Antenna and Propagation

“EM Wave Radiation”

Dr. Cahit Karakuş, 2019

How electromagnetic waves bending in the atmosphere?

Common Powers

Prefix	Symbol	Power of 10	Power of 2	Prefix	Symbol	Power of 10
Kilo	K	1 thousand = 10^3	$2^{10} = 1024$	Milli	m	1 thousandth = 10^{-3}
Mega	M	1 million = 10^6	2^{20}	Micro	μ	1 millionth = 10^{-6}
Giga	G	1 billion = 10^9	2^{30}	Nano	n	1 billionth = 10^{-9}
Tera	T	1 trillion = 10^{12}	2^{40}	Pico	p	1 trillionth = 10^{-12}
Peta	P	1 quadrillion = 10^{15}	2^{50}	Femto	f	1 quadrillionth = 10^{-15}
Exa	E	1 quintillion = 10^{18}	2^{60}	Atto	a	1 quintillionth = 10^{-18}
Zetta	Z	1 sextillion = 10^{21}	2^{70}	Zepto	z	1 sextillionth = 10^{-21}
Yotta	Y	1 septillion = 10^{24}	2^{80}	Yocto	y	1 septillionth = 10^{-24}

speed of light in a vacuum	c	$2{\cdot}997\,924\,58 \times 10^{8}$ m s^{-1} (by definition)
permeability of a vacuum	μ_0	$4\pi \times 10^{-7}$ H m^{-1} (by definition)
permittivity of a vacuum	ϵ_0	$1/\mu_0 c^2 = 8{\cdot}854\,187\,817\ldots \times 10^{-12}$ F m^{-1}
elementary charge	e	$1{\cdot}602\,177\,33(49) \times 10^{-19}$ C
Planck constant	h	$6{\cdot}626\,075\,5(40) \times 10^{-34}$ J s
$h/2\pi$	$\hbar$	$1{\cdot}054\,572\,66(63) \times 10^{-34}$ J s
Avogadro constant	N_A	$6{\cdot}022\,136\,7(36) \times 10^{23}$ mol^{-1}
unified atomic mass constant	m_u	$1{\cdot}660\,540\,2(10) \times 10^{-27}$ kg
mass of electron	m_e	$9{\cdot}109\,389\,7(54) \times 10^{-31}$ kg
mass of proton	m_p	$1{\cdot}672\,623\,1(10) \times 10^{-27}$ kg
Bohr magneton $eh/4\pi m_e$	μ_B	$9{\cdot}274\,015\,4(31) \times 10^{-24}$ J T^{-1}
molar gas constant	R	$8{\cdot}314\,510(70)$ J K^{-1} mol^{-1}
Boltzmann constant	k_B	$1{\cdot}380\,658(12) \times 10^{-23}$ J K^{-1}
Stefan–Boltzmann constant	σ	$5{\cdot}670\,51(19) \times 10^{-8}$ W m^{-2} K^{-4}
gravitational constant	G	$6{\cdot}672\,59(85) \times 10^{-11}$ N m^{2} kg^{-2}
Other data		
acceleration of free fall	g	$9{\cdot}806\,65$ m s^{-2} (standard value at sea level)

All about Energy

Energy – the ability to do work.
Work – what is accomplished when a force was put on an object and that object was moved.
Force – a push or pull that requires energy.

There are two major classes of energy:

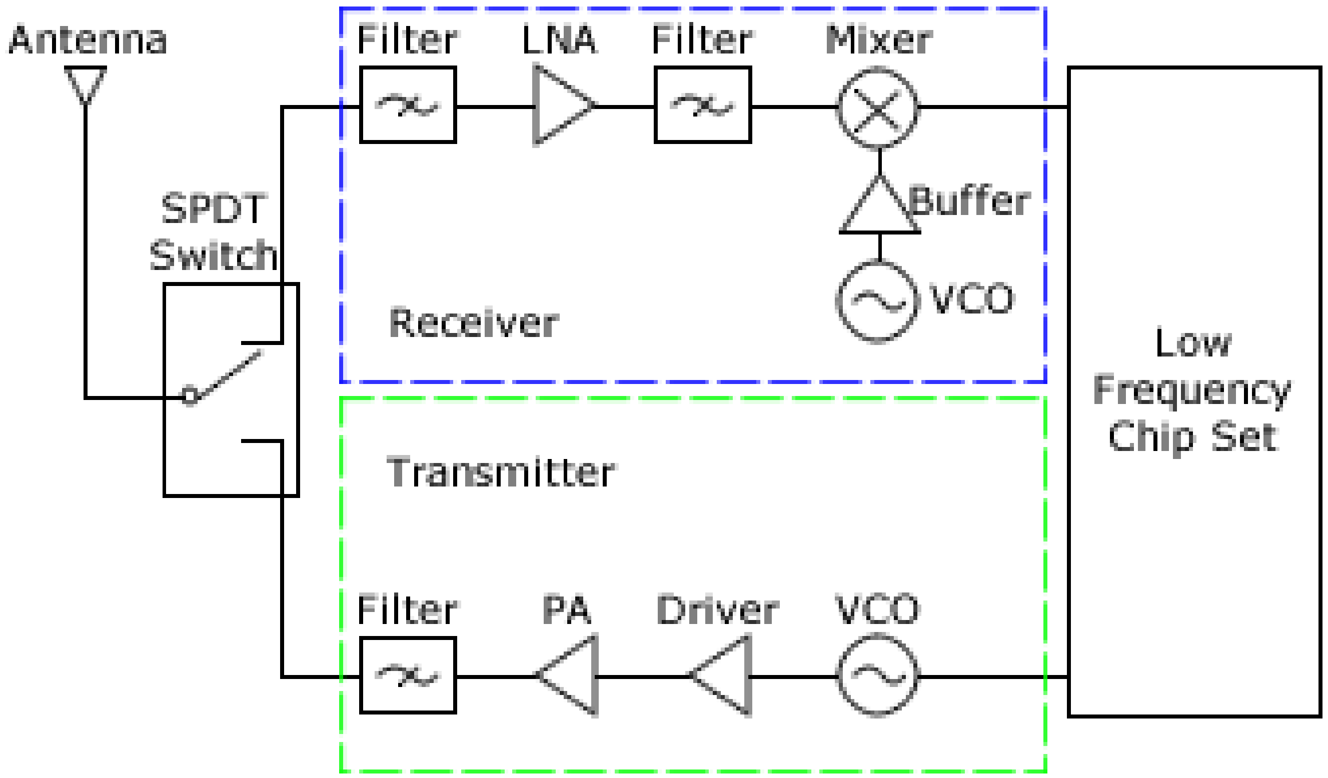
1. Potential Energy
2. Kinetic Energy

Potential Energy - The energy of position <u>or</u> stored energy. Objects that are resting have high potential energy. Objects that are cooler have high potential energy.
Kinetic Energy – The energy of motion. Objects that are moving have a high kinetic energy. High temperature objects also have a high kinetic energy.

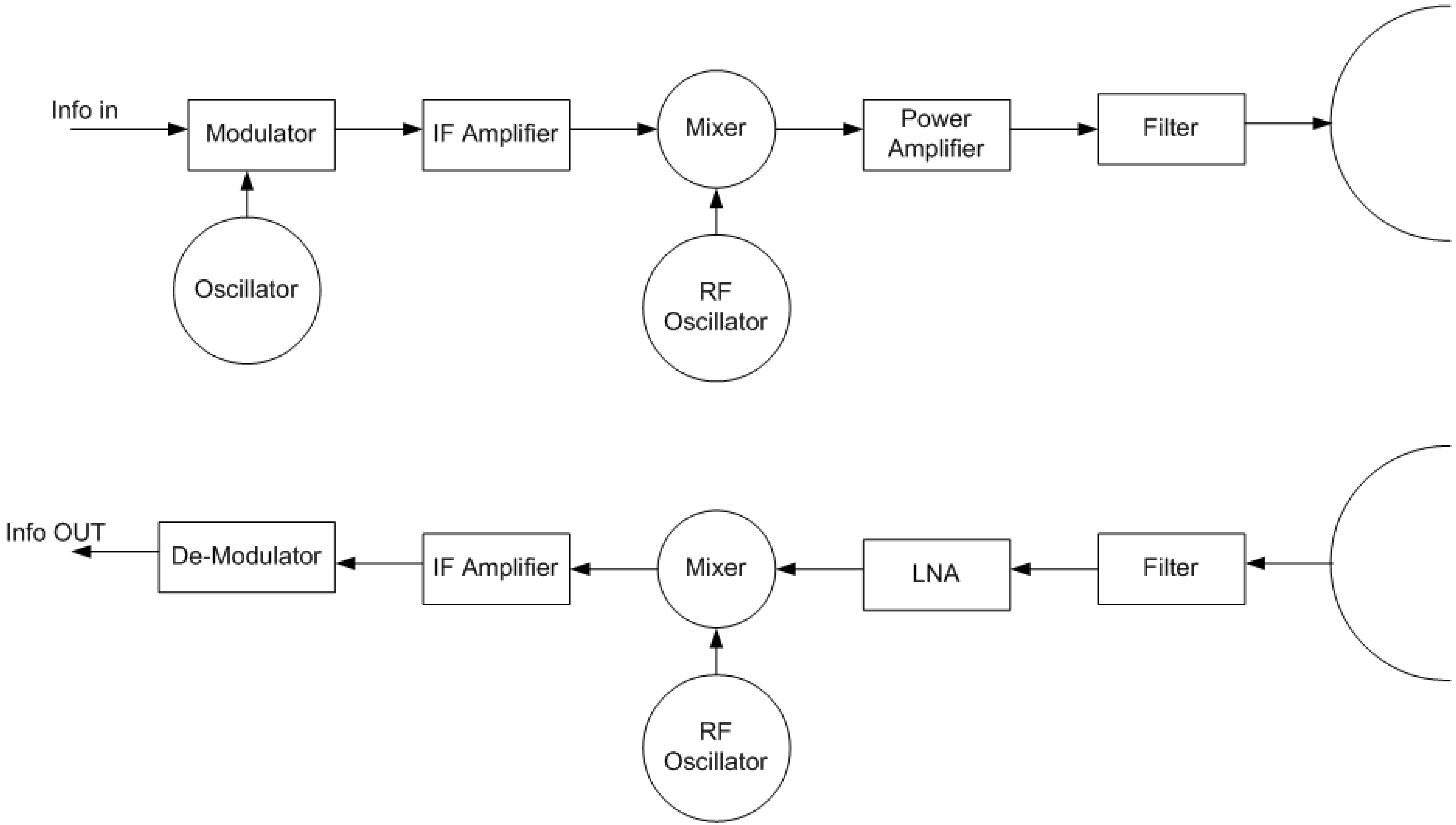
Potential and Kinetic Energies are inverse.

Electromagnetic Energy – energy that travels in the form of a wave. The Sun gives off Electromagnetic Energy

Wireless Communication Systems


Antenna
SPDT
Switch
Filter
LNA
Filter
Mixer
Buffer
VCO
Receiver
Transmitter
Filter
PA
Driver
VCO
Low
Frequency
Chip Set

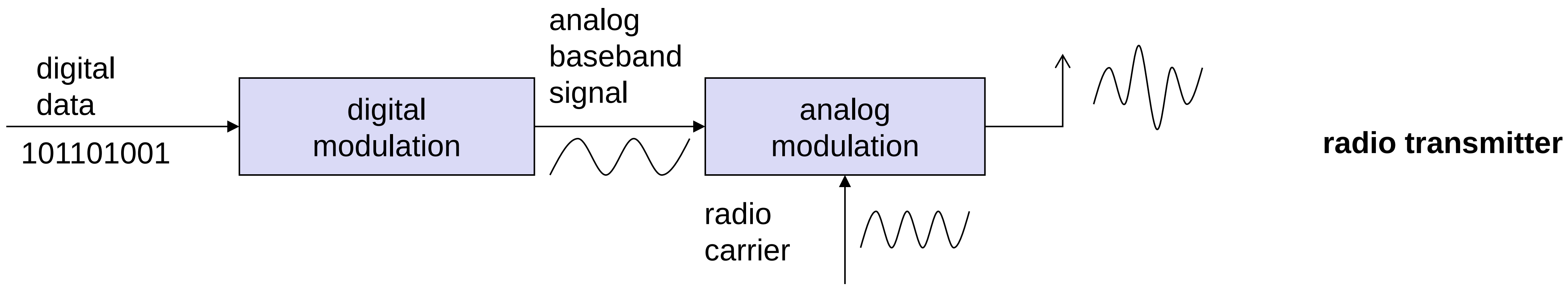
Block diagram for wireless communication system

