جمهورية العراق
وزارة التعليم العالي و البحث العلمي
جامعة بغداد
كلية العلوم
قسم الفلك و الفضاء

محاضرات علمية لمختبر

الفلك الراديوي I

Radio Astronomy I Lab.

المرحلة الرابعة / قسم الفلك والفضاء

العام الدراسي 2023-2024

الفصل الدراسي الاول

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Department of Astronomy and Space

First Semester

Radio Astronomy Lab.

Fourth Class

-Name of Experminet/First Course:

1. Calculate the distance for travelling radio wave.
2. Calculate the wavelength and the frequency of the radio wave using multi frequencies (Hz, KHz, MHz and GHz).
3. Calculate the wavelength and the frequency of Jupiter's Decametric emission (DAM).
4. Calculate the flux density from the data of radio Jove archive.
5. Calculate the flux density of Jupiter from the data of radio Jove archive.
6. Calculate the flux density of the Sun from the data of radio Jove archive.
7. Explain the oscilloscope Demonstration.
8. Explain the Function Generator Demonstration.

- Equipments that used in Lab.:

1. Computers+UPS.
2. Oscilloscope.
3. Function generator.

Experiment No.(1)

Electromagnetic Radio Wave

-Equipment: Computer using Q.B. program.

-Aim: Calculate the distance for travelling radio wave.

-Theory:

One of the most important areas of the science known as physics is the study of waves. Throwing a rock into a quiet pond create a common example of waves that is easy to see. After the splash, small waves, or ripples, move outward from the point where the rock hit the water. These waves propagate, or move on their own, outward. They move at a seemingly constant speed until they reach shore or just fade away. These ripples demonstrate some key features of waves:

1. Waves require energy to be created. The source of the wave energy was kinetic energy from the rock.

2. Waves can carry energy. Some of the kinetic energy of the rock was given to the leaf after being carried by the waves.

3.Waves propagate on their own. While the rock falls to the bottom and sits there, the waves move outward after they are created with no additional push required.

Field is a physics term for a region that is under the influence of some force that can act on matter within that region. For example, the Sun produces a gravitational field that attracts the planets in the solar system and thus influences their orbits. Stationary electric charges produce electric fields, whereas moving electric charges produce both electric and magnetic fields. Regularly repeating changes in these fields produce what we call electromagnetic radiation. Electromagnetic radiation transports energy from point to point. This radiation propagates (moves) through space at 299,792 km per second (about 186,000 miles per second). That is, it travels at the speed of light. Indeed light is just one form of electromagnetic radiation. Some other forms of electromagnetic radiation are X-rays, microwaves, infrared radiation, AM and FM radio waves, and ultraviolet radiation. The properties of electromagnetic radiation depend strongly on its frequency. Frequency is the rate at which the radiating electromagnetic field is oscillating. Frequencies of electromagnetic radiation are given in Hertz (Hz), named for Heinrich Hertz (1857-1894), the first person to generate radio waves. One Hertz is one cycle per second.

The Electromagnetic Spectrum

Light is electromagnetic radiation at those frequencies to which human eyes (and those of most other sighted species) happen to be sensitive. But the electromagnetic spectrum has no upper or lower limit of frequencies. It certainly has a much broader range of frequencies than the human eye can detect. In order of increasing frequency (and decreasing wavelength), the electromagnetic spectrum includes radio frequency (RF), infrared (IR, meaning “below red”), visible light, ultraviolet (UV, meaning “above violet”), X-rays, and gamma rays. These designations describe only different frequencies of the same phenomenon: electromagnetic radiation. The frequencies shown in the following two diagrams are within range of those generated by common sources and observable using common detectors. Ranges such as microwaves, infrared, etc., overlap. They are categorized in spectrum charts by the artificial techniques we use to produce them, see figure (1).

Radio waves like all electromagnetic waves travel at the speed of light. The standard symbol for the speed of light is $c=3\times10^{8}$m/s. Since radio waves travel in a constant speed, the distance travel is given by:

$$d=c\times t \quad \ldots\ldots\ldots(1.1A)$$

Where:

d:is the distance for radio wave to reach the Earth.

c:is the speed of light.

t:is time required for radio wave to reach the Earth, measure in days and decimals.

