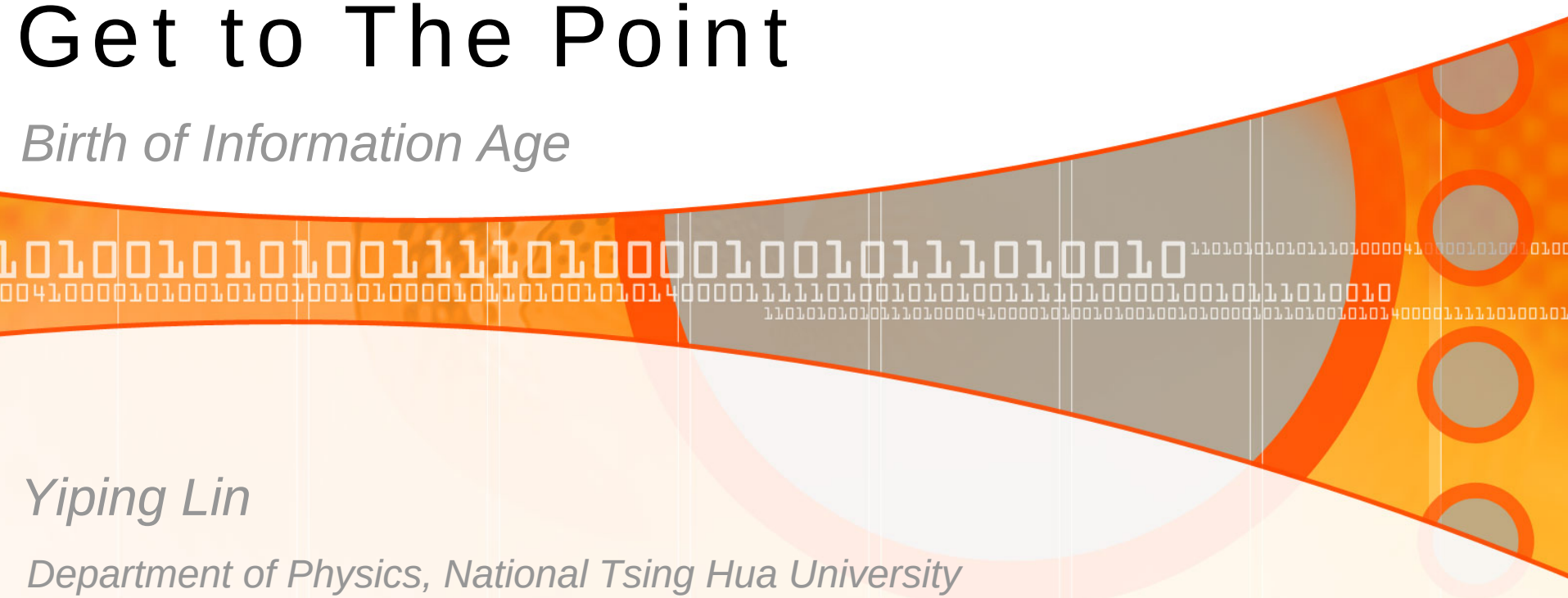
Get to The Point

Birth of Information Age



Yiping Lin

Department of Physics, National Tsing Hua University

The Most Important Invention in 20th Century

Transistor

- Amplification
- Voltage stabilization
- Signal modulation

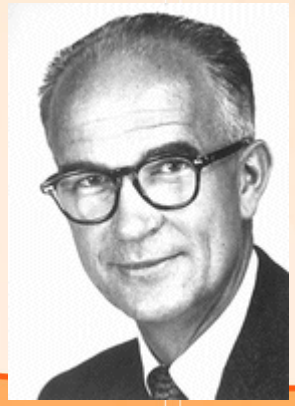
Analog circuit

- Switching
- & many others!

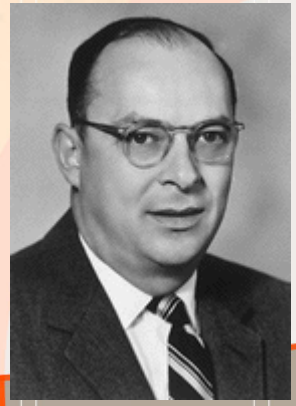
Digital circuit

Key active component in all modern electronics !

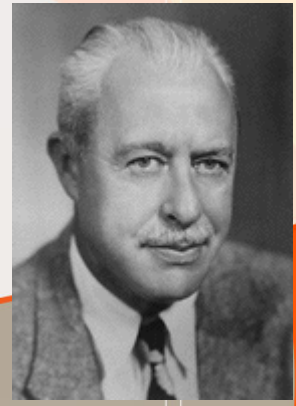
The Inventors: William Shockley, John Bardeen, Walter Brattain



