A Short History of Telecommunication

1800 - 1900	The pioneer era
1900 - 1940	The dawn of radio technology
1940 - 1950	The emergence of the computer
1950 - 1965	The era of diversification
1965 - 1975	The rise of the Internet
1975+	The era of ubiquitous mobile communication

Evolution of cellular networks 1G → 6G

6G

1-10 Gbps

5G

100-1000 Mbps

4G

2 Mbps

3G

64 Kbps

2G

2.4 Kbps

1G

New Spectrum

Disruptive Technologies

Cell-less Networks

Disaggregation and virtualization

Energy Efficiency

Artificial Intelligence

Voice calling

SMS

Internet

Internet of Applications

Massive broadband and Internet of Things

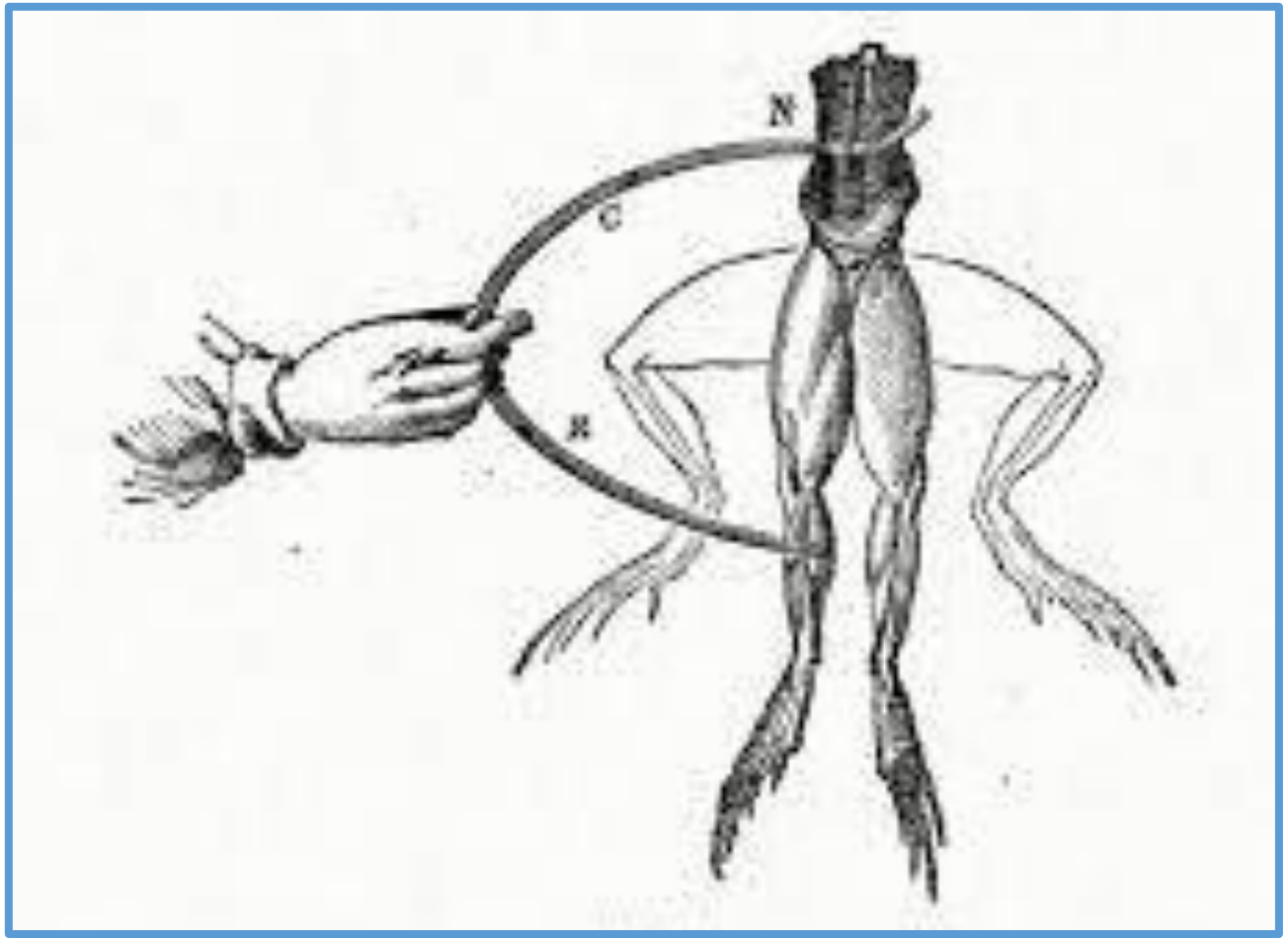
Towards a Fully Digital and Connected World

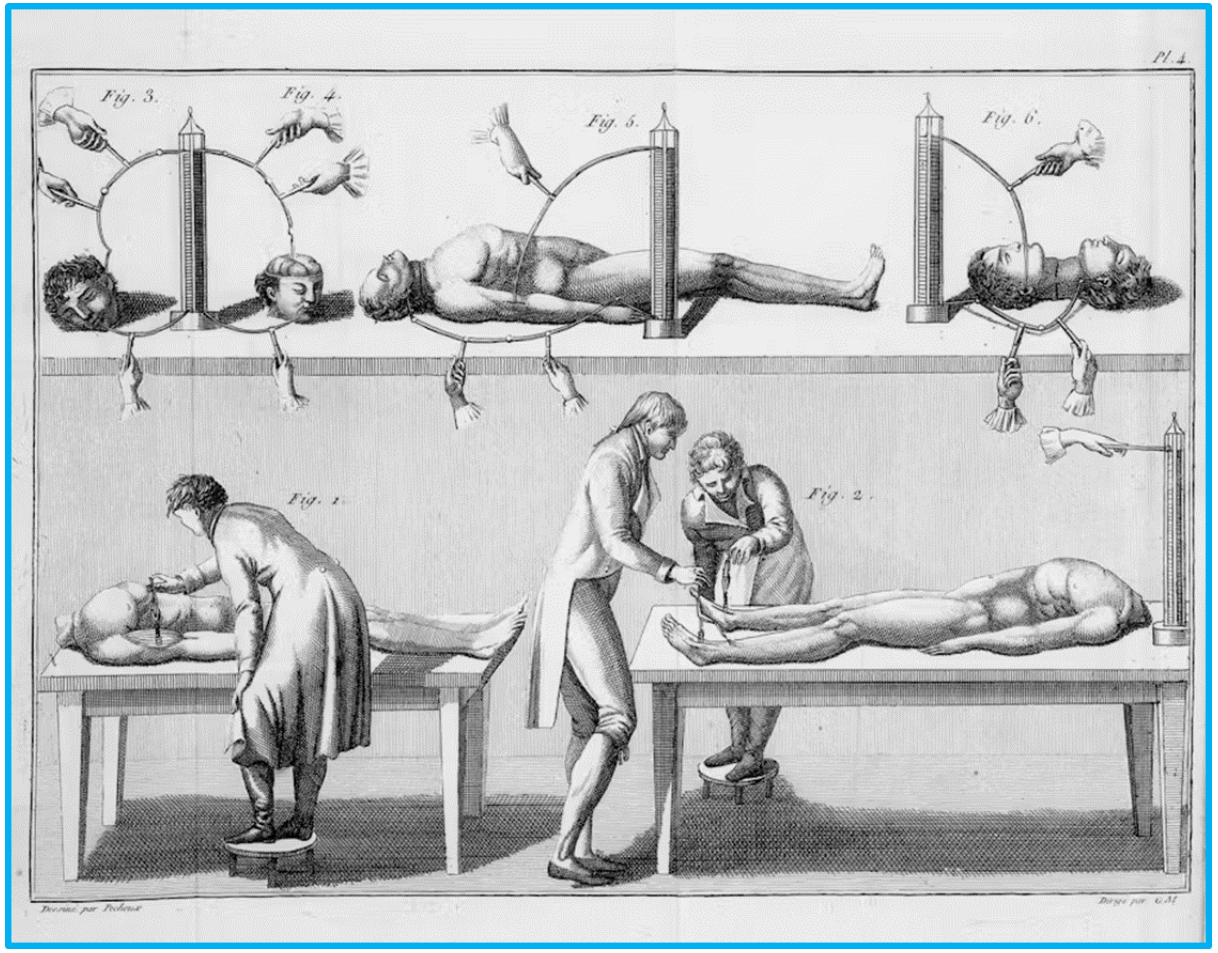
1980 1990 2000 2010 2020 2025-2030 time

6G will revolutionize the wireless evolution from “connected things” to “connected intelligence”.

Prolog - late 18th century – electricity and life

Luigi Galvani, an Italian physician, physicist, biologist and philosopher, studied **animal electricity**. In **1780**, he discovered that the **muscles of dead frogs' legs twitched when struck by an electrical spark**.



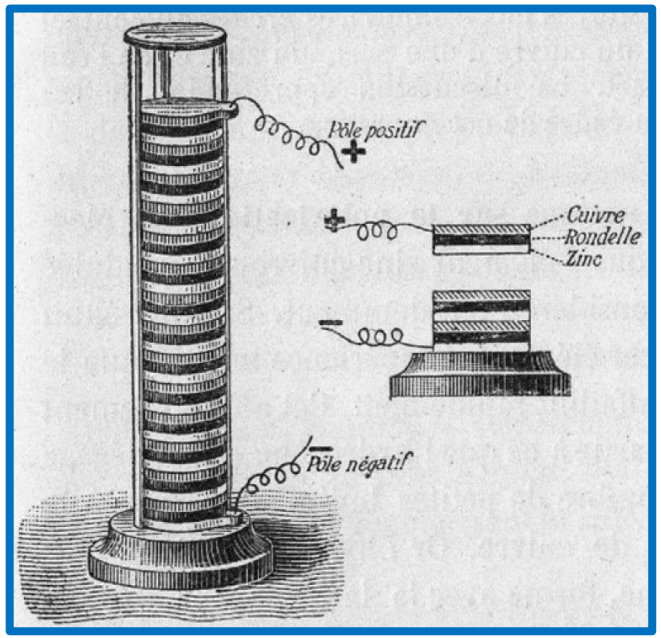


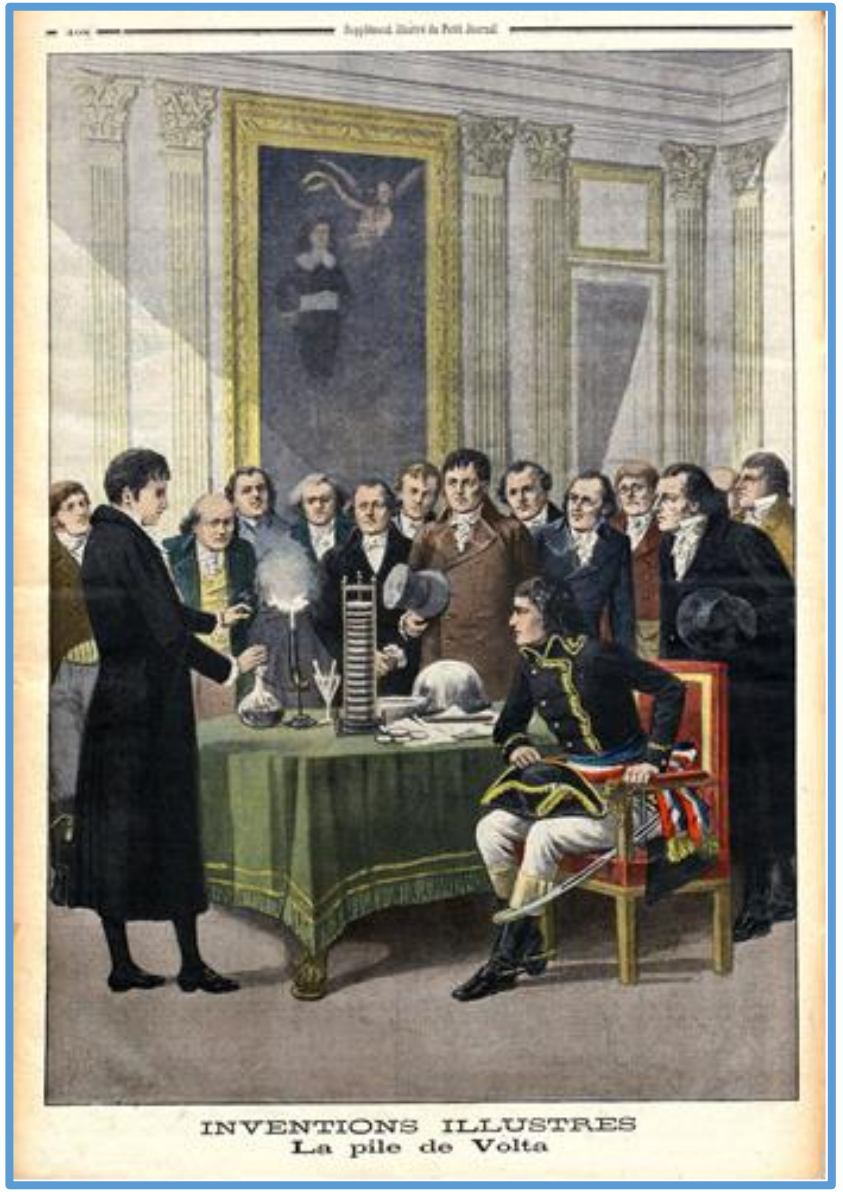
1800 - 1900 The pioneer era

1799 Volta invents battery
1820 Oersted shows that electric currents create magnetic fields
1830 Henry and Faraday discover induction
1844 First long-distance telegraph
1858 First transatlantic telegraph
1866 Maxwell publishes his theory of electromagnetism
1875 Telephone invented by Bell
1888 Experiments by Hertz verify Maxwell’s theory
1895 Marconi demonstrates radio over significant distances

1799 Volta invents battery

Alessandro Giuseppe Volta (1745 – 1827) is the inventor of the electric battery, which reliably stored an electric current and allowed the current to be used in a controlled environment. **Volta proved that electricity could be generated chemically**. Volta's invention sparked a great amount of scientific excitement and **led others to conduct similar experiments**.




INVENTIONS ILLUSTRES
La pile de Volta

1818 Success - Frankenstein

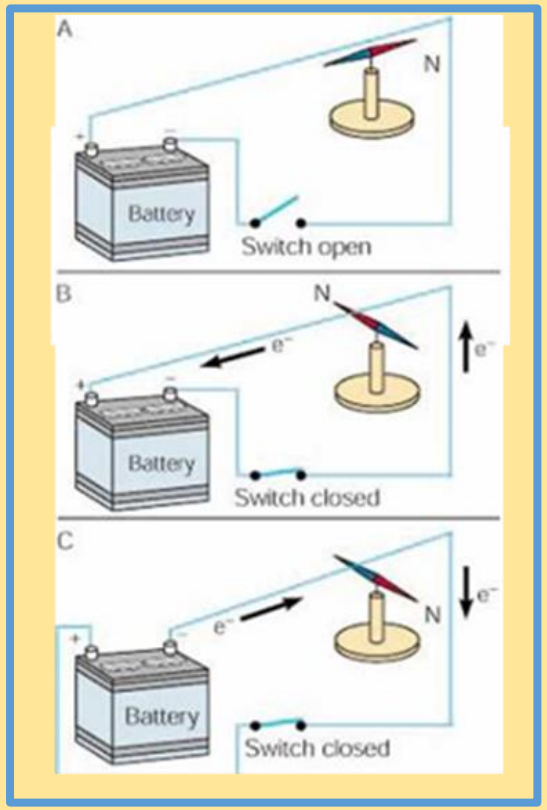
Galvani's experiments with electricity and dead tissues inspired the famous novel by

Mary Shelley

Frankenstein laboratory - details

1822 Ørsted shows that electric currents create magnetic fields

Hans Christian Ørsted (1777-1851), Danish physicist and chemist. His discovery that **electric current deflects a compass** needle showed a relation between electricity and magnetism and marked the beginning of the study of electromagnetism. The unit of magnetic field strength, the Oersted [Oe], is named after him.

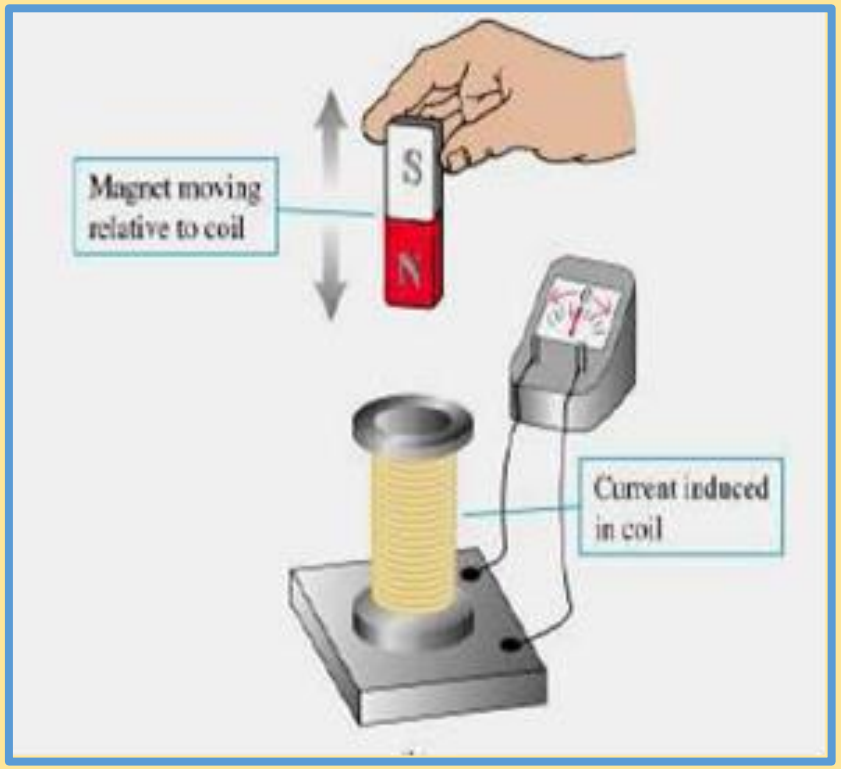


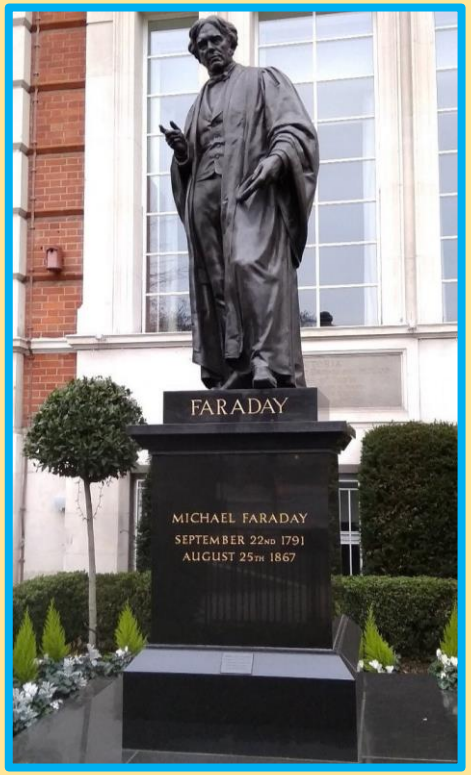
$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

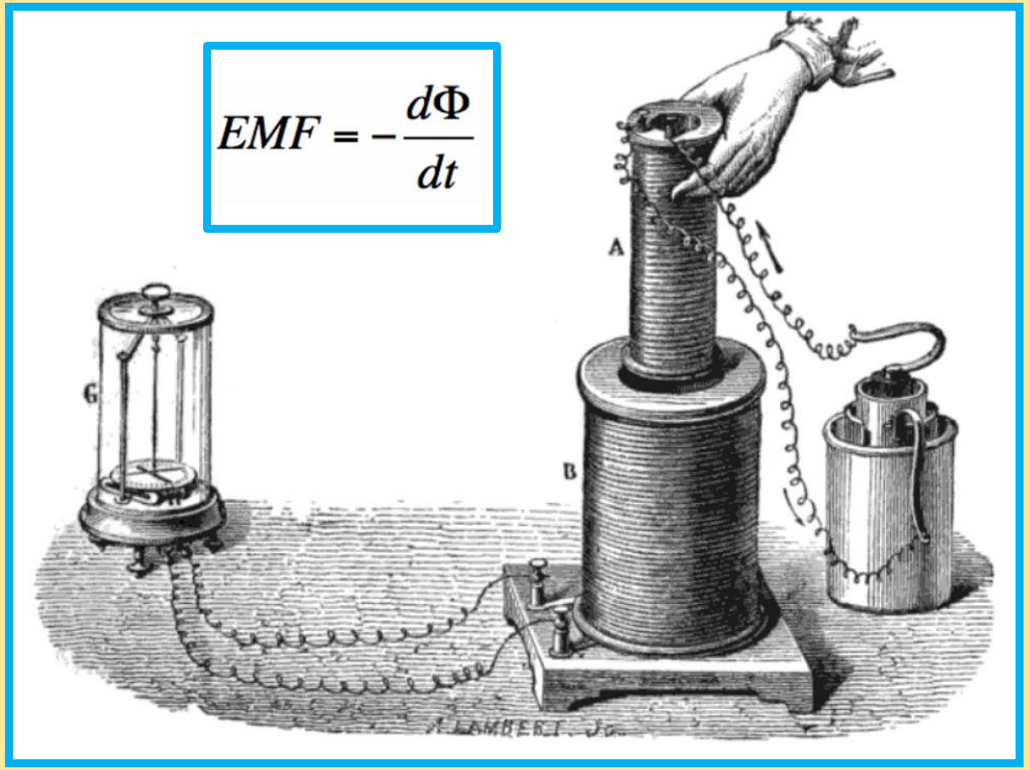
1830 Henry and Faraday discover induction

The American **Joseph Henry** (1797-1878) was the first to observe electromagnetic induction, showing that **changing magnetic fields produce electric fields**.