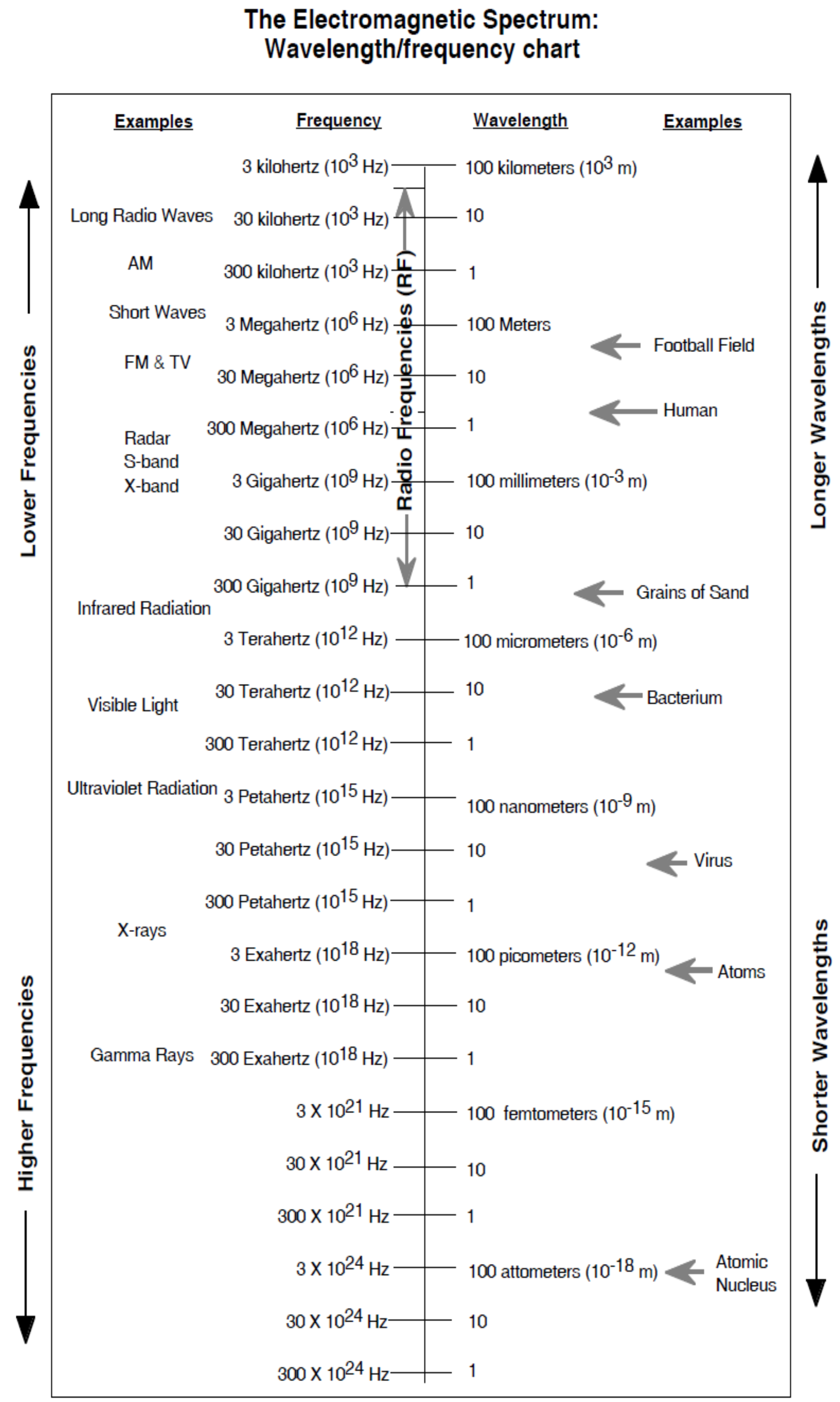

Figure (1): The Bands of Electromagnetic Spectrum.

-Procedure:

According to eq.(1.1A) the only constant is the speed of light that is, c=3 $\times 10^8$ m/s, that is input by the user. The user can also input the distance or time of the radio wave according to the question.

In our program the user will input:

1. The speed of light, that is constant value, c=3 $\times 10^8$ m/s.

2.The time of radio wave to reach the Earth , there were multi form of time unit for time, he should convert it to second unit (time measured in days and decimals) to match the unit of the speed of light. The output of the program will be the distance of radio wave to reach the Earth, measured in meter unit.

-Problems:

1.How far does a radio wave travel in 5 minutes? (answer:9 $\times 10^{10}$m).

2.How far does a radio wave travel in 20 seconds? (answer:6 $\times 10^{9}$m).

3.How far does a radio wave travel in 30 minutes? (answer:5.4 $\times 10^{11}$m).

4.How far does a radio wave travel in 4 hours? (answer:4.32 $\times 10^{12}$m).

5.How far does a radio wave travel in 2 days? (answer:5.18 $\times 10^{13}$m).

6.How long does it take radio waves to travel from Earth to Moon, a distance of 400000 km? (answer:1.33 second).