1910-1989

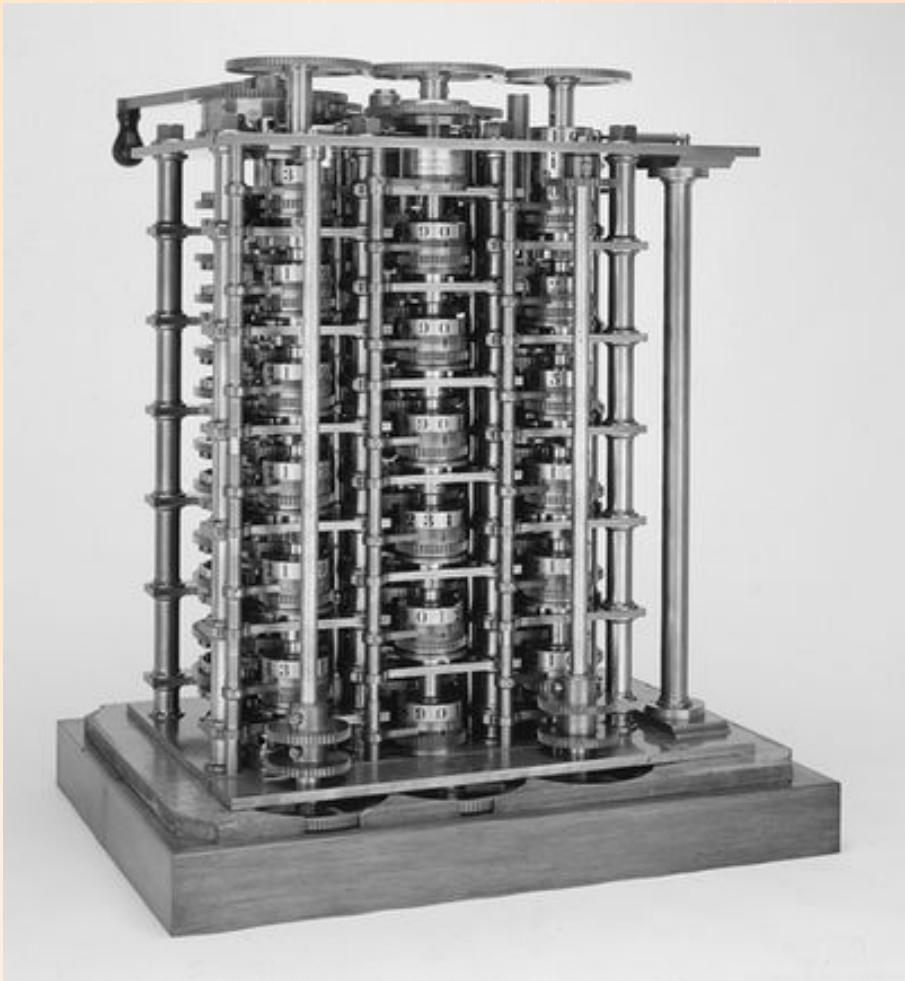


1908-1991



1902-1987

The First Computer



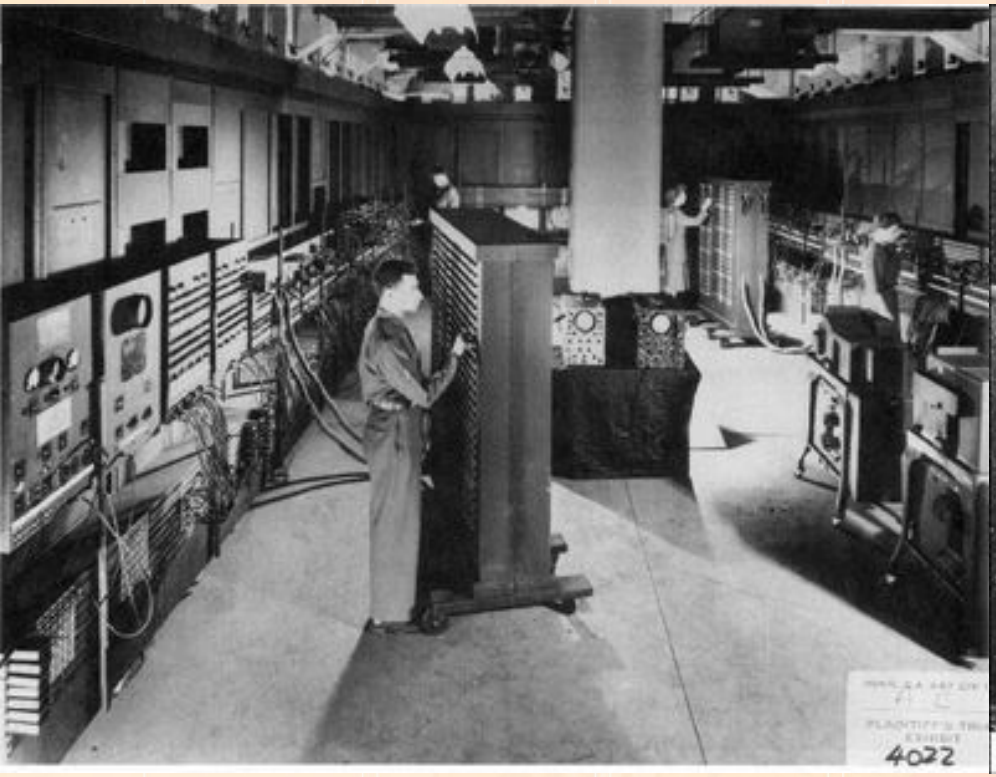
- The Babbage Difference Engine(1832)
  - 2,500 parts
  - 6 years to build
  - Cost: £17,470 ~ NT$ 1 million

