- Tools & Safety
- Resonance
- Bode Plots
- Wires – theory vs reality
- Amplitude Modulation
- Diodes

2 handouts
lecture notes
pset1

Acknowledgements:
Lecture material adapted from Prof Qing Hu & Prof Jae Lim, 6.003
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Lab & Checkoff Logistics

- Open lab with no scheduled lab sessions – lab can be done any time the lab is open.
- Start early – 32 students with 17 + 6 lab stations
- Staffed lab hours posted.
- Material on cart and round table; additional parts available from parts bins near the center columns and from EDS 38-500.
- Lab reports should be turned in for grading.

Tools & Safety

- Correct tools makes life easier!
- Understand power ratings.
- All EECS Instructional Laboratories lab kit voltages are **below 50 volts peak or 50 volts DC**. See staff if you are working with voltages greater than 50 volts.
- All students must read and sign the safety form
  https : / / eecs-ug.scripts.mit.edu:444/safety/index.py/6.101

Decibel (dB) – 3dB point

$$dB = 20\log\left(\frac{V_o}{V_i}\right) \qquad dB = 10\log\left(\frac{P_o}{P_i}\right)$$

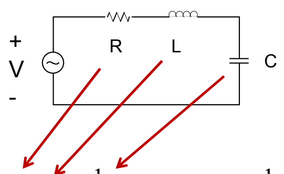
$\log_{10}(2)$=.301

3 dB point = ?

half power point

100 dB =	100,000	= 10^5
80 dB =	10,000	= 10^4
60 dB =	1,000	= 10^3
40 dB =	100	= 10^2

Resonance (Series RLC) – Key points



$$Z = R + sL + \frac{1}{sC} = R + j(\omega L - \frac{1}{\omega C})$$

- Applies to more complex RLC circuits
- At resonance: power is maximum
- At resonance: phase angle zero, i.e. capacitive reactance = inductive reactance, or impedance is real

Bandwidth and Q (Series RLC)

- BW (hertz) = $\frac{\omega_h - \omega_l}{2\pi} = \frac{R}{2\pi L}$
- Q* (quality factor, radians) $\frac{resonant \;\; frequency}{bandwidth}$

$$Q = \frac{1}{R}\sqrt{\left(\frac{L}{C}\right)}$$

- Higher Q implies more selectivity

*Agarwal/Lang Foundation of Analog Digital Elect Circuits equation 14.47, p 794

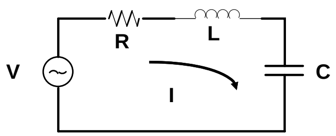
Summary – Parallel Series RLC

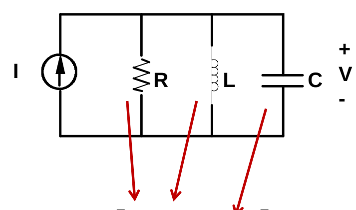
Parallel	Series
$f_O = \frac{1}{2\pi\sqrt{LC}}$	$f_O = \frac{1}{2\pi\sqrt{LC}}$
$Q = 2\pi \; f_o RC$	$Q = \frac{2\pi \; f_O L}{R}$
$BW = (f_h - f_l) = \frac{1}{2\pi RC}$	$BW = (f_h - f_l) \;\; = \frac{R}{2\pi L}$

$$\omega_0 = \frac{1}{\sqrt{LC}} = 2\pi f_0$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Series Parallel Duality





$$V = I\left[R + jwL + \frac{1}{jwC}\right] \qquad I = V\left[\frac{1}{R} + \frac{1}{jwL} + jwC\right]$$

Series		Parallel
V	⟷	I
R	⟷	1/R
L	⟷	C
C	⟷	L

TABLE 32.1 *Analogies Between Electrical and Mechanical Systems*

Electric Circuit		One-Dimensional Mechanical System
Charge	$Q \leftrightarrow x$	Position
Current	$I \leftrightarrow v_x$	Velocity
Potential difference	$\Delta V \leftrightarrow F_x$	Force
Resistance	$R \leftrightarrow b$	Viscous damping coefficient
Capacitance	$C \leftrightarrow 1/k$	(k = spring constant)
Inductance	$L \leftrightarrow m$	Mass
Current = time derivative of charge	$I = \frac{dQ}{dt} \leftrightarrow v_x = \frac{dx}{dt}$	Velocity = time derivative of position
Rate of change of current = second time derivative of charge	$\frac{dI}{dt} = \frac{d^2Q}{dt^2} \leftrightarrow a_x = \frac{dv_x}{dt} = \frac{d^2x}{dt^2}$	Acceleration = second time derivative of position
Energy in inductor	$U_L = \frac{1}{2}LI^2 \leftrightarrow K = \frac{1}{2}mv^2$	Kinetic energy of moving object
Energy in capacitor	$U_C = \frac{1}{2}\frac{Q^2}{C} \leftrightarrow U = \frac{1}{2}kx^2$	Potential energy stored in a spring
Rate of energy loss due to resistance	$I^2R \leftrightarrow bv^2$	Rate of energy loss due to friction
RLC circuit	$L\frac{d^2Q}{dt^2} + R\frac{dQ}{dt} + \frac{Q}{C} = 0 \leftrightarrow m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$	Damped object on a spring

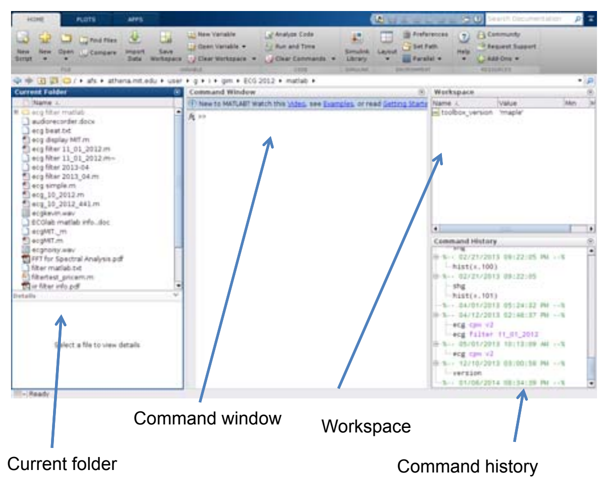
*https://web.njit.edu/~levyr/Physics_121/chapter32.**ppt***

Bode Plot - Review

- A Bode plot is a graph of the magnitude (in dB) or phase of the transfer function versus frequency.
- Magnitude plot on log-log scale
  – Slope: 20dB/decade, same as 6dB/octave
- Bode plot provides insight into impact of RLC in frequency response.
- Stable networks must always have poles and zeroes in the left-half plane.