Example:

1. How long does it take radio waves to travel from Mars to Earth when Earth and Mars are on the same side of the Sun? (See figure (2)).

In this example, we calculate the time required for radio wave to travel from Mars to Earth, the user must input:

1. Orbit radius of Mars $R_M \approx 2.28 \times 10^{11}$m.

2. Orbit radius of Earth $R_E \approx 1.50 \times 10^{11}$m.

Then subtract (Orbit radius of Mars from Orbit radius of Earth) according to equation (1.2A), then the user used eq.(1.1A) to measure the time of radio wave to reach the Earth in second unit.

$$d = R_M - R_E \quad \text{.....(1.2A)}$$

$d=2.28 \times 10^{11}-1.50 \times 10^{11}$

$d=7.8 \times 10^{10}$

$t=d/c$

$t=7.8 \times 10^{10}/3 \times 10^{8}$, t=260 second.

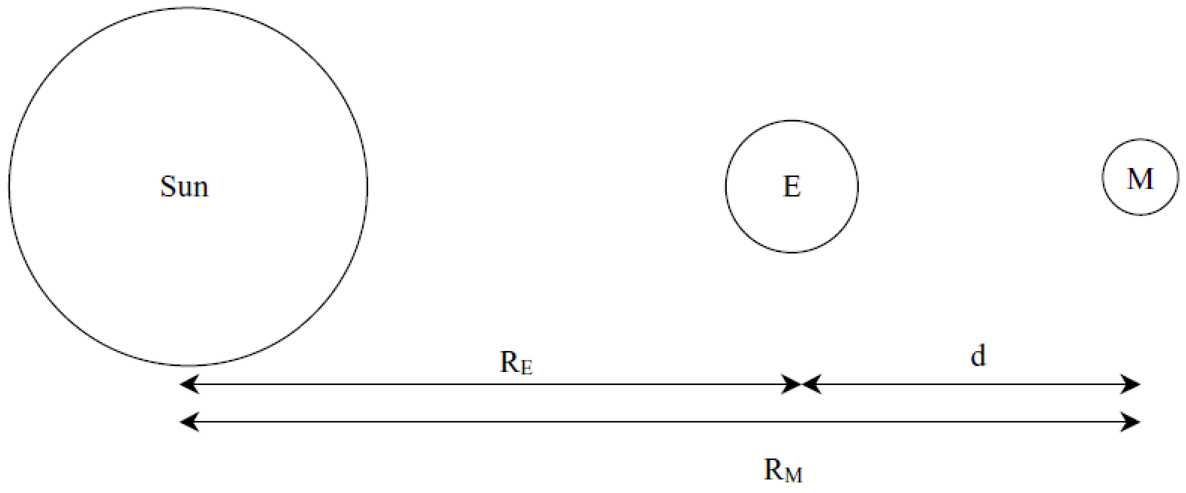

Figure (2): The distance of the planets with respect to the Sun.

Use the following table below for the problems:

Planet	Radius of the Orbit (km)
Mercury	57910000
Venus	108200000
Earth	149600000
Mars	227940000
Jupiter	778330000
Saturn	1429400000

In the following problems assume that the planets are on the same side of the Sun (as close to one another as possible).

-Problems:

1.How long would it take radio waves to travel from Jupiter to Mars? (answer:1.83×10^{3} second).

2.How long would it take radio waves to travel from Jupiter to Venus? (answer:2.23×10^{3} second).

3.How long would it take radio waves to travel from Jupiter to Saturn? (answer:2.17×10^{3} second).

4.How long would it take radio waves to travel from Mercury to Mars?(answer:5.6×10^{2} second).

Radio Astronomy Lab.

Exp. (2)

Study of Planck's Radiation Law using Different Temperatures

Aim: Investigating of Planck's radiation law as a function of a radio wavelength using different temperatures.

Introduction

All objects at temperatures above absolute zero radiate energy in the form of electromagnetic waves. Not only do objects radiate electromagnetic energy, but they also may absorb or reflect such energy incident on them. Kirchhoff (1859) showed that a good absorber of electromagnetic energy is also a good radiator. A perfect absorber is called a *blackbody*, and it follows that such a body is also a perfect radiator. A blackbody absorbs all the radiation falling upon it at all wavelengths, and the radiation from it is a function of only the temperature and wavelength. Such a body is an idealization, since no body having this property exists. However, some bodies made of carbon or lampblack absorb most of the incident radiation in the visible and infrared part of the spectrum and closely approximate an ideal blackbody over this wavelength region. A blackbody may be approximated by the hole in the wall of a box or enclosure at a uniform temperature *T*. Radiation falling on the hole from outside passes through it into the box and is completely absorbed by multiple reflections from the inside walls, except for the small fraction of radiation reflected back out the hole. However, this fraction will be negligible if the hole is sufficiently small compared to the other dimensions of the box. The radiation which does emerge from the hole is characteristic of a blackbody radiator at a temperature *T*. To reduce edge effects, the hole should be large compared to the wavelength and the box large compared to the hole. The brightness of the radiation from a blackbody is given by *Planck's* *radiation law*. This law, formulated by Max Planck (1901), states that the brightness of a blackbody radiator at a temperature *T* and frequency *v* is expressed by

