Transistors

1947: W.H. Brattain and J. Bardeen (Bell Labs, USA)...
J.P. Pierce (Bell Labs): tran(sfer)+(re)sistor = transistor.
1949: W. Schockley theoretically described bipolar junction transistor.
1956: Nobel Prize.
Transistors

Through experiments seeking understanding and use of surface physics in germanium, John Bardeen and Walter Brattain found the transistor effect and invented the point contact transistor on December 16, 1947. A photograph of one of their first devices is shown in Fig. 1. While they widened the experiments and pondered the data and surface state models of the structures, Bill Shockley, challenged by their accomplishment, worked out by late January 1948 a bulk hypothesis for transistor action. His key assumption was the electrical injection of excess minority mobile charge carriers into a quasi-neutral bulk semiconductor. He also, in the same work, invented the junction diode and the bipolar transistor.
Transistors

The first transistor was invented at Bell Laboratories on December 16, 1947 by William Shockley (seated at Brattain's laboratory bench), John Bardeen (left) and Walter Brattain (right). This was perhaps the most important electronics event of the 20th century, as it later made possible the integrated circuit and microprocessor that are the basis of modern electronics.
Transistors

Fig. 2. William Shockley, seated, and John Bardeen, left, listen as Walter Brattain describes the Bardeen–Brattain invention (Courtesy of Lucent Technologies–Bell Labs Innovations).

Fig. 1. Primitive transistor. The small dark rectangle on the formed metal support at lower left center is polycrystalline germanium. The triangle impinging on it is an insulator with metal on near and far surfaces, making two contacts to the crystal (Courtesy of Lucent Technologies–Bell Labs Innovations).
Transistors

James M. Early (A'48–SM'54–F'59–LF'88) was born in Syracuse, NY, in 1922. He received the B.S. degree in pulp and paper manufacturing from New York State College of Forestry, Syracuse in 1943 and the M.Sc. and Ph.D. in electrical engineering from Ohio State University (OSU), Columbus, in 1948 and 1951, respectively.

He served in the U.S. Army from 1943 to 1945. In 1951, he joined Bell Telephone Laboratories at Murray Hill, NJ, as Member of Technical Staff. He worked on grown and alloy germanium transistors.

2) The most powerful tool is a theory. Shockley’s work had enormous direct impact and, I believe, stimulated greatly the whole of science.

3) On a first independent task, finding theory useless is bad for young engineers and scientists. Some young scientists assigned to work on the point contact transistor found in its empirical behavior no place for theory, and left the field.
The first junction transistor

http://library.thinkquest.org/C006224/history.html
History

After years of research and experimentation involving literally hundreds of scientist from around the world, the final breakthrough in the development of the transistor was left to three men. **Dr Walter Brattain**, **Dr John Bardeen** and **Dr William Shockley** all three scientists working at Bell laboratories, are the men credited with this significant achievement. In December 1947 they made the historic discovery of the transistor effect and in so doing developed the very first transistor device. In 1956 their achievement was acknowledged when they were awarded the Nobel Prize for physics.

[http://library.thinkquest.org/C006224/history.html](http://library.thinkquest.org/C006224/history.html)
Transistors

(a)

(b)

Structures and symbols of (a) \( pnp \) and (b) \( npn \) transistors

\[ \text{Tran(sfer) + (re)sistor} = \text{Transistor} \]
# Transistors

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>The structure and operation of a BJT</td>
</tr>
<tr>
<td>2.2</td>
<td>Basic configurations and modes of operation</td>
</tr>
<tr>
<td>2.3</td>
<td>Static volt-ampere characteristics of BJT</td>
</tr>
<tr>
<td>2.3.1</td>
<td>The Ebers-Moll representation of the BJT</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Static volt-ampere characteristics</td>
</tr>
<tr>
<td>2.3.3</td>
<td>The real $U-I$ characteristics</td>
</tr>
<tr>
<td>2.4</td>
<td>Two port representation of the transistor</td>
</tr>
<tr>
<td>2.5</td>
<td>Transistor models</td>
</tr>
<tr>
<td>2.5.1</td>
<td>T-type model</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Π-type model</td>
</tr>
<tr>
<td>2.6</td>
<td>Transistor high frequency characteristics</td>
</tr>
<tr>
<td>2.7</td>
<td>Types of BJTs</td>
</tr>
</tbody>
</table>
ELEKTRONIKOS ĮTAISAI

TRANISTORS

TRANISTORS

(a)

(b)

q(U_{bE} - U_{EB})

q(U_{bK} + U_{KB})

W

q(U_{bE} - U_{EB})

W_c

W_v

stanislovas.staras@el.vgtu.lt
Bipolar junction transistor

\[ I_E = I_{Ep} + I_{En} \]

\[ I_{Ep} = I_{Cp} + I_{Epr} \]

\[ I_C = I_{Cp} + I_{C0} \]

\[ I_B = I_{En} + I_{Epr} - I_{C0} \]

... There are four important components of the currents in a BJT...

\[ I_E = I_C + I_B \quad \Rightarrow \quad I_C \approx I_E \]

... The emitter current can control the output collector current...
Bipolar junction transistor

DC current gain: \[ A = \frac{I_{Cp}}{I_E} \]

\[ A = \frac{I_{Cp}}{I_E} = \frac{I_{Ep}}{I_E} \frac{I_{Cp}}{I_{Ep}} = \gamma \delta \]

The *emitter injection efficiency*, is the ratio of the hole current injected into the base from the emitter to the total emitter-base junction current.

