



Who Invented the Integrated Circuit?

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IEEE Pikes Peak Region

Life Member

May 2020



Kilby and Noyce

Photos
(Kilby, TI Noyce, Intel)

Commemorative Microchip Stamp

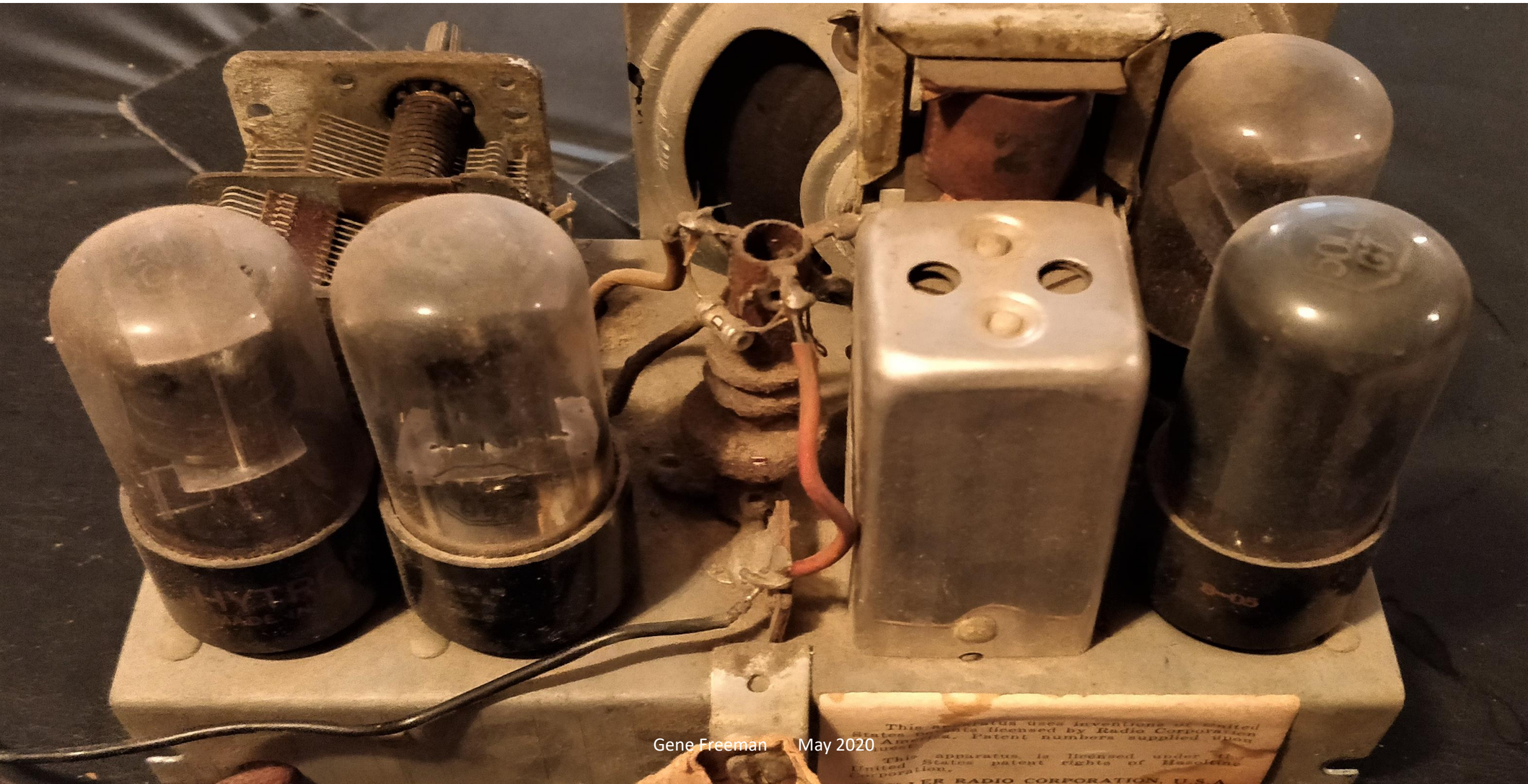


Image:
Computer-
Stamps.com



Motivation

Trav-ler 4 Tube Tabletop AM Radio around 1949



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Discrete
passives
and point to
point wiring

Motivators

- Computers
- Space vehicles
- Decrease power, space, cost
- Increase reliability




Tyranny of Numbers

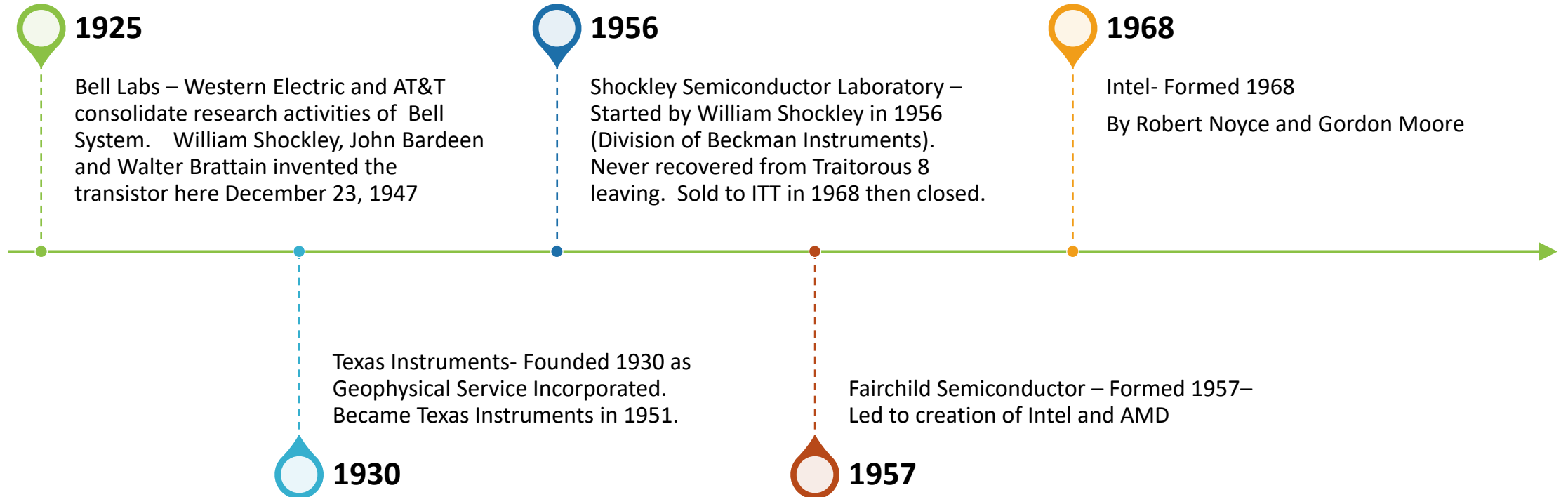
- In an article celebrating the tenth anniversary of the invention of the computer, J. A. Morton, A Vice President of Bell Labs wrote in Proceedings of the IRE in 1958:
- “For some time now, electronic man has known how 'in principle' to extend greatly his visual, tactile, and mental abilities through the digital transmission and processing of all kinds of information. However, all these functions suffer from what has been called 'the **tyranny of numbers**.' Such systems, because of their complex digital nature, require hundreds, thousands, and sometimes **tens of thousands of electron devices**. Each element must be made, tested, packed, shipped, unpacked, retested, and **interconnected one-at-a-time** to produce a whole system.”



Solution elements


- Active Components: Vacuum Tubes to transistors
 - Passive Components: Discrete to integrated form
 - Wires to integrated wires
- 