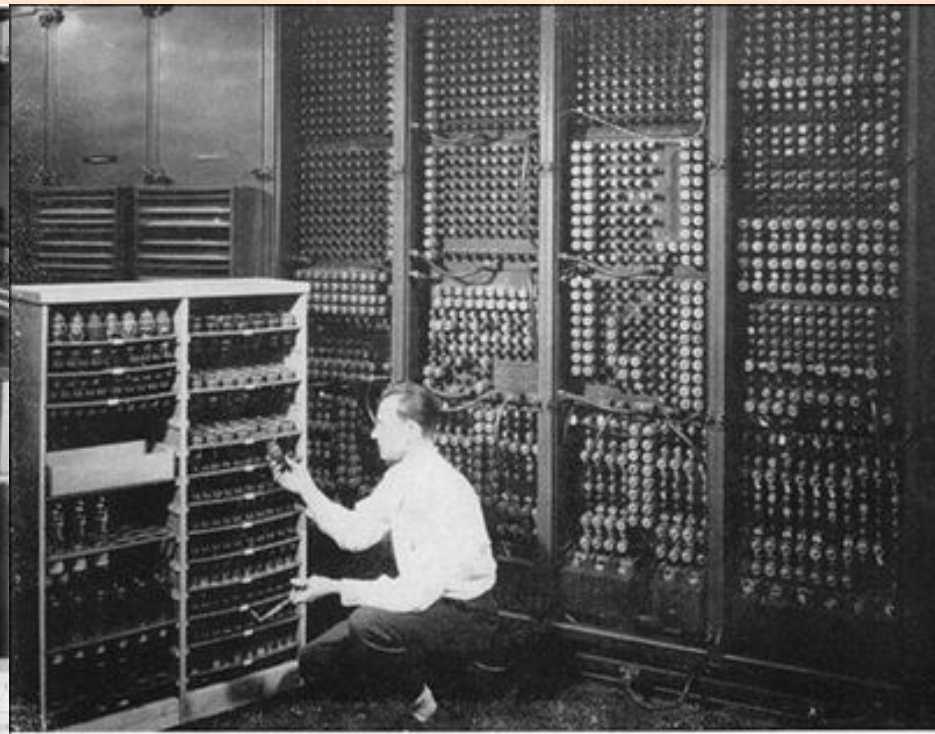
Idea: Newton's method of difference

$p(x) = 2x^2 - 3x + 2$

$p(0)=2.0$		
	2.0−1.72=0.28	
$p(0.1)=1.72$		**0.28−0.24=0.04**
	1.72−1.48=0.24	
$p(0.2)=1.48$		**0.24−0.20=0.04**
	1.48−1.28=0.20	
$p(0.3)=1.28$		**0.20−0.16=0.04**
	1.28−1.12=0.16	
$p(0.4)=1.12$		

First Electronic Computer





Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

1946 Built by John W. Mauchly (computer architecture)
J. Presper Eckert (circuit engineering)
, Moore School of E. E., U. Penn.

Named "Electrical Numerical Integrator And Calculator"

A "Monster"
17,468 vacuum tubes, 7200 crystal diodes; Weighed 27t, 167m^2 and ate up 150kW

UNIVAC

- Process each digit serially
- Add two 10-digit numbers at a rate of 100,000 addition per sec
- Operate at a clock freq. of 2.25 MHz

1951

THE EVENING BULLETIN, PHILADELPHIA

Network 'Drafts' Univac for Election Coverage

Univac, the electronic computer which will be used by the Columbia Broadcasting System in its television coverage of the November 4 elections, gets a test run under the supervision of (from left) Harold Sweeney, chief operator; J. Presper Eckert, one of the machine's inventors, and CBS commentator Walter Cronkite, at the Eckert-Mauchly Computer Corp., 3747 Ridge av.

Stevenson

Continued From First Page

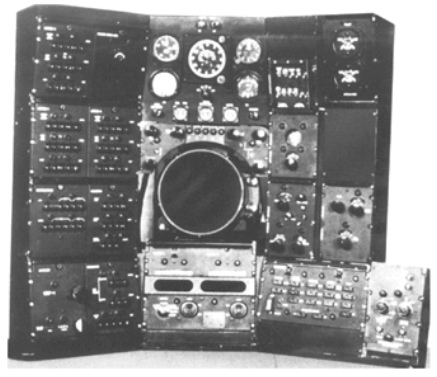
nd ruthlessly on misconduct wher-

CBS to Use Electronic Robot To Forecast Election Results

First Transistorized Computer

1955 TRAnisitor DIgital Computer

- Built by Bell Lab for U.S. Air Force
- Consisted of 700 point-contact transistors and 10,000 germanium diodes
- Compact & reliable; Light enough to be installed in a B-52 Stratofortress



Vail.. We Have a Problem

1900

How can we flight for competition due to the expiration of Bell's patent?

Bring on transcontinental phone sevice

1907

1906: Lee De Forest developed a triode in a vacuum tube that can amplify the signal

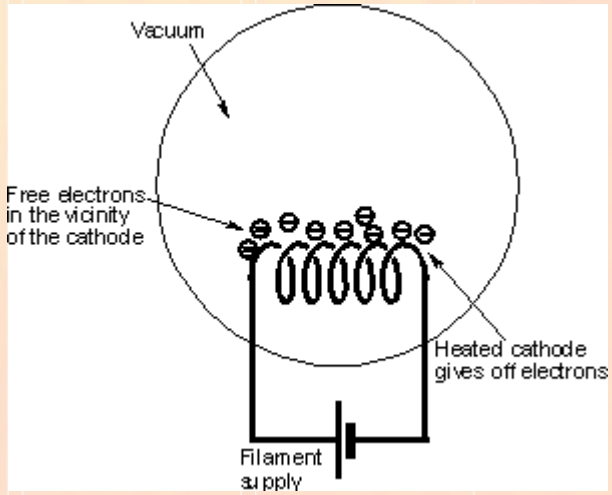
1907: AT&T bought De Forest's patent and improved the device.

Can talk across any distance as long as amplifiers are along the way!

Some Like It Hot

- *Thermonic emission*
  - *First reported by Gruthrie in 1873*
  - *Rediscovered by Edison in 1880*
    - *"Edison Effect"; Patented in 1883; No use*
  - *"Heat engine"*
    - *Heat ⇒ Electrical energy*
- *Richardson's Law (1901)*

