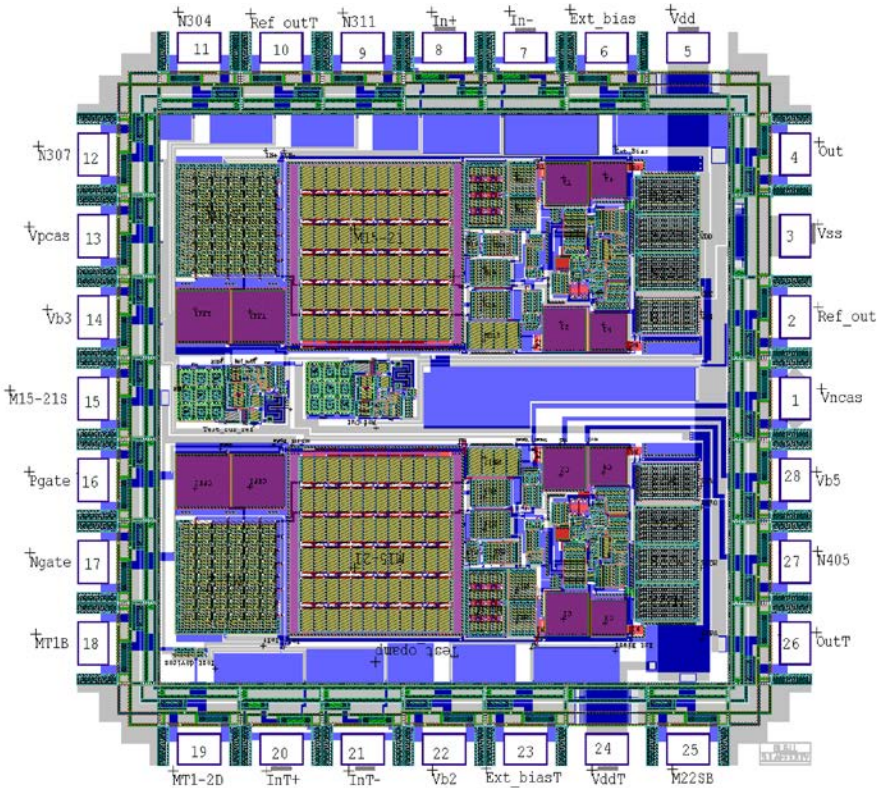
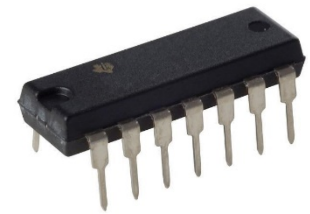
EE 330
Lecture 4

- Key Historical Developments (continued)
- Some other statistical issues (for fun)

The Integrated Circuit





June 23, 1964 J. S. KILBY 3,138,743

MINIATURIZED ELECTRONIC CIRCUITS

Filed Feb. 6, 1959 4 Sheets-Sheet 1

Fig. 1.

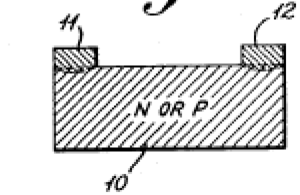


Fig. 1a.

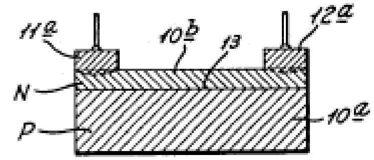


Fig. 2.

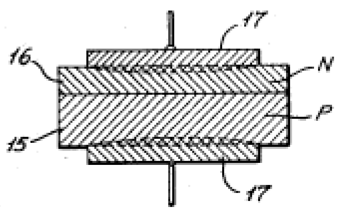


Fig. 2a.

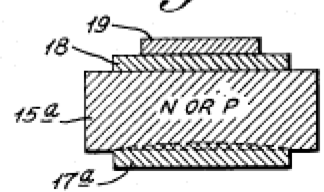
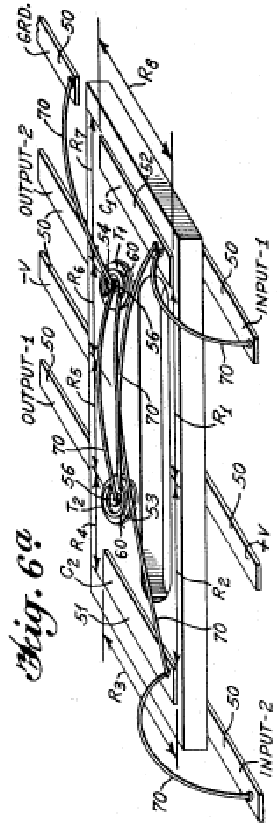
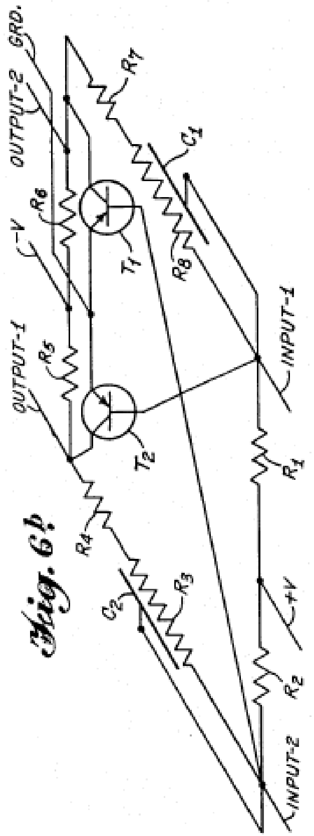


Fig. 5.

MINIATURIZED ELECTRONIC CIRCUITS

Filed Feb. 6, 1959 4 Sheets-Sheet 2





INVENTOR

Jack S. Kilby

BY

Stevens, Davis, Miller & Mosher

ATTORNEYS

United States Patent BEST AVAILABLE COPY [15] 3,643,138
Kilby [45] **Feb. 15, 1972**

[54] **SEMICONDUCTOR DEVICE**

[72] Inventor: **Jack St. Clair Kilby**, Dallas, Tex.

[73] Assignee: **Texas Instruments Incorporated**, Dallas, Tex.

[22] Filed: **Jan. 29, 1962**

[21] Appl. No.: **169,557**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 791,602, Feb. 6, 1959, Pat. No. 3,138,743, and a continuation-in-part of 811,476, May 6, 1959, abandoned, and a continuation-in-part of 811,486, May 6, 1959, Pat. No. 3,138,744.

[52] **U.S. Cl.** **317/235**, 317/234, 317/101
[51] **Int. Cl.** **H01l 19/00**
[58] **Field of Search** 317/234, 235, 101, 231

[56] **References Cited**

UNITED STATES PATENTS

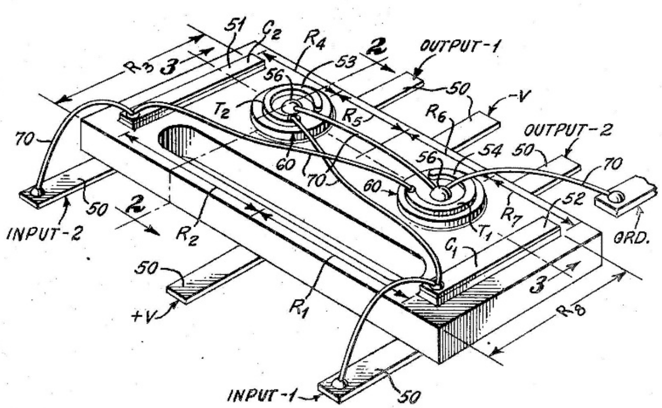
2,680,220	6/1954	Starr et al.	317/235
2,709,232	5/1955	Thedieck	317/235
2,792,538	5/1957	Pfann	317/235
2,796,562	6/1957	Ellis et al.	317/234
2,890,395	6/1959	Lathrop et al.	317/234
2,910,634	10/1959	Rutz	317/235
3,038,085	6/1962	Wallmark et al.	307/88.5

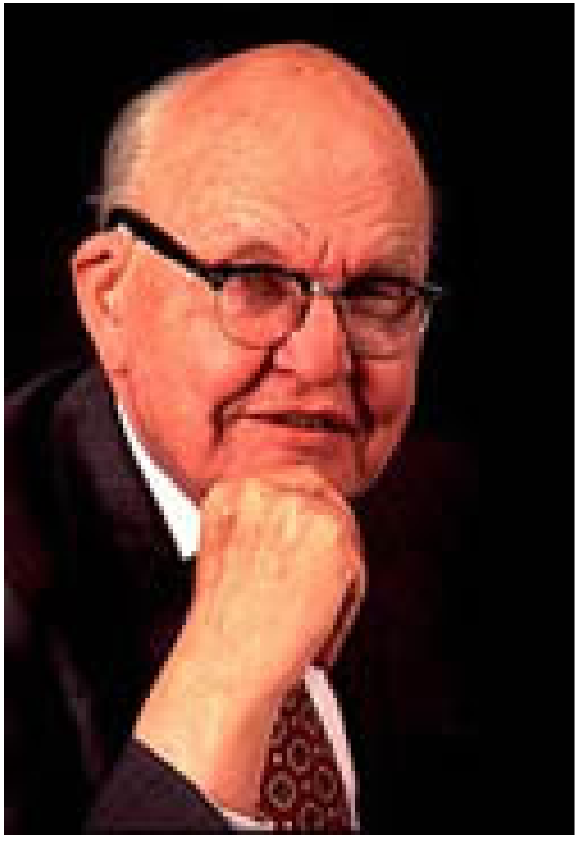
Primary Examiner—James D. Kallam
Attorney—James O. Dixon, Andrew M. Hassell, Robert C. Peterson and Stevens, Davis, Miller and Mosher

EXEMPLARY CLAIM

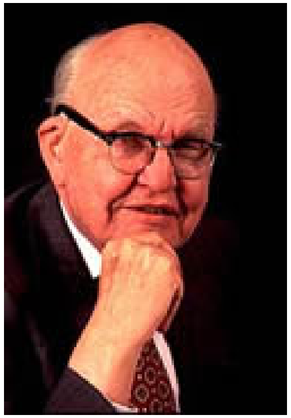
1. A semiconductor device comprising:
   a. a wafer of semiconductor material having two major faces;
   b. said wafer being so shaped as to define a plurality of regions within said wafer and adjacent to one of said major faces;
   c. at least some of said regions being electrically isolated within said wafer from others of said regions;
   d. said regions having at least one portion thereof extending to said one major face;
   e. at least some of said portions having selected locations on said one major face for electrical contact to said region;
   f. an insulating material on said one major face of the wafer excluding at least said selected locations;
   g. at least one electrically conductive area in contact with said insulating material and spaced from said wafer thereby;
   h. said electrically conductive area being disposed in cooperative relationship with respect to a selected one of said isolated regions so as to provide the electrical function of a discrete electrical circuit component; and
   i. a plurality of metallic interconnections providing electrically conductive paths between said selected locations on different ones of said regions and between another selected one of said locations and said electrically conductive area.