$$B = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1} \qquad (1)$$

Equation (1) could be also written in term of wavelength as given by:

$$B_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/kT\lambda} - 1} \qquad (2)$$

where B_λ = brightness of blackbody radiator in terms of unit wavelength, watts m^{-2} m^{-1} rad^{-2}
h = Planck's constant (= 6.63×10^{-34} joule sec)
c = velocity of light (= 3×10^8 m sec^{-1})
λ = wavelength, m
k = Boltzmann's constant (= 1.38×10^{-23} joule K^{-1})
T = temperature, K

The brightness *B* for a blackbody radiator at four temperatures is shown graphically in Fig. 1.

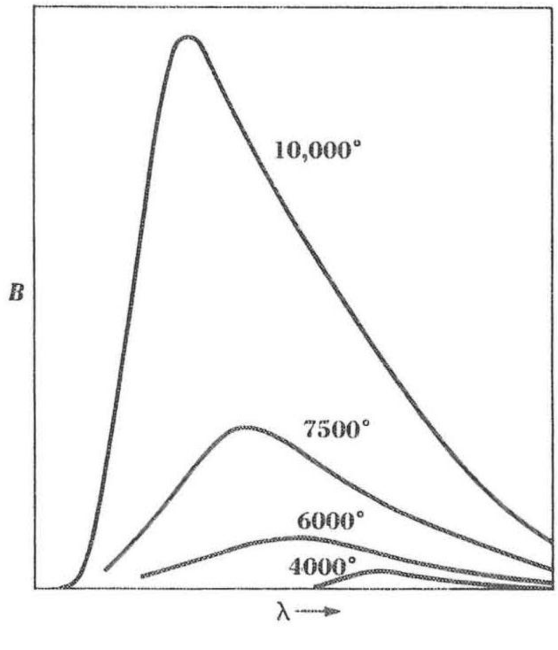

Fig. 1. Planck-radiation-law curves for a blackbody radiator as a function of wavelength at four temperatures.

Methodology

- Set the certain range of wavelength in unit (m). For example, (0.2-1) m.
- Compute the brightness (*B*) using eq. (2).
- Take different values of temperatures (at less three input values for temperature).
- Complete the following table.

No.	T_1= (K)		T_2= (K)	T_3= (K)
	λ (m)	B (watts m^{-3} rad^{-2})	B (watts m^{-3} rad^{-2})	B (watts m^{-3} rad^{-2})
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

- Plot *B* as a function of the wavelength (λ).

Questions

- Define the brightness.
- Which is dominant in equation (2), the temperature or the wavelength?
- Does the brightness in radio band larger than the brightness in visible band, and Why?
- Discuss your results.

Radio Astronomy Lab.

Exp. (3)

Study the Polarization for Radio Waves

Aims:

- Study the polarization principle of the radio waves.
- Investigation the linear and circular polarization for radio waves.
- Apply the first Stokes parameters (*I*).

Introduction

Since an electromagnetic wave is a transverse wave, the electric or magnetic field vector in the wave oscillates along a certain direction within a plane which is perpendicular to the direction of the propagation, and moves with the wave, such a wave is said to be "polarized". The polarization is the direction of the electric field in the propagating electromagnetic wave (see Figure 1).

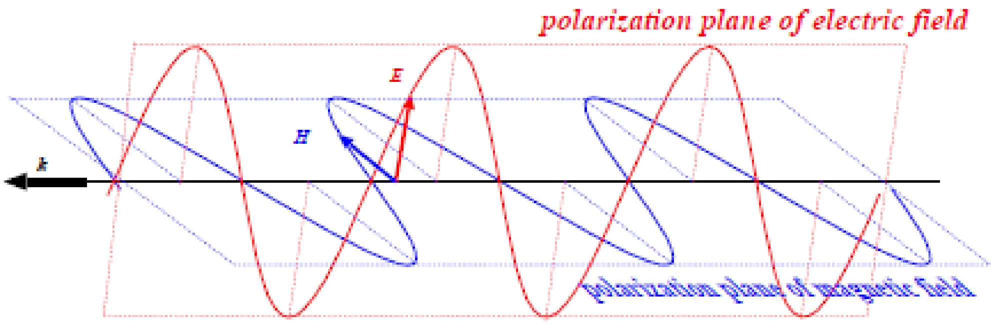

Figure 1: An electromagnetic wave as a polarized wave.

