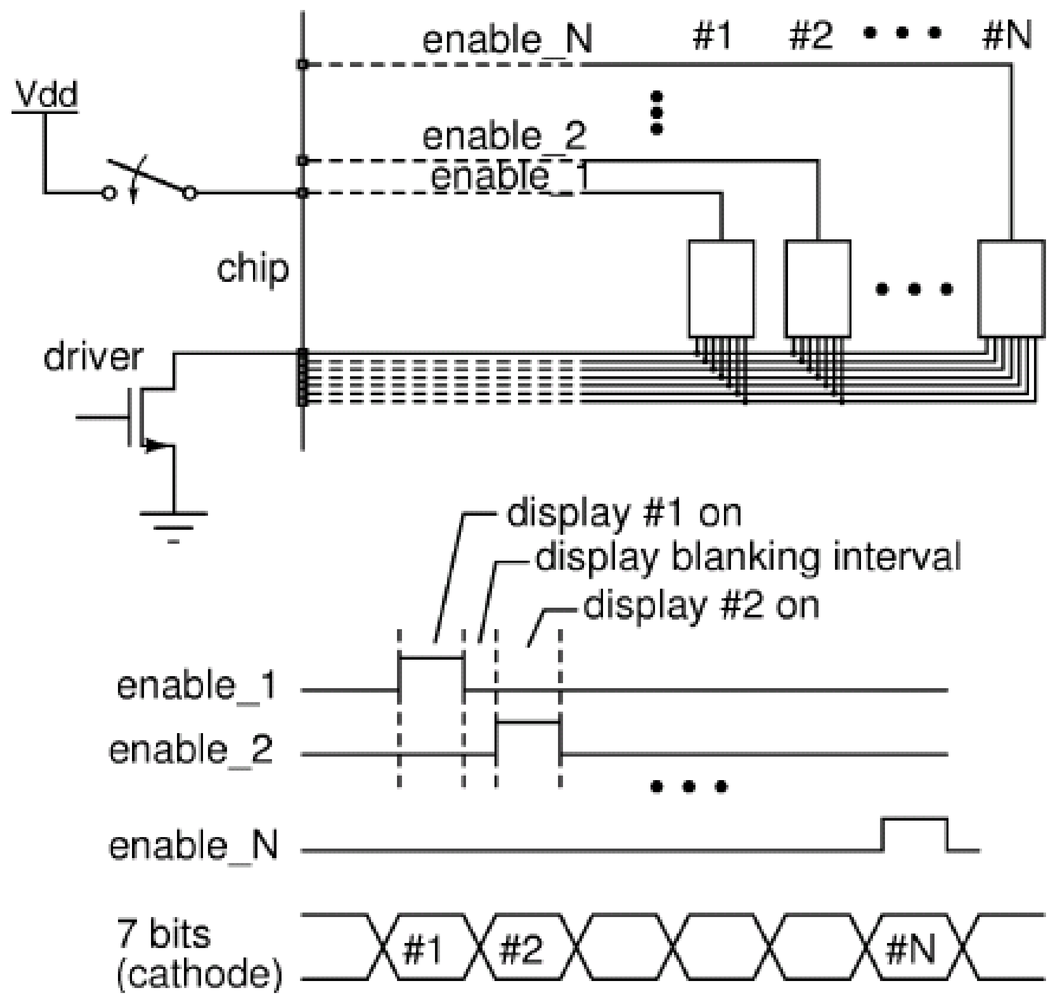


Driving a 7 segment display



- Simple
- 7*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

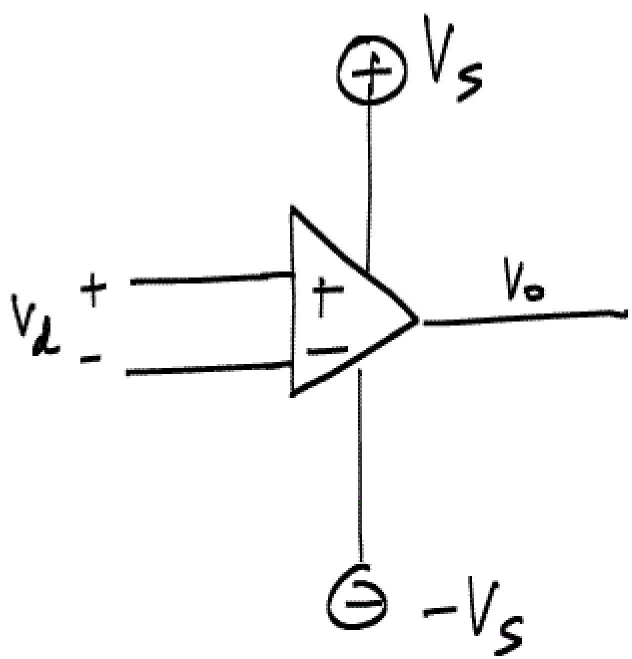
Analog

Analog circuit components

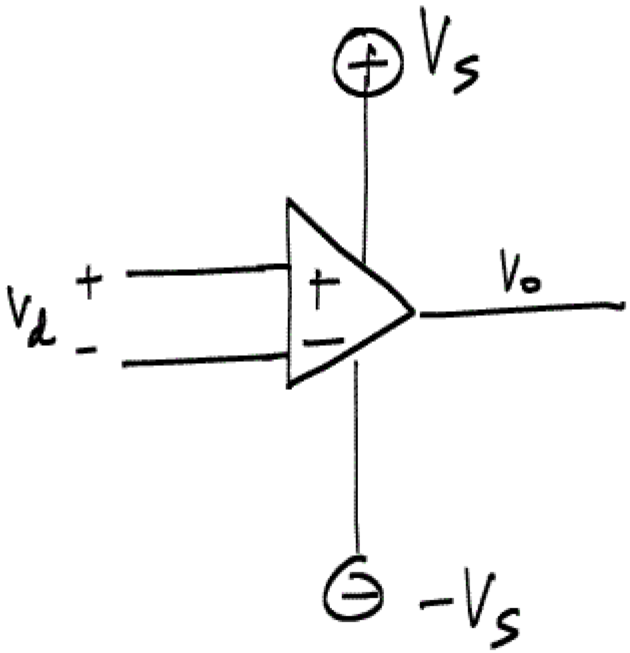
- Opamp
- CMOS inverter
- Transistors
- Diodes

Opamp

- Provides a high gain
- Used to provide <u>negative feedback</u>
- v_d=0 in negative feedback



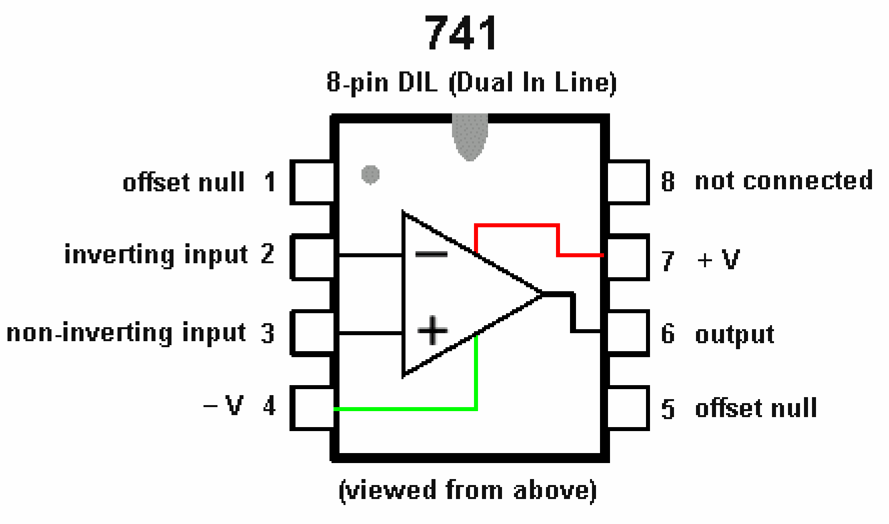
Opamp



V_s : 6 – 20V
for typical opamps

- $\frac{v_o}{v_d}$: very large @ dc
- In negative feedback:
  $v_d \simeq 0$

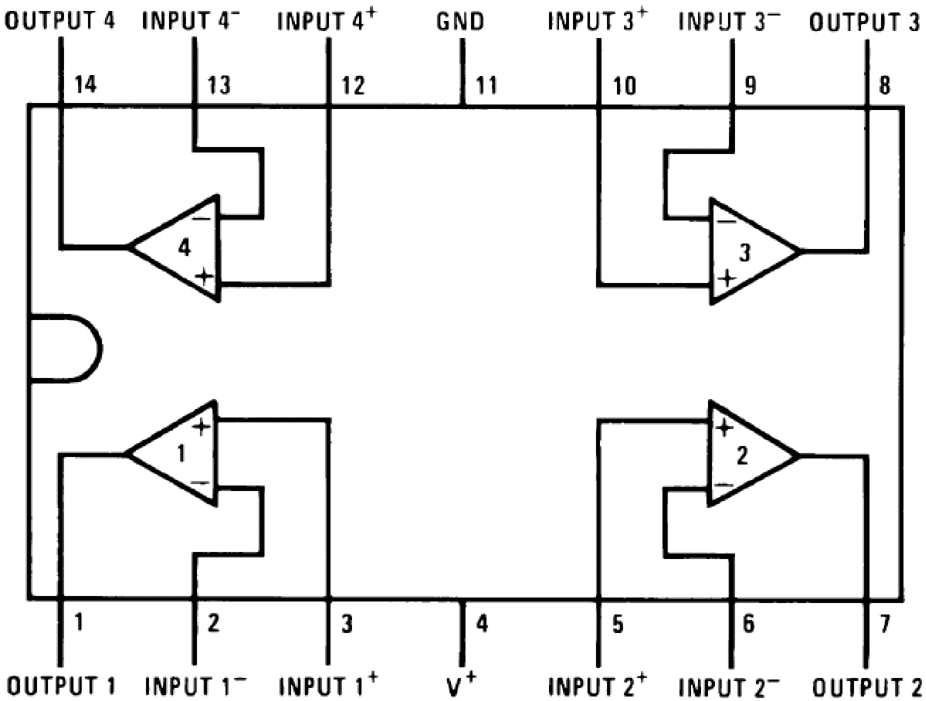
Opamp: LM741



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

Figure reproduced from manufacturer’s datasheet

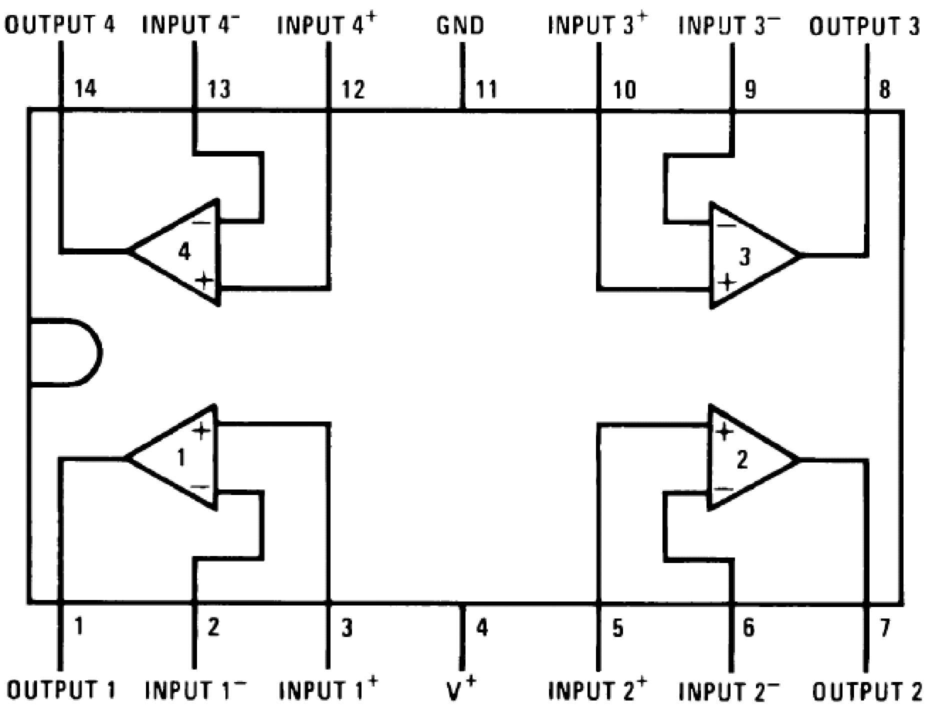
Opamp: LM324



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

Figure reproduced from manufacturer's datasheet

Opamp: LF347

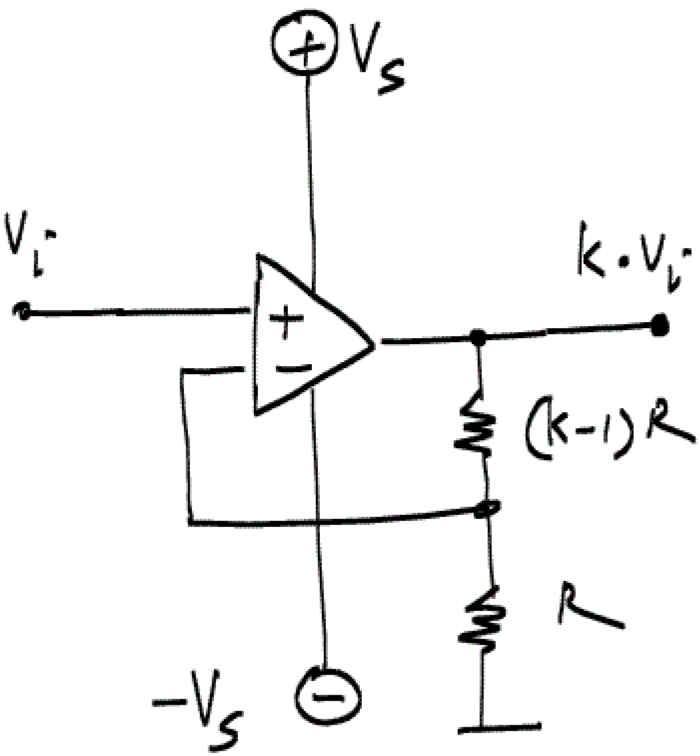


- 4 opamps in a package
- 4MHz gain bandwidth product
- 13V/μs slew rate

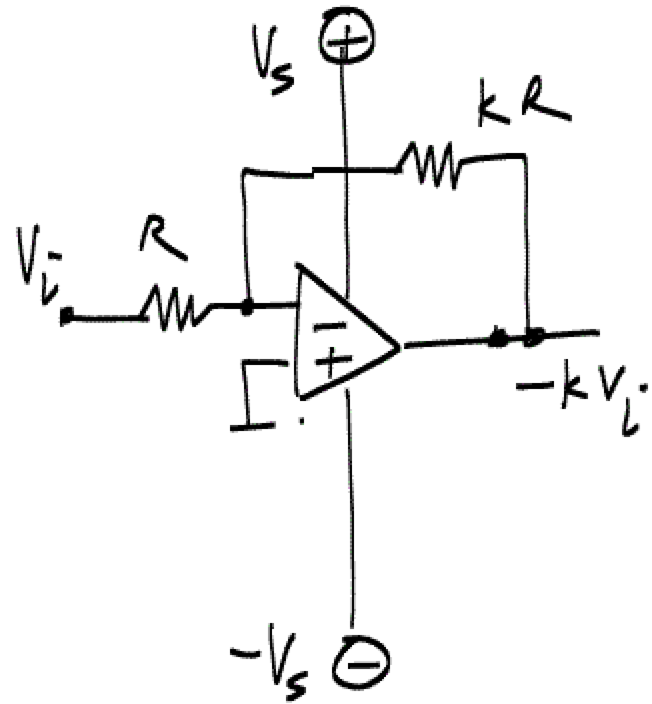
- OUR CHOICE!