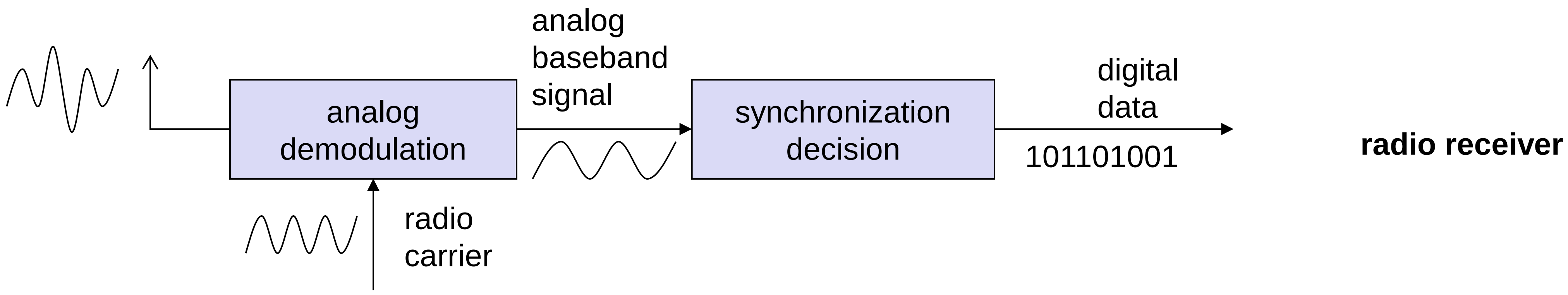


Verici - Alıcı

- Transmitter: Pt, Gt, Lt
- Radiation: FSL, Fading
- Receiver: Pr, Gr, Lr

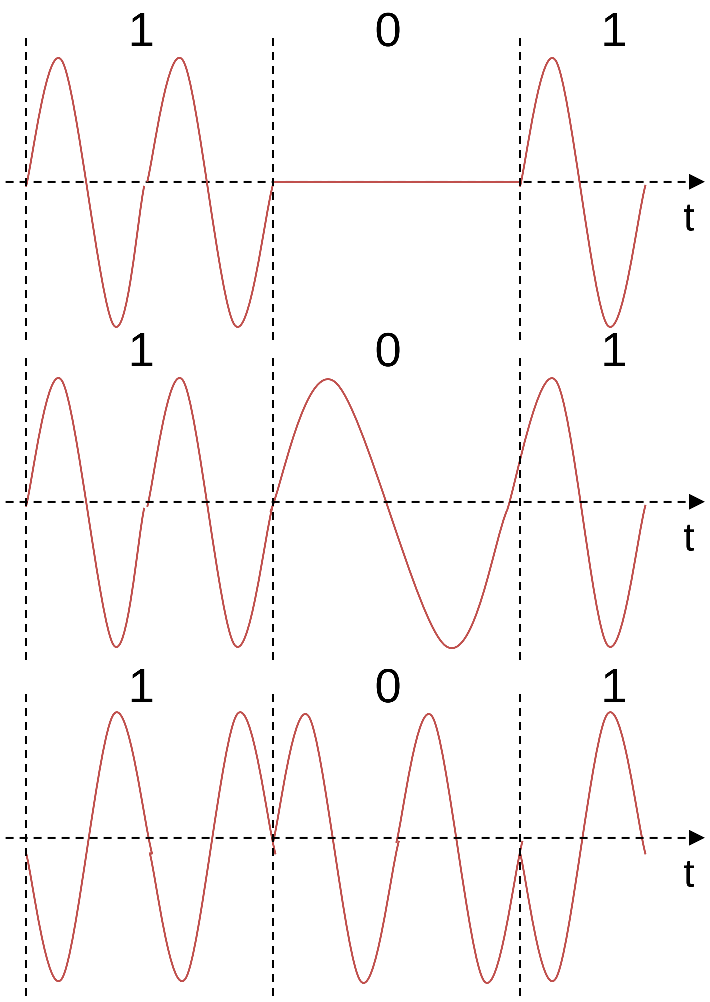
Modulation and Demodulation

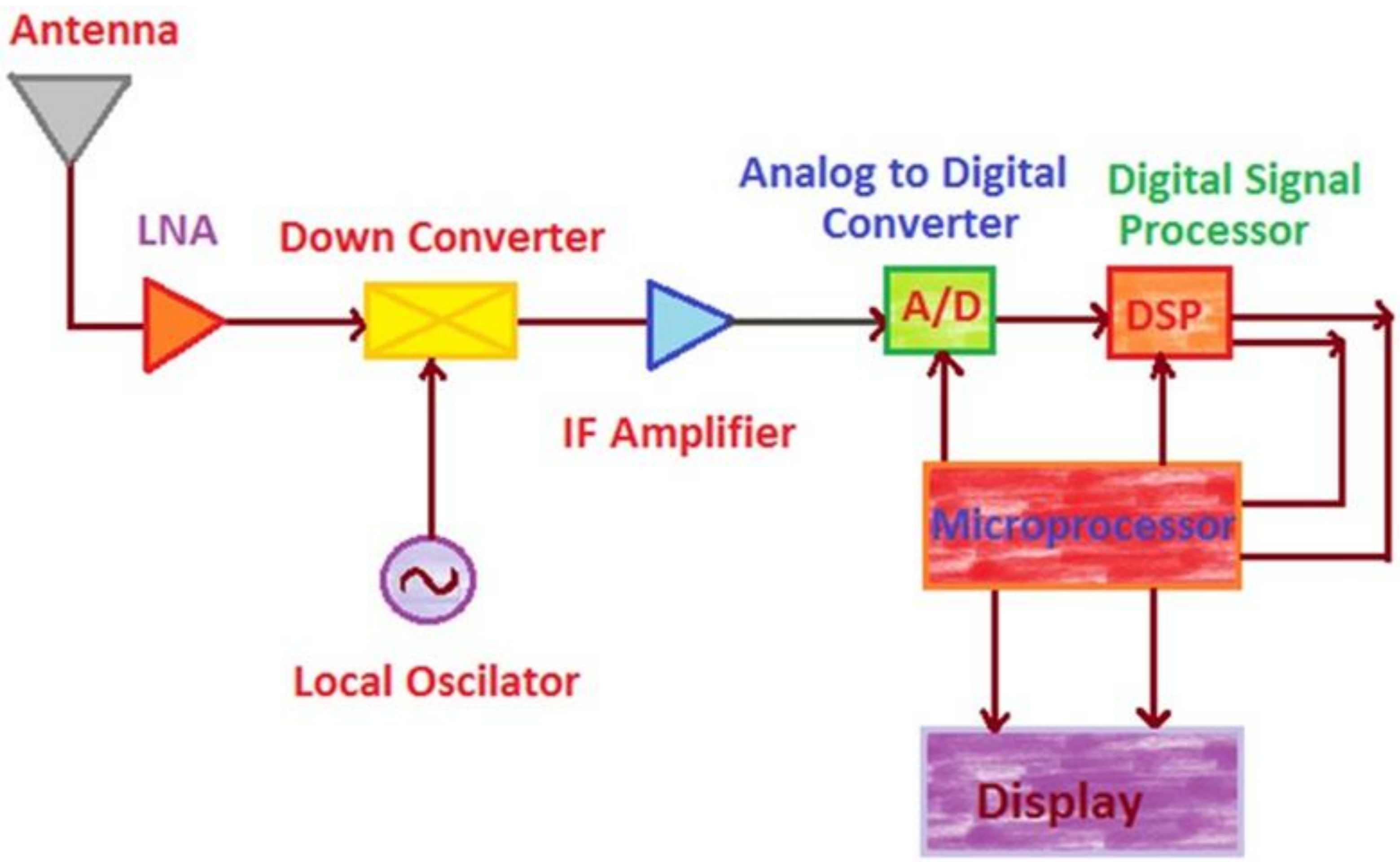




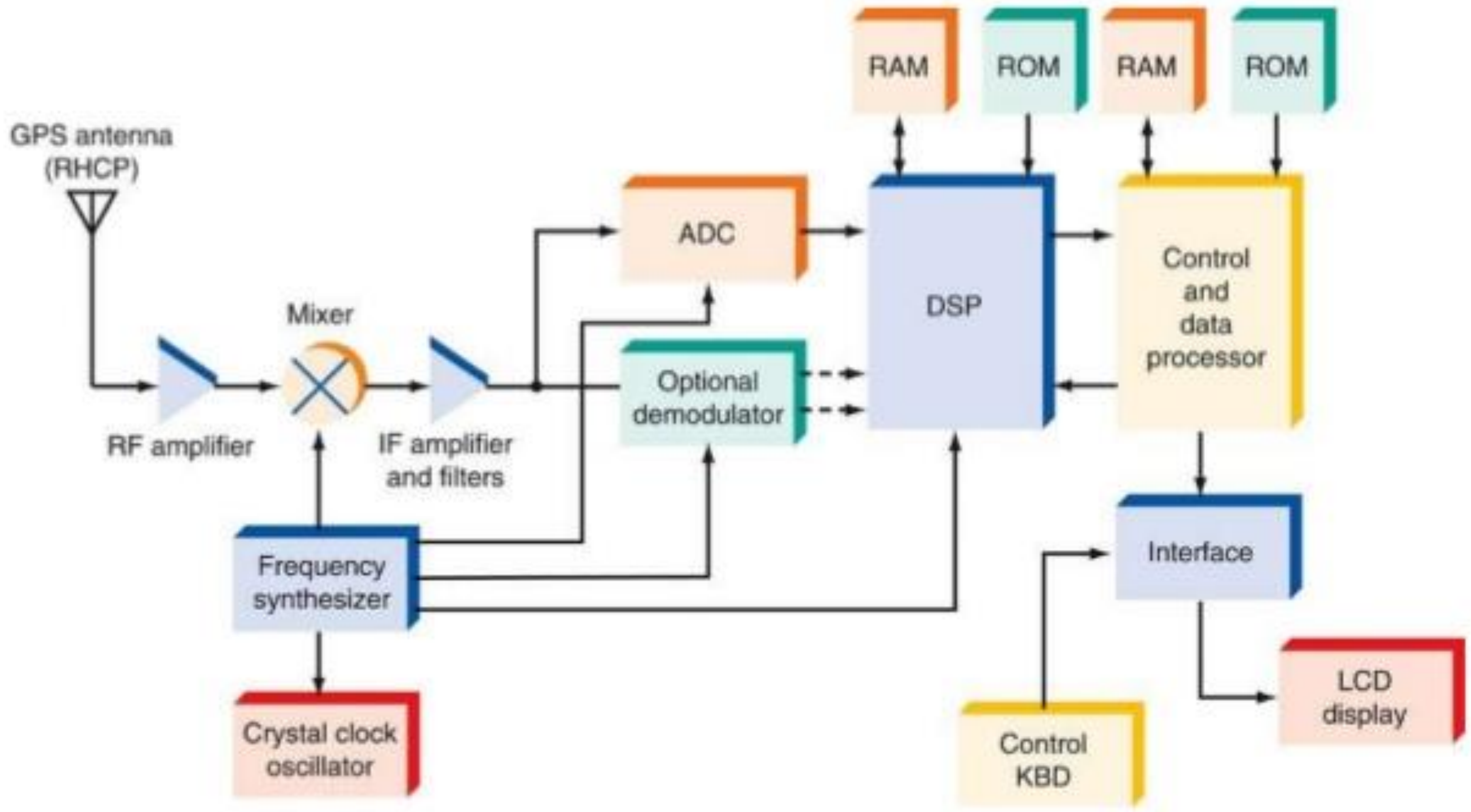
Digital Modulation

- Modulation of digital signals known as Shift Keying
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- Frequency Shift Keying (FSK):
  - needs larger bandwidth
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference




Antenna
LNA
Down Converter
IF Amplifier
Local Oscilator
Analog to Digital Converter
A/D
Digital Signal Processor
DSP
Microprocessor
Display

Global Positioning System



: A GPS receiver.

Electromagnetic Teory

Computational Electromagnetics

- Computational Electromagnetics has been successfully applied to several engineering areas, including:
  - Antennas
  - Microwave devices and circuits
  - Surveillance and intelligence gathering
  - Communications
  - Homeland Security
  - Energy generation and conservation
  - Biological electromagnetic (EM) effects
  - Medical diagnosis and treatment
  - Electronic packaging and high speed circuits
  - Superconductivity
  - Law enforcement
  - Environmental issues
  - Avionics
  - Signal Integrity

Overview of Computational Electromagnetics

- **Engineering Electromagnetics**
  - The study of electrical and magnetic fields and their interaction
  - Governed by Maxwell's Equations
    (Faraday's Law, Ampère's Circuital Law, and Gauss' Laws)

- **Maxwell's Equations relate the following Vector and Scalar Fields**

  $\mathbf{E}$: the Electric Field Intensity Vector (V/M)

  $\mathbf{H}$: the Magnetic Field Intensity Vector (A/m)

  $\mathbf{D}$: the Displacement Flux Density Vector (C/m^2)

  $\mathbf{B}$: the Magnetic Flux Density Vector (T)

  $\mathbf{J}$: the Current Density Vector (A/m^2)

  ρ: the Volume Charge Density (C/m^3)

  μ: is the Permeability of the medium (H/m)

  ε: the Permittivity of the medium (F/m)

Maxwell's Equations

Faraday's Law:

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

Gauss' Laws:

$$\nabla \cdot \mathbf{B} = 0 \qquad \nabla \cdot \mathbf{D} = \rho$$

Ampère's Circuital Law:

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

Constitutive Equations:

$$\mathbf{B} = \mu \mathbf{H} \qquad \mathbf{D} = \varepsilon \mathbf{E}$$

1 Maxwell's equations

$$\text{curl}\,\boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$ Faraday's law

$$\text{curl}\,\boldsymbol{B} = \mu_0 \boldsymbol{J} + \frac{1}{c^2}\frac{\partial \boldsymbol{E}}{\partial t}$$ Ampere's law

$$\text{div}\,\boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$ Field diverges from electric charges

$$\text{div}\,\boldsymbol{B} = 0$$ No magnetic monopoles

$$\varepsilon_0 = 8.854\times 10^{-12} \text{ Farads/metre} \qquad \mu_0 = 4\pi \times 10^{-7} \text{ Henrys/metre}$$

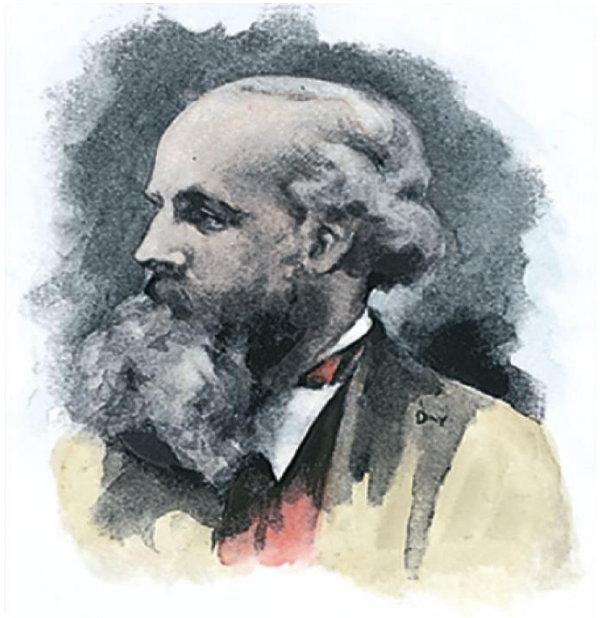
$$\varepsilon_0\mu_0 = \frac{1}{c^2} \qquad c = 2.998\times 10^8 \text{ m/s} \approx 300,000 \text{ km/s}$$

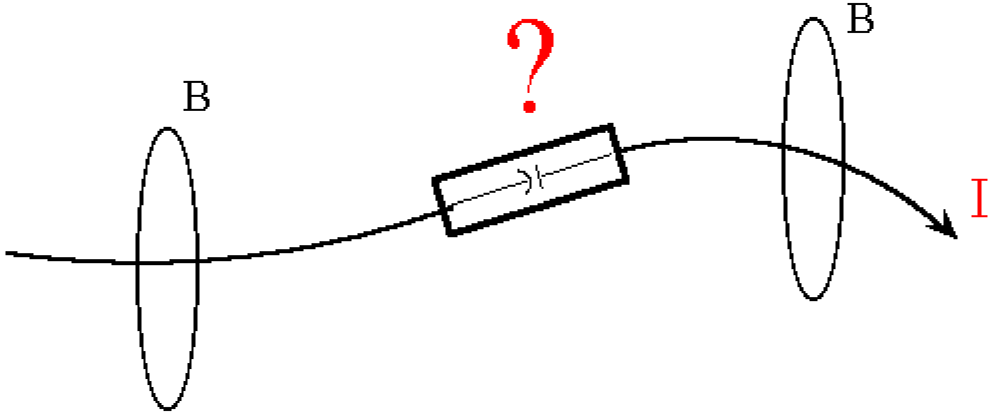
Conservation of charge

$$\frac{\partial \rho}{\partial t} + \text{div}\,\boldsymbol{J} = 0$$

James Clerk Maxwell

- 1831 – 1879
- Scottish theoretical physicist
- Developed the electromagnetic theory of light
- His successful interpretation of the electromagnetic field resulted in the field equations that bear his name.
- Also developed and explained
  - Kinetic theory of gases
  - Nature of Saturn’s rings
  - Color vision





Will there still be a magnetic field around the capacitor?

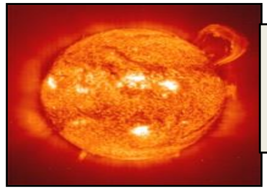
A changing magnetic flux produces an Electric field

A changing electric flux produces a Magnetic field

Fundamental Properties of Electromagnetic Radiation

"Radiation is an energy in the form of electro-magnetic waves or particulate matter, traveling in the air."