4 Claims, 33 Drawing Figures

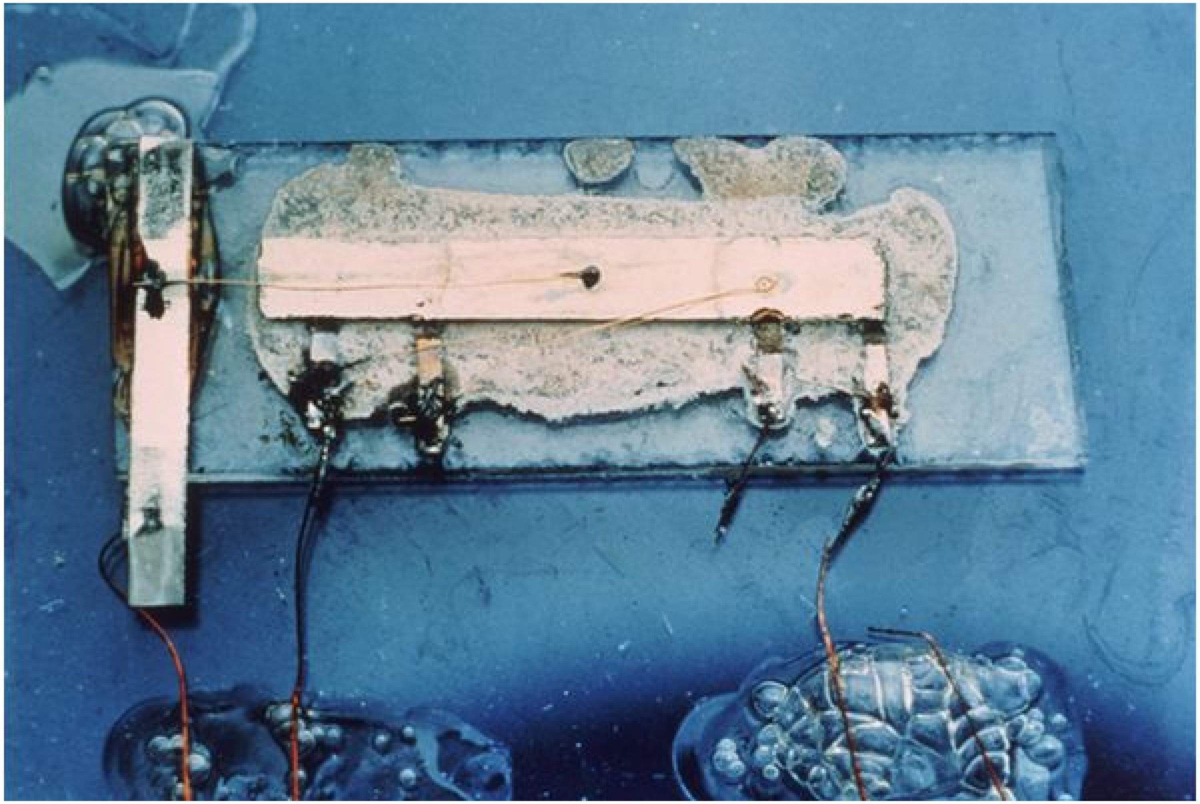




Jack Kilby



Jack Kilby



Kilby’s Integrated Circuit (germanium)

http://www.ti.com/corp/docs/kilbyctr/jackstclair.shtml

There are few men whose insights and professional accomplishments have changed the world. Jack Kilby is one of these men. His invention of the monolithic integrated circuit - the microchip - some 45 years ago at Texas Instruments (TI) laid the conceptual and technical foundation for the entire field of modern microelectronics. It was this breakthrough that made possible the sophisticated high-speed computers and large-capacity semiconductor memories of today's information age.

Mr. Kilby grew up in Great Bend, Kansas. With B.S. and M.S. degrees in electrical engineering from the Universities of Illinois and Wisconsin respectively, he began his career in 1947 with the Centralab Division of Globe Union Inc. in Milwaukee, developing ceramic-base, silk-screen circuits for consumer electronic products.

In 1958, he joined TI in Dallas. During the summer of that year working with borrowed and improvised equipment, he conceived and built the first electronic circuit in which all of the components, both active and passive, were fabricated in a single piece of semiconductor material half the size of a paper clip. The successful laboratory demonstration of that first simple microchip on September 12, 1958, made history.

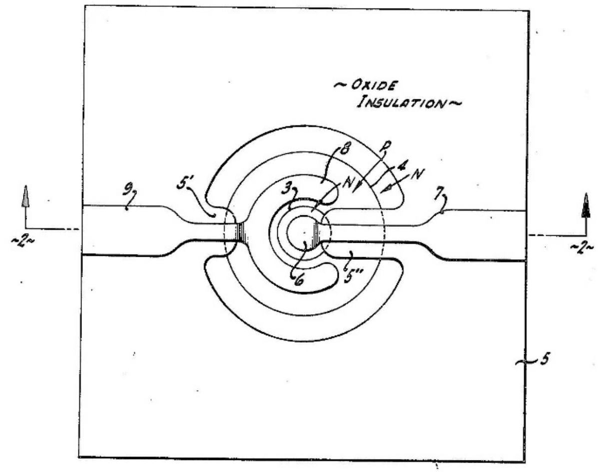
Jack Kilby went on to pioneer military, industrial, and commercial applications of microchip technology. He headed teams that built both the first military system and the first computer incorporating integrated circuits. He later co-invented both the hand-held calculator and the thermal printer that was used in portable data terminals.

April 25, 1961 R. N. NOYCE 2,981,877

SEMICONDUCTOR DEVICE-AND-LEAD STRUCTURE

Filed July 30, 1959 3 Sheets-Sheet 1

FIG-1



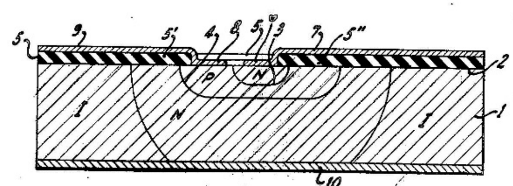
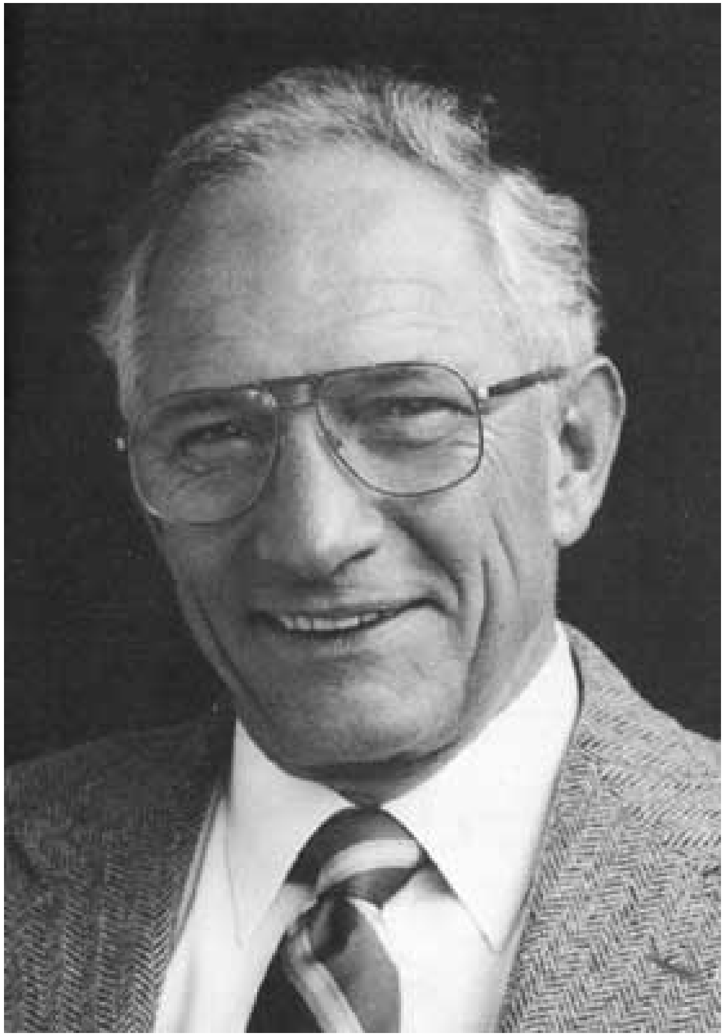


FIG-2

INVENTOR.
ROBERT N. NOYCE

BY Lippincott & Ralls

ATTORNEYS



Robert Noyce

http://www.ideafinder.com/history/inventors/noyce.htm

Robert Norton Noyce was born December 12, 1927 in Burlington, Iowa. A noted visionary and natural leader, Robert Noyce helped to create a new industry when he developed the technology that would eventually become the microchip. Noted as one of the original computer entrepreneurs, he founded two companies that would largely shape today’s computer industry—Fairchild Semiconductor and Intel.

Bob Noyce's nickname was the "Mayor of Silicon Valley." He was one of the very first scientists to work in the area -- long before the stretch of California had earned the Silicon name -- and he ran two of the companies that had the greatest impact on the silicon industry: Fairchild Semiconductor and Intel. He also invented the integrated chip, one of the stepping stones along the way to the microprocessors in today's computers.

Noyce, the son of a preacher, grew up in Grinnell, Iowa. He was a physics major at Grinnell College, and exhibited while there an almost baffling amount of confidence. He was always the leader of the crowd. This could turn against him occasionally -- the local farmers didn't approve of him and weren't likely to forgive quickly when he did something like steal a pig for a college luau. The prank nearly got Noyce expelled, even though the only reason the farmer knew about it was because Noyce had confessed and offered to pay for it.

While in college, Noyce's physics professor Grant Gale got hold of two of the very first transistors ever to come out of Bell Labs. Gale showed them off to his class and Noyce was hooked. The field was young, though, so when Noyce went to MIT in 1948 for his Ph.D., he found he knew more about transistors than many of his professors.

After a brief stint making transistors for the electronics firm Philco, Noyce decided he wanted to work at Shockley Semiconductor. In a single day, he flew with his wife and two kids to California, bought a house, and went to visit Shockley to ask for a job -- in that order.

As it was, Shockley and Noyce's scientific vision -- and egos -- clashed. When seven of the young researchers at Shockley semiconductor got together to consider leaving the company, they realized they needed a leader. All seven thought Noyce, aged 29 but full of confidence, was the natural choice. So Noyce became the eighth in the group that left Shockley in 1957 and founded Fairchild Semiconductor.

Noyce was the general manager of the company and while there invented the integrated chip -- a chip of silicon with many transistors all etched into it at once. Fairchild Semiconductor filed a patent for a semiconductor integrated circuit based on the planar process on July 30, 1959. That was the first time he revolutionized the semiconductor industry. He stayed with Fairchild until 1968, when he left with Gordon Moore to found Intel.