Key Companies in the Story



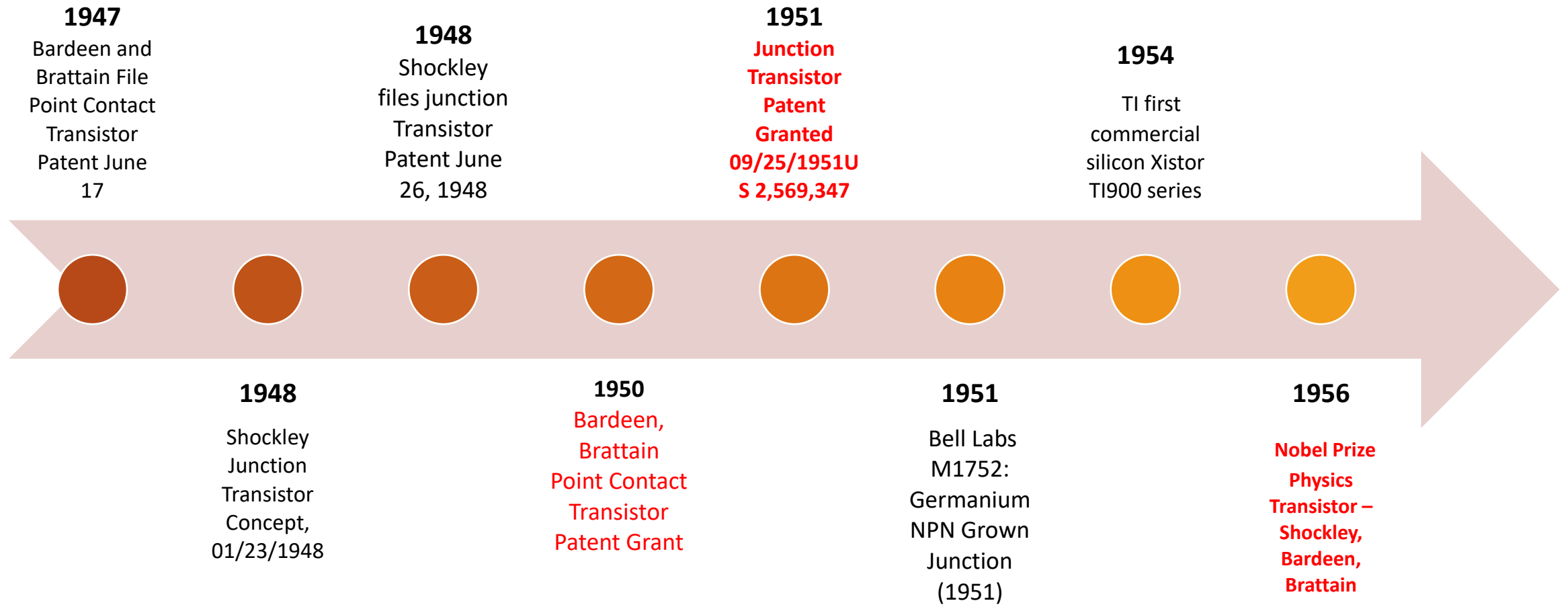
Traitorous eight

- Gordon Moore (Moore's Law) Intel Co-Founder
- Sheldon Roberts
- Eugene Kleiner, founder of Kleiner Perkins
- Robert Noyce, Co founded Fairchild Semiconductor 1957 and Intel 1968
- Victor Grinich
- Julius Blank
- Jean Hoerni, developed the Planar Process, key for Xistors and ICs
- Jay Last



Shockley and the Transistor

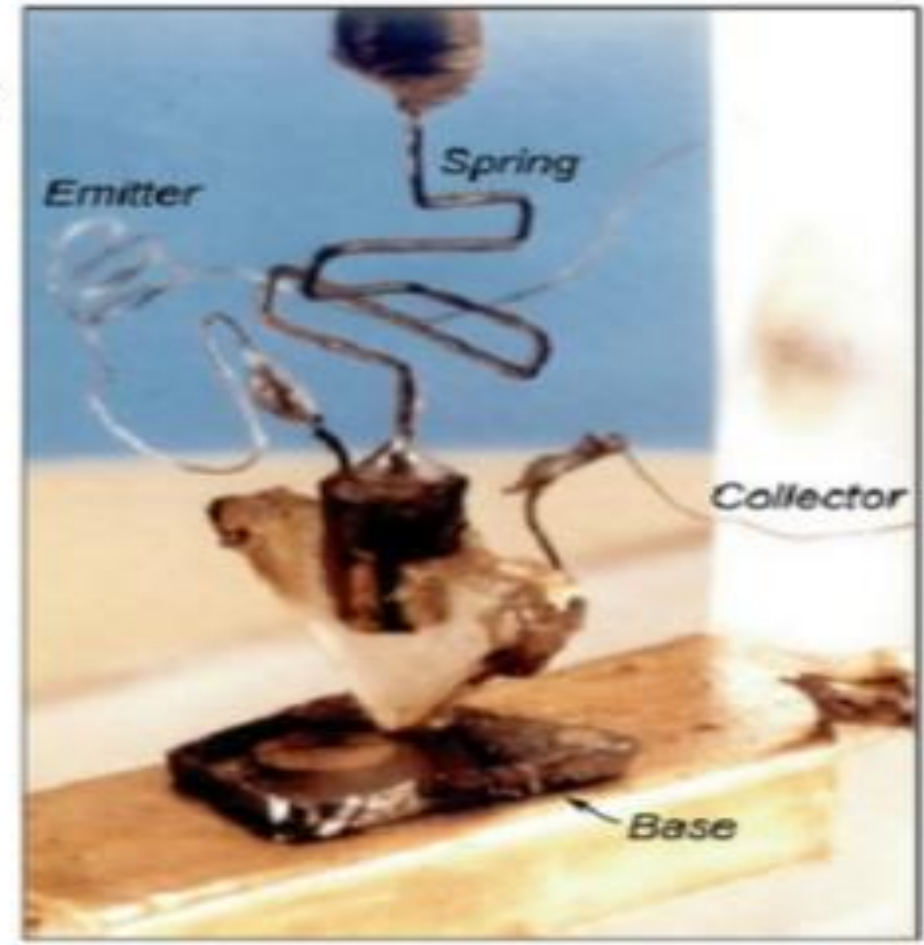
Transistor Timeline



Point-Contact Transistor - first transistor ever made

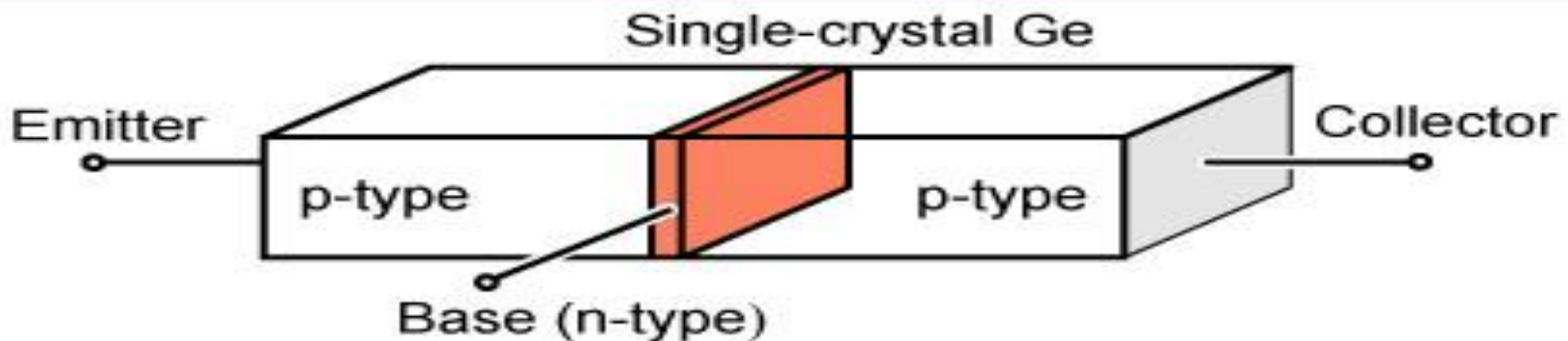
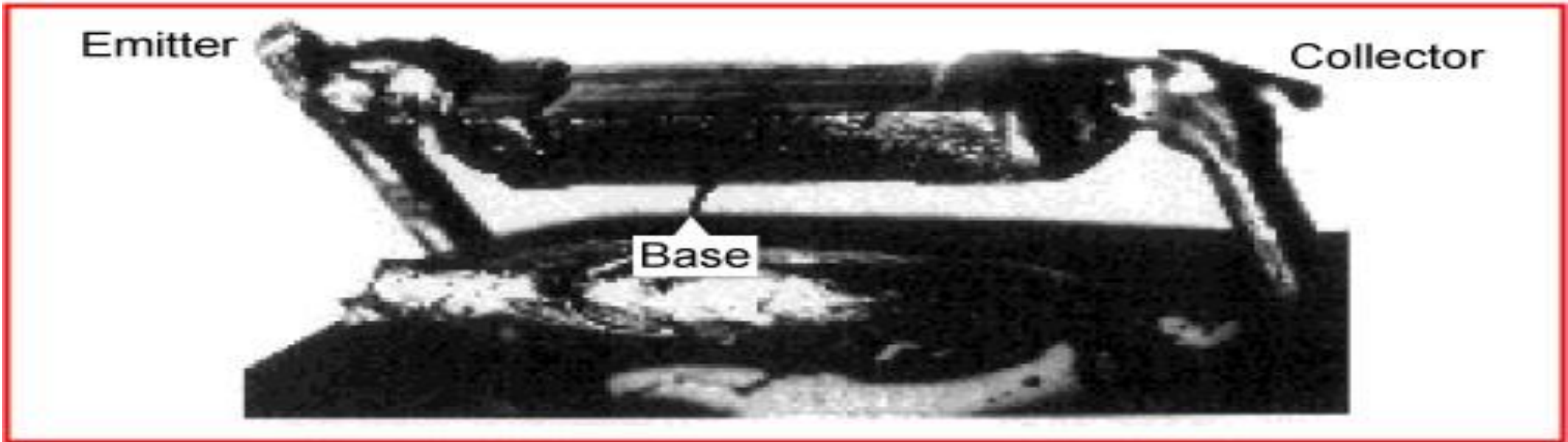
The first transistor was a point-contact transistor