  Received Nobel prize in Physics in 1928



$$J = AT^2 e^{\frac{-W}{kT}}$$

$$A = \frac{4\pi m k^2 e}{h^3}$$

Corrected for Shockley Effect

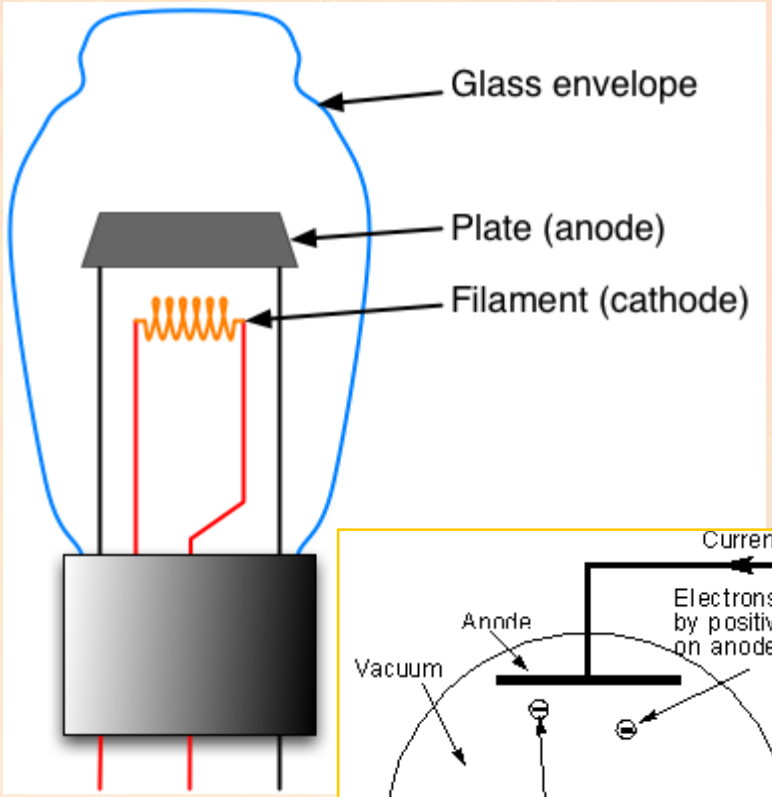
Field-enhanced

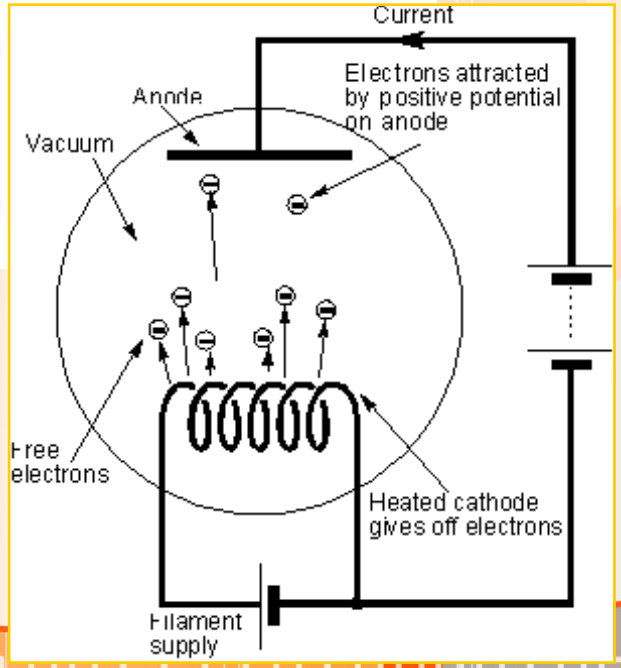
$$J(E_s, T, W) = AT^2 e^{\frac{-(W-\Delta W)}{kT}}$$

$$\Delta W = \left(\frac{eE_C}{4\pi\varepsilon_0}\right)^{1/2}$$

W: work function

Vaccum Tube - Diode





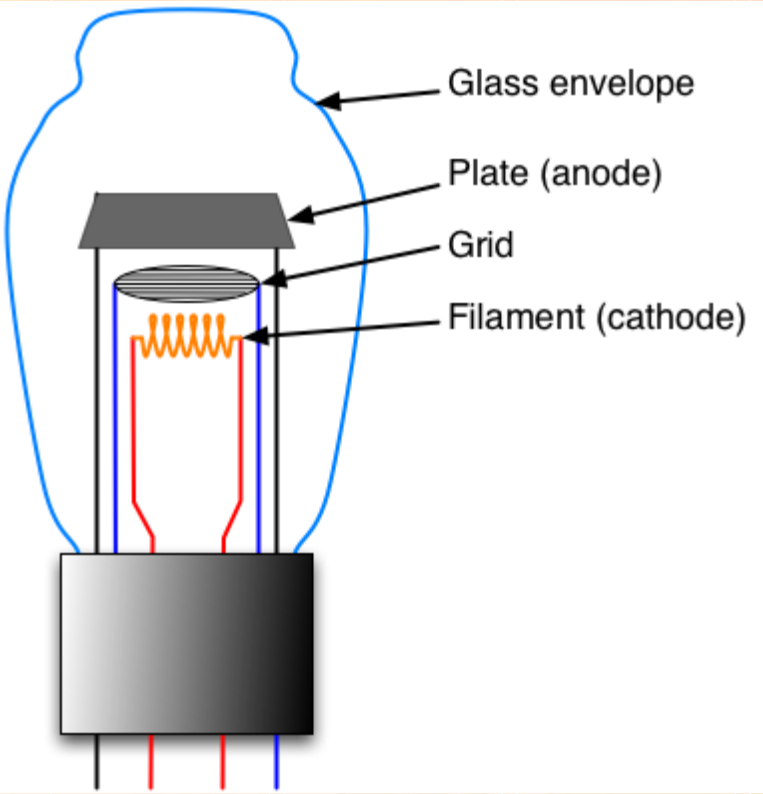
Thermionic emmision ⇒ Space charges

In the anode:

- With +*V*: Current flows
  - *I* increases as *V* till the space charges are neutralized
  - Need to increase *T* for more energetic electrons
- With –V: No current flows
  - Repel electrons leaving the cathode
  - No emission from anode for it's not hot

⇒ Enable the current rectification "oscillation valve" or kenotron (invented by Fleming in 1904)

Vacuum Tube - Triode



Q: How can we control the amount of current flow?