- The three basic ways in which energy can be transferred include, conduction, convection, and radiation
- Energy may be conducted directly from one object to another as when a pan is in direct physical contact with a hot burner
- The Sun bathes the Earth's surface with radiant energy causing the air near the ground to increase in temperature
- The less dense air rises, creating convectional currents in the atmosphere
- The transfer of energy by electromagnetic radiation is of primary interest to remote sensing because it is the only form of energy transfer that can take place in a vacuum such as the region between the Sun and the Earth



Electromagnetic Radiation Models

To understand how electromagnetic radiation is created, how it propagates through space, and how it interacts with other matter, it is useful to describe the processes using two different models:

- the ***wave*** model, and
- the ***particle*** model

Radyasyon: Işıma - Yayınım

- Radyasyon, dalga, parçacık veya foton olarak adlandırılan elektromanyetik yayınım yapan enerjidir. Radyasyon, daima doğada var olan ve birlikte yaşadığımız bir olgudur. Radyo ve televizyon iletişimini olanaklı kılan radyodalgaları; tıbta, endüstride kullanılan x-ışınları; güneş ışınları; günlük hayatımızda alışkın olduğumuz radyasyon çeşitleridir.
- Radyasyonu temel olarak iki şekilde sınıflandırabiliriz. Bunlar "parçacık" ve "dalga" tipi radyasyonlardır. Parçacık radyasyonu; belli enerjiye sahip çok hızlı hareket eden minik parçacıkları ifade eder. Bunlar hızla giden mermilere benzerler, ancak gözle görülemeyecek kadar küçüktürler. Dalga tipi radyasyon; belli bir enerjiye sahip ancak kütlesiz radyasyon çeşididir. Bunlar, titreşim yaparak ilerleyen elektrik ve manyetik enerji dalgaları gibidir. Görünür ışık dalga tipi radyasyonun bir çeşididir. Bütün dalga tipi radyasyonlar ışık hızıyla (3x10^8 m/saniye) hareket ederler.
- Gözlerimizin fark edebileceği en yüksek enerjili ışık mor renkli ışıktır. Radyasyonun enerjisi arttıkça ışık rengi mor renk ötesine gider ve morötesi olarak adlandırılır. Morötesi ışığı göremez veya hissedemeyiz, ancak ortamda mevcuttur ve eğer şiddeti büyükse ciltte bırakacağı güneş yanığına benzer yanık izleri ile varlığı hissedilir.

İyonize ve İyonize Olmayan Işıma

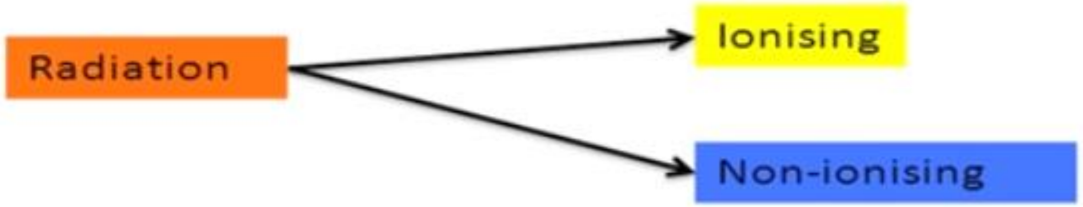
- İyonize olmayan dalgalar ise Ses dalgaları, Radyo dalgaları, Mikrodalga, Kızıl ötesi ışık, Görünen ışık, ve Morötesi ışık olarak sıralanır. İyonize olmayan dalgalar girdikleri dokulara enerjilerini aktararak ısısını artırır ya da hücre zarlarının çalışma biçimini değiştirir.
- İyonize radyasyon, Gamma ve X ışınları olarak sıralanır. İyonize radyasyon insan hücrelerinin değişimine neden oldukları, kanser oluşturdukları ve kromozomları değiştirdikleri için tehlikelidir.
- İyonize radyasyon kararsız atomlar tarafından üretilir. Kararsız atomlar kararlı atomlardan farklıdır çünkü fazla enerjiye veya kütleye veya her ikisine birden sahiptir.
- Kararsız atomların radyoaktif olduğu söylenir. Stabiliteye ulaşmak için, bu atomlar fazla enerjiyi veya kütleyi açığa çıkarır veya yayar. Bu emisyonlara radyasyon denir.

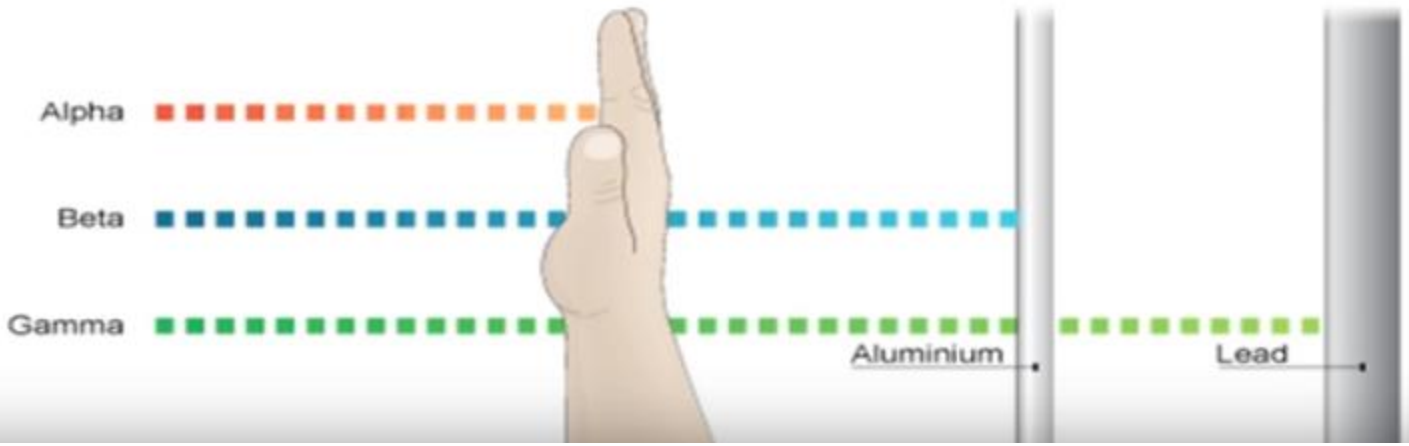
İyonlaştırıcı radyasyon

- Parçacık ve dalga tipi radyasyonları da yine iki gruba ayırmamız mümkündür. Bunlar, “iyonlaştırıcı” ve “iyonlaştırıcı olmayan” radyasyonlardır.
- İyonlaştırıcı radyasyon, çarptığı maddede yüklü parçacıklar (iyonlar) oluşturabilen radyasyon demektir.
- O halde iyonlaştırıcı radyasyonlar, önlem alınmadığı takdirde tüm canlılar için zararlı olabilecek radyasyon çeşitleridir.
- Başlıca beş iyonlaştırıcı radyasyon çeşidi vardır. Bunlar, Alfa parçacıkları, Beta parçacıkları, X ışınları, Gama ışınları ve Nötronlardır.
- İyon meydana gelmesi yani iyonizasyon olayı herhangi bir maddede meydana gelebileceği gibi insanlar dahil tüm canlılarda da oluşabilir.
- İyonlaştırıcı radyasyonlar, önlem alınmadığı takdirde tüm canlılar için zararlı olabilecek radyasyon çeşitleridir.

Radiation – a quick overview

What is radiation?
Energy in the form of *waves* or *moving particles* emitted by an atom or other body as it changes from a higher energy state to a lower energy state.





Alfa parçacığı

- Alfa ışınlarının özelikleri: Fotoğraf filmlerine etki ederler. + yüklü oldukları için elektrik ve manyetik alanda - kutup ‘ a doğru saparlar. Karşilaştiklari moleküllerden elektron kopararak , iyonlaşmaya neden olurlar.
- Alfa parçacığı iki proton ve iki nötrondan oluşmuş bir helyum ($_2He^4$) çekirdeğidir ve pozitif yüklüdür. α işaretiyle sembolize edilirler. Çekirdeğin alfa çıkararak parçalanması olayı atom numarası büyük izotoplarda görülür ve genellikle doğal radyoaktif atomlarda rastlanır. Alfa parçacıklarını çok küçük kalınlıklardaki maddelerle (örneğin ince bir kağıt tabaka ile) durdurmak mümkündür. Bunun sebebi, diğer radyasyon çeşitlerine göre sahip oldukları nispeten büyük elektrik yükleridir. Sahip oldukları bu elektrik yükü, alfa parçacıklarının herhangi bir madde içerisinden geçerken yolları üzerinde yoğun bir iyonlaşma meydana getirmelerine ve bu yüzden de enerjilerini çabucak kaybetmelerine yol açar. Enerjilerini bu şekilde çabucak kaybeden alfa parçacıklarının erişme uzaklıkları da dolayısıyla çok kısadır. Bu yüzden de normal olarak dış radyasyon tehlikesi yaratmazlar. Ancak, mide, solunum ve yaralar vasıtasıyla vücuda girdiklerinde tehlikeli olabilirler.

Beta parçacıkları

- Çekirdekteki enerji fazlalığı çekirdek civarında, $E = mc^2$ eşitliğiyle açıklanabilen, bir kütle oluşturur. Bu kütle çekirdekteki fazla yükü alır ve dışarıya bir beta ışını olarak çıkar. Bunlar pozitif veya negatif yüklü elektronlardır. Pozitif yüklü elektronlar "$\boldsymbol{\beta^+}$" ile, negatif yüklü iyonlar ise "$\boldsymbol{\beta^-}$" işaretiyle sembolize edilirler. Çekirdekteki enerji fazlalığı proton fazlalığından meydana geliyorsa $\boldsymbol{\beta^+}$, nötron fazlalığından meydana geliyorsa $\boldsymbol{\beta^-}$ çıkar.
- Beta parçacıkları da alfa parçacıkları gibi belli bir yük ve kütleye sahip olduklarından madde içerisinden geçerken yolları üzerinde iyonlaşmaya sebep olurlar. Ancak bu iyonlaşma, alfa parçacıklarının oluşturduğu iyonlaşmadan daha azdır. Çünkü bu parçacıklar alfa parçacıklarına göre daha hafif ve yüz kere daha giricidirler. Yine de bunlardan korunmak için ince alüminyum levhadan yapılmış bir zırh malzemesi yeterlidir.

Gama ışınları

- Gama ışınlarının kaynağı atomun çekirdeğidir. Bu ışınlar atom çekirdeğinin enerji seviyelerindeki farklılıklardan meydana gelir. Çekirdek bir alfa veya bir beta parçacığı çıkarttıktan sonra genellikle kararlı bir durumda olmaz. Fazla kalan çekirdek enerjisi bir elektromanyetik radyasyon halinde yayınlanır. Gama ışınları, beta ışınlarından daha yüksek enerjili ve dolayısıyla daha girici (nüfuz edici) ışınlardır. γ sembolize edilirler.
- Gama ve x ışınlarının, alfa ve beta parçacıklarına göre madde içine nüfuz etme kabiliyetleri çok daha fazla, iyonlaşmaya sebep olma etkileri ise çok daha azdır. Ancak birkaç santimetre kalınlığındaki kurşun tuğlalarla ve sadece belli bir kısmı durdurulabilir. Madde içerisinden geçerken üstel bir fonksiyon şeklinde bir şiddet azalmasına uğrarlar. Yüksüz olduklarından elektrik ve manyetik alanda sapma göstermezler.

X ışınları

- Röntgen ışınları da denilen **X ışınları**, görünür ışık dalgaları ve mor ötesi ışınları gibi dalga şeklindedir. Bir atoma dışarıdan gelen veya gönderilen yüksek enerjili elektronlar o atomun ilk halkalarından elektronlar koparırlar. Atomdan kopan bu elektronun yerine daha yüksek seviyelerden (üst halkalardan) elektronlar atlayarak kopan elektronun yerindeki boşluğu doldururlar. Bu sırada ortaya çıkan enerji fazlalığı X ışını şeklinde dışarı salınır.
- Çekirdek içerisinde bulunan protonlardan bir tanesi hareketi esnasında atomun ilk halkalarındaki elektronu yakalar ve nötrleşir. Yakalanan bu elektronun halkasındaki boşalan yere diğer bir halkadan bir elektron atlamasıyla X ışını meydana gelebilir.
- Bunların dışında da X ışını yapay olarak, röntgen tüplerinde de elde edilir. Tüp içerisinde ısıtılmış katottan yayılan elektronlar, onbinlerce voltluk gerilimle hızlandırılarak karşıdaki hedef anota çarptırılır. Bu çarpışma sonucu elektronlar durdurulurken elektronların kaybettiği enerji X ışınları olarak yayınlanır. Bu olaya Bremmstrahlung (Frenleme ışını) olayı, çıkan X ışınlarının oluşturduğu sürekli spektruma da Bremmstrahlung adı verilir.

Nötronlar

- Nötronlar yüksüz parçacıklardır.
- Bu özelliklerinden dolayı herhangi bir madde içerisine kolaylıkla nüfuz edebilirler.
- Doğrudan bir iyonlaşmaya sebep olmazlar.
- Ancak atomlarla etkileşmeleri, iyonlaşmaya neden olan alfa ve beta parçacıkları, gama veya x ışınlarının ortaya çıkmasına neden olabilir.
- Nötronlar sadece kalın beton, su veya parafin kütleleriyle durdurulabilirler.

Foton

- Foton, elektromanyetik alanın kuantumu, Işığın temel "birimi" ve tüm elektromanyetik ışınların kalıbı olan temel parçacıktır. Foton ayrıca elektromanyetik kuvvet'in kuvvet taşıyıcısıdır.
- Foton hem dalga hem de parçacık özelliği gösterir.
- Bohr Atom Modeli (Niels David Bohr 1875–1962) :
- Elektronlar çekirdek etrafında belirli uzaklıklardaki katmanlarda dönerler, rasgele dolanmazlar.
- Kararlı hallerin tamamında elektronlar çekirdek etrafında dairesel yörünge izlerler.
- Yüksek enerji düzeyinde bulunan elektron, düşük enerji düzeyine geçerse fotonlar halinde EM ışıma yapar.

Terminology of Electromagnetic Wave

A few facts:

1. The Sun produces (**radiates**) mostly visible light
2. The Earth gives off (**re-radiates**) mostly infrared (**heat**) at night
3. Red light has the longest wavelength
4. Blue-Violet light has the shortest wavelength
5. Gamma rays have the shortest wavelengths of the electromagnetic spectrum
6. Radio waves have the longest wavelengths of the entire spectrum
7. Short waves are the most dangerous because there are more crests passing by
8. Long waves are the safest because there are less crests passing by

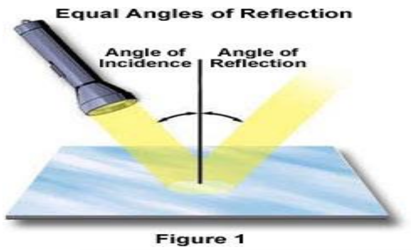
Energy can neither be created nor destroyed. It can only be transferred from one form to another.

