The smart ones behind smart phones

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Indian Institute of Science Education and Research Pune, India

Exciting Science Outreach Group, June 2015

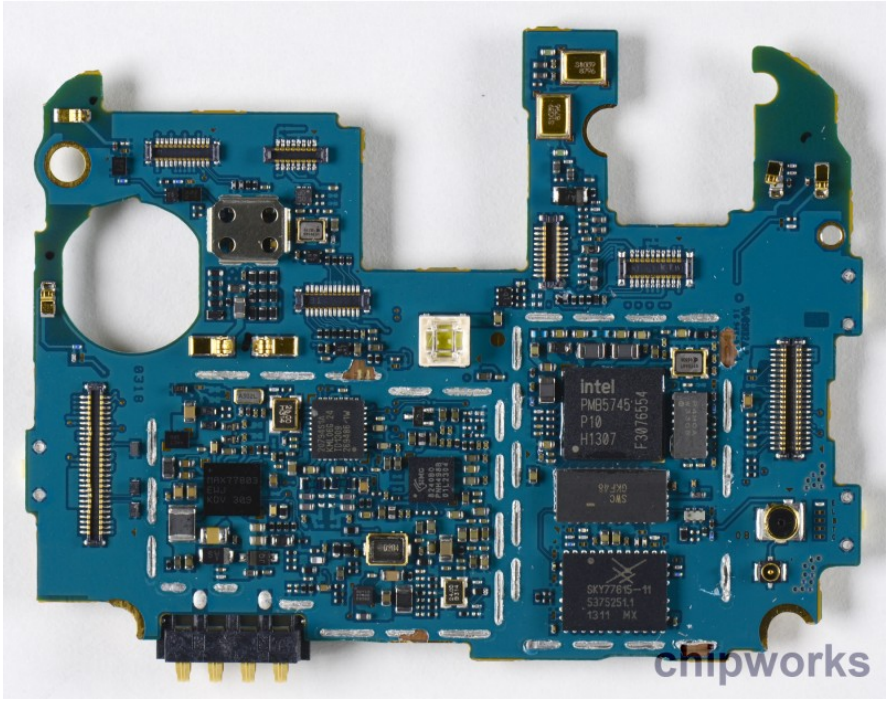
What is this talk (not) about?

*

- This talk is not about smart phones
- You will not learn how to use one
- You will not learn what it is capable of doing

** The images in these slides are taken from various internet sources*

What is this talk about?



- You might learn bits of what makes a smartphone work
- You might learn bits of what has gone into its making
- The talk is largely about the science behind the device

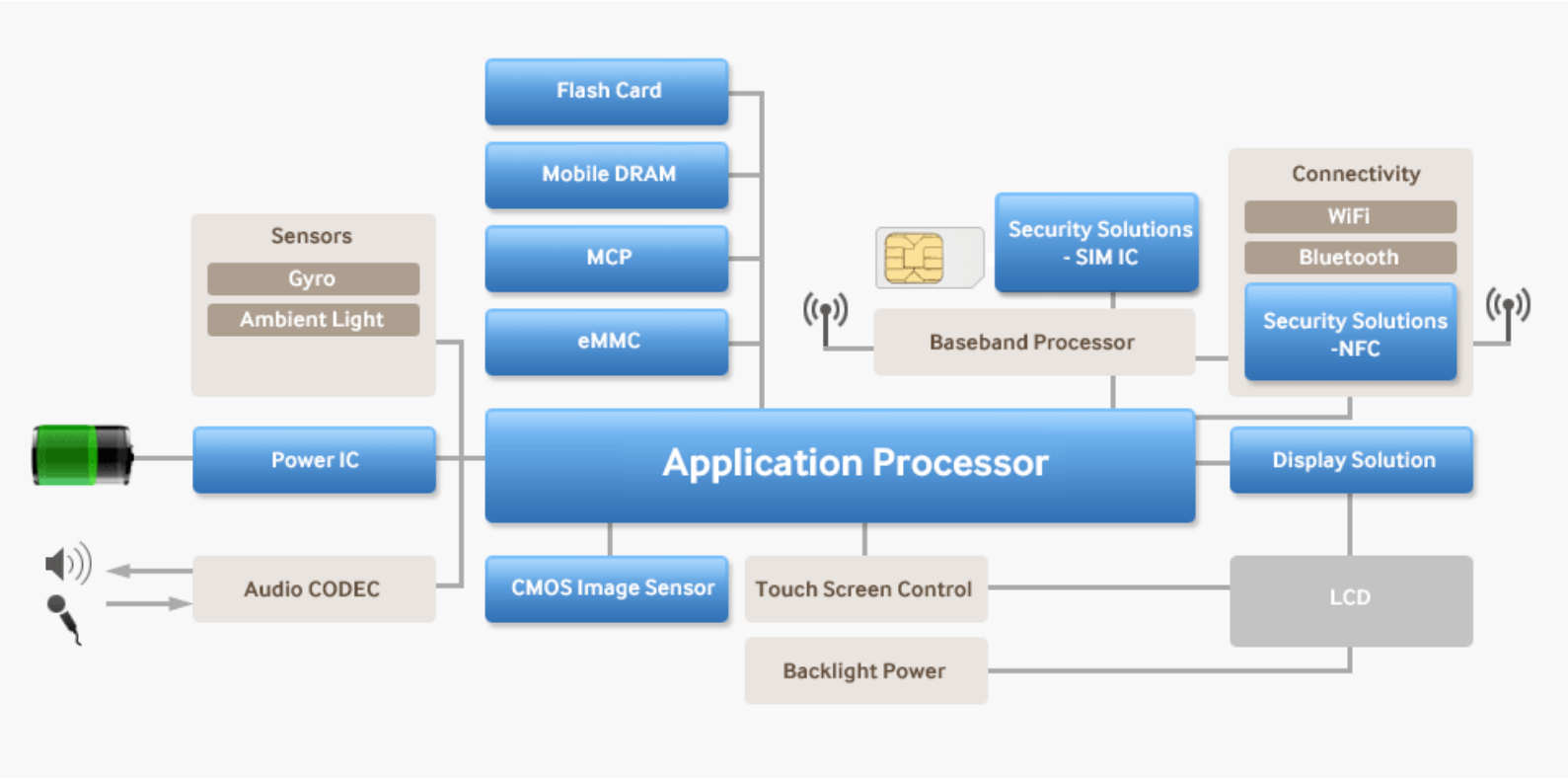
What is this talk about?

- All this is not as simple as I am trying to make it out
- Please don't carry the impression *"Oh, that's all there is to it!"*
- There's a lot, it's complex, and I don't understand much of it . . .
- I am not really qualified to talk about smart phones as I don't have one!

What is a smart phone capable of?

- making a phone call, sending and receiving text, pictures etc.
- recording voice, images, messages
- providing reminders, memos, alarms, alerts

What is there inside a smart phone?



- a transmitter, a receiver, a memory, a display controller, a master processor, battery, display, speaker, microphone, etc.
- each unit actually consists of several tiny electronic circuits, with many tracks and components

What is there inside a smart phone?

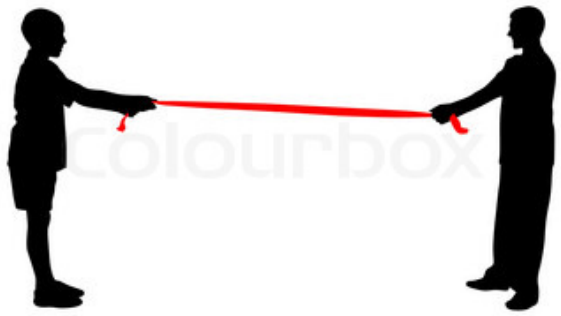
- But from a physics point of view it boils down to . . .
  - ability to send and receive electromagnetic signals
  - creating and manipulating electronic data

What is Communication?