A: Apply another potential between cathode & anode

Place a "grid" electrode:

- Change the voltage at grid, so does the amount of electrons flowing

⇒ Electrostatically "control" the plate current

⇒ A sensitive amplifier of voltage

⇒ Electrostatically "control" the plate current

"Audion" (now known Triode)

- invented by De Forest in 1906
- patented in 1907 for use in radio communication.

Vail.. We Have a Problem

1900

How can we flight for competition due to the expiration of Bell's patent?

Bring on transcontinental phone sevice

1907

1906: Lee De Forest developed a triode in a vacuum tube that can amplify the signal

1907: AT&T bought De Forest's patent and improved the device.

Can talk across any distance as long as amplifiers are along the way!

Well, not a fully solution yet.

Drawbacks of vacuum tube:

- Was unreliable
- Needed too much power
- Produce too much heat

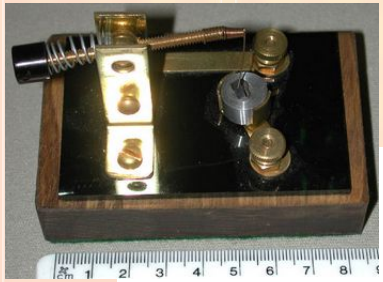
⇒ A better solution needed (1930s)

Hope?

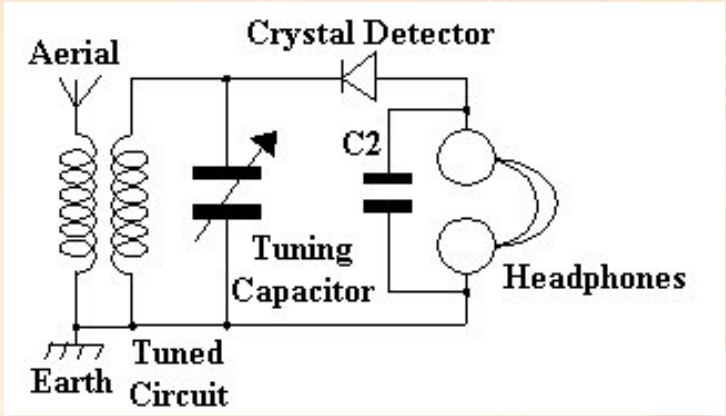
Semiconductors!

Crystal Detector - Cat's Whisker

- *Principle of operation discovered by Brau (1874)*
  - *Patented in 1899*
- *Used in radio receiver by Pickard*
  - *Patented for a Si detector in 1906*
  - *"Cat's Whisker"*



Simple crystal set



Drawbacks of crystal detector:

- Needed fine tune
- Was unreliable

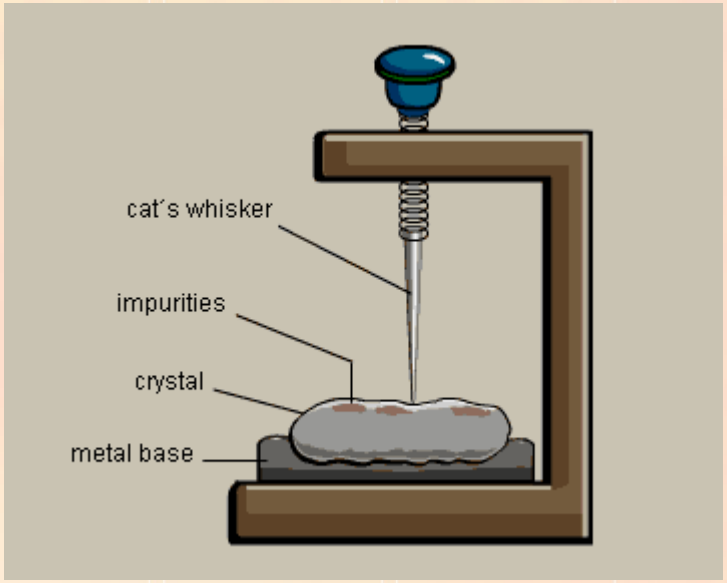
Suppressed by vacuum tube

But, it's the basic concept of transistor!

How Does A Crystal Diode Work

"Magic spot"

When the whisker was over a "magic spot", an electrical signal traveled down the metal wire & through the crystal

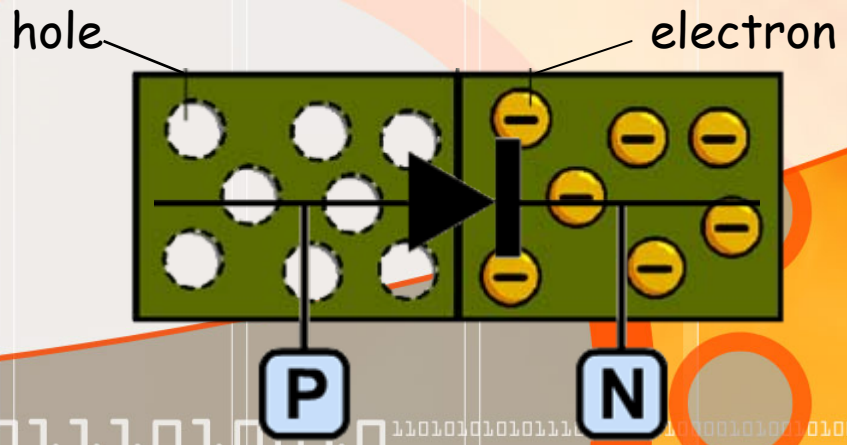


Crystal: often galena (PbS), iron pyrite (FeS_2), zincite (ZnO); sometimes Si and Ge
Point contact: Phosphor bronze wire, or gold

But ***How*** ?

