• Resonance
• Bode Plots
• Wires – theory vs reality
• Amplitude Modulation
• Diodes

Acknowledgements:
Lecture material adapted from Prof Qing Hu & Prof Jae Lim, 6.003
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Decibel (dB) – 3dB point

\[ dB = 20 \log \left( \frac{V_o}{V_i} \right) \]

\[ dB = 10 \log \left( \frac{P_o}{P_i} \right) \]

\[ \log_{10}(2) = 0.301 \]

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
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, workspace (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

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

• for loop

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

• while loop

```matlab
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
```
Resonance (Series RLC) – Key points

- 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

\[
Z = R + sL + \frac{1}{sC} = R + j(\omega L - \frac{1}{\omega C})
\]
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 frequencies in radians

- freqs(num,denom,range) plots frequency response and phase angle
Bode vs Freqs Plots

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

\[ f = \frac{1}{2\pi \sqrt{LC}} \]

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

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)
Bode in Hz

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

\( R=1 \quad L=47\text{uh} \quad C=1.8\text{nf} \quad f=540\text{khz} \)

```matlab
[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
```
Bandwidth and Q (Series RLC)

- \( BW = \omega_2 - \omega_1 = \frac{R}{L} \)

- \( Q^* \) (quality factor)

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

- Higher Q implies more selectivity

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

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

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

<table>
<thead>
<tr>
<th>Series</th>
<th>Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>I</td>
</tr>
<tr>
<td>R</td>
<td>1/R</td>
</tr>
<tr>
<td>L</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
<td>L</td>
</tr>
</tbody>
</table>
Summary – Parallel Series RLC

Parallel

\[ w_o = \frac{1}{\sqrt{LC}} \]

\[ Q = w_o RC \]

\[ BW = \frac{1}{RC} \]

Series

\[ w_o = \frac{1}{\sqrt{LC}} \]

\[ Q = \frac{w_o L}{R} \]

\[ BW = (w_2 - w_1) = \frac{R}{L} \]

\[ \omega_0 = \frac{1}{\sqrt{LC}} = 2\pi f \]

\[ f = \frac{1}{2\pi \sqrt{LC}} \]
Selectivity and Q

L = 47\,\text{uh}
C = 1.8\,\text{nf}
f = 540\,\text{kHz}

<table>
<thead>
<tr>
<th>R</th>
<th>Q</th>
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<tr>
<td>1</td>
<td>160</td>
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<tr>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
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Selectivity and Q

L = 47 uH
C = 1.8 nF
f = 540 kHz

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<th>R</th>
<th>Q</th>
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</tr>
<tr>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
</tr>
</tbody>
</table>
Lab 1 Topics

- Resonance, Q, bandwidth
- Transformers and impact on load and bandwidth
- Diode detector, demodulation
- Simple AM transmitter and receiver
Lab 1

12-100 pF trimmer

L [Antenna]

10 Ω

V_s [Function Generator]

C

R_{source}

Pri-Sec turns ratio = 4:1

Metal shield ["can"]

Pri [3 pins]

SEC [2 pins]

R_{LOAD}

R_{SERIES}

C

[2 pins]
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

Wires have inductance and resistance

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

Voltage drop across wires

LC ringing after transitions

30-50mv voltage drop in chip

Power supply noise
Bypass (Decoupling) Capacitors

- 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

Electrolytic Capacitor 10uf

Bypass capacitor 0.1uf typical

Through hole PCB (ancient) shown for clarity.
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

\[ T = \frac{1}{f_1} \]

\[ V = |A \sin(\omega_0 t)| \quad \omega_0 = 2\pi f_1 \]

\[ V_n = \frac{A}{n\pi} \]

\[ V_n = \frac{2A}{n\pi} \quad (n \text{ ODD}) \]

\[ V_n = \frac{4A}{\pi} \frac{1}{4n^2 - 1} \]

\[ V_n = \frac{4A}{(n\pi)^2} \quad (n \text{ ODD}) \]
Time Domain Analysis

\[ v = A_c \cos \omega_c t \ast KA_m \cos \omega_m t \]

\[ v = A_c \cos \omega_c t + \frac{KA_m}{2} [\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t] \]
**Amplitude Modulation (AM) of a Complex Exponential Carrier**