- Sound and light are elements of human communication – we are adapted to voice, pictures, words, text – what we readily perceive with our senses
- We need to understand how human communication elements and a machine signal can be interlinked

Communication and Data : Example

- Imagine two persons holding a rope
- They agree to jerk the rope when they wish to communicate
- To make sense of the jerk, there has to be a pre-decided code



signal	meaning
jerk up-down	something
jerk left-right	something else

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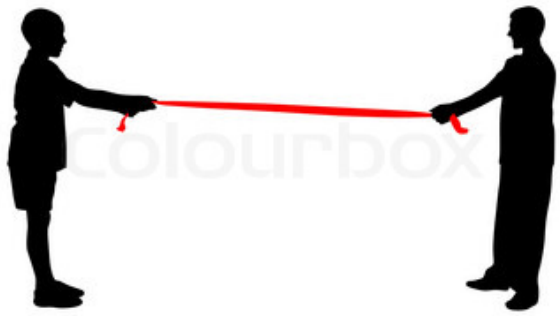

signal	meaning	value
jerk up-down	something	1
jerk left-right	something else	0

Binary Data

- An instance of 2-level (binary) code is called a bit
- Example with 3 bits

signal	meaning
0,0,0	Meaning 1
0,0,1	Meaning 2
0,1,0	Meaning 3
0,1,1	Meaning 4
1,0,0	Meaning 5
1,0,1	Meaning 6
1,1,0	Meaning 7
1,1,1	Meaning 8

n bits $\Rightarrow 2^n$ distinct codes

- The meaning is for us to decide . . .
  8 letters, 8 musical notes, 8 numbers, or 8 colours. . .

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Key Parameters for Communication

- But this is merely a toy . . .
- For meaningful communication we need much more . . .
- Better connection scheme
  - Long distance
  - Fast
  - Robust
- Much more information (data)
  - visual (text, images . . .)
  - audible (speech, sounds,. . .)

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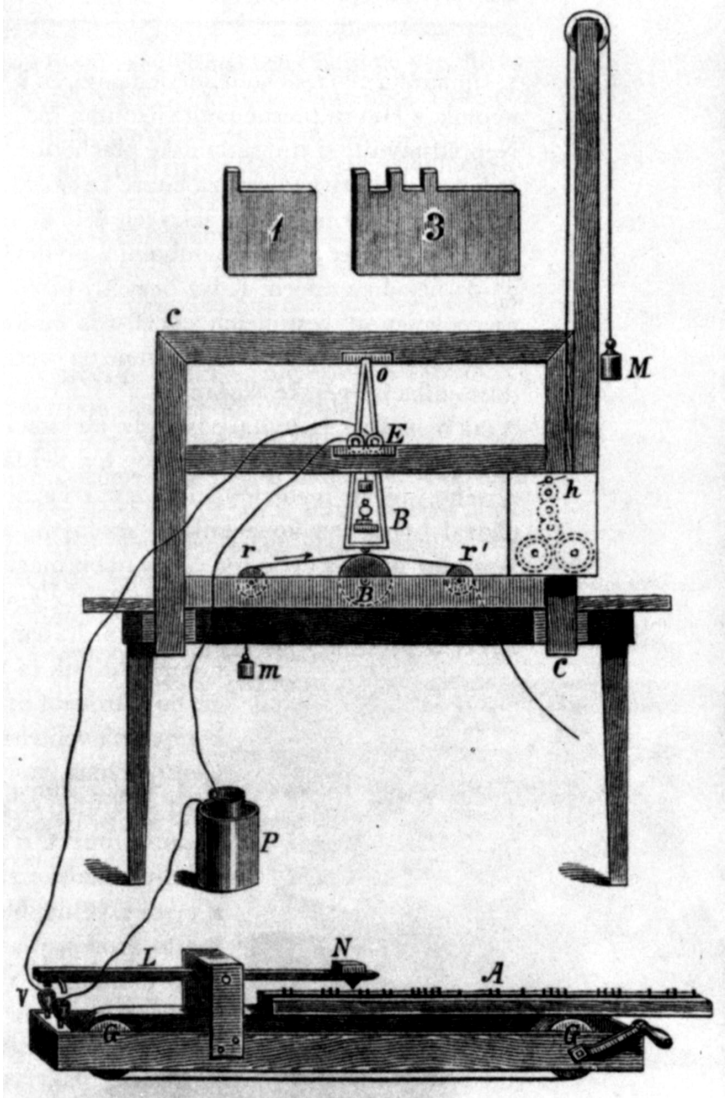
Electric Communication

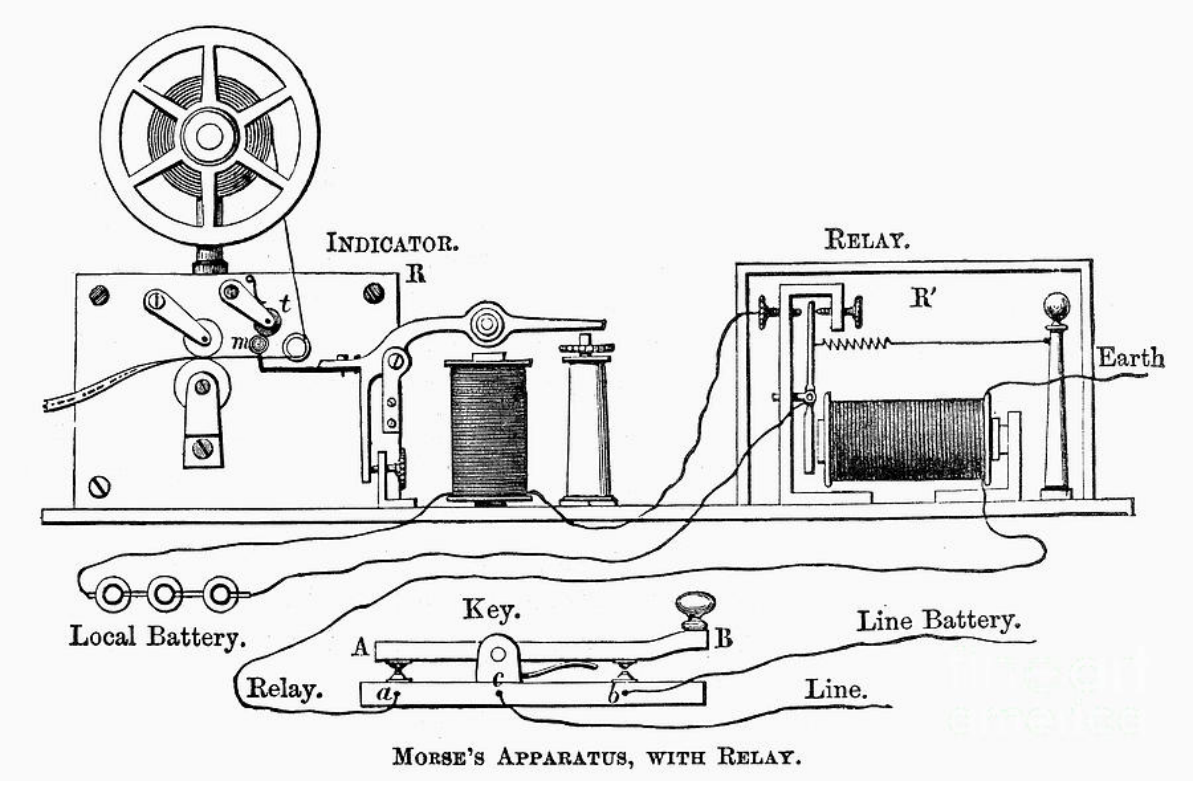
- 1830: Joseph Henry demonstrated electrical communication over a wire
- A current sent over a mile long wire activated an electromagnet causing a bell to strike



The Telegraph

- Samuel Morse and Alfred Vail, in 1838 invented the switch key
  - When depressed it completed an electric circuit and sent a signal
  - The receiver was an electromagnet, moving a marker on a paper

Switch closed short: mark = '·'
Switch closed long: mark = '—'



MORSE'S APPARATUS, WITH RELAY.