Figure reproduced from manufacturer's datasheet

Opamp: Amplifiers



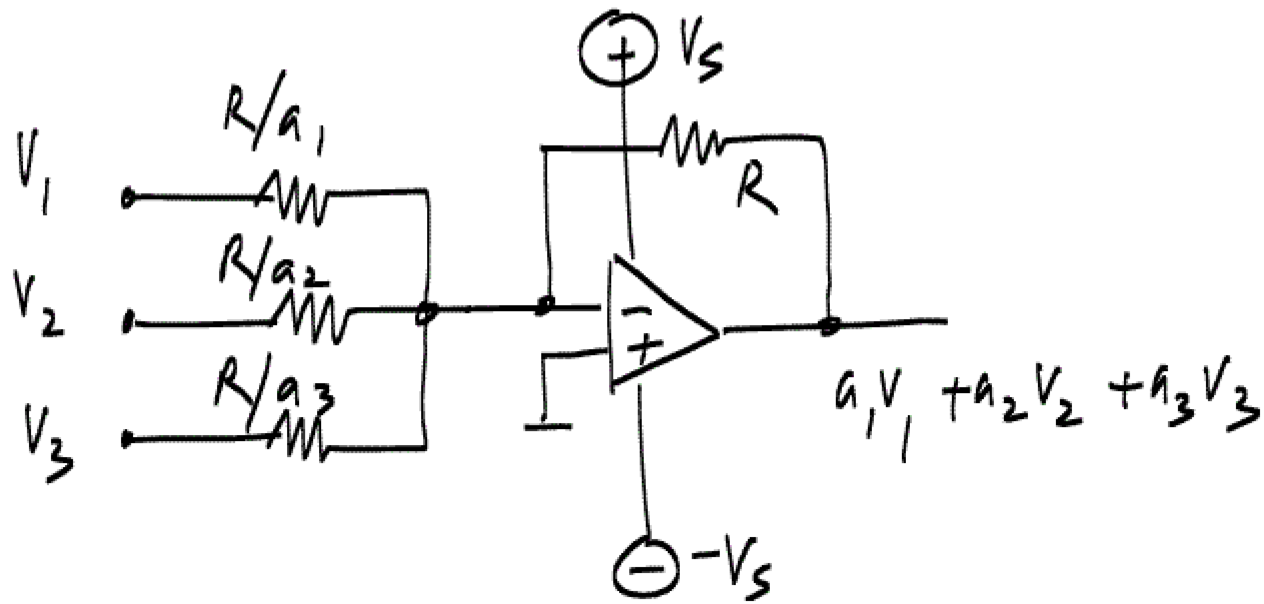
Non inverting amplifier



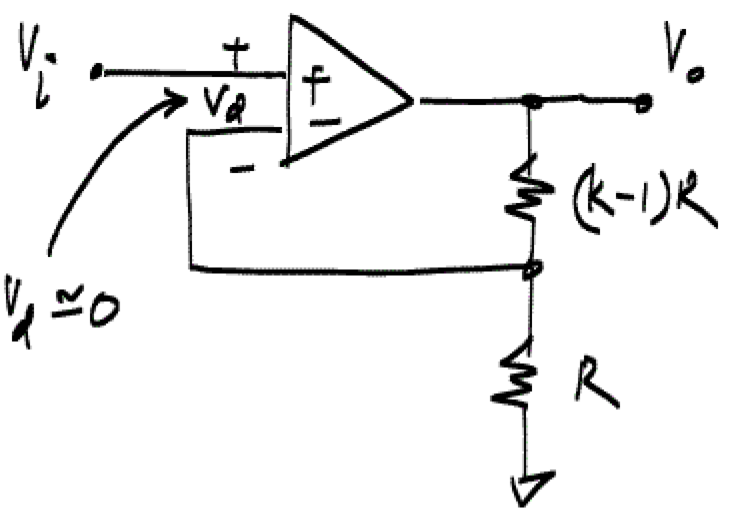
Inverting amplifier

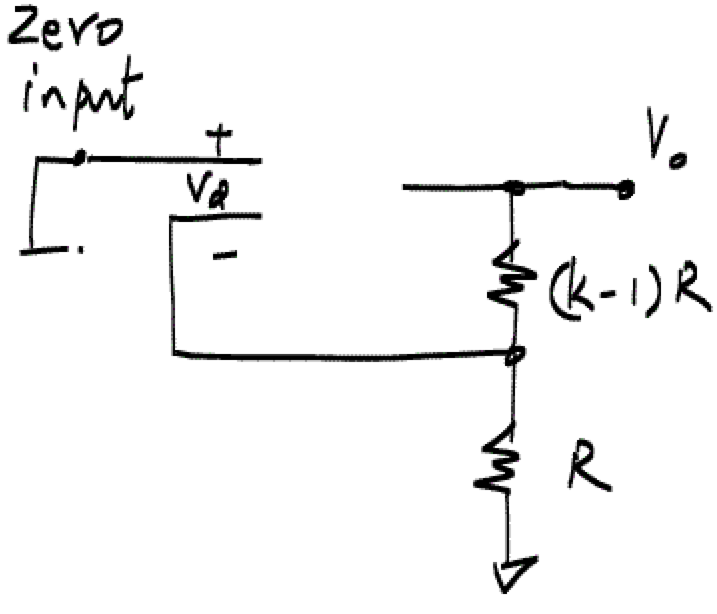
R ~ kΩ to tens of kΩ

Opamp: Adders



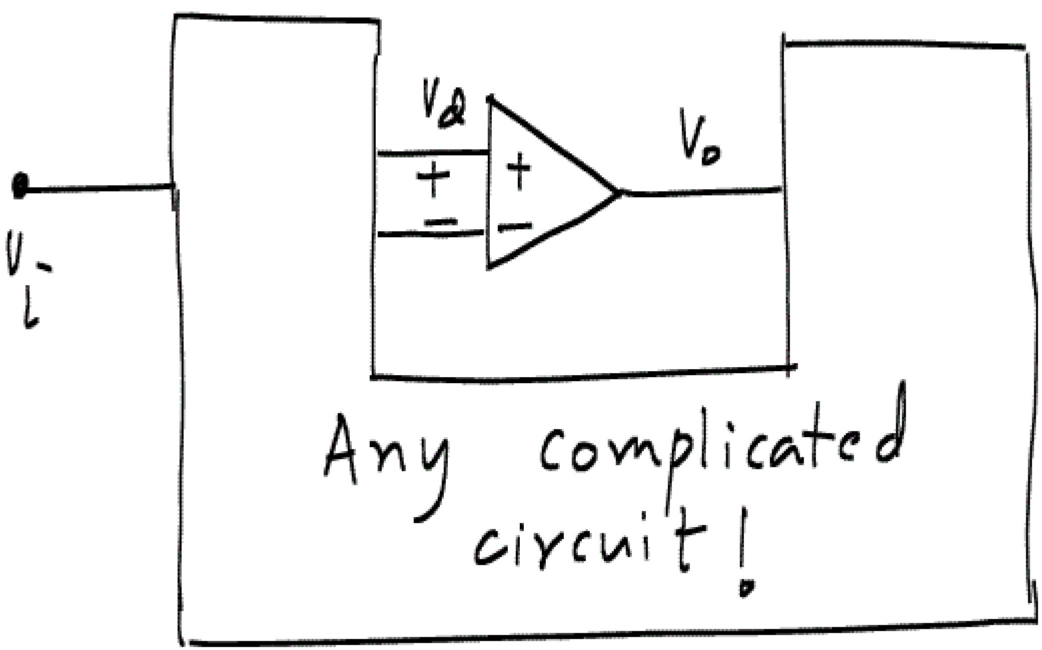
Opamp: Negative feedback



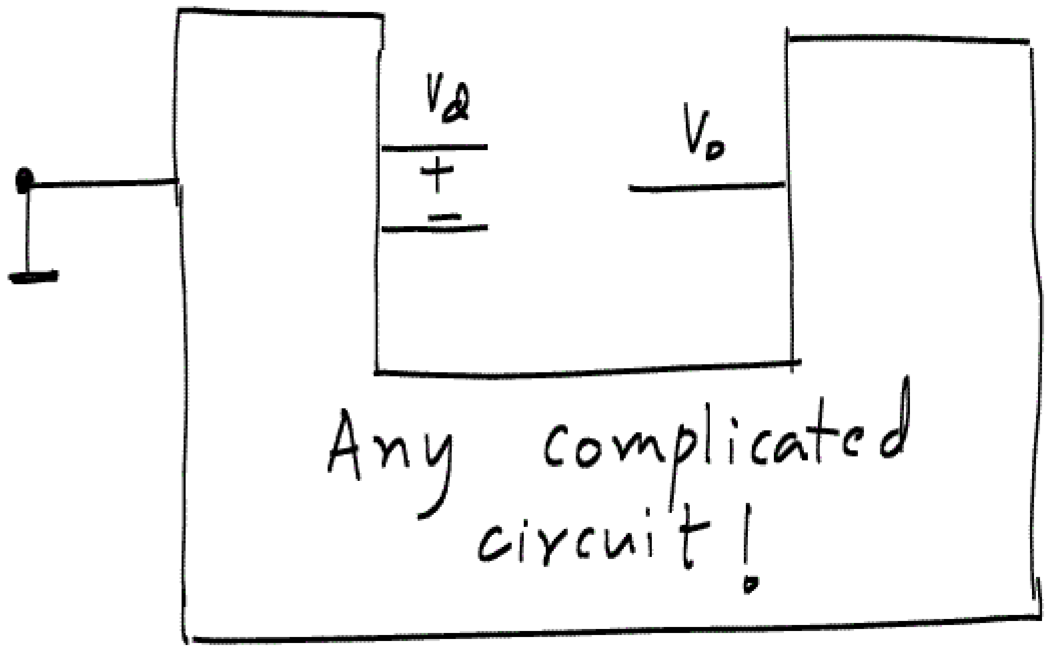


$$\frac{V_d}{V_o} = -\frac{1}{k} \quad \text{(negative)}$$

Opamp: Negative feedback

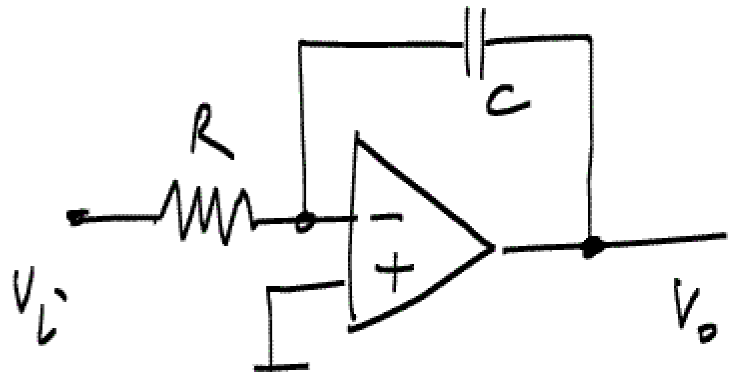


Opamp: Negative feedback

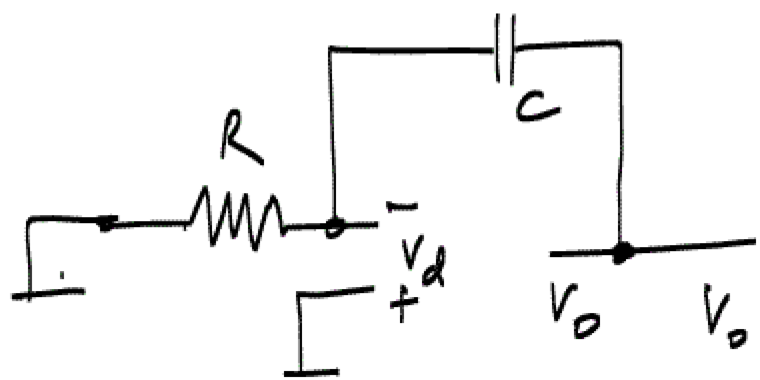


$\frac{v_d}{v_o}$ should be negative at dc with the opamp removed

Opamp: Integrator??

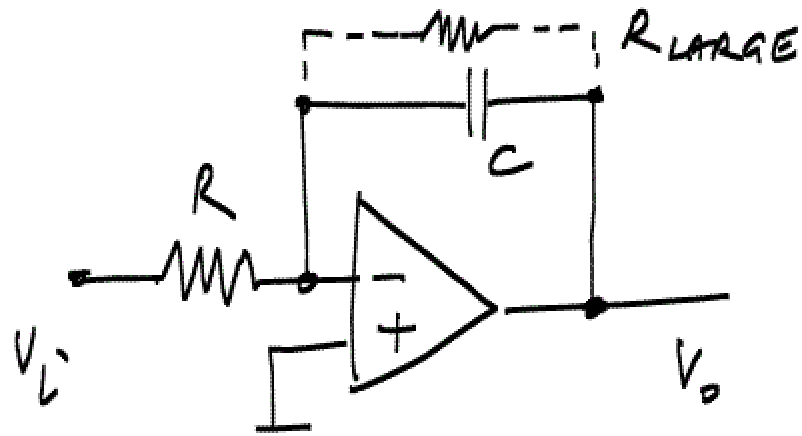


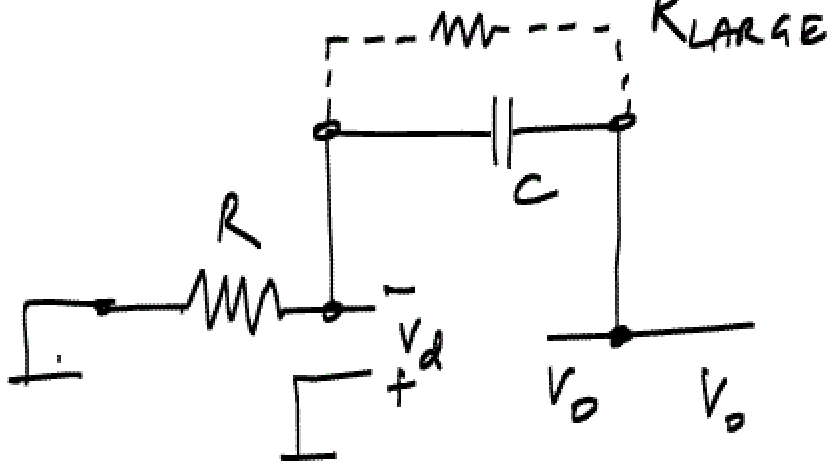
Doesn't work!



$$\frac{v_d}{v_o} = 0 \text{ at dc}$$

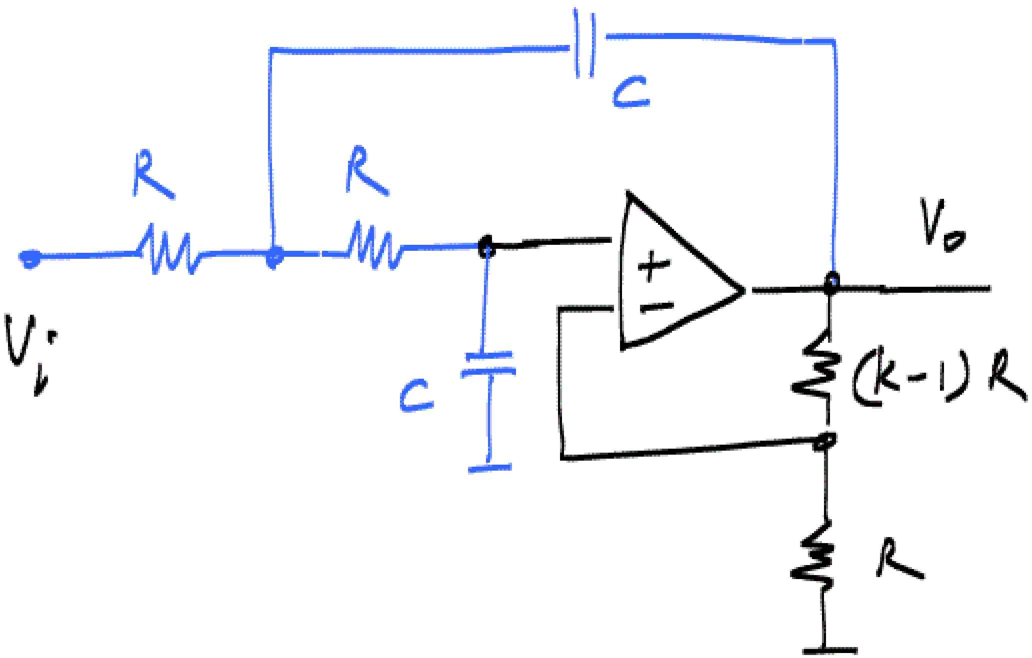
Opamp: Integrator??