There are 3 ways to transfer energy:

1. Conduction **2. Convection** **3. Radiation**

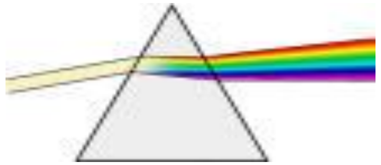
When visible light hits the ground 4 different things can happen to it:

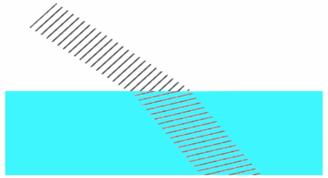
1. Reflected 2. Refracted 3. Scattered 4. Absorbed



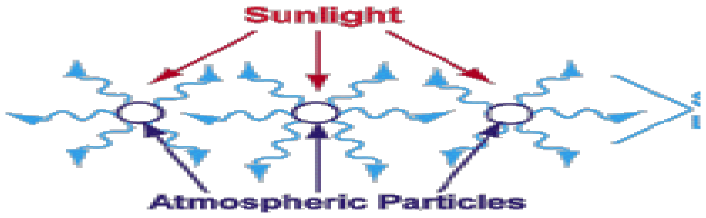
Reflected – light is bounced back in the same direction from which it came

Refracted – light is bent as it passes through something

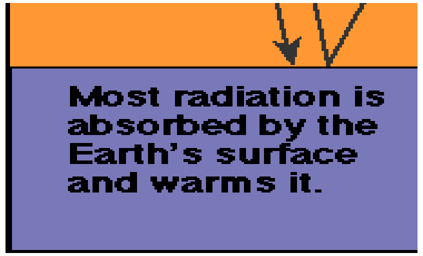




Scattered – the energy is bounced back in many directions



Absorbed – the light is taken in by the object that the light hits (the temperature will rise)

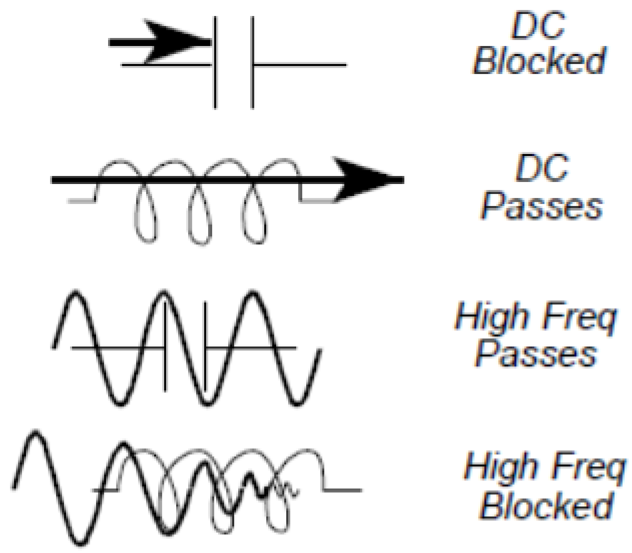


Frequency Response

	Inductor *	Capacitor *	Resister
DC	Pass	Block	Attenuate
Low Freq AC	Attenuate *	Attenuate *	Attenuate
High Freq	Block	Pass	Attenuate

* Attenuation varies as a function of the value of the each device and the frequency

"Cartoon" memory aid

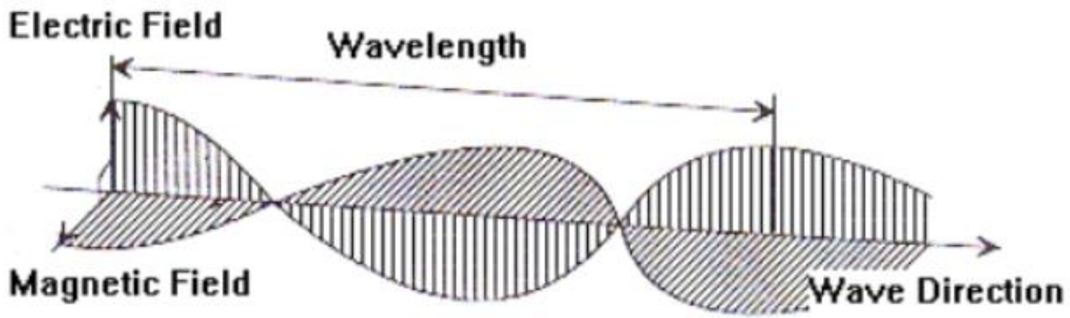


R
XL=wL
XC=1/wC

Elektromanyetik Işıma
(EMR: Electromagnetic Radiation)

- To understand how EMR is created, how it propagates through space, and how it interacts with other matter, it is useful to describe the processes using two different models: the wave model, and the particle model.

Electromagnetic waves

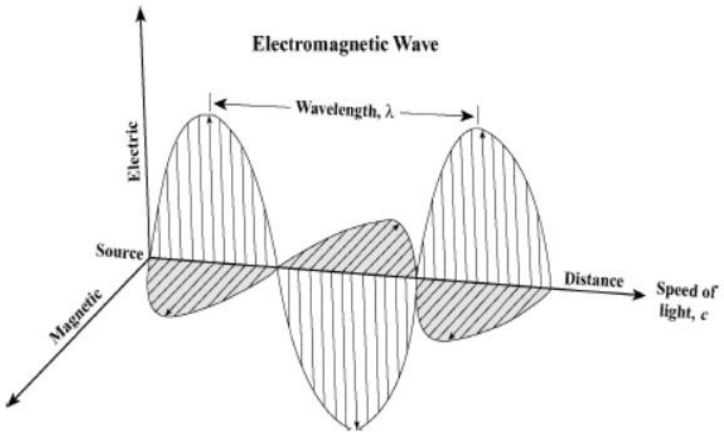


- ★ EM waves are energy transported through space in the form of periodic disturbances of electric and magnetic fields
- ★ EM waves travel through space at the same speed, c = 2.99792458×10^8 m/s, commonly known as the speed of light
- ★ An EM wave is characterized by a **frequency** and a **wavelength**
- ★ These two quantities are related to the speed of light by the equation **speed of light = frequency x wavelength**

Wave Model of Electromagnetic Radiation

The EM wave consists of two fluctuating fields—one electric (E) and the other magnetic (B).

The two vectors are in phase and are at right angles (orthogonal) to one another, and both are perpendicular to the direction of travel.



Electric Field (E)

E is the effect produced by the existence of an electric charge, e.g. an electron, ion, or proton, in the volume of space or medium that surrounds it.

$E=F/q$ F = is the electric force experienced by the particle

q= particle charge

E= is the electric field where the particle is located

Magnetic Field (B)

B is the effect produced by a change in velocity of an electric charge q

Wave Model of Electromagnetic Energy

- EM waves propagate at the speed of light, c, and consists of an electric field E and a magnetic field B.
- E varies in magnitude in the direction perpendicular to the traveling direction; B is perpendicular to E.
- E is characterized by: frequency (wavelength), amplitude, polarization, phase.

Wave equation:

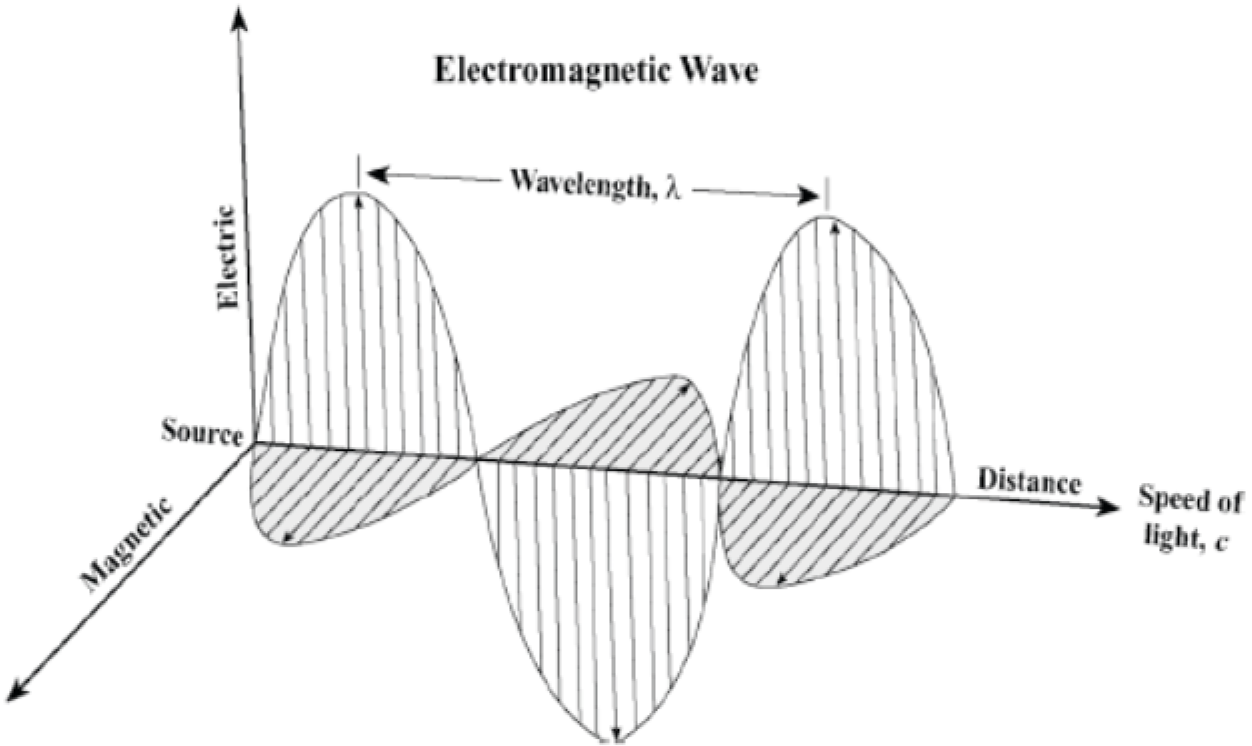
$$E_x = E_o \exp i(\omega t - kz)$$

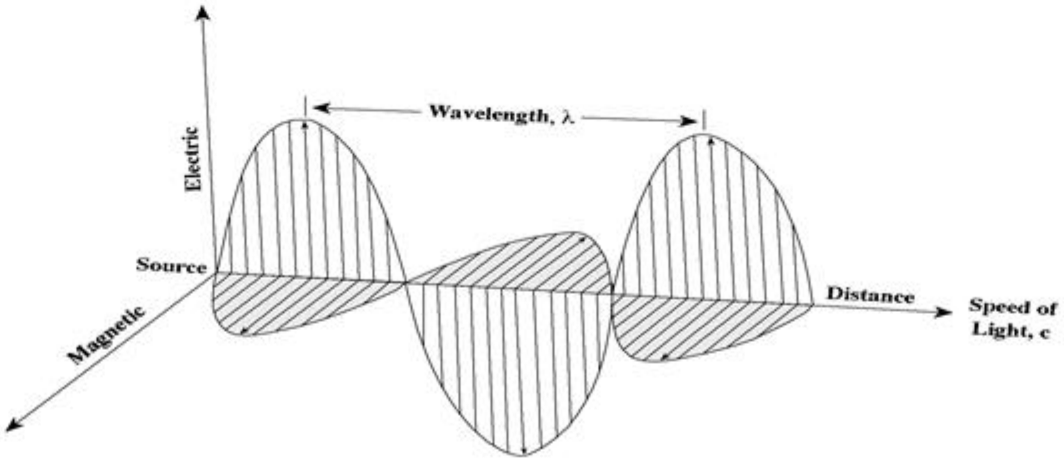
$k = 2\pi/\lambda$ = wave number

$\omega = 2\pi f$ =angular frequency

f = frequency

Φ =phase

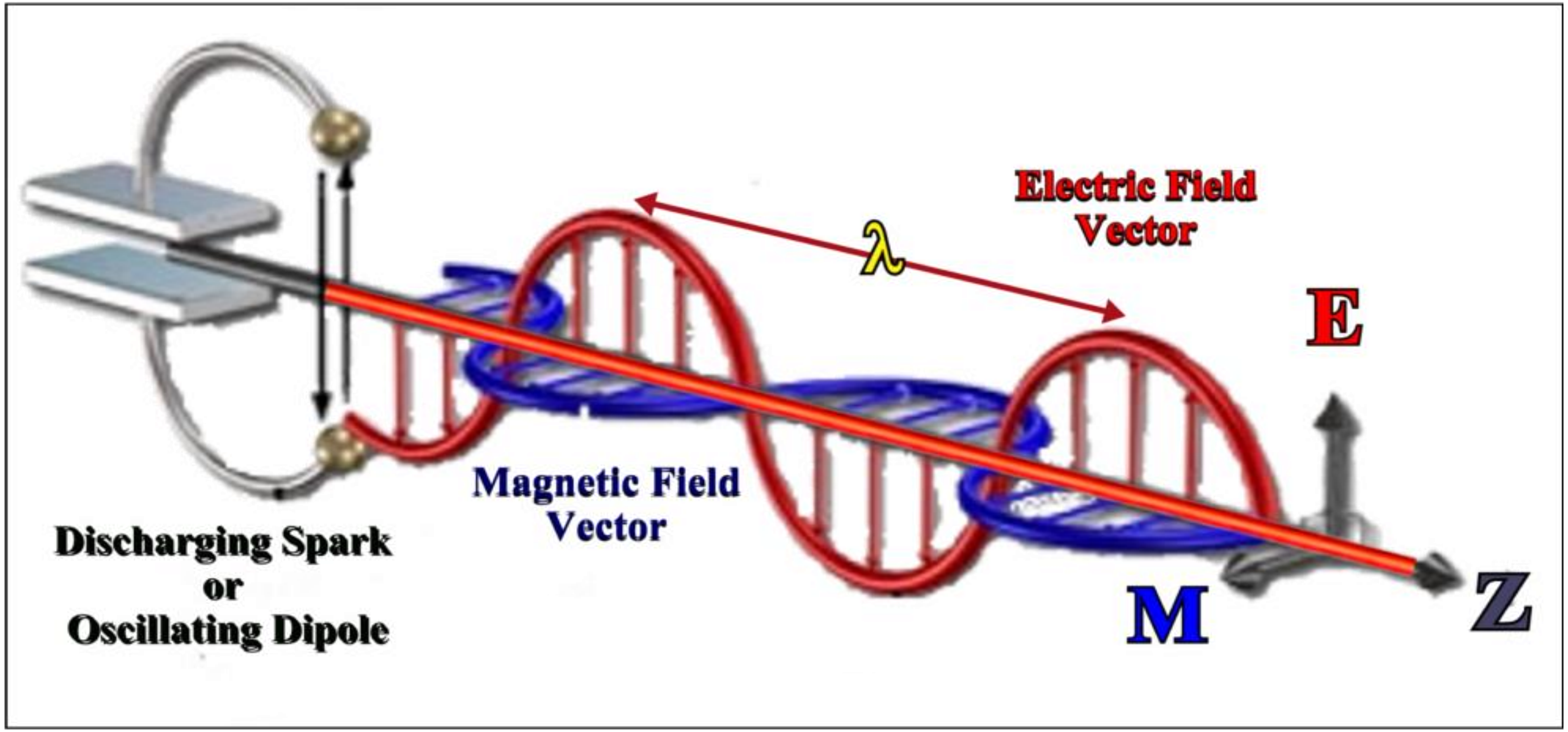




The Wave Model of Electromagnetic Energy

- **Frequency**: the number of wavelengths that pass a point per unit time
- **Wavelength**: the mean distance between maximums (or minimums)
- Common units: micrometers (μm) or nanometers (nm)
- One cycle per second is termed one **hertz** (1 Hz)

Electromagnetic Field Orientation



Terminology of a Wave

A wave is usually described by the following terms :

- Amplitude
- Wavelength (λ)
- Frequency (*f*)
- Period (T)
- Wave velocity (v)

- Elektromanyetik ışıma, elektrik ve manyetik alanların dalgalar şeklinde yayıldığı bir ortamdan veya vakumdan yayılan enerji şeklidir. Dalga, bir ortamda enerji taşıyan bir uyarıcıdır.
- Dalganın hızı, dalganın frekansı ile dalga boyunun çarpımıdır.
- The amplitude is the maximum displacement of the medium from its equilibrium position. Unit : *Volt, Amper*
- The wavelength (λ) is the minimum distance between two points which are in phase. Unit : *Meter*

  Dalga boyu (λ), birbirini izleyen iki tepeciğin en alt ya da en üst noktaları arasındaki uzaklıktır.
- The frequency (ƒ) is the number of complete oscillations made in one second. Unit : *Hz*

  Frekans (f), belirli bir noktadan birim zamanda geçen max veya min sayısıdır. Birimi 1/zaman yani 1/s olup saniyedeki çevrim sayısıdır.