A simple 2-level code for the Telegraph

The Morse Code consists of $\leq$ 5 instances of a dash or a dot

A •–	J •–––	S •••	1 •————
B –•••	K –•–	T –	2 ••–––
C –•–•	L •–••	U ••–	3 •••––
D –••	M ––	V •••–	4 ••••–
E •	N –•	W •––	5 •••••
F ••–•	O –––	X –••–	6 –••••
G ––•	P •––•	Y –•––	7 ––•••
H ••••	Q ––•–	Z ––••	8 –––••
I ••	R •–•	0 –––––	9 ––––•

i do not understand morse code

••|–•••–––|–•–––––|••–––•–•••••–•–––•–••|–––––•–•••••|–•–•––––––•••

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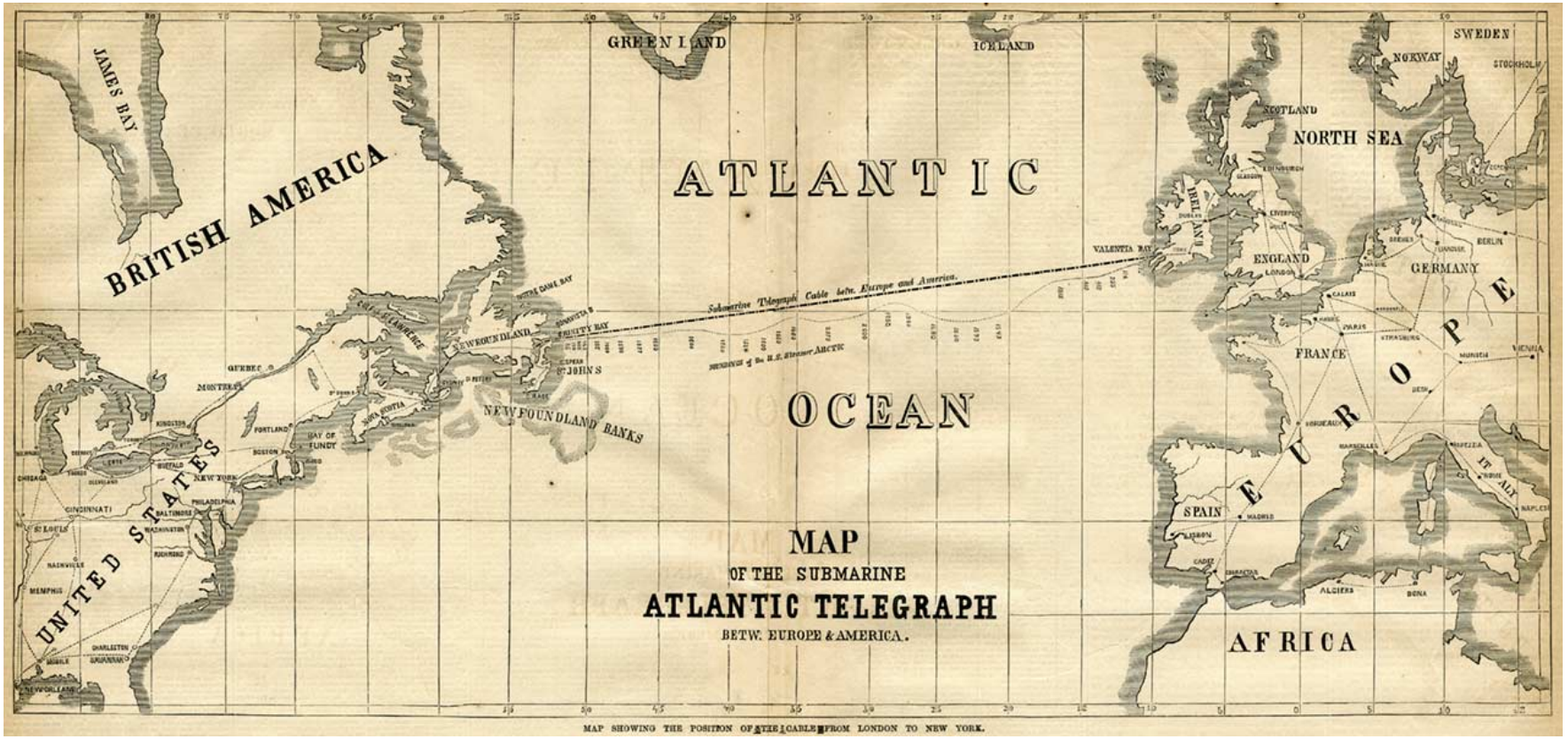
••|–••–––|–•––––|••–––•––••–••–•––•–••|––––––•–•••••|–•–•––––––…

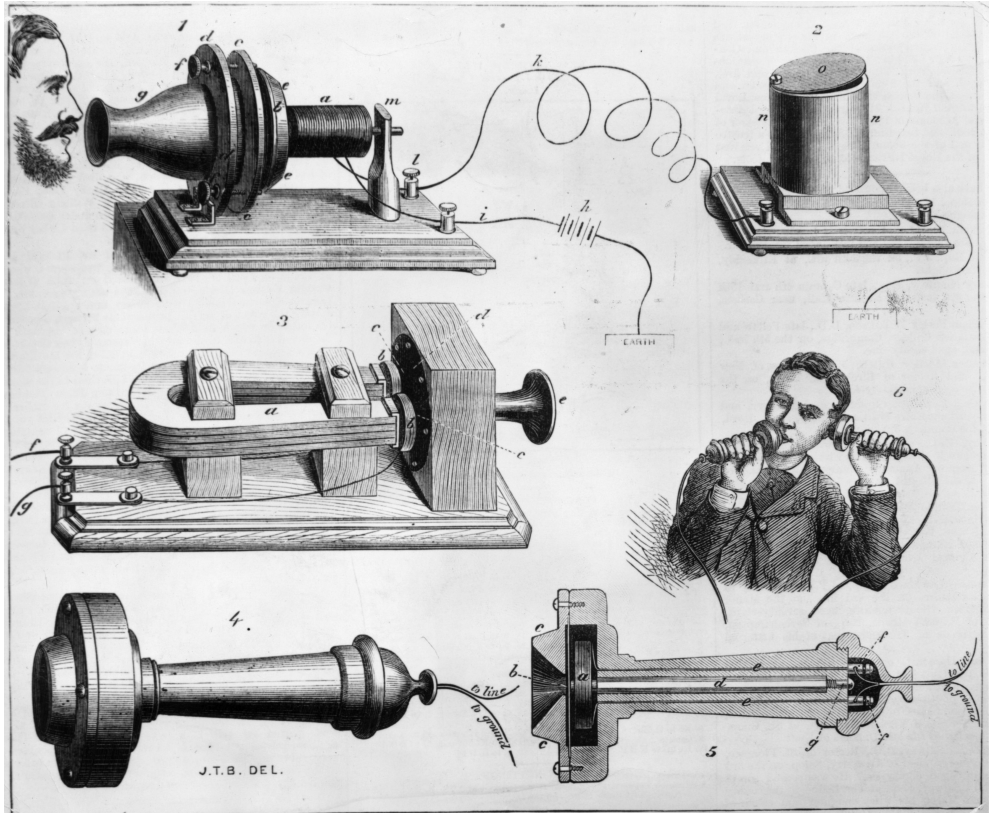
The Telegraph

1858–1866: Trans-atlantic cable was laid for telegraph communication between Britain and America



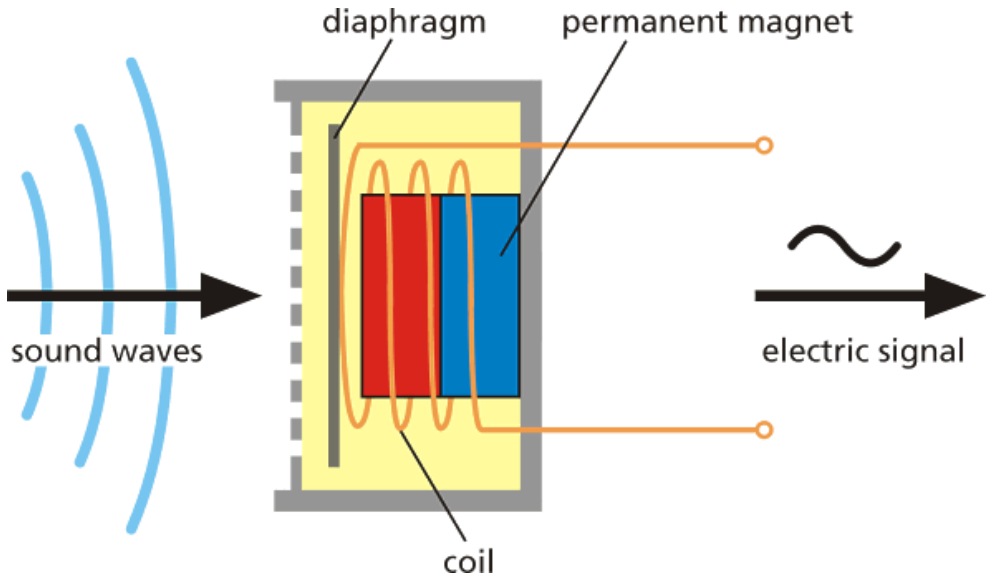
Converting Sound to Electrical Signals

- 1875–77: Bell developed an acoustic telegraph and Hughes, Berliner and Edison developed the microphone
- This was the precursor to the telephone



