Inductors: equivalent circuit model

\[ L \quad R \quad C \]

**Miniature Inductors & R.F.**

**MINIATURE INDUCTORS**
- Vacuum epoxy cast for stability.
- Consistent air gap for good permeability.
- Low profile and pin mounted for PC application.
- 7/8" diameter, 0.362" long.
- Stainless steel and high purity copper.

**Selection Table**

<table>
<thead>
<tr>
<th>Cat. No.</th>
<th>Inductance (L)</th>
<th>Idc (mA)</th>
<th>Nominal Q</th>
<th>Freq. kHz</th>
<th>D.C. resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>621G</td>
<td>1.0</td>
<td>51</td>
<td>40</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>621J</td>
<td>2.2</td>
<td>34</td>
<td>40</td>
<td>45</td>
<td>4.5</td>
</tr>
<tr>
<td>621L</td>
<td>4.7</td>
<td>23</td>
<td>38</td>
<td>40</td>
<td>8.2</td>
</tr>
<tr>
<td>621N</td>
<td>10.0</td>
<td>16</td>
<td>38</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>621Q</td>
<td>22.0</td>
<td>11</td>
<td>38</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>622S</td>
<td>47</td>
<td>13.7</td>
<td>65</td>
<td>16</td>
<td>27</td>
</tr>
<tr>
<td>622U</td>
<td>100</td>
<td>9.3</td>
<td>64</td>
<td>15</td>
<td>49</td>
</tr>
<tr>
<td>622W</td>
<td>220</td>
<td>6.4</td>
<td>60</td>
<td>13</td>
<td>122</td>
</tr>
<tr>
<td>622Y</td>
<td>470</td>
<td>4.3</td>
<td>54</td>
<td>10</td>
<td>218</td>
</tr>
<tr>
<td>622ZA</td>
<td>1000</td>
<td>2.9</td>
<td>45</td>
<td>8</td>
<td>400</td>
</tr>
</tbody>
</table>

**R.F. CHOICES**
- Low loss ceramic or powdered iron forms.
- Tolerance ± 10% on Inductance.
- Catalog numbers 1720, 1820, 1920 designed for heavy duty use in linear amplifiers or other power amplifiers applications. Utilization of the ceramic, especially with standard resistors and the 14-20 mounting bolt.

**Selection Table**

[Table data]

[Diagram of miniature inductors and R.F. components]

**Chokes**

1508 1598 1582 1581 1504 1503 1586
RLC notch filter
Ideal L vs. Real L

\[ \frac{|V_{out}|}{|V_{in}|} \]

[Graph showing the frequency response of the RLC notch filter for both ideal and real inductors.]
Diodes

*a non-linear circuit element*

- 2-terminal **quantum** device
- **A diode only conducts in one direction !!!**
- Non-linear → **Ohm’s Law** doesn’t apply!
  - There is no $Z_{\text{diode}}$
  - **Thevenin’s theorem** doesn’t apply!

- **Calculus:** you can linearize a function/system in the vicinity of some $V_0$ or $I_0$.
  
  → **Ohm’s law**, $Z_{\text{diode}}$, and **Thevenin’s theorem** can only be used locally around some value of $V_0$ and $I_0$.
  
  → i.e. you can still write down a differential equation for your circuit.
Semiconductors have a modest resistivity:

Normally we think of electrons moving in a circuit

In a semiconductor things are a little different

→ We think of either holes or electrons.
  → Holes (+ charge)
  → Electrons (- charge)

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>$1.70 \times 10^{-8} , \Omega \cdot m$</td>
</tr>
<tr>
<td>Silicon</td>
<td>6400 , \Omega \cdot m</td>
</tr>
<tr>
<td>Rubber</td>
<td>$\sim 10^{13} , \Omega \cdot m$</td>
</tr>
</tbody>
</table>
The PN junction

- Made from differently doped silicon
  - N region has more electrons
  - P region had more holes
- At the **PN junction** the holes & electrons recombine to form small insulating **depletion** region.