MATLAB

- Matlab windows: current folder, command, work space (workspace), command history (commandhistory)
- Set folder to your favorite folder
- Built in help in command window
- docking/undocking



MATLAB commands

- % comment delimiter
- MATLAB arrays starts with index=1
  – a = [4,5,6] is a row vector a(2)=5
  – b = [7;8;9] is a column vector
- ";" don't print values
- Variables are case sensitive
- Variables must start with a letter $A \neq a$
- who/whos: list the current variables in short/long form
- shg – show recent graph, pop to the front
- use apostrophes for FILENAME
- format shortENG – display engineering notation

MATLAB

pi	3.14159265
i,j	sqrt(-1) imaginary unit
zeros(n,m)	an n x m matrix of zeros
ones(n,m)	an n x m matrix of ones
+ -	addition, subtraction
*/ ^	multiplication, division, power
sqrt	square root

MATLAB Matrix Operation

```
>> a=[2,3,4]
a =     2    3    4

>> b=[1,0,0]
b =    1    0    0

>> c=a+b
c =    3    3    4

>> d=a*b  % dot product operation
??? Error using ==> mtimes
Inner matrix dimensions must agree.

>> d=a.*b
d =    2    0    0

>> e=a*b'  % ' transpose
e =    2
```

MATLAB Flow Control

- if else statement

```
if a == 0
    b = a;
else
     b = 1/a;
end
```

- for loop

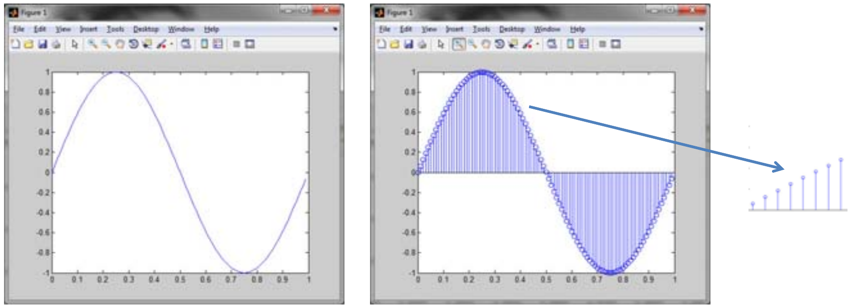
```
n = 100
for m = 1:n
    a(m) = a(m) + 1;
end
```

- while loop

```
n = 10
while n > 0
    n = n – 1
end
```

MATLAB example sin(x)

```
>> t=[0:1/100:1-1/100]; % create t from 0 to .99,  100 values
>> x=sin(2*pi*t);
>> plot(t, x);
>> stem(t,x);
>> shg
```



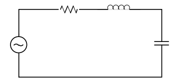
MATLAB Functions bode, freqs

- BODE(SYS,W) uses the vector W of frequencies (in radians/TimeUnit) to evaluate the frequency response
- [MAG,PHASE] = BODE(SYS,W) and [MAG,PHASE,W] = BODE(SYS) return the response magnitudes and phases in degrees (along with the frequency vector W if unspecified).
- SYS is the transfer function expressed as numerator and denominator in the form

$$SYS = \frac{d + eS}{aS^2 + bS + c}$$

- bode(num,denom,range)
  num=[d e], denom=[a b c], range= desired freqencies in radians
- freqs(num,denom,range) plots frequency response and phase angle

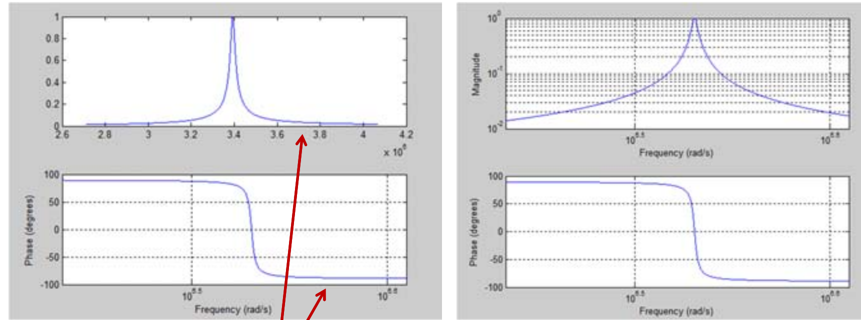
Bode vs Freqs Plots



$$\frac{I(s)}{V(s)} = \frac{1}{Z(s)} = \frac{\frac{s}{L}}{s^2 + \frac{R}{L}s + \frac{1}{LC}}$$

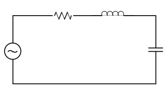
R=1 L=47uh C=1.8nf f=540khz

```
format shortENG
num=[1/L 0]
denom=[1 R/L 1/(L*C)]
f=1/(2*pi*sqrt(L*C))
w=2*pi*f
w_range = [.8*w:20:1.2*w];
h=bode(num,denom,w_range);
magh=abs(h);
plot(w_range,magh)
shg
freqs(num,denom,w_range)
```



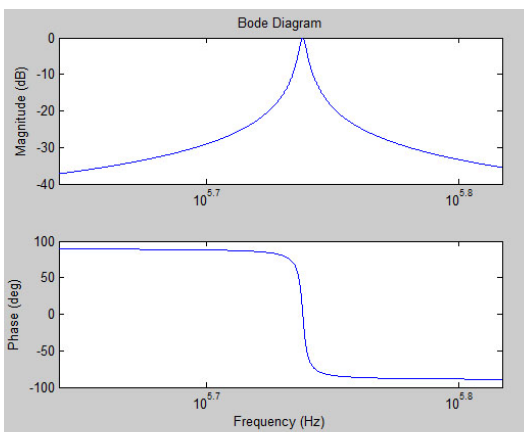
not same scale bode freqs

Bode in Hz



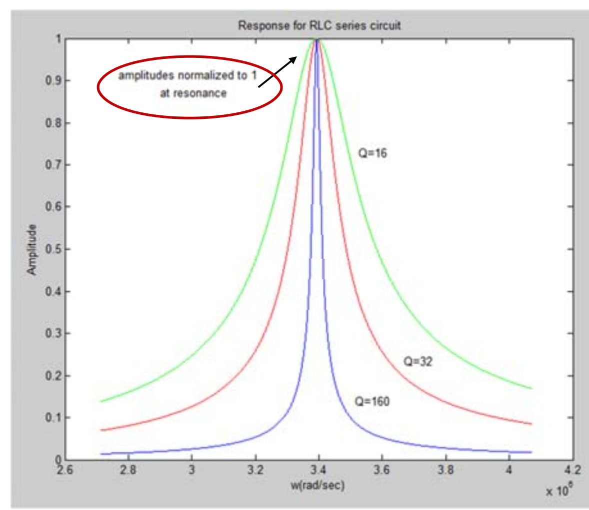
$$\frac{I(s)}{V(s)} = \frac{1}{Z(s)} = \frac{\frac{s}{L}}{s^2 + \frac{R}{L}s + \frac{1}{LC}}$$

R=1 L=47uh C=1.8nf
f=540khz




```
[Mag, Phase, W] = bode(num, denom, w_range);
Freq_Hz = W/2/pi;
Mag_dB = 20*log10(Mag);
subplot(2,1,1)
semilogx(Freq_Hz, Mag_dB)
title('Bode Diagram')
ylabel('Magnitude (dB)')
subplot(2,1,2)
semilogx(Freq_Hz,Phase)
xlabel('Frequency (Hz)')
ylabel('Phase (deg)')
shg
```