The Englishman **Michael Faraday** (1791-1867) investigated induction in detail and published his findings first. The mathematical description of this phenomenon is called **Faraday's law** of electromagnetic induction.

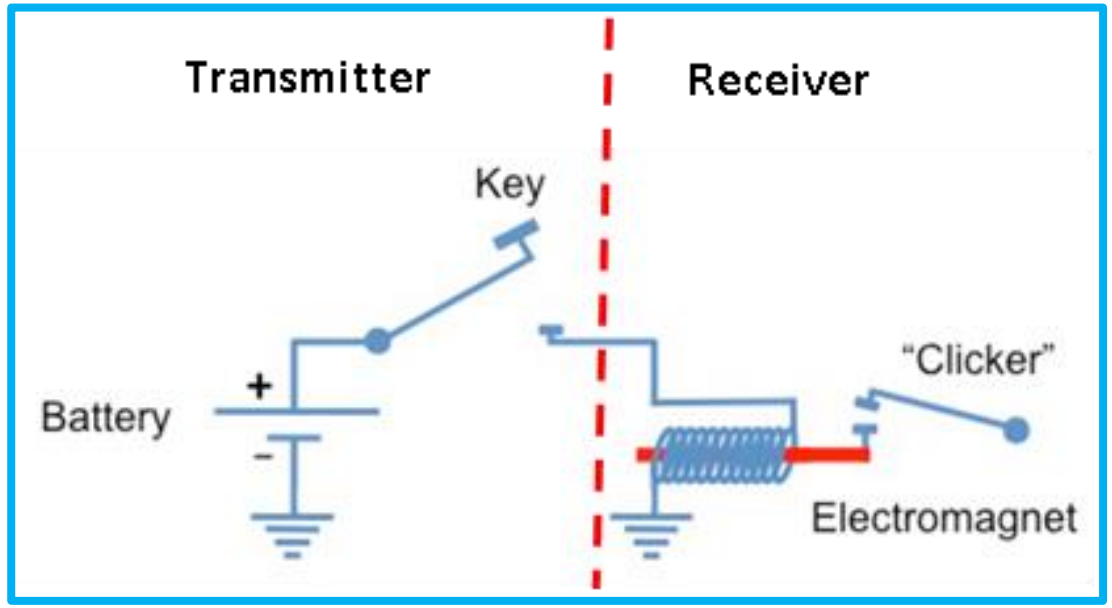


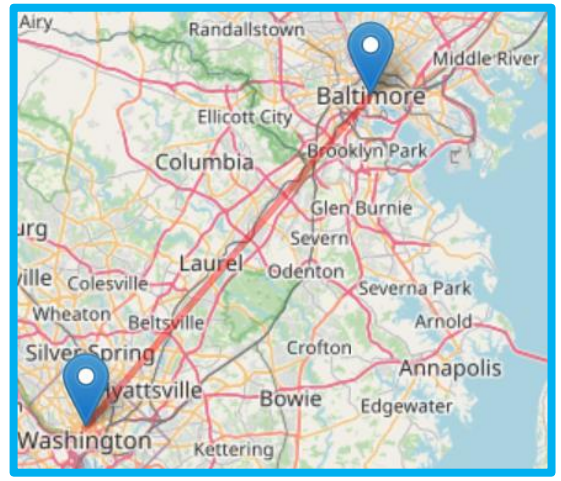




1844 The first long-distance telegraph

After years of study and experiment, **Samuel F. B. Morse** (1791-1872) demonstrated electric long-distance communication by telegraphy. Morse ran 160 miles of cable from the Capitol in Washington to Baltimore. The first message "**What Hath God Wrought**" in **Morse code** was received and returned to Morse on May 24, 1844. The message suggested by Miss Ellsworth, the daughter of the Commissioner of Patents, was intended to express the wonder of the achievement of the telegraph.





The first telephone NY-LA message: "What Hath God Wrought"

The first telegraph message

"What Hath God Wrought"

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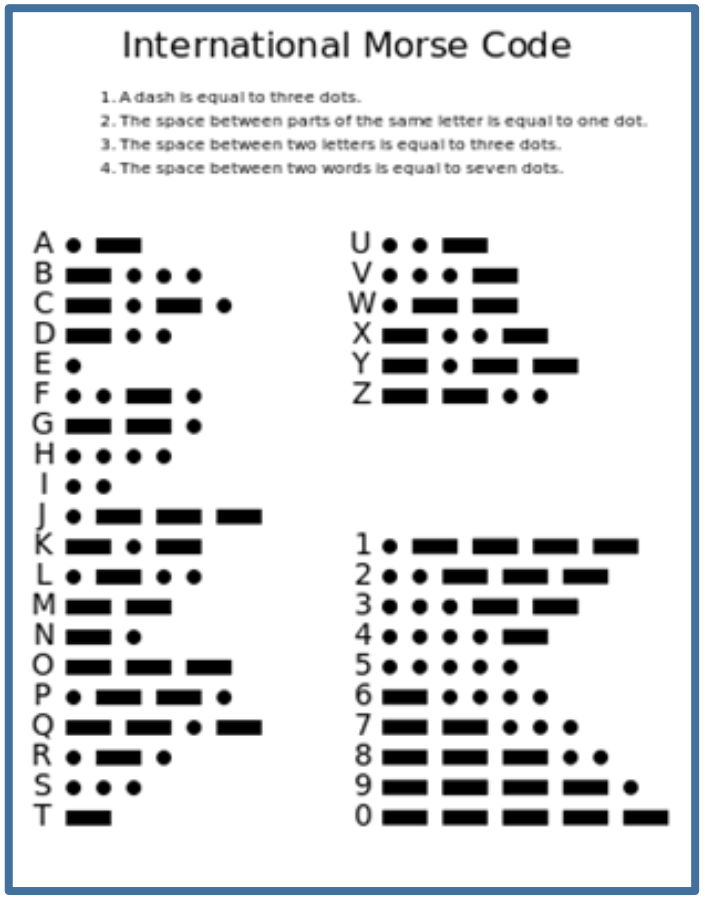
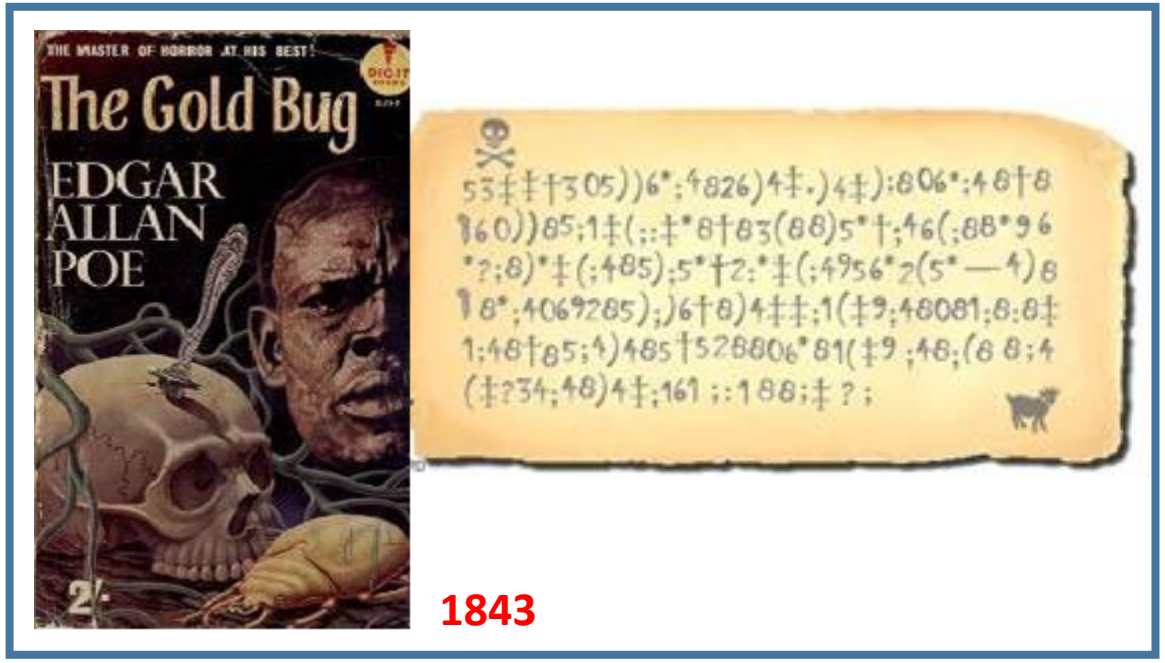


The frequency of the letters of the alphabet in English

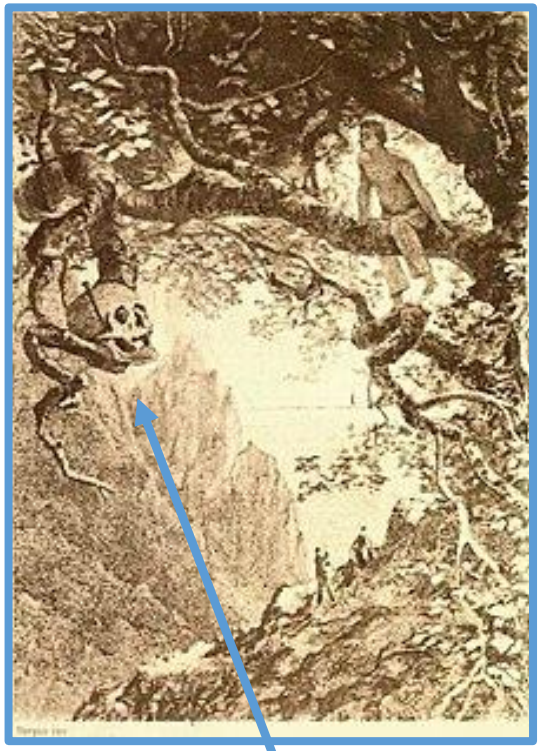
The inventor of Morse code, Samuel Morse gave the simplest codes to the most frequently used letters. The figures he came up with were:

12,000	E	2,500	F
9,000	T	2,000	W, Y
8,000	A, I, N, O, S	1,700	G, P
6,400	H	1,600	B
6,200	R	1,200	V
4,400	D	800	K
4,000	L	500	Q
3,400	U	400	J, X
3,000	C, M	200	Z



1843

The Gold Bug

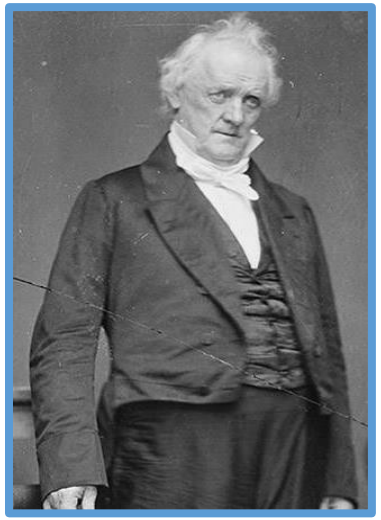


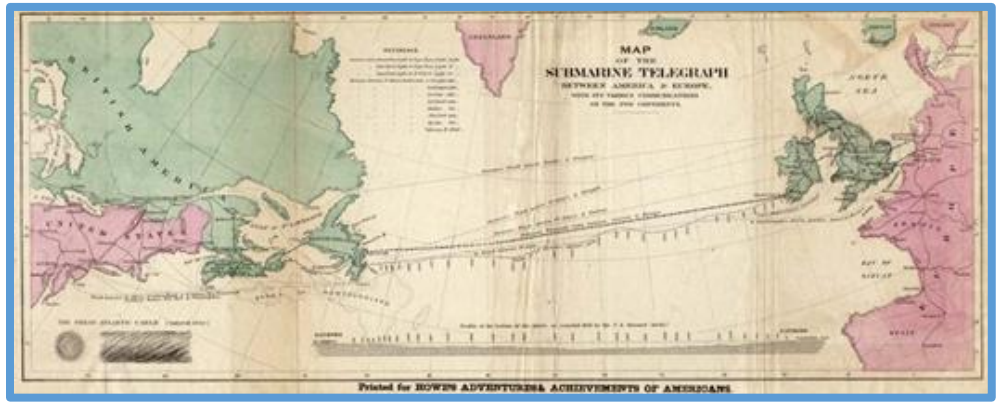
53++!305))6*;4826)4+)4+).;806*;48!8]60))85;1+8*:+(;:+*8!83(88)5*!;
46(;88*96*?;8)*+(;485);5*!2:*+(;4956*2(5*-4)8]8*;4069285);)6!8)4++;
1(+9;48081;8:8+1;48!85;4)485!528806*81(+9;48;(88;4(+?34;48)4+;161;: 188;+?;

A good glass in the bishop's hostel in the devil's seat forty-one degrees and thirteen minutes northeast and by north main branch seventh limb east side shoot from the left eye of the **death's head** a bee-line from the tree through the shot fifty feet out.

1858 First transatlantic telegraph (Transcontinental telegraph 1861, Train 1869)

The first test signals were sent on 5 August, 1858, between Trinity Bay, Newfoundland and Valentia, Ireland (4600-km cable!). As it took some time to adjust the instruments, it was not until 16 August that **Queen Victoria and President Buchanan** exchanged messages. Queen Victoria's **message of 98 words took sixteen hours to send! Buchanan's was 143 words in rapid ten hours!**





"Glory to God in the highest; on earth, peace, and good will toward men"

The cable insulation degraded so rapidly that the messages became unintelligible by 1 September.

1866 Maxwell publishes his theory of electro-magnetism

James Clerk Maxwell (1831-1879) was a Scottish physicist whose greatest work was his contribution to electromagnetic theory. Maxwell's famous **equations of the electromagnetic field** were mathematical interpretations of Faraday's concepts. Equations describe that **electricity and magnetism propagates through space at the speed of light**.

Maxwell's equations

Electric Force

$$\nabla \cdot \mathbf{D} = \rho_v$$

An electric charge is a source of an electric field.

Magnetic Force

$$\nabla \cdot \mathbf{B} = 0$$

There are no such things as "magnetic charges". Magnetic lines of force always form closed loops and never diverge from a point source.

Electromagnetic Induction

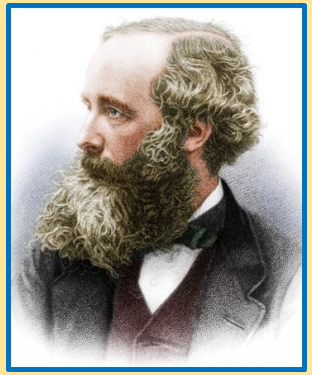
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

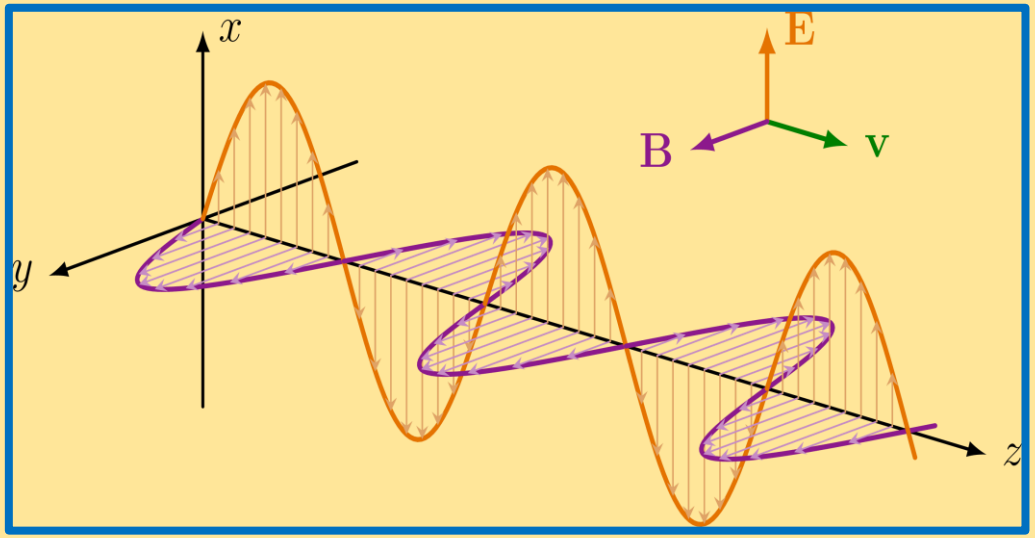
*Voltage is generated in a conductor as it passes through a magnetic field or cuts magnetic lines of force. This was **Faraday's** great discovery.*

Magnetic Effect of Electric Current

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$$

*An electric current is always surrounded by a magnetic field. This was the conclusion that Faraday had derived from **Oersted's** experiment.*





Maxwell's mathematics

We may now express Q in terms of u, v, w and V,

$$Q = \iiint K \left(\left|\frac{\overline{dV}}{dx}\right|^2 + \left|\frac{\overline{dV}}{dy}\right|^2 + \left|\frac{\overline{dV}}{dz}\right|^2\right) dx\,dy\,dz + \iiint \frac{1}{K}\,(u^2+v^2+w^2)\,dx\,dy\,dz$$
$$+ 2\iiint \left(u\frac{dV}{dx} + v\frac{dV}{dy} + w\frac{dV}{dz}\right) dx\,dy\,dz. \quad (13)$$

186.] THEOREM III. *If V is any function of x' and y', and if x' and y' are conjugate functions of x and y, then*

$$\iint \left(\frac{d^2V}{dx^2} + \frac{d^2V}{dy^2}\right) dx\,dy = \iint \left(\frac{d^2V}{dx'^2} + \frac{d^2V}{dy'^2}\right) dx'\,dy',$$

the integration being between the same limits.