The first point-contact transistor
John Bardeen, Walter Brattain, and William Shockley
Bell Laboratories, Murray Hill, New Jersey (1947)



The First Junction Transistor

First transistor with diffused pn junctions by William Shockley
Bell Laboratories, Murray Hill, New Jersey (1949)

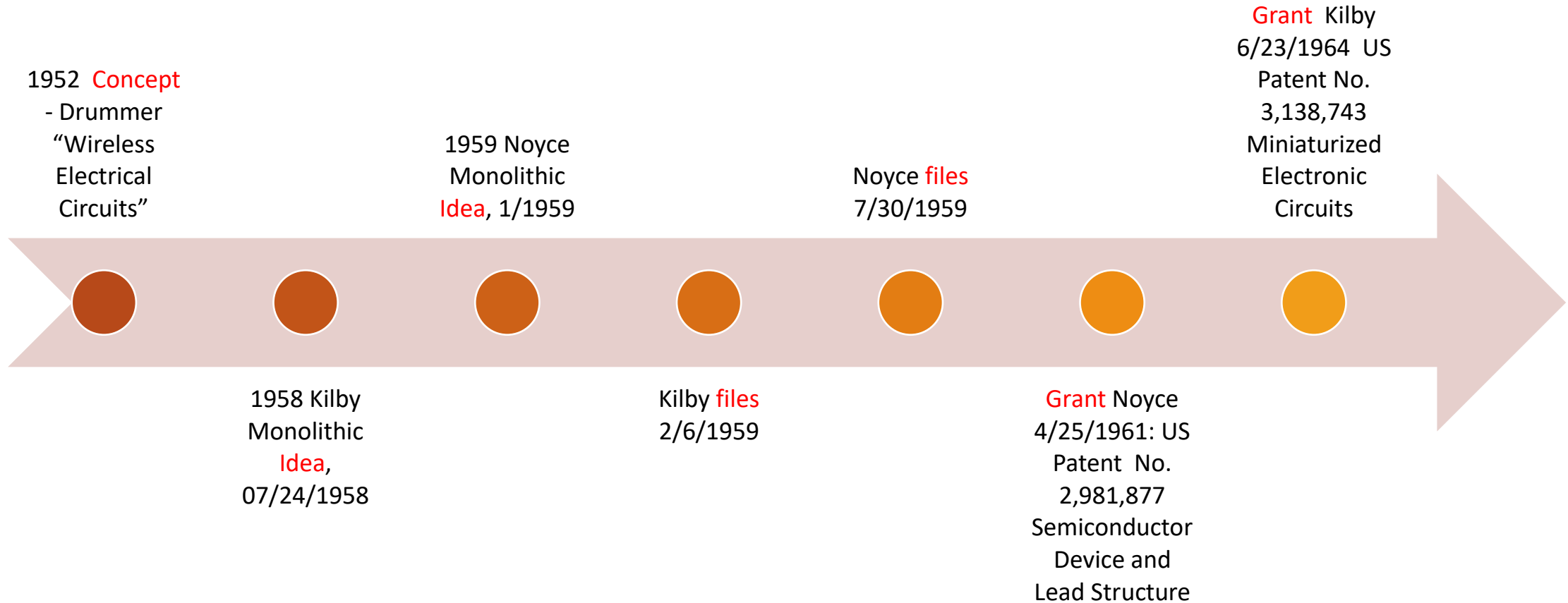


Source: thebronxchronicle.com



The Integrated Circuit

Integrated Circuit Invention



Earliest Reference to IC Challenge

- Jack Morton, head of transistor manufacturing at Bell Telephone Laboratories, described an early conception of such a circuit. In a 1949 internal report he noted: “Imagine a technique in which...the connecting leads and passive elements are ‘printed’ in one continuous fabrication process. ...We do not know the technology of doing these things... Here then is the challenge.”



Drummer – Wireless Electrical Circuits

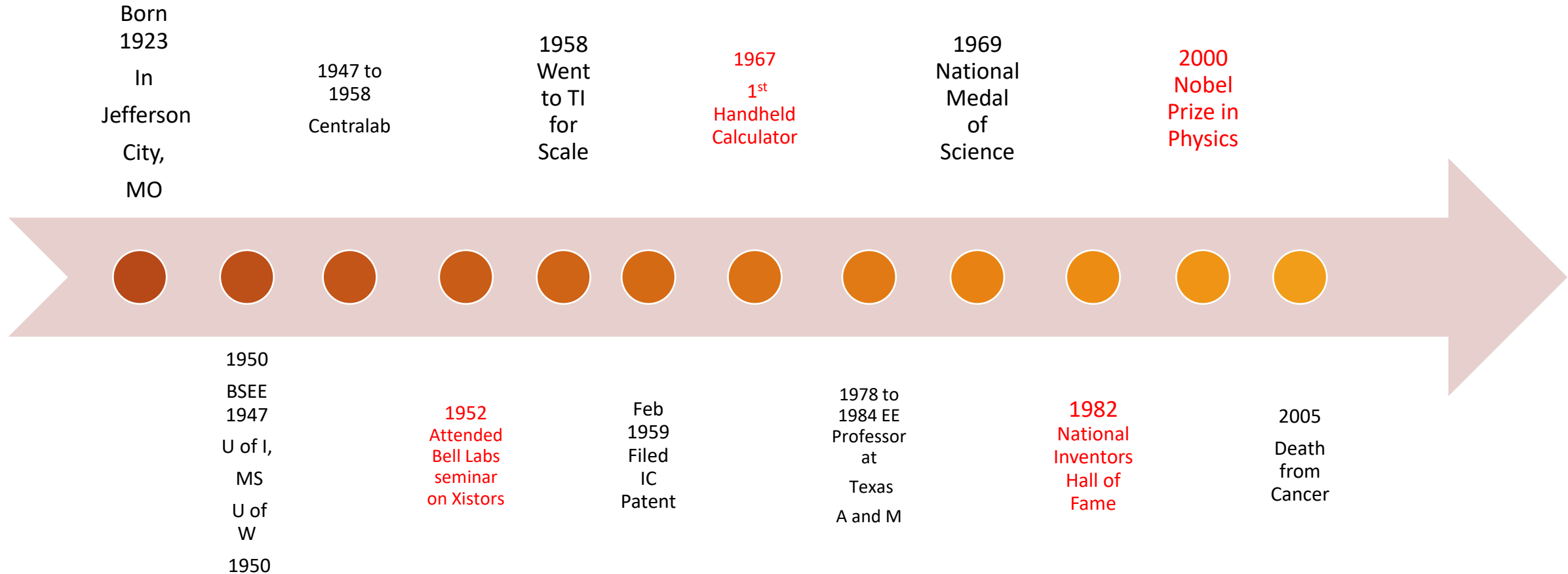
Geoffrey Drummer – Wireless Electrical Circuits