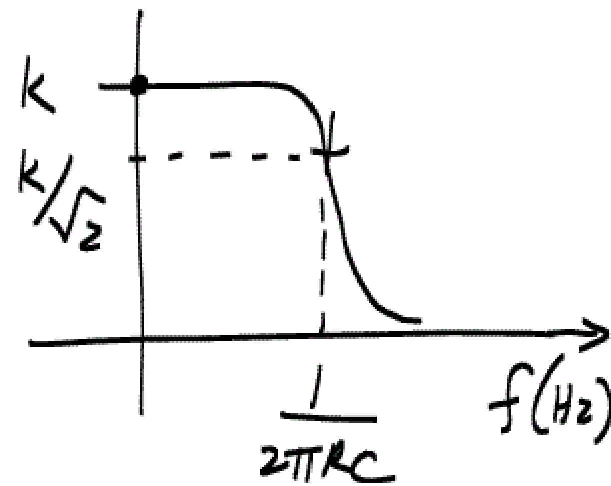
$$\frac{V_d}{V_o} = \frac{-R}{R + R_{LARGE}} \quad \text{at dc}$$

Opamp: Filters



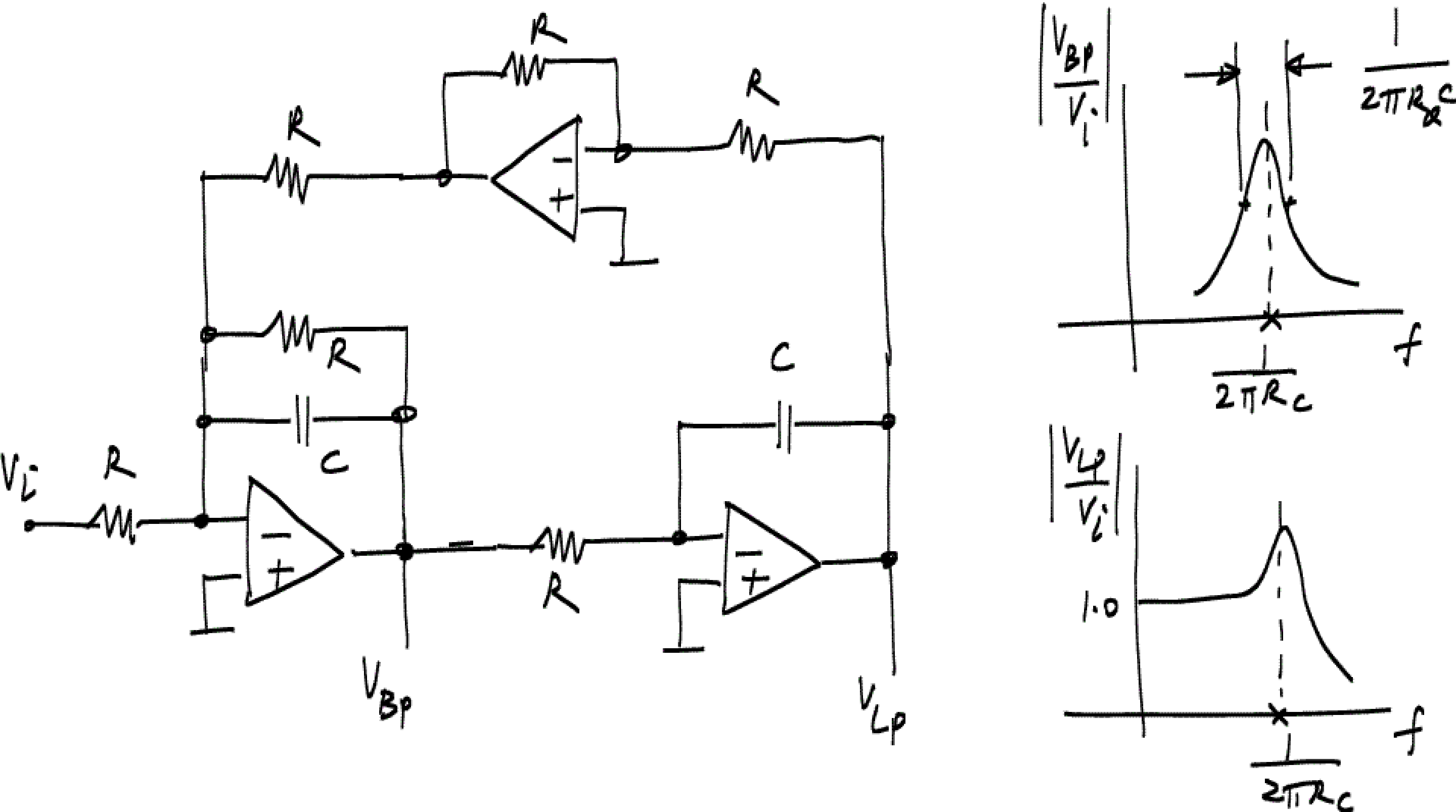
$3 - k = \sqrt{2}$

$\Rightarrow$ Maximally flat response



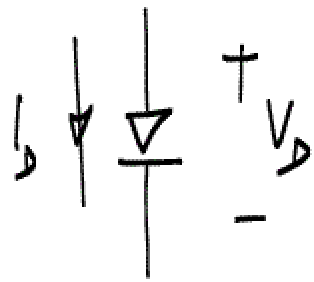
$$\frac{V_o}{V_i} = \frac{1}{(sCR)^2 + sCR(3-k) + 1}$$

Opamp: Filters

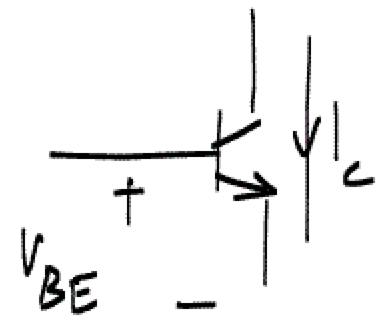


Opamp: Logarithmic amplifiers

Diode.



Bipolar transistor



$$I_D \simeq I_s \exp\left(\frac{V_D}{V_t}\right)$$

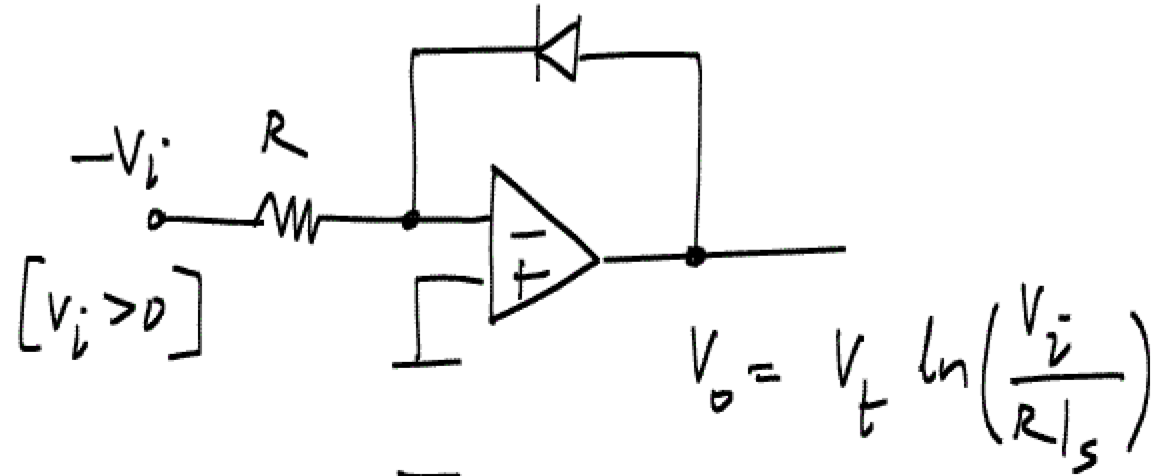
$$I_C \simeq I_s \exp\left(\frac{V_{BE}}{V_t}\right)$$

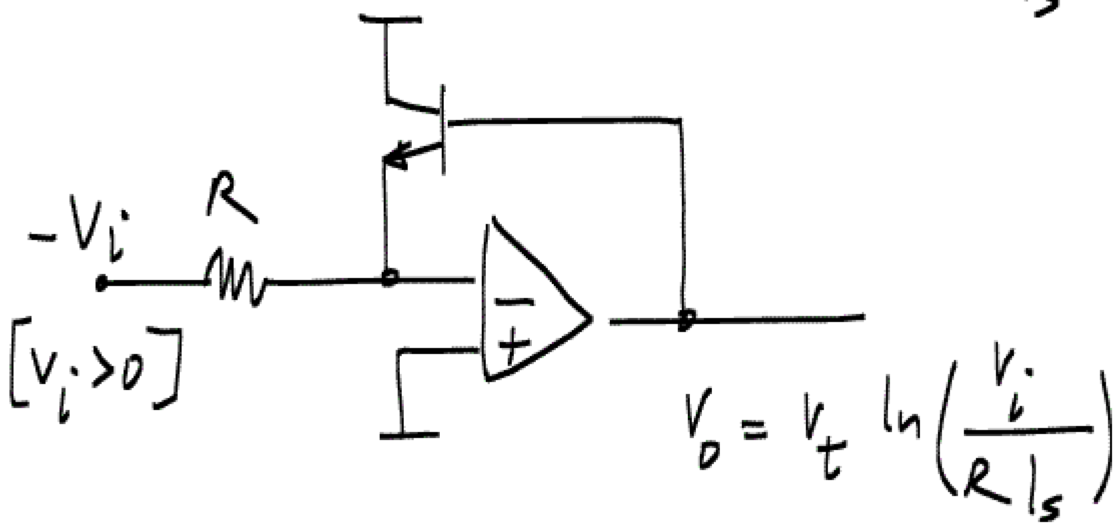
$$V_D \simeq V_t \ln\left(\frac{I_D}{I_s}\right)$$

$$V_{BE} \simeq V_t \ln\left(\frac{I_C}{I_s}\right)$$

$$V_t = \frac{kT}{q} \simeq 25.9\,\text{mV @ R.T.}$$

Opamp: Logarithmic amplifiers



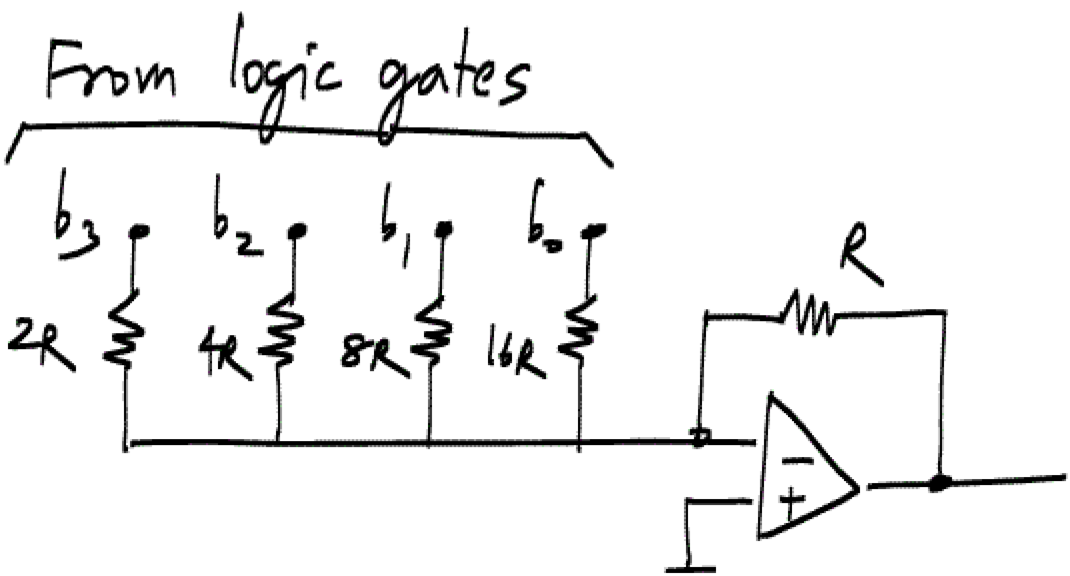


Opamp: Digital to analog converter

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

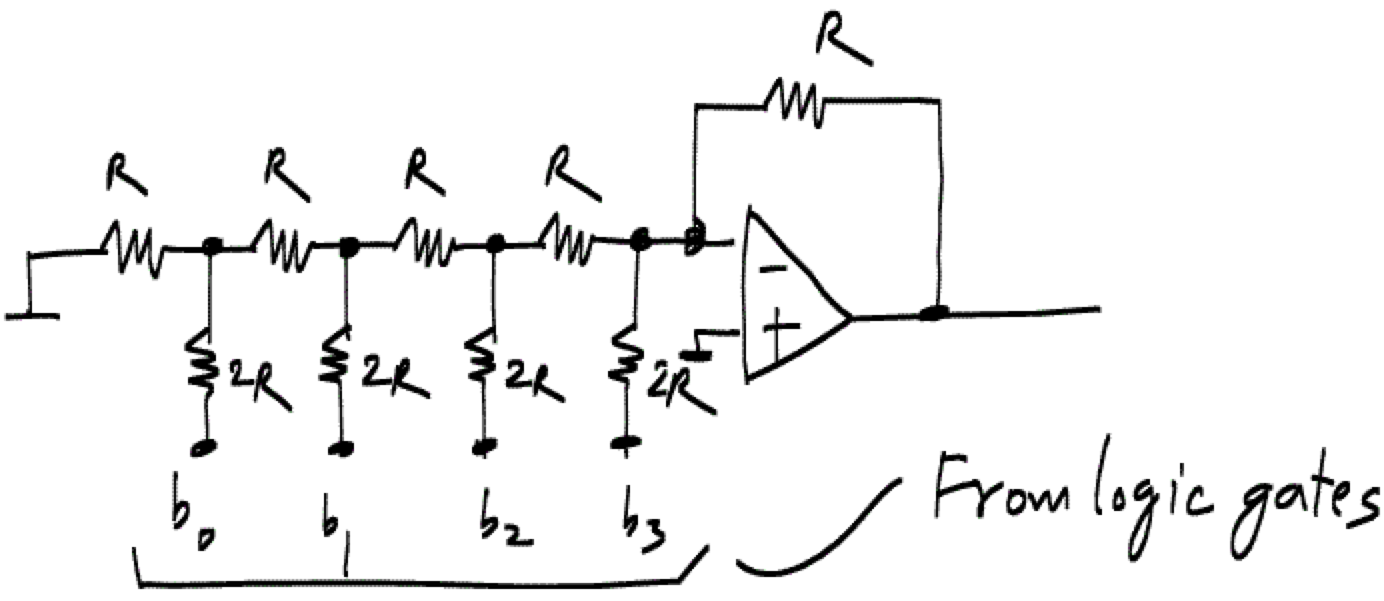


Opamp: Digital to analog converter

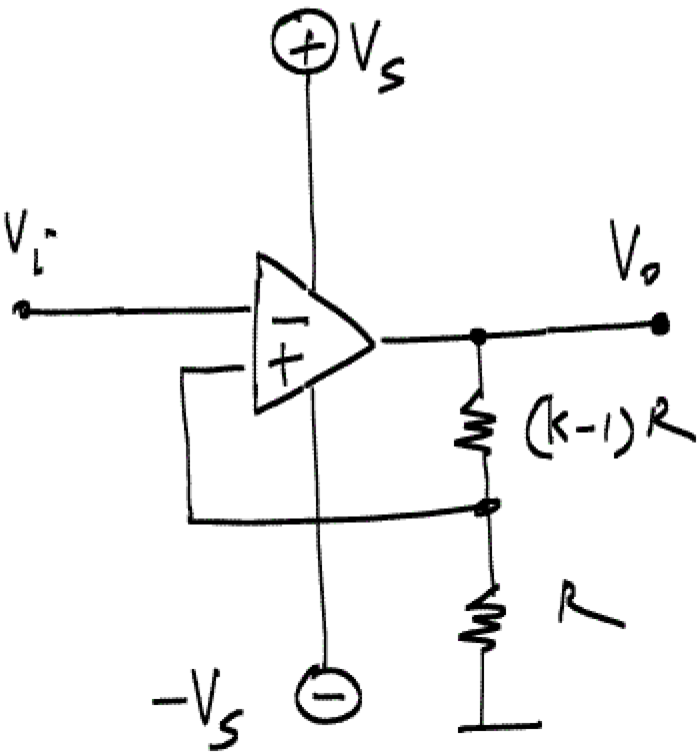
Digital input D_{in} : $b_3 \, b_2 \, b_1 \, b_0$