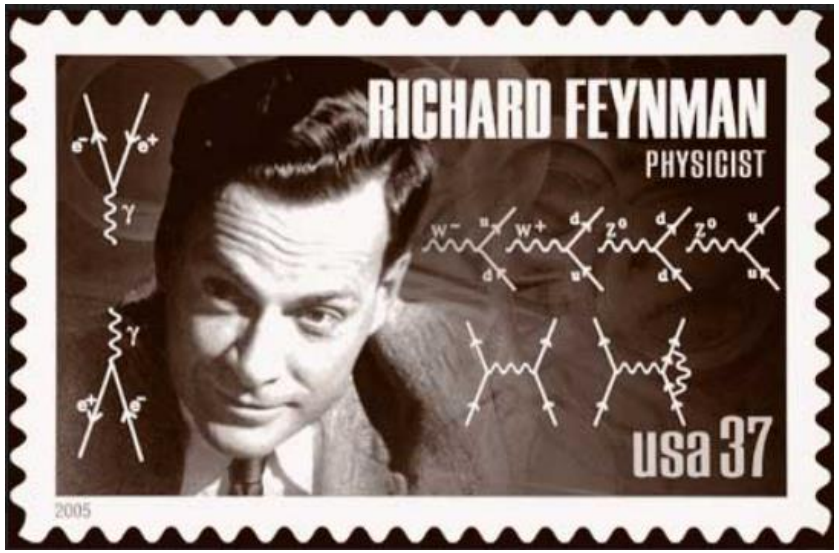
For
$$\frac{dV}{dx} = \frac{dV}{dx'}\frac{dx'}{dx} + \frac{dV}{dy'}\frac{dy'}{dx},$$

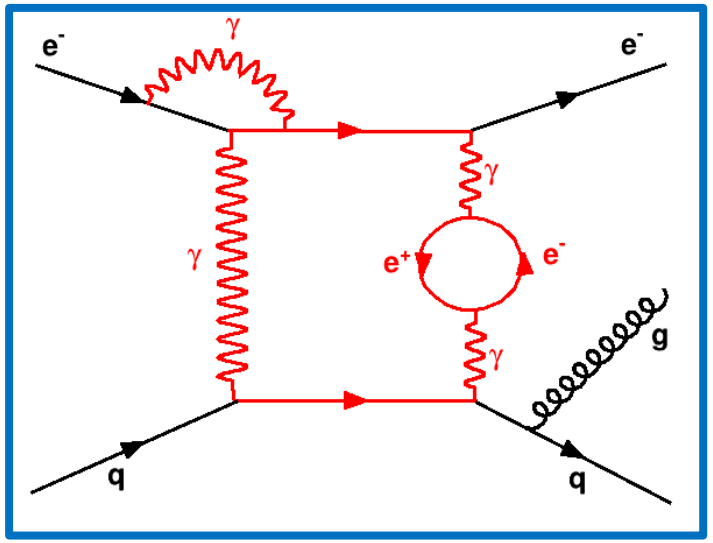
$$\frac{d^2V}{dx^2} = \frac{d^2V}{dx'^2}\left(\frac{dx'}{dx}\right)^2 + 2\frac{d^2V}{dx'\,dy'}\frac{dx'}{dx}\frac{dy'}{dx} + \frac{d^2V}{dy'^2}\left|\frac{\overline{dy'}}{dx}\right|^2$$
$$+ \frac{dV}{dx'}\frac{d^2x'}{dx^2} + \frac{dV}{dy'}\frac{d^2y'}{dx^2};$$

and
$$\frac{d^2V}{dy^2} = \frac{d^2V}{dx'^2}\left|\frac{\overline{dx'}}{dy}\right|^2 + 2\frac{d^2V}{dx'\,dy'}\frac{dx'}{dy}\frac{dy'}{dy} + \frac{d^2V}{dy'^2}\left|\frac{\overline{dy'}}{dy}\right|^2$$
$$+ \frac{dV}{dx'}\frac{d^2x'}{dy^2} + \frac{dV}{dy'}\frac{d^2y'}{dy^2}.$$

Feynman and Maxwell

Richard P. Feynman (1918 – 1988) was an American theoretical physicist. He assisted in the development of the atomic bomb during World War II. For contributions to the development of quantum electrodynamics, Feynman received the **Nobel Prize** in Physics in 1965.

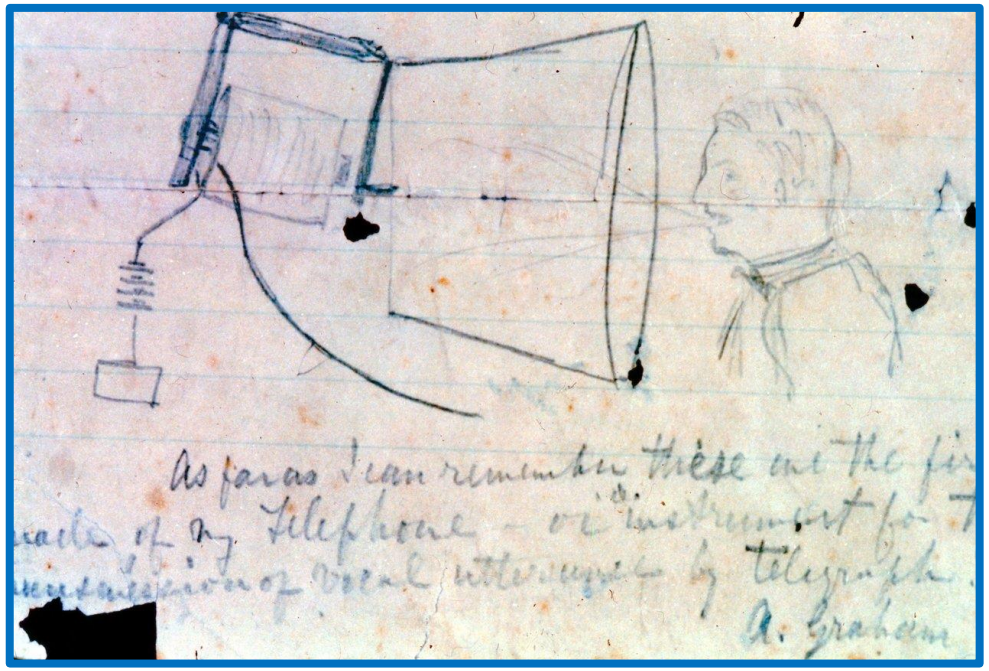


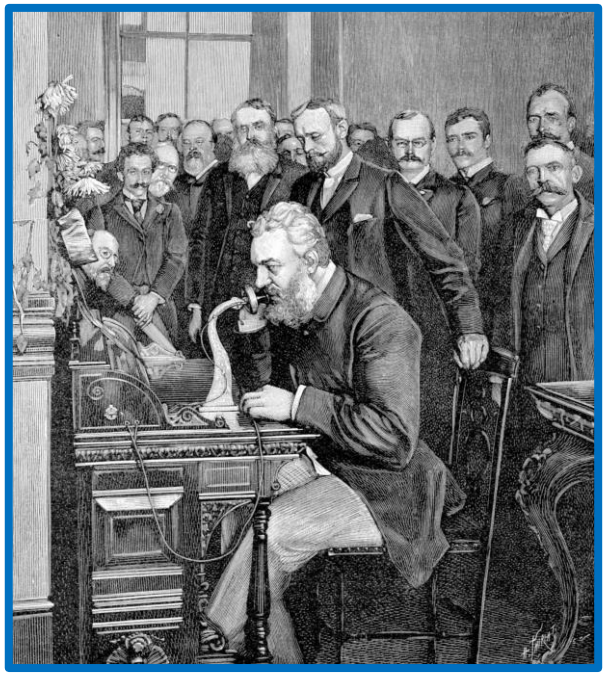


"From a long view of the history of mankind, seen from, say**, ten thousand years from now**, there can be little doubt that the **most significant event of the 19th century** will be judged as Maxwell's discovery of the laws of electrodynamics.

1875 Telephone invented by Bell

Alexander Graham Bell (1847-1922) was born in Scotland in a family that had taught speech to people with speech defects. Bell took up his family profession, which lead him on to research in the area of sound and speech, modeling human speech production and visualizing and recording speech. With the help of a repair mechanic Thomas Watson, Bell was able to devise an apparatus implementing his **discovery that sounds can be transmitted by electricity.** The famous first intelligible sentence ever heard over the proto-telephone was "**Mr. Watson, come here, I want you**!"



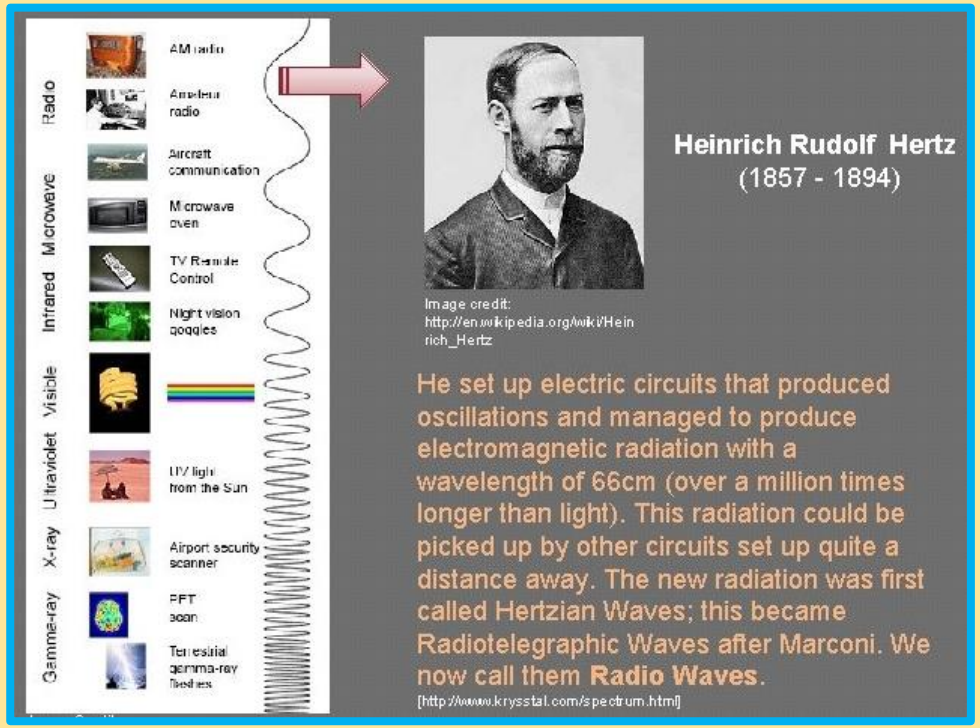


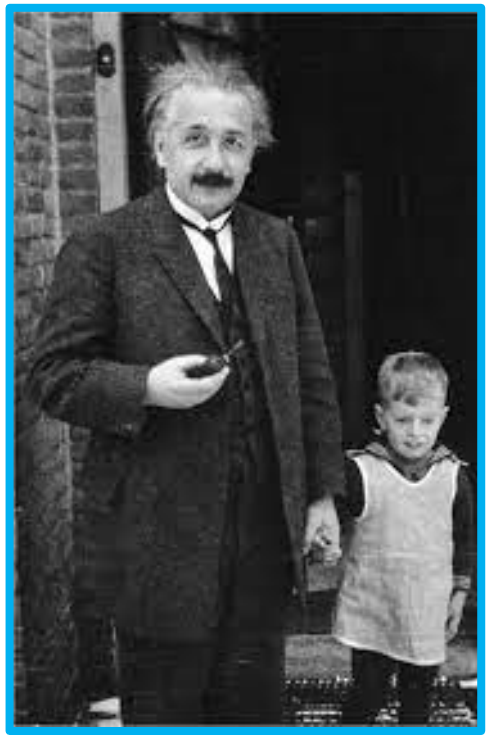
1888 Experiments by Hertz verify Maxwell's theory

Heinrich Rudolf Hertz (1857-1894) **demonstratet experimentally the production and detection of Maxwell's postulated waves.** This discovery leads directly to radio, television and radar.

Hertz did not realize the practical importance of his experiments. He stated that,

"It's of no use whatsoever this is just an experiment that proves Maestro Maxwell was right - we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there."





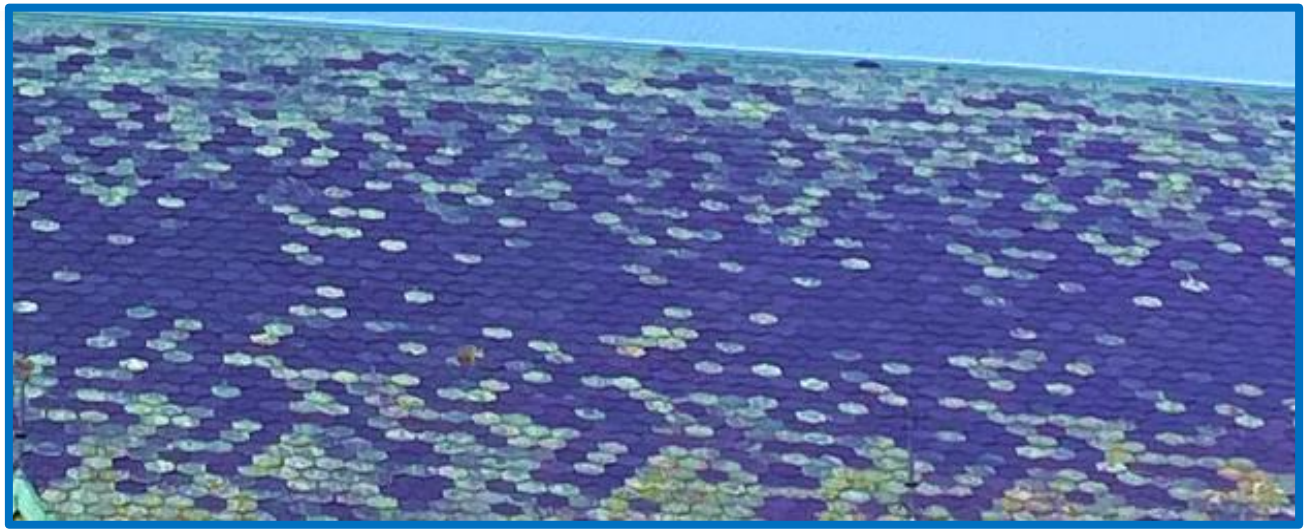
Kyrkan i Lomma :-)

Hellmuth Hertz (1920-1990)

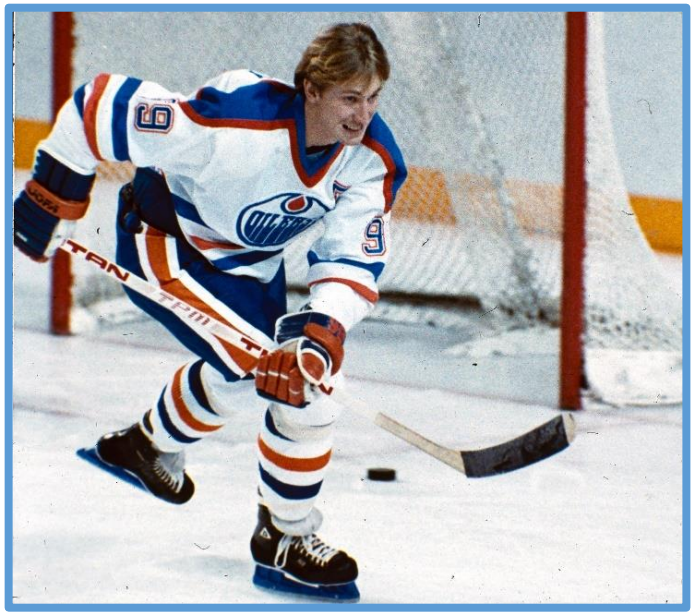
Poisson distribution formula

$$P(X = k) = \frac{e^{-\lambda}\lambda^k}{k!}$$

- X is a random variable following a Poisson distribution
- k is the number of times an event occurs
- $P(X = k)$ is the probability that an event will occur k times
- e is Euler's constant (approximately 2.718)
- λ is the average number of times an event occurs



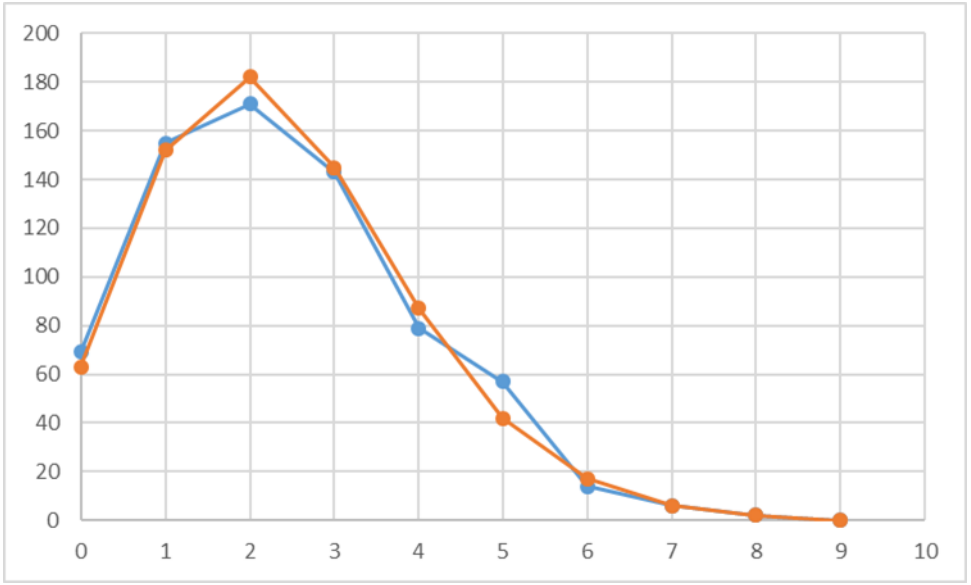
The Great One and Poisson



During **Wayne Gretzky's** (1961+) days as an Edmonton Oiler, he scored a remarkable 1669 points in 696 games, for a rate of $\lambda = 1669/696 = 2.39$ points per game.

