Passives: Resistors
Resistors

- **Resistance is bad for digital circuits**
  - But, often want large-valued, well-controlled R for analog
  - E.g., a 1kOhm resistor made out of copper interconnect (~200mΩ/□) would require 5000 □'s

- **Fortunately, most processes include explicit provisions for large resistors**
  - Up to ~20nm, typically unsilicided poly or n-well
  - Typically get ~1kΩ/□
  - Even with explicit resistors, still need to watch out for a few things however

Resistor Variations

- **Almost always temperature dependent:**

- **Also often voltage dependent:**
Systematic Variations from Layout

- Example:

```
R  
2R?
```

- Use unit element instead:

```
2R
   
R
```

Better Unit Element
**Resistor Layout (cont.)**

Serpentine layout for large values:

Better layout (mitigates offset due to thermoelectric effects):


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**Electromigration and Parasitics**

- **Electromigration rules limit maximum current density**
  - Same value resistance must be physically larger to carry more current
  - Hence, more current $\rightarrow$ larger capacitive parasitics
Passives: Capacitors

Capacitors

• Simplest capacitor:

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substrate

• What’s the problem with this?
Capacitors

- “Improved” capacitor:

- Is this only 1 capacitor?

### Capacitor Options

<table>
<thead>
<tr>
<th>Type</th>
<th>C [aF/μm²]</th>
<th>$V_C$ [ppm/V]</th>
<th>$T_C$ [ppm/°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate</td>
<td>10,000</td>
<td>Huge</td>
<td>Big</td>
</tr>
<tr>
<td>Poly-poly (option)</td>
<td>1000</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Metal-metal</td>
<td>50</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Metal-substrate</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal-poly</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poly-substrate</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junction caps</td>
<td>~ 1000</td>
<td>Big</td>
<td>Big</td>
</tr>
</tbody>
</table>
MOS Capacitor

- High non-linearity, temperature coefficient
- But, still useful in many applications, e.g.:
  - (Miller) compensation capacitor
  - Bypass capacitor (supply, bias)

“MOM” Capacitors

- Metal-Oxide-Metal capacitor. Free and most common in modern CMOS.
- Use lateral flux (∼L_{min}) and multiple metal layers to realize high capacitance values
MOM Capacitor Cross Section

- Use a wall of metal and vias to realize high density
- More layers — higher density
  - May want to chop off lower layers to reduce $C_{\text{bot}}$
- Reasonably good matching and accuracy

Another MOM Option
Capacitor Parasitics

Passives: Inductors
What About Inductors?

- Mostly not used in analog/mixed-signal design
  - Usually too big
  - More of a pain to model than R’s and C’s
  - But they do occasionally get used
- Example inductor app.: shunt peaking
  - Can boost bandwidth by up to 85%!
  - Q not that important (L in series with R)
  - But frequency response may not be flat

Spiral Inductors

- Used widely in RF circuits for small L (~1-10nH).
- Use top metal for Q and high self resonance frequencies.
  - Very good matching and accuracy – if you model them right