the electric field vector can also oscillate in the ±x-direction and the magnetic field vector then would oscillate in the ±y-direction. In fact, the electric field can oscillate in any other direction in the xy-plane, while the magnetic field oscillates along the perpendicular line in the xy-plane. Moreover, the electric field is not required to stay pointing in the same direction. For example, the electric field could rotate around the z-axis as the wave propagates; the magnetic field would then also rotate so as to stay perpendicular to the electric field.

For any individual electromagnetic wave chain, then, we need only to measure the electric field in the x-direction and the electric field in the y-direction, and then we have measured the vector's components, which is sufficient for a complete description of the whole vector. These two base electric field measures we can call horizontal polarization and vertical polarization. When the phase difference is zero or 45°, the total electric field vector will oscillate in a fixed direction in the xy-plane, a case that is called linear polarization.

If the magnitudes of oscillation of the electric field in the x- and y-directions are equal and the phase difference between them is exactly $\pm\pi/2$ radians, then the total electric field vector will be constant in magnitude but will rotate around the z-axis, tracing out a circle (as will the magnetic field vector). This case is called circular polarization, as shown in Figure 2.

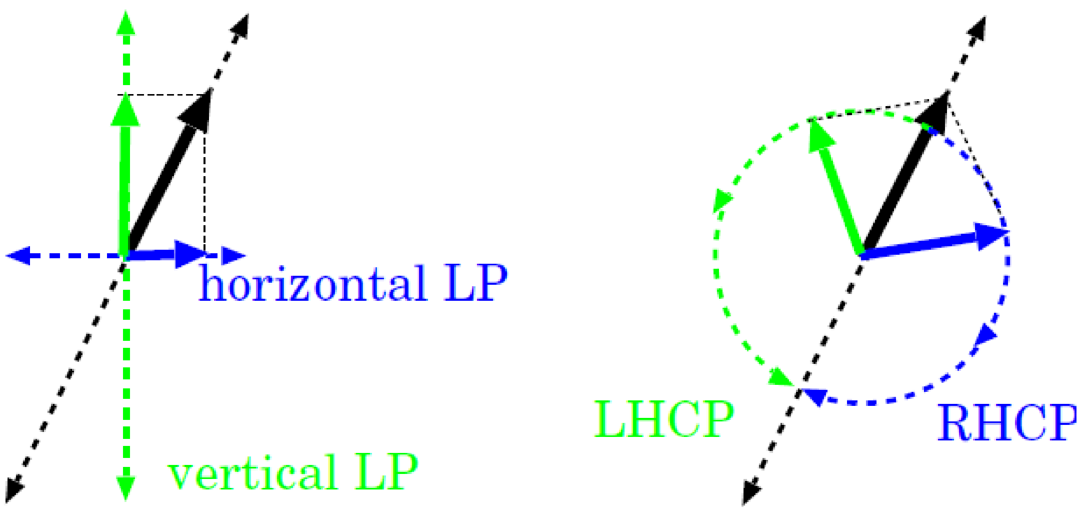

Figure 2: Representation of a polarized wave as a linear combination of two independent linear (Left), or circular (Right), polarization components.

For simplicity, we consider an electric field composed of just two components with identical frequencies but with an amplitude and a phase difference. Representing the sinusoidal waves as cosines, the first field can be represented by:

$$E_x = E_{xo} \cos(wx) \,. e^{-0.5x} \qquad (1)$$

where:

ω is the angular frequency of the oscillation and is related to the wave frequency by $\omega = 2\pi\nu$ and the radiation propagates in either the *x*- or *z*-direction.

The second field, with the same frequency, and direction, but with different amplitude and phase (∅), is given by:

$$E_y = E_{yo} \cos(wx + \emptyset) \,. e^{-0.5x} \qquad (2)$$

In 1852, Sir George Stokes developed a set of four parameters as a means of quantifying polarization in a more useful way. Here, we will give the mathematical definitions of the first Stokes parameters. This first parameter, labeled *I*, is equal to the total intensity of all the radiation. So, *I* equal the sum of the intensities of all orthogonal polarizations. For, horizontal and vertical linear polarizations or left and right circular polarizations, so we can write *I* as

$$I = I_x + I_y$$

or

$$I = I_L + I_R \qquad (3)$$

where: I_x and I_y are the intensities of any two orthogonal linear polarizations I_L and I_R are the intensities of the left circular and right circular polarizations.