- The period (T) is the time taken for one complete oscillation. It is related to frequency by $T = 1/f$, Unit : s

The speed of light in a vacuum.

When Maxwell calculated the speed of propagation of electromagnetic waves, he found:

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = \frac{1}{\sqrt{(8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2})(4\pi \times 10^{-7}\,\mathrm{N \cdot s^2/C^2})}}$$

$$= 3.00 \times 10^8\,\mathrm{m/s}$$

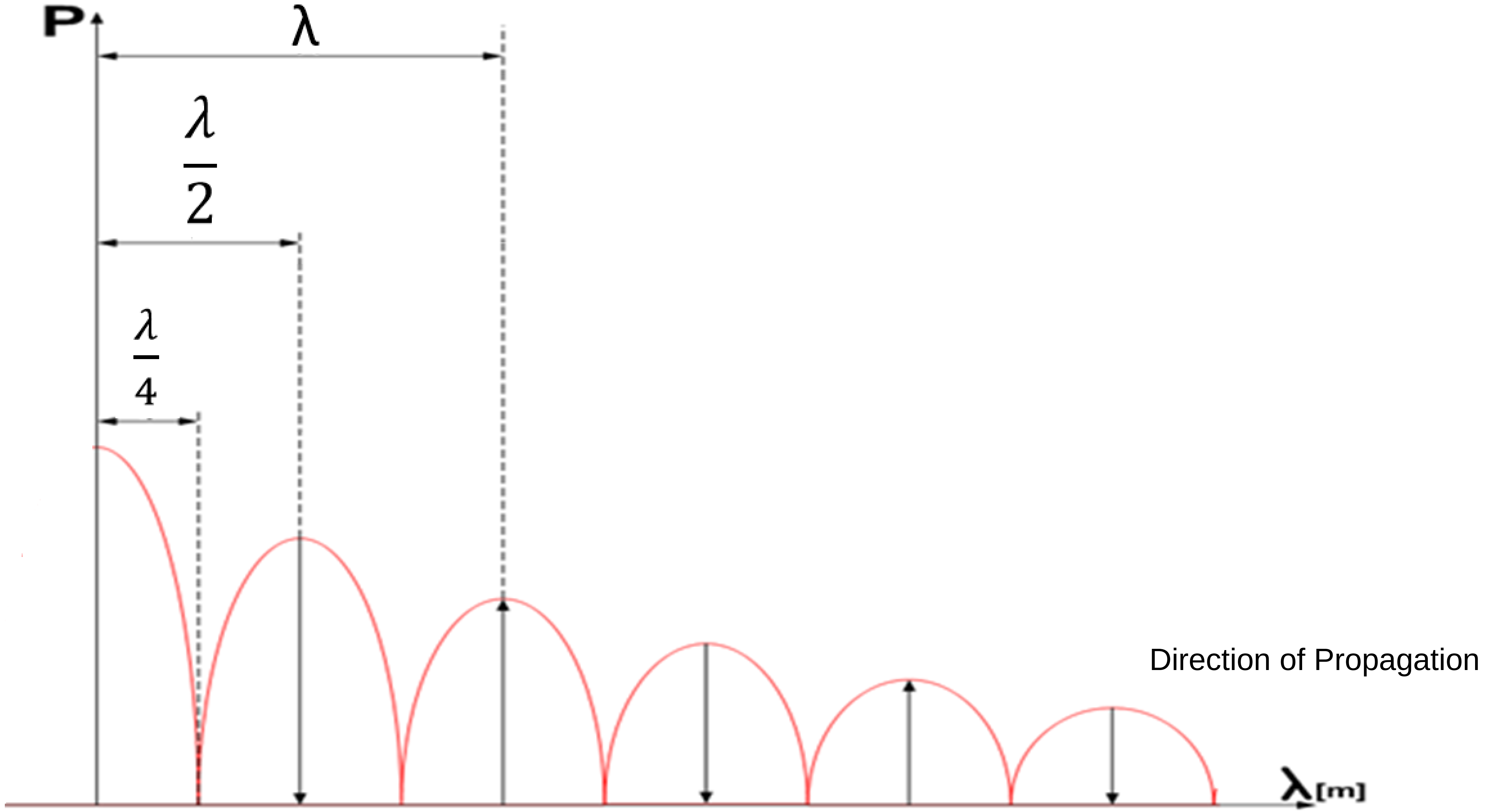
This is the speed of light in a vacuum.

Over the years, measurements have become more and more precise; now the speed of light is defined to be:

$$c = 2.99792458 \times 10^8\,\mathrm{m/s}$$

The frequency of an electromagnetic wave is related to its wavelength: $c = \lambda f$

Radiation Power

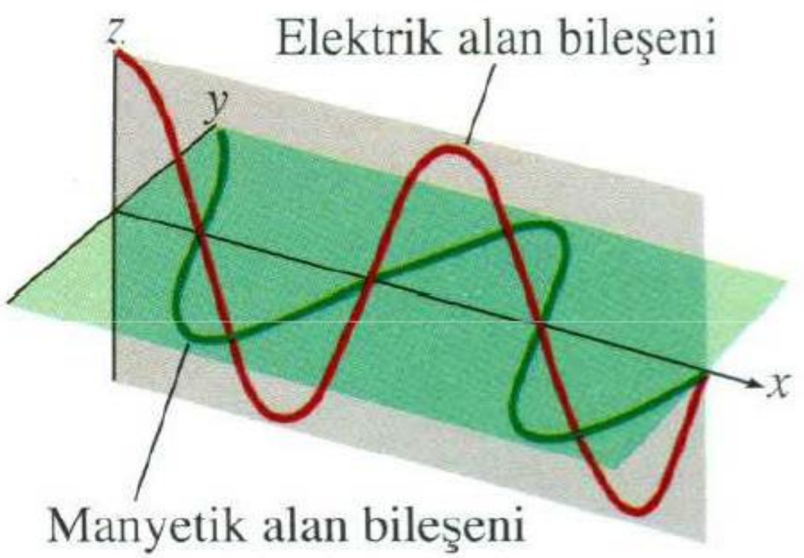


Elektromanyetik Teori

- Maxwell tarafından 1864-1865'de ortaya atılmıştır.
- 1887'de Hertz'in deneyleri ile doğrulanmıştır.
- Huygens, ışık dalgaları ile elektromanyetik dalgaların aynı karakterde olduklarını belirten teorik tahmin ve kuralları geliştirmiştir.

Elektromanyetik Işıma

Dalgalar, su dalgaları, ses dalgaları, ışık dalgaları gibi birçok farklı türde olabilirler. 1873'de **Maxwell** görünür ışığın elektromanyetik dalgalardan oluştuğunu öne sürmüştür. ***Maxwell kuramına*** göre, bir elektromanyetik dalganın, bir elektrik alan bileşeni, bir de manyetik alan bileşeni bulunur.



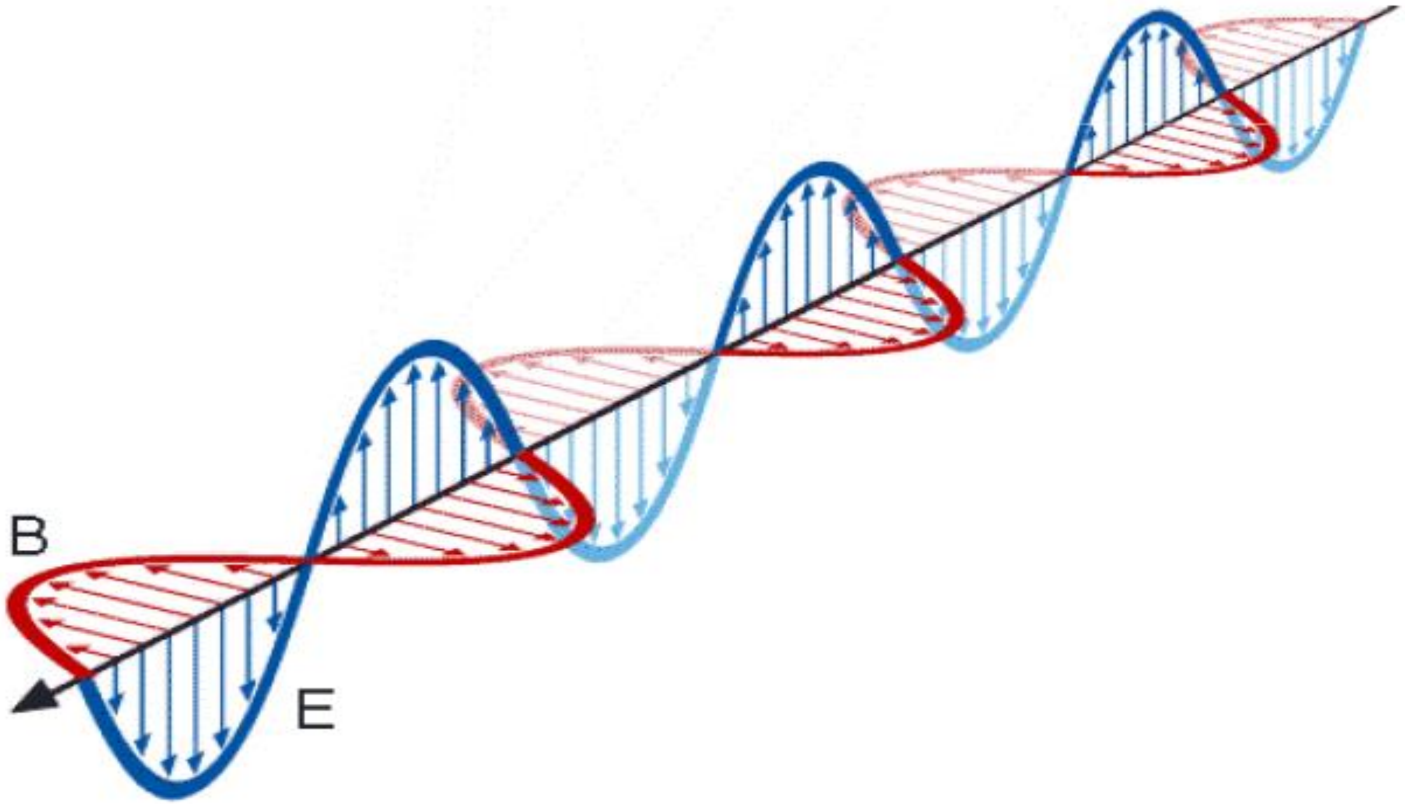
Bu iki bileşen aynı dalga boyu, aynı frekans ve dolayısıyla aynı hıza sahip olmasına karşın, birbirlerine dik iki düzlemde yol alırlar. Enerjinin, elektromanyetik dalgalar halinde yayınlanması ve iletilmesi, ***elektromanyetik ışıma*** olarak adlandırılır.

Electromagnetic Waves

- In a vacuum, the EM wave propagates at the speed of light. In the atmosphere, the wave propagates with a speed slower than the speed of light. The wave's speed, direction of propagation, and amplitude are dependent upon several atmospheric variables including temperature, moisture, and pressure.

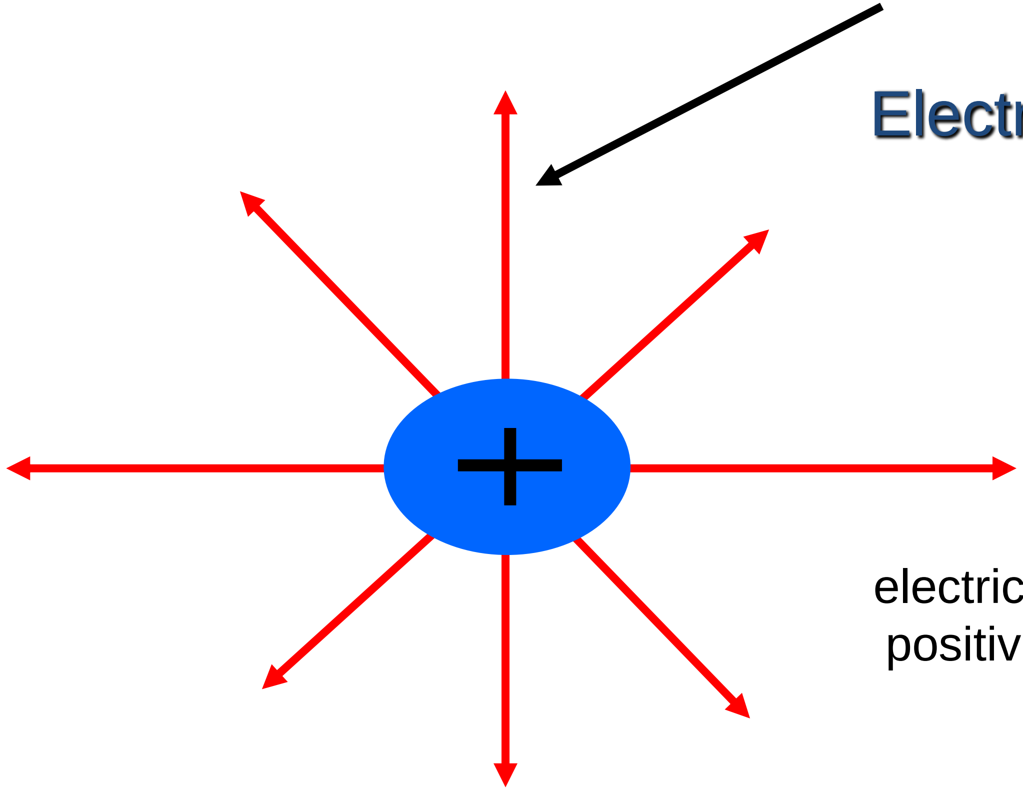
- Electromagnetic (EM) propagation effects of the lower atmosphere on the radar, electronic warfare, or communication systems. The effects are optical interference, diffraction, tropospheric scatter, refraction, evaporation and surface-based ducting, and water vapor absorption under horizontally homogeneous atmospheric conditions.

Elektromanyetik dalgalar vakumda yaklaşık 3.00x10^8 m/s hızla yol alırlar. Bu hız, bir ortamdan bir diğer ortama farklılık göstermesine karşın, bu fark hesaplamalarda ihmal edilir. ***Elektromanyetik ışımanın hızı***, yani ışık hız, c sembolü ile gösterilir. ***Elektromanyetik ışımanın dalga boyu*** ise, genellikle nanometre cinsinden (nm) verilir.