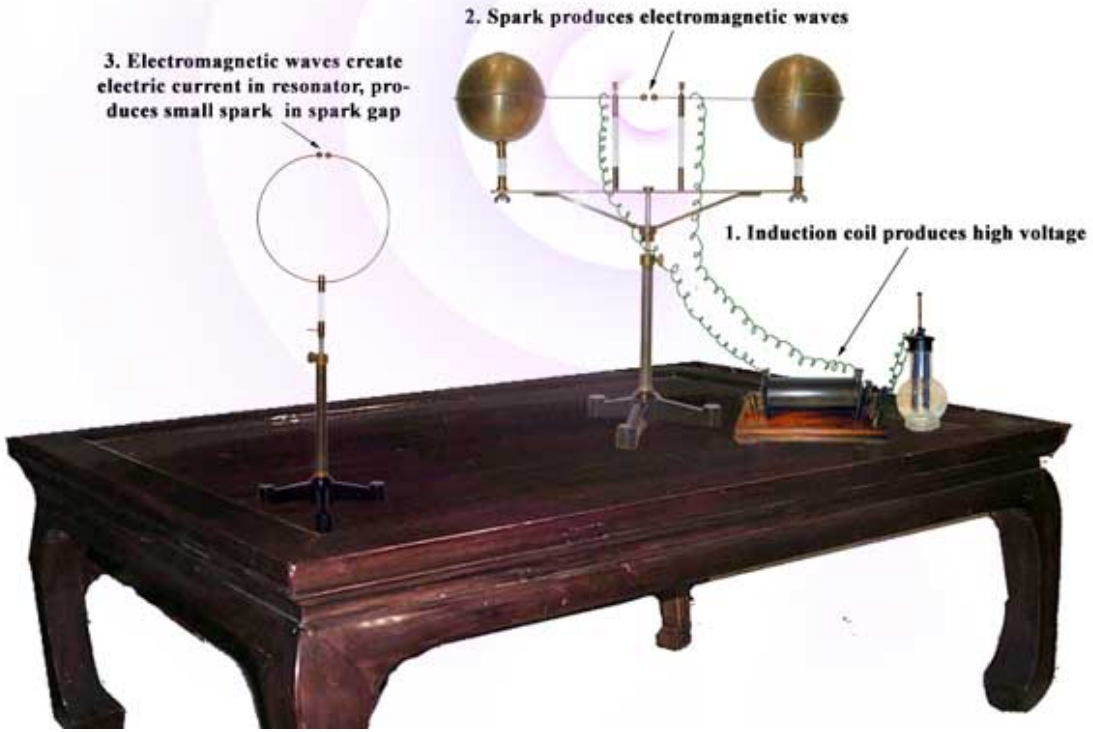
Converting Sound to Electrical Signals

- . . . but the physics behind this dates to 1831–32, when Faraday and Henry discovered electromagnetic induction



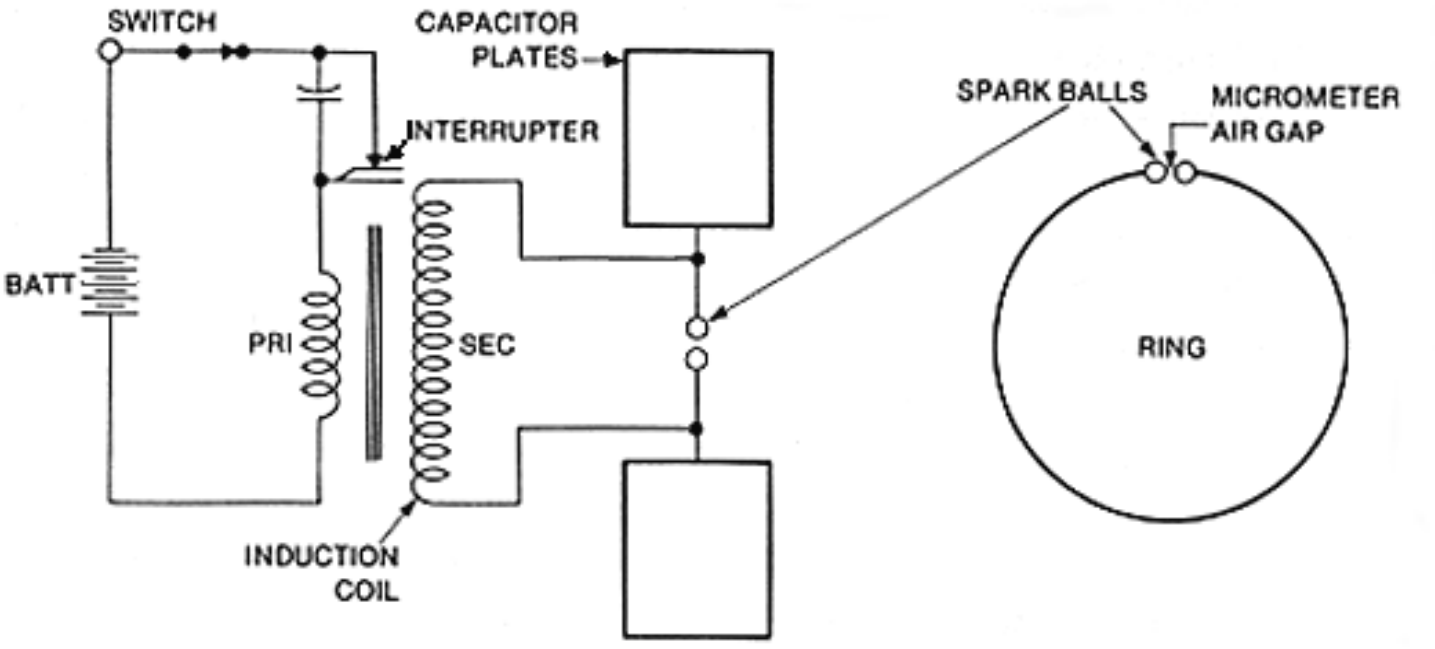
Wireless Communication

Demonstration of Electromagnetic Radiation



- Hertz in 1887 demonstrated the existence of electromagnetic waves (predicted by Maxwell in 1865)
- In 1888 he showed that they could travel without a medium at a finite speed over a distance
- These waves could be used for wireless communication

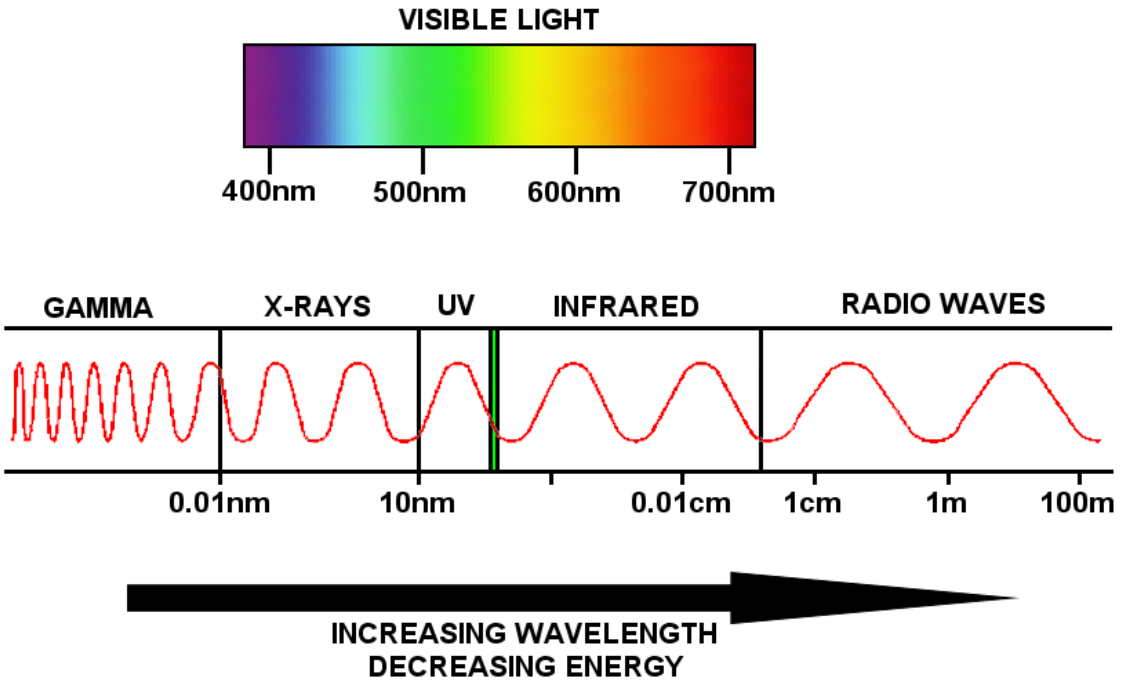
Demonstration of Electromagnetic Radiation



- The circuit on left generates a spark in the gap between the spheres
  - this causes a spark in the gap between the spheres of the receiver
  - even though the two are not in contact!