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

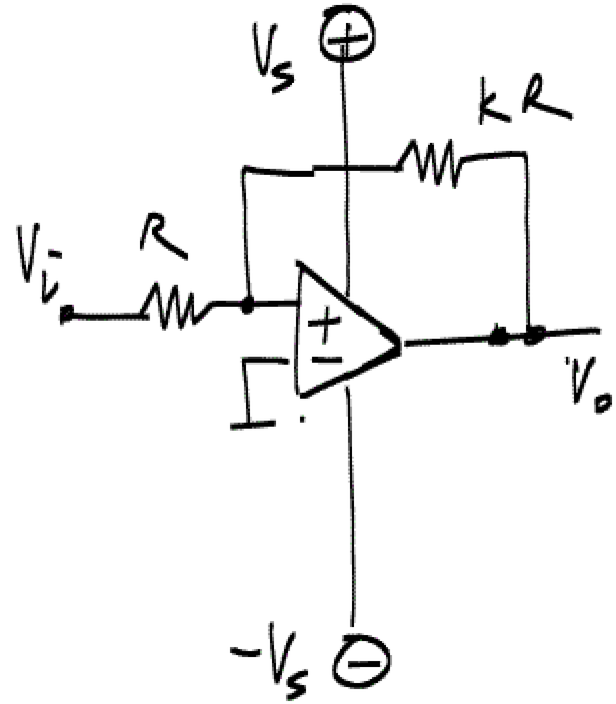
V_{ref} : Full scale voltage



Opamp: Schmitt trigger



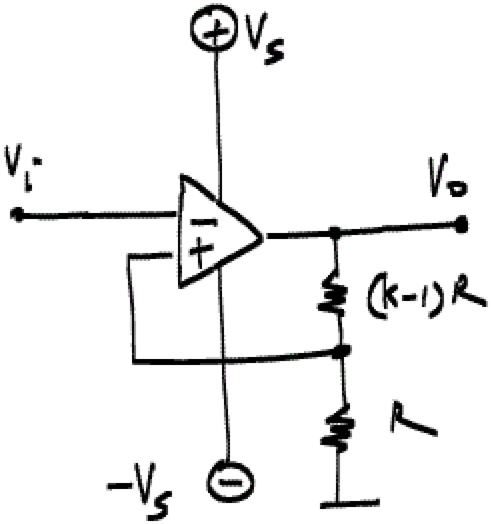
Inverting Schmitt trigger

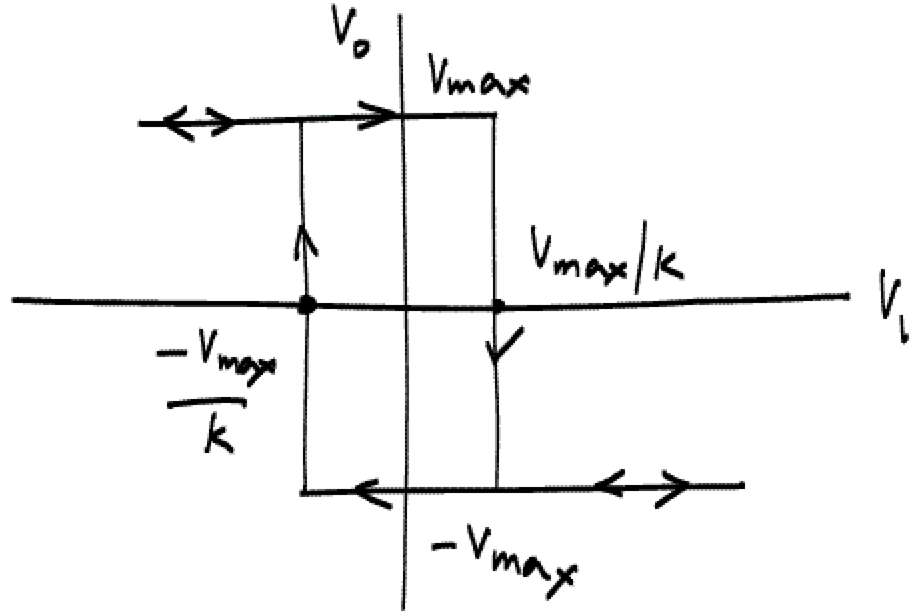


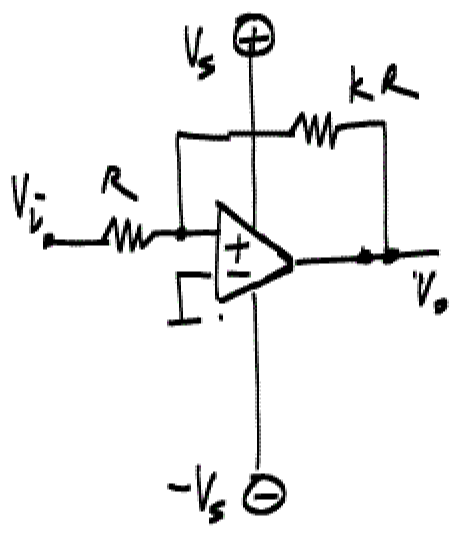
Non inverting schmitt trigger

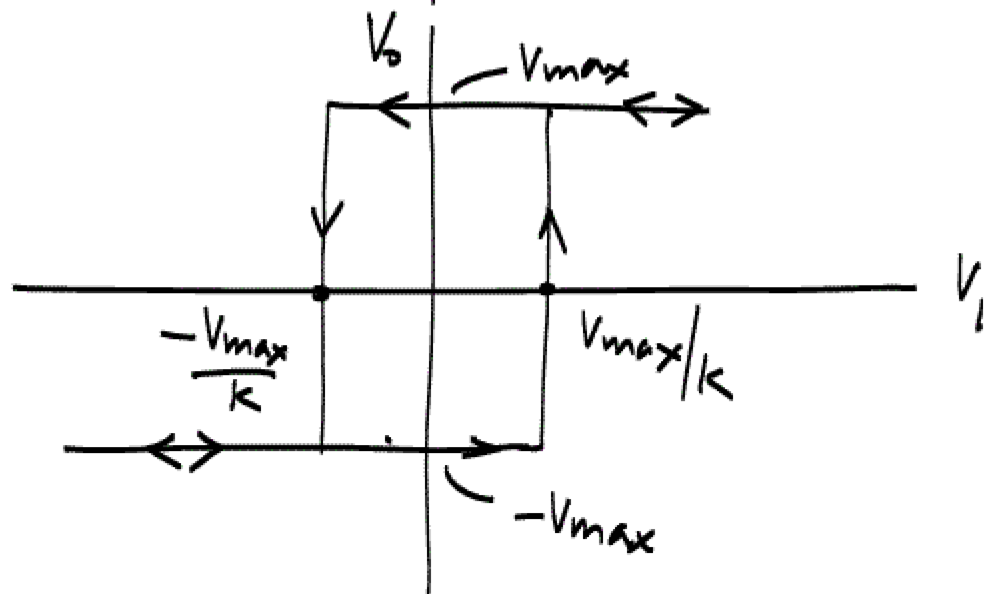
POSITIVE FEEDBACK: $V_d \neq 0$!

Opamp: Schmitt trigger



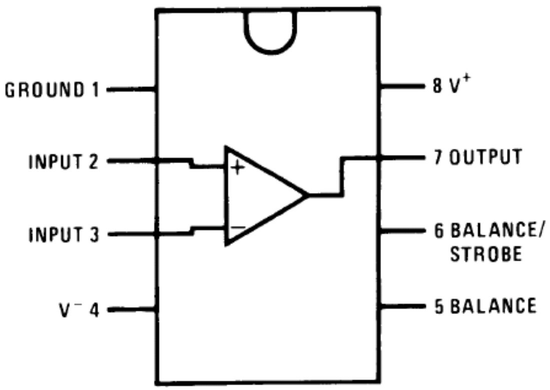






Comparator

Dual-In-Line Package



00570434

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

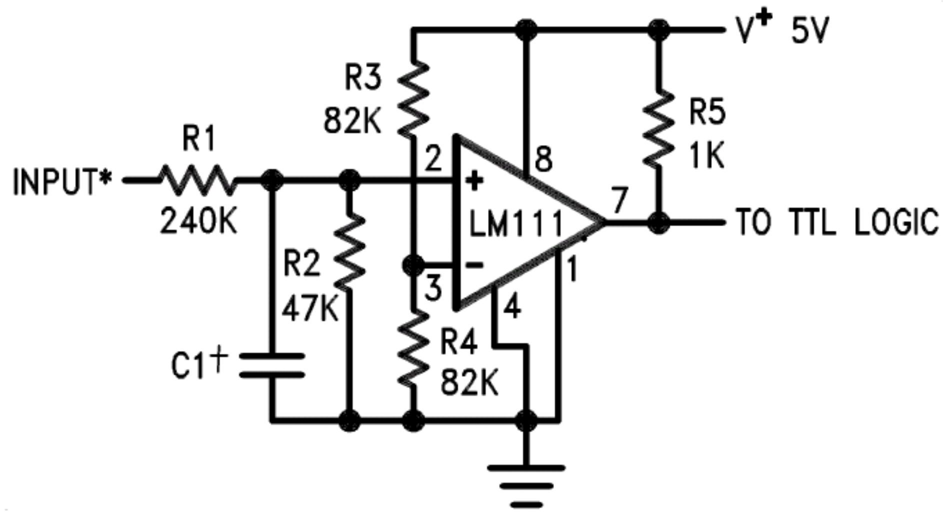
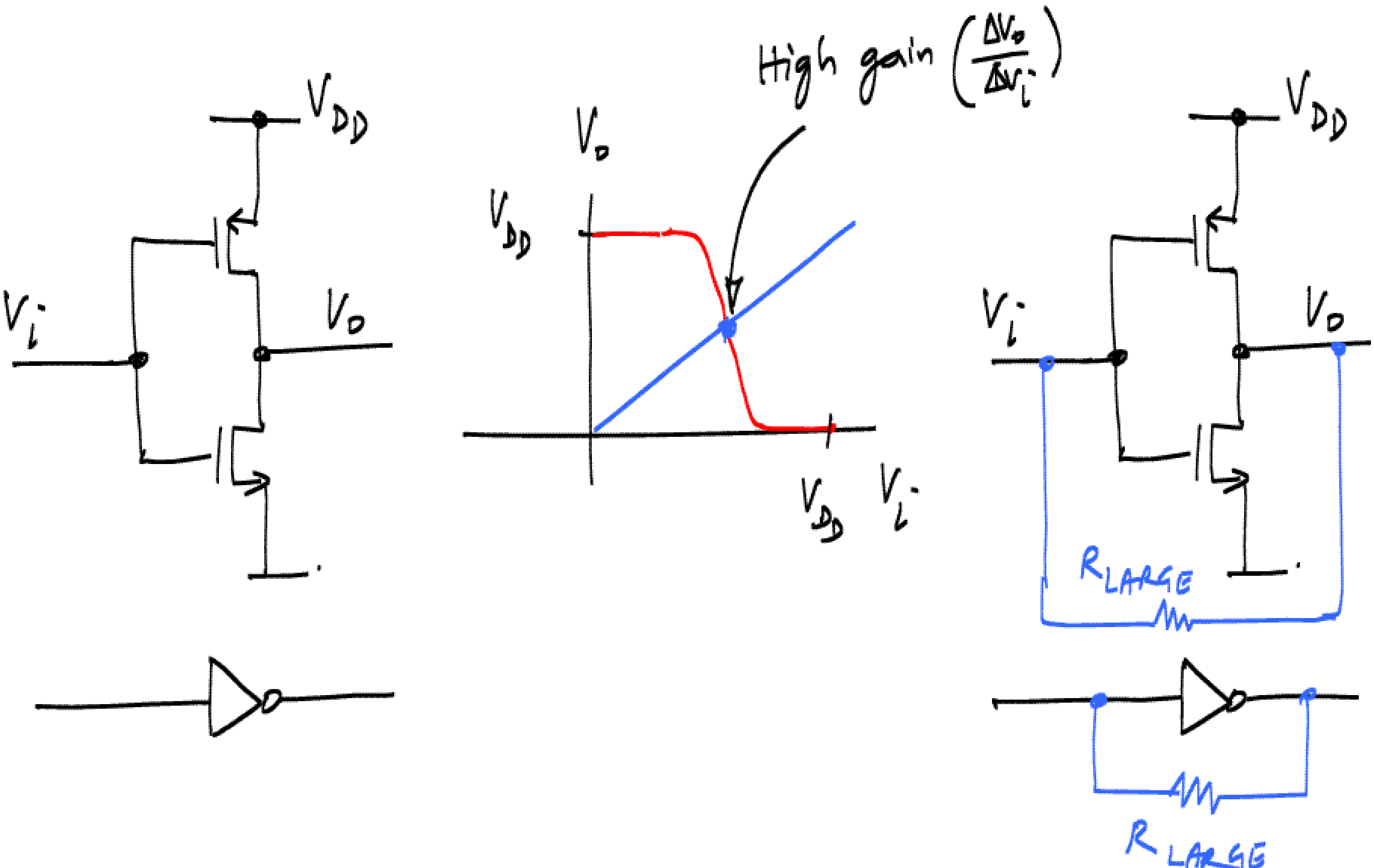
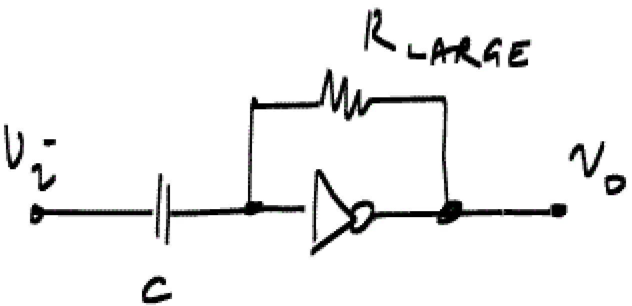