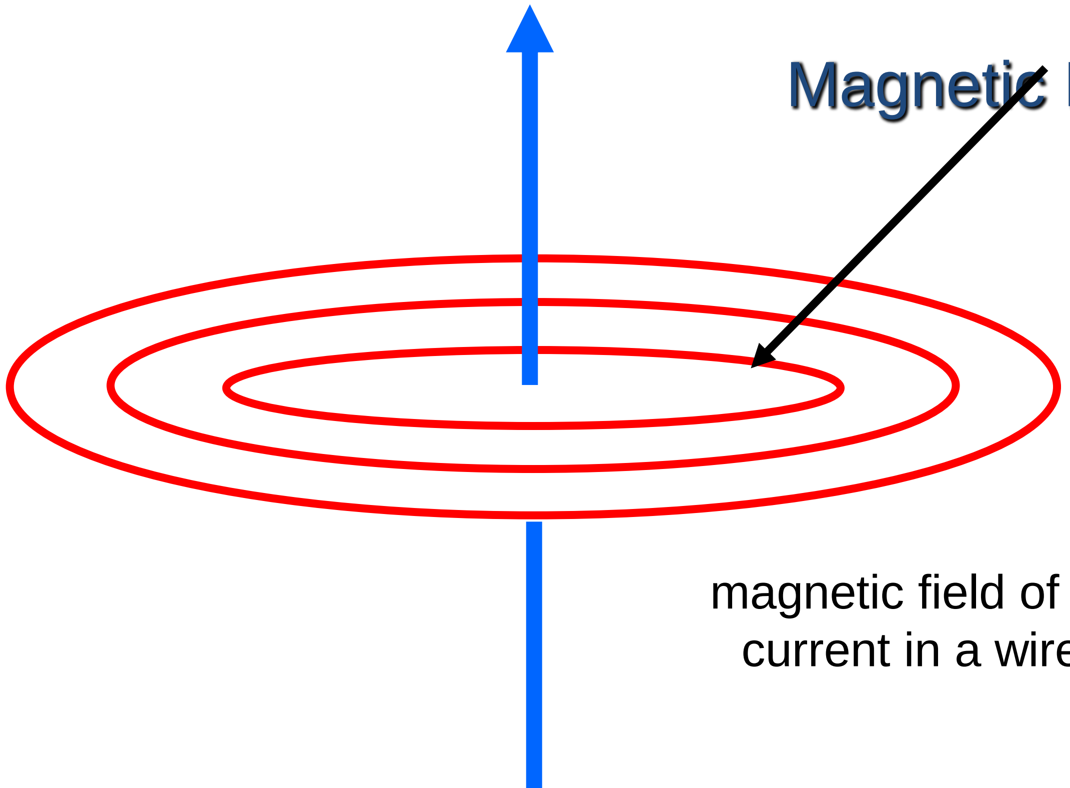
Electromagnetic waves

- EM waves include radio, microwaves, x-rays, light waves, gamma rays, Infrared radiation



Electric Field

electric field of a positive charge



Magnetic Field

magnetic field of a current in a wire

Free space electromagnetic wave

Wave in lossy medium

$$E_x = E_0 e^{-\gamma z} e^{j\omega t} = E_0 \cdot e^{-\alpha z} \cdot e^{-j\beta z} \cdot e^{j\omega t}$$

Attenuation increases with z

Phase varies with z

Periodic time variation

$\gamma = \alpha + j\beta$ Propagation constant

α Attenuation constant

β Phase constant

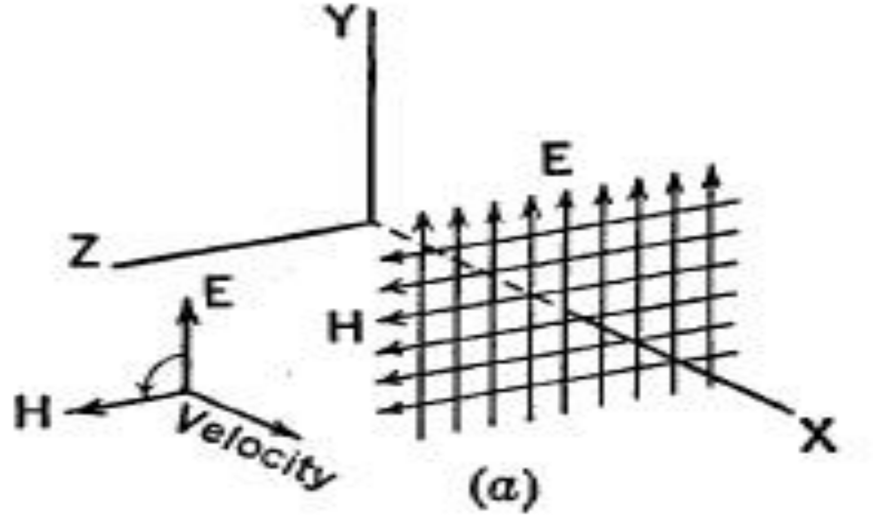
Power flow

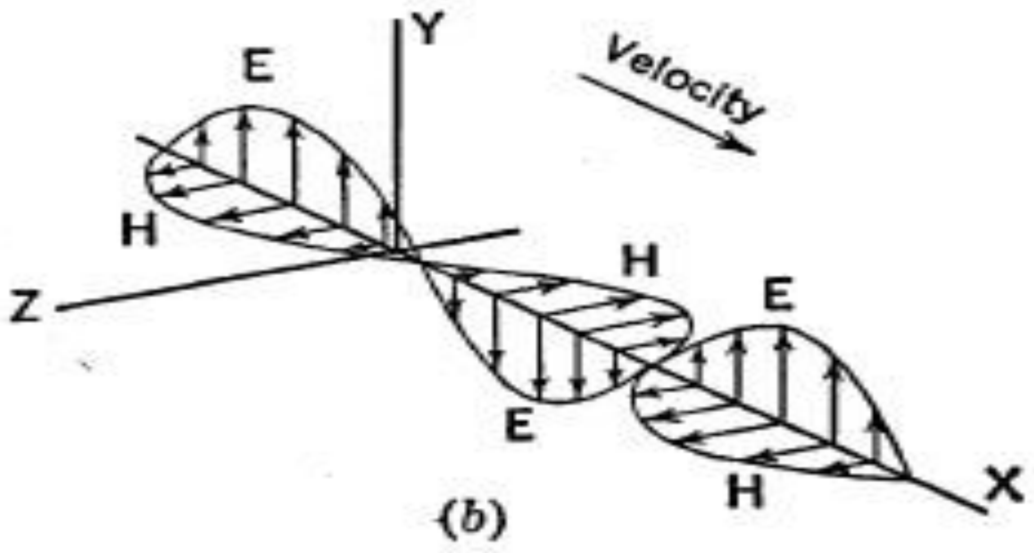
Poynting vector $$\vec{S} = \vec{E} \times \vec{H}$$

Average power density $$S_{av} = \frac{1}{2}\left|E_x\right|^2 \frac{1}{Z_0} = \frac{1}{2}\left|H_y\right|^2 Z_0$$

EM waves in free space

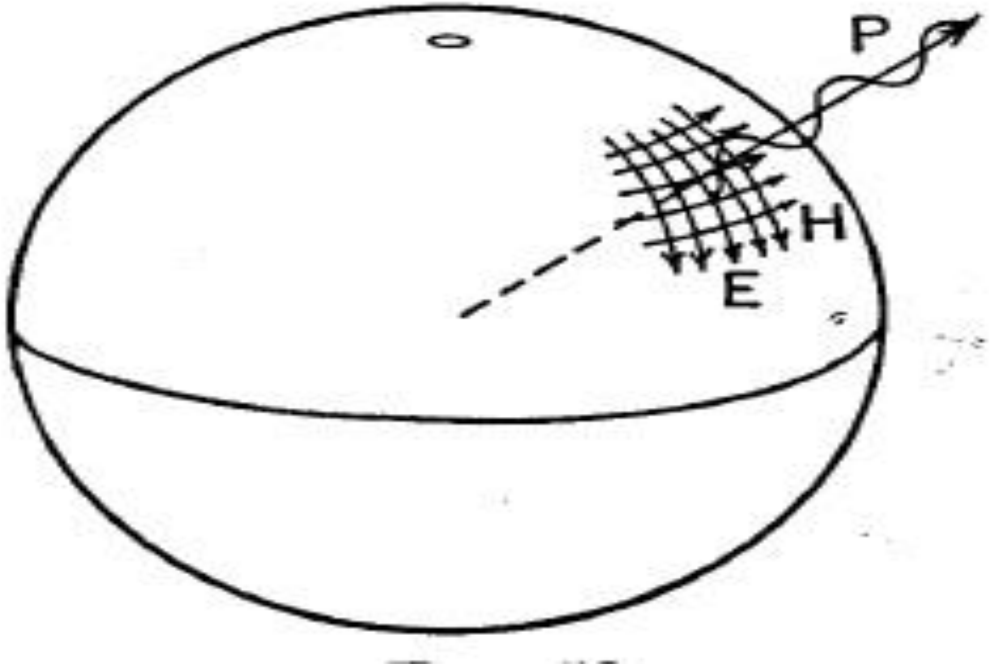
- $C^2 = 1/(\varepsilon_o\mu_o)$ so $C = 3 \times 10^8$ m/s
  - $\varepsilon_o = 8.855 \times 10^{-12}$ Farads/m
  - $\mu_o = 1.2566 \times 10^{-6}$ Henrys/m
- EM waves in free space propagate freely without attenuation
- What is a plane wave?
  - Example is a wave propagating along the x-direction
  - Fields are constant in y and z directions, but vary with time and space along the x-direction
  - Most propagating radio (EM) waves can be thought of a plane waves on the scale of the receiving antenna





E & H fields and Poynting Vector for Power Flow

- Power flow in the EM field
  - **P** = **E** x **H** (**P** is Poynting vector)
    - In free space **E** and **H** are perpendicular
    - **P** is perpendicular to both **E** and **H**
- Plane wave radiated by an antenna
  - **P** = **E** x **H** -> $E_o\ H_o\ \mathrm{Sin}^2(\omega t\text{-}kx)$
  - $P = [E_o^2/\eta]\ \mathrm{Sin}^2(\omega t\text{-}kx)$
  - $\mathbf{P}_{\mathbf{avg}} = (1/2)\ [E_o^2/\eta]$ in W/m^2
  - η = impedance of free space
    = 377 Ω



A wave is a function of both space and time.

$$\frac{d^2E_s}{dz^2} + \beta^2 E_s = 0 \qquad (10.3)$$

where $\beta = \omega/u$ and E_s is the phasor form of E. The solution to eq. (10.3) are

$$E^+ = Ae^{j(\omega t - \beta z)} \qquad (10.4a)$$

$$E^- = Be^{j(\omega t + \beta z)} \qquad (10.4b)$$

$$E = Ae^{j(\omega t - \beta z)} + Be^{j(\omega t + \beta z)} \tag{10.4c}$$

where A and B are real constants.

For the moment, let us consider the solution in eq. (10.4a). Taking the imaginary part of this equation, we have

$$E = A \sin (\omega t - \beta z) \tag{10.5}$$

This is a sine wave chosen for simplicity; a cosine wave would have resulted had we taken the real part of eq. (10.4a). Note the following characteristics of the wave in eq. (10.5):

1. It is time harmonic because we assumed time dependence $e^{j\omega t}$ to arrive at eq. (10.5).
2. A is called the *amplitude* of the wave and has the same units as E.
3. $(\omega t - \beta z)$ is the *phase* (in radians) of the wave; it depends on time t and space variable z.
4. ω is the *angular frequency* (in radians/second); β is the *phase constant* or *wave number* (in radians/meter).

$T = 1/f$, where f is the *frequency* (the number of cycles per second) of the wave in Hertz (Hz). Hence,

$$\boxed{u = f\lambda} \tag{10.6b}$$

Because of this fixed relationship between wavelength and frequency, one can identify the position of a radio station within its band by either the frequency or the wavelength. Usually the frequency is preferred. Also, because

$$\omega = 2\pi f \tag{10.7a}$$

$$\beta = \frac{\omega}{u} \tag{10.7b}$$

and

$$\beta = \frac{2\pi}{\lambda}$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega} \tag{10.7c}$$

Light is a traveling EM wave

So…Maxwell's equations tell us that the velocity of EM wave is equal to the speed of light ⇨ i.e. light travels as an EM wave.

$\lambda = c / f$

λ = wavelength (m)

c = speed of light (m/s)

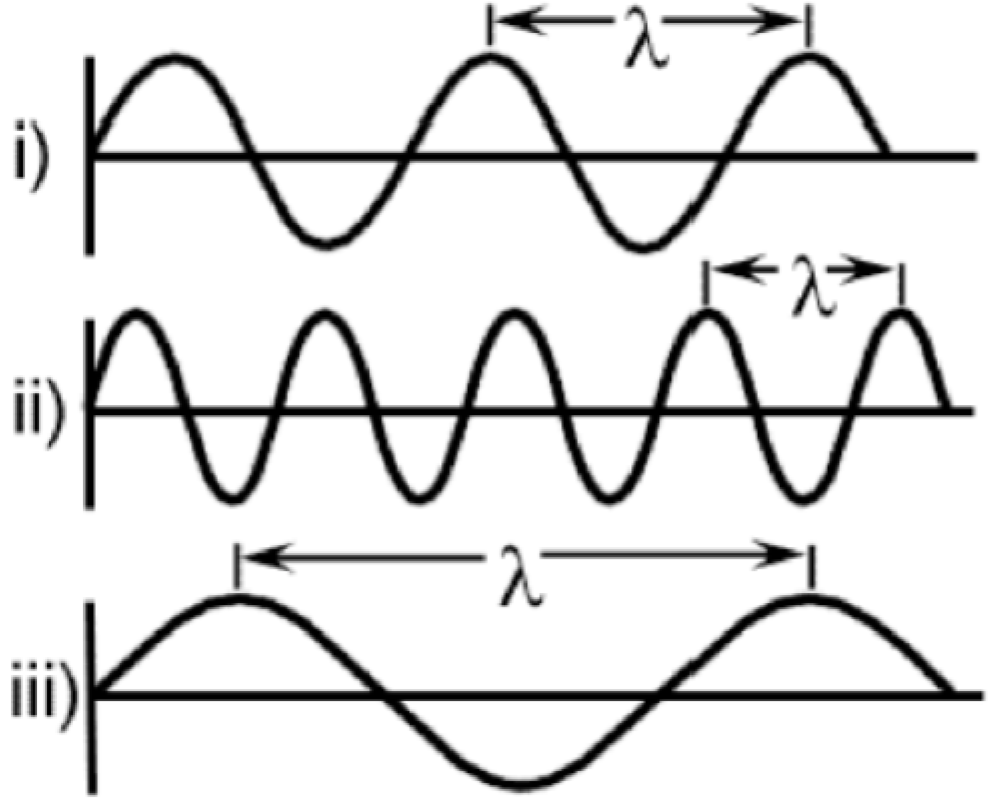
f = frequency (hz or s-1)

c = 300,000 km/s

f = 5.6 GHz; λ = 5.6 cm

f = 1.2 GHz; λ = 24 cm.

λ = 0.4 mm; f = 750 GHz.



Light is a traveling EM wave

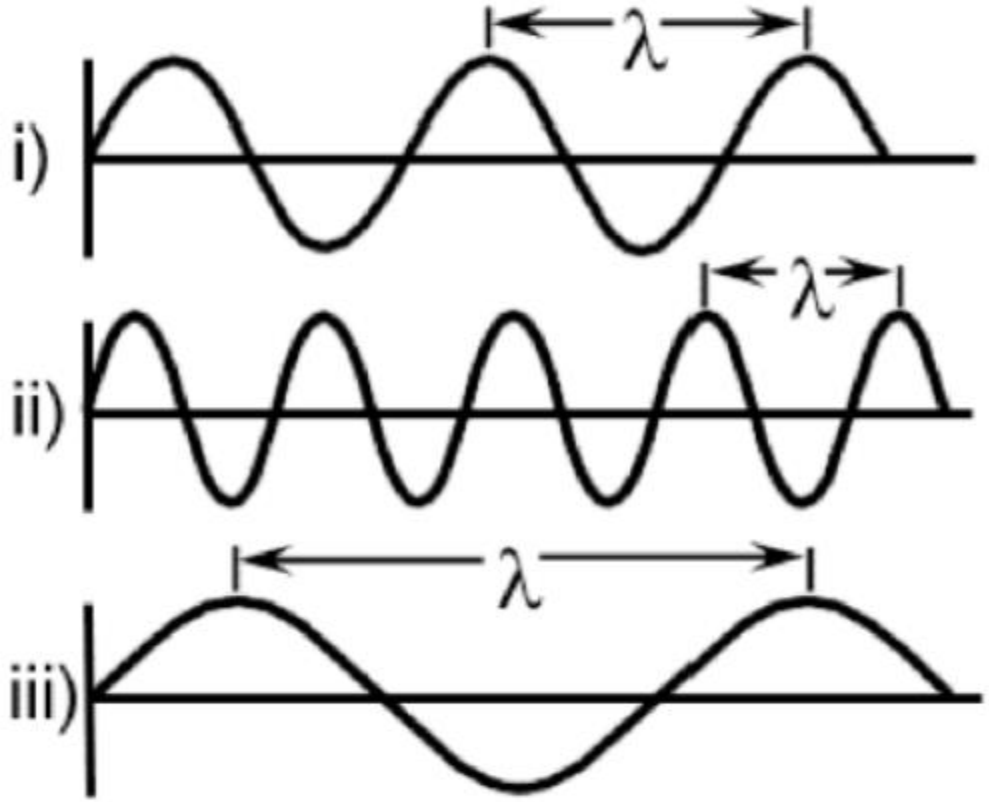
Maxwell's equations also tell us that EM waves don't carry any material with them. They only transport **energy**:

$E = h f = h c / \lambda$

c = speed of light (m/s)
h = Planck's constant.
f = frequency (hz or s^{-1})
λ=wavelength

High-frequency electromagnetic waves have a short wavelength and high energy;

Low-frequency waves have a long wavelength and low energy



The electric field in free space is given by

$$\mathbf{E} = 50 \cos (10^8 t + \beta x) \, \mathbf{a}_y \text{ V/m}$$

(a) Find the direction of wave propagation.

