Microwave Components

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Resistors
Capacitors
Inductors
Ground

....and other useful mythological concepts....
Resistors

George Frederick Ohm’s famous question:

What is the current density in amperes per square meter in a material inside an electric field?

\[ \bar{J} = \sigma \bar{E} \]
$\sigma$ converts E field energy to Heat

Thermodynamics says that it’s tough to get energy back once it is converted to heat.

As a convenience, we often model any conversion of energy to a form that we can’t get back as a resistance.
\[
\frac{\text{amps}}{m^2} \quad \bar{J} = \sigma \bar{E} \quad \frac{1}{\text{ohm-m}} \quad \frac{\text{volts}}{m}
\]

\[
\frac{\text{amps}}{m^2} = \frac{1}{\text{ohm-m}} \quad \frac{\text{volts}}{m}
\]

\[
\text{amps} = \frac{\text{volts}}{\text{ohms}}
\]

\[
\text{volts} = \text{amps} \times \text{ohms}
\]

\[
V = IR
\]
Capacitor:

A region in space where energy is stored in an electric field.

\[ U_e = \frac{1}{2} C V^2 = \frac{1}{2} \int \varepsilon \bar{E} \cdot \bar{E} \, dV \]
Integrate over the electric field energy in a volume and divide by the voltage required to set it up:

\[
C = \frac{1}{V^2} \int_V \varepsilon \vec{E} \cdot \vec{E} \, dV
\]

Example:

\[
\varepsilon \bar{E} = \nabla V
\]

\[
C = \frac{\varepsilon A}{d} \quad \text{simple parallel plate capacitor}
\]
Chip cap on Board

X-ray view
RF Field view

schematic model
Depending on the relative size of all the elements in the model and the frequency of the signal, the chip capacitor may look like a capacitor, a resistor, an inductor, a low-pass filter, an antenna, or.....

In your circuit, a different model will be needed. Many of the elements in the model depend on the circuit the capacitor is connected to.
Inductor:

A region in space where energy is stored in a magnetic field.

\[ U_H = \frac{1}{2} LI^2 = \frac{1}{2} \int_\mathcal{V} \mu \bar{H} \cdot \bar{H} \, dV \]
Integrate over the magnetic field energy in a volume and divide by the current required to set it up:

\[
L = \frac{1}{I^2} \int_V \mu \mathbf{H} \cdot \mathbf{H} \, dV
\]
example:

first, use Ampere’s Law to find the H field inside a solenoid

\[ \oint \mathbf{H} \cdot d\mathbf{l} = \int_{S} \mathbf{J} \cdot d\mathbf{s} \]

\[ H = \mu \frac{NI}{l} \]

Then use the volume of a cylinder and plug into the formula for L

\[ \text{vol} = \pi a^2 l \]
Inductance of Solenoid

\[ L = \frac{1}{I^2} \int_{V} \mu \bar{H} \cdot \bar{H} \, dV \]

\[ L = \mu \frac{N^2 I^2}{I^2} \int_{V} dV \]

volume of cylinder:

\[ \int_{V} dV = \pi a^2 l \]
Approximate Inductance of Solenoid

\[ L = \mu \frac{N^2 I^2}{I^2 l^2} \pi a^2 l \]

\[ L = \mu N^2 \frac{\pi a^2}{l} \]
Chip L on Board

Look closely
DC H fields

RF Field view
RF Field view

schematic model
As with capacitor, a chip inductor can be a capacitor, inductor, resistor, antenna, the primary or secondary of a transformer, a modulator for a piezoelectric device with a metal contact....
Ground \( \downarrow \)
Where E Field Lines Terminate
What could be simpler?

Engineering Student Ground
Radio Frequency Ground
mm wave Ground
Other Passive Components:

- transformers
- antennas
- transmission lines
- networks
- directional couplers
- 3 dB splitters
- and many others

Remember: a component model is obtained by looking at E and H fields. E and H fields strongly depend on how the component is used. L C R values and component models are just approximations. Your results will vary.