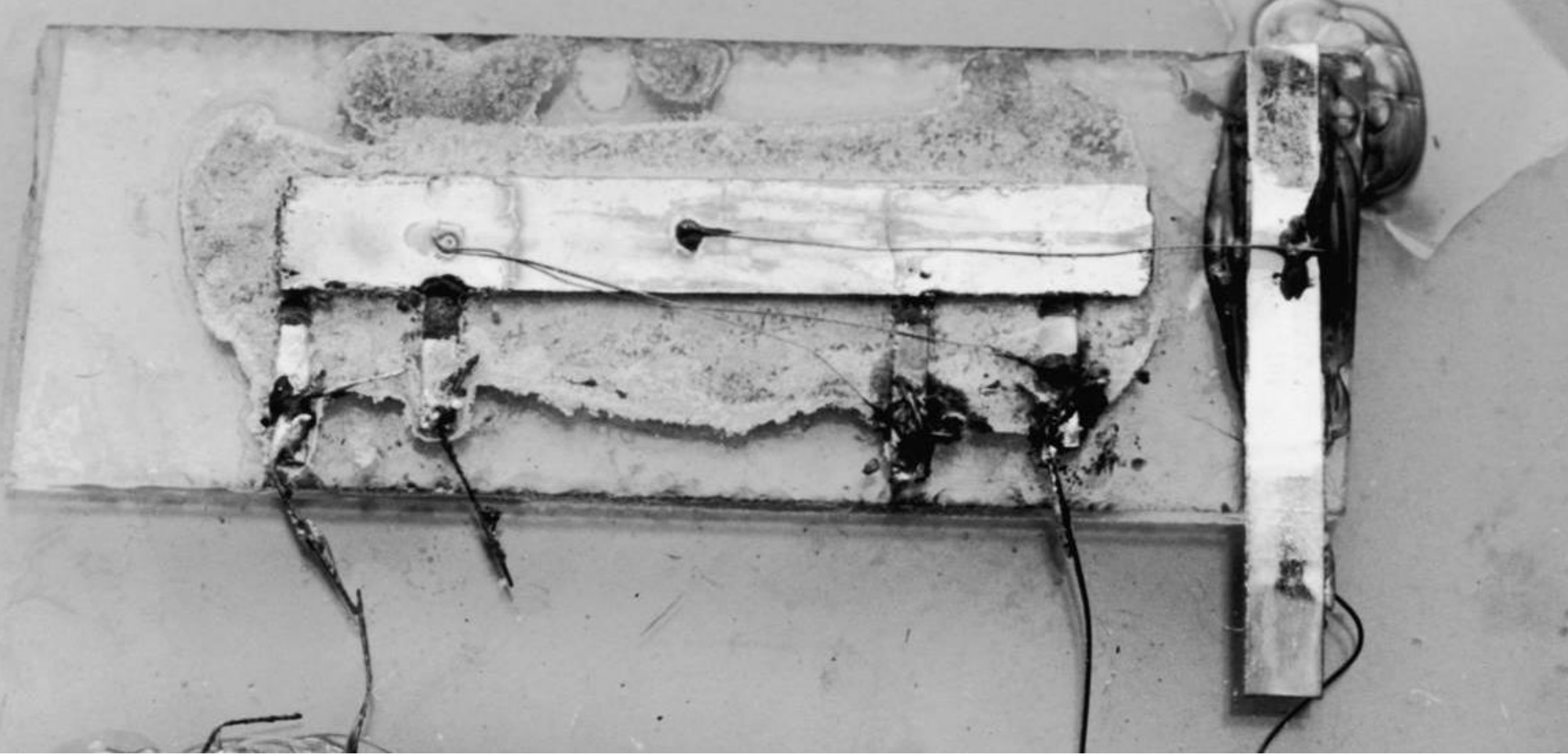
- Ran a testing group at the Telecommunications Research Establishment at Malvern, England
- “Wireless”: meant not a radio but electrical circuits free of connecting wires and soldered joints
- May 1952. At the Symposium on Progress in Quality Electronic Components, held in Washington DC he said:
- ‘It seems now possible to envisage electronic equipment in a solid block with no connecting wires. The block may consist of layers of insulating, conducting, rectifying, and amplifying materials, the electrical functions being connected directly by cutting out areas of the various layers”
- Drummer failed to get financing from his government for the work to implement the idea.



Kilby and Texas Instruments

Jack Kilby Timeline





Original Kilby Circuit

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Source: [cnet.com](https://www.cnet.com)

June 23, 1964

J. S. KILBY

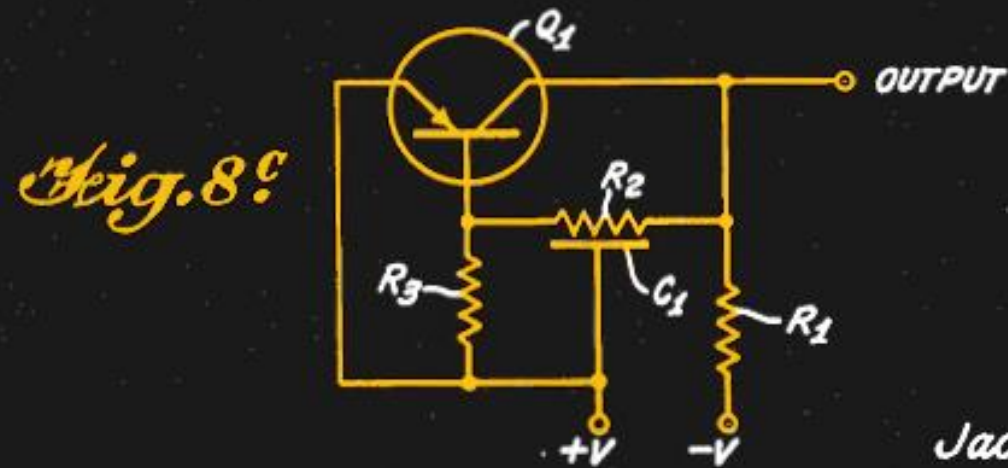
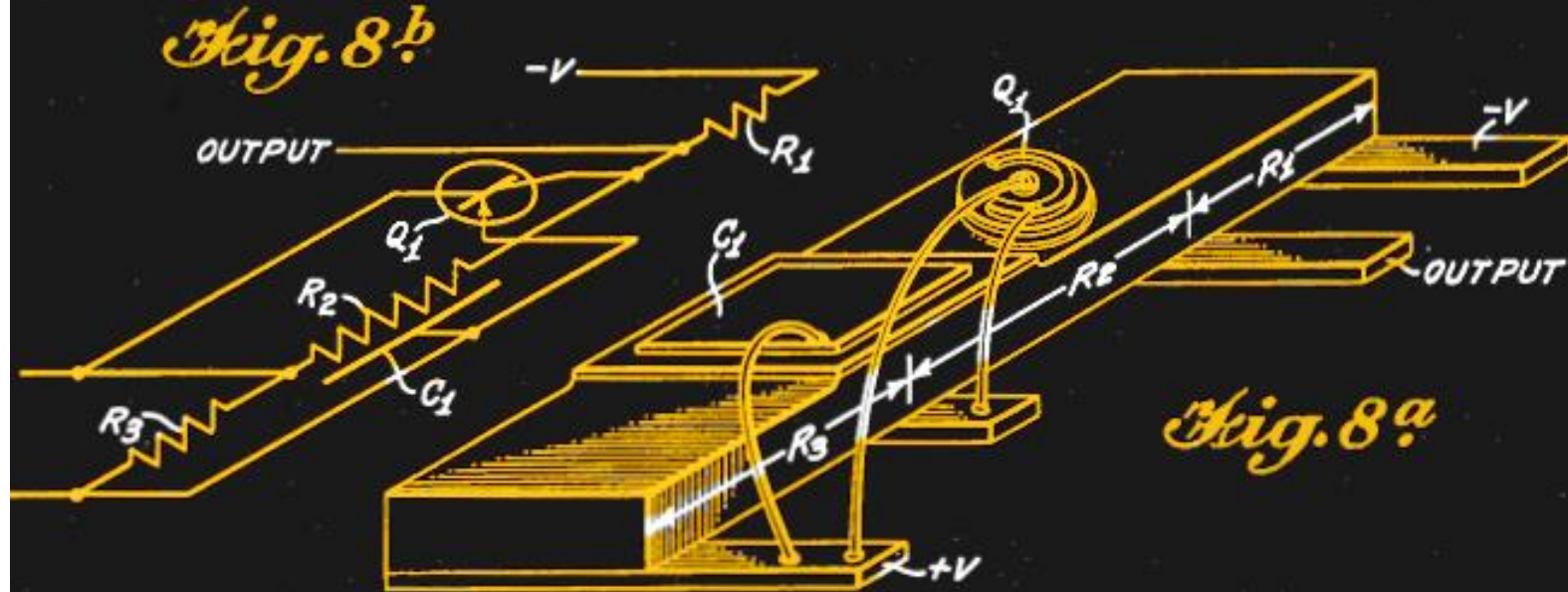
3,138,743