Selectivity and Q



L=47uh
C=1.8nf
f=540khz

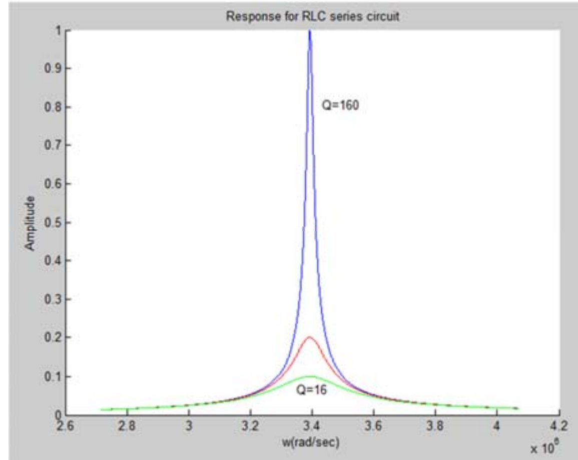
R	Q
1	160
5	32
10	16

```
r=1
l=4.7e-5
c=1.8482e-009
num=[1/l 0]
denom=[1 r/l 1/(l*c)]
f=1/(2*pi*sqrt(l*c))
w=2*pi*f
w_range = [.8*w:20:1.2*w]
[w,mag1]=bode_gh(1,l,c)
[w,mag5]=bode_gh(5,l,c)
[w,mag10]=bode_gh(10,l,c)
hold on
plot(w,mag1)
plot(w,mag5/max(mag5),'r-')
shg
plot(w,mag10/max(mag10),'g-')
shg
xlabel('w(rad/sec)')
shg
ylabel('Amplitude')
shg
title(' Response for RLC series circuit')
shg
```

```
bw1=1/(2*pi*l)
q1=f/bw1
bw5=5/(2*pi*l)
q5=f/bw5
bw10=10/(2*pi*l)
q10=f/bw10

>> bw1=1/(2*pi*l)
bw1 =  3.3863e+003
>> f
f =  5.4000e+005
>> q1=f/bw1
q1 =  159.4683
>> bw5=5/(2*pi*l)
bw5 =  1.6931e+004
>> q5=f/bw5
q5 =   31.8937
>> bw10=10/(2*pi*l)
bw10 =  3.3863e+004
>> q10=f/bw10
q10 =   15.9468
```


Selectivity and Q



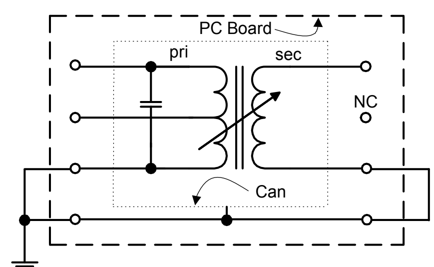
L=47uh
C=1.8nf
f=540khz

R	Q
1	160
5	32
10	16

Lab 1 Topics

- Resonance, Q, bandwidth
- Transformers and impact on load and bandwidth
- Diode detector, demodulation
- Simple AM transmitter and receiver

Proper External Grounding for Lab 1 IF Transformer



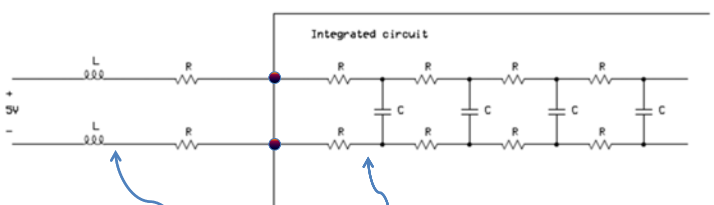
Schematics & Wiring

- IC power supply connections generally not drawn. All integrated circuits need power!
- Use standard color coded wires to avoid confusion.
  - red: positive
  - black: ground or common reference point
  - Other colors: signals
- Circuit flow, signal flow left to right
- Higher voltage on top, ground negative voltage on bottom
- Neat wiring helps in debugging!

Wire Gauge

- Wire gauge: diameter is inversely proportional to the wire gauge number. Diameter increases as the wire gauge decreases. 2, 1, 0, 00, 000(3/0) up to 7/0.
- Resistance
  - 22 gauge .0254 in 16 ohm/1000 feet
  - 12 gauge .08 in 1.5 ohm/1000 feet
  - High voltage AC used to reduce loss
- 1cm cube of copper has a resistance of 1.68 micro ohm (resistance of copper wire scales linearly : length/area)

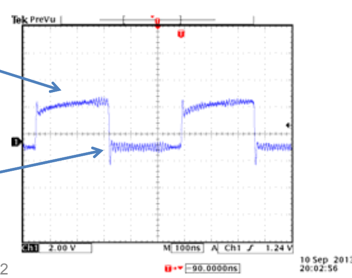
Wires Theory vs Reality - Lab 1



30-50mv voltage drop in chip

Wires have inductance and resistance

power supply noise



$L\frac{di}{dt}$ noise during transitions

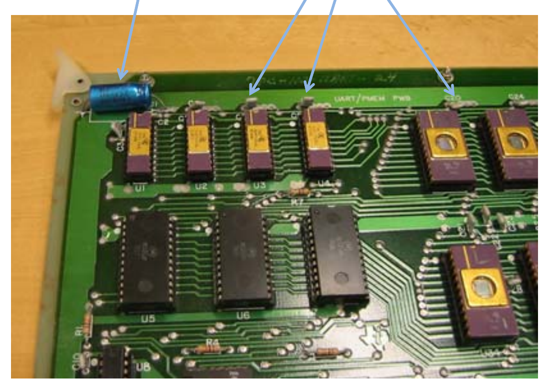
Voltage drop across wires

LC ringing after transitions

Bypass (Decoupling) Capacitors

Electrolytic Capacitor 10uf

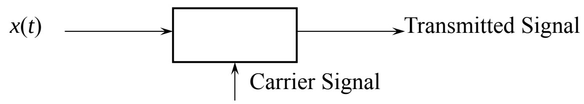
Bypass capacitor 0.1uf typical



Through hole PCB (ancient) shown for clarity.

- Provides additional filtering from main power supply
- Used as local energy source – provides peak current during transitions
- Provided decoupling of noise spikes during transitions
- Placed as close to the IC as possible.
- Use small capacitors for high frequency response.
- Use large capacitors to localize bulk energy storage

The Concept of Modulation (modulating a carrier)



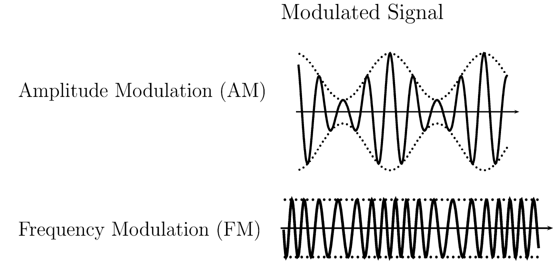
Why?

- More efficient to transmit E&M signals at higher frequencies.
- Transmitting multiple signals through the same medium using different carriers.
- Increase signal/noise ratio in lock-in measurements.
- others...

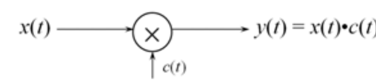
How?