At Intel he oversaw Ted Hoff's invention of the microprocessor -- that was his second revolution.

At both companies, Noyce introduced a very casual working atmosphere, the kind of atmosphere that has become a cultural stereotype of how California companies work. But along with that open atmosphere came responsibility. Noyce learned from Shockley's mistakes and he gave his young, bright employees phenomenal room to accomplish what they wished, in many ways defining the Silicon Valley working style was his third revolution.

The key patents that revolutionized the electronics field:

Jack Kilby (34 years old at invention)	patent: 3,138,743
Filed Feb 6, 1959	Issued June 23, 1964
Robert Noyce (31 years old at invention)	patent: 2,981,877
Filed July 30, 1959	Issued April 25, 1961

Key Historical Developments

- 1971 Intel Introduces 4004 microprocessor (2300 transistors, 10u process) intel®

Silicon Gate MOS 4004

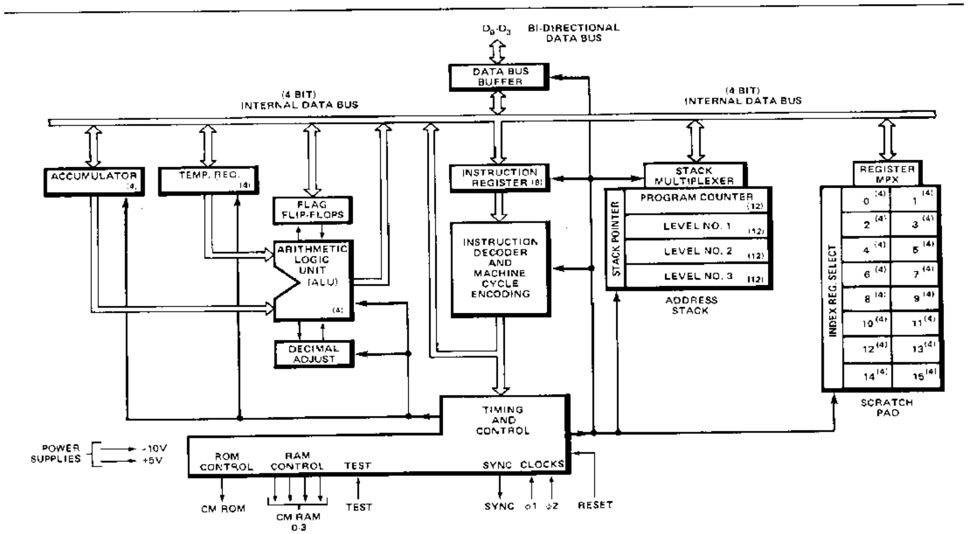
SINGLE CHIP 4-BIT P-CHANNEL MICROPROCESSOR

- 10.8 Microsecond Instruction Cycle
- CPU Directly Compatible With MCS-4 ROMs and RAMs
- Easy Expansion—One CPU can Directly Drive up to 32,768 Bits of ROM and up to 5120 Bits of RAM
- 4-Bit Parallel CPU With 46 Instructions
- Instruction Set Includes Conditional Branching, Jump to Subroutine and Indirect Fetching
- Binary and Decimal Arithmetic Modes

The Intel® 4004 is a complete 4-bit parallel central processing unit (CPU). It is designed to be used in test systems, terminals, billing machines, process control and random logic replacement applications. The 4004 easily interfaces with keyboards, switches, displays, A-D converters, printers and other peripheral equipment.

The CPU can directly address 4K 8-bit instruction words of program memory and 5120 bits of data storage RAM. Sixteen index registers are provided for temporary data storage. Up to 16 4-bit input ports and 16 4-bit output ports may also be directly addressed.

The 4004 is fabricated with P-channel silicon gate MOS technology.



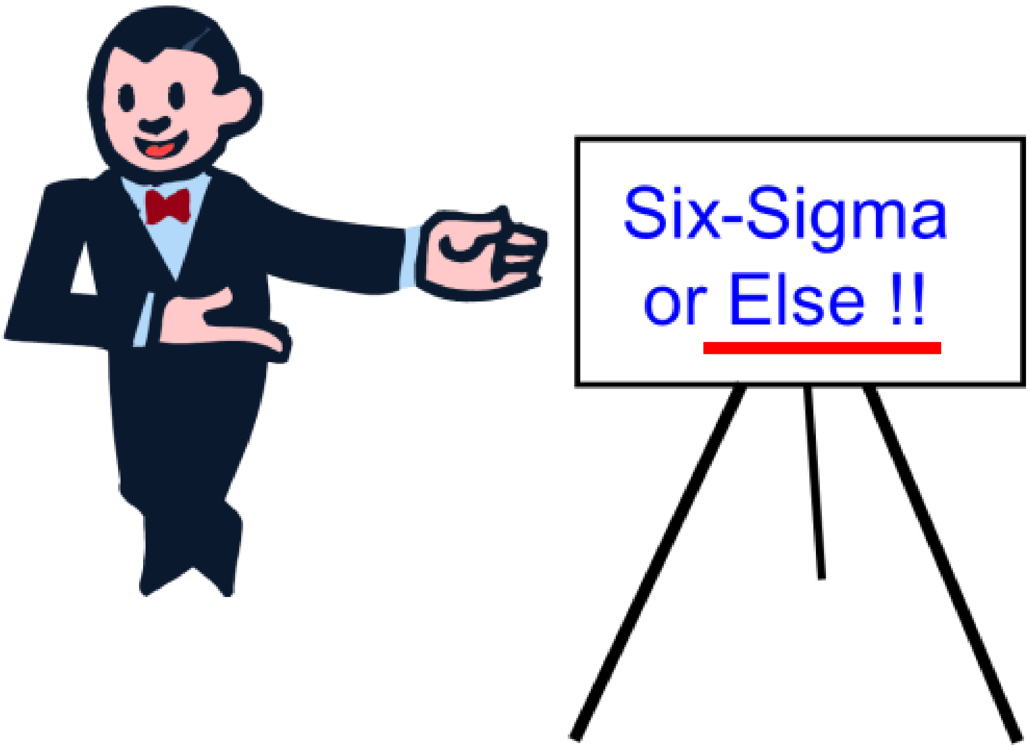
Six-Sigma or Else !!

How serious is the “or Else” in the six-sigma programs?

Genre	Reality game show
Created by	Mark Burnett
Composer(s)	David Vanacore (Vanacore Music), Jeff Lippencott and Mark T. Williams, Ah2 Music
Country of origin	United States
Production	
Executive producer(s)	Mark Burnett, Donald J. Trump, Jay Bienstock
Release	
Original network	NBC
Original release	January 8, 2004 – present

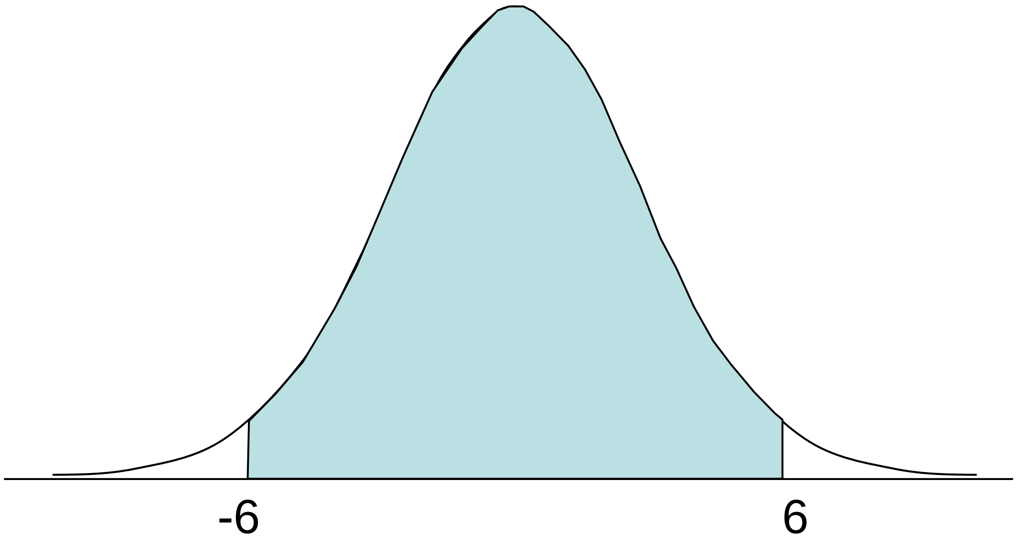
This is not a political advertisement !!

Meeting the Real Six-Sigma Challenge



Yield at the Six-Sigma level

(Assume a Gaussian distribution)

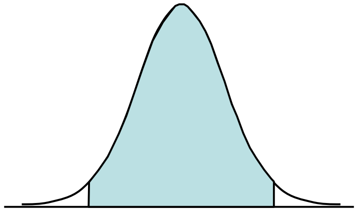


$$Y_{6sigma} = 2F_N(6) - 1$$

$$Y_{6sigma} = 0.9999999980$$

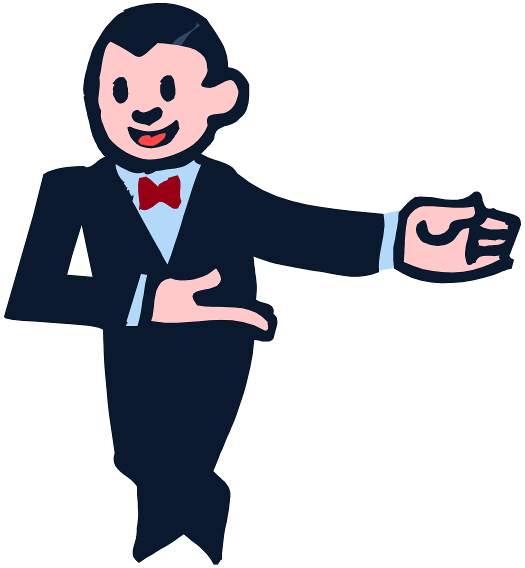
This is approximately 2 defects out of 1 billion parts

Yield at Various Sigma Levels



No Sigma	Yield	Defect Rate
1	0.682689492	0.317311
2	0.954499736	0.0455
3	0.997300204	0.0027
4	0.999936658	6.33E-05
5	0.999999427	5.73E-07
6	0.9999999980	1.97E-09
7	0.9999999999974	2.56E-12

Six-sigma performance is approximately 2 defects in a billion !



Six-Sigma or Else !!