The *base transport factor*, is the ratio of the hole current across the collector junction to that across the emitter junction.

The DC current gain can be increased increasing the main current and decreasing other currents.
Bipolar junction transistor

Configurations:
- Common base (CB)
- Common emitter (CE)
- Common collector (CC)

Regions of operation:
- Reverse-active
- Saturation
- Cut-off
- Forward-active
CB, CE and CC circuits
Bipolar junction transistor

The ac current gain:

\[ K_I = \alpha = \frac{dI_C}{dI_E} \]

\[ I_C = I_{Cp} + I_{C0} \]

\[ K_I = \alpha = A + I_E \frac{dA}{dI_E} \cong A < 1 \]

\[ K_U = \left| \frac{dU_{CB}}{dU_{EB}} \right| = \frac{R_L}{r_{EB}} \frac{dI_C}{dI_E} \cong \alpha \frac{R_L}{r_{EB}} \]

\[ K_P = K_U K_I \cong \frac{R_L}{r_{EB}} \]

... Voltage and power amplification is possible when a BJT is in the CB configuration.
Bipolar junction transistor

AC current gain:

\[ K_I = \beta = \frac{\frac{\mathrm{d}I_C}{\mathrm{d}I_B}}{\frac{\mathrm{d}I_E}{\mathrm{d}I_C}} = \frac{\frac{\mathrm{d}I_C}{\mathrm{d}I_E}}{1 - \frac{\mathrm{d}I_C}{\mathrm{d}I_E}} \ldots = \frac{\alpha}{1 - \alpha} \]

\[ \beta = \frac{\alpha}{1 - \alpha} \]

\[ K_U = \left| \frac{\frac{\mathrm{d}U_{CE}}{\mathrm{d}U_{BE}}}{\frac{\mathrm{d}I_C}{\mathrm{d}I_B}} \right| = \frac{\frac{R_L \mathrm{d}I_C}{\mathrm{d}I_B}}{r_{BE} \frac{\mathrm{d}I_B}{\mathrm{d}I_B}} = \frac{R_L}{r_{BE}} \beta \]

\[ K_P \gg 1 \]

Amplification of AC current, voltage and power.
## Bipolar junction transistor

<table>
<thead>
<tr>
<th>Gain</th>
<th>CB</th>
<th>CE</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_I$</td>
<td>$\alpha &lt; 1$</td>
<td>$\beta &gt;&gt; 1$</td>
<td>$&gt;&gt; 1$</td>
</tr>
<tr>
<td>$K_U$</td>
<td>$&gt;&gt; 1$</td>
<td>$&gt;&gt; 1$</td>
<td>$&lt; 1$</td>
</tr>
<tr>
<td>$K_P$</td>
<td>$&gt;&gt; 1$</td>
<td>$&gt;&gt; 1$</td>
<td>$&gt;&gt; 1$</td>
</tr>
</tbody>
</table>

**Gain properties of BJT**
Bipolar junction transistors

1. The ________ region of a BJT is thinnest, the ________ region is the largest, and the ________ region is the most heavily doped.

2. (Electrons, Holes) are the majority carriers in the base region of a pnp BJT.

3. Which of the transistor currents is always the largest? Which is the smallest? Which two currents are relatively close in magnitude?

4. A BJT is in its common-base configuration. Its $A$ is 0.98 and its $I_{C0}$ is 25 nA. Compute its exact value of $I_C$ when its $I_E$ is 1 mA.

5. The collector current of an npn BJT is 2 mA, the base current is 40 $\mu$A. Compute and approximate values of $\alpha$ and $\beta$.

6. If a BJT has an $\alpha$ of 0.98, what is its $\beta$? Find also $\beta$ if $\alpha = 0.99$. Comment on the results.
After years of research and experimentation involving literally hundreds of scientists from around the world, the final breakthrough in the development of the transistor was left to three men. **Dr Walter Brattain**, **Dr John Bardeen** and **Dr William Shockley** all three scientists working at Bell laboratories, are the men credited with this significant achievement. In December 1947 they made the historic discovery of the transistor effect and in so doing developed the very first transistor device. In 1956 their achievement was acknowledged when they were awarded the Nobel Prize for physics.
___trailing the Transistor  History.mht