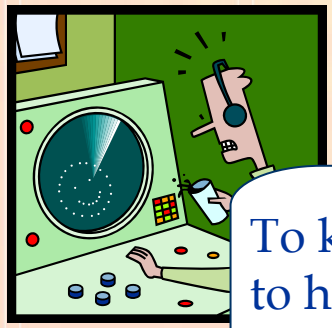
Because of the *impurities* in crystal,
i.e. a property of the *semiconductor* the crystal was made of

- Rectifier ⇒ Diode (1919) coined by Eccles
- Used (still) as
  - Detector in TV or radio receiver
  - Converter of AC to DC in power supply



Set Up Stage for the Invention

- *Crystal dectecor*
  - *Provided inexpensive radio receivers*
  - *Helped win over WWII*
  - *Helped set the stage for the transistor*
- *Problem in crystals*
  - *Slow response & burnt our often*
  - *Searched for the best crystal*
    - *Germanium (Benzer , Purdue)*
  - *Better growth and dopping techniques*



Bell's research director, and later its president

Marvin Kelly

To keep AT&T strong is to have a top-notch basic research program

⇒ Solid State Physics Group

Why *Solid State*?

For their phone system

Better amplifier

- sturdier & efficient

For future customer

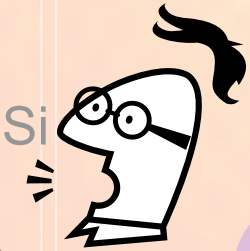
e.g. the US military

Especially, Shockley's semiconductor group

Miracle Month – Nov. 17-Dec. 23, 1947

- Getting Wet
  - 11/17: Brattain dumped the Si device into water

    ⇒ the largest amplification so far!
  - Blocking on surface was cancelled out by water



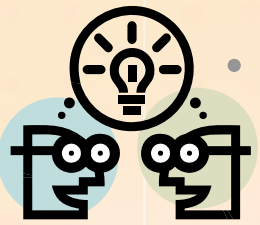
- Big Amplification
  - 12/08: Bardeen suggested:

Let's try Ge!

- Got a big jump – about 330 times

  But in the opposite direction

  It's hole moving!



- Putting the Idea to Use
  - 11/21: When Bardeen was told, he got an idea

Brattain, push a metal point to Si surrounding by DI water but not touch the water.

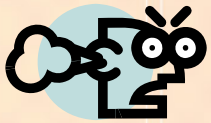
- It worked! – but very small.

- Not For All
  - Big jump only work for very low freq.
  - Culprit: Water? Try GeO_2
  - 12/12: Brattain did

But nothing happened!

Miracle Month – Nov. 17-Dec. 23, 1947

- Brattain's Mistake
  - Washed GeO_2 off by accident



Mad at himself

  - Fiddled with the point contact anyway

And got voltage amplification for all frequencies

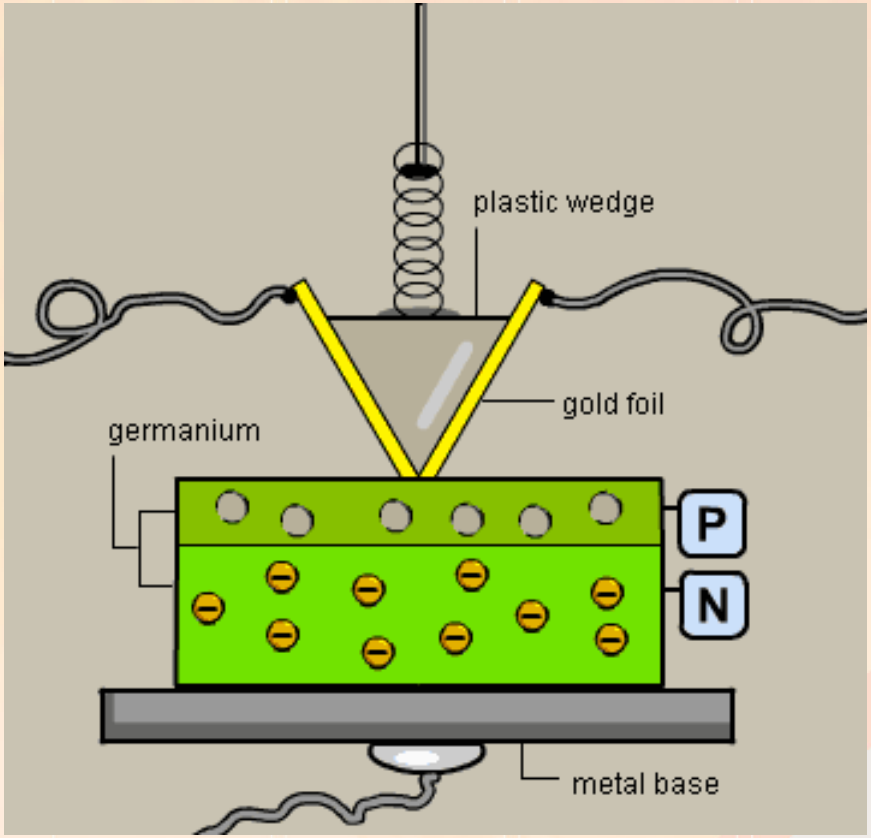
- Bring It All Together
  - Large amplification at some freq.; small amplification for all freq.
  - Key components:
    - A Ge slab & two gold point contacts closely placed

- Showing off
  - 12/23: by Brattain & Bardeen

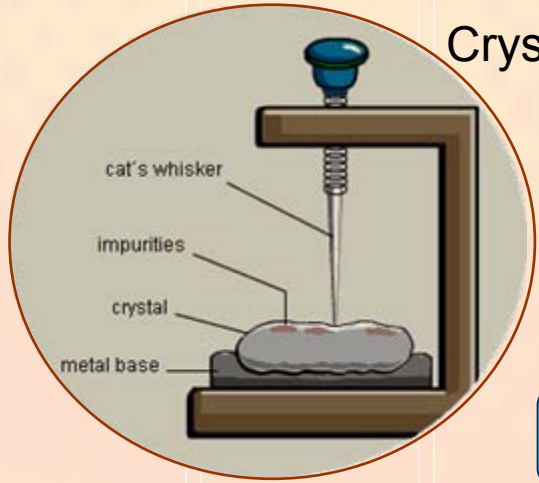
The 1st point-contact transistor was born!