Methodology

- Set the certain distance for any axis (x or z). For example, (x = 0 to 3).
- Set a certain value for amplitudes (E_{xo} and E_{yo}).
- Set a certain value of the wave number (*w*).
- Generate the first field using Eq. (1).
- Generate the second field using Eq. (2).
- Input different values of the phase (∅) between two components.
- Using the data as given in the following table, to apply Eq. (3).

No.		E_{xo}	E_{yo}
1	0	25	0
2	0	0	25
3	π/4	30	25
4	π/4	25	25
5	π/2	25	25
6	-π/2	25	25

- Display the results.

Questions:

- Define the polarization.
- What is the strongest types of polarization (linear or circular) and Why?
- Does the astronomical radio source polarized or un-polarized sources?
- Discuss your results.

Radio Astronomy Lab.

Exp. (4)

Study the Effect of Coherence for the Radio Waves

Aims:

- Investigating the coherence principle of the radio waves.
- Study the two radio waves at different phase.
- Study the two radio waves at different values of angular frequency.

Introduction

Coherence of an optical field is understood as the ability of light to interfere. Some features of the interference pattern provide a quantitative measure of the coherence between light vibrations at two points in space and at the two instants of time. Coherence in this sense was originally realized with the experiments of Thomas Young and Michelson in optics. Now it is used in any field that involves waves, such as acoustics, electrical engineering, neuroscience, and quantum mechanics as it is the basis for commercial applications such as holography, radio antenna arrays, optical and radio telescopes interferometers. This experiment is trying to find the answer to the question of what happens when two or more light waves overlap in some region of space in time. So we take into account the fact, that, because of the finite extension of any physical source, and because of the finite spectral range of any radiation, coherent as well as incoherent superposition takes place side by side; the vibrations in the two beams will then be partially correlated, that one can say that the field is partially coherent.

In wave mechanics, two or more wave sources are perfectly coherent if they have constant phase difference and the same frequency. It is often convenient to divide coherence effects into two classifications as temporal and spatial. Temporal coherence relates with the wavelength of the wave giving insight to coherence length. The temporal coherence describes the correlation of a fixed point in a wave observed at different moments in time. Therefore, it gives an idea about the spectral bandwidth. Whereas spatial coherence relates with the transverse wavefront profile of the beam giving insight to coherence area. This coherence describes the correlation between different points of the same transverse wave profile in space at a fixed time. Therefore, it gives an idea of spatial bandwidth.

For simplicity, we consider a beam of electromagnetic radiation composed of just two identical wave chains—with identical frequencies and directions of travel—but with a phase difference. Representing the sinusoidal waves as cosines, the first wave chain can be represented by:

$$\vec{E}_1 = E_0 \cos(\omega t)\hat{y} \tag{1}$$

where:
ω is the angular frequency of the oscillation and is related to the wave frequency by $\omega = 2\pi\nu$ and the radiation propagates in either the *x*- or *z*-direction.

The second wave chain, with the same amplitude, frequency, and direction, but with different phase, is given by:

$$\vec{E}_2 = E_0 \cos(\omega t + \Delta\phi)\hat{y} \tag{2}$$

Therefore, the intensity of the total beam, then, is,

$$I_{\text{total}} = 2I_1 \left\langle \left[1 + \cos(\Delta\phi) \right] \right\rangle \tag{3}$$

The term $\cos(\Delta\phi)$ is the *interference term* and dictates whether the interference is constructive or destructive when the waves are added.

Methodology

- Set the certain distance for any axis (x or z). For example, (x =0 to 3).
- Set a certain period of time (*t*).
- Set a certain value of the wave number (*w*).
- Generate the first wave using Eq. (1).
- Generate the second wave using Eq. (2).
- Input different values of the phase ($\Delta\varphi$) between two waves.
- Compute the total intensity (I_{total}) using eq. (3).
- Change the value of (*w*), then repeat the above steps.
- Complete the following table.

No.	$\Delta\varphi$	*w*	I_{total}
1	0	1	
2	π	2	
3	$-\pi$	3	
4	$\pi/2$	4	
5	$\pi/4$	5	
6	$\pi/6$	10	

- Plot *I* as a function of the distance (*x*).

Questions:

- Define the coherence.
- Which is dominant in equation (2), the angular frequency or the interference term?
- Does the astronomical radio source coherent or incoherent sources?
- Discuss your results.

Experiment No.(5)

The Flux Density of Jupiter

-Equipment: Computer using Q.B. program.