(b) Calculate β and the time it takes to travel a distance of $\lambda/2$.

(c) Sketch the wave at $t = 0$, $T/4$, and $T/2$.

Solution:

(a) From the positive sign in $(\omega t + \beta x)$, we infer that the wave is propagating along $-\mathbf{a}_x$. This will be confirmed in part (c) of this example.

(b) In free space, $u = c$.

$$\beta = \frac{\omega}{c} = \frac{10^8}{3 \times 10^8} = \frac{1}{3}$$

or

$$\beta = 0.3333 \text{ rad/m}$$

If T is the period of the wave, it takes T seconds to travel a distance λ at speed c. Hence to travel a distance of $\lambda/2$ will take

$$t_1 = \frac{T}{2} = \frac{1}{2}\frac{2\pi}{\omega} = \frac{\pi}{10^8} = 31.42 \text{ ns}$$

Alternatively, because the wave is traveling at the speed of light c,

$$\frac{\lambda}{2} = ct_1 \qquad \text{or} \qquad t_1 = \frac{\lambda}{2c}$$

But

$$\lambda = \frac{2\pi}{\beta} = 6\pi$$

Hence,

$$t_1 = \frac{6\pi}{2(3 \times 10^8)} = 31.42 \text{ ns}$$

(c) At $t = 0, \quad E_y = 50 \cos \beta x$

At $t = T/4, E_y = 50 \cos \left(\omega \cdot \frac{2\pi}{4\omega} + \beta x \right) = 50 \cos (\beta x + \pi/2)$

$= -50 \sin \beta x$

At $t = T/2, E_y = 50 \cos \left(\omega \cdot \frac{2\pi}{2\omega} + \beta x \right) = 50 \cos(\beta x + \pi)$

$= -50 \cos \beta x$

E_y at $t = 0, T/4, T/2$ is plotted against x as shown in Figure 10.3. Notice that a point P (arbitrarily selected) on the wave moves along $-\mathbf{a}_x$ as t increases with time. This shows that the wave travels along $-\mathbf{a}_x$.

Problem 1: The electric field amplitude of a uniform plane wave propagating in the $\vec{\mathbf{z}}$ direction in the free-space is 250V/m. If $\mathbf{E} = E_x\vec{\mathbf{x}}$ and ω=1.00Mrad/s, find:

(a) The frequency;

(b) The wavelength;

(c) The period

(d) The wavenumber

(e) The impedance

(f) The amplitude of H_y

(g) The real instantaneous expression of H_y

(h) Repeat (a)~(g) for the same EM wave in glass with refractive index 1.5.

Solutions:

(a) $\omega = 2\pi f \Rightarrow f = \dfrac{\omega}{2\pi} = 1.59 \times 10^5 Hz = 159 kHz$

(b) $f\lambda_0 = c \Rightarrow \lambda_0 = \dfrac{c}{f} = 1.88 \times 10^3 m = 1.88 km$ $\qquad c = \dfrac{1}{\sqrt{\varepsilon_0 \mu_0}} = 3 \times 10^8 \, {}^{m}\!/_{s}$

(c) $T = \dfrac{1}{f} = 6.28 \times 10^{-6} s = 6.28 \mu s$

(d) $\beta_0 = \dfrac{2\pi}{\lambda_0} = \dfrac{\omega}{c} = 0.033 rad / \text{m}$

(e) $\eta_0 = \dfrac{E_x}{H_y} = \sqrt{\dfrac{\mu_0}{\varepsilon_0}} = \sqrt{\dfrac{4\pi \times 10^{-7}}{8.857 \times 10^{-12}}} = 376.7\Omega$

(f) $\eta_0 = \frac{E_x}{H_y} \Rightarrow \hat{H}_y = \frac{\hat{E}_x}{\eta_0} = 0.664 \, A/m$

(g) $H_y = 0.664\cos(10^6 t - 0.033z) \, A/m$

(h) $f = 159kHz \, , T = 6.28\mu s$ (not change) $\qquad v = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{c}{n} = 2\times10^8 \, m/s$

$$f\lambda_m = v \Rightarrow \lambda_m = \frac{v}{f} = \frac{\lambda_0}{n} = 1.26\times10^3 m = 1.26km$$

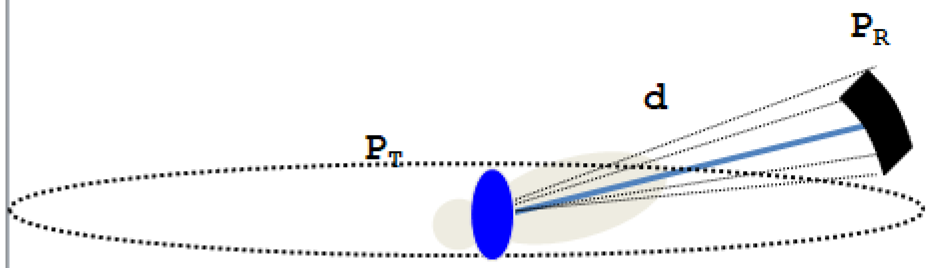
$$\beta_m = \frac{2\pi}{\lambda_m} = \frac{\omega}{v} = n\beta_0 = 0.05rad/\mathrm{m}$$

$$\eta_m = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_0\mu_r}{\varepsilon_0\varepsilon_r}} = \sqrt{\frac{\mu_0}{\varepsilon_0 n^2}} = \frac{\eta_0}{n} = 251.1\Omega$$

$$\hat{H}_y = \frac{\hat{E}_x}{\eta_m} = 0.996 \, A/m \qquad H_y = 0.996\cos(10^6 t - 0.05z) \, A/m$$

Free space loss Propagation

Free Space Propagation Model



$$P_{Di} = \frac{P_T}{4\pi d^2} W/m^2$$

Isotropic power density

$$P_D = \frac{P_T G_T}{4\pi d^2}$$

Power density along the direction of maximum radiation

$$P_R = P_D A_{eff}$$

Power received by Antenna

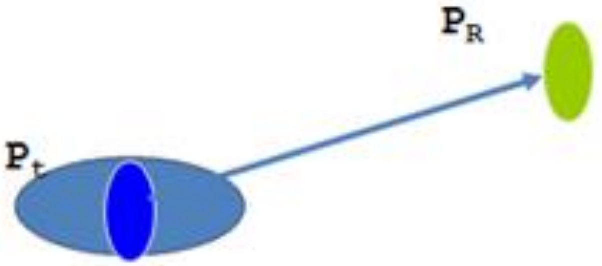
$$P_R = \frac{P_T G_T}{4\pi d^2} A_{eff} \qquad \frac{A_{eff}}{G} = \frac{\lambda^2}{4\pi}$$

Predict received signal strength when the transmitter and receiver have a clear line-of-sight path between them

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

Also known as Friis free space formula

Path Loss (relative measure)



$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2$$

$$\frac{P_R}{P_T} = G_T G_R \frac{0.57 * 10^{-3}}{(df)^2}$$

f is in MHz
d is in Km

$$\left(\frac{P_R}{P_T} \right)_{dB} = (G_T)_{dB} + (G_R)_{dB} - (32.5 - 20 \log_{10} d - 20 \log_{10} f)$$

Path Loss represents signal attenuation (measured on dB) between the effective transmitted power and the receive power (excluding antenna gains)

Elektromagnetik dalga yayınım

$$P_r = P_t\, G_t\, L_t\, G_r\, L_r\, (\frac{\lambda}{4\pi R})^2$$

Burada

P_r: alış güç seviyesi, (Watt)

P_d: alış güç yoğunluğu, (W/m^2)

P_t: verici çıkış gücü, (Watt)

G_t: verici anten kazancı, (numerik),

L_t: verici tarafta hat kaybı, (numerik),

G_r: alıcı anten kazancı (numerik),

L_r: alıcı tarafta hat kaybı (numerik),

R: Alıcı verici antenler arasındaki uzaklık (metre),

$$\lambda = \frac{c}{f}$$

Burada

λ: dalga uzunluğu, (metre),

c=ışık hızı=3 x 10^8m/s

f=frekans, (Hz=1/s) dir.

Elektromagnetik dalga yayınım

Denklem logaritmik olarak düzenlenirse, Pr, dBm cinsinden aşağıdaki biçimde yazılır.

$P_r = P_t + G_t + G_r - L_t - L_r - FSL$ (2)

FSL: terim serbest uzay yol kaybı olarak adlandırılır.

FSL= $32.45 + 20\log(R_{km} \times f_{MHz})$

Verici antenden R m uzaktaki güç yoğunluğu

$$P_d = \frac{P_t G_t L_t}{4\pi R^2} \quad W/m^2 \qquad (3)$$

Serbest uzaydaki uzak alanda elektrpmagnetik dalganın taşıdığı güç yoğunluğu elektrik alan şiddetinden de hesaplanır.

$$P_d = \frac{E^2}{\eta_0} = \frac{E^2}{120\pi} \quad W/m^2 \qquad (4)$$

Electric and Magnetic Fields

- For waves we use the following units:
  - Electric field strength **E** (V/m) Magnetic field strength **H** (A/m) Power density P_D (W/m^2)
  - Ohm's law holds if characteristic impedance Z of medium is used
- For free space, Z = 377 Ohm

Ohm's Law in Space

$$Z = E / H$$

Power Density

$$P_D = \frac{E^2}{Z} = H^2 Z = EH$$

Attenuation of Free Space

- Power stays the same but power density is reduced with increasing distance r
- Power density is total power divided by surface area of sphere
- Unit: watts/meter

$$P_D = \frac{P_t}{4\pi r^2}$$

Free Space Electric Field

- **Electric field strength is relatively easy to measure**
- **Often used to specify signal strength**
- **Unit: volts/meter**

$$E = \sqrt{\frac{30P_t}{r}}$$

e.i.r.p.

- Equivalent Isotropically Radiated Power (in a given direction):

$$e.i.r.p. = PG_i$$

- The product of the power supplied to the antenna and the antenna gain (relative to an isotropic antenna) in a given direction

Electromagnetic Spectrum
Frekans Planlama

The Electromagnetic Spectrum

The range of electromagnetic signals encompassing all frequencies is referred to as the electromagnetic spectrum.

- A signal is located on the frequency spectrum according to its frequency and wavelength.

Frequency is the number of cycles of a repetitive wave that occur in a given period of time.

- A cycle consists of two voltage polarity reversals, current reversals, or electromagnetic field oscillations.
- Frequency is measured in cycles per second (cps).
- The unit of frequency is the hertz (Hz).

Wavelength is the distance occupied by one cycle of a wave and is usually expressed in meters.

- Wavelength is also the distance traveled by an electromagnetic wave during the time of one cycle.
- The wavelength of a signal is represented by the Greek letter lambda (λ).

Wavelength (λ) = speed of light ÷ frequency

Speed of light = 3×10^8 meters/second

Therefore:

$\lambda = 3 \times 10^8 / f$

Example:
What is the wavelength if the frequency is 4MHz?

$\lambda = 3 \times 10^8 / 4$ MHz

= 75 meters (m)

The Electromagnetic Spectrum

- The EM spectrum is the ENTIRE range of EM waves in order of increasing frequency and decreasing wavelength.
- As you go from left → right, the wavelengths get smaller and the frequencies get higher. This is an inverse relationship between wave size and frequency. (As one goes up, the other goes down.) This is because the speed of ALL EM waves is the speed of light (300,000 km/s).
- The higher the frequency, the more energy the wave has.
- EM waves do not require media in which to travel or move.
- EM waves are considered to be transverse waves because they are made of vibrating electric and magnetic fields at right angles to each other, and to the direction the waves are traveling.
- Inverse relationship between wave size and frequency: as wavelengths get smaller, frequencies get higher.

Radio waves: Have the longest wavelengths and the lowest frequencies; wavelengths range from 1000s of meters to .001 m

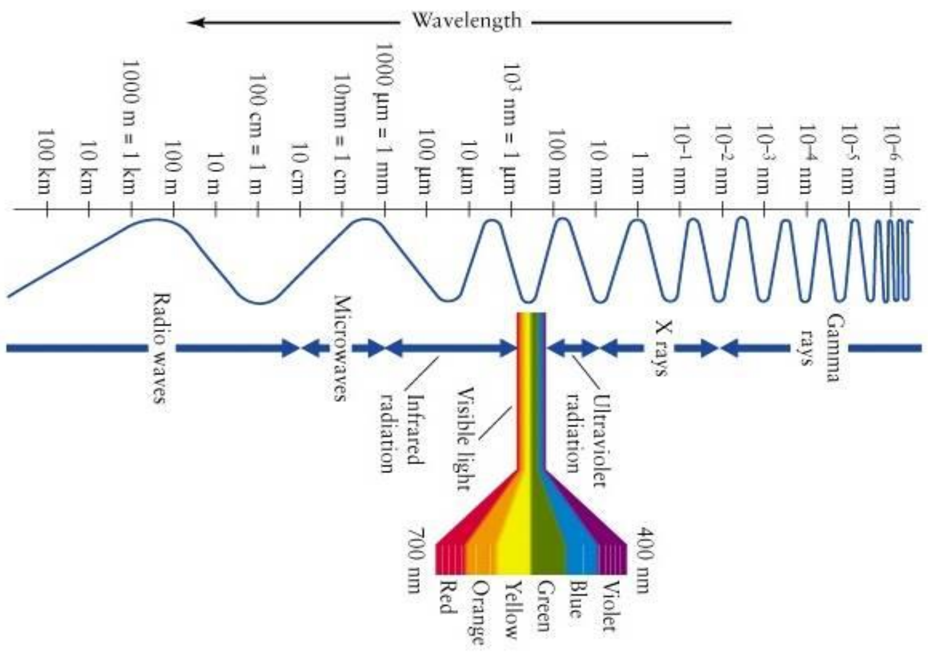
- Used in: RADAR, cooking food, satellite transmissions

Infrared waves (heat): Have a shorter wavelength, from .001 m to 700 nm, and therefore, a higher frequency.

- Used for finding people in the dark and in TV remote control devices

Visible light: Wavelengths range from 700 nm (red light) to 30 nm (violet light) with frequencies higher than infrared waves.