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

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

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

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

$= X(j(\omega - \omega_c))$
Asynchronous Demodulation

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

\[ y(t) = (A + x(t)) \cos \omega_c t \]
AM with Carrier (for different Amplitudes of A)

\[ (x_m(t) + A) \cdot c(t) \]

\[ x_m(t) \]

\[ c(t) \]

\[ y(t) = x_m(t) \cdot c(t) \]
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

<table>
<thead>
<tr>
<th>Value</th>
<th>femto</th>
<th>pico</th>
<th>nano</th>
<th>micro</th>
<th>milli</th>
<th>centi</th>
<th>deci</th>
<th>Other Important Ratings</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$10^{-15}$</td>
<td>$10^{-12}$</td>
<td>$10^{-9}$</td>
<td>$10^{-6}$</td>
<td>$10^{-3}$</td>
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### VALUES LESS THAN ONE

<table>
<thead>
<tr>
<th>UNIT</th>
<th>QUANTITY</th>
<th>fA</th>
<th>pA</th>
<th>nA</th>
<th>µA</th>
<th>mA</th>
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<tbody>
<tr>
<td>Ampere</td>
<td>Current</td>
<td>fA</td>
<td>pA</td>
<td>nA</td>
<td>µA</td>
<td>mA</td>
</tr>
<tr>
<td>Farad</td>
<td>Capacitance</td>
<td>fF</td>
<td>pF</td>
<td>nF</td>
<td>µF</td>
<td>mF</td>
</tr>
<tr>
<td>Henry</td>
<td>Inductance</td>
<td>µH</td>
<td>mH</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hertz</td>
<td>Frequency</td>
<td>Hz</td>
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<td></td>
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<tr>
<td>Ohm</td>
<td>Impedance, Resistance</td>
<td>nV</td>
<td>µV</td>
<td>mV</td>
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<td></td>
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<tr>
<td>Volt</td>
<td>EMF, PD</td>
<td>nW</td>
<td>µW</td>
<td>mW</td>
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<tr>
<td>Watt</td>
<td>Power</td>
<td>fW</td>
<td>pW</td>
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</table>

### Values One And Greater

<table>
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<tr>
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<th>QUANTITY</th>
<th>[units]</th>
<th>deca</th>
<th>hecto</th>
<th>kilo</th>
<th>mega</th>
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<th>tera</th>
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<tr>
<td>Ampere</td>
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<td>F</td>
<td>H</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Henry</td>
<td>Inductance</td>
<td>H</td>
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<td>Frequency</td>
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<td>Volt</td>
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<td>V</td>
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<td>Power</td>
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</table>

Other Important Ratings: Voltage Rating, Ripple Current Rating, Current Rating, Power Rating.
## Standard Values

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Standard Decade Values (Industry and Military Standards), Preferred Values for Resistors, Capacitors, Zener Diodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>±1%</td>
<td>±2%</td>
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<tr>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>1.01</td>
<td>1.49</td>
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<tr>
<td>1.04</td>
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<td>1.93</td>
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<tr>
<td>1.35</td>
<td>1.98</td>
</tr>
<tr>
<td>1.40</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Values per decade: 192, 96, 48, 24, 12, 6

±0.1%, ±0.25%, and ±0.5%
Diodes

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

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

\( V_T = 25.9 \text{ mV when } T = 300K, \text{ room temperature.} \)
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

\[ I_D \approx I_s e^{\frac{qv_D}{kT}} \]

\[ \frac{kT}{q} = 26 \text{mV} \quad \text{thermal voltage} \]

\[ I_s = 10 \text{pA} \]
Reverse Breakdown Voltage

Low doped diodes have higher breakdown voltage

Zener Diode

- 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)

<table>
<thead>
<tr>
<th>JEDEC Type Number (Note 1)</th>
<th>Nominal Zener Voltage $V_Z @ I_{ZT}$</th>
<th>Zener Test Current $I_Z$ (Note 2)</th>
<th>Maximum Zener Impedance $Z_{ZT} @ I_{ZT}$</th>
<th>Maximum Reverse Current $I_R @ V_R$</th>
<th>Maximum Zener Current $I_{ZM}$</th>
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<tbody>
<tr>
<td>1N4370A</td>
<td>2.4</td>
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<td>30</td>
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<td>1N4371A</td>
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<td>1N4372A</td>
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6.101 Spring 2017
1N4001-1N4007

Ratings and Characteristic Curves (TA = 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