- *Many* methods

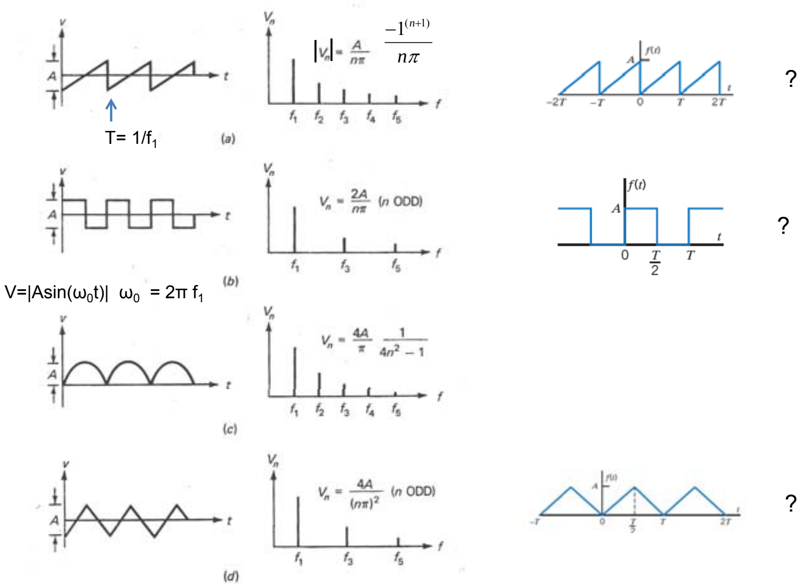
Two of Many Methods of Modulation



Focus is on
Amplitude Modulation (AM)



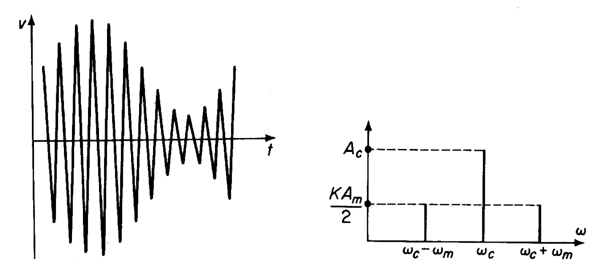
Fourier Series



Time Domain Analysis

$$v = (A_c + KA_m \cos\omega_m t) * \cos\omega_c t$$

$$v = A_c \cos\omega_c t + \frac{KA_m}{2}[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t]$$



*A*mplitude *M*odulation (AM) of a Complex Exponential Carrier

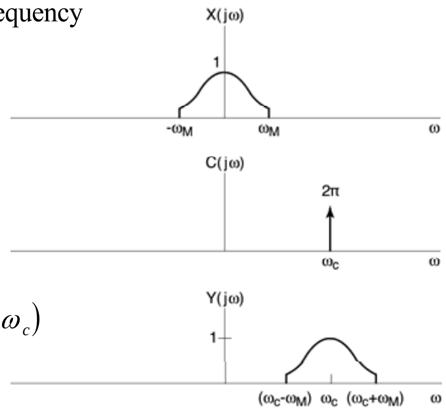
$c(t) = e^{j\omega_c t}, \ \omega_c$ — carrier frequency

$y(t) = x(t)\, e^{j\omega_c t}$

$$Y(j\omega) = \frac{1}{2\pi} X(j\omega) * C(j\omega)$$

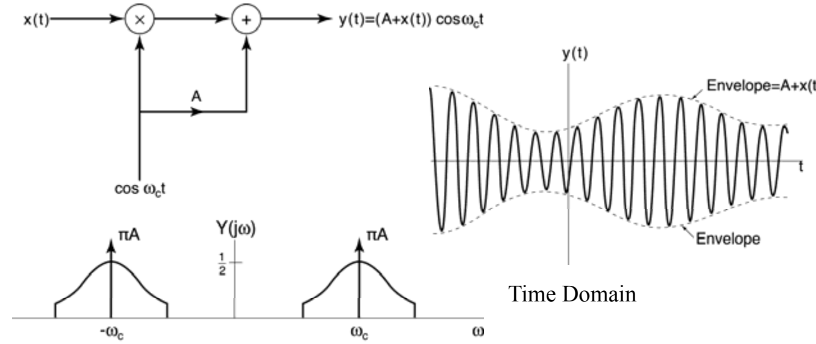
$$= \frac{1}{2\pi} X(j\omega) * 2\pi\delta(\omega - \omega_c)$$

$$= X\left(j(\omega - \omega_c)\right)$$



Asynchronous Demodulation

- Assume $\omega_c >> \omega_M$, so signal envelope looks like $x(t)$
- Add same carrier

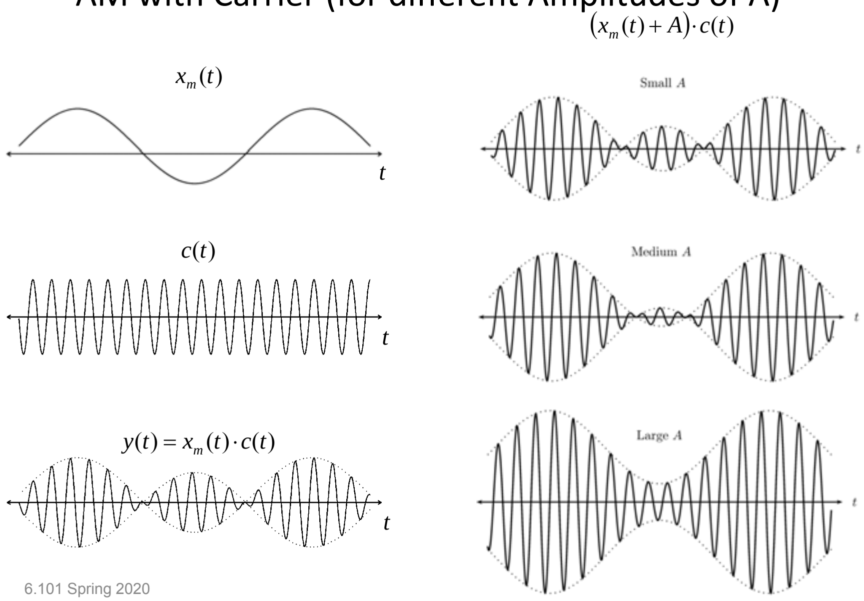


Frequency Domain

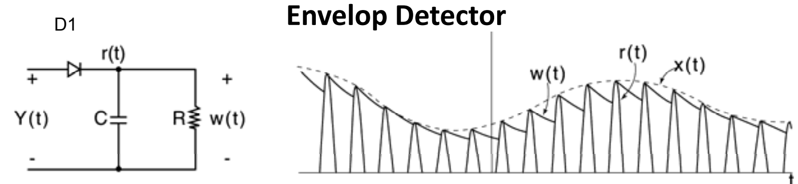
Time Domain

A + *x*(*t*) > 0 why?

AM with Carrier (for different Amplitudes of A)



Asynchronous Demodulation (continued)
Envelop Detector



In order for it to function properly, the envelop function must be positive definite, *i.e.* $A + x(t) > 0$.

Simple envelop detection for asynchronous demodulation.

D1: 1N914 or 1N4148

Disadvantages of asynchronous demodulation:

Requires extra transmitting power.