$$P(X = k) = \frac{e^{-\lambda}\lambda^k}{k!}$$

Points	*Actual # Games*	*# Predicted by Poisson*
0	69	63.27
1	155	151.71
2	171	181.90
3	143	145.40
4	79	87.17
5	57	41.81
6	14	16.71
7	6	5.72
8	2	1.72
9	0	0.46

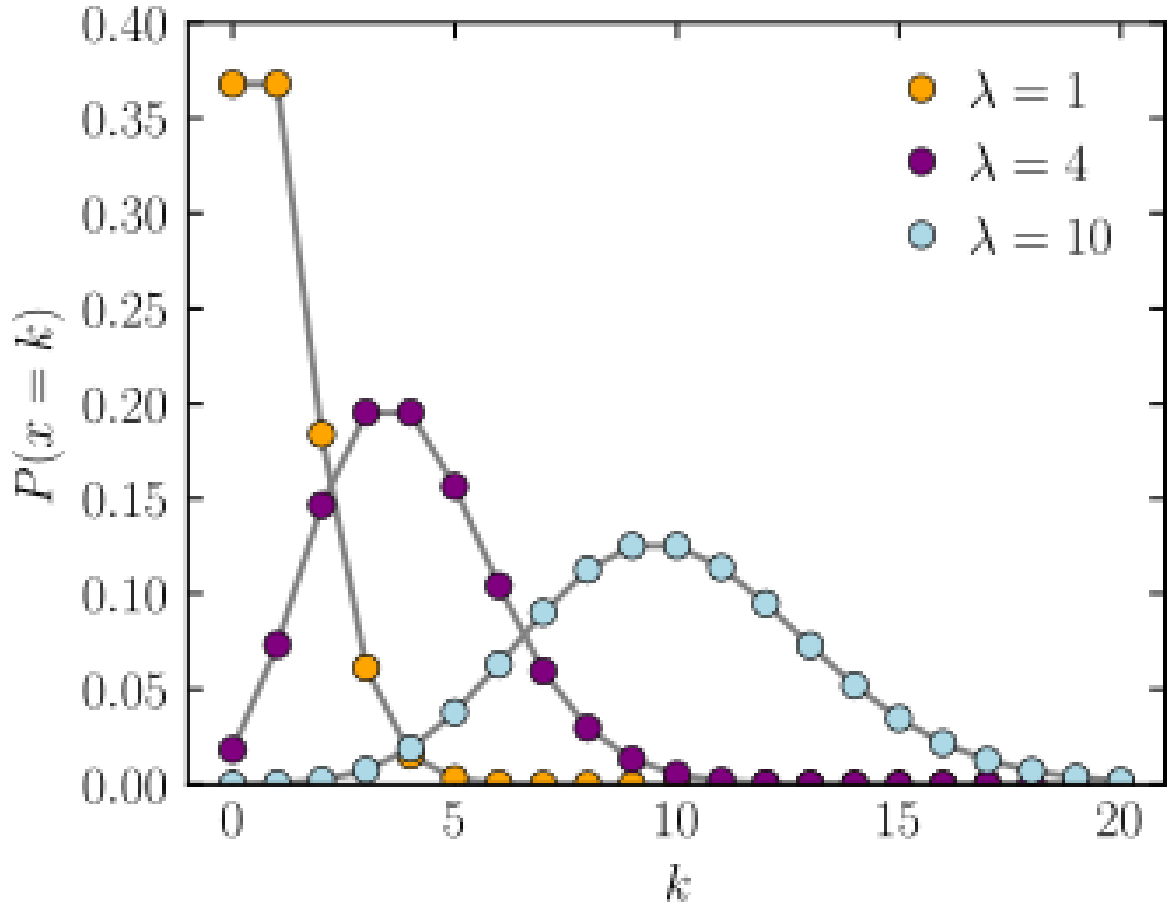


Examples of Poisson distribution in telecommunications

- **Call center staffing:** A call center can use the distribution to predict the number of calls it will receive in a given hour to determine **how many agents to schedule**.
- **Network traffic:** It can model the number of phone calls or data requests that arrive at a **base station** or server in a specific timeframe to help with **capacity planning**.
- **Network reliability:** The distribution is used to analyze the frequency of events like call drops. For instance, if the average is 3 call drops per hour, the probability of 0, 5, or any other number of drops can be calculated to assess network quality.
- **Service Level Agreements (SLAs):** Telecommunication companies can validate SLAs by calculating the probability of exceeding a certain number of events (e.g., call drops) in a given period.

The packets arriving to a **router** are known to follow a Poisson Process with a **rate of 4 000 per sec**.

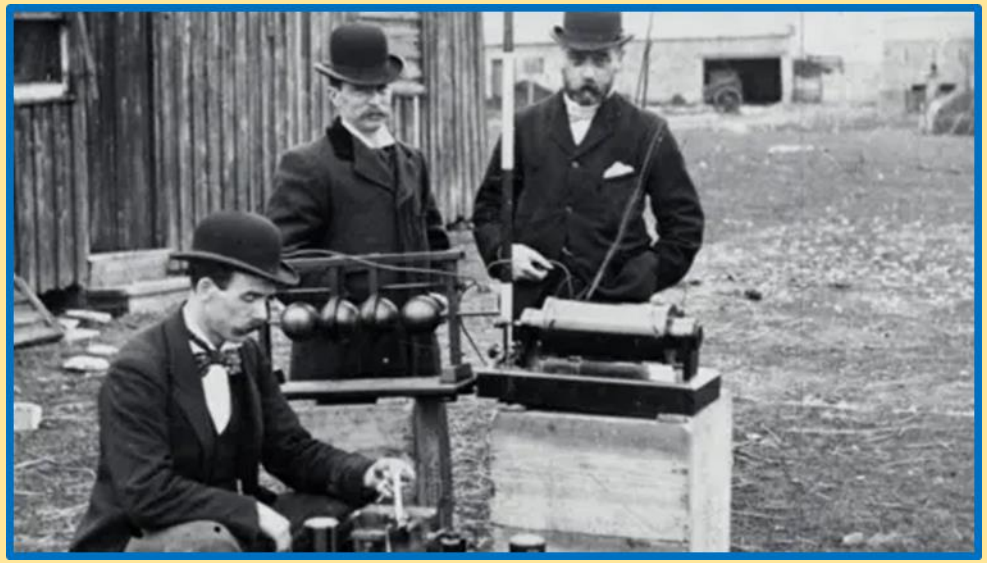
Find the probability that more than 9 000 packets arrive in 1 second.



1895 Marconi demonstrates radio over significant distances

Guglielmo Marconi, (1874-1937) Italian electrical engineer, is the inventor of the first practical **radio-signaling** system. In 1895, he had developed an apparatus with which he succeeded in sending signals to a point a **few kilometers** away by means of a directional antenna. After patenting his system in Great Britain, he formed Marconi's Wireless Telegraph Company in 1897.

In 1899, he established communication across the English Channel.



*In his Nobel Prize acceptance speech (1909), Marconi, who was much more a **tinkering engineer** than a scientist, freely admitted he didn't really understand how his invention worked.*

PRESSMEDDELANDE

13 oktober 2025

Ekonomipriset 2025

Kungl. Vetenskapsakademien har beslutat utdela Sveriges Riksbanks pris i ekonomisk vetenskap till Alfred Nobels minne 2025 till Joel Mokyr, Philippe Aghion och Peter Howitt

"för att ha förklarat innovationsdriven ekonomisk tillväxt"

med ena hälften till

Joel Mokyr

Northwestern University, Evanston, IL, USA
Eitan Berglas School of Economics, Tel Aviv University, Israel

"för att ha identifierat förutsättningarna för ihållande tillväxt genom teknologisk utveckling"

och med andra hälften gemensamt till

Philippe Aghion

Collège de France och INSEAD, Paris, Frankrike, The London School of Economics and Political Science, Storbritannien

Peter Howitt

Brown University, Providence RI, USA

"för teorin om ihållande tillväxt genom kreativ förstörelse"

***Joel Mokyr** har visat att för att innovationer ska avlösa varandra i en självgenererande process **räcker det inte med att veta att något fungerar**. **Man behöver också ha vetenskapliga förklaringar till varför.** Före den industriella revolutionen saknades ofta det senare. Det gjorde det svårt att bygga vidare på nya upptäckter och uppfinningar.*

1900-1940 The dawn of radio technology

1901	First transatlantic wireless message from United Kingdom to Canada
1904	Diode tube is invented
1906	First transmission of speech and music via a wireless link
1906	De Forest announces the triode
1912	The sinking of the Titanic highlights the importance of wireless communication
1920	First modern radio broadcast
1921	Detroit Police Department conducts field tests with mobile radio
1928	Gaussian thermal noise papers by Nyquist
1929	Electronic TV system is demonstrated by Zworykin
1933	Armstrong devises FM

1901 The first transatlantic wireless message from United Kingdom to Canada

On 12 December, 1901 **Guglielmo Marconi** at St. John's, Newfoundland, using a kite borne aerial floating 55 meters above ground, received a signal from Poldhu, Cornwall, 2170 miles across the Atlantic, consisting of the Morse letter ‘S’ (· · ·).

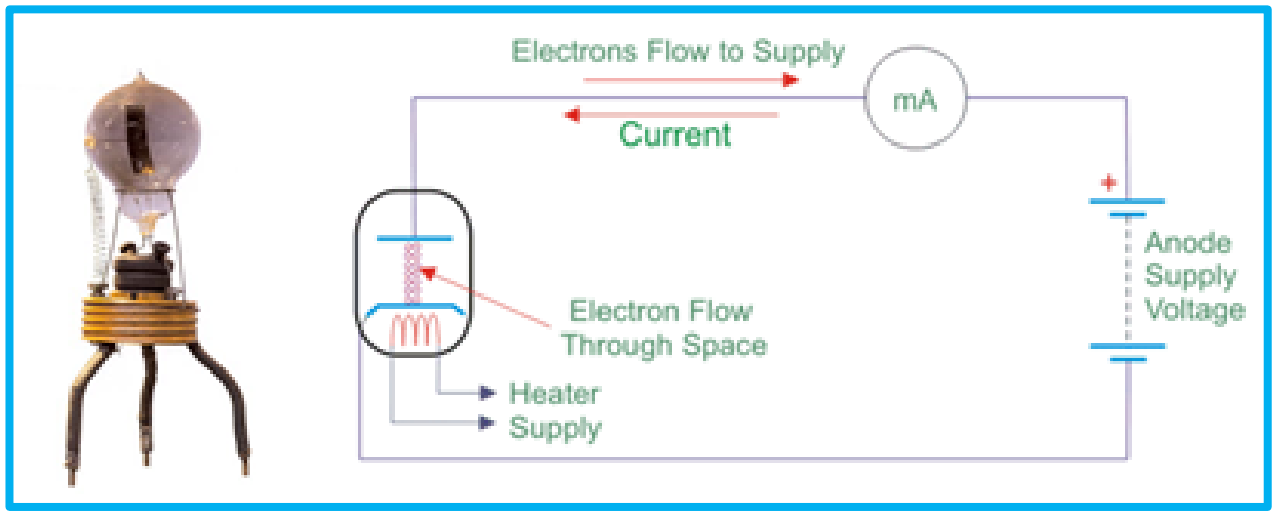
f = 500 kHz

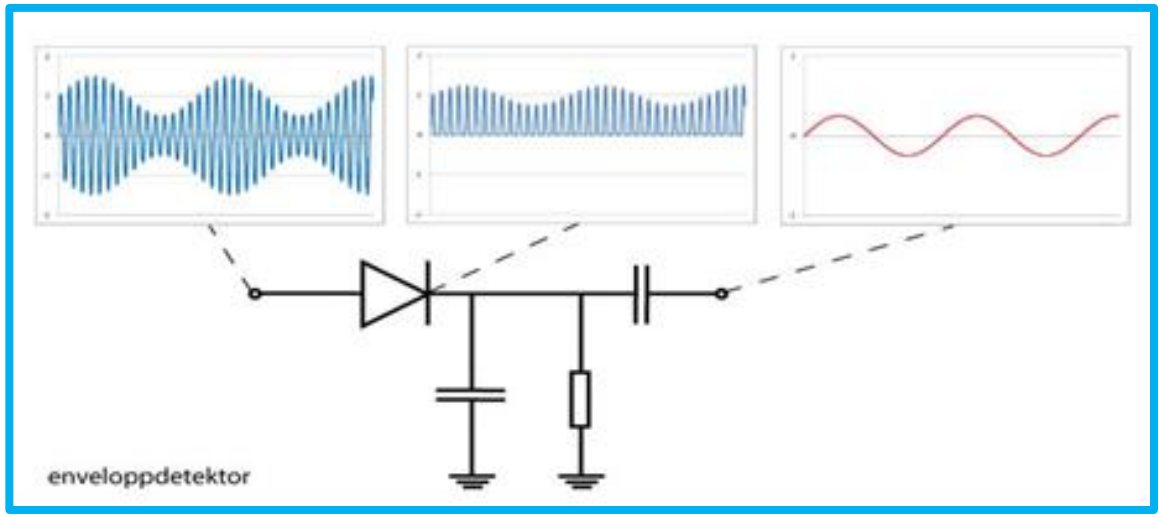
His system was soon adopted by the British and Italian navies, and by 1907 had been much improved that a **transatlantic wireless telegraph service** was established for so public use.

On his death (1937), wireless stations throughout the world closed down. For two minutes, silence returned once more to the ether and the airwaves were as quiet as they had been before Marconi.

1904 The Diode tube is invented

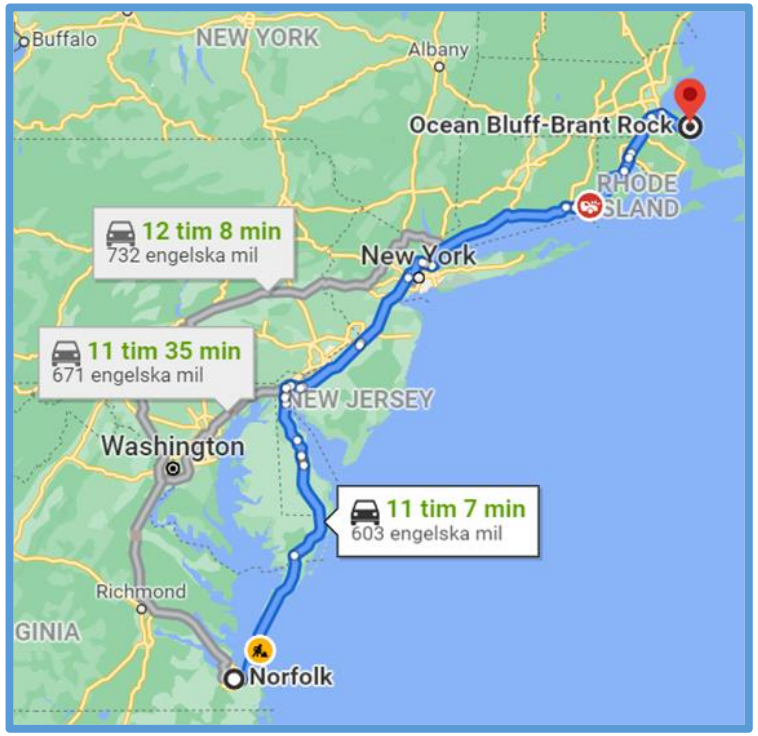
John Ambrose Fleming (1849-1945) patented the **diode tube**. Working from Edison's discovery that heated metal (cathode) will give off electrons which, in a vacuum tube, will move in one direction only toward an unheated plate (anode), Fleming constructed a tube in which he placed a cathode, an anode and two electrodes. His discovery was **the first radio-wave detector capable of rectification**.





1906 First transmission of speech and music via wireless link

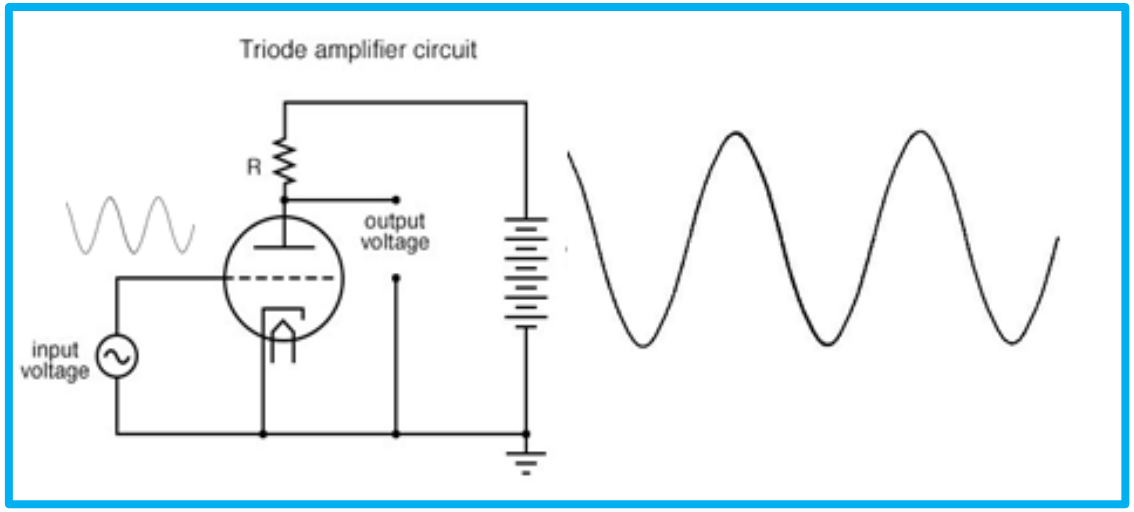
Reginald Aubrey Fessenden, (1866-1932) was Canadian-born physicist and electrical engineer. After designing a high-frequency alternator, on Christmas Day 1906 he broadcasted speech and music from a home-made transmitting station at Brant Rock, Massachusetts. The **AM radio broadcast** began with Fessenden playing **'O, Holy Night'** on the violin. This was the first program of speech and music ever transmitted by radio and could be heard by wireless operators as far away as Norfolk Virginia.



https://www.youtube.com/watch?v=ymYLUNj9LcI

1906 De Forest announces the Triode

Lee De Forest (1873-1961) was a prolific inventor with more than 300 patents in the fields of wireless telegraphy, radio, wire telephone, sound-on-film, picture transmission, and television. He is most widely known for introducing **a third electrode into the diode**, creating **the triode which could amplify radio signals and generate oscillations**. In 1910, De Forest staged the first radio broadcast in history from the Metropolitan Opera House in New York (Puccini's Tosca, with Enrico Caruso).



https://www.youtube.com/watch?v=5ak3kX6TKWc

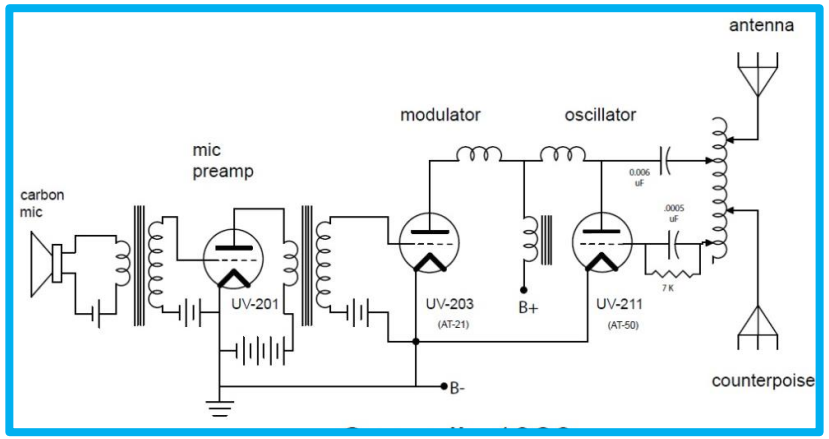
1912 The sinking of the Titanic highlights the importance of wireless communication

A major contribution to the Titanic disaster that started on 14 April, 1912 at 11:40 pm was the fact that **all radio operators at sea used the same spectrum space**. Since the Titanic had the strongest transmitter, and constantly used it, other nearby operators were overwhelmed and some of them shut down their radio sets. Consequently, the early distress signals from the sinking ship went unheard by some potential rescuers.