It is assumed that the performance or yield will drop, <u>for some reason</u>, by 1.5 sigma after a process has been established

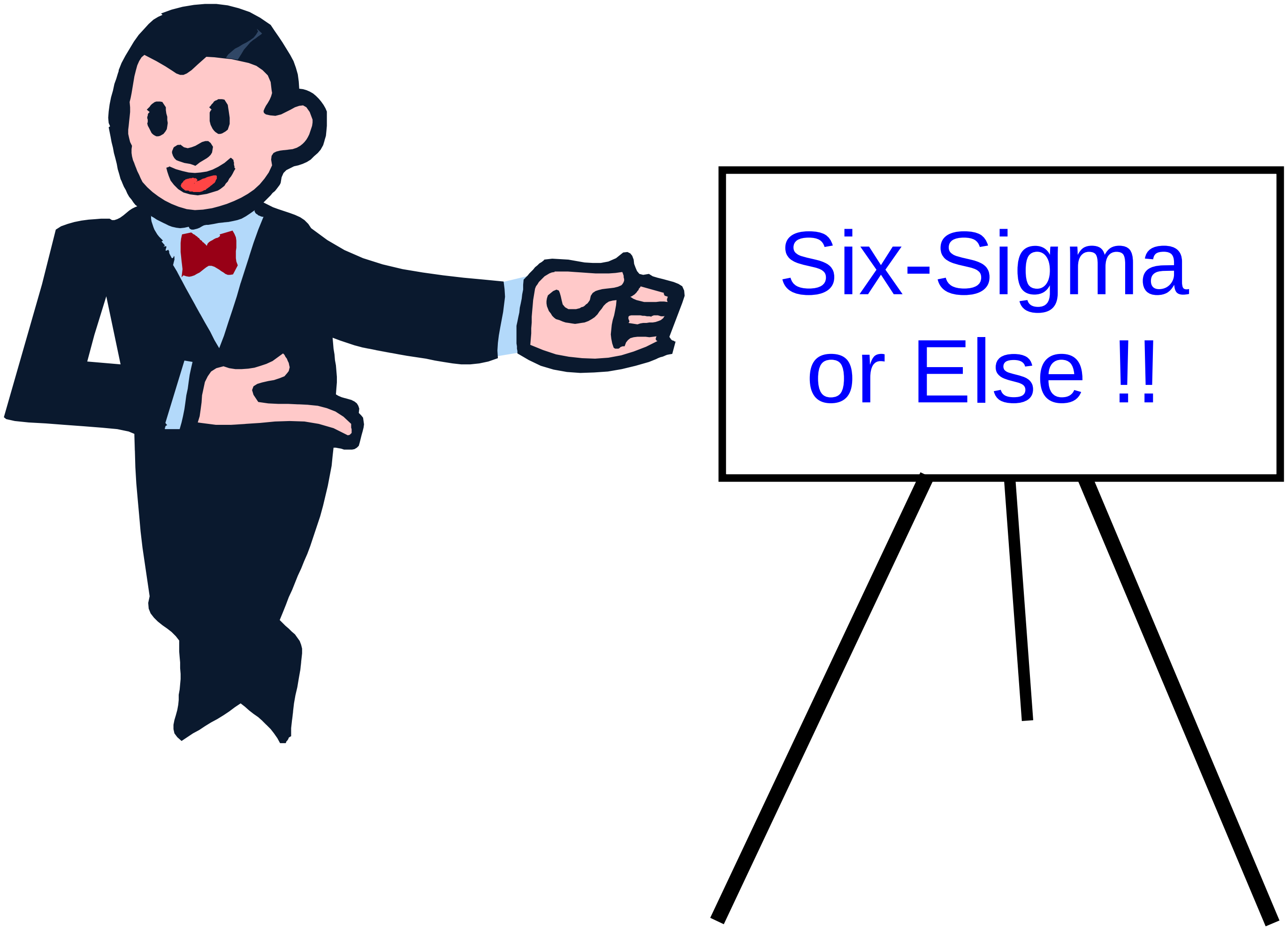
Initial "six-sigma" solutions really expect only 4.5 sigma performance in steady-state production

Assumption : Processes of interest are Gaussian (Normal)

4.5 sigma performance corresponds to 3.4 defects in a million

Observation: Any Normally distributed random variable can be mapped to a N(0,1) random variable by subtracting the mean and dividing by the variance

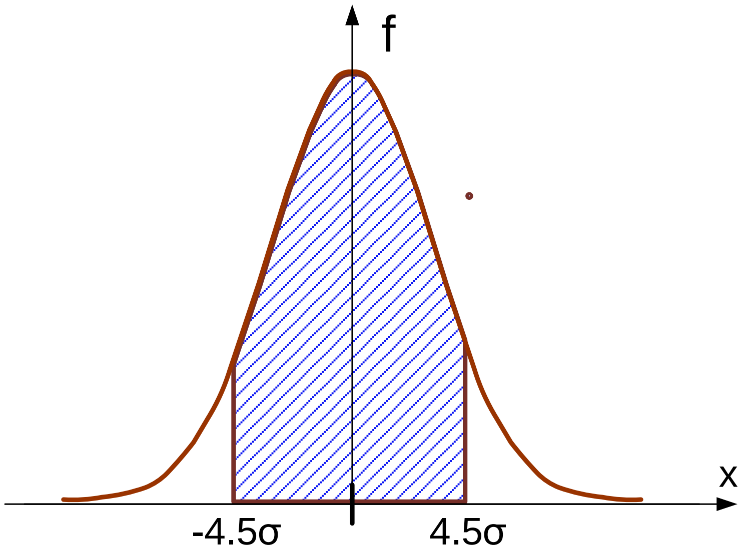
Meeting the Real Six-Sigma Challenge

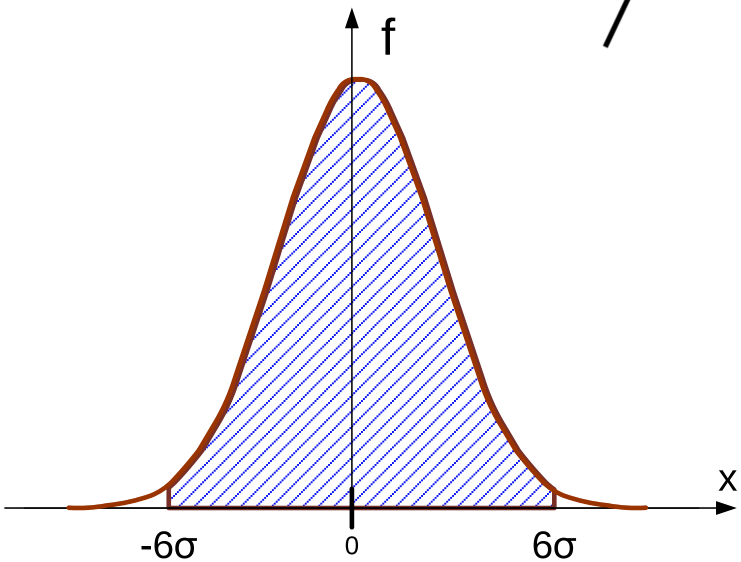


Highly Statistical Concept !

The Six-Sigma Challenge

Two-sided capability:





Long-term Capability

Tails are 6.8 parts in a million

Short-term Capability

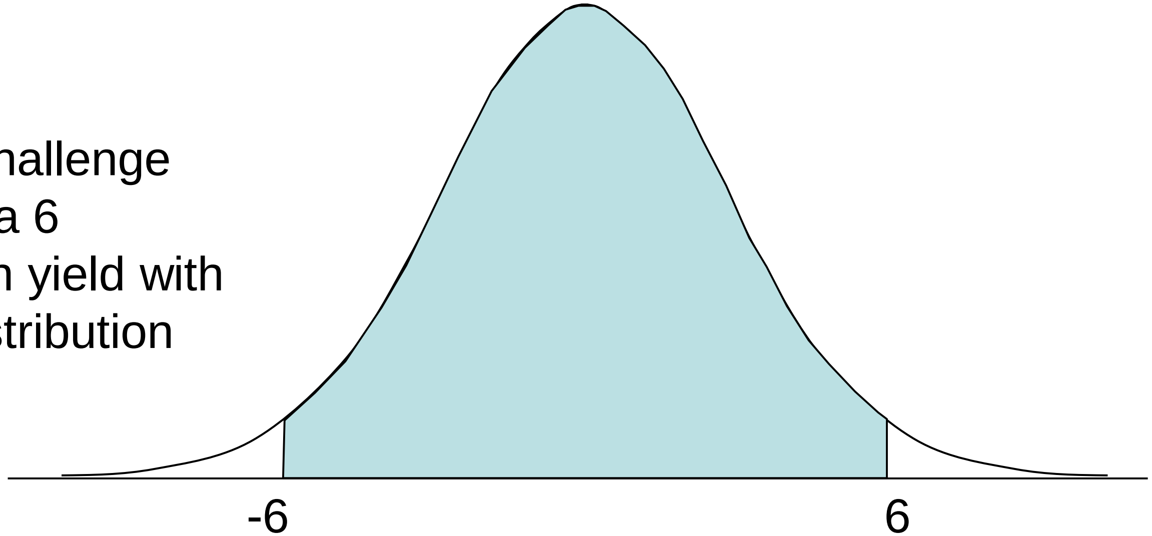
Tail is 2 parts in a billion

Six Sigma Performance is Very Good !!!

Example: Determine the maximum die area if the circuit yield is to initially meet the "six sigma" challenge for hard yield defects (Assume a defect density of 1cm^{-2} and only hard yield loss). Is it realistic to set six-sigma die yield expectations on the design and process engineers?

Solution:

The "six-sigma" challenge requires meeting a 6 standard deviation yield with a Normal (0,1) distribution



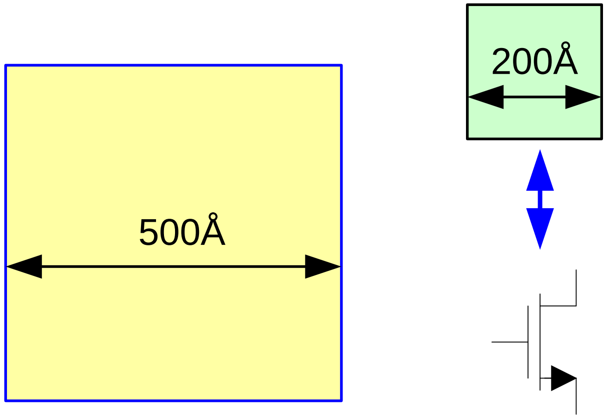
$$Y_{6\text{sigma}} = 2F_N(6) - 1$$

Solution cont:

$$Y_H = e^{-Ad}$$

$$A = \frac{-\ln(Y_H)}{d}$$

$$A = \frac{-\ln(.9999999980)}{1\text{cm}^{-2}} = 2.0E-9\text{cm}^2 = 2.5E5(\overset{o}{A})^2$$



This is comparable to the area required to fabricate a single transistor in a state of the art 20nm process