Figure reproduced from manufacturer’s datasheet

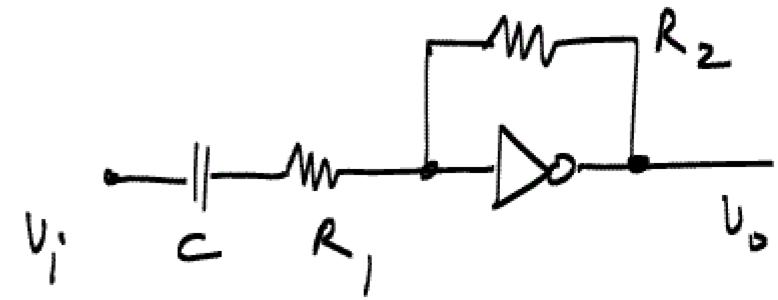
CMOS inverter for analog



CMOS inverter for analog



$$\frac{v_o}{v_i} \simeq -g_m \cdot r_{ds}$$

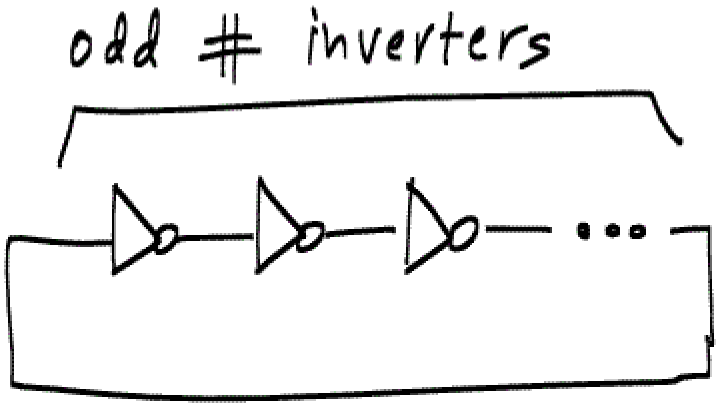


$$\frac{v_o}{v_i} \simeq -\frac{R_2}{R_1}$$

[Small values of $\frac{R_2}{R_1}$]

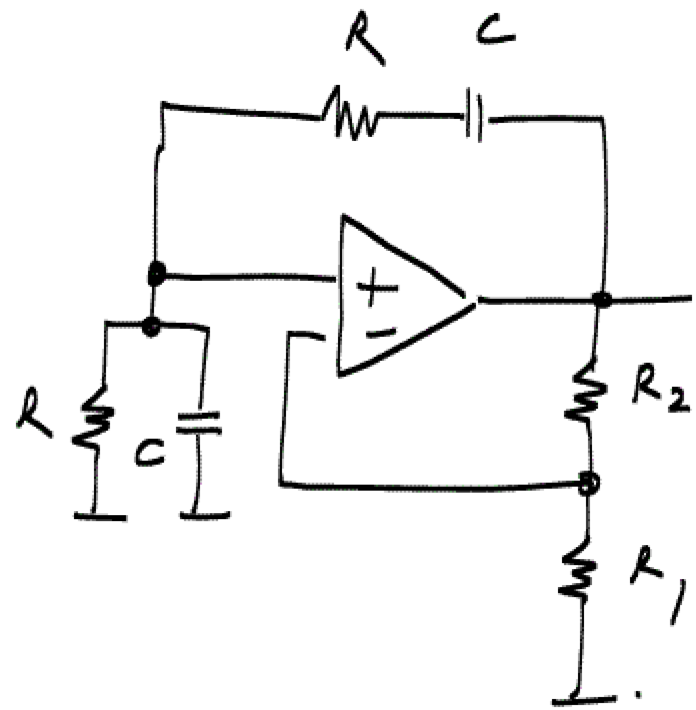
Many other circuits at
http://www.ee.iitm.ac.in/vlsi/courses/ec330_2010/start

Oscillator circuits



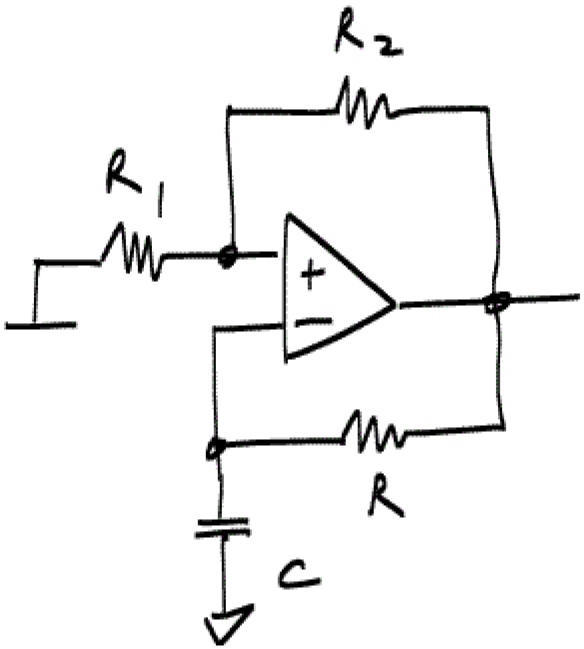
$$f_{osc} = \frac{2N}{t_d}$$

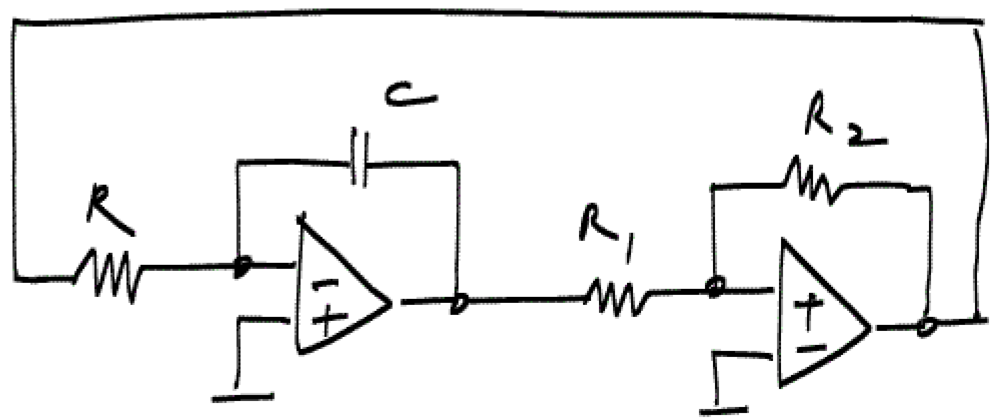
t_d : inverter delay



$\frac{R_2}{R_1} = 2$; Try slightly more than 2 if it doesn't oscillate

Oscillator circuits





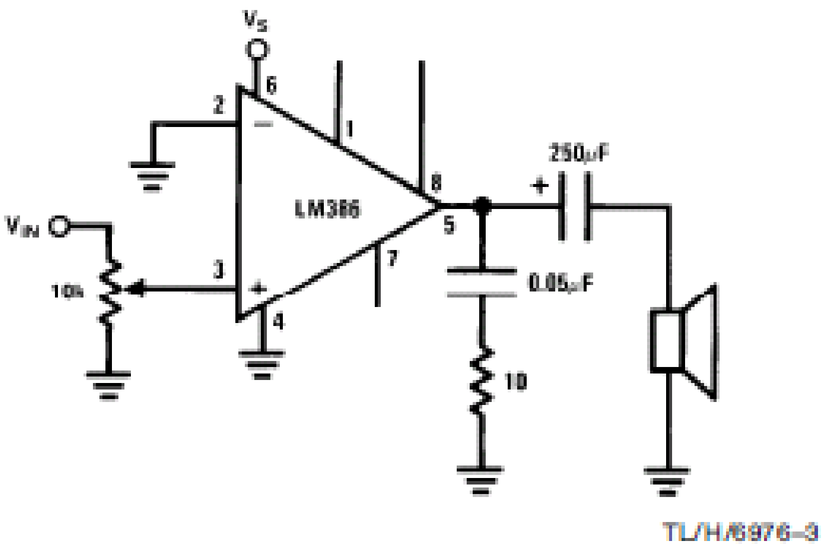
Audio power amplifier-LM386

- 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

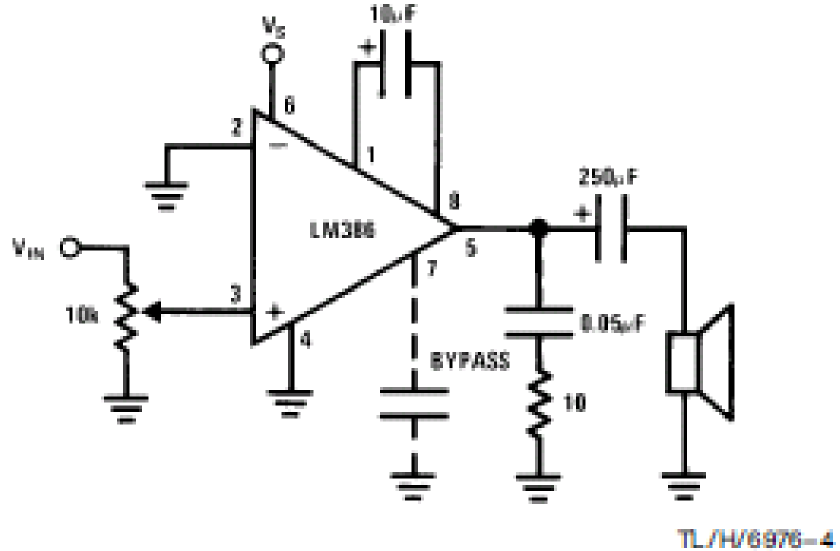


Figure reproduced from manufacturer’s datasheet

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

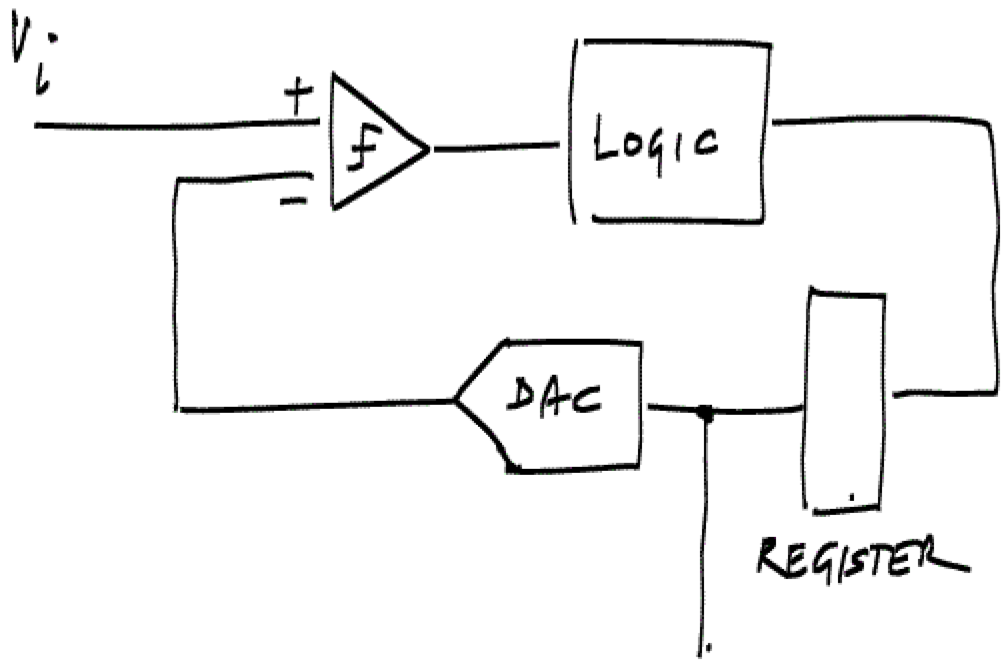
Suggestions for projects

Calculator

- Optimization
  - Minimize the number of chips
  - Combine the adder/subtractor
- Multiplier
  - Shift and add