On the other hand, those nearby ships which heard the message from Titanic came and saved many lives.

1920 The first modern radio broadcast

At 6:00 pm, Tuesday, 2 November, 1920, the KDKA AM1100 radio station in Pittsburgh made the historicfirst broadcast, reporting election returns in the Harding vs. Cox presidential race. **(Harding won.)**



100 watt

1925 Radiotjänst

AB Radiotjänst (sedermera SR) bildades 21 mars 1924. Företaget, som ägdes av den svenska pressen, nyhetsbyrån TT och intressenter inom radioindustrin, fick då statens tillstånd att bedriva rundradioverksamhet i Sverige.

Klockan 10.55 den 1 januari 1925 påannonserades Radiotjänsts första program av **Sven Jerring**. Det var en högmässa från **Sankt Jacobs kyrka** i Stockholm som kunde höras i cirka 40 000 mottagare.

RADIOTJÄNST

1922 Detroit Police Department conducts field tests with mobile radio

It was the time of prohibition and law-enforcement agencies in their fight with organized crime needed to improve their odds**. The first radio systems** installed in Detroit, Michigan, were **one-way**, sometimes using Morse code, with police officers getting out of their cars and then calling their stations on a wired telephone. The initial experiments were based on conventional **amplitude modulation.**

Al Capone (1899-1947)

1928 Gaussian thermal noise paper by Nyquist

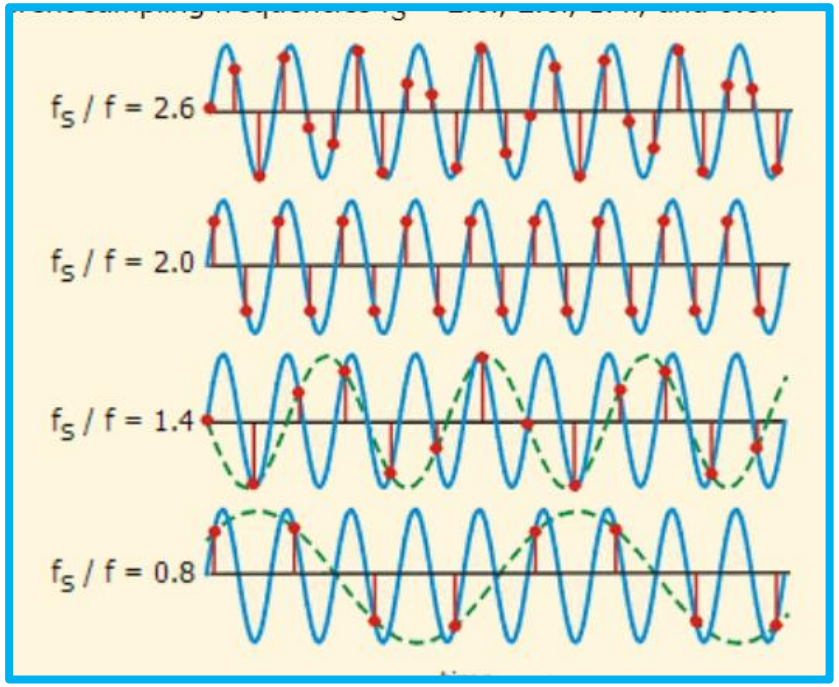
Harry Nyquist (1889-1976) who was born in Sweden moved to USA in 1907. After earning a Ph.D. in physics from Yale University he joined the research department at the American Telephone & Telegraph Company (AT&T).

In 1928, Nyquist provided **a mathematical foundation for the study of thermal noise**:

$$V^2 = 4kTRF$$

which sets an irreducible minimum on the noise power generated by a resistor R at temperature T in the frequency band F.

Nyquists, Shannon, Kotelnikov **Sampling theorem**:
If a function x(t) contains no frequencies higher than B Hertz, it is completely determined by giving its ordinates at a series of points spaced 1/(2B) seconds apart.



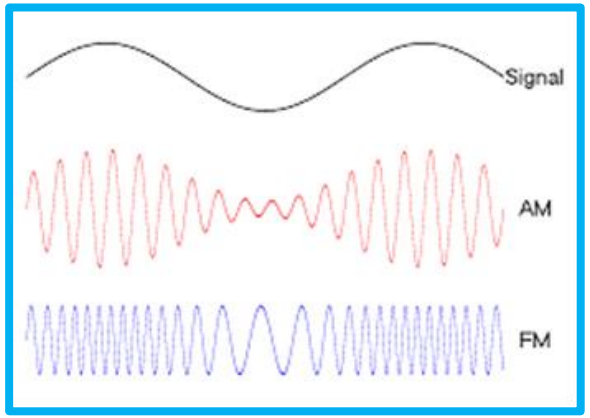
1929 Electronic TV system is demonstrated by Zworykin

A Russian immigrant **Vladimir Zworykin** (1889-1982) is called the father of electronic television. He built the first practical TV camera tube called the Iconoscope in 1923.. In the following years Zworykin improved his inventions and on 18 November, 1929, at a convention of radio engineers, he demonstrated a **complete TV system consisting of television camera and receiver.**

1933 Armstrong invents FM

Edwin Armstrong (1890-1954) was one of the most important contributors to the development of radio technology. In 1933, in four patents, he solved the **static-noise problem** that was tormenting radio communication based on amplitude modulation. Instead of modulating the amplitude, his new system was based on **modulation of frequency (FM)**. For the first time, this technique made it possible to transmit high-fidelity radio programs.

Acceptance of this new revolutionary technology by the radio industry was not enthusiastic. **Industry prefers evolutionary improvements not revolutions.** Radio communication based on frequency modulation required change in both transmitters and receivers, and as such it was very expensive.



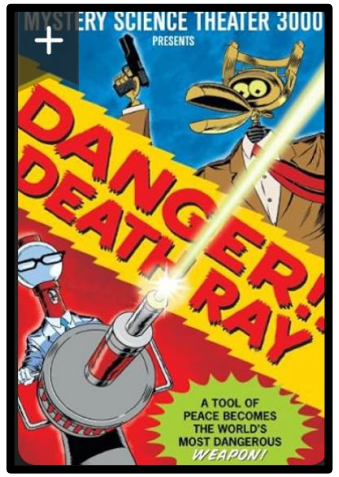
1940 - 1950 The emergence of the computer

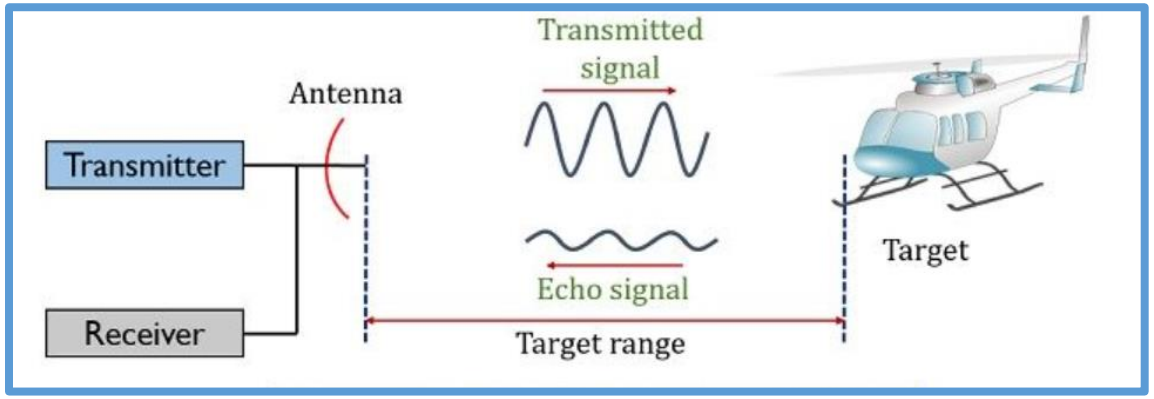
1940+	Massive use of radar during World War II
1941	Hedy Lamarr invents Frequency Hopping Spread Spectrum communication technique
1945	Computer architecture is described by von Neumann
1945	Arthur C. Clarke proposes the use of satellites for communication
1946	First commercial mobile telephone system in USA
1948	Transistor demonstrated
1948	Shannon publishes his theory of information

1940-1945 Massive use of radar during World War II

In the mid-1930s the Air Ministry asked British physicist Sir **Robert Watson-Watt** (1892-1973), superintendent of a radio department at the National Physical Laboratory, if it was possible to disable remote targets by some form of '**death ray**' using a radio beam. Although he rejected the proposal as unrealistic, Watson-Watt prepared a report in February 1935 entitled '**The Radio Detection of Aircraft by Radio Methods**' in which he described what soon radar became.

Radar was patented in April, 1935 and the first practical radar system was produced in the same year.

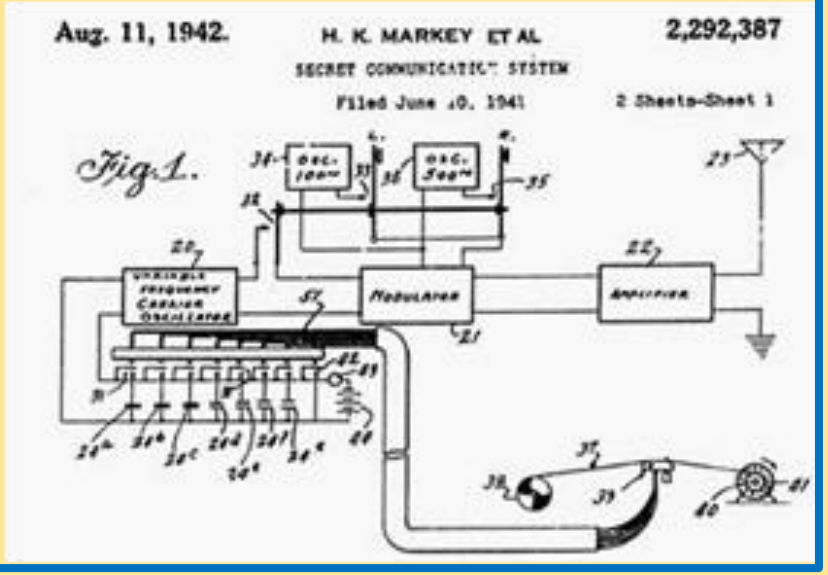


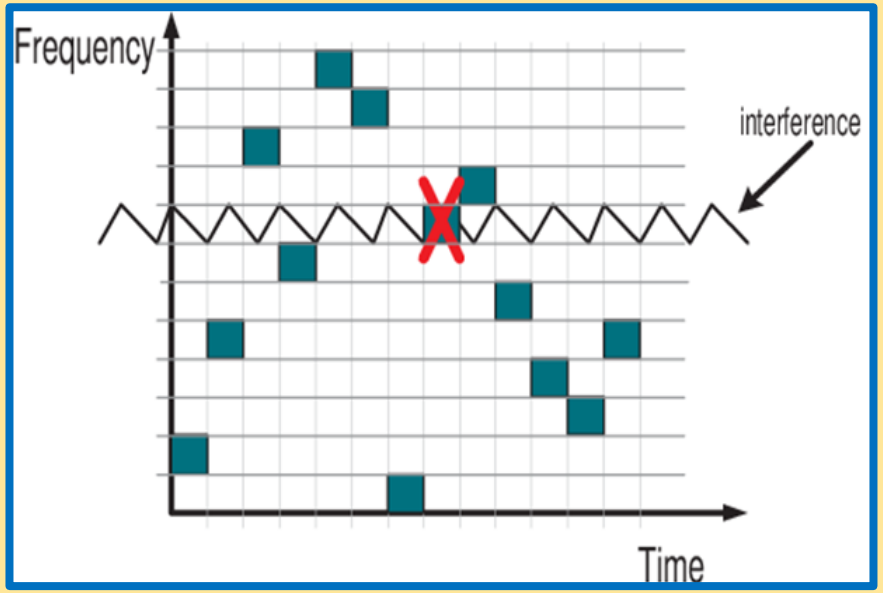



PAX

1941 Hedy Lamarr invents Frequency Hopping Spread Spectrum communication technique

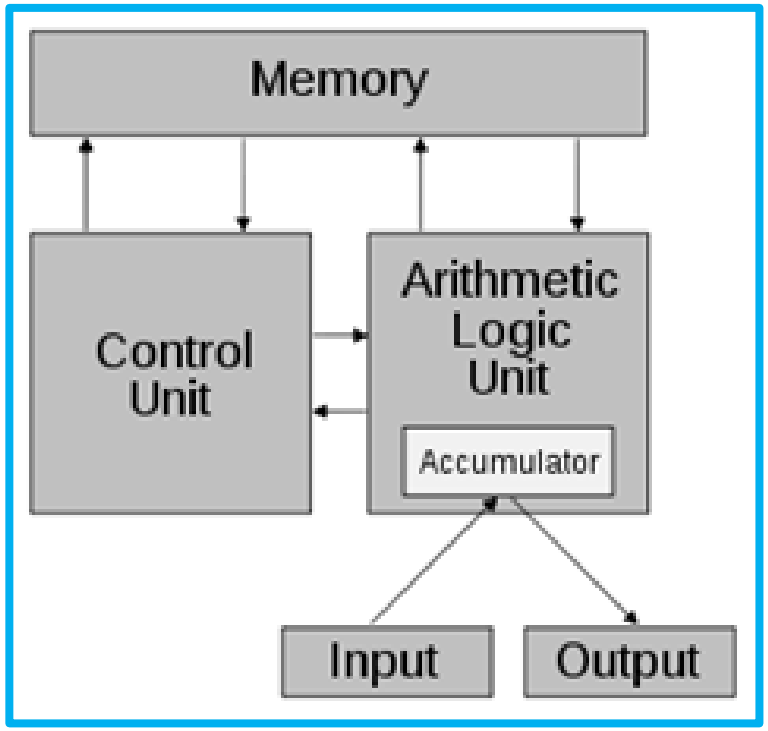
The Czech born Hollywood actress, **Hedy Lamarr** (1913-2000), famous for starring in the movie Ecstasy, invents a method that would make it difficult to jam radio-guided torpedoes. The early prototype was based on **the transmitter and the receiver synchronously, seemingly randomly hopping between 88 frequencies**. Frequency hopping used in Bluetooth and WIFI can be seen as an implementation of her idea!

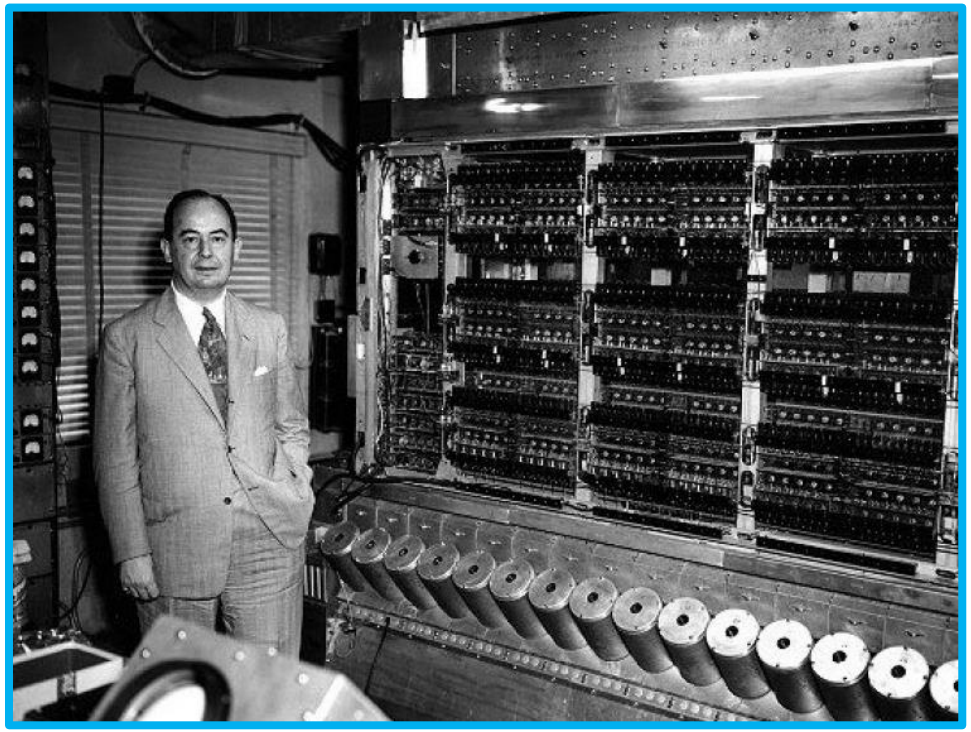




1945 Computer architecture is described by von Neumann

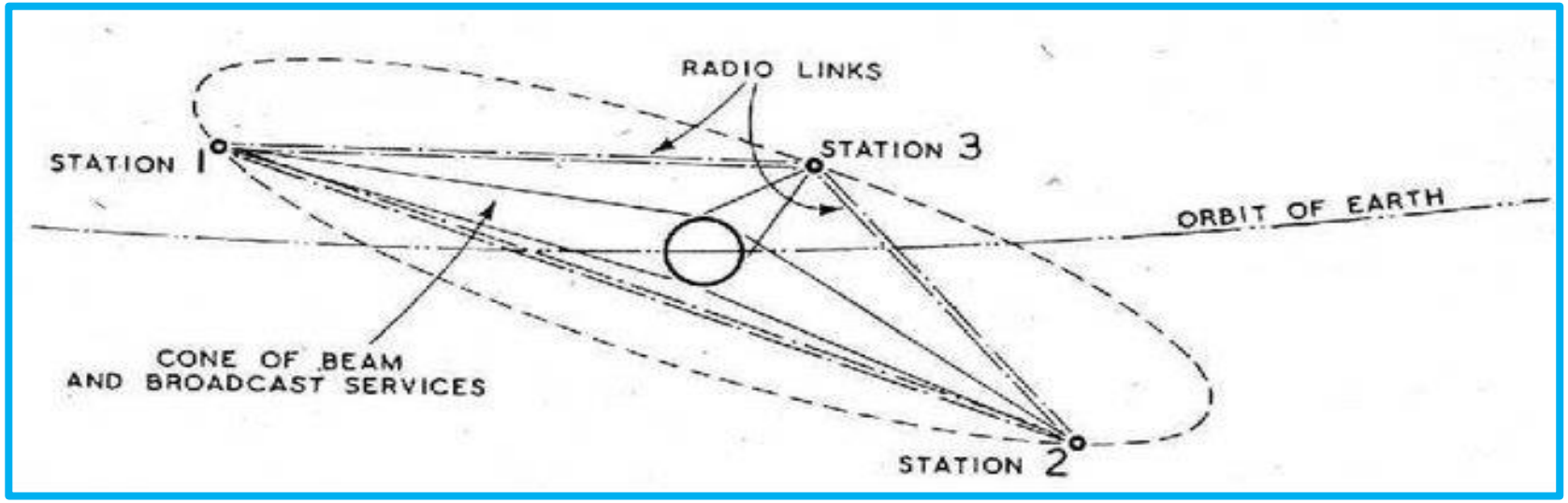
The great American mathematician **John von Neumann** (1903-1957), wrote in June 1945 a report "Draft Report on the EDVAC" *(Electronic Discrete Variable Automatic Computer)* describing the concept of the stored-program computer, the basis for the future computer industry. von Neumann was not the sole inventor of the computer but he was the first to describe it. The architecture of modern computers is often called **van Neumann architecture** to honor his contribution.