Point-contact Transistor

- A Close Look



Crystal Detector



Diode

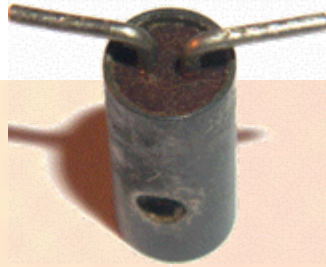
Two terminal device

- Considered as a crystal detector with two whiskers

Triode

- Three-terminal device
  Two on gold foil & one on metal base

Side Note



- Naming the big thing (05/48)

Ballot
Semiconductor Triode
Solid Triode
Surface States Triode
Crystal Triode
Iotatron
Transistor ☑

coined by John R. Pierce

Combination of transconductance, transfer, resistor

- Telling the Military
  - Bell's concern: classification
  - 06/23/48: Presented for the Military officers

- Type-A transistor

  Mass-product version of point-contact ones

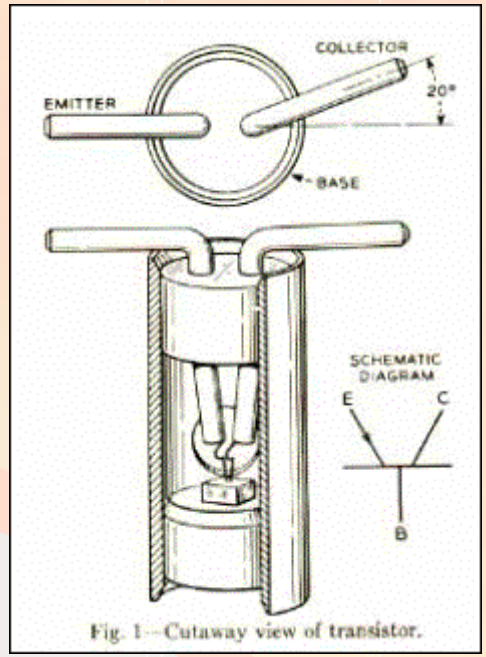
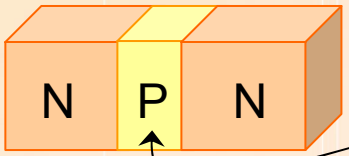


Fig. 1—Cutaway view of transistor.

First one (Ge) sold in 1949

Shockley's Invention 1948-1951

- Unhappy Shockley 
  - New Year 1948: Thought how to improve B&B's transistor
    Semiconductor "sandwich" 
  - Rejected as a co-author in patent
    - Wanted to build his own
  - 1/23/48: Idea came together



Very different idea from point-contact transistor

Current passes through semiconductors, not the surface

No idea whether it works

- Eureka Moment
  - 02/18/48: It can work
    Told others about his idea
- More works on
  - How current transports
    Bardeen's theory: only on surface
    Richard Haynes's exp on Ge (1948)

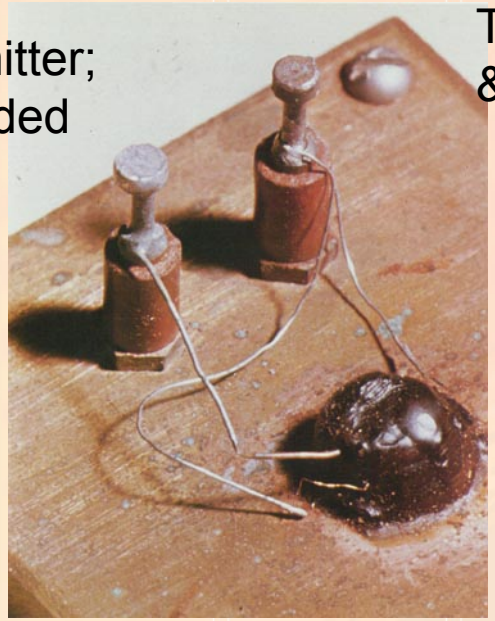
⇒ Need very thin & pure middle layer

- How crystal affects
  Old cut vs Single
  Gordon Teal's growth technique (1949)

Junction Transistor

To emitter; grounded

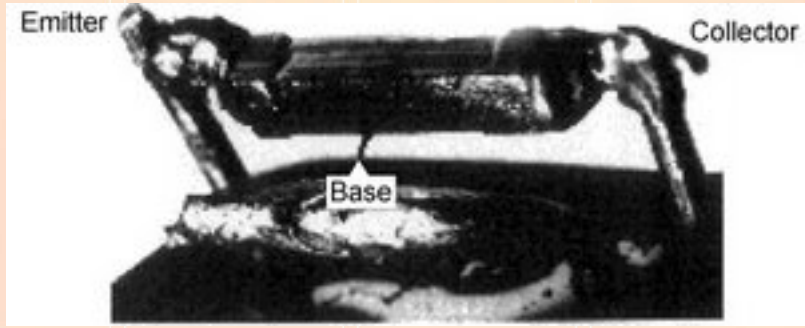
To based & collector

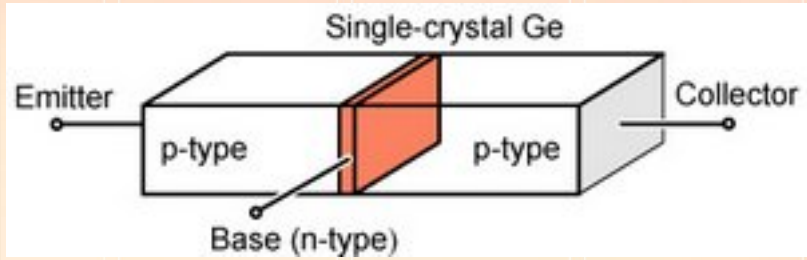


1950

Re-creation
Actual size: 0.5" tall

Another version





Also called Bipolar Junction Transistor

1956-1958: Made it flat

- Bell's "mesa" transistor
- Fairchild's "planar" transistor

1958: 1st Si transistor (Teal)