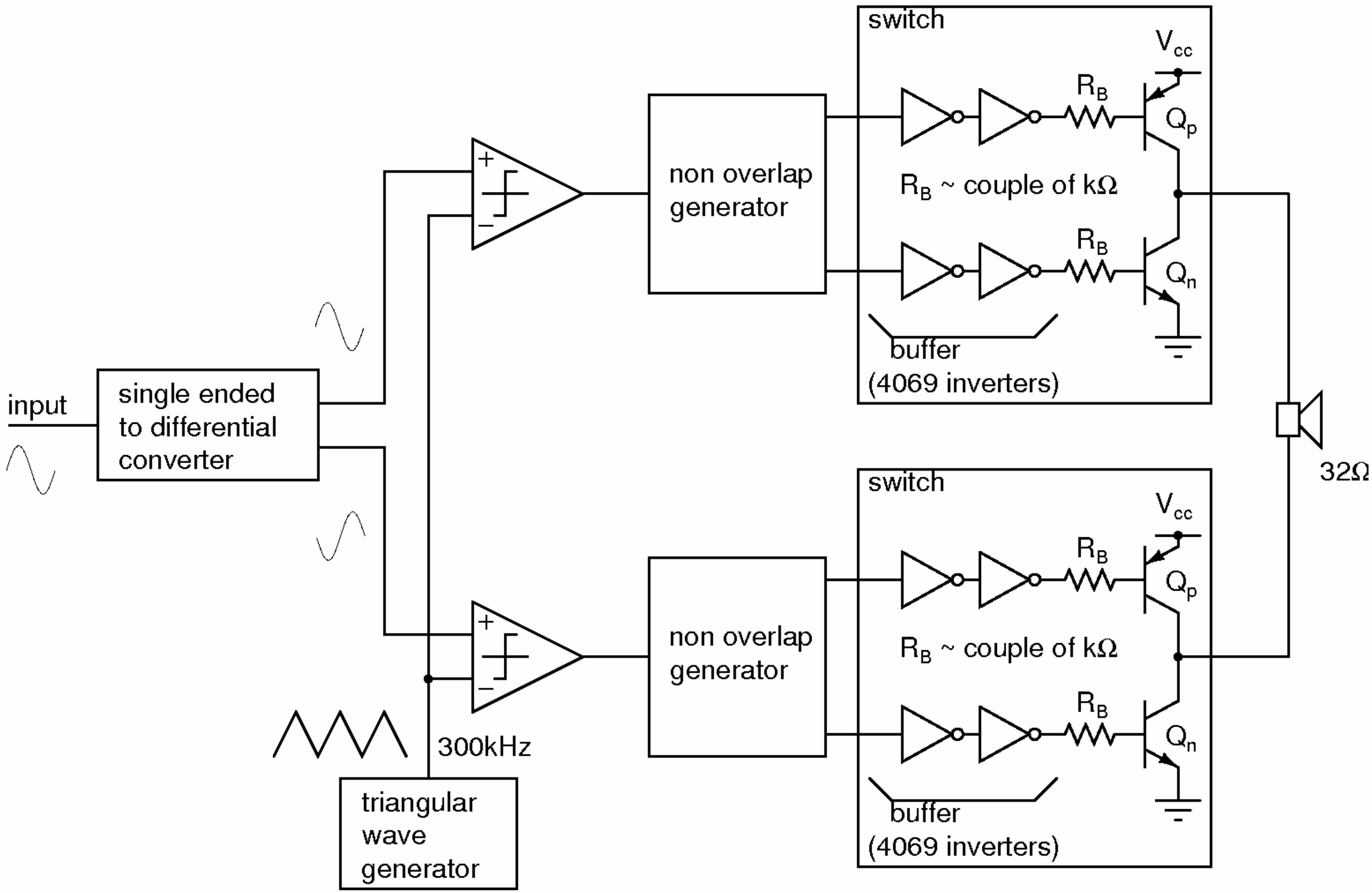
Analog to digital converter

- ADC using DAC and binary search



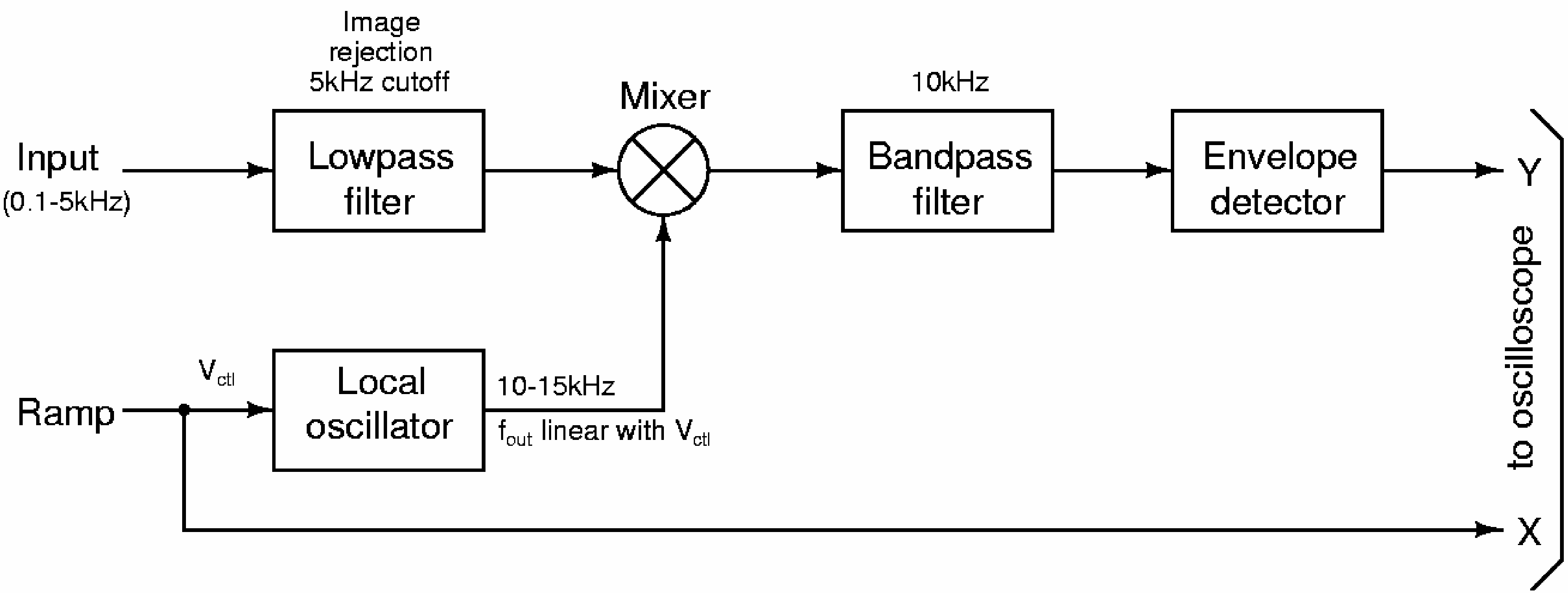
Digital code should result in a DAC output of V_i

Class D audio amplifier



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

Spectrum analyzer



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

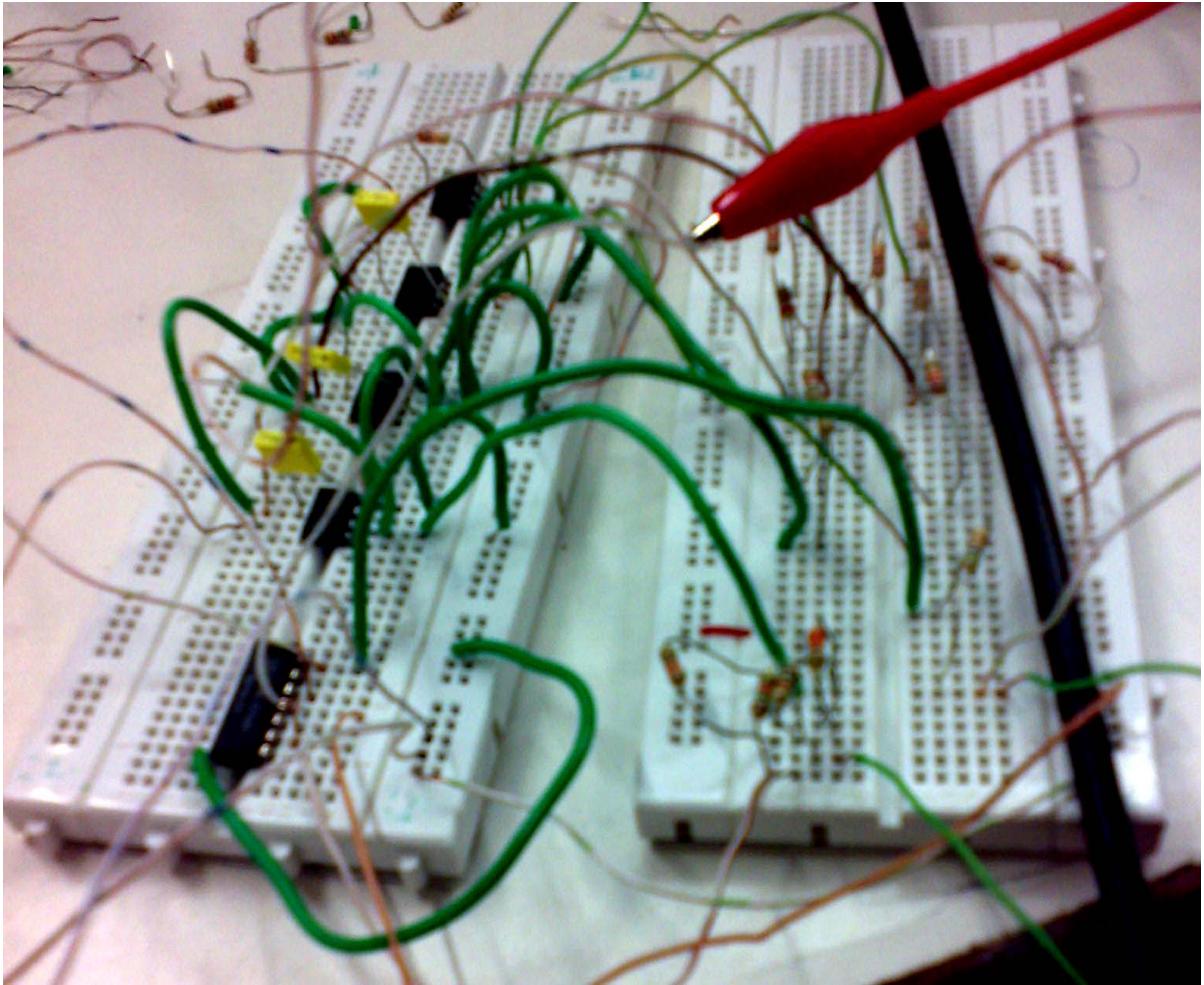
http://www.ee.iitm.ac.in/~nagendra/misc/20071006iitm_shaastra.pdf

Assembling circuits

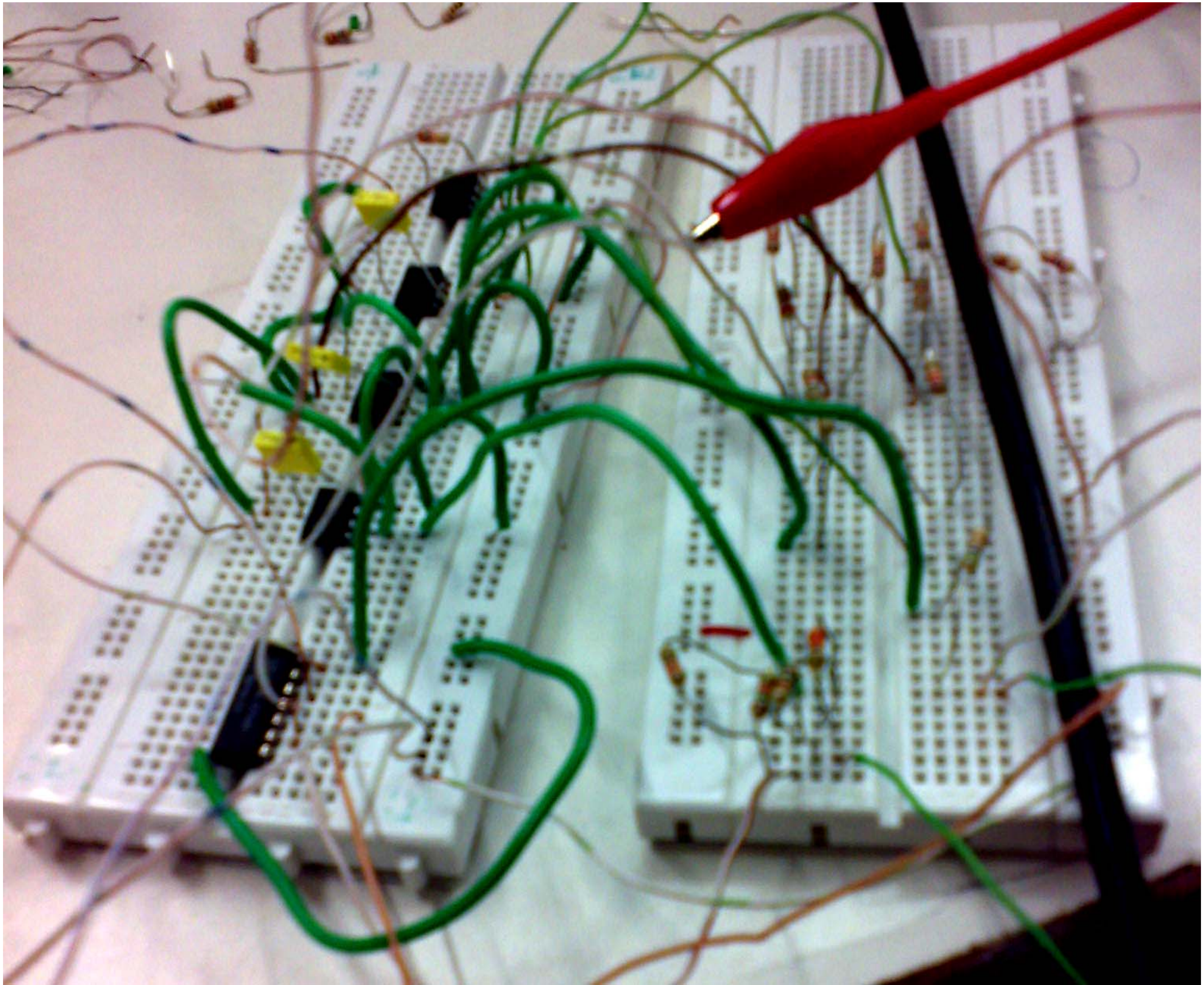
Assembling circuits

- Breadboard
  - Quick assembly
  - Low frequency/low precision circuits
  - Not very robust
- PCBs
  - Takes time for assembly
  - High frequency/high precision circuits
  - Very robust