-Aim: Calculate the flux density of Jupiter

-Theory:

The most interesting planet for radio astronomy studies is Jupiter. As beautiful and fascinating as it is visually, it is even more fascinating and complex to observe in the radio frequency range. Most of the radiation from the Jupiter system is much stronger at longer wavelengths than would be expected for thermal radiation. In addition, much of it is circularly or elliptically polarized-not at all typical of thermal radiation. Thus, it must be concluded that non-thermal processes similar to those taking place in galaxies are at work. That is, ions and electrons accelerated by the planet's spinning magnetic field are generating synchrotron radiation. Jupiter is 318 times as massive as Earth. Its magnetic axis is tilted 15° from its rotational axis and offset from the planet's center by 18,000 km. Its polarity is opposite that of Earth (that is, a compass needle would point south).

- Procedure:

1.Use the value of the flux density (average) of Jupiter from the previous experiment (2A):

2.If Jupiter is at opposition, the planets are at their smallest distance (Use Jupiter=5.2 A.U. from the Sun), The Earth-Jupiter distance in A.U. is:

$$D_{EJ}=5.2\text{A.U.}-1.0\text{A.U.}=4.2\text{ A.U.} \quad \ldots.(2.1B)$$

3.Convert this distance to meters.

$$D_{EJ}=4.2\text{A.U}\,(1.5\times10^{11}\text{m/1A.U.})=6.3\times10^{11}\text{m} \quad \ldots.(2.2B)$$

The radio signals will travel outward at the same rate (the speed of light), filling a sphere centered at the storm.

4. Calculate the surface of sphere of this radius by:

$$A=4\pi r^2\ldots\ldots..(2.3B)$$

$$A=4\pi(6.3\times10^{11})^2=5.0\times10^{24}m^2$$

For every watt radiated by Jupiter, there will be (1/area) number of watts on each square meter at Earth. Since we received flux in $W/(m^2Hz)$ at our antenna, the power emitted from Jupiter in a 1 Hz bandwidth is called the spectral power, w.

5.The spectral power (w) is simply the power per unit frequency and can be computed easily by:

$$w=\text{Flux density}\times\text{Area} \quad ….(2.4B)$$

$$w=S\times A$$

The answer shows how many watts of power Jupiter emitted for each Hertz of bandwidth. During a typical Jupiter storm, radio waves are emitted over a frequency range of about (10 MHz, 10 MHz bandwidth). Assuming that there is equal power per hertz across the entire band width,

6. The total power (W) of this solar burst is given by:

$$W_{\text{total power}}= w\times(10\times10^6Hz) \quad …..(2.5B)$$

-Problems:

(Assume a 10 MHz bandwidth for Jupiter emissions)

1.If the flux density of a storm were found to be 1.52×10^{-20} $W/(m^2Hz)$ when the Earth-Jupiter distance of a storm was 4.5A.U., what would be the total power?(8.7×10^{11}W).

1.If the flux density of a storm were found to be 1.35×10^{-20} $W/(m^2Hz)$ when the Earth-Jupiter distance of a storm was 4.8A.U., what would be the total power?(8.8×10^{11}W).

3.If the flux density of a storm were found to be 1.44×10^{-20} $W/(m^2Hz)$ when the Earth-Jupiter distance of a storm was 4.4A.U., what would be the total power?(8.7×10^{11}W).

The Flux Density of the Sun

-Equipment: Computer using Q.B. program.

-Aim: Calculate the flux density of the Sun.

-Theory:

The Sun was one of the first objects studied by early radio astronomers. It is not as powerful an emitter of radio waves as many other objects, but its close proximity to us makes it appear radio-bright to us here on the third planet. In the year 2000, the Sun is expected to peak in sunspot number and the related solar activity level. That means there should be lots of solar flares on the Sun's surface and the Earth should receive a number of geomagnetic storms as a result. In other words, this should be an exciting time to begin monitoring the Sun with radio receivers and magnetometers.

If we assume that the radio emissions from the Sun are sent out uniformly in all directions, then the radio energy that we receive on Earth is only a small fraction of the total power emitted by the Sun. Because the radio emissions are sometimes beamed in narrow angles, our calculation is an upper limit to the total power of each burst. The true complex nature of each type of radio burst is unknown and scientists are still learning how these radio bursts are created and how they propagate in space.

Solar radio bursts are classified as follows:

Type I Short, narrow band events that usually occur in great numbers together with a broader band continuum. May last for hours or days.

Type II Slow drift from high to low frequencies. Often show fundamental and second harmonic frequency structure.

Type III Rapidly drift from high to low frequencies. May exhibit harmonics. Often accompany the flash phase of large flares.

Type IV Flare-related broad-band continua.

Type V Broad-band continua which may appear with III bursts. Last 1 to 2 minutes, with duration increasing as frequency decreases.