1945 Arthur C. Clarke proposes the use of satellites for communication

In his paper "Extra-Terrestrial Relays: Can Rocket Stations Give World-wide Radio Coverage?" that appeared in the Wireless World: Radio and Electronics in May 1945, **Arthur C. Clarke** (1917-2008, the author of 2001 Space Odyssey) argues that geo-synchronous satellites and space stations would allow world-wide communications. **Three space-crafts set equidistant in synchronous orbit would cover the whole world**. Clarke went on to say that "A true broadcast service, giving constant field strength at all times over the whole globe would be invaluable, not to say indispensable, in a world society."



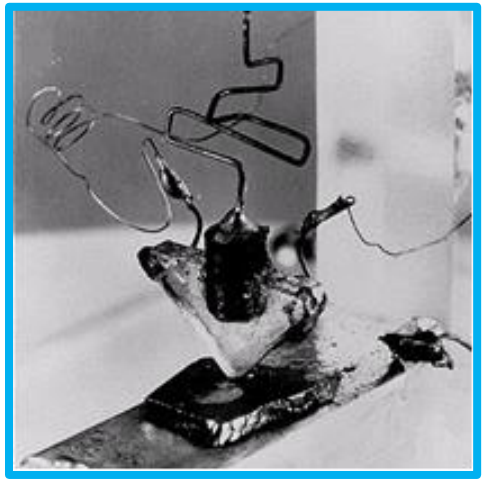
1946 First commercial mobile telephone system in USA

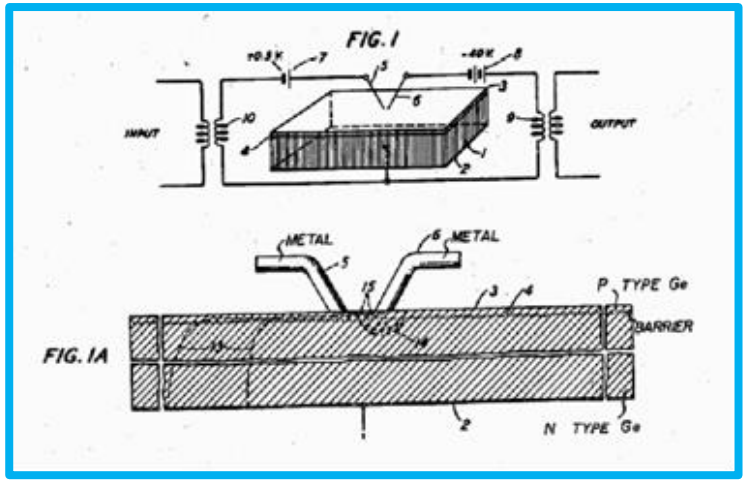
On 17 June, 1946 AT&T and Southwestern Bell introduced the first American commercial mobile radio- telephone service to private customers in Saint Louis, Missouri.

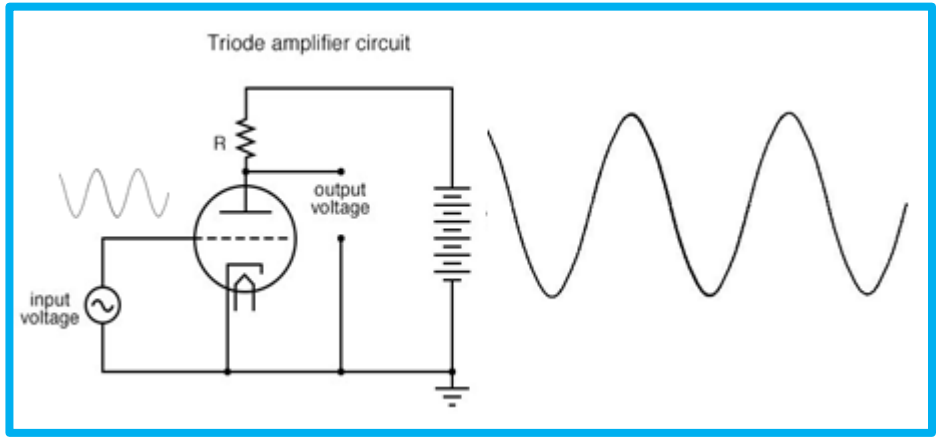
The system operated on six channels in the 150 MHz band with 60 kHz channel spacing. **The centrally located antenna operated at 250 watts and 40 kg mobile stations in a car at 20 watts.** The mobile stations did not transmit back to the central tower but to one of five receivers placed across the city.

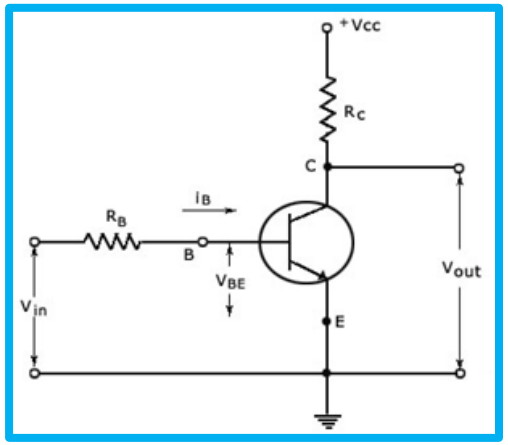
1948 Transistor demonstrated

The three scientists from Bell labs, **J. Bardeen, W. Brittain and W. Schockley** who invented the transistor 1948 were jointly awarded the Nobel Prize in physics in 1956

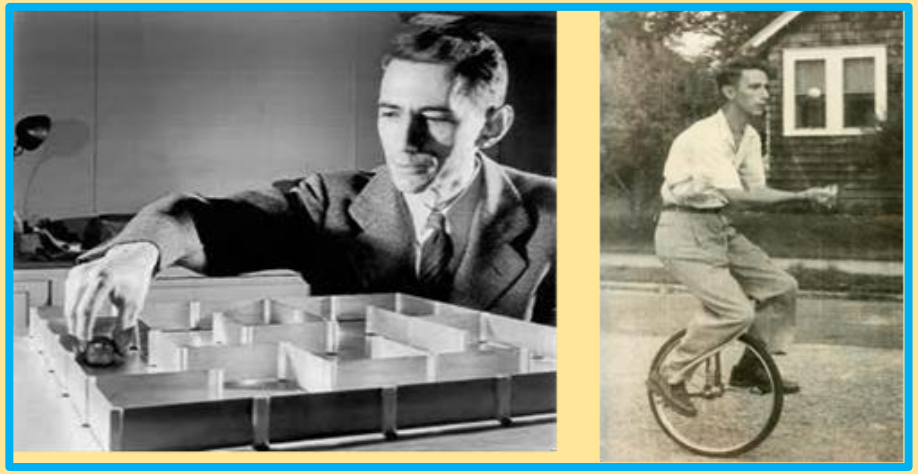


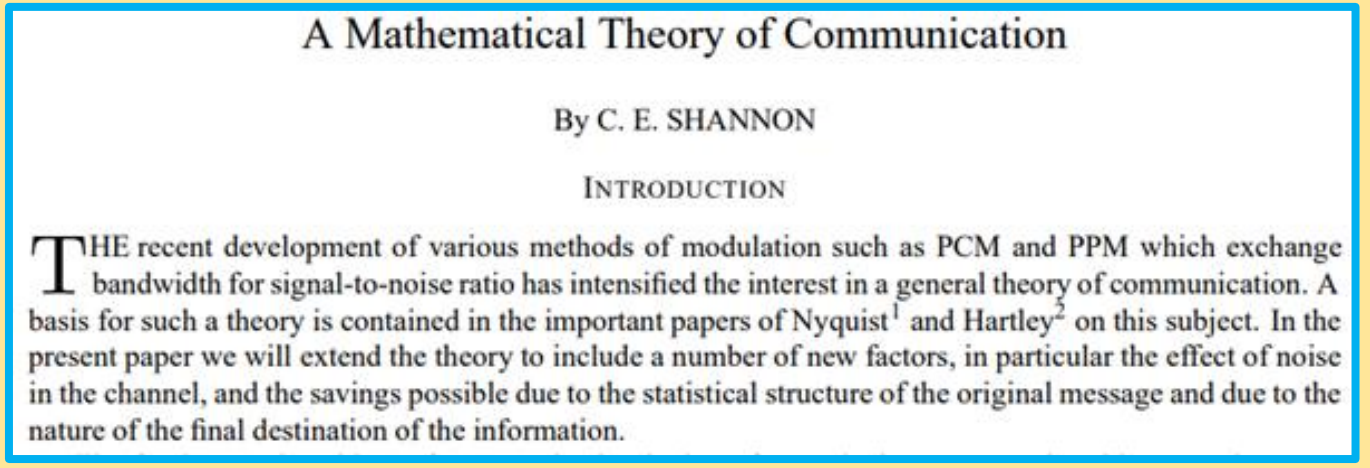






1948 Shannon publishes his Theory of Communication





A Mathematical Theory of Communication

By C. E. SHANNON

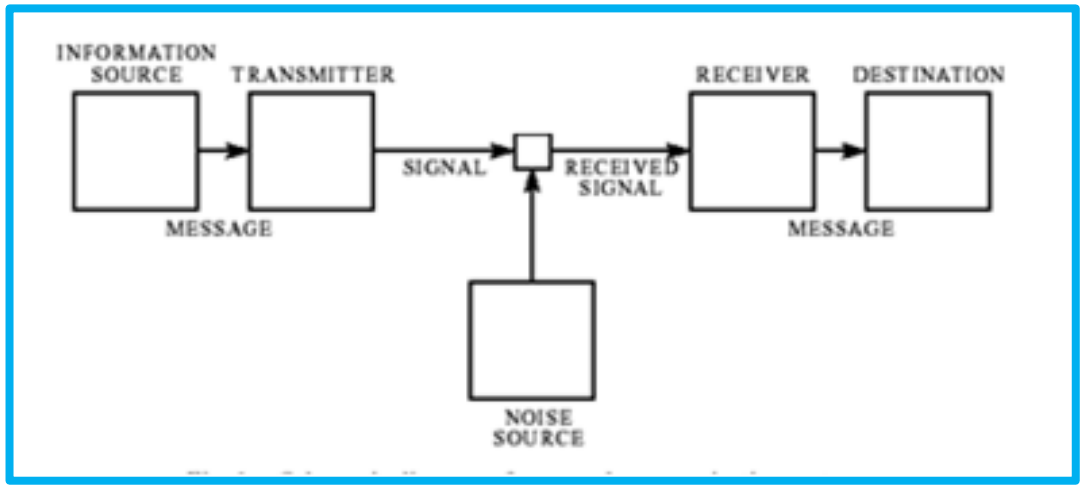
INTRODUCTION

THE recent development of various methods of modulation such as PCM and PPM which exchange bandwidth for signal-to-noise ratio has intensified the interest in a general theory of communication. A basis for such a theory is contained in the important papers of Nyquist[1] and Hartley[2] on this subject. In the present paper we will extend the theory to include a number of new factors, in particular the effect of noise in the channel, and the savings possible due to the statistical structure of the original message and due to the nature of the final destination of the information.

Claude Shannon (1916-2001). American mathematician and electrical engineer who laid the theoretical foundations for digital circuits and information theory.

- In 1940 he earned a master's degree in electrical engineering with a thesis on 'A symbolic Analysis of Relay and Switching Circuits' where he used **Boolean algebra** for theoretical analysis of digital circuits.
- His major work is a paper entitled '**A Mathematical Theory of Communication**' which he published in 1948. In this work he laid the **foundations of Information Theory**. Even the omnipresent name, **bit, for a single binary digit**, was introduced in this paper.

Shannon separated the technical problem of delivering a message from the problem of understanding its meaning. This separation allows the communication engineers to concentrate on the problems of message delivery.



The paper includes the famous formula for the capacity of a communication channel in the presence of noise

$$C = W \log_2 (1+S/N)$$

Shannon's approach was abstract and general and was applicable to both digital and analogue systems. That one person in one scientific paper created a new scientific discipline is unique in the history of science.

1950 – 1965 The era of diversification

1956 First transatlantic telephone cable
1957 The first satellite
1958 Invention of the Laser
1958 First Integrated circuits demonstrated by Jack Kilby
1960 Error-correcting codes begin rapid development
1961 The first communication experiment with passive satellites
1961 Leonard Kleinrock invents packet-switching technology.
1965 Moore’s law presented

1956 First transatlantic telephone cable

The first transatlantic telephone cable (TAT-1) was completed and opened for service. The 7242 km cable provided 36 high-quality telephone circuits **from London to New York and Montreal**.

Name	In service	Type	Initial channels	Final channels	Western end	Eastern end
TAT-1	1956–1978	Galvanic	36	51	Newfoundland	Scotland
TAT-2	1959–1982	Galvanic	48	72	Newfoundland	France
TAT-3	1963–1986	Galvanic	138	276	New Jersey	England
TAT-4	1965–1987	Galvanic	138	345	New Jersey	France
TAT-5	1970–1993	Galvanic	845	2,112	Rhode Island	Spain
TAT-6	1976–1994	Galvanic	4,000	10,000	Rhode Island	France
TAT-7	1978–1994	Galvanic	4,000	10,500	New Jersey	England
TAT-8	1988–2002	Fiber-optic	40,000	–	New Jersey	England, France

1957 The first satellite

On 4 October 1957 Sputnik, the first artificial satellite, was launched into space by the USSR. Weighing just **84 kg**, it proved heavy enough to ignite a race for space domination between the two Cold War enemies, USA and USSR. Sputnik orbited the earth **16 times every 24 hours** and broadcasted radio signals (beeps) to earth on **20.005 and 40.002 MHz** during three weeks. The transmitter power was **1 Watt**.

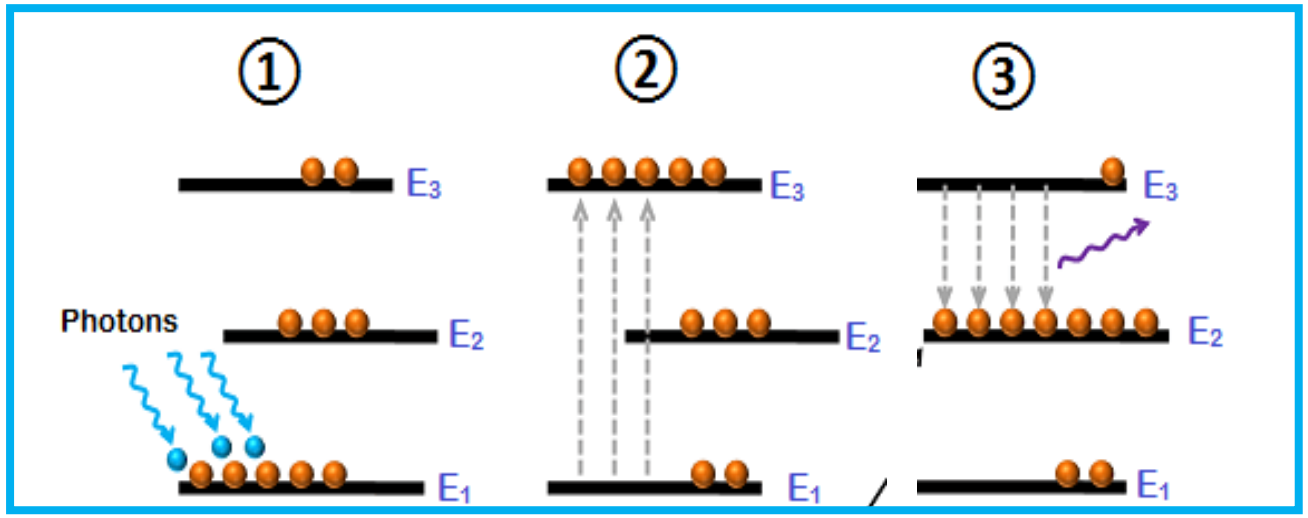
The New York Times.

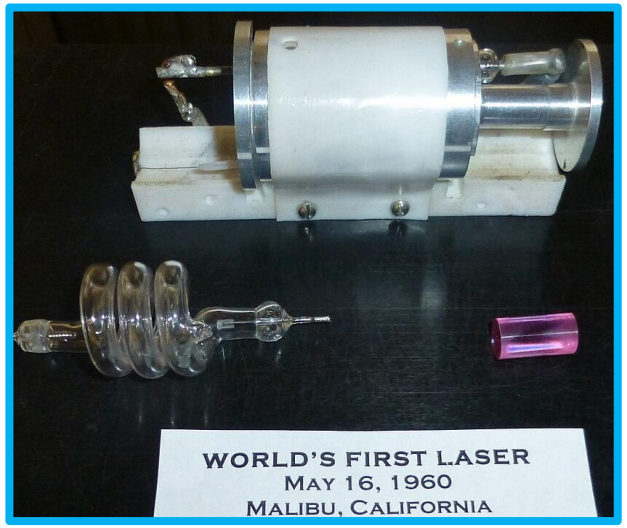
SOVIET FIRES EARTH SATELLITE INTO SPACE;
IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.;
SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

1958 Invention of the laser

Invention of he laser, which stands for **Light Amplification by Simulated Emission of Radiation**, can be dated to 1958 with the publication of a paper in Physical Review, “Infrared and Optical Masers”, by A.L. Schawlow and **Ch. H.Townes** (who got the Nobel price 1964) at Bell Labs.

In the paper they proposed that the principles of the maser could be extended to the optical regions of the spectrum. Two years later a working laser was built by Hughes Aircraft Company.



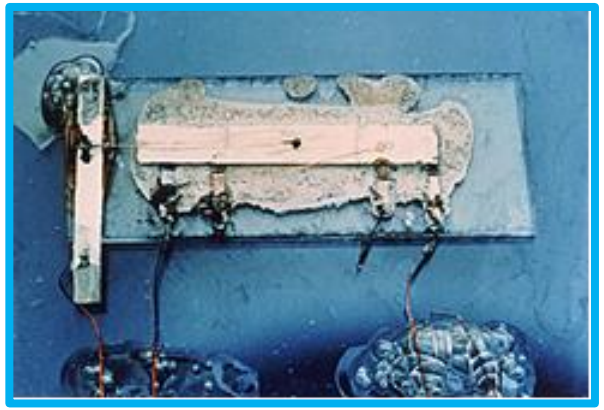


Today's worldwide optical-fiber network, necessary for Internet is powered by a laser.