![Diagram of PN junction with labels for P-silicon, depletion region, and N-silicon]
How a diode works

Depletion E-field

Reverse Bias

Depletion Region is larger

Forward Bias

Depletion Region is smaller

Combination of electrons and holes occurs near the junction.

Holes move to junction from the positive side.

Electrons move to junction from the negative side.
Diode: I-V characteristic curve

- **Reverse bias**
  - Current $I = 0$
  - Voltage $V = V_d$

- **Forward bias**
  - Current $I$ increases exponentially
  - Voltage $V ightarrow 0$

- **Ideal Diode**
  - No voltage drop
  - $V_d = 0.6 V$

- **Standard diode symbol**
  - P-type end
  - N-type end

- **Real Diode**
  - Voltage $V_d$
  - Current $I$ increases with $V$

[Image from www.mtmi.vu.lt]
Diode: I-V characteristic curve II

- Simple model
  - Current can only flow one direction
  - A 0.6V “diode drop” when conducting
  - $IR = V_{IN} - 0.6\, V$
  - Useful for designing circuits.

  - Not so useful for designing circuits.

- A little negative is OK
  A lot is “bad” – smoke!!!!
Diode Spec Sheet

1N/FDLL 914/A/B / 916/A/B / 4148 / 4448
Small Signal Diode

Absolute Maximum Ratings* (See circuit and application notes)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vmax</td>
<td>Maximum Rectified Reverse Voltage</td>
<td>100</td>
<td>V</td>
</tr>
<tr>
<td>Io</td>
<td>Average Rectified Forward Current</td>
<td>200 mA</td>
<td></td>
</tr>
<tr>
<td>If</td>
<td>Peak Rectified Current</td>
<td>400 mA</td>
<td></td>
</tr>
<tr>
<td>Iref</td>
<td>Non-repetitive Peak Forward Current</td>
<td>1 C</td>
<td>A</td>
</tr>
<tr>
<td>Tstg</td>
<td>Storage Temperature Range</td>
<td>-65 to 200°C</td>
<td>°C</td>
</tr>
</tbody>
</table>

*These ratings are defined as the limits beyond which the reliability of the device may be impaired.

Thermal Characteristics

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pd</td>
<td>Power Dissipation</td>
<td>900</td>
<td>MW</td>
</tr>
<tr>
<td>RthJA</td>
<td>Thermal Resistance, Junction to Ambient</td>
<td>300</td>
<td>°C/W</td>
</tr>
</tbody>
</table>
## Electrical Characteristics

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{BR}</td>
<td>Breakdown Voltage</td>
<td>1200°C</td>
<td>1200</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V_{F}</td>
<td>Forward Voltage</td>
<td></td>
<td>660</td>
<td>720</td>
<td>mV</td>
</tr>
<tr>
<td>V_{R}</td>
<td>Reverse Voltage</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td>μA</td>
</tr>
<tr>
<td>C_{R}</td>
<td>Reverse Leakage</td>
<td></td>
<td>2.0</td>
<td>1.0</td>
<td>μA</td>
</tr>
</tbody>
</table>

### Typical Characteristics

1. **Figure 1:** Reverse voltage vs reverse current (V_{R} = 10 to 100 μA)
2. **Figure 2:** Reverse current vs reverse voltage (V_{R} = 10 to 100 μA)
3. **Figure 3:** Forward voltage vs forward current (V_{F} = 1 to 100 μA)
4. **Figure 4:** Forward current vs forward voltage (V_{F} = 1 to 100 μA)
Applications

- Circuit Protection

- Rectification
  - half wave rectifier
  - full wave rectifier
  - Power Supplies

- Frequency manipulation
  - Frequency multiplier
  - Mixers
Fourier Transform (FFT) of Full Wave Rectifier

Fourier space representation of rectified output