Units

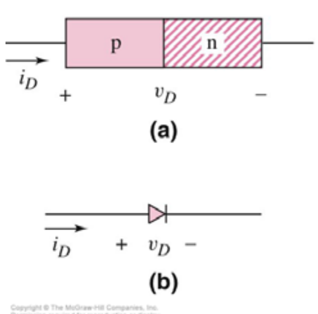
					Quantification For Electronic Elements				
		femto 10^{-15}	pico 10^{-12}	nano 10^{-9}	micro 10^{-6}	milli 10^{-3}	centi 10^{-2}	deci 10^{-1}	Other Important Ratings
					VALUES LESS THAN ONE				
UNIT	QUANTITY								
Ampere	Current	fA	pA	nA	µA	mA			
Farad	Capacitance	fF	pF	nF	µF	[mF]			Voltage Rating, Ripple Current Rating
Henry	Inductance				µH	mH			Current Rating
Hertz	Frequency								
Ohm	Impedance, Resistance					mΩ			Power Rating
Volt	EMF, PD			nV	µV	mV			
Watt	Power	fW	pW	nW	µW	mW			
					Values One And Greater				
UNIT	QUANTITY	[units] 10^{0}	deca 10^{1}	hecto 10^{2}	kilo 10^{3}	mega 10^{6}	giga 10^{9}	tera 10^{12}	
Ampere	Current	A							
Farad	Capacitance	F							Voltage Rating, Ripple Current Rating
Henry	Inductance	H							Current Rating
Hertz	Frequency	Hz			kHz	MHz	GHz		
Ohm	Imped, Resis	Ω			kΩ	MΩ			Power Rating
Volt	EMF, PD	V			kV				
Watt	Power	W			kW				

Standard Values

TABLE I Standard Decade Values (Industry and Military Standards), Preferred Values for Resistors, Capacitors, Zener Diodes

*	±1%	±2%	*	±1%	±2%	*	±1%	±2%	*	±1%	±2%	*	±1%	±2%	*	±1%	±2%	±5%	±10%	±20%
1.00	1.00	1.00	1.47	1.47	1.47	2.15	2.15	2.15	3.16	3.16	3.16	4.64	4.64	4.64	6.81	6.81	6.81	1.00	1.00	1.00
1.01			1.49			2.18			3.20			4.70			6.90			1.10		
1.02	1.02		1.50	1.50		2.21	2.21		3.24	3.24		4.75	4.75		6.98	6.98		1.20	1.20	
1.04			1.52			2.23			3.28			4.81			7.06			1.30		
1.05	1.05	1.05	1.54	1.54	1.54	2.26	2.26	2.26	3.32	3.32	3.32	4.87	4.87	4.87	7.15	7.15	7.15	1.50	1.50	1.50
1.06			1.56			2.29			3.36			4.93			7.23			1.60		
1.07	1.07		1.58	1.58		2.32	2.32		3.40	3.40		4.99	4.99		7.32	7.32		1.80	1.80	
1.09			1.60			2.34			3.44			5.05			7.41			2.00		
1.10	1.10	1.10	1.62	1.62	1.62	2.37	2.37	2.37	3.48	3.48	3.48	5.11	5.11	5.11	7.50	7.50	7.50	2.20	2.20	2.20
1.11			1.64			2.40			3.52			5.17			7.59			2.40		
1.13	1.13		1.65	1.65		2.43	2.43		3.57	3.57		5.23	5.23		7.68	7.68		2.70	2.70	
1.14			1.67			2.46			3.61			5.30			7.77			3.00		
1.15	1.15	1.15	1.69	1.69	1.69	2.49	2.49	2.49	3.65	3.65	3.65	5.36	5.36	5.36	7.87	7.87	7.87	3.30	3.30	3.30
1.17			1.72			2.52			3.70			5.42			7.96			3.60		
1.18	1.18		1.74	1.74		2.55	2.55		3.74	3.74		5.49	5.49		8.06	8.06		3.90	3.90	
1.20			1.76			2.58			3.79			5.56			8.16			4.30		
1.21	1.21	1.21	1.78	1.78	1.78	2.61	2.61	2.61	3.83	3.83	3.83	5.62	5.62	5.62	8.25	8.25	8.25	4.70	4.70	4.70
1.23			1.80			2.64			3.88			5.69			8.35			5.10		
1.24	1.24		1.82	1.82		2.67	2.67		3.92	3.92		5.76	5.76		8.45	8.45		5.60	5.60	
1.26			1.84			2.71			3.97			5.83			8.56			6.20		
1.27	1.27	1.27	1.87	1.87	1.87	2.74	2.74	2.74	4.02	4.02	4.02	5.90	5.90	5.90	8.66	8.66	8.66	6.80	6.80	6.80
1.29			1.89			2.77			4.07			5.97			8.76			7.50		
1.30	1.30		1.91	1.91		2.80	2.80		4.12	4.12		6.04	6.04		8.87	8.87		8.20	8.20	
1.32			1.93			2.84			4.17			6.12			8.98			9.10		
1.33	1.33	1.33	1.96	1.96	1.96	2.87	2.87	2.87	4.22	4.22	4.22	6.19	6.19	6.19	9.09	9.09	9.09			
1.35			1.98			2.91			4.27			6.26			9.20					
1.37	1.37		2.00	2.00		2.94	2.94		4.32	4.32		6.34	6.34		9.31	9.31				
1.38			2.03			2.98			4.37			6.42			9.42					
1.40	1.40	1.40	2.05	2.05	2.05	3.01	3.01	3.01	4.42	4.42	4.42	6.49	6.49	6.49	9.53	9.53	9.53			
1.42			2.08			3.05			4.48			6.57			9.65					
1.43	1.43		2.10	2.10		3.09	3.09		4.53	4.53		6.65	6.65		9.76	9.76				
1.45			2.13			3.12			4.59			6.73			9.88					
* +/-0.1%, +/-0.25%, and +/-0.5%												Values per decade			192	96	48	24	12	6

Diodes



$$I_D = I_s\left(e^{\frac{qv_D}{kT}} - 1\right)$$

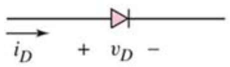
kT/q is also known as the thermal voltage, V_T.

V_T = 25.9 mV = ~ 26mv when T = 300K, room temperature.

Finger Tips Facts

- Current thru pn junction doubles for every 26mv (at room temperature) or 10x for every 60mv
- Temperature coefficient of silicon diode is ~2mv/degC at room temperature
- Small signal resistance of pn junction is
  1 ohm @26 ma, 26 ohm @1ma

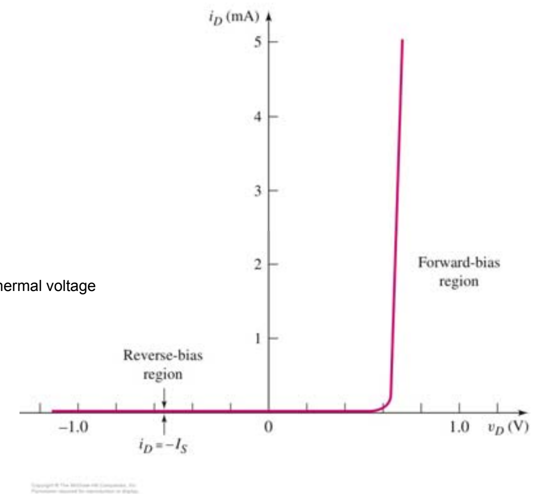
Diode V-I Characteristic



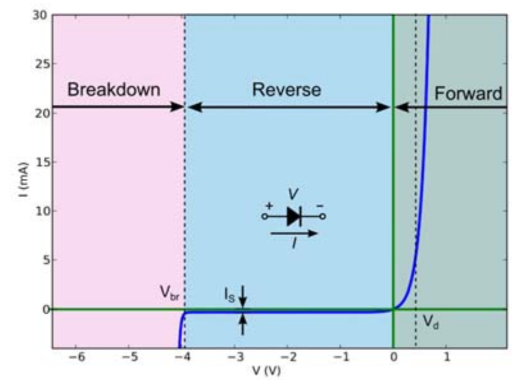
$$I_D \cong I_s e^{\frac{qv_D}{kT}}$$

$$\frac{kT}{q} = 26mv$$ ← thermal voltage

$$I_s = 10pa$$



Reverse Breakdown Voltage

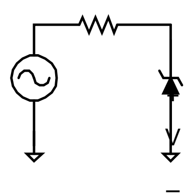


http://en.wikipedia.org/wiki/File:Diode_current_wiki.png

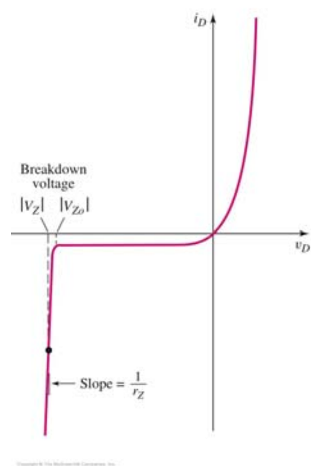
Low doped diodes have higher breakdown voltage

Zener Diode

4.7k



- Zener diodes will maintain a fixed voltage by breaking down at a predefined voltage (zener voltage).