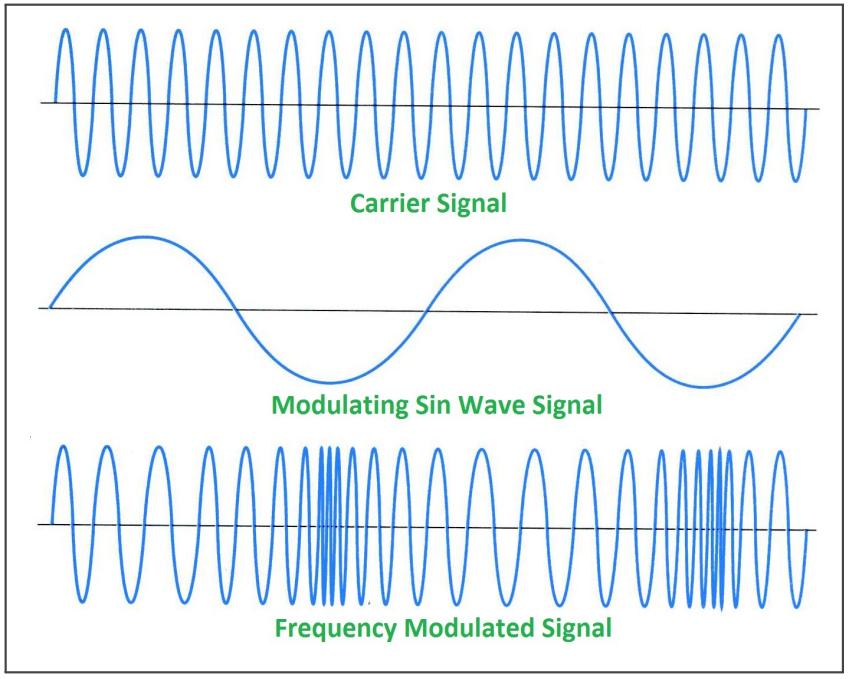
Electromagnetic Radiation

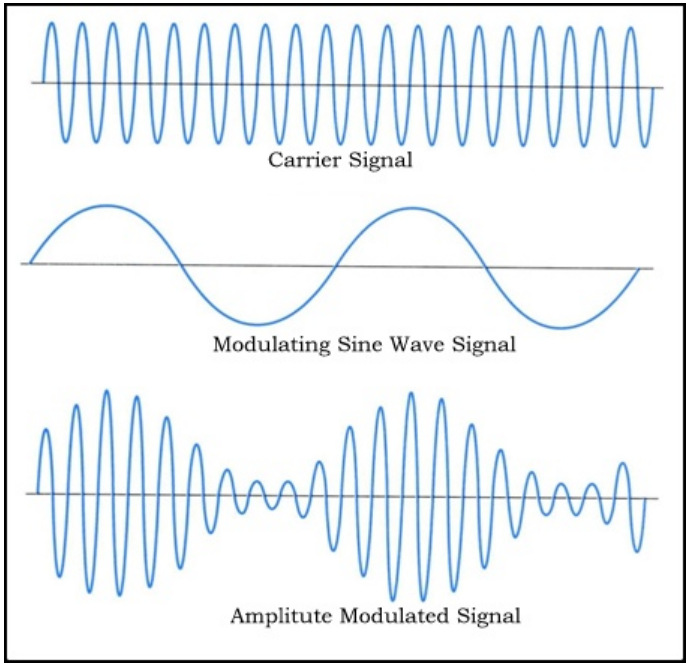
- EM radiation is everywhere – due to natural as well as human activities
  - visible light, x-rays, radiowaves, microwaves, are all EM radiation
  - it is a common feature of devices: phones, radio and television, microwave ovens, aircraft navigation, medical diagnostics
- EM radiation is characterised by a wavelength



Radio Communication

- The EM radiation needs to be *controlled* or *modified* to send data
- The technical term is modulation of the wave; there can be frequency modulation or amplitude modulation
- The rule for modulation and its interpretation must be pre-decided





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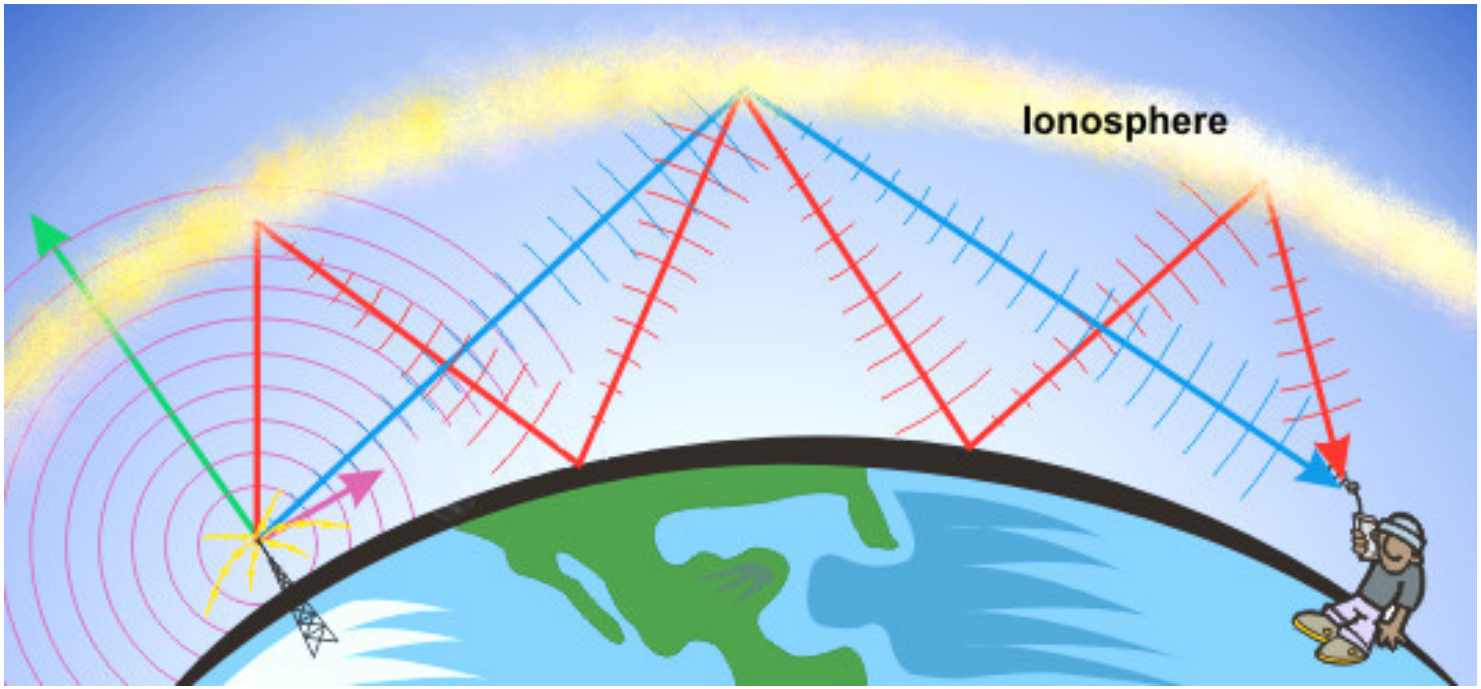
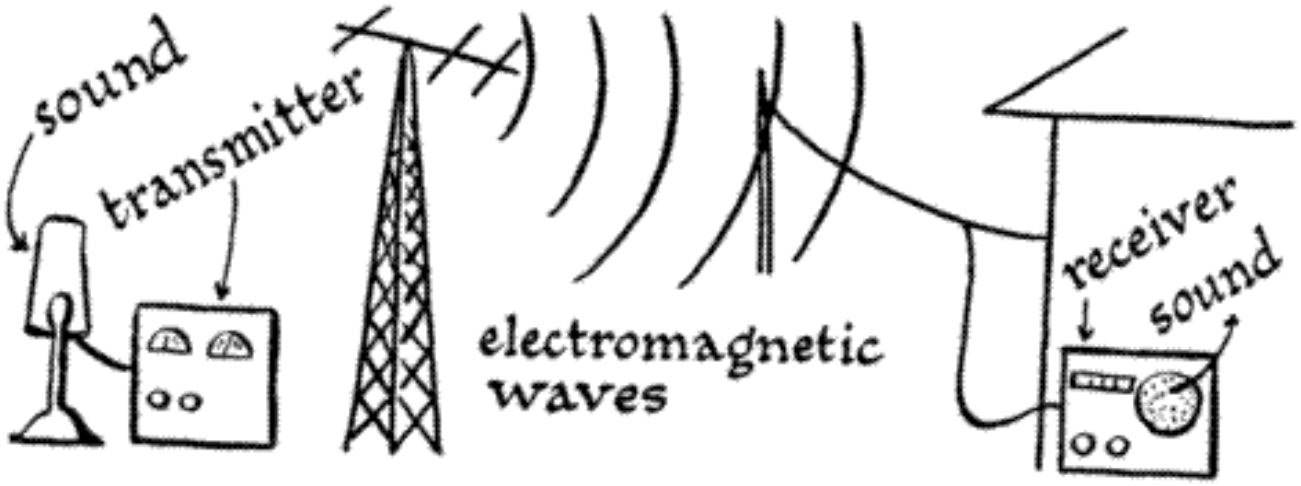