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Transient Response

Fast reverse recovery diode needed for switching power supplies
# Diodes

<table>
<thead>
<tr>
<th>Type</th>
<th>Max Vr</th>
<th>Max I Continuous</th>
<th>Recovery time</th>
<th>Capacitance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1N914</td>
<td>75V</td>
<td>10ma</td>
<td>4ns</td>
<td>1.3pf</td>
</tr>
<tr>
<td>1N4002</td>
<td>100V</td>
<td>1000ma</td>
<td>3500ns</td>
<td>15pf</td>
</tr>
<tr>
<td>1N5625</td>
<td>400</td>
<td>3000ma</td>
<td></td>
<td>40pf</td>
</tr>
<tr>
<td>1N1084</td>
<td>4000</td>
<td>30,000ma (peak)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>50,000ma</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Diode types

<table>
<thead>
<tr>
<th>Diode Name</th>
<th>Diode Symbol</th>
<th>Used for:</th>
<th>Special Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1N4001: Rectifier Diode, Fast Switching Rectifier</td>
<td>![Diode Symbol]</td>
<td>Converting AC to DC, Linear and switching power supplies</td>
<td>Can be had in very high current capacities, too slow for hf signal use.</td>
</tr>
<tr>
<td>1N914, 1N4148: Signal Diode</td>
<td>![Diode Symbol]</td>
<td>HF rectification, detection</td>
<td>Small t&lt;sub&gt;r&lt;/sub&gt; = few ns</td>
</tr>
<tr>
<td>1N7XX: Zener Diode</td>
<td>![Diode Symbol]</td>
<td>Voltage reference, regulation</td>
<td>Used in reverse breakdown</td>
</tr>
<tr>
<td>1N7XX: Light-emitting Diode [LED]</td>
<td>![Diode Symbol]</td>
<td>Indication, 7-segment displays</td>
<td>V&lt;sub&gt;F&lt;/sub&gt;'s vary with color</td>
</tr>
<tr>
<td>1N7XX: Photodiode</td>
<td>![Diode Symbol]</td>
<td>Light detection, mech.-electrical conversion; solar cell</td>
<td>Reverse current is increased by light; in FWD direction=solar cell</td>
</tr>
<tr>
<td>1N7XX: Optocoupler</td>
<td>![Diode Symbol]</td>
<td>Electrical isolation</td>
<td>LED and photodiode in an opaque package</td>
</tr>
<tr>
<td>1N7XX: Schottky Diode</td>
<td>![Diode Symbol]</td>
<td>VHF rectification, detecting small signals</td>
<td>No stored charges, &gt;300 MHz, 0.25V V&lt;sub&gt;F&lt;/sub&gt; [metal jn]</td>
</tr>
<tr>
<td>1N7XX: Varactor Diode</td>
<td>![Diode Symbol]</td>
<td>Tuning radio and TV receivers</td>
<td>Fairly linear C with V&lt;sub&gt;r&lt;/sub&gt;</td>
</tr>
<tr>
<td>1N7XX: Varistor</td>
<td>![Diode Symbol]</td>
<td>AC line spike protection</td>
<td>2 back-back zeners</td>
</tr>
<tr>
<td>1N7XX: Current Regulator</td>
<td>![Diode Symbol]</td>
<td>Constant current source</td>
<td></td>
</tr>
<tr>
<td>1N7XX: Step-recovery Diode</td>
<td>![Diode Symbol]</td>
<td>&quot;snap&quot; diode generates harmonics, f multipliers</td>
<td>Exploits reverse-current phenomenon</td>
</tr>
<tr>
<td>1N7XX: Back Diode</td>
<td>![Diode Symbol]</td>
<td>Very small signal rectification</td>
<td>V&lt;sub&gt;r&lt;/sub&gt; smaller than V&lt;sub&gt;F&lt;/sub&gt;</td>
</tr>
<tr>
<td>1N7XX: Tunnel Diode</td>
<td>![Diode Symbol]</td>
<td>High frequency oscillators</td>
<td>Part of forward char. has negative resistance</td>
</tr>
<tr>
<td>1N7XX: Laser Diode</td>
<td>![Diode Symbol]</td>
<td>Reading, writing CD, DVD etc.</td>
<td></td>
</tr>
<tr>
<td>1N7XX: PIN Diode</td>
<td>![Diode Symbol]</td>
<td>RF switching diode</td>
<td></td>
</tr>
</tbody>
</table>
Diode Circuits