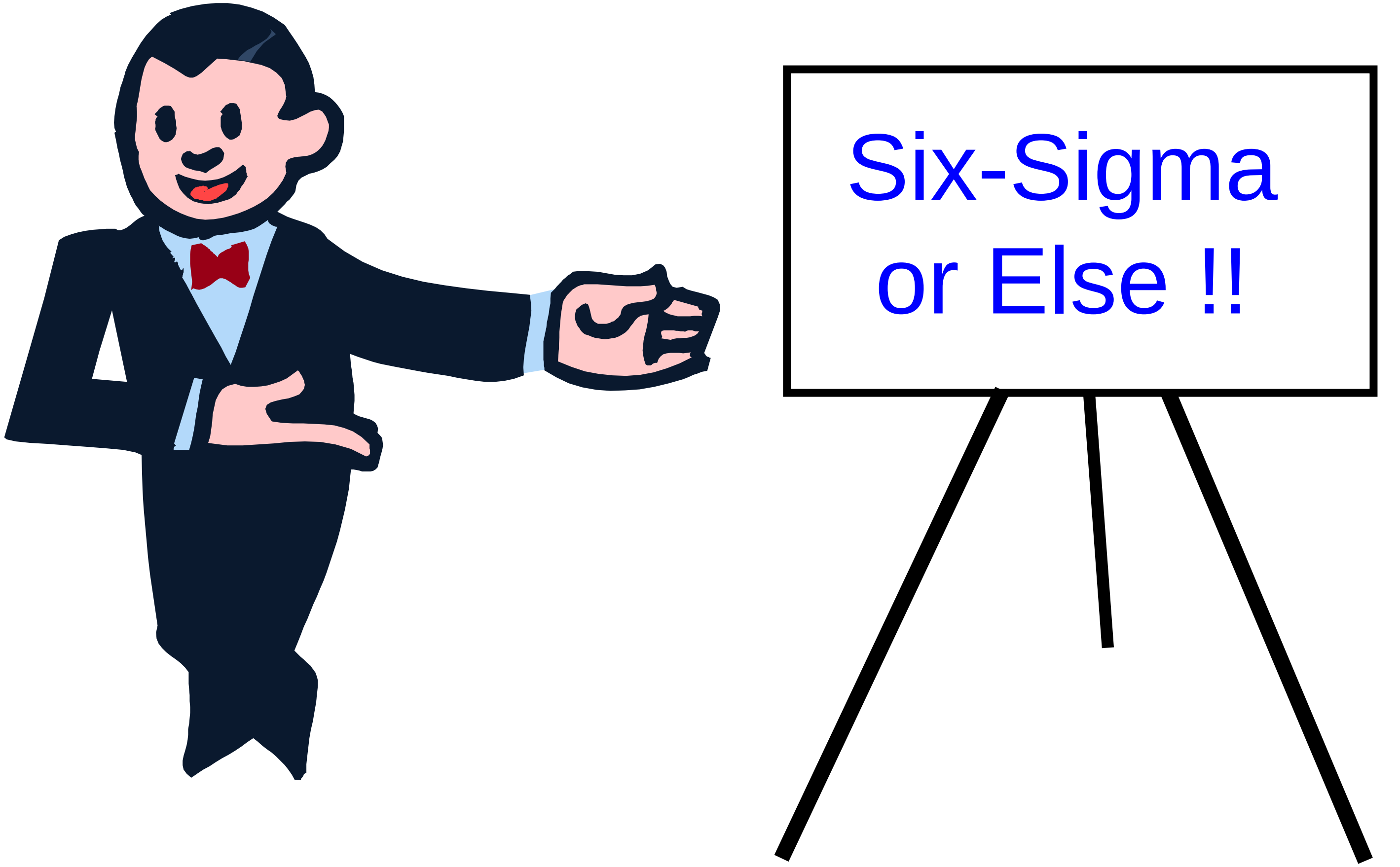
Solution cont:

Is it realistic to set six-sigma die hard yield expectations on the design and process engineers?

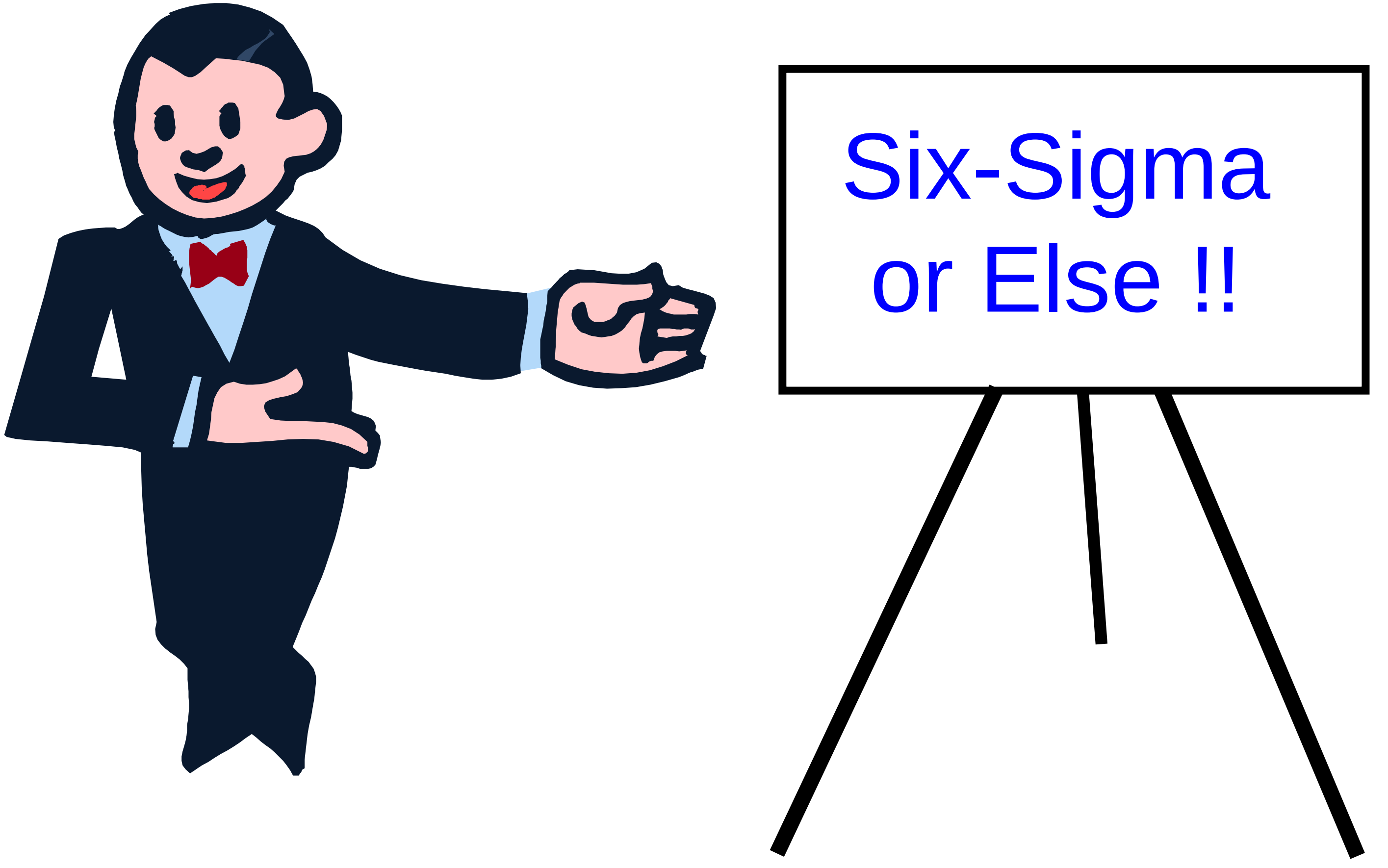
The best technologies in the world have orders of magnitude too many defects to build any useful integrated circuits with die yields that meet six-sigma performance requirements !!

Arbitrarily setting six-sigma design requirements will guarantee financial disaster !!

Meeting the Real Six-Sigma Challenge



Meeting the Real Six-Sigma Challenge



Improving a yield by even one sigma often is VERY challenging !!

Statistics can be abused !

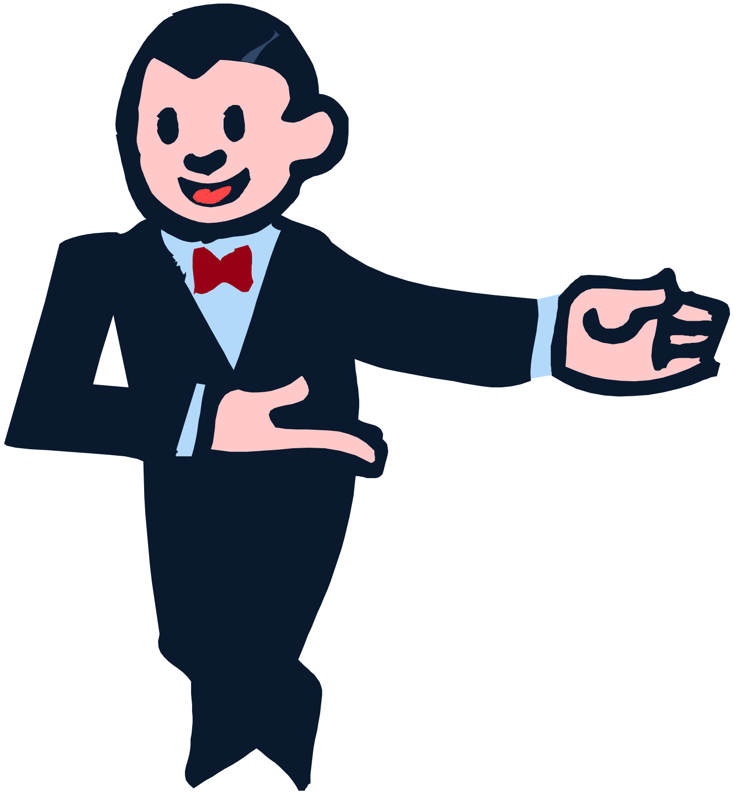
Many that are not knowledgeable incorrectly use statistics

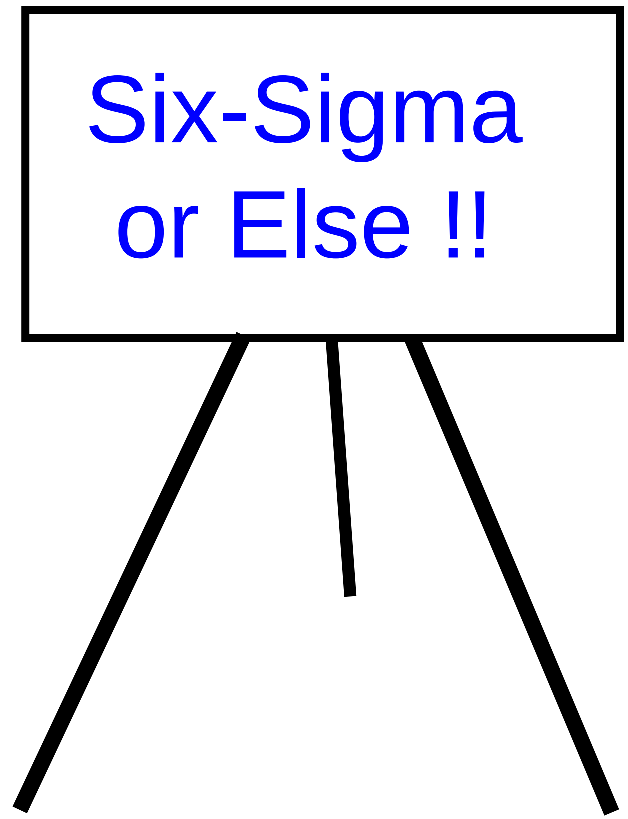
Many use statistics to intentionally mislead the public

Some openly abuse statistics for financial gain or for manipulation purposes

Keep an open mind to separate “good” statistics from “abused” statistics

Meeting the Real Six-Sigma Challenge

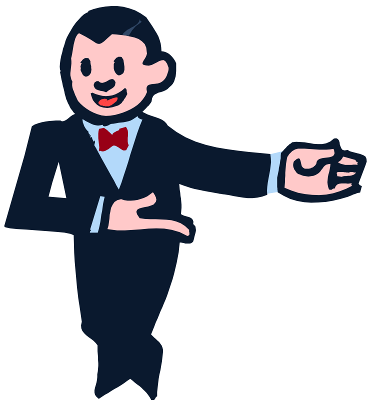




How has Motorola fared with the 6-sigma approach?