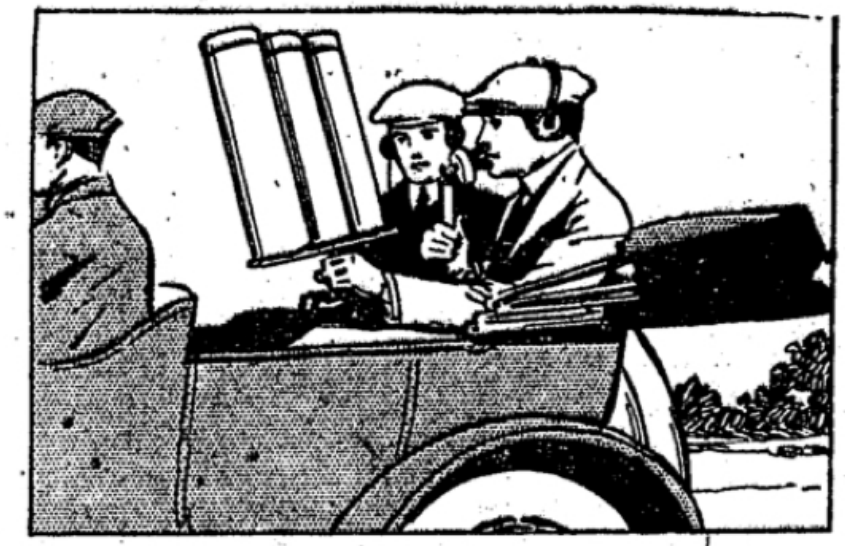
- Radio waves are reflected by the ionosphere of the earth – so they can make long hops
- 1895 Guglielmo Marconi developed a crude, but working, radio-telegraph system
- 1901: Marconi succeeded in transmitting Morse Code across the Atlantic Ocean
- 1919: A text message of the first non-stop transatlantic flight of two British aviators was sent from Galway, Ireland to London.

Radio and TV Broadcasting



- 1920: Radio broadcasting began
- 1927: Electronic television was demonstrated in San Francisco
- Unlike the telegraph, this was *one-to-many* communication (a single station transmitting to multiple users)
- These *broadcasting* schemes are precursors to the cell phone

Car phone

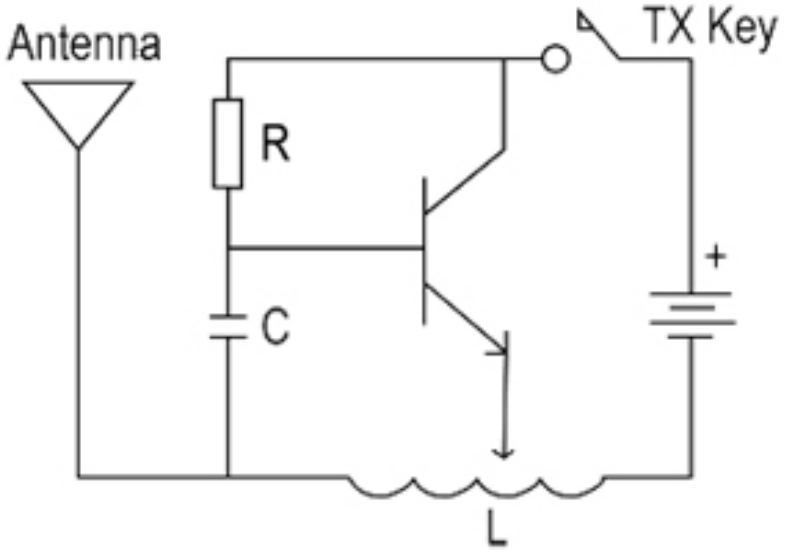


Transmitting and Receiving a Telephone Message in a Moving Motor Car.

- 1920: Devices that could transmit and receive radio messages were being developed
- Experiments with a wireless telephone – from a moving car to the garage (half a kilometer away)
- 1940s: Technology for mobile phones had started developing
- This was the precursor to the *walky-talky* and person-to-person railway, police, and military communications

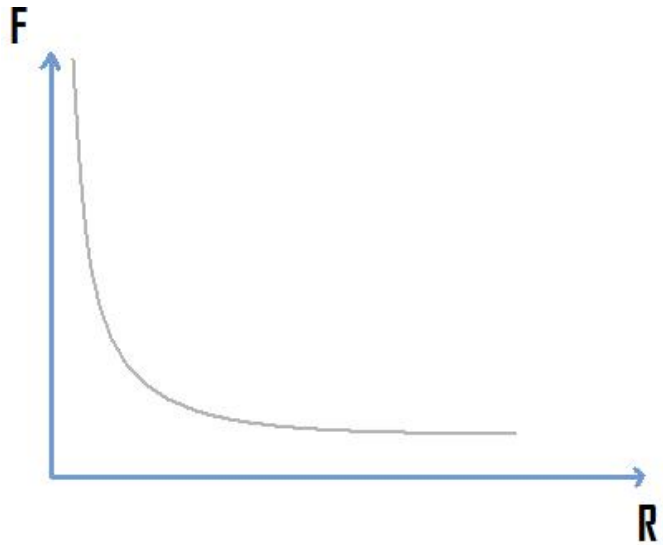
The next breakthrough

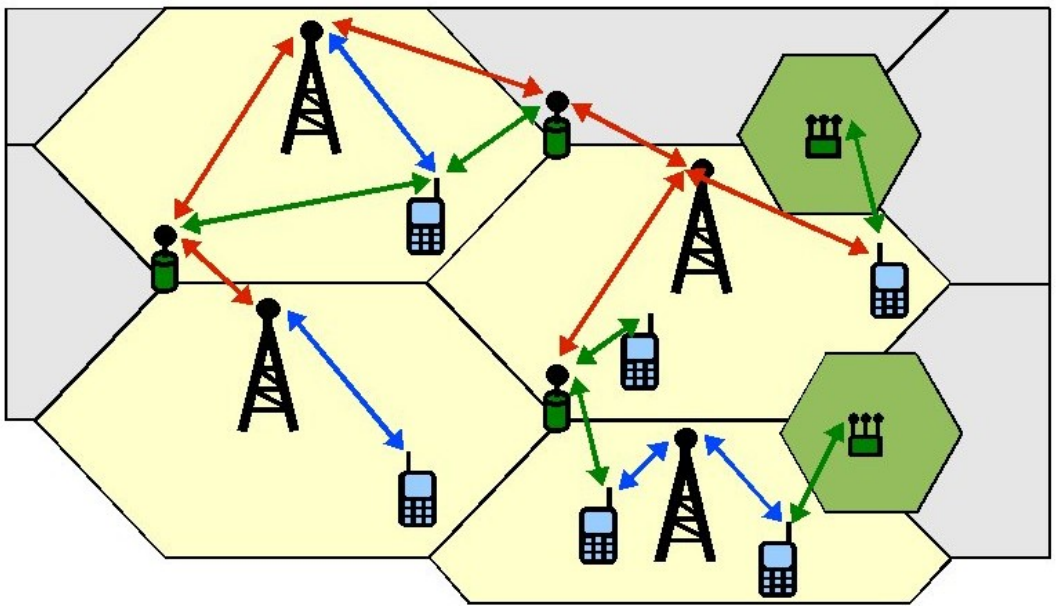
- Communication using radiowaves had been demonstrated by end-19th century and was in use through the two wars.
- But the apparatus was bulky and range was limited.
- Compact transmitters and receivers became possible only after the invention of the solid state transistor by Bardeen, Shockley, Brattain in 1947