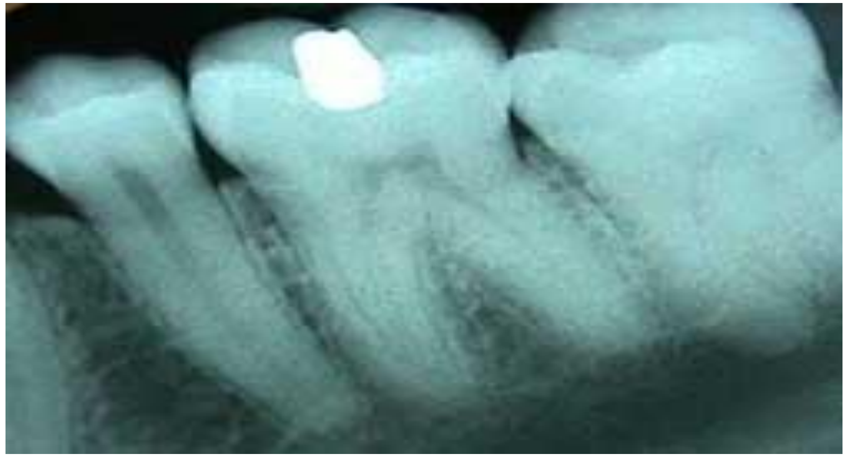
- These are the waves in the EM spectrum that humans can see.
- Visible light waves are a very small part of the EM spectrum!



Ultraviolet Light: Wavelengths range from 400 nm to 10 nm; the frequency (and therefore the energy) is high enough with UV rays to penetrate living cells and cause them damage.

- UV ışığını görememize rağmen, arılar, yarasalar, kelebekler, bazı küçük kemirgenler ve kuşlar görebiliyor.
- Cildimizdeki UV vücudumuzda D vitamini üretir. Çok fazla UV güneş yanığı ve cilt kanserine neden olabilir. UV ışınları giysilerle kolayca engellenir.
- Sterilizasyon için kullanılır çünkü bakterileri öldürürler.

X-Rays: Wavelengths from 10 nm to .001 nm. These rays have enough energy to penetrate deep into tissues and cause damage to cells; are stopped by dense materials, such as bone.

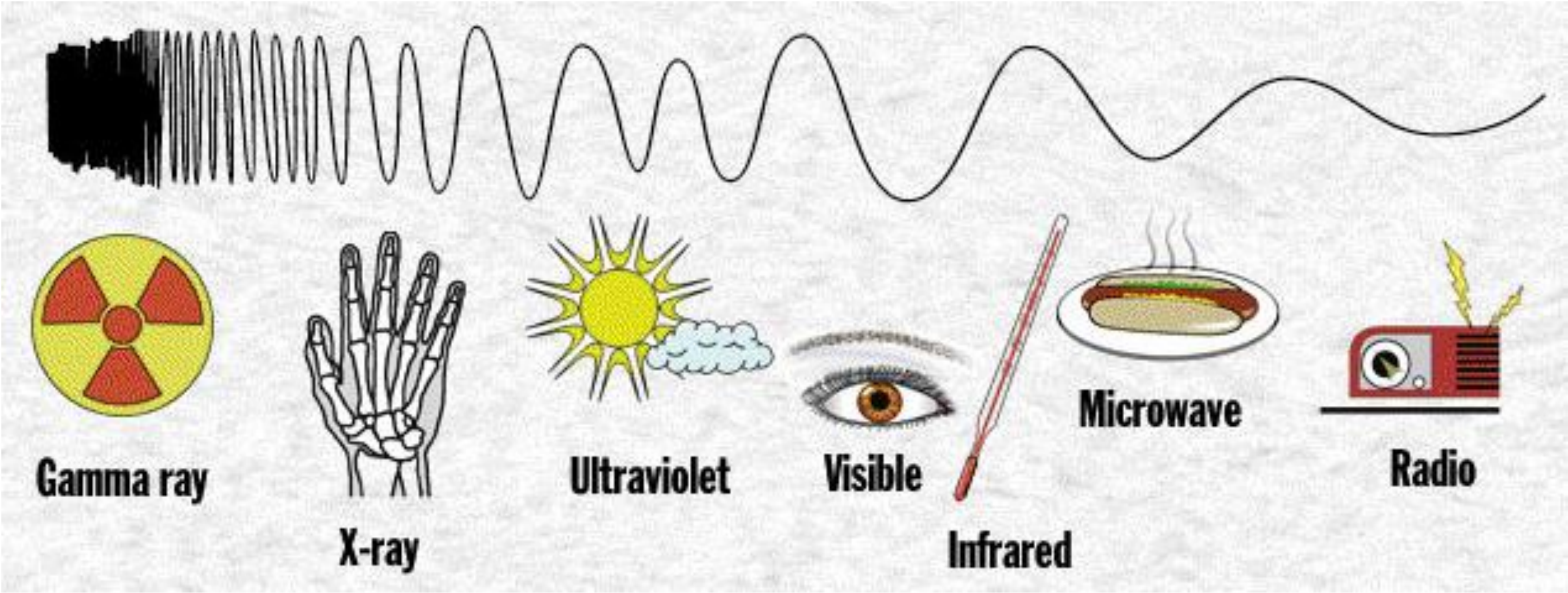


- Used to look at solid structures, such as bones and bridges (for cracks), and for treatment of cancer.

Gamma Rays: En fazla enerjiyi taşıyan ve en kısa dalga boylarına sahip, metrenin bir trilyonundan (10-12) daha az.

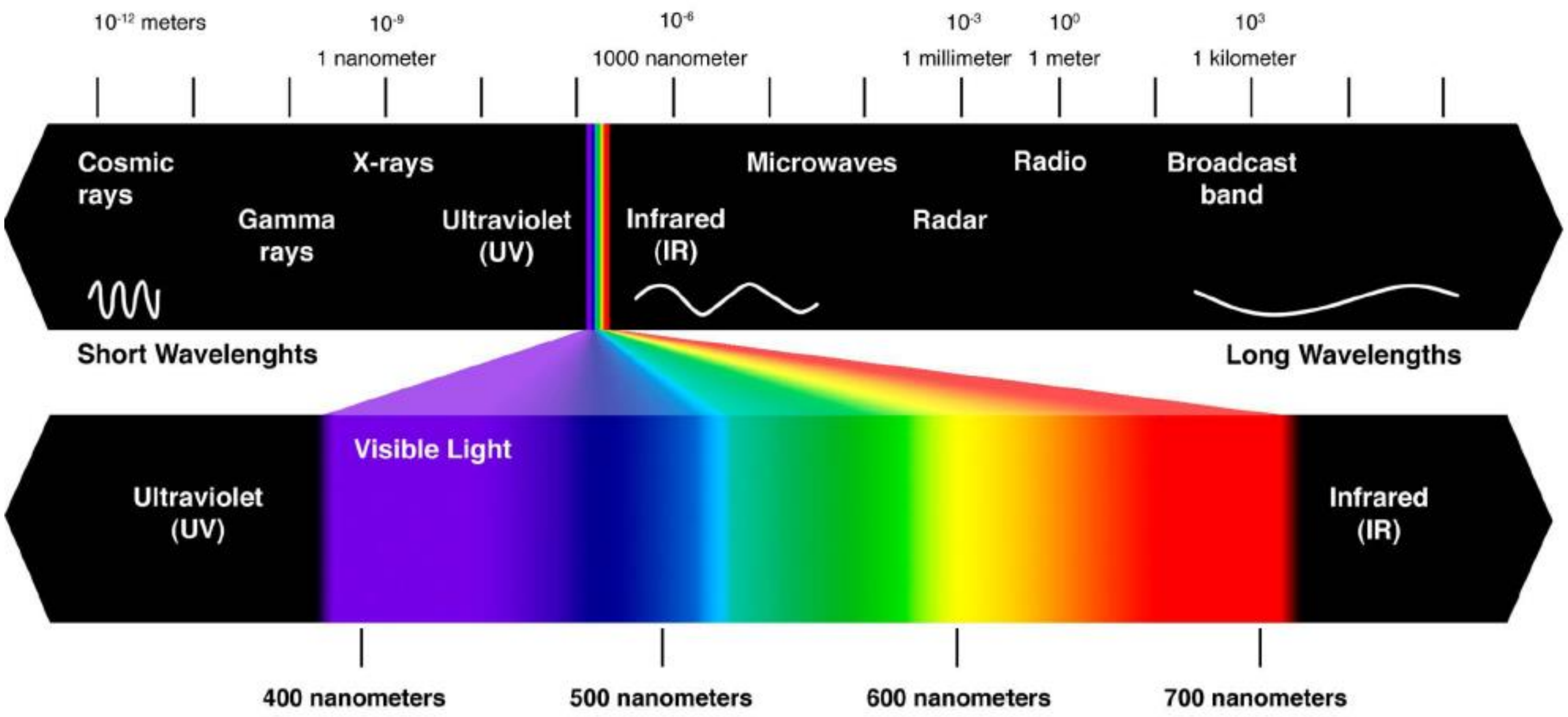
- Gama ışınları çoğu malzemeden kolayca geçebilecek kadar enerjiye sahiptir; onları durdurmak için 3-4 ft kalınlığında bir beton duvara ihtiyacınız olacak!
- Gama ışınları, nükleer santrallerdeki nükleer reaksiyonlar, nükleer bombalar ve yeryüzünde doğal olarak meydana gelen elementler tarafından salınır.
- Bazen kanserlerin tedavisinde kullanılır.

The Electromagnetic Spectrum

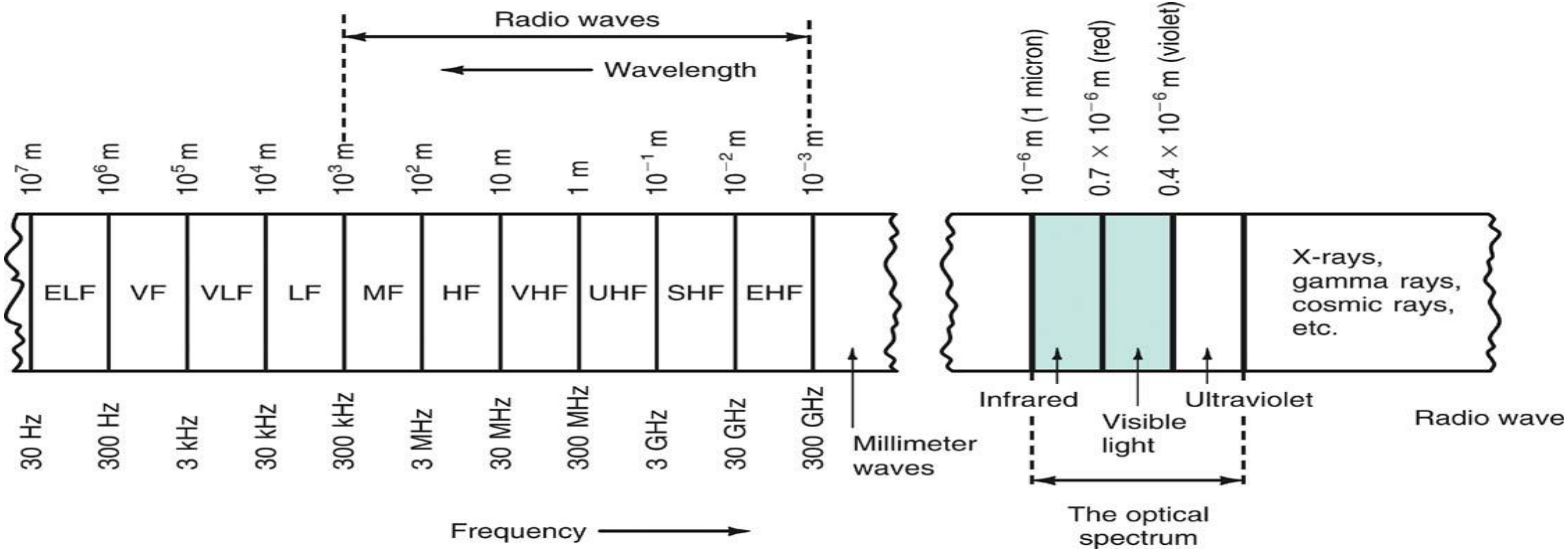


An electromagnetic wave consists of electric and magnetic fields which vibrate - thus making waves.
Short wavelengths have a high frequency. Long wavelengths have a low frequency.
High frequency waves have high energy. Low frequency waves have low energy.

The electromagnetic spectrum



The Electromagnetic Spectrum



The electromagnetic spectrum.

Frequency Spectrum Range

- General Radio Frequency Spectrum
  - 30 - 300 Hz Extremely Low Frequency (ELF)
  - 300 - 3 kHz Voice Frequency (VF)
  - 3 - 30 kHz Very Low Frequency (VLF)
  - 30 - 300 kHz Low Frequency (LF)
  - 300 - 3 MHz Medium Wave Frequency (MW)
  - 3 - 3 0 MHz Short Wave Frequency (SW)
  - 30 - 300 MHz Very High Frequency (VHF)
  - 300 - 3000 MHz Ultra High Frequency (UHF)
  - 3 - 30 GHz Super High Frequency (SHF)
  - 30 - 300 GHz Extremely High Frequency (EHF)
- Microwave Spectrum
  - 0.3 GHz to 3000 GHz

- **Depending on the frequency range bands are designated for operating reasons**
  - L Band 1 to 2 GHz
  - S Band 2 to 4 GHz
  - C Band 4 to 8 GHz (Satellite TV channels)
  - X Band 8 to 12 GHz (Lab purposes)
  - Ku Band 12 to 18 GHz
  - K Band 18 to 26 GHz
  - Ka Band 26 to 40 GHz (Water vapour)
  - Q Band 30 to 50 GHz
  - U Band 40 to 60 GHz
  - V Band 46 to 56 GHz
  - W Band 56 to 100 GHz and even higher (Atmospheric studies)

BROAD USAGE

- **AM radio**: 535 - 1,700 kHz (0.535 - 1.7 MHz)
- **Short wave** - 5.9 - 26.1 MHz
- **Citizens band (CB) radio** - 27 MHz.
- **FM radio**: 88 - 108 MHz.
- **Television** - 54 - 220 MHz.
- **Microwave band:** 0.3 to 300 GHz
  - **Mobile phones**: 824 - 849 MHz
  - **Global Positioning System**: 1.2 -1.6 GHz
  - **Blue tooth devices:** Around 2.4 GHz
  - **RADAR: Weather Military**
  - **Satellite Communication**
  - **Long distance trunk telephone**
  - **Microwave oven:** 2.45 GHz

MICROWAVE RADIO

- 1.7 – 2.7 GHz: Personal Commn. System
- 3.8 – 4.2 GHz: Public Operator Band (TV downlink)
- 5.9 – 7.1 GHz: Public Operator Band (TV uplink)
- 7.1 – 8.5 GHz: Long distance
- 10.7 – 11.7 GHz: Public Operator Band
- 12.7 – 13.3, 14.4 – 15.4, 21.2 – 23.6, 24.5 – 26.5, 37 – 39.5 GHz: Communication channel
- 17.7 – 19.7 GHz: Public Operator Band

General Frequency Ranges

- **Microwave frequency range**
  - 1 GHz to 300 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- **Radio frequency range**
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- **Infrared frequency range**
  - Roughly, 3×10^{11} to 2×10^{14} Hz
  - Useful in local point-to-point multipoint applications within confined areas

Kaynaklar

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- Lecture notes from internet.

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Sincerely,

Dr. Cahit Karakuş

cahitkarakus@gmail.com

thank you