Motorola, Inc. (pronounced) was an American multinational[6] telecommunications company based in Schaumburg, Illinois, which was eventually divided into two independent public companies, Motorola Mobility and Motorola Solutions on January 4, 2011, after losing $4.3 billion from 2007 to 2009.[7]

Meeting the Real Six-Sigma Challenge



How has Motorola fared with the 6-sigma approach?

MOTOROLA

Former type	Public company
Industry	Telecommunications
Fate	Divided into Motorola Mobility and Motorola Solutions
Successor	Motorola Mobility Motorola Solutions
Founded	September 25, 1928
Defunct	January 4, 2011

- Sold military activities to General Dynamics 2000/2001
- Sold automotive products in 2006
- Spun of discrete components as ON semiconductor in 1999
- Spun of SPS as Freescale in 2003 - Acquired by NXP in 2015
- Sold Motorola Mobility to Google in 2011 – Acquired by Lonovo in 2014
- Motorola Solutions has 16,000 employees (ref fall 2018) , down from over 150,000 in mid ‘90s

The “Motorola” saga continues

Freescale Semiconductor

Semiconductor manufacturing company

Freescale Semiconductor, Inc. was an American multinational corporation headquartered in Austin, Texas, with design, research and development, manufacturing and sales operations in more than 75 locations in 19 countries. Wikipedia

Headquarters: Austin, TX

CEO: Gregg A. Lowe (Jun 2012–)

Number of employees: 17,300 (2013)

Defunct: December 7, 2015

Parent organization: Freescale Semiconductor Holdings I Ltd

Subsidiaries: Freescale Semiconductor ...an Ltd, MORE

Qualcomm, NXP strike $38B semiconductor deal | PitchBook
https://pitchbook.com/news/articles/qualcomm-nxp-strike-38b-semiconductor-deal
Oct 27, 2016 - **Qualcomm** has agreed to acquire **NXP** Semiconductors for $110 per ... The **deal** represents an enterprise value of $47 billion and an equity ...

Trump Blocks Broadcom's Bid for Qualcomm - The New York Times
https://www.nytimes.com/2018/03/12/.../trump-broadcom-qualcomm-merger.html
Mar 12, 2018 - Image. **Broadcom** had been trying for months to buy **Qualcomm**, and .... change the world of **mergers** and acquisitions and open the door to the ...

Will China Approve Qualcomm's NXP Acquisition? - Forbes
https://www.forbes.com/sites/.../05/.../will-china-approve-qualcomms-nxp-acquisition/
May 16, 2018 - Qualcomm's deal to purchase **NXP** Semiconductors has been caught in the crosshairs of the trade tensions between the U.S. and China, with ...

Chinese regulators approve Qualcomm purchase of NXP for US$44 ...
https://www.scmp.com › Business › Companies
Jun 15, 2018 - Chinese regulators have approved US semiconductor company Qualcomm's proposed US$44 billion **acquisition** of Dutch chip maker **NXP** ...

Qualcomm drops NXP acquisition, leaves analysts concerned about ...
https://www.marketwatch.com › Industries › The Ratings Game
Jul 26, 2018 - Nearly two years after Qualcomm Inc. announced its intent to **acquire NXP** Semiconductors NV, investors are pleased that the company is ...

http://www.chicagomag.com/Chicago-Magazine/September-2014/What-Happened-to-Motorola/

Not every important Motorola innovation during Bob's time led to a physical product. For example, in the early 1980s—a period when American companies were struggling to compete with superior products pouring out of Japan—Motorola developed a system for total quality management called Six Sigma. (A Six Sigma process is one in which 99.99966 percent of products are free from manufacturing defects.) A good chunk of the Fortune 500, including General Electric, IBM, and Boeing, wound up adopting it.

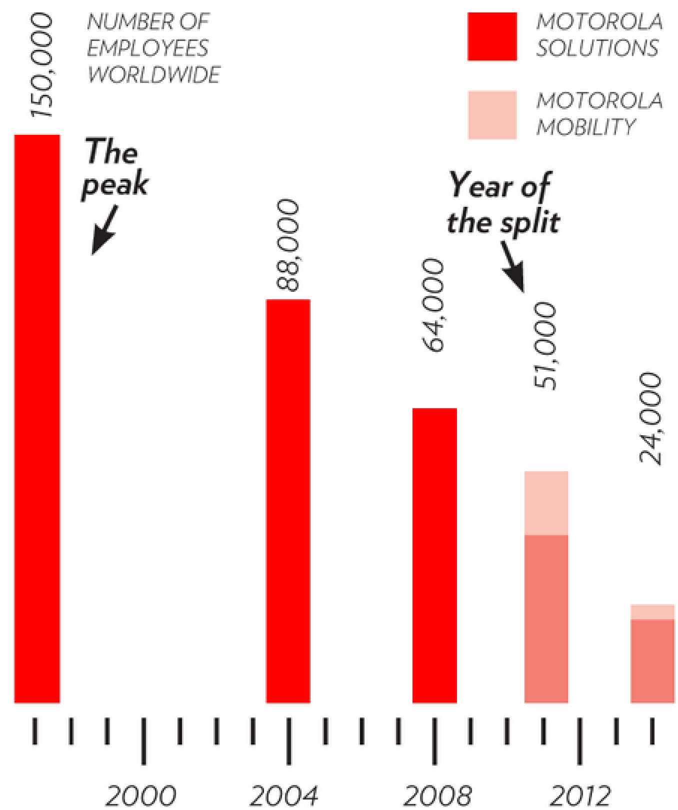
Motorola Mobility acquired by Lonovo in 2014

MOTOROLA SOLUTIONS

Type	Public
Traded as	NYSE: MSI S&P 500 Component
Industry	Telecommunications equipment
Predecessor	Motorola, Inc.
Founded	January 4, 2011; 7 years ago
Headquarters	Chicago, Illinois, U.S.
Key people	Greg Brown (Chairman and CEO)
Products	Two-way radios, radio systems, managed services and smart public safety applications
Revenue	▲ US$6.38 billion (2017)[1]
Operating income	▲ US$1.28 billion (2017)[1]
Net income	▼ US$-155 million (2017)[1]
Total assets	▼ US$8.21 billion (2017)[1]
Total equity	US$-1.74 billion (2017)[1]
Number of employees	16,000 (2018)[2]
Subsidiaries	Airwave Solutions Avigilon
Website	www.motorolasolutions.com

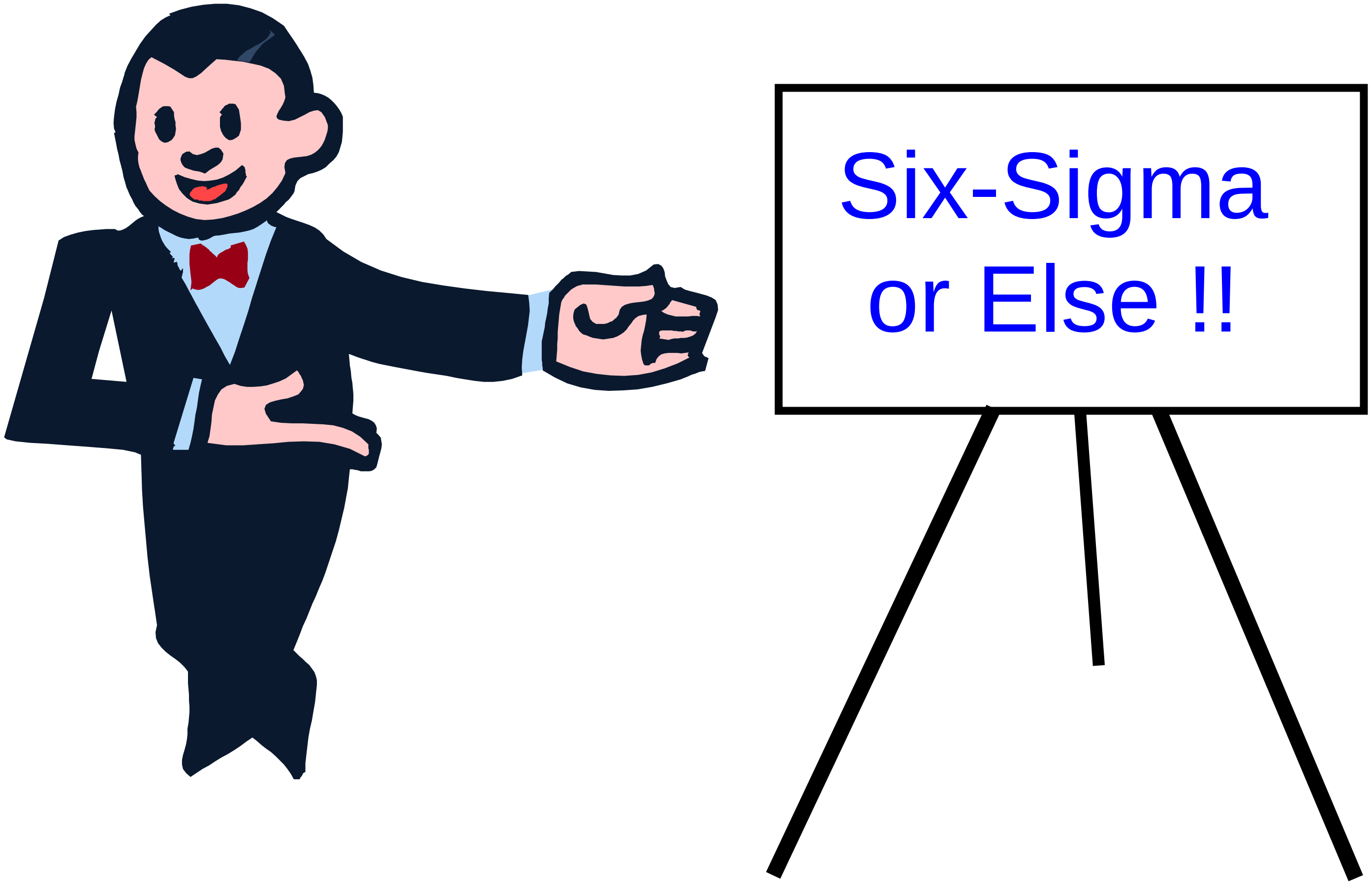
A Drastic Slimdown

In the past 17 years, Motorola and its spinoffs have reduced their total work force by 84 percent.*



NOTES: *They did so in large part by conducting layoffs and selling businesses. Motorola Solutions will shed 4,500 more jobs this fall, when Zebra Technologies completes its purchase of the company's enterprise division. Data for 2014 as of June 30.
SOURCES: Google; Motorola Solutions.