Powerful Transmitters and Receivers

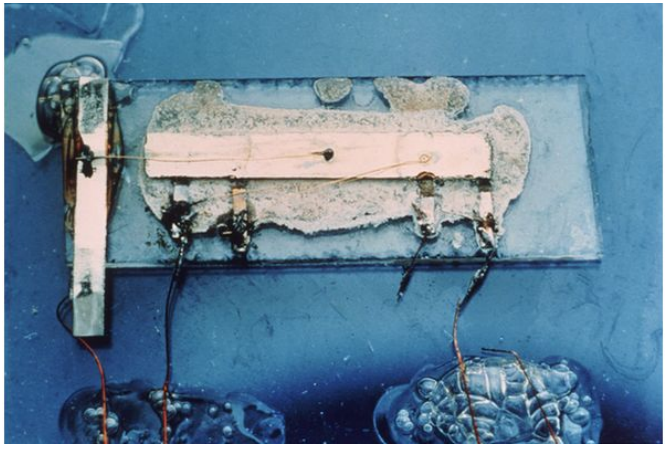
- Intensity of a radiowave falls off as $1/r^2$
- So multiple relay stations become necessary to cover large areas and multiple users
- Compact transmitters and receivers are essential to scale up the network

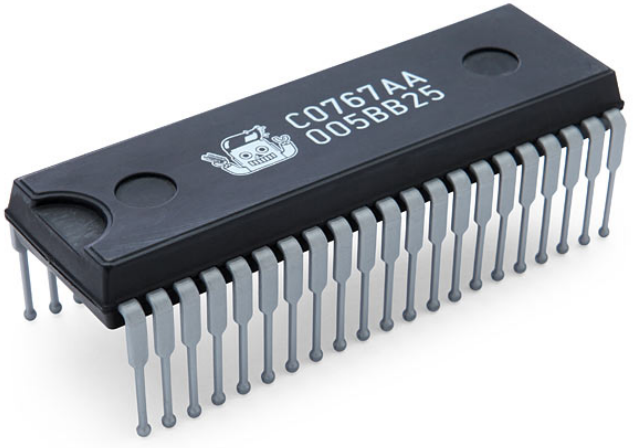




Semiconductor Revolution

- 1958: Integrated circuit – building many components on a single chip of germanium (earlier attempts 1949–1952)
- Better understanding of quantum mechanics – controlling the properties of material by adding impurities – dopants
- Big breakthrough was VLSI 1980s – compact circuits and large data processing power and transistor based memory in desktop computers





Key Parameters for Communication

Long distance connection using electrical or electromagnetic signals

Binary [digital] encoding for lots of information

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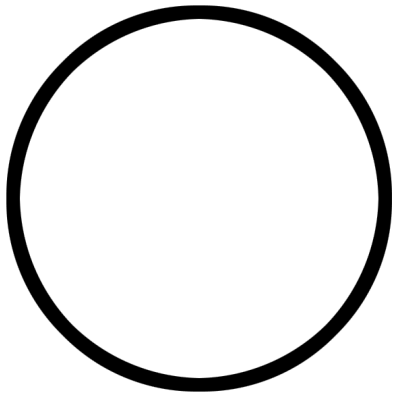
Digitizing of Data : Pictures



- How do you store this picture by a [binary] code?

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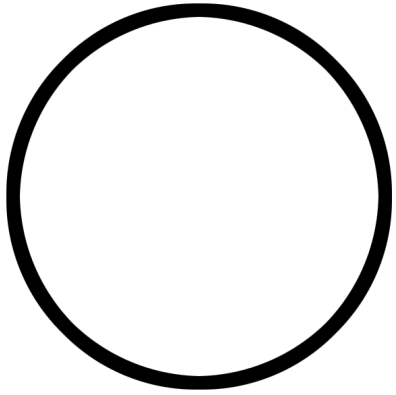

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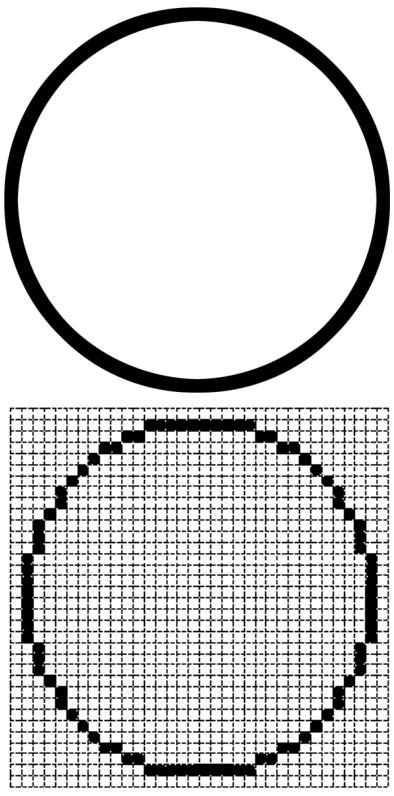
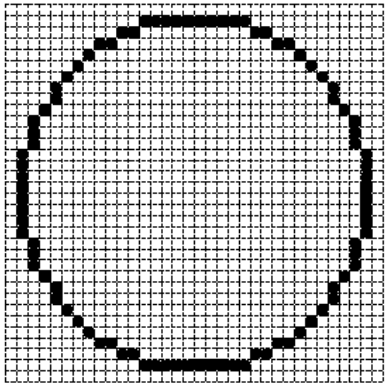
Interpretation of Data : Picture



- Break up the picture into a grid (Say a 16×16 grid)
- Check how the grid squares are filled
  - More than half-filled square $\mapsto 1$
  - Less than half filled square $\mapsto 0$
  - List out zeros and one in a sequence

Interpretation of Data : Picture



=

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	**1**	**1**	**1**	**1**	0	0	0	0	0	0
0	0	0	0	0	**1**	**1**	0	0	**1**	**1**	0	0	0	0	0
0	0	0	**1**	**1**	0	0	0	0	0	0	**1**	**1**	0	0	0
0	0	**1**	0	0	0	0	0	0	0	0	0	0	**1**	0	0
0	0	**1**	0	0	0	0	0	0	0	0	0	0	**1**	0	0
0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0
0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0
0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0
0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0
0	0	**1**	0	0	0	0	0	0	0	0	0	0	**1**	0	0
0	0	**1**	0	0	0	0	0	0	0	0	0	0	**1**	0	0
0	0	0	**1**	**1**	0	0	0	0	0	0	**1**	**1**	0	0	0
0	0	0	0	0	**1**	**1**	0	0	**1**	**1**	0	0	0	0	0
0	0	0	0	0	0	**1**	**1**	**1**	**1**	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Digitizing of Data : Pictures

- The idea is actually not new. . .
- Newspaper pictures have been a grid of dots for years!

LARGEST NET SALES of any Daily Newspaper Printed in Northern, Southern, Central or Western India.

REGD. No. B111

The Times of India

ESTABLISHED 1838

NO. 195. VOL. CIX. BOMBAY: FRIDAY, AUGUST 15, 1947 PRICE TWO ANNAS

DO NOT PAY MORE

BIRTH OF INDIA'S FREEDOM

Pandit Nehru

NEW CABINET OF INDIA

Fourteen Members

PANDIT NEHRU TO BE PREMIER

NATION WAKES TO NEW LIFE

Mr. Nehru Calls For Big Effort From People

"INCESSANT STRIVING TASK OF FUTURE"

Assembly Members Take Solemn Pledge

WILD SCENES OF JUBILATION IN DELHI

From Our Special Representative

NEW DELHI, AUGUST 14.

ENTIRE DELHI KEPT AWAKE TO WITNESS THE HISTORIC EVENT OF

STATE VISIT TO KARACHI

Their Excellencies Lord and Lady Mountbatten speaking to Service representatives at the Mauripur Airport on their arrival in Karachi from Delhi on Wednesday.

LORD MOUNTBATTEN GREETS PAKISTAN

FRENZIED ENTHUSIASM IN BOMBAY

Crowds In Festive Mood

THE national flag was hoisted over the 74-year-old Bombay Civil Secretariat at midnight when the citizens of Bombay greeted the dawn of independence with solemn invocation and frenzied rejoicing.

"Citizens of free India—you are now free"—said the Prime Minister, Mr. B. G. Kher, in raising the flag at the midnight ceremony, which was attended by all Ministers and departmental heads and employees of the Bombay Government.

His declaration was greeted with cheers from the thousands who gathered at the approaches to the Secretariat.