1958 First Integrated circuits demonstrated by Jack Kilby

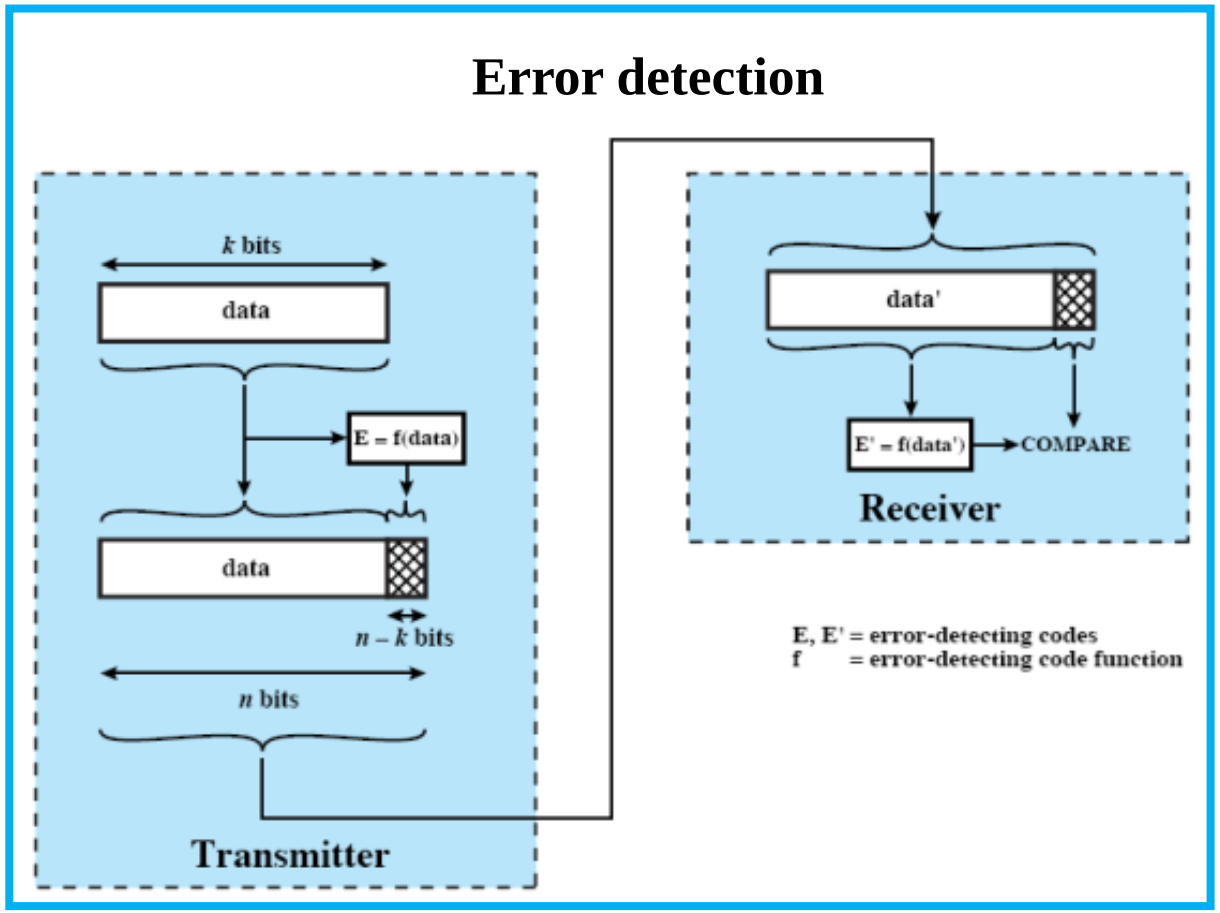
Press release on the Nobel Prize in Physics 2000:

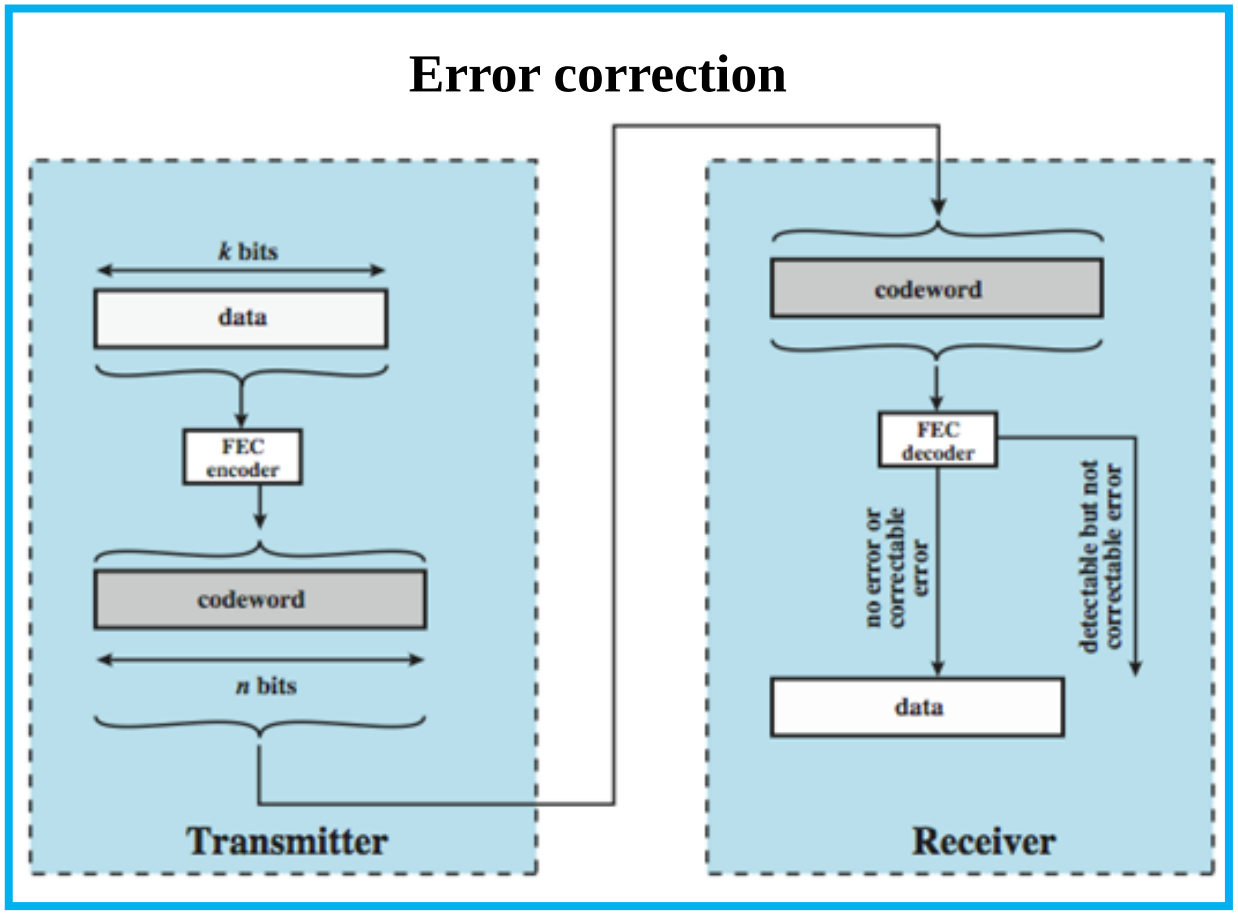
The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2000 to **Jack S. Kilby**, Texas Instruments, Dallas, USA "for his part in the **invention of the integrated circuit**"



Two simple but fundamental requirements are put on a modern information system for it to be practically useful. It must be **fast**, so that large volumes of information can be transferred in a short time. The user's apparatus must be **small** so that there is room for it in offices, homes or pockets.

1960 Error-correcting codes begin rapid development





1961 The first communication experiment with passive satellites

On 28 January, the US Navy made a successful experiment using the moon as a reflector for messages sent from Pearl Harbour to Washington.

The first communication satellite to be put in orbit was Echo 1 on 12 August 1961. It was a gigantic Mylar **polyester balloon, 30.5 m in diameter**, covered with a special aluminum coating designed to **reflect** the communication signals transmitted at **960 MHz and 2390 MHz.** In a series of tests, the satellite was used to redirect transcontinental and intercontinental **telephone, radio, and television signals**. The success of Echo 1 paved the way for future communications satellites.

1961 Leonard Kleinrock invents packet-switching technology

Leonard Kleinrock at MIT published the first paper on packet-switching theory: "**Information Flow Communication in Large Communication Nets**". It become theoretical basis for internet.

Information Flow in Large Communication Nets

Proposal for a Ph.D. Thesis

Leonard Kleinrock

I. Statement of the Problem:

The purpose of this thesis is to investigate the problems associated with information flow in large communication nets. These problems appear to have wide application, and yet, little serious research has been conducted in this field. The nets under consideration consist of nodes, connected to each other by links. The nodes receive, sort, store, and transmit messages that enter and leave via the links. The links consist of one-way channels, with fixed capacities. Among the typical systems which fit this description are the Post Office System, telegraph systems, and satellite communication systems.

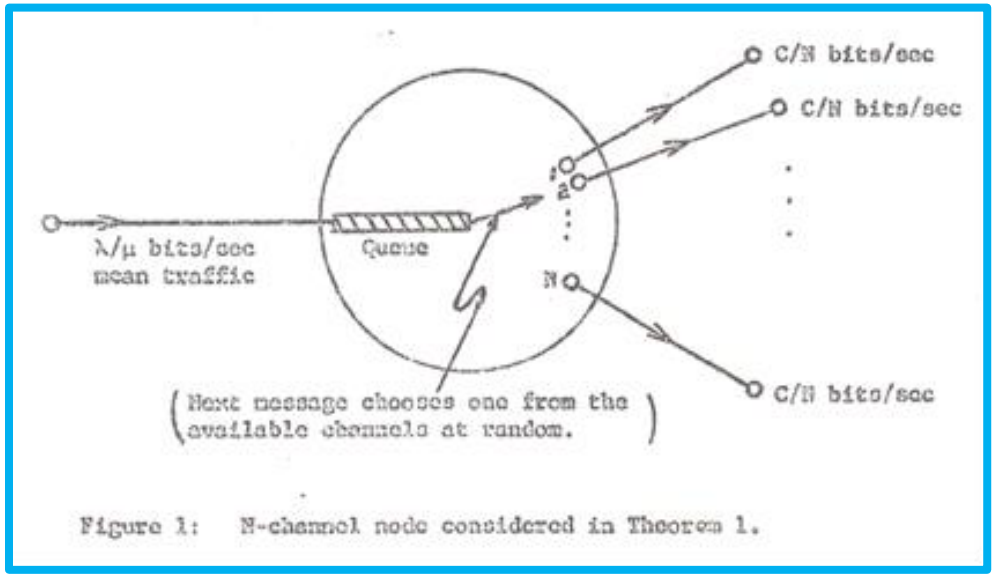
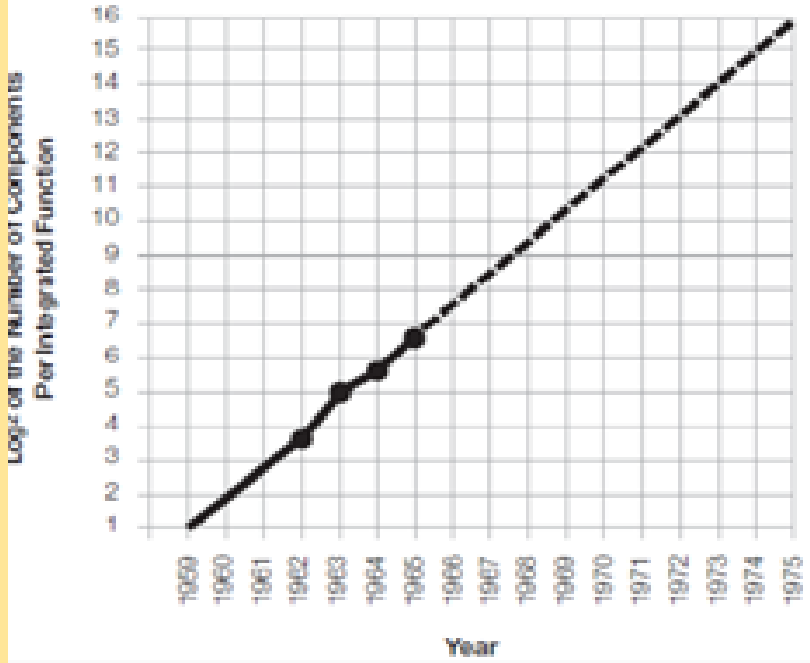


Figure 1: N-channel node considered in Theorem 1.

1965 Moore’s law presented

Progress in information technology is due to the access to constantly increasing computing power (which is the consequence of Moore’s law.)

Moore's law is the observation that the number of transistors in an integrated circuit (chip) doubles about every two years (*Smaller, faster transistors, less energy*)



Quote:

The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years.

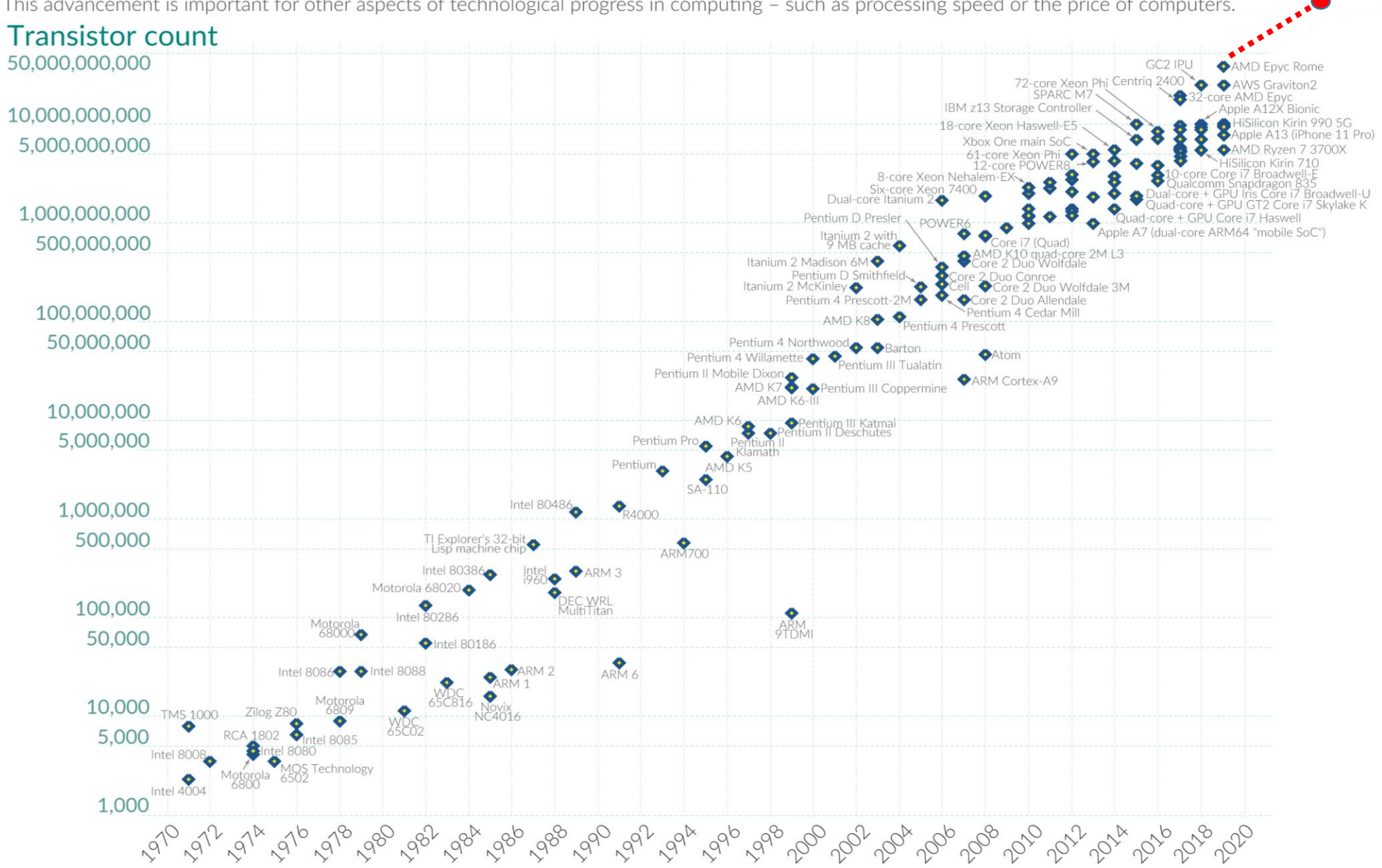
Cramming more components onto integrated circuits (Gordon E. Moore, Electronics; 1965)

Gordon Earle Moore is co-founder of Intel Corporation. As of March 2021, Moore's net worth is reported to be $12.6 billion.

Moore's Law: The number of transistors on microchips doubles every two years

2024 NVIDIA Blackwell GPU chip
208 000 000 000 transistors

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.



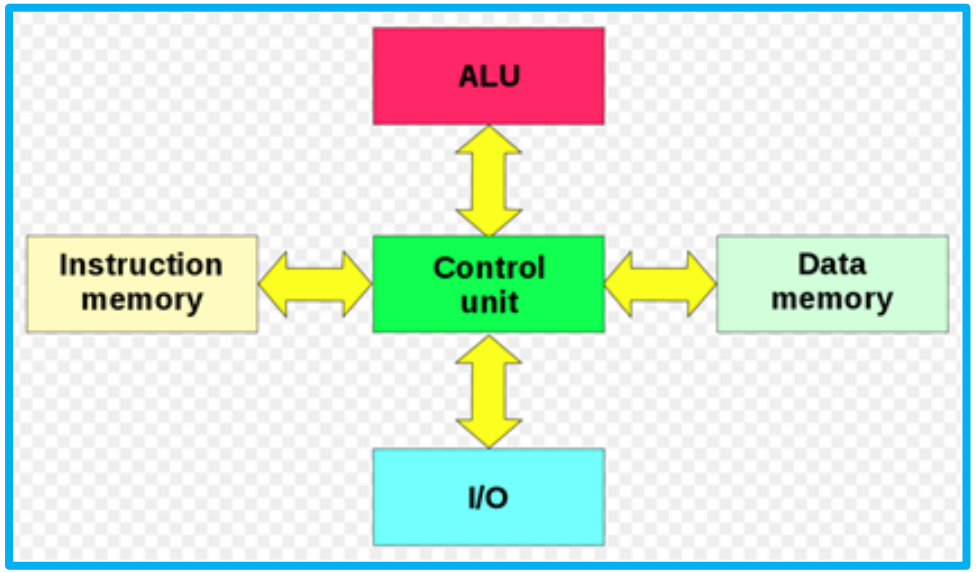
wikipedia.org

1965-1975 The rise of the Internet

1965 The first commercial electronic exchange
1968 DOD initiates the ARPANET development
1970 Low-loss optical fibers demonstrated
1971 The first microprocessor
1974 TCP/IP invented

1965 The first commercial electronic exchange

The electronic exchange 1ESS (Electronic Switching System) from ATT introduced the principle of stored-program control.



System was controlled by Harvard architecture central processor. 200 kHz clock.