MINIATURIZED ELECTRONIC CIRCUITS

Filed Feb. 6, 1959

4 Sheets-Sheet 4

Patent
Drawing of
Phase Shift
Oscillator



INVENTOR

Jack S. Kilby

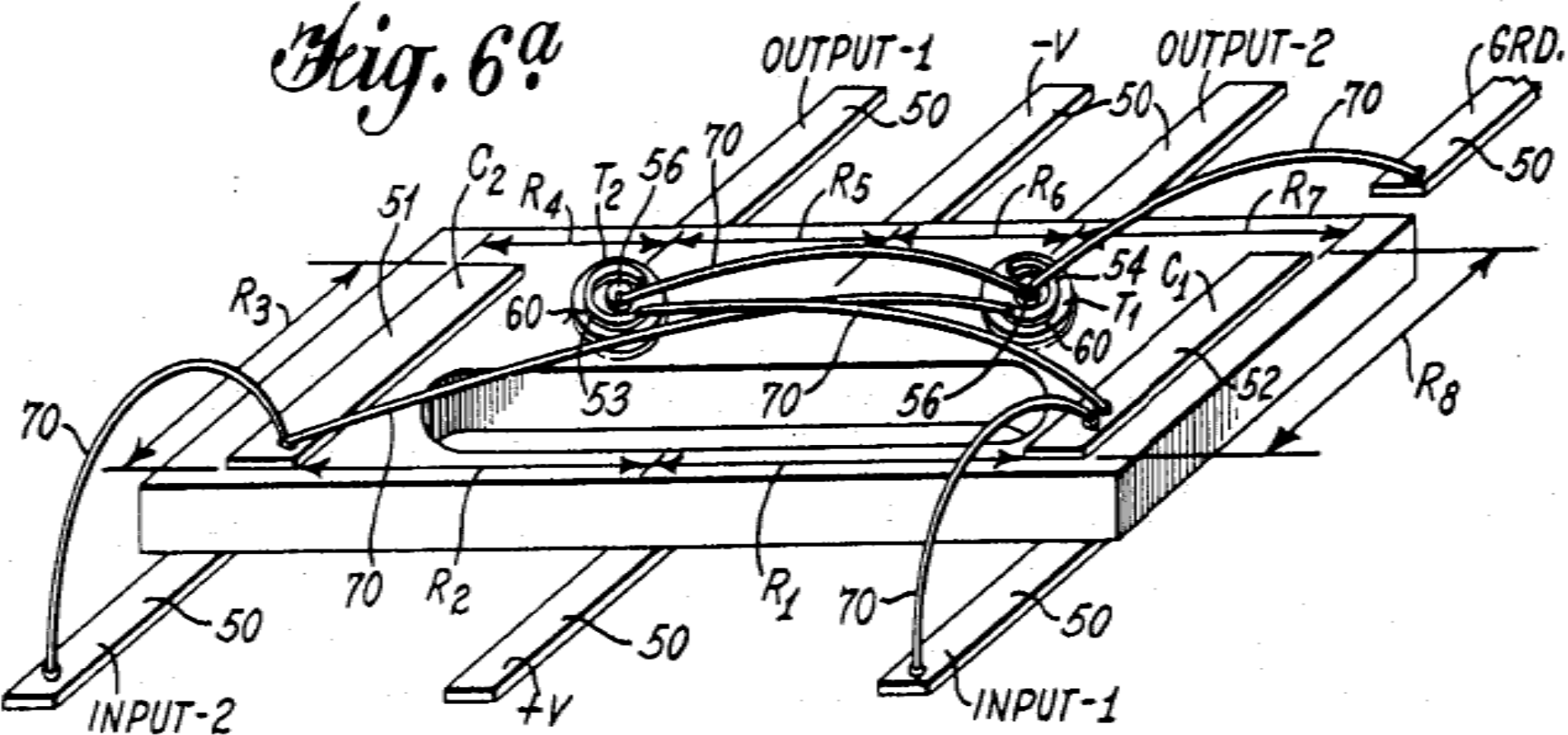
Jack Kilby Invention Path

- Integration and Interconnection
- Integration – All parts of the circuit could be made from the same material
- Interconnection – wires could be printed onto the chip as part of the production process.
- For the proof of concept Kilby integrated all the circuit components but didn't have time to work out the interconnection so he connected the parts of the chip by hand with gold wires which was not a large scale production solution

Filing on
February 6,
1959

- Worrying RCA was going to apply for a patent , they needed a picture of the interconnection solution. Lacking a model they used the demo chip (the “flying wire”) picture.
- Although the invention has been shown and described in terms of specific embodiments, it will be evident that changes and modification are possible which do not in fact depart from the inventive concepts taught herein.
- “ connections may be provided in other ways. For example... silicon oxide may be evaporated on the semiconductor circuit wafer.... Material such as gold may then be laid down on the [oxide] to make the necessary electrical connections.”

Multivibrator Circuit from 3,138,743 Kilby

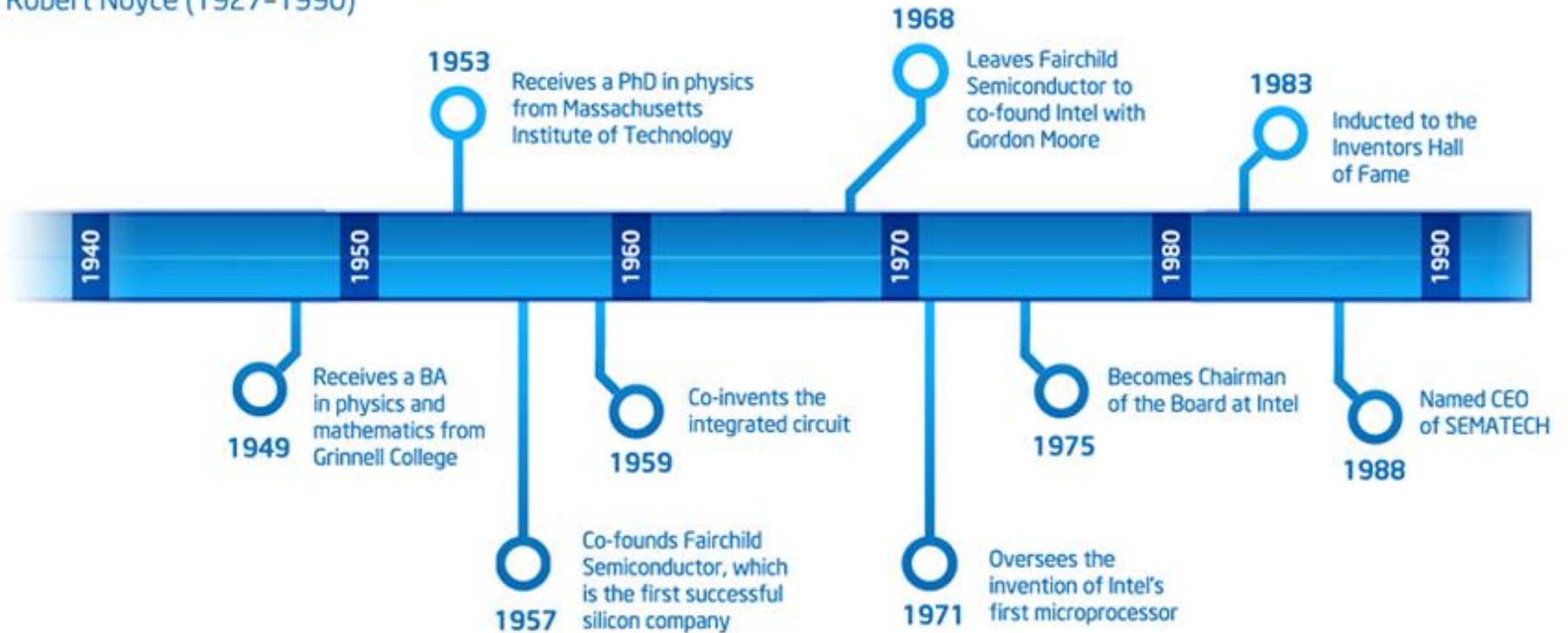




Noyce and Fairchild Semiconductor

The Life of an Innovator

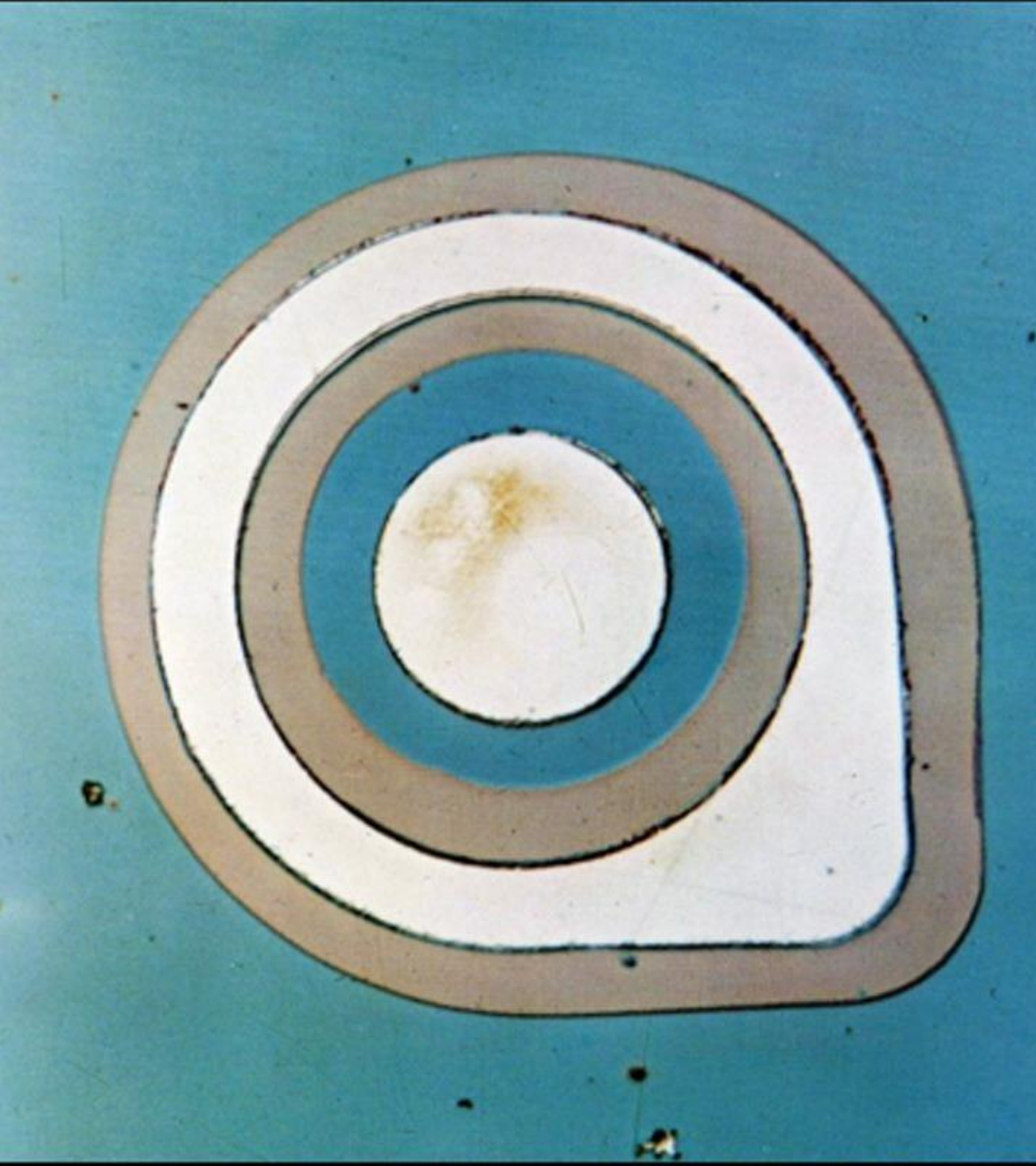
A look back at the career and accomplishments of Robert Noyce (1927-1990)