A strong police guard kept order with the greatest difficulty till the conclusion of the ceremony when they lost control and hundreds swarmed through the Building to yield enthusiasm. Their spirit was that of the hundreds of thousands who marched cheering through the illuminated streets of Bombay, uninterruptedly shouting slogans in a multitude of tongues, which turned the city at midnight into a Babel.

Bombay in the early hours of Friday morning was a pedestrians'

"MAY BOMBAY PROSPER"

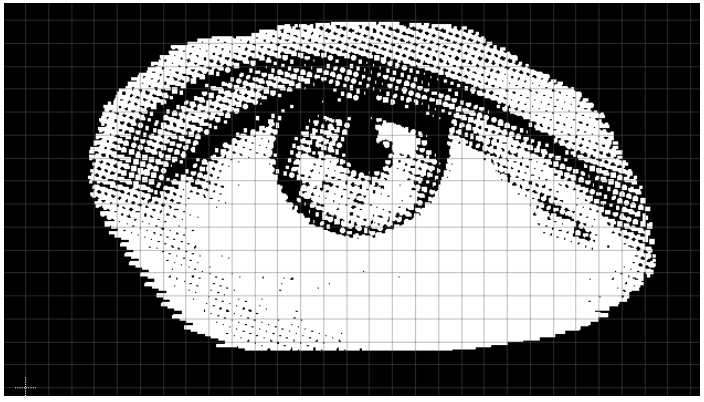
Governor's Message

GOOD WISHES TO FREE INDIA

Sir John Colville, Governor of Bombay, has sent greetings to the people of Bombay Province on the occasion of India's emergence as a full-fledged Dominion.

The message says: "This is the Appointed Day. At midnight last night the In-

Interpretation of Data : Picture



- How about a more complex picture. . . with shades?

Interpretation of Data : Picture

- More complex pictures can be handled by
  - having a finer grid (more data)
  - a code for ‘grey’ shades
  - each dot is a grey level
  - 0–255 levels = 8 bits (even more data)
- How about a colour picture?

Interpretation of Data : Picture

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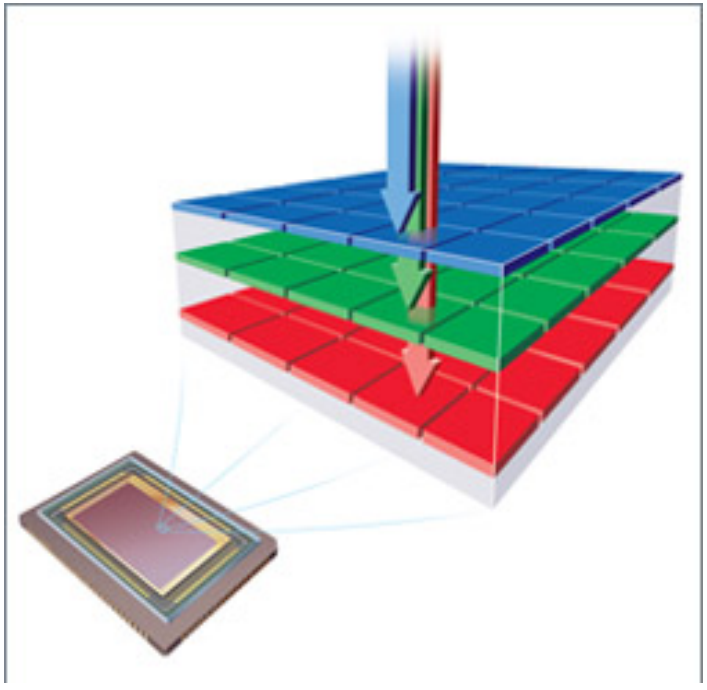
  - a code for ‘grey’ shades
  - each dot is a grey level
  - 0–255 levels = 8 bits (even more data)
- How about a colour picture?

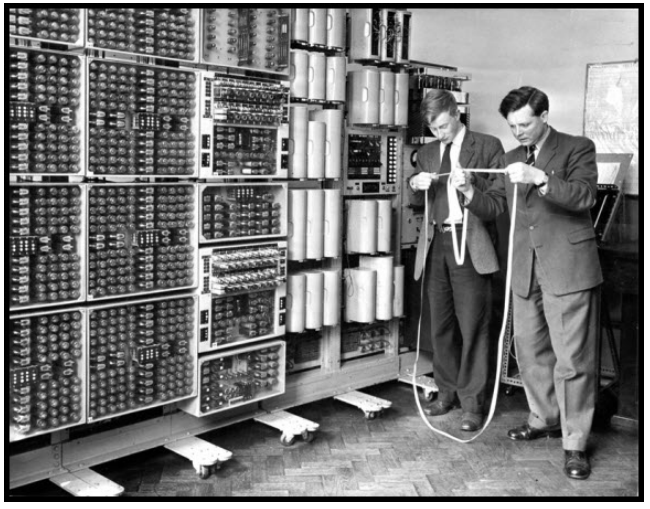
Interpretation of Data : Picture

- Colour information . . . even more data
  - one layer for each primary colour Red Green Blue
  - each layer has the same grid
  - each little box on the grid can be assigned 256 levels of each colour (8 bits each)
- A 6-MP camera picture has: $6,000,000 \times 8 \times 3$ bits!
- How do you handle so much data?



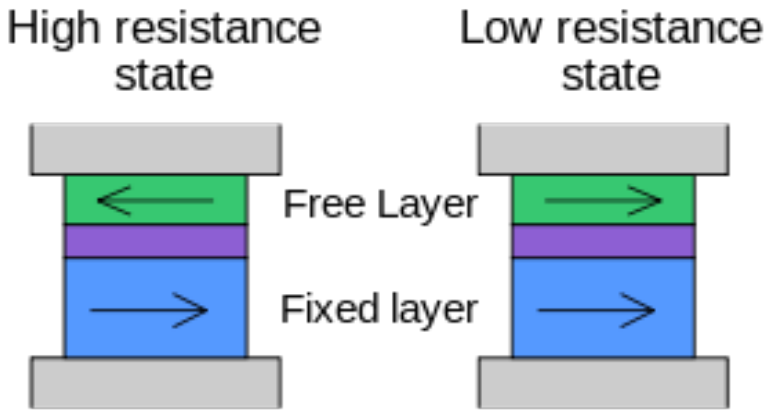
Advent of Computers

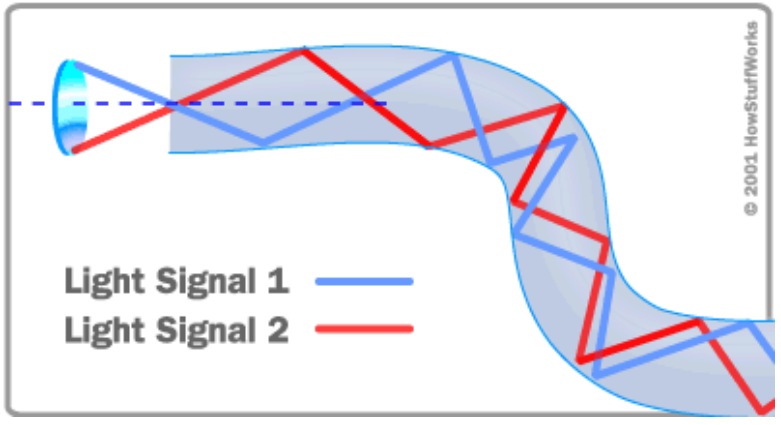
- By the 1950s computers appeared – mostly used for solving complex problems in science and technology
- Their role in communication grew rapidly after 1969
- Specialised hardware and software was developed through the 1970s
- Data was not restricted to solving equations – it started pouring in from various sources – communication data, statistical data, word processing, image processing
- 1982 Internet Protocols were established



Data Handling Revolution

- The next big breakthrough was GMR 1995 – compact, high data capacity magnetic hard disks
- Another breakthrough was semi-conductor lasers and optical fibre communication – fast, high capacity data transmission





Cellphone/smart phone progress

- Motorola introduced some of the first cellphones to the public during the 1983.
  - weighed 1 kg, cost Rs. 600,000!
- First smartphone 1993
  - IBM and BellSouth, with a touch screen
  - Nokia Communicator with web browsing and email
- Blackberry in 2002 and iPhone in 2007 were game changers

Summary

- A smart phone seems like a recent phenomenon, but has roots going back to over 100 years
- The major breakthroughs have been
  - Invention of Telegraph, Morse Code, Telephone
  - Hertz's demonstration of electromagnetic radiation
  - Modulation and demodulation of radio waves using a code
  - Converting sound, image and text to digital formats
  - Revolution in electronics and semiconductor devices

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Happy Communication!