Zener Breakdown

- Actually caused by two effects: avalanche effect and zener effect.
- Avalanche effect: electron/holes entering depletion region is accelerating by the electric field, collides and creates additional electron/hole pairs – like a snow avalanche; occurs above 5.6V; has positive temperature coefficient
- Zener effect: heavy doping of PN junction results in a thin depletion layer. Quantum tunneling results in current flow; occurs below 5.6V; has negative temperature coefficient
- At 5.6V, two effects balance is near zero temperature coefficient.

Silicon Zener Diode Series

1N746 thru 1N759, 1N4370A thru 1N4372A

Features

- Available in JAN, JANTX and JANTXV per MIL-PRF-19500/127
- Double Plug Construction
- Metallurgically Bonded
- Also available in DO-213 MELF style package

Maximum Ratings

Operating Temperature: -65°C to +175°C
Storage Temperature: -65°C to +175°C
DC Power Dissipation: 500 mW @ +50°C
Power Derating: 4 mW / °C above +50°C
Forward Voltage @ 200mA: 1.1 volts maximum

Electrical Specifications @ +25 °C (Unless Otherwise Specified)

JEDEC TYPE NUMBER (NOTE 1)	NOMINAL ZENER VOLTAGE V_Z @ I_{ZT}	ZENER TEST CURRENT I_{ZT} (NOTE 2)	MAXIMUM ZENER IMPEDANCE (NOTE 3) Z_{ZT} @ I_{ZT}	MAXIMUM REVERSE CURRENT I_R @ V_R		MAXIMUM ZENER CURRENT I_{ZM}
	VOLTS	mA	OHMS	µA	VOLTS	mA
1N4370A	2.4	20	30	100	1.0	155
1N4371A	2.7	20	30	60	1.0	140
1N4372A	3.0	20	29	30	1.0	125
1N746A	3.3	20	28	5	1.0	120
1N747A	3.6	20	24	3	1.0	110
1N748A	3.9	20	23	2	1.0	100
1N749A	4.3	20	22	2	1.0	90
1N750A	4.7	20	19	5	1.5	85
1N751A	5.1	20	17	5	2.0	75
1N752A	5.6	20	11	5	2.5	70
1N753A	6.2	20	7	5	3.5	65
1N754A	6.8	20	5	2	4.0	60
1N755A	7.5	20	6	2	5.0	55
1N756A	8.2	20	8	1	6.0	50
1N757A	9.1	20	10	1	7.0	45
1N758A	10.0	20	17	1	8.0	40
1N759A	12.0	20	30	1	9.0	35

1N4001-1N4007

Ratings and Characteristic Curves (T_A = 25°C unless otherwise noted)

FIG. 1 - FORWARD CURRENT DERATING CURVE

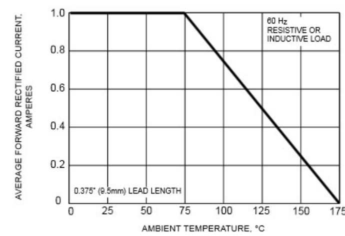


FIG. 2 - MAXIMUM NON-REPETITIVE PEAK FORWARD SURGE CURRENT

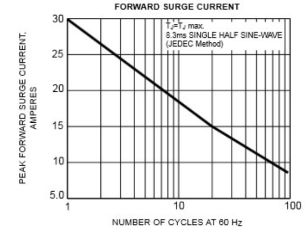


FIG. 3 - TYPICAL INSTANTANEOUS FORWARD CHARACTERISTICS

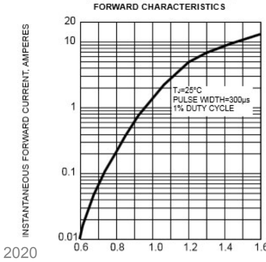
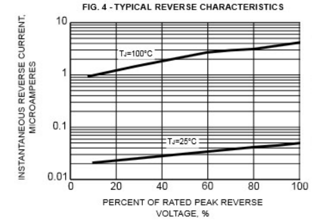
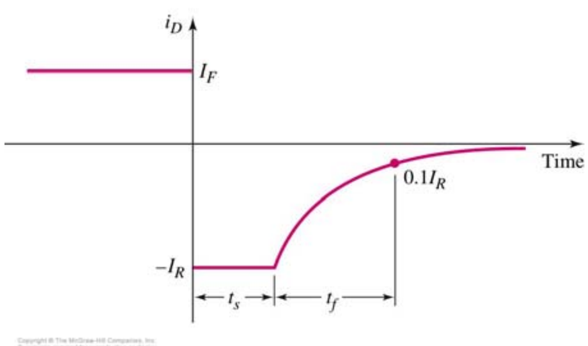


FIG. 4 - TYPICAL REVERSE CHARACTERISTICS



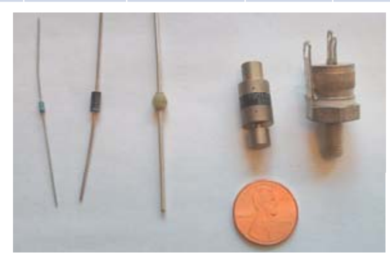
Transient Respopnse



Fast reverese recovery diode needed for switching power supplies

Diodes

Type	Max Vr	Max I Continous	Recovery time	Capaciitance
1N914	75V	10ma	4ns	1.3pf
1N4002	100V	1000ma	3500ns	15pf
1N5625	400	3000ma		40pf
1N1084	4000	30,000ma (peak)		
	400	50,000ma		



1N4001

1N914, 1N4148

1N7XX

Pulse Ox

Diode types

Diode Name	Diode Symbol	Used for:	Special Characteristics
Rectifier Diode, Fast Switching Rectifier		Converting AC to DC; Linear and switching power supplies	Can be had in very high current capacities, too slow for hf signal use.
Signal Diode		HF rectification, detection	Small t_r = few ns
Zener Diode		Voltage reference, regulation	Used in reverse breakdown
Light-emitting Diode [LED]		Indication, 7-segment displays	V_F 's vary with color
Photodiode		Light detection, mech.-electrical conversion; solar cell	Reverse current is increased by light; in FWD direction=solar cell
Optocoupler		Electrical isolation	LED and photodiode in an opaque package
Schottky Diode		VHF rectification, detecting small signals	No stored charges, >300 MHz, 0.25V V_F [metal jn]
Varactor Diode		Tuning radio and TV receivers	Fairly linear C with V_R
Varistor		AC line spike protection	2 back-back zeners
Current Regulator		Constant current source	
Step-recovery Diode		"snap" diode generates harmonics, f multipliers	Exploits reverse-current phenomenon
Back Diode		Very small signal rectification	V_R smaller than V_F
Tunnel Diode		High frequency oscillators	Part of forward char. has negative resistance
Laser Diode		Reading, writing CD, DVD etc.	
PIN Diode		RF switching diode	

