The four known interactive (at a distance) **forces of nature.**
strong force, weak force, gravity, **electromagnetism**.
Electromagnetism - interacts with electrically charged particles; it can be radiated through free space..
ElectroMagnetism (em) is manifested as interrelated electric (E) and magnetic (H) fields.

Retrospective and Perspective

Jean Baptiste Joseph Fourier (1768 – 1830) derived the Fourier series, which is used to de-construct waveforms into their constituent sine/cosine components.
Georg Simon Ohm (1789 – 1854) derived Ohm's law V = IR or R = V/I in **1827** .
Michael Faraday (1791 - 1867) in **1830** showed that electricity and magnetism are interrelated.
James Clerk Maxwell (1831 - 1879) united knowledge of electricity, magnetism and optics into a single electromagnetic (em) theory in the period **1864 - 1873**. **Maxwell's equations** (four partial differential equations) together with the Lorentz force (the interaction force between a charge and an electromagnetic field) is the expression of that theory.
Heinrich Rudolf Hertz (1857 – 1894) in 1887 demonstrated the reality of RF electromagnetic waves.

The Transverse ElectroMagnetic (TEM) Wave
A TEM wave has five properties **velocity, direction, magnitude, polarisation, period/frequency**.
'c' the velocity in free space c = 299,792,458 metres per second ≈ $3*10^8$ m/s
The velocity of propagation through or along any medium other than space will be less than 'c'.
Direction, change the polarity of <u>only one field</u> (E or H) and it will reverse the direction of travel.
The magnitude is measured as the 'Field Strength' of its two components
E field (Electric field) - units are volts/metre **H field** (Magnetic field) - units are amps/metre
Polarisation is referenced to the E field (usually vertical or horizontal & sometimes circular).
Impedance of free space Z_0 (unit is ohms) is the ratio of the E & H fields in free space.
$Z_0 = E/H \approx 120\pi\ \Omega$ (cf. ohms law R = V/I) Note Z_0 is an impediance. it does not 'absorb' energy.
Power Density in watts/square meter $P_d = EH \approx E^2/120\pi$ (cf. $P = VI = V^2/R$)

A sine wave is a periodic vector function **where** $E_i = E_m \sin\phi$ or $H_i = H_m \sin\phi$
A vector is a quantity that has a magnitude E_m or H_m and direction (phase) $\sin\phi$.
Period 'p'is the time required to complete one 360 degree cycle.
Frequency 'f' = 1/p is the number of cycles per second unit is Hertz (Hz).

The Wavelength is dependant on the velocity $\lambda = cp = c/f$
λ @ 2.45GHz (Microwave ovens and WiFi) in free space is 122 mm (4.8 inches)

The Electomagnetic Spectrum (and the dual nature of em radiation)
radio - infra-red - visible -ultraviolet.- extremeUV - gamma rays - x rays - cosmic rays
The energy of a photon is E = hf where h = Planck's constant 4.136×10^{-15} eV sec
The Radio Frequency (RF) Spectrum (above 0.3MHz)

Band	**Freq MHz**	**λ**
MF	0.3 - 3	1000 - 100m
HF	3 -30	100 - 10m
VHF	30 - 300	10 - 1m
UHF	300 - 3000	1 - 0.1m
SHF, (μ–wave)	3000 - 30,000	100mm - 10 mm
EHF, (mm-wave)	30GHz - 300GHz	10mm 1mm

Skin Effect - at RF, current only flows close to the surface due to em-field/electron interaction

Transmission line: an arrangement of conductors (or a dielectric [glass fibre] used to convey em energy).
Balance-to-ground - A transmission line may be unbalanced or balanced in relation to ground.
Examples of transmission lines include
Unbalanced, eg micro-strip on PCBs and coax. **Balanced,** open-wire and twisted-pair cable (e.g..cat5)
Special types, wave-guide and fibre optic, (the smallest dimension must be > λ/2)
For a theoretical lossless transmission line characteristic impedance Z = E/H ohms
The velocity of propagation on a transmission line is less than 'c', velocity factor $v_f = v/c$
'Boundary conditions' An E field must be at right angles, an H field must be parallel.

Standing waves.
The difference between a short circuit and an open circuit is λ/4, (that's about 33mm at 2.4GHz)

RF Conectors - are designed to maintain the characteristic impedance and prevent reflections.
Balun is a device to used to match a balanced line to an unbalanced antenna or vice-versa.
A duplexer is a device that allows bi-directional (duplex) communication over a single transmission line by isolating the receiver from the transmitter.**λ/2 Dipole Radiator**

deciBel or **dB** is the ratio of two powers (eg Power out/Power in) expressed on a logarithmic scale.
dB = 10log (P_{out}/P_{in}). if Pin > Pout i.e. the circuit has a loss then express it as **dB = - 10log (P_{in}/P_{out})**
log 1 = 0 log 2 ≈ 3 log 10 = 1 log 100 = 2 log 1000 = 3
a power gain of 2000 = 10 log (2*1000) = 10log 2 + 10log 1000 = 32dB
dBm is an actual power relative to one mW dBm = 10 log P in mW/1mW
2mW = 3dBm, 10mW = 10dBm, 200mW=23dBm, 0.1mW = -10dBm, 1μW = -30dBm
Why use dB? Because transmission path losses/gains can easily be calculated by summation.

Isotropic Radiator (Aerial)
Isotropic irradiance (power density) $P_d = P_t/4\pi r^2$ (inverse square law)
(where P_t = Tx Power in watts & r is radius in metres from antenna)

Aerials - Reciprocity theorem
near field < 3λ, E/H ≠ 120π, **far field** > 3λ the relationship E/H = 120π applies
Aerial gain dBi measured against Effective Isotropic Radiated Power (EIRP). gain of a λ/2 dipole ≈ 2.15 dBi
Polarization Mismatch Loss (dB) = 20 log (cos ϑ) where ϑ is the misalignment angle
For ϑ = 45° the loss is 3 dB and for ϑ = 90° it is theoretically an infinite loss.
Some common Aerial types
E field probes 1/2 wave dipole, 1/4 wave dipole, folded dipole, co-linear. yagi,
H field probe. Loop antenna
Parabolic reflector with horn illuminator, helical antenna.
The aperture of an antenna is the area that captures energy from a passing radio wave. For a dish antenna, the aperture is the size of the reflector, for λ/2 wire antennas the aperture is roughly an ellipse with an area of about 0.13 λ^2, and Yagi-Uda antennas have apertures larger than this.

Propagation - reflection, refraction, absorption, knife edge refraction, multipath fading

signal to noise ratio (s/n)
the signal at the receiver is low and is susceptible interference from noise
natural thermal noise from the receiver aerial and transmission line,
receiver front-end amplifier and mixer (frequency changer) noise
other interference, co-channel, adjacent channel, multipath interference
s/n and bandwidth are the two factors that determine the data capacity of a channel (more next month).