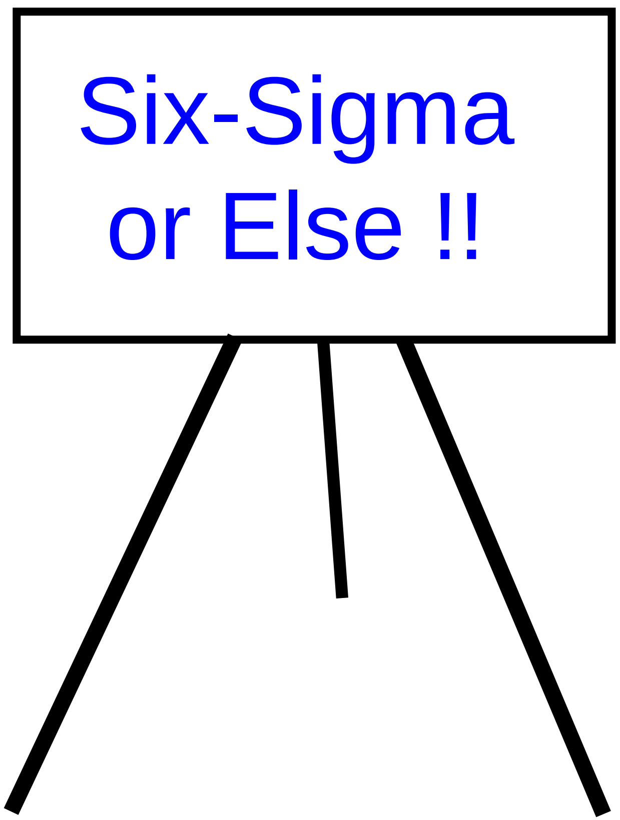
Meeting the Real Six-Sigma Challenge



Six-sigma capability has almost nothing to do with optimizing profits and, if taken seriously, will likely guarantee a financial fiasco in most manufacturing processes

Meeting the real Six-Sigma Challenge

Meeting the real Six-Sigma Challenge



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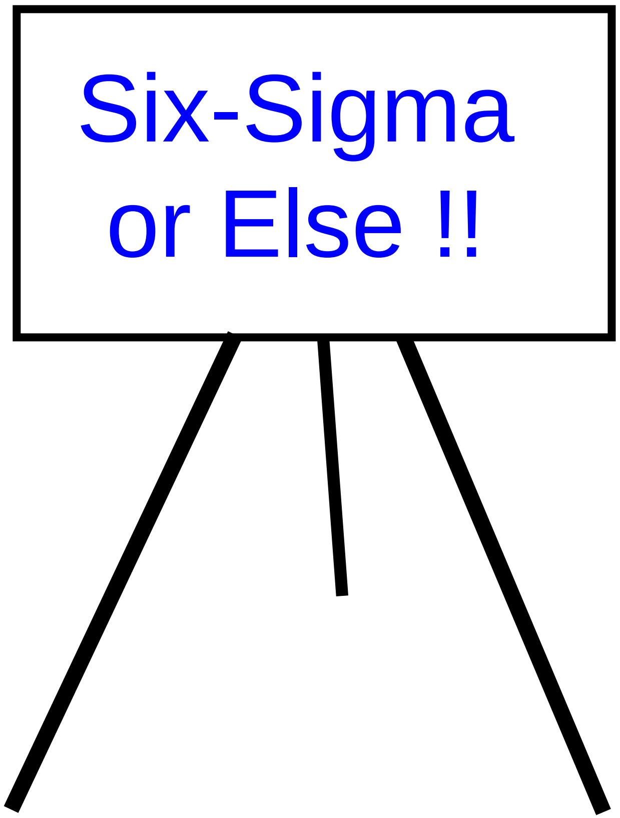
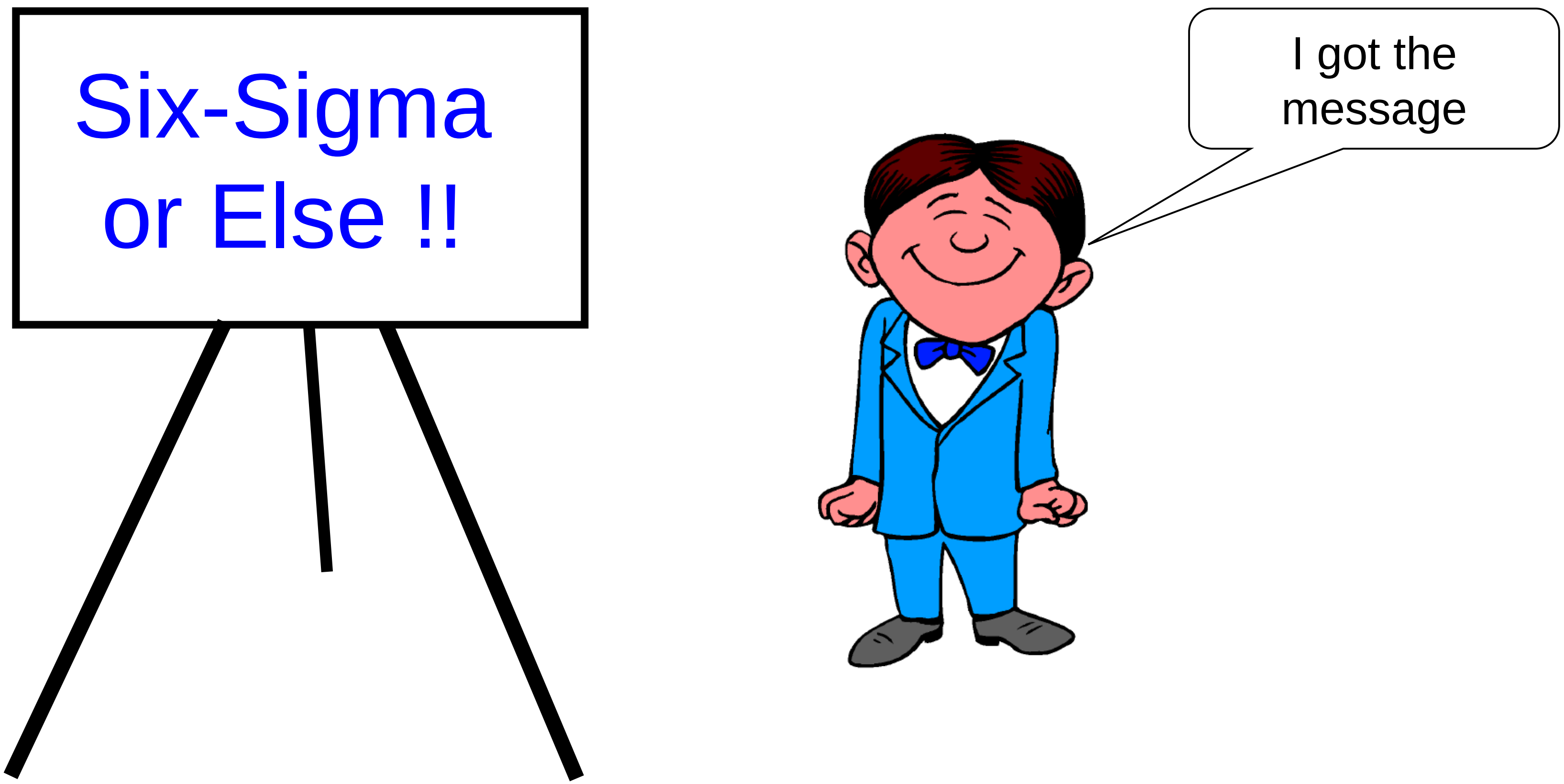
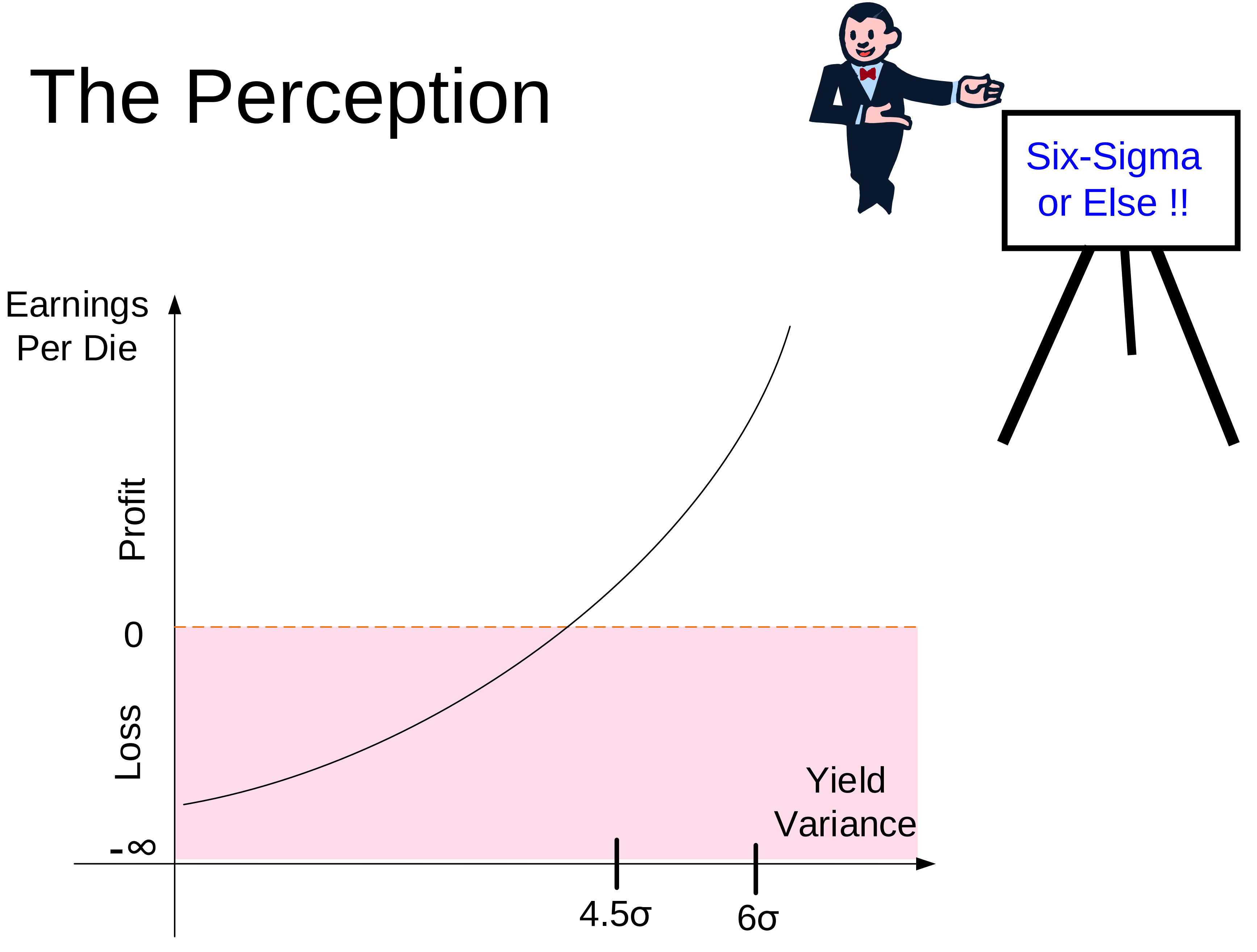