- Ge transistors broke down at high temperature

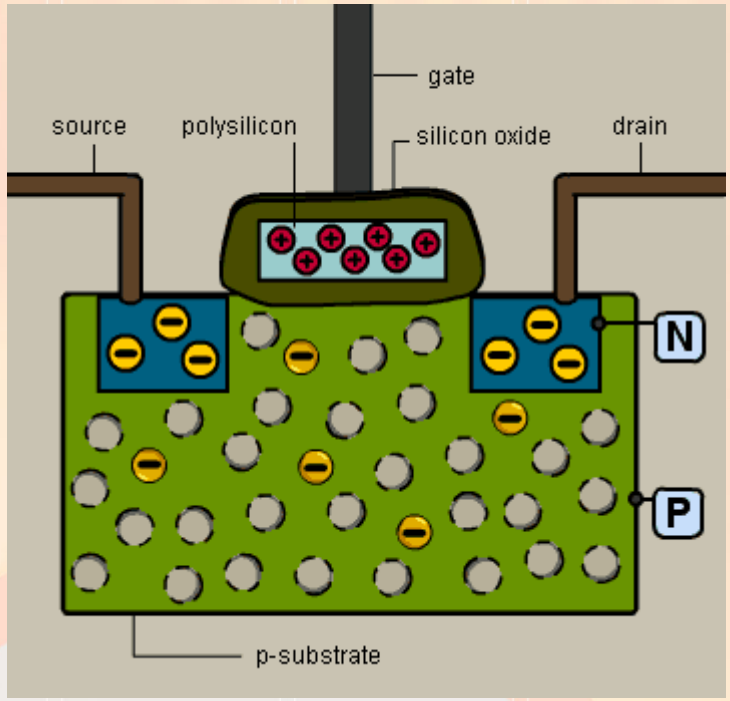
Field-Effect Transistor

- "Unipolar transistor"
  - Need only one type of carriers
  - Relying on an electric field to control the conductance of a "channel"

Types:

- Junction FET
- Metal-Semiconductor FET
- Metal-Oxide-Semiconductor FET
- High Electron Mobility Transistor (HEMT)

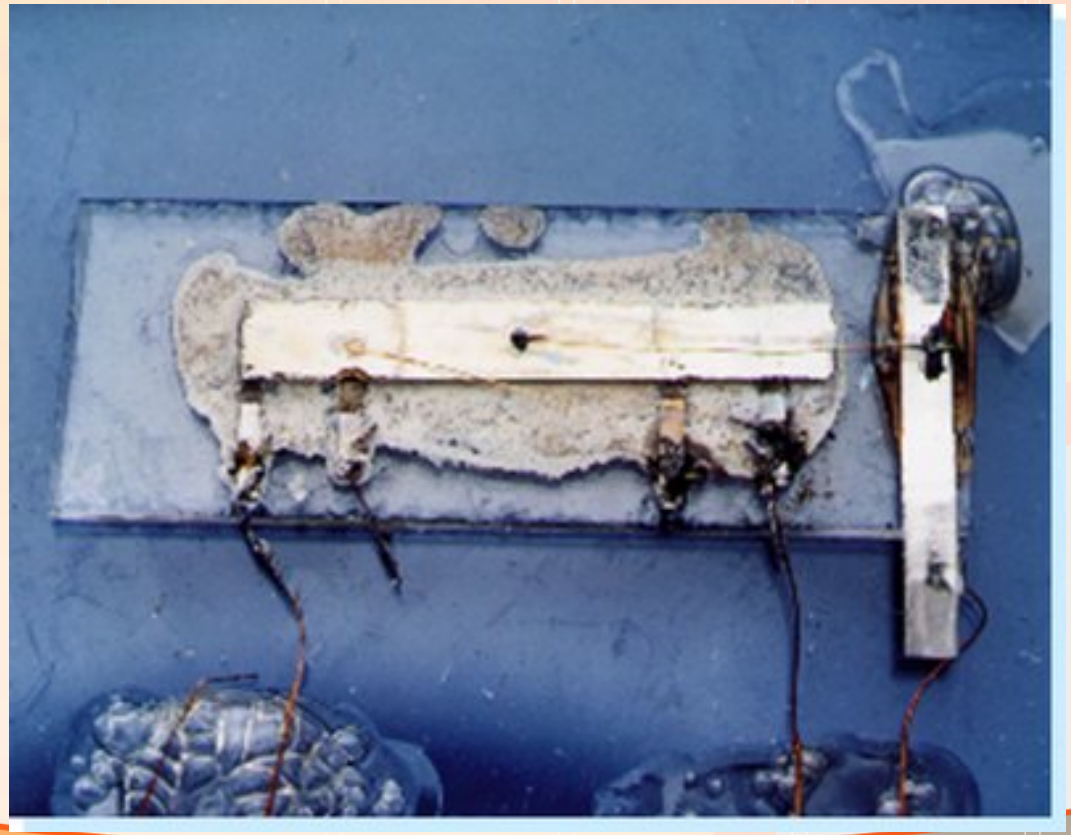
Metal-Oxide Semiconductor Field-Effect Transistor



n-channel transistor

Invention of Integrated Circuit

Why not use semiconductor to make capacitor & resistor and put them all together?



09/12/1958

Jack Kilby built a model

02/06/1959

TI filed a patent

01/1959

Robert Noyce got the same idea

Fairchild filed a patent after TI

References

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  - *Wikipedia*
  - *Images by Googling*