Figure 8.15
Ideal peak sampler.
RC Equation

\[ V_s = 5 \text{ V} \]

Switch is closed \( t < 0 \)

Switch opens \( t > 0 \)

\[ V_s = V_R + V_C \]

\[ V_s = i_R R + V_C \quad i_R = \frac{C}{R} \frac{dV_c}{dt} \]

\[ V_s = RC \frac{dV_c}{dt} + V_c \]

\[ V_C = V_s \left( 1 - e^{-\frac{t}{RC}} \right) \]

\[ e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots \]

\[ = \sum_{n=0}^{\infty} \frac{x^n}{n!} \]

Is RC in units of time?
More Diode Circuits

Basic Negative Shunt Clipper

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = 0 \text{ V} \]
\[ V_{out} = V_{in} - V_{Z} \]

Basic Positive Shunt Clipper

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = 0 \text{ V} \]
\[ V_{out} = V_{in} + V_{Z} \]

Biased Negative Shunt Clipper

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = 0 \text{ V} \]
\[ V_{out} = V_{in} - V_{Z} \]

Biased Positive Shunt Clipper

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = 0 \text{ V} \]
\[ V_{out} = V_{in} + V_{Z} \]

Variable Shunt Clipper

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = R_R \]
\[ V_{out} = V_{in} - V_{R} \]

Zener Shunt Clipper (Clipped, Zenered)

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = R_R \]
\[ V_{out} = V_{Z} \]

Zener Shunt Clipper (+Clipped, -Zenered)

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = R_R \]
\[ V_{out} = -V_{Z} \]

Symmetrical Zener Shunt Clipper

\[ V_{in} 0 \text{ V} \]
\[ V_{R} = R_R \]
\[ V_{out} = -V_{Z} \]
Clamping Circuit

**Negative Clamper**

![Diagram of a negative clamper circuit](image)

**Positive Clamper**

![Diagram of a positive clamper circuit](image)

**Output**

\[
\begin{align*}
+V_{pk} &= +0.7 \text{ V} \\
-V_{pk} &= -V_{in \text{ pk-pk}}
\end{align*}
\]

\[
\begin{align*}
+V_{pk} &= +V_{in \text{ pk-pk}} \\
-V_{pk} &= -0.7 \text{ V}
\end{align*}
\]

**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-Oximetry

• 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*

Wearable Heart Rate Monitor
“Fitbit” Lab

SFH 7050: 3 leds, 1 photodiode in one package
Transimpedance Amplifier
(Current to Voltage Converter)

\[ I_r = I_p \]

\[ V_{out} = I_p R_f \]

Transimpedance Amplifier

(Current to Voltage Converter)

At low frequency \( V_{out} = I_{diode} R3 \)

\[ I_{diode} \approx 5 \times 10^{-9} \quad R3 = 4 \times 10^6 \]

\[ V_{out} = 20 \text{mv} \]
“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

- The RMS voltage for a sinusoid is that value which will produce the same heating effect (energy) as an equivalent DC voltage.

- Energy:
  \[
  \int P dt = \int_0^\pi v_i dt = \frac{1}{r} \int_0^\pi v^2 dt
  \]

- For DC,
  \[
  v_{rms}^2 \times \pi
  \]

- Equating and solving, \( A = \sqrt{2} \ v_{rms} \)
RMS Derivation

\[
\frac{v_{\text{rms}}^{2} \times \pi}{r} = \frac{1}{r} \int_{0}^{\pi} v^{2} \, dt = \frac{1}{r} \int_{0}^{\pi} A^{2} \sin^{2} t \, dt
\]

\[
\int_{0}^{\pi} \sin^{2} \, dt = \left[ \frac{t}{2} - \frac{1}{4} \sin 2t \right]_{0}^{\pi}
\]

\[
\frac{v_{\text{rms}}^{2} \pi}{r} = \frac{A^{2}}{r} \left[ \frac{t}{2} - \frac{1}{4} \sin 2t \right]_{0}^{\pi}
\]

\[
A = \sqrt{2} \cdot v_{\text{rms}}
\]

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Agilent Function Generator

Turn on output!
Agilent DMM
Oscilloscope

Menu driven soft key/buttons

Cursor controls
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