The concept of improving reliability (really profitability) is good – its just the statistics that are abused!

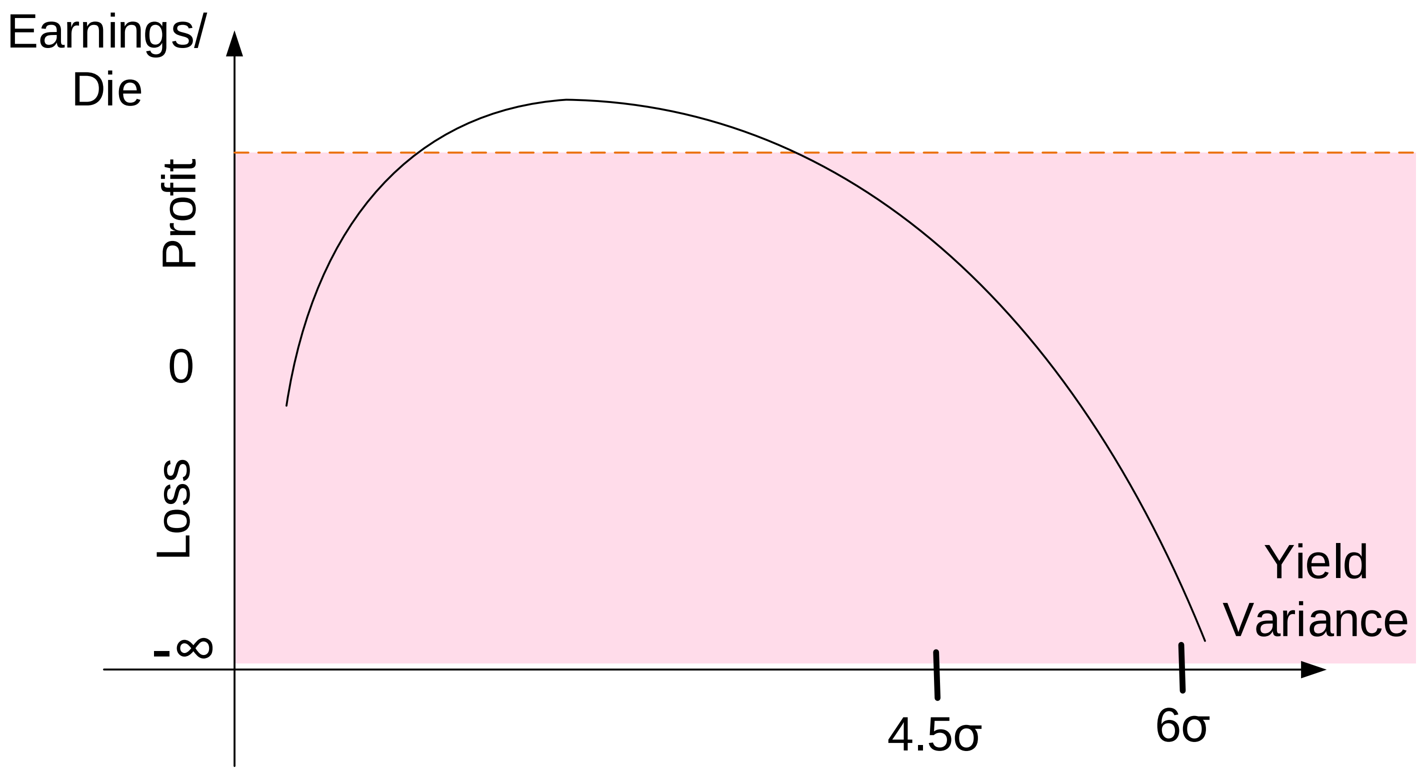
Meeting the real Six-Sigma Challenge



The Perception

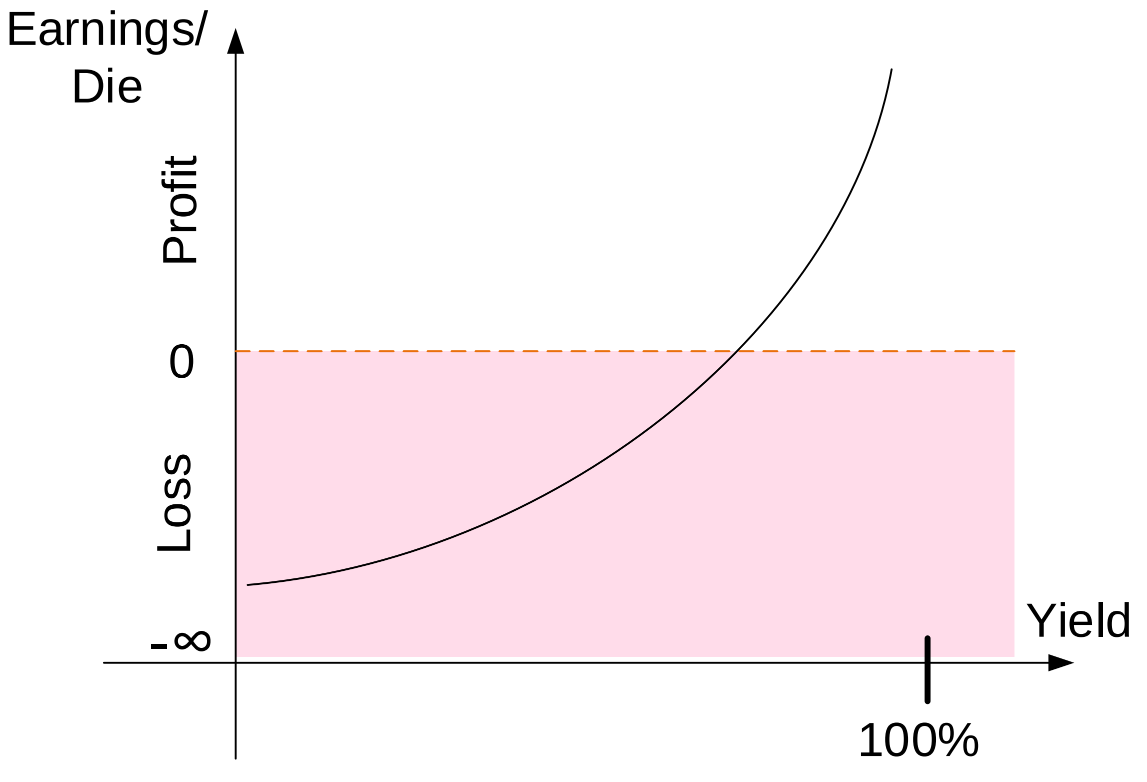


The Reality



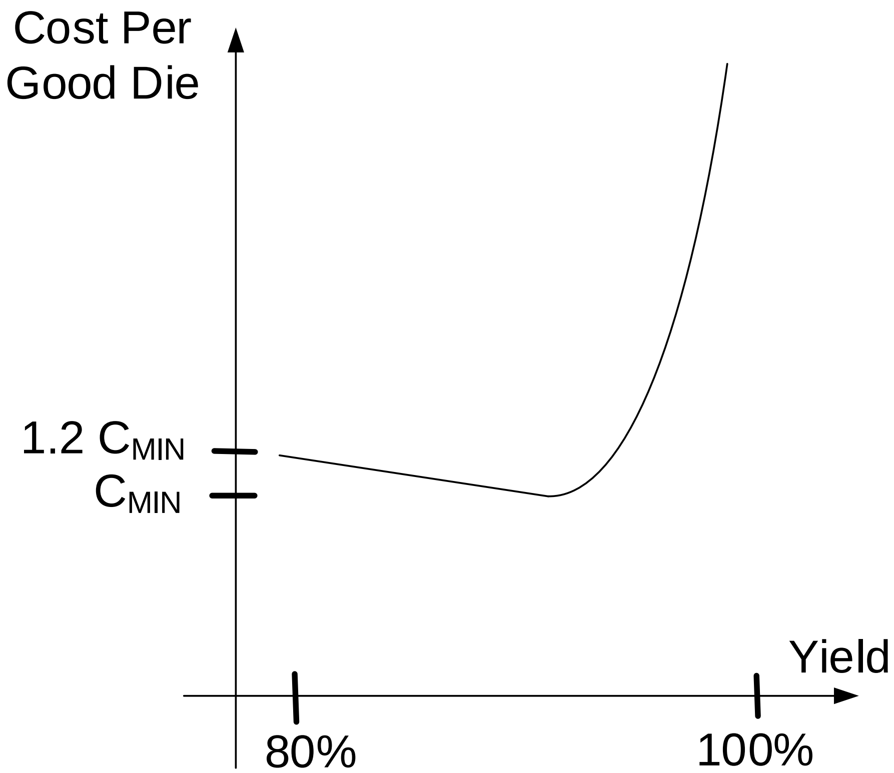
- Designing for 4.5σ or 6σ yield variance will almost always guarantee large losses
- Yield targets should be established to optimize earnings not yield variance

The Perception on Yield



Perception is often that goal should be to get yields as close to 100% as possible

The Reality about Yield



- Return on improving yield when yield is above 95% is small
- Inflection point could be at 99% or higher for some designs but below 50% for others
- Cost/good die will ultimately go to ∞ as yield approaches 100%

Designers goal should be to optimize profit, not arbitrary yield target

End of Lecture 4