1969 US DoD initiates the ARPANET development

A prototype network linking four computers at universities in California and Utah was specified. (University of California Los Angeles (UCLA), University of California Santa Barbabra (UCSB), University of Utah, Stanford Research Institute (SRI)). Data were to be carried by a new revolutionary technique called **packet-switching**. The network became operational in 1969. Despite frequent crashes, the network proved that packet-switching worked. In 1971 the network linked 23 computers. ARPANET, forerunner to the Internet, became international in 1973 when it was linked to University College in London.

1970 Low-loss optical fibres demonstrated

The design principles of an **optical fiber cable for communication using laser light** were published in 1966 by Standard Telecom Labs in UK.

In 1970, Robert Maurer led a team at US Company Corning Glass which produced the first optical fiber with acceptable attenuation (less than **1 dB/km**).

The first field trial of an optical fiber telephone system was carried out by Western Electric and Bell Labs in 1975. The cable carried 144 optical fibers with a capacity of 100 000 telephone circuits.

1971 The first microprocessor

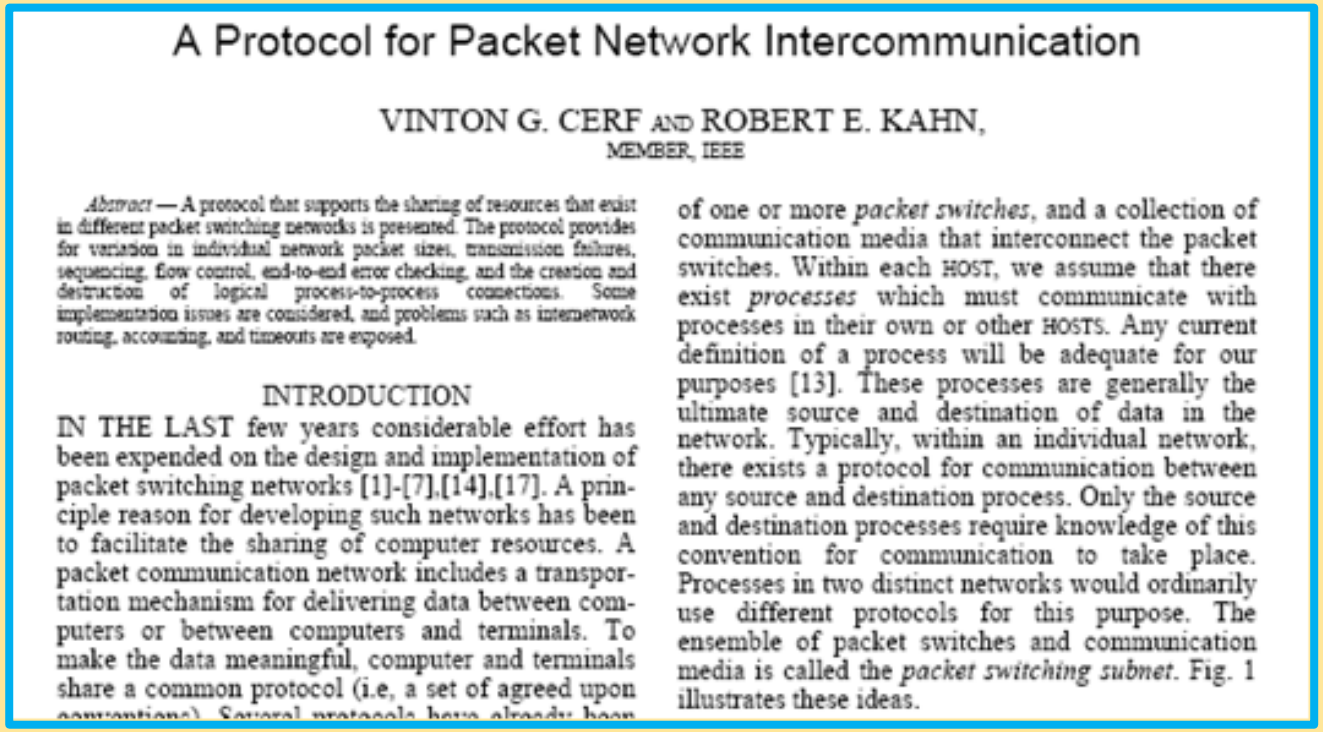
Intel introduced its popular 4004 4-bit microprocessor, starting the evolution of Intel's famous line of 8080, 386, 486, and Pentium processors.

The Intel 4004 microprocessor was originally designed as a cost-reduction chip for the Japanese calculator company, Busicom. Though it consisted of only **2,300 transistors** (10 microns, MOS technology), this was the first chip to combine all the main elements of the large mainframe onto a single piece of silicon.
The 4004 ran at a clock speed of **750kHz**, computed at 0.06 MIPS and had an addressing capacity of 4 kilobytes. It had about as much power as one of the first real computers, the ENIAC, which occupied 3,000 cubic feet of space and contained 18,000 tubes.

The Pioneer 10 spacecraft that was launched on 2 March 1972, the first spacecraft to enter the Asteroid Belt, used the 4004 microprocessor.

1974 TCP/IP invented

Transmission Control Protocol/Internet Protocol (TCP/IP) was created by **Vint Cerf** (1943 -) and **Robert Kahn** (1938 -) and published as " **A Protocol for Packet Network Interconne**ction", IEEE Trans. Comm. Tech., May 1974. The revolutionary idea was to enclose the messages in electronic envelopes forming a "packet" – the responsibility of TCP. A system of gateways linking the different networks routes each packet to its destination – the responsibility of IP.



A Protocol for Packet Network Intercommunication

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Abstract — A protocol that supports the sharing of resources that exist in different packet switching networks is presented. The protocol provides for variation in individual network packet sizes, transmission failures, sequencing, flow control, end-to-end error checking, and the creation and destruction of logical process-to-process connections. Some implementation issues are considered, and problems such as internetwork routing, accounting, and timeouts are exposed.

INTRODUCTION

IN THE LAST few years considerable effort has been expended on the design and implementation of packet switching networks [1]-[7],[14],[17]. A principle reason for developing such networks has been to facilitate the sharing of computer resources. A packet communication network includes a transportation mechanism for delivering data between computers or between computers and terminals. To make the data meaningful, computer and terminals share a common protocol (i.e, a set of agreed upon conventions). Several protocols have already been

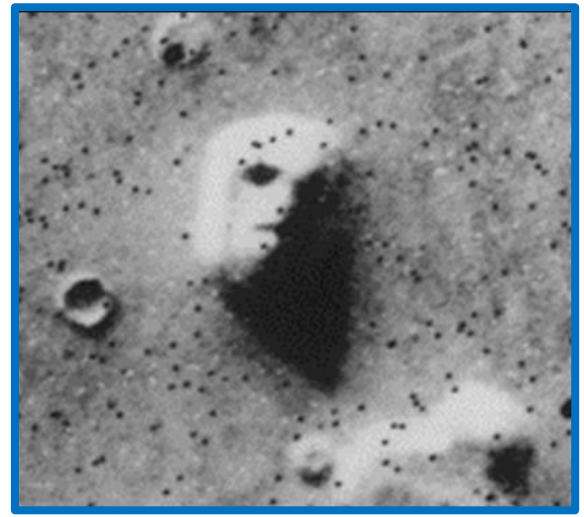
of one or more *packet switches*, and a collection of communication media that interconnect the packet switches. Within each HOST, we assume that there exist *processes* which must communicate with processes in their own or other HOSTS. Any current definition of a process will be adequate for our purposes [13]. These processes are generally the ultimate source and destination of data in the network. Typically, within an individual network, there exists a protocol for communication between any source and destination process. Only the source and destination processes require knowledge of this convention for communication to take place. Processes in two distinct networks would ordinarily use different protocols for this purpose. The ensemble of packet switches and communication media is called the *packet switching subnet*. Fig. 1 illustrates these ideas.

1975+ The era of ubiquitous mobile communication

1976 Viking 1 lands on Mars and sends digital pictures to Earth.
1980s Digital communication takes over analog communication
1980s Deployment of analog cellular systems worldwide
1989 World Wide Web invented
1992 First digital mobile telephone system, GSM begins in Europe
1998 Bluetooth Special Interest Group founded

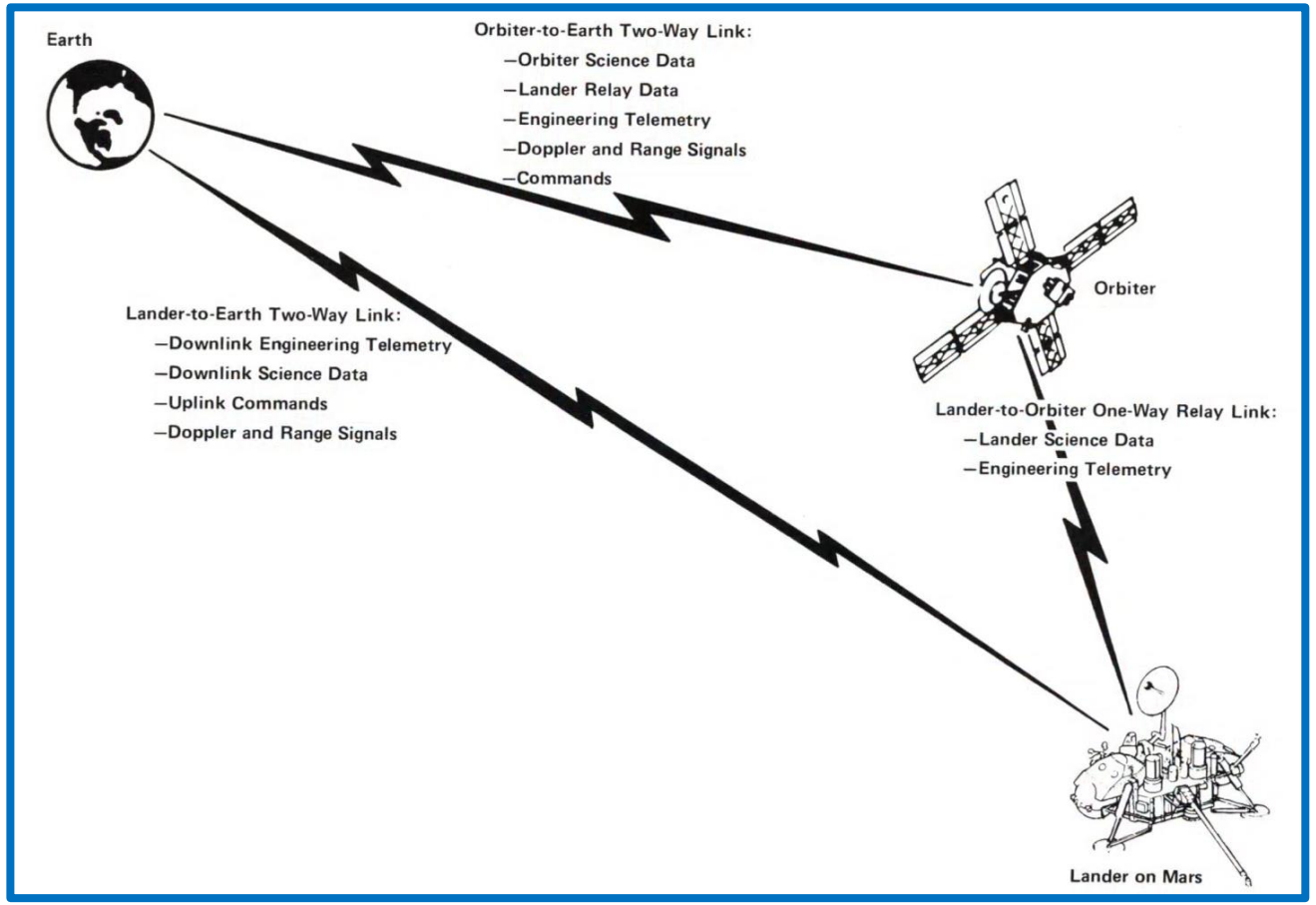
1976 Viking 1 lands on Mars and sends digital pictures to Earth

Viking 1, consisting of an orbiter and a lander, was launched from Cape Canaveral, Florida on 20 August, 1975. The probe went into Mars orbit on 19 June, 1976, and the lander set down on 20 July, 1976. It performed a programmed search for Martian microorganisms and sent back incredible color panoramas of its surroundings.



On 31 July 1976, a NASA press release said the formation "resembles a human head." However, NASA scientists had already correctly interpreted the image as an optical illusion caused by the illumination angle of the Sun, the formation's surface morphology and the resulting shadows, giving the impression of eyes, nose and mouth.

The lander had two means of returning data to Earth: **a relay link up to the orbiter and back, and by using a direct link to Earth**. The orbiter could transmit to Earth (S-band, 2-4 GHz, 15-7,5 cm) at 2,000 to 16,000 bit/s (depending on distance between Mars and Earth), and the lander could transmit to the orbiter at 16,000 bit/s. The data capacity of the relay link was about 10 times higher than the direct link.



1980s Digital communication takes over analog communication

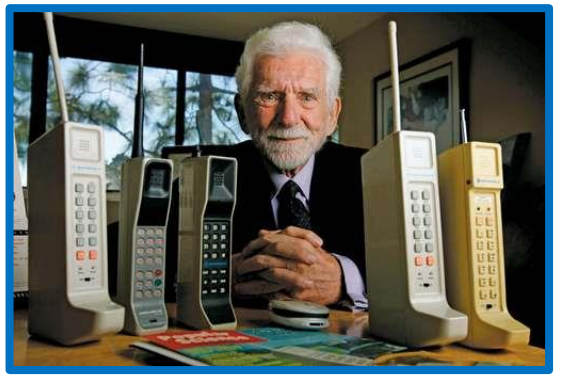
Advantages of Digital Communication compared to Analog Communication

- The viability of regenerative repeaters. At each repeater station the pulses are detected and new clean pulses are transmitted to the next repeater station.
- Digital hardware implementation is flexible and permits the use of VLSI circuits and computers.
- Digital signals can be coded to yield extremely low error rates and high fidelity as well as privacy.
- It is easier and more efficient to multiplex several digital signals than analog signals.
- Digital signal storage is relatively easy and inexpensive.
- Reproduction with digital messages is extremely reliable without deterioration.

1980 – 1990 Deployment of analog cellular systems worldwide

1981 - Nordic Mobile Telephone (NMT)

One of the earliest commercial cellular radio systems developed jointly by organizations in Nordic countries. It comes in two variants – NMT450 the original specification operating in the **450 MHz** band and **particularly suited to covering wide areas (15 watt effect)** with low usage densities – and **NMT900** introduced in the late 1980s and designed to support handheld portable devices in urban environments.

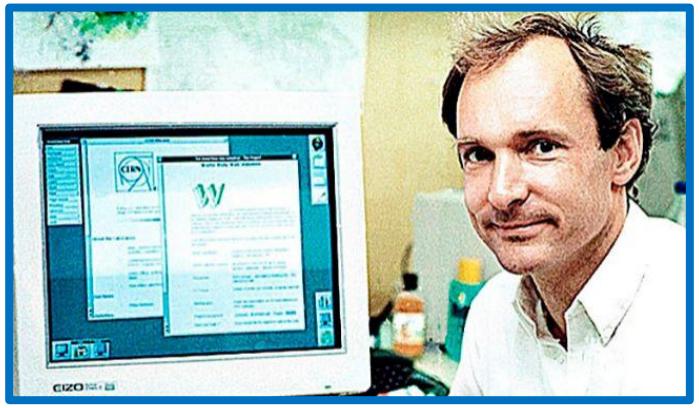


1982 - Advanced Mobile Phone Systems (AMPS)

The first-generation cellular radio standard developed in the USA. An analogue system at **800 MHz** using different frequency carriers to create communication channels in a technique **FDMA**. (Frequency Division Multiple Access). The spectrum is divided into **30 kHz channels**.

1989 World Wide Web invented

Tim Berners-Lee invented the World Wide Web in the late 1980s while working at CERN, in Geneva. He wrote the first WWW client and the first WWW server along with most of the communications software, defining URLs, HTTP and HTML



W3C
World Wide Web Consortium

In 1994 Berners-Lee established the **World Wide Web Consortium** (W3C), with himself as chairman, to prevent WWW from disintegrating into a number of proprietary and conflicting systems. W3C develops standards and guidelines to help everyone build a web based on the principles of accessibility, internationalization, privacy and security.

1992 The first digital mobile telephone system, GSM, in Europe

The GSM is the European contributions to evolution of wireless telephony. GSM was designed in standardization committees by the major European telecommunications operators and manufacturers.

GSM milestones

1982 **Groupe Spécial Mobile** created within CEPT. The original French name was later changed to Global System for Mobile Communications. The first two years of the GSM were dedicated to discussions of the fundamental principles

1982 The basic requirements for GSM, grouped into five areas, were stated in 1982 and revised in 1985

- Services
- Quality of service and security
- Radio frequency utilization
- Network aspects
- Cost aspects

1984 Four working parties were created.

WP1 - for the definition of services.

WP2 - for the specification of radio transmissions (this subject stayed dominant until 1987)

WP3 - for all other issues, network architecture, specification of the signalling protocols, and of the open interfaces between network entities.

WP4 - dealing with implementation of data services.

1985 A detailed list of Recommendations was decided and work was centered on drafting them. The Recommendations were sorted into 13 series.
In 1991 the list included more than 130 Recommendations with a total of over 5000 pages.
The Recommendations cover

- the full specification of radio interface between the mobile stations and the infrastructure
- the interfaces and signaling protocols between network entities.

1987 Main radio transmission techniques are chosen based on prototype evaluation in 1986. **TDMA** is chosen as access method.

1987 GSM Memorandum of Understanding is signed in Copenhagen, with GSM launch date of 1 July
This memorandum covers areas such as compatibility of numbering and routing plans, service introduction, definition of tariff principles and accounting procedures.

1989 GSM becomes an ETSI technical committee, the main advantage being the inclusion of members from industry and user groups as well as operators.

1990 The phase 1 GSM900 specifications are frozen.

1991 First GSM systems demonstrated at Telecom 91 exhibition

1992 Commercial operations in Europe. The first GSM operator is Radiolinja OY in Finland.

1999 Over 400 GSM networks operational in Europe, America, Asia, Africa and Australia

Basic requirements for GSM

(original text as published by the committee in 1985)

Services

- The system shall be designed such that mobile stations can be used in all participating countries.
- In addition to telephone traffic, the system must allow maximum flexibility for other types of services, e.g. ISDN related services.
- The services and facilities offered by PSTN/ISDN and other public networks should as far as possible be available in the mobile system. The system should also offer additional facilities taking into account the special nature of mobile communications.
- It should be possible for mobile stations belonging to the system to be used on board ships, as an extension to the land mobile service. Aeronautical use of GSM mobile stations should be prohibited.
- In addition to vehicle-mounted stations, the system shall be capable of providing for **handheld stations** and other categories of mobile stations.

1998 Bluetooth Special Interest Group founded

The history of Bluetooth starts back in 1994 when a couple of researchers at Ericsson, in Lund, had a vision of a **low-cost, low-power and small-size radio interface** between mobile phones and computers. The original modest goal was to **replace the cumbersome cables** used to connect these devices; the result after the subsequent development is a technology that changed the world. Bluetooth is named after Harald “Bluetooth” Gormsson, a Danish king in the 10th century who united warring tribes. The Bluetooth logo is based on the symbols he used for his initials.