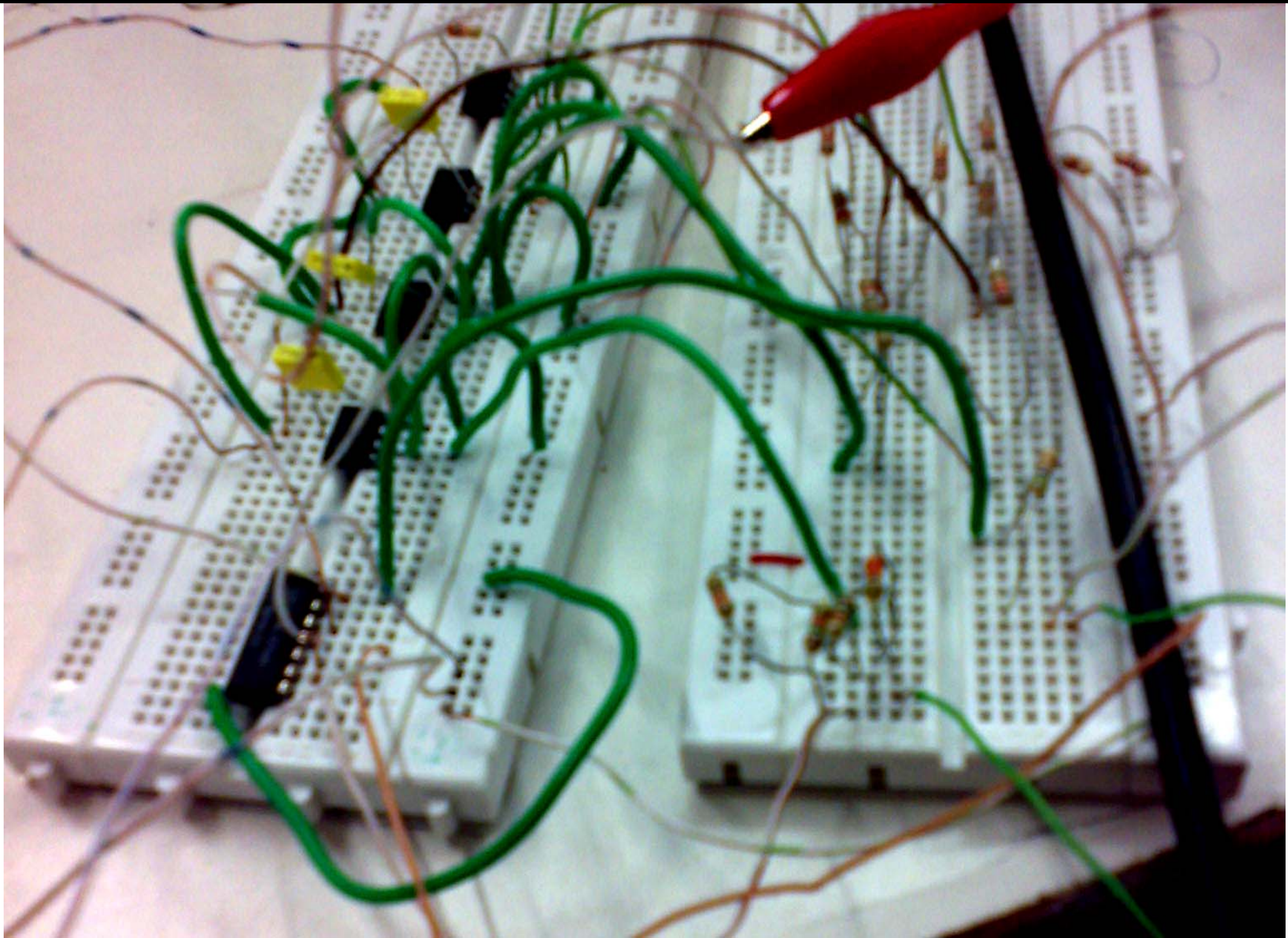
A Neat Board : Guaranteed ☺ …

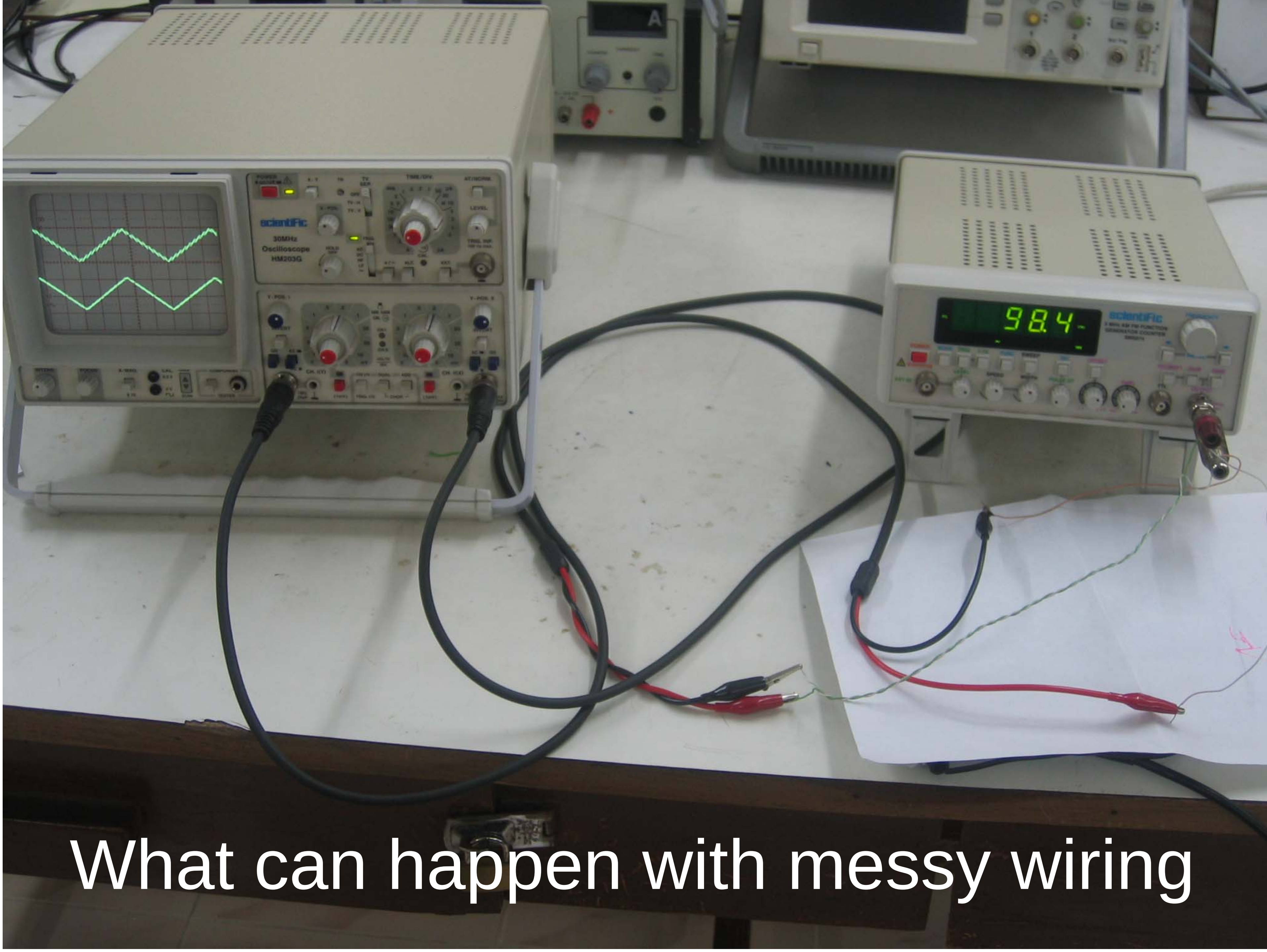


Guaranteed ☺ : Not to work ! …

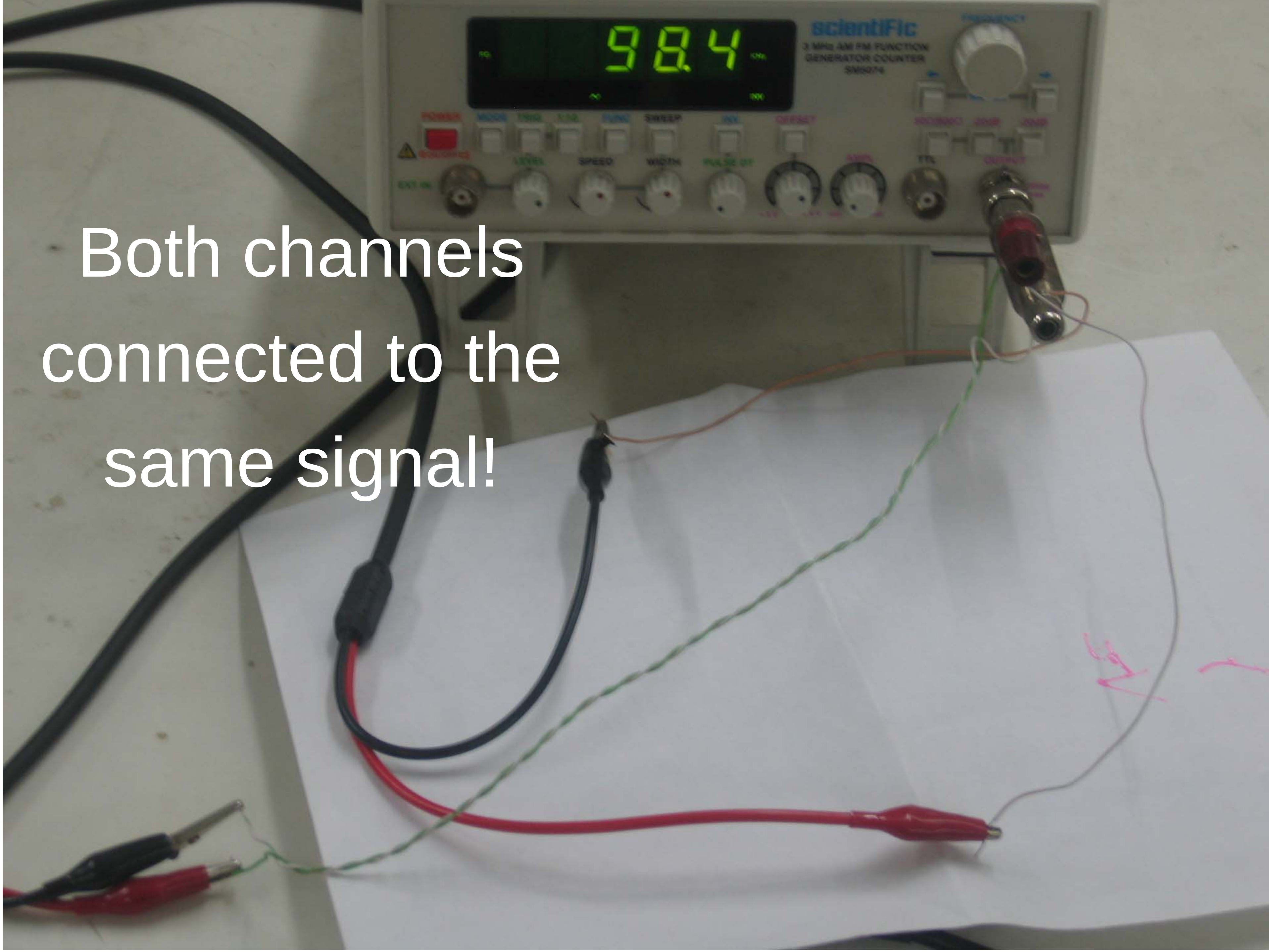


Spaghetti is good stuff, but not on your board

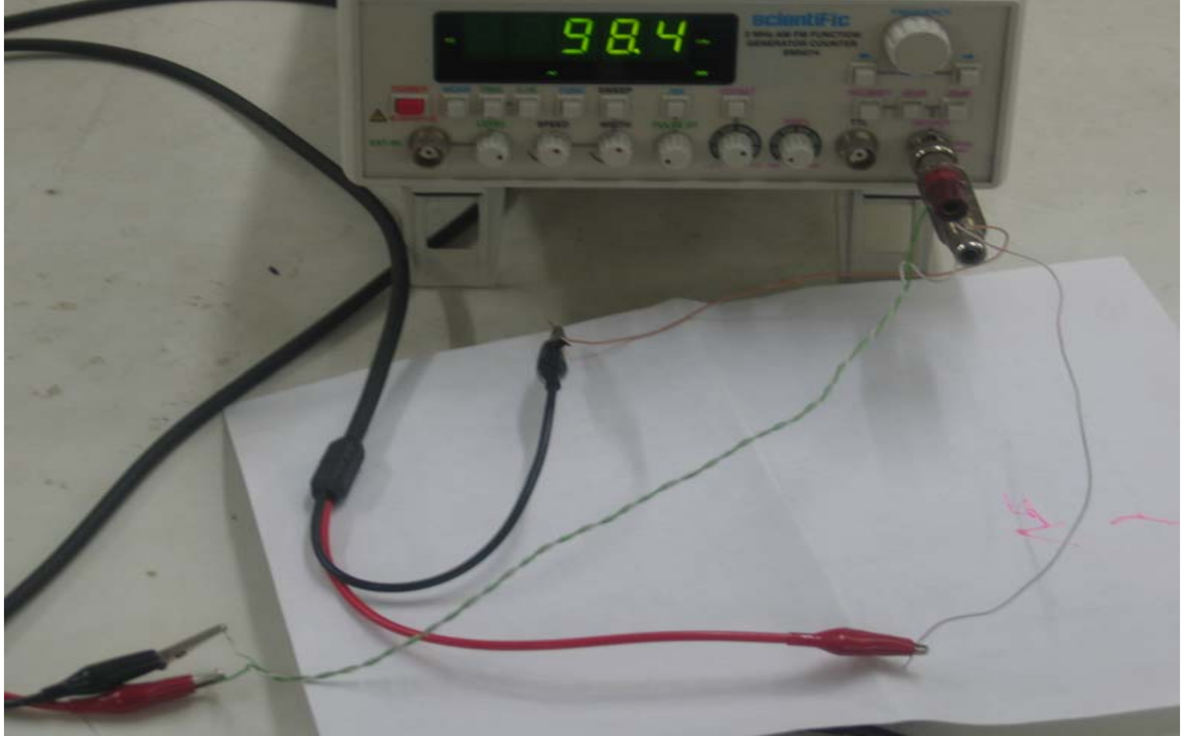


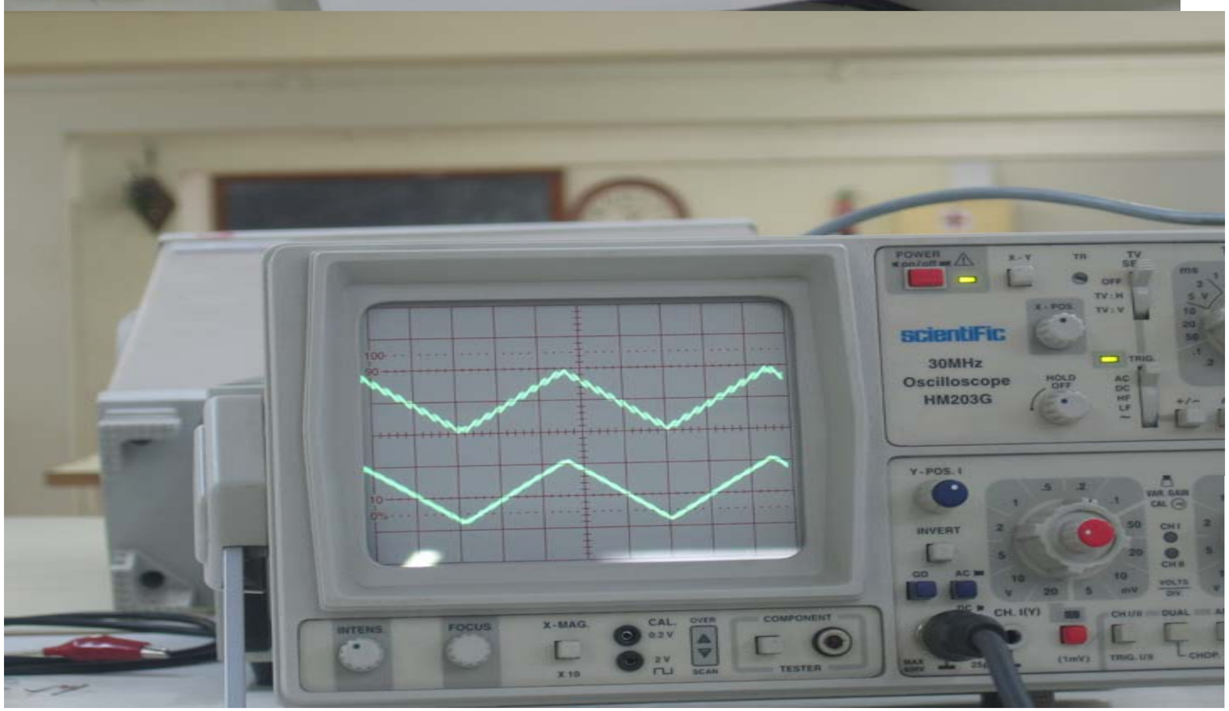


What can happen with messy wiring

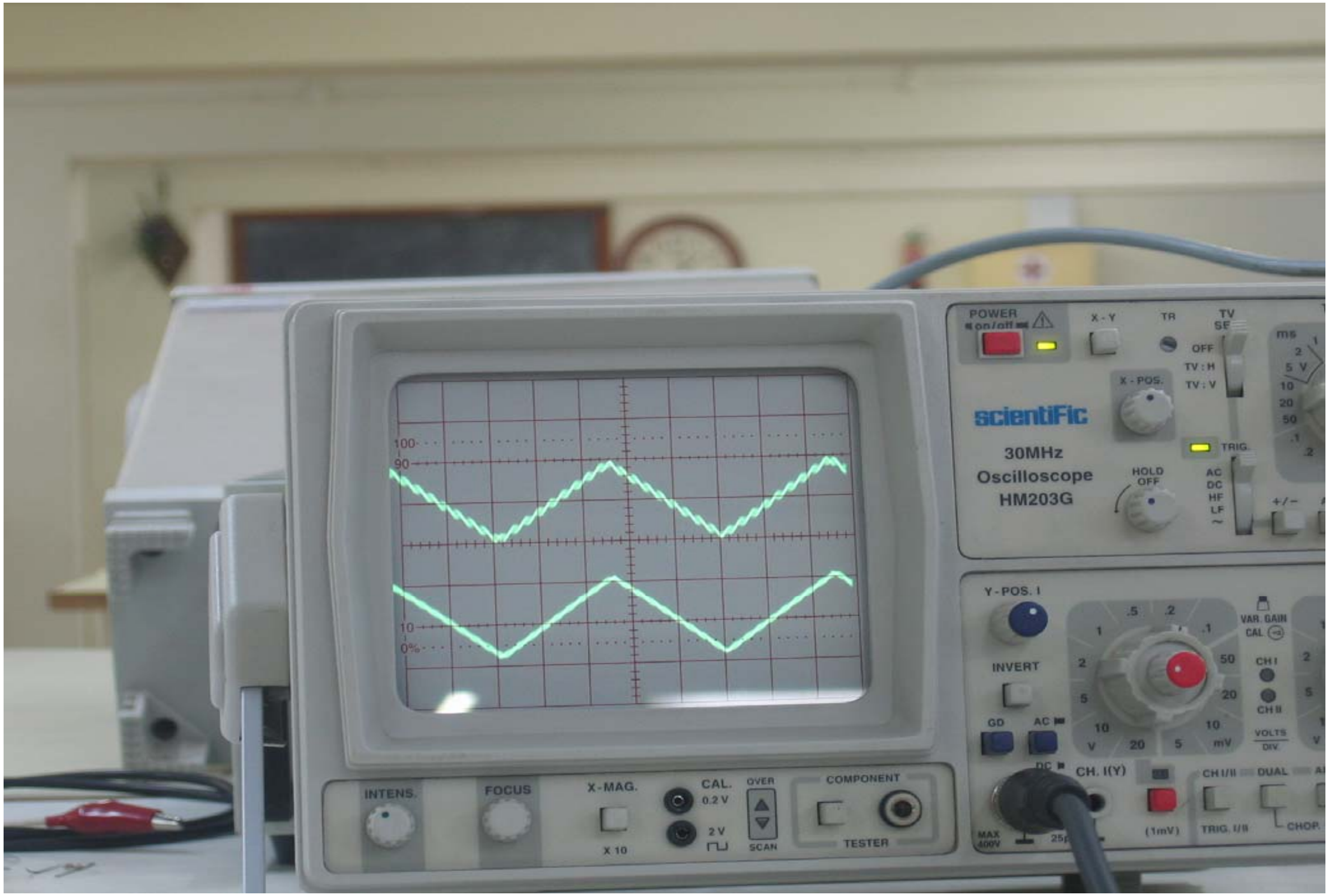


Both channels connected to the same signal!