From intel . com

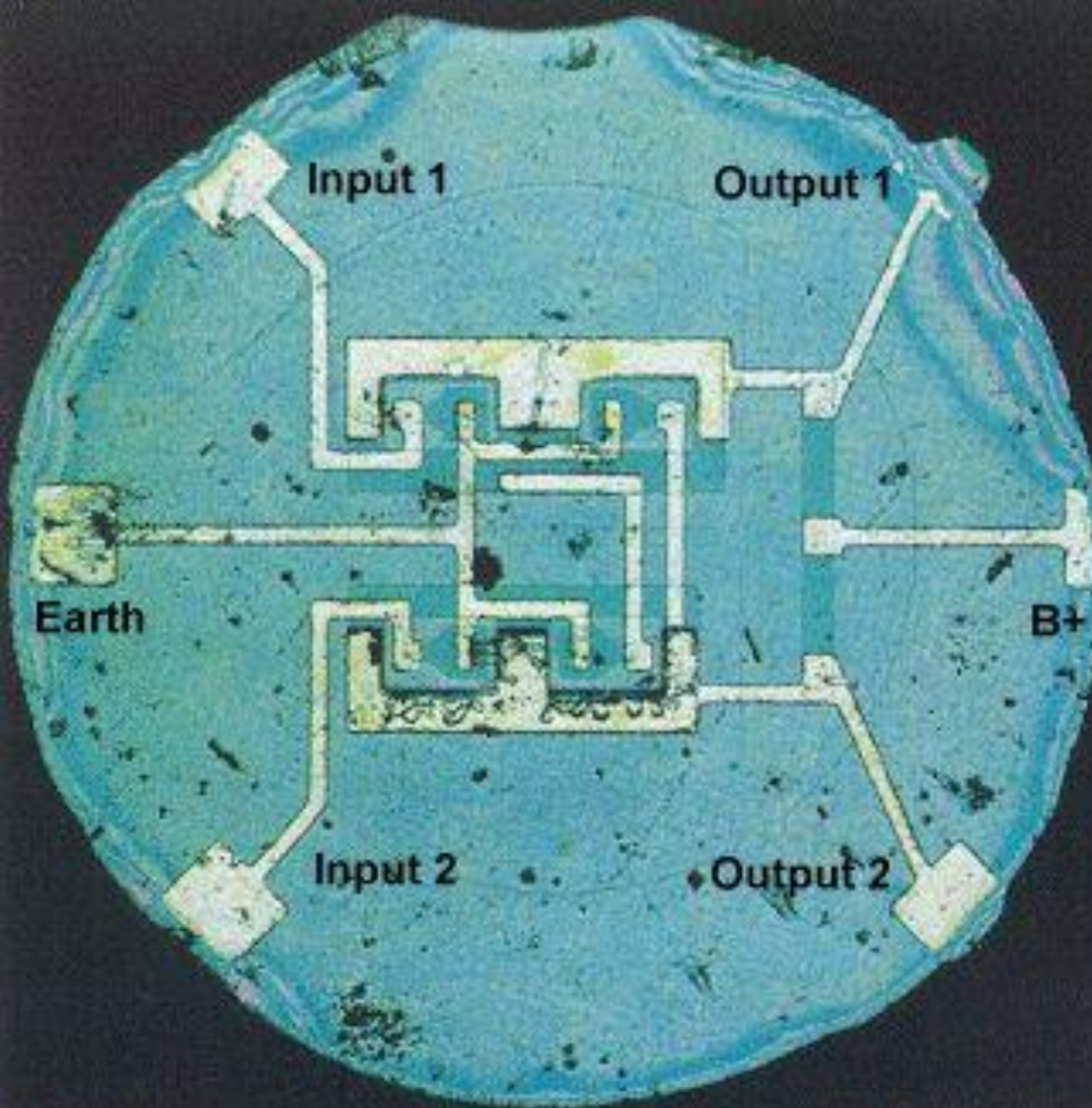
Robert Noyce Invention Path

- Noyce had recognized the possibility of printing connecting strips of metal on a chip
- This was made possible by Jean Hoerni's invention of the planar process (filed May 1, 1959), this led him to the idea of integration.
- Spring of 1959 Fairchild engaged in working out details of the planar process so Noyce had a description and drawing of a chip with the interconnections built right in.
- 1st part of the application was interconnections
- Leads could be deposited at the same time and in the same manner as the components themselves.
- There were no wires in the pictures....



Photomicrograph
of Model 2N1613
planar transistor

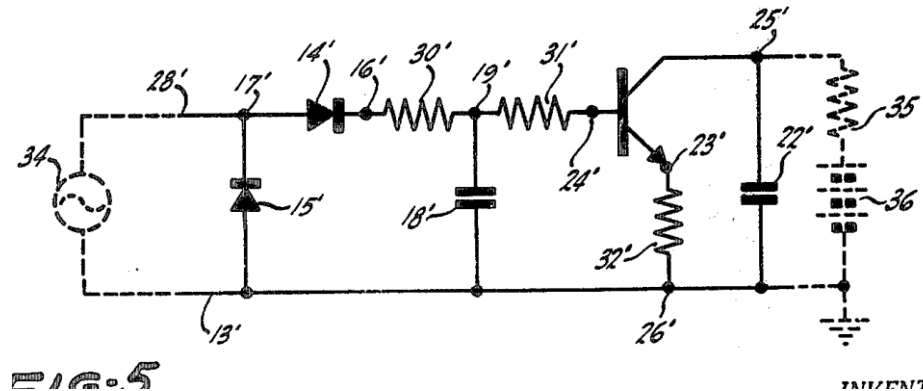
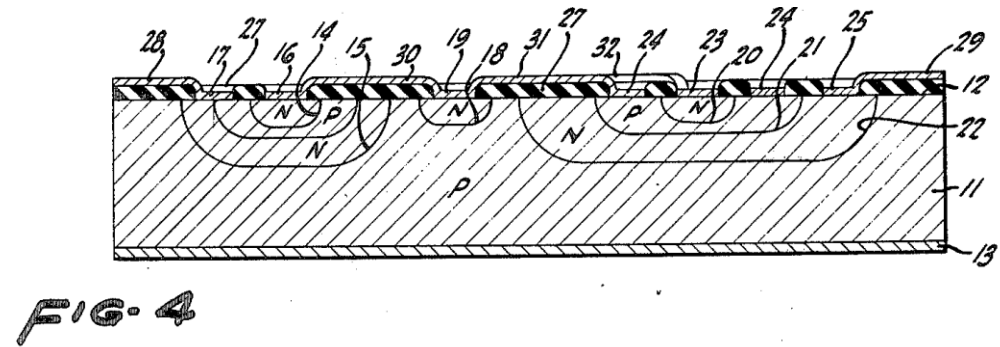
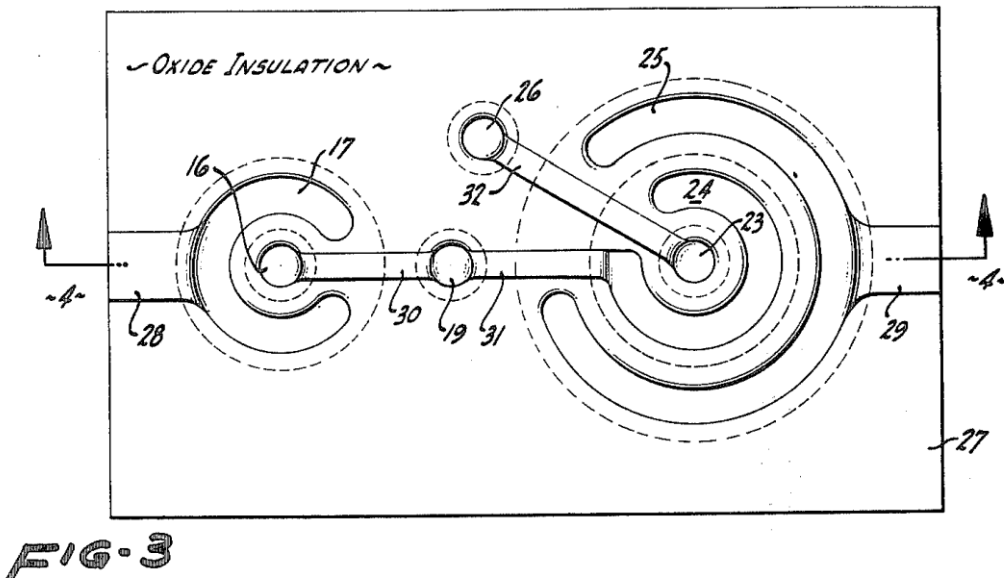
Source: spectrum.ieee.org