Diode Circuits

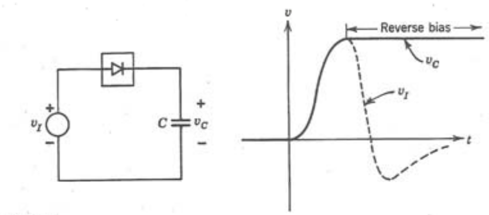
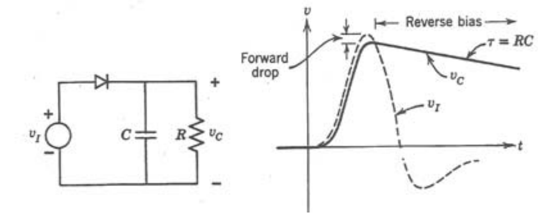
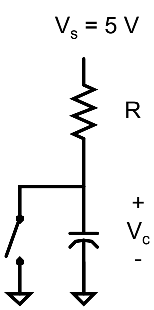


Figure 8.15
Ideal peak sampler.



RC Equation



$V_c = 5\left(1 - e^{-\frac{t}{RC}}\right)$

V_s = 5 V

Switch is closed t<0

Switch opens t>0

$V_s = V_R + V_C$

$V_s = i_R R + V_c \quad i_R = C\frac{dV_c}{dt}$

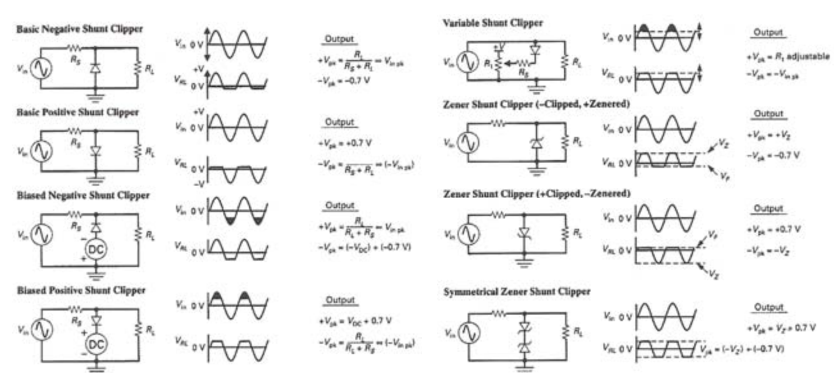
$V_s = RC\frac{dV_c}{dt} + V_c$

$$V_c = V_s\left(1 - e^{-\frac{t}{RC}}\right)$$

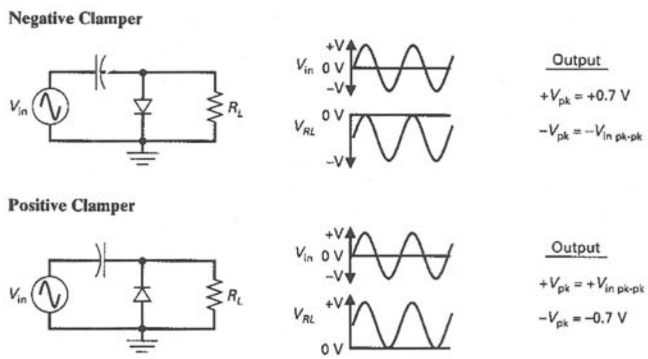
$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots = \sum_{n=0}^{\infty} \frac{x^n}{n!}$$

Is RC in units of time?

More Diode Circuits



Clamping Circuit

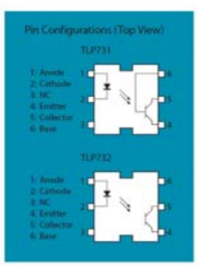


RC time constant limitation

Light Emitting Diode

- LED's are pn junction devices which emit light. The frequency of the light is determined by a combination of gallium, arsenic and phosphorus.
- Red, yellow and green LED's are in the lab
- Diodes have polarity
- Typical forward current 10-20ma

Optical Isolators



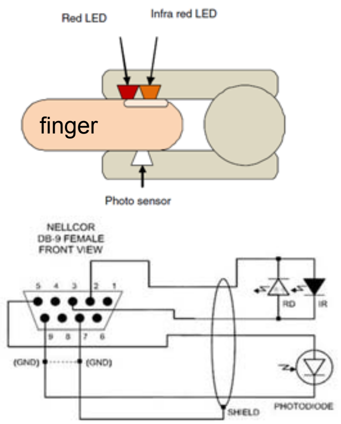
- Optical Isolators are used to transmit information optically without physical contact.
- Single package with LED and photosensor (BJT, thyristor, etc.)
- Isolation up to 4000 Vrms
- Used in pulse-oximetry

Nellcor DS-100 Pulse-ox

Pulse-Oximetery

- A non-invasive photoplethysmographical (PPG) approach for measuring pulse rate and oxygen saturation in blood.
- Oximetry developed in 1972, by Takuo Aoyagi and Michio Kishi
- Commercialized by Biox in 1981 and Nellcor in 1983.

Pulse-Oximetry Sensor



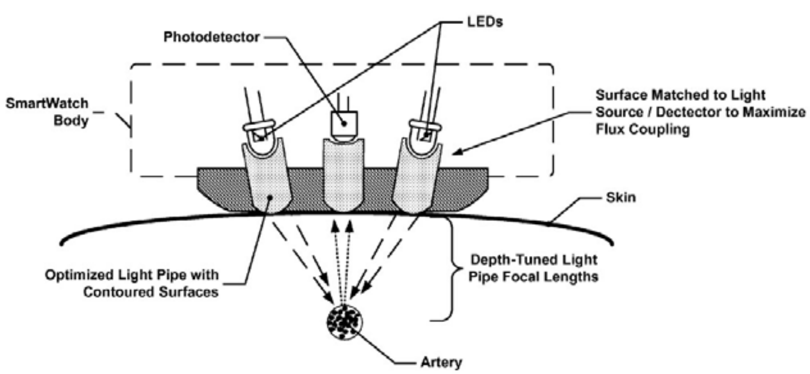
Why plastic DB-9?

http://energymicroblog.files.wordpress.com/2012/11/figure-1.png

Pulse-Oximetry

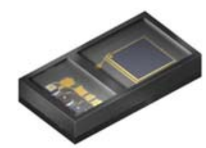
- Two measurements:
  – Pulse rate
  – Oxygen saturation
  – Challenge: measuring 5-20 nA!
- Heart rate easily accomplished with two IC's!