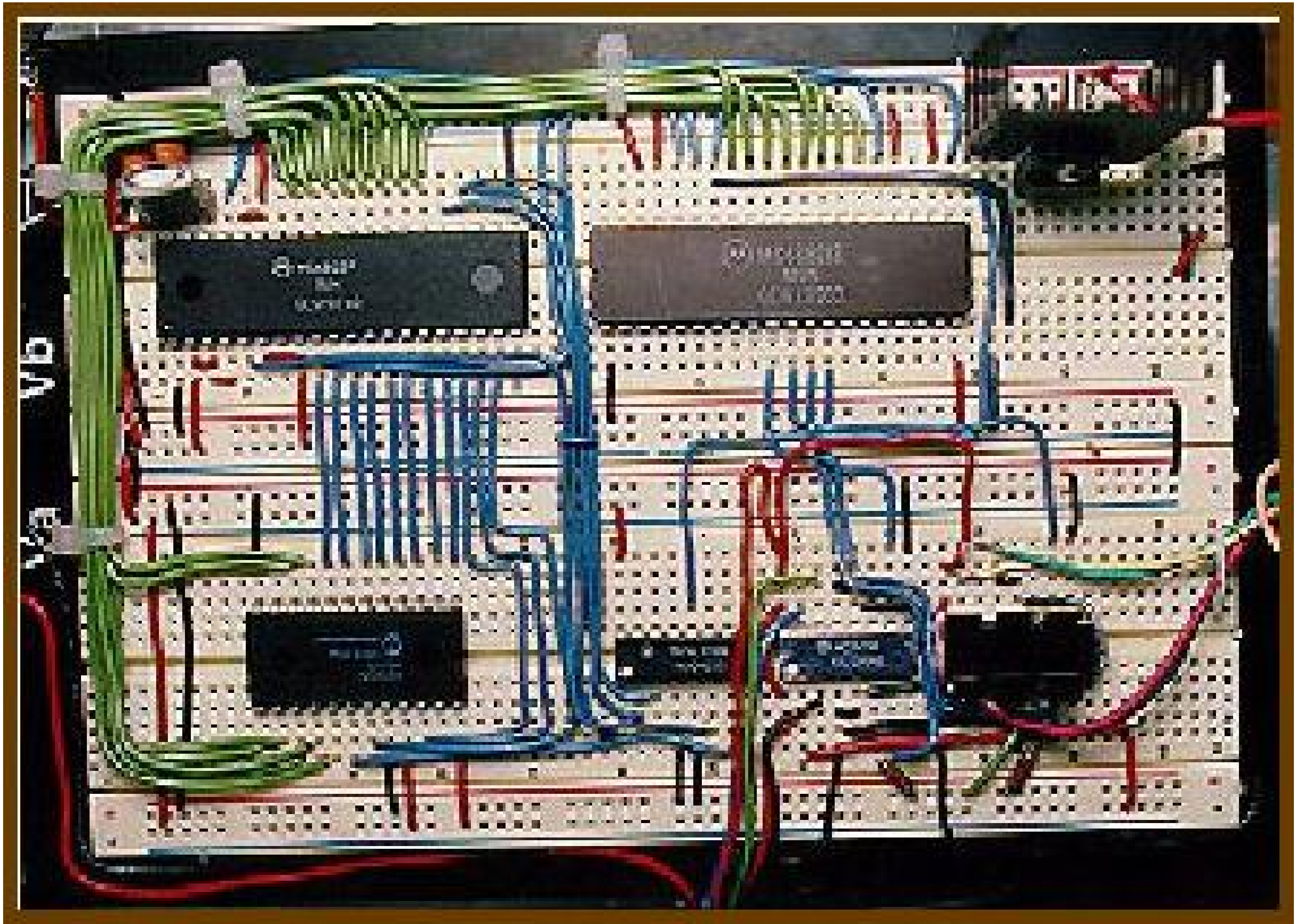

98.4
scientiFic


scientiFic
30MHz
Oscilloscope
HM203G
POWER
Y-POS. I
INVERT
INTENS
FOCUS
X-MAG.
CAL.
COMPONENT
TESTER
CH. I(Y)
DUAL
TRIG.

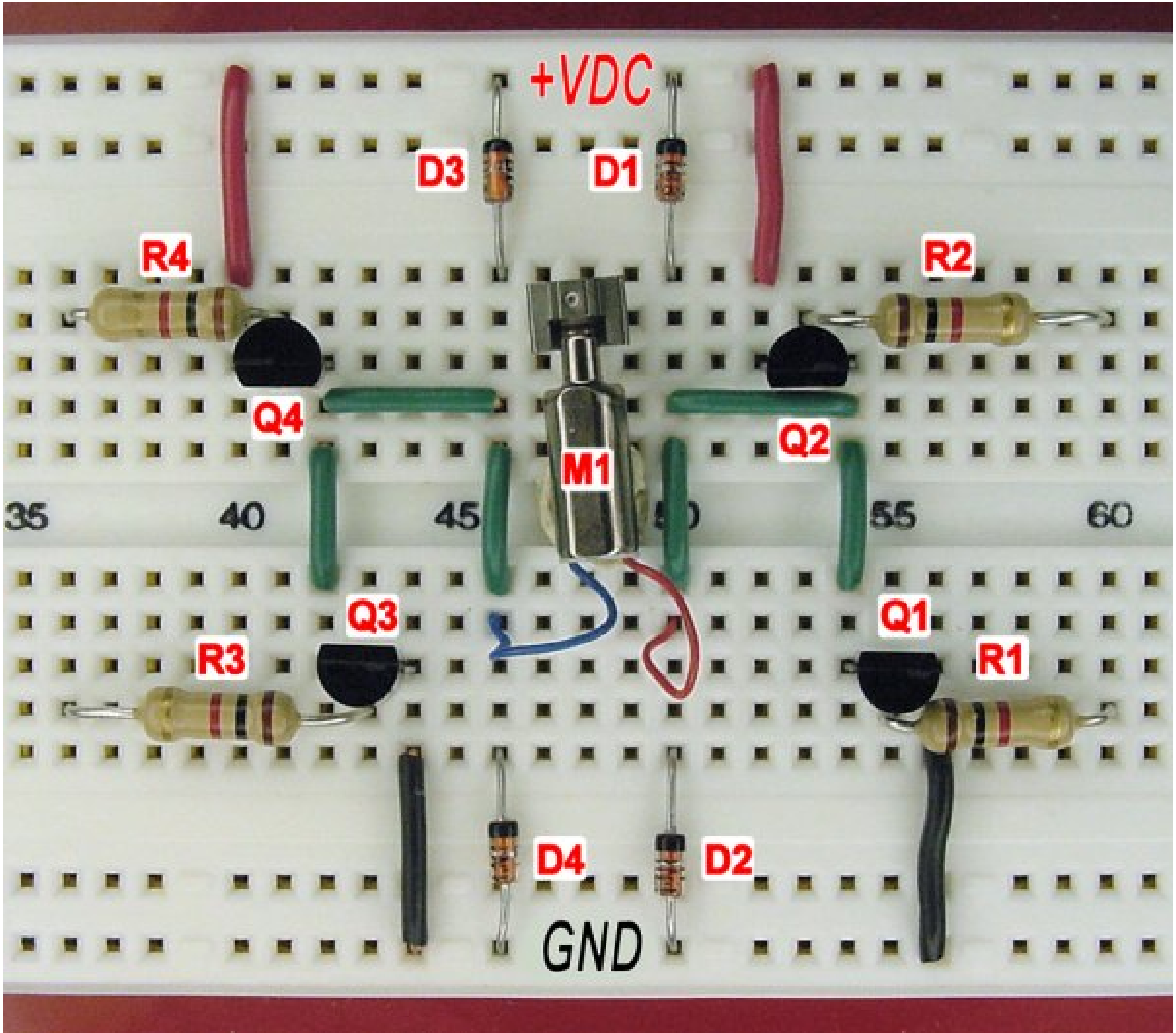
What can happen with messy wiring



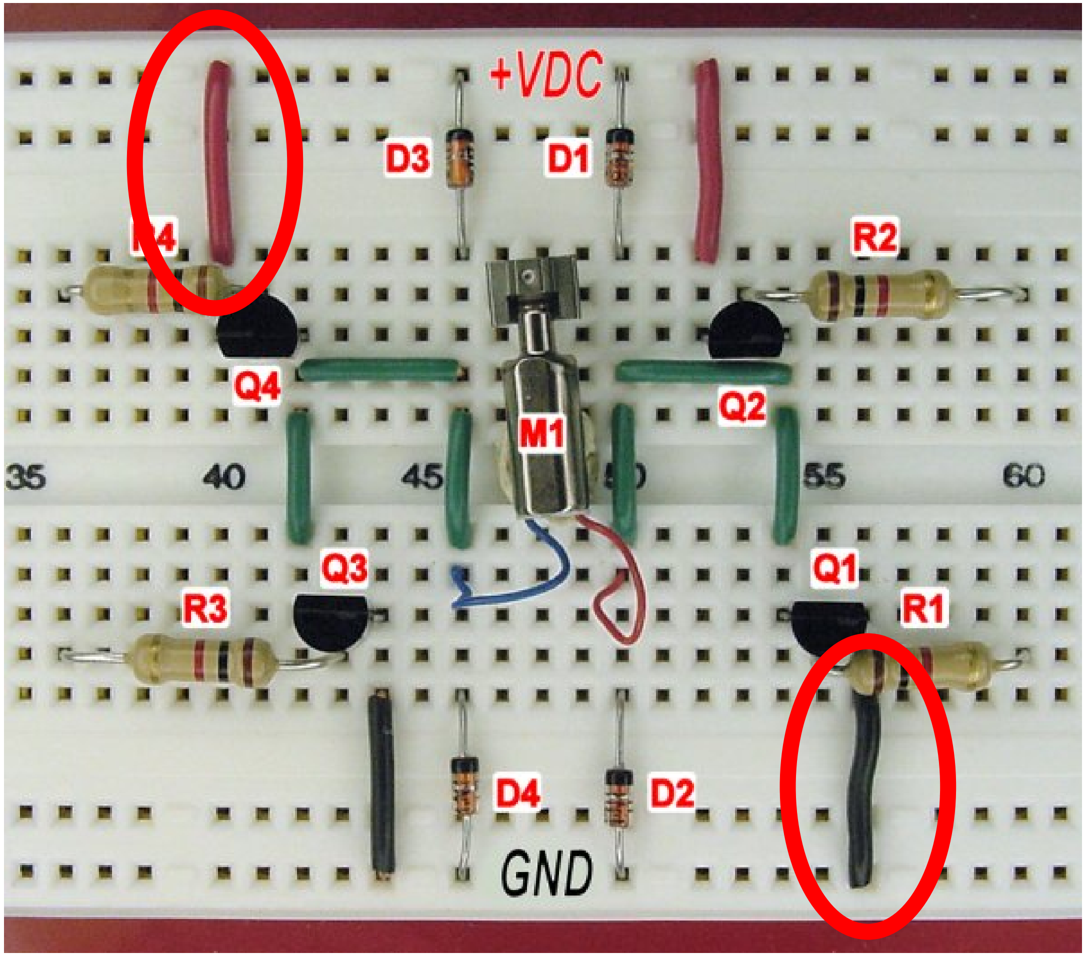
A Neatly Wired Breadboard



Another one…

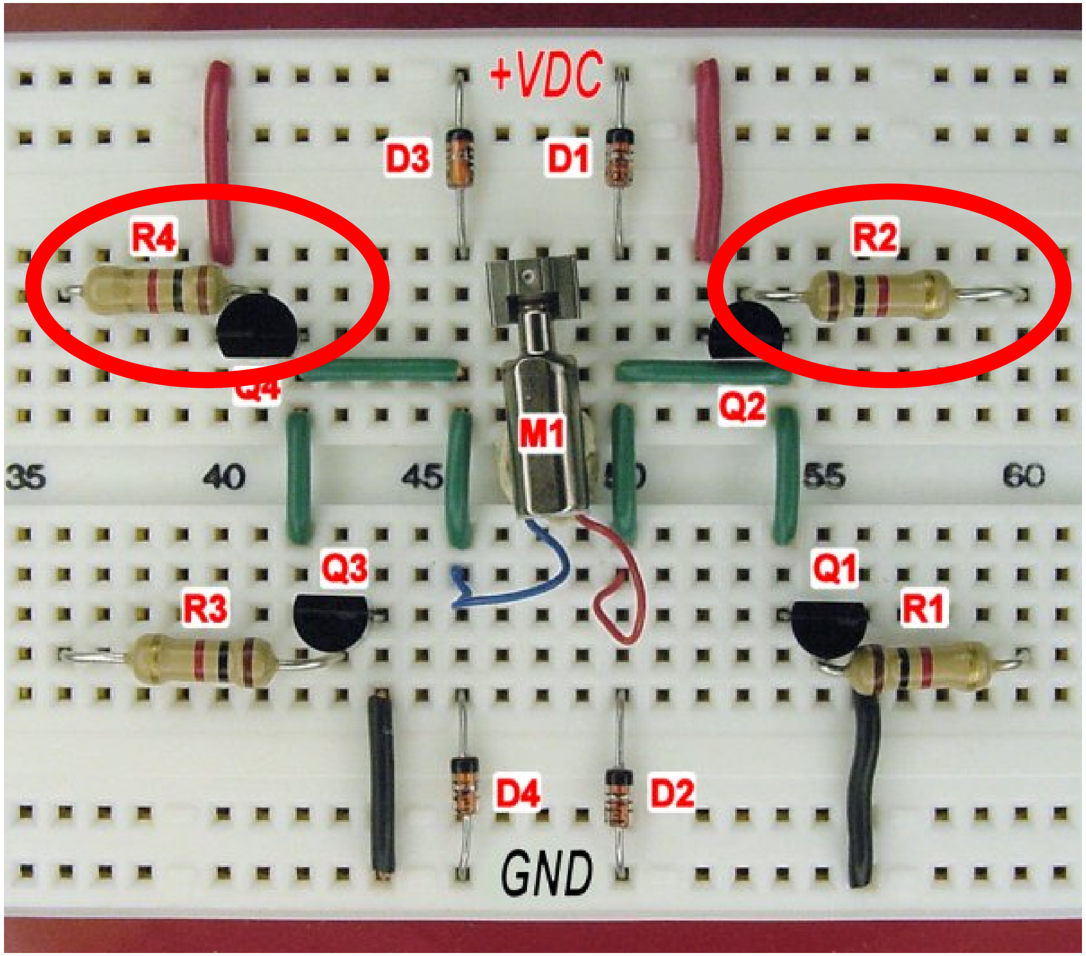


Good practices



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
  - http://www.flashwebhost.com/circuit/index.php
  - http://www.juliantrubin.com/fairprojects/electronics/radio.html
  - http://my.integritynet.com.au/purdic/
- 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)
- http://www.ee.iitm.ac.in/ nagendra/E4332/2005/handouts/digital-clock.pdf
  - 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