Noyce's First Chip

Source: chiphistory.org

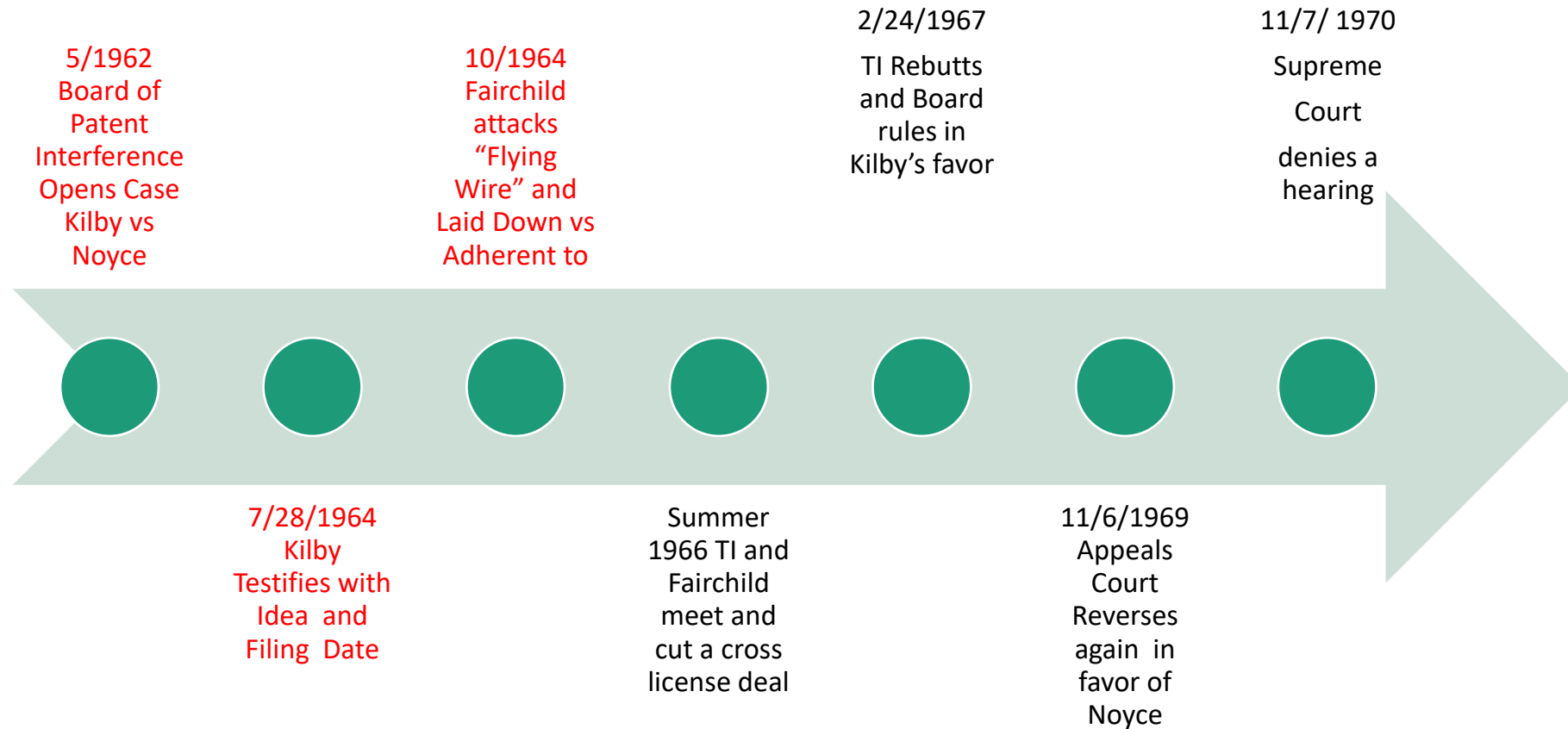
Semiconductor Device and Lead Structure – Noyce – Filed July 30, 1959





Patent Battle

Legal Battle Timeline



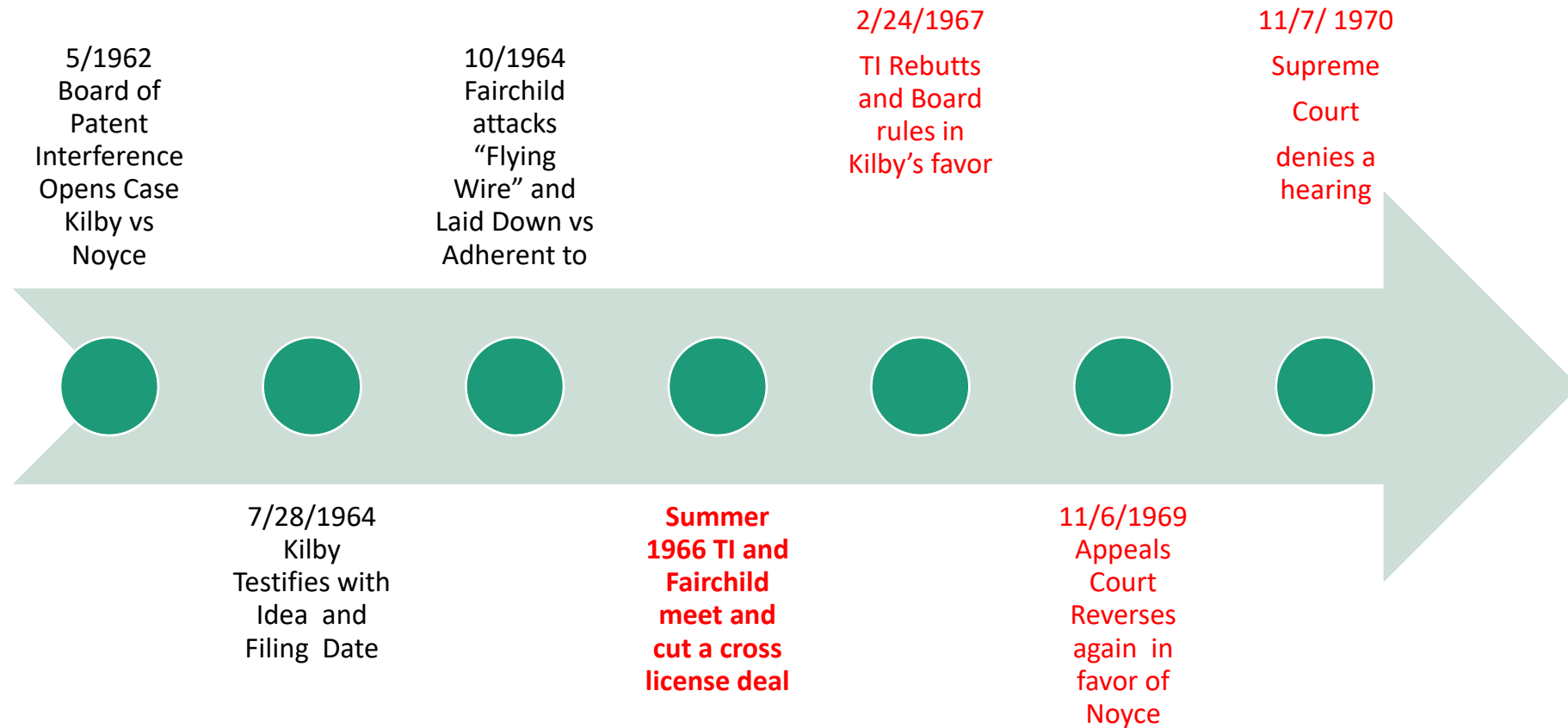
Kilby Interconnect Description

- Connections may be provided in other ways (gold wires thermally bonded was the primary example)
- ...silicon oxide may be evaporated on the semiconductor circuit wafer through a mask.
- ... to cover the wafer completely except at the points where electrical contact is to be made
- ...Electrically conducting material such as gold may then be **laid down** on the insulating material to make the necessary electrical circuit connections.