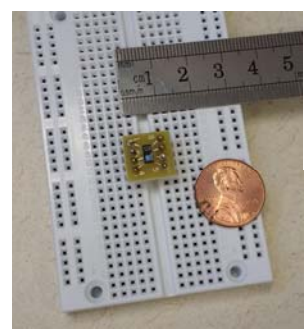
Reflective PPG*

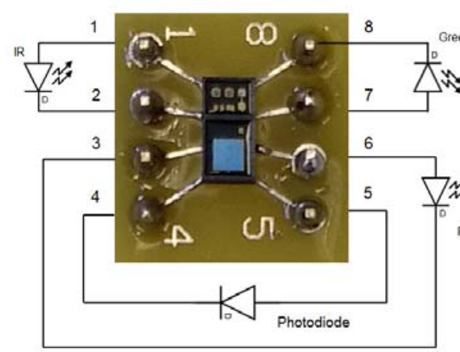


*Fitbit Patent: US 2014/0275852
Wearable Heart Rate Monitor

"Fitbit" Lab

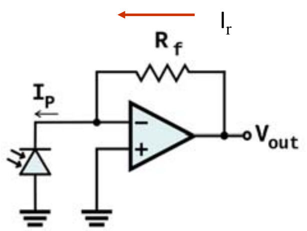






SFH 7050: 3 leds, 1 photodiode in one package

Transimpedance Amplifier
(Current to Voltage Converter)

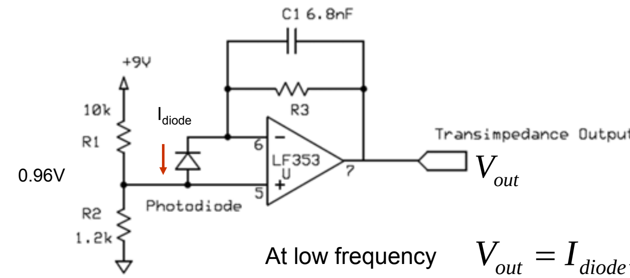


$I_r = I_p$

$V_{out} = I_p R_f$

http://en.wikipedia.org/wiki/File:TIA_simple.svg

Transimpedance Amplifier
(Current to Voltage Converter)

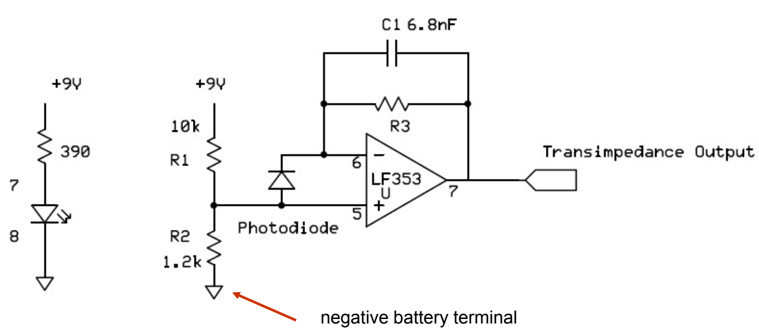


At low frequency $V_{out} = I_{diode} R3$

$$I_{diode} \approx 5x10^{-9} \quad R3 = 4x10^{6}$$

$$V_{out} = 20mv$$

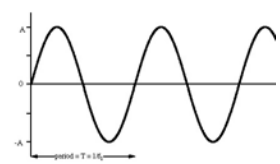
“Fitbit” Lab

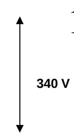


Virtual ground at 4.5V not shown

Voltage

- What is the equation describing the voltage from a 120VAC outlet?
- 120 VAC is the RMS (Root Mean Square Voltage)
- 60 is the frequency in hz
- Peak to peak voltage for 120VAC is 340 volts!

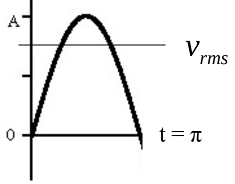


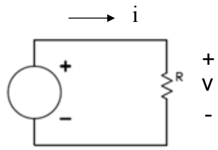


$$120\sqrt{2}\sin 2\pi 60t = 169.7\sin 2\pi 60t$$

RMS Voltage

$v = A \sin t$





- The RMS voltage for a sinusoid is that value which will produce the same heating effect (energy) as an equivalent DC voltage.
- Energy = $\int P dt = \int_0^{\pi} vi dt = \frac{1}{r}\int_0^{\pi} v^2 dt$
- For DC, $\frac{v_{rms}^2 \times \pi}{r}$
- Equating and solving, $\mathbf{A} = \sqrt{2}\, v_{rms}$

RMS Derivation

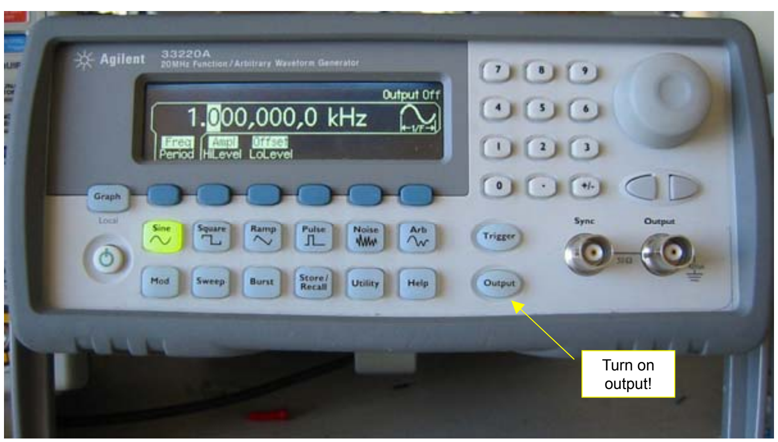
$$\frac{v_{rms}^2 \times \pi}{r} = \frac{1}{r}\int_0^{\pi} v^2 dt = \frac{1}{r}\int_0^{\pi} A^2 \sin^2 t dt$$

$$\int_0^{\pi} \sin^2 dt = [\frac{t}{2} - \frac{1}{4}\sin 2t]_0^{\pi}$$

$$\frac{v_{rms}^2 \pi}{r} = \frac{A^2}{r}[\frac{t}{2} - \frac{1}{4}\sin 2t]_0^{\pi}$$

A = $\sqrt{2}\, v_{rms}$

Agilent Function Generator

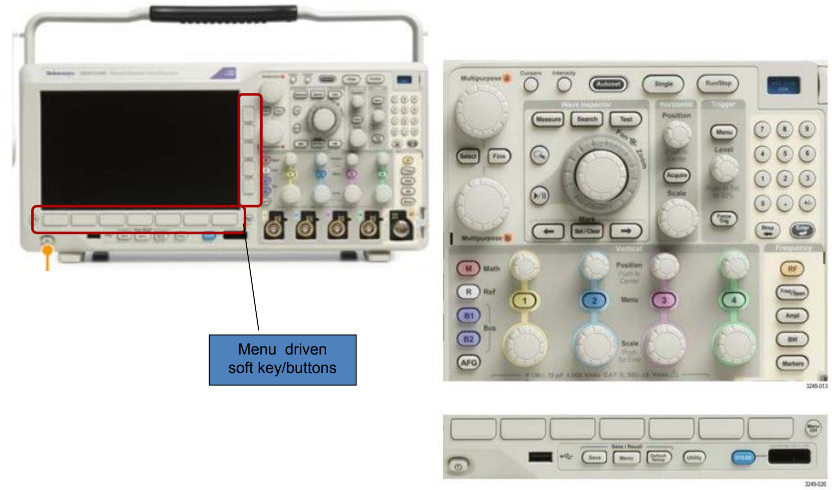


Agilent DMM

Oscilloscope Controls

- Auto Set, soft menu keys
- Trigger
  - channel,
  - slope,
  - Level
- Input
  - AC, DC coupling,
  - 10x probe,
  - 1khz calibration source,
  - probe calibration,
  - bandwidth filter
- Signal measurement
  - time,
  - frequency,
  - voltage
  - cursors
  - single sweep
- Image capture
  Data export

Tektronix Oscilloscope



Agilent Oscilloscope