Noyce Interconnect Description

- In brief, the present invention utilizes
 - Dished junctions extending to the surface of the body of extrinsic semiconductor
 - Insulating surface layer consisting essentially of oxide of the same semiconductor extending across the junctions
 - Leads in the form of vacuum-deposited or otherwise formed metal strips extending over and **adherent to** the insulating oxide layer for making electrical connections to and between various region of the semiconductor body without shorting the junctions

Legal Battle Timeline



Resolution of the Dispute


- US Supreme Court Kilby was denied. 10 years and 10 months after Kilby applied for his patent, Noyce won... however...
- In the 10 years while the case was litigated, ICs were recognized as the most important new product in the history of electronics. By the time the courts resolved the issue ICs were a multi-billion dollar industry.
- Summer of 1966 a deal was cut. TI and Fairchild cross licensed each other Any other firm had to arrange licenses with both. Generally the royalty was 2-4 % of the licensee's profit from chip production.
- Both Kilby and Noyce inducted into National Inventors Hall of Fame. Kilby gets credit for idea of integrating components on a chip and Noyce for practical way to interconnect them.

Value of the Court Battle?

- So hardly anyone paid attention to the final court decision.
- 10 years, 10K pages, \$1M in legal fees, the result in Electronic News was “patent appeals court finds for Noyce on IC’s”
- “IC Patent reversal won’t change much”



Nobel Prize in Physics - 2000



The Nobel Prize in Physics 2000 was awarded "for basic work on information and communication technology" with one **half jointly** to Zhores I. Alferov and Herbert Kroemer "for developing semiconductor heterostructures used in high-speed- and opto-electronics" and the other **half** to Jack S. Kilby "for his part in the invention of the integrated circuit."



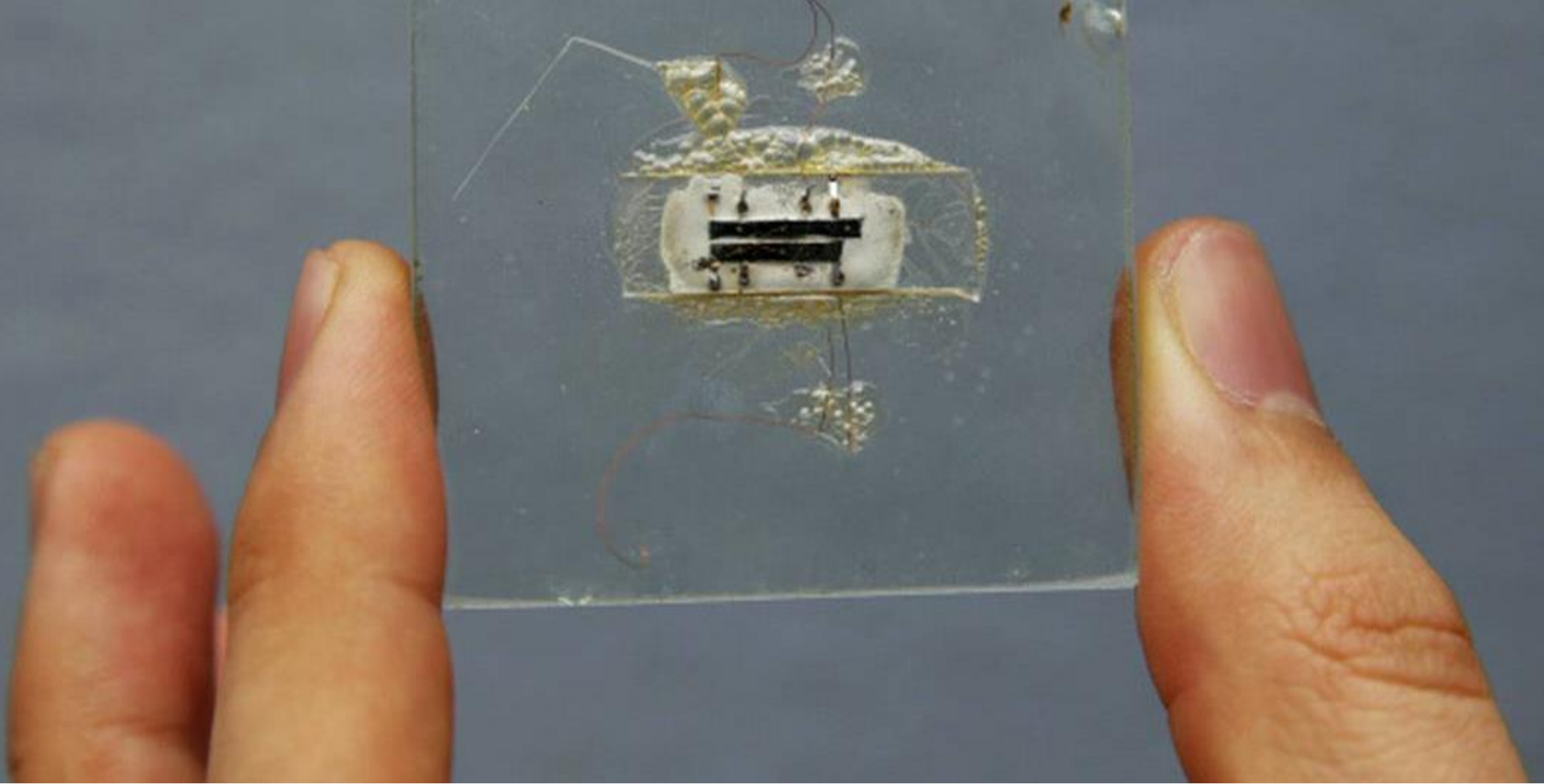
Work

The discovery of the small electronic component, the transistor, created new opportunities to amplify and control electrical signals. New materials were used and transistors gradually became smaller. Independently of one another, in 1959 Jack Kilby and Robert Noyce showed that many transistors, resistors, and capacitors could be grouped on a single board of semiconductor material. The integrated circuit, or microchip, came to be a vital component in computers and other electronic equipment.



Kilby Accepts Nobel Prize for Physics – December 10, 2000

Source: nobelprize.org



To Scale

Source: [thehindu.com](https://www.thehindu.com)

Gene Freeman May 2020

CHRISTIE'S

MEDIA ALERT | NEW YORK | 22 MAY 2014

CHRISTIE'S TO SELL HISTORIC 1958 MICROCHIP— PROTOTYPE USED IN NOBEL PRIZE-WINNING INVENTION DESIGNED BY TEXAS INSTRUMENTS' JACK KILBY

ESTIMATE: \$1,000,000 - \$2,000,000

**ON VIEW IN CHRISTIE'S LONDON GALLERIES AT SOUTH KENSINGTON MAY 22, 23, 27 & 28;
ON VIEW IN NEW YORK ROCKEFELLER CENTER JUNE 14-18, PRIOR TO JUNE 19 SALE**



A prototype microchip, one of the most important advancements in the history of computing, made by Tom Yeagan for Jack Kilby, Texas Instruments, (1958), accompanied by a 3-page statement by Yeagan and another prototype silicon chip. Estimate: \$1,000,000 to \$2,000,000.

Source: electronicsweekly.com

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fluid, &

Hospital,

stayed with him at the hospital day and night for about a week. During this time, I called Jack to tell him the location of some things that he might need. Dr. Bradford was our doctor.

I assisted Jack in his work on semiconductor networks. I remember working on the first unit, a phase shift oscillator. At the time, I was assigned to Stacy Watelski and had been working for him on germanium transistor having a horseshoe base and dot emitter. In this work, I evaporated metal to form the base and emitter. I heated the germanium and then evaporated the metal. When metal hit the germanium, it became alloyed.

Tom Yeargan's Letter that went with prototype

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Some Final Observations

- When the time is right there is more than one inventor
- Legal processes take so long that sometimes the businesses move ahead anyway
- Shockley had leadership positives and negatives but the negatives dominated
- Kilby was an individual contributor at heart
- Noyce was an inventor but could scale to the CEO role

References

- Stan Augarten, Bit by Bit, Ticknor and Fields, 1984
- George Gilder, Microcosm, Simon and Schuster, 1989
- Robert Noyce et al., Microelectronics, Scientific American, W. H. Freeman, 1977
- T.R. Reid, The Chip, Random House, 1985
- Arjun Saxena, “Monolithic Concept and the Inventions of Integrated Circuits by Kilby and Noyce”; NSTI-Nanotech 2007
- Robert Somerville, The Chipmakers , Understanding Computers Series, Time Life Books, 1990



Questions and Comments