- Procedure:

1.Use the value of the flux density (average) of the Sun from the previous experiment (2A):

2. Take the Earth-Sun distance in D_{ES}=1A.U.

3.Convert this distance to meters by:.

$$D_{ES}=1A.U\ (1.5\times10^{11}m/1A.U.)=1.5\times10^{11}m \quad ....(2.1C)$$

The radio signals will travel outward at the same rate (the speed of light), filling a sphere centered at the storm.

4. Calculate the surface of sphere of this radius by:

$$A=4\pi r^2........(2.2C)$$

$$A=4\pi(1.5\times10^{11})^2=2.8\times10^{24}m^2$$

For every watt radiated by the Sun, there will be (1/area) number of watts on each square meter at Earth. Since we received flux in W/(m^2.Hz) at our antenna, the power emitted from Sun in a 1 Hz bandwidth is called the spectral power, w.

5.The spectral power (w) is simply the power per bandwidth (Watts/frequency) and can be computed by:

$$w=\text{Flux density}\times\text{Area} \quad ....(2.3C)$$

$$w=S\times A$$

So the Sun emitted 4800 watts of power for each hertz of bandwidth over it emitted radio waves. During a typical solar burst radio waves are emitted over a frequency range of about 1 MHz (a 1 MHz bandwidth) Assuming that there is equal power per hertz across the entire bandwidth.

6. The total power (W) of this solar burst is:

$$W_{total\ power}= w\times(1\times10^6Hz) \quad .....(2.4C)$$

This is much more powers than can be put out by the largest power planet in the world. This amount of power would be enough to power a large city during the storm.

-Problems:

1.If the flux density of a storm were found to be 1.5 $\times 10^{-20}$ W/(m^2Hz) when the Earth-Sun distance of a storm was 1 A.U., what would be the total power? .

2.If the flux density of a storm were found to be 1.42 $\times 10^{-20}$ W/(m^2Hz) when the Earth-Sun distance of a storm was 1.8 A.U., what would be the total power. ?

3.If the flux density of a storm were found to be 1.20 $\times 10^{-20}$ W/(m^2Hz) when the Earth-Sun distance of a storm was 1.4 A.U., what would be the total power?

Radio Astronomy Lab.

Exp. (7)

Determination of Sun Brightness Temperature at the Wavelength of 21 cm

Aims: Study of the emission mechanism for wavelength of the 21 cm
Simple definition of the brightness and antenna temperatures.
Determination of Sun brightness temperature.

Introduction

Most of the radio data obtained from distant objects like stars, galaxies, pulsars, and quasars are useful for studying the universe. One of the important radio data is the hydrogen line emission at 21 cm wavelength, and this line has different applications in radio astrophysics. This line arises from transitions between the hyperfine structure levels in the ground state of the hydrogen atom. A lot of radio emissions especially from the sun have been studied over decades. Also, many empirical models have been proposed for the solar atmosphere based on spectral lines emissions using Very Large Array(VLA). Solar radio observations at frequency of 1.42 GHz (equivalent 21 cm wavelength) provides valuable information on the structure and dynamics of the solar atmosphere. At this frequency, we could measure the solar brightness temperature, solar radio flux, and understanding the basic of the physical processes operating in quiet and active regions of solar atmosphere. Most of the solar radio waves originate from the chromosphere and corona. One of the important issues is the solar brightness temperature at centimeter wavelengths measured by different technical methods.

The brightness concept could be defined as the energy received at earth per unit time, per unit area, per unit frequency, and per unit solid angle. The brightness is an adequate measurement of the radiation intensity of the resolved source. This intensity could be considered as the brightness of the source at the given frequency being observed. One of important terms that used to express of source brightness is the brightness temperature (T_B). T_B is a method of defining temperature dependent on the brightness. Astronomical sources have varying (T_B) depending on which part of the electromagnetic spectrum measurements is to be taken.

This feature is useful, so the normal expression of T_B of a radio source brightness is B, and could be given as:

$$T_B = \frac{\lambda^2}{2k} B \qquad (1)$$

where λ is radio wavelength, k is the Boltzmann constant (Joule/K), and B is the brightness measured in (W/m^2. Hz. rad^2).

The concept of antenna temperature (T_A) could be defined as temperature of a radio source as sensed by an antenna, and has nothing common with the temperature of the antenna body.

Assuming no losses or other contributions between the antenna and the receiver, then (T_A) could be written by:

$$P_A = kGT_A \mathrm{d}v \qquad (2)$$

G is the antenna gain, dv is the receiver frequency bandwidth.

Then the T_B could be computed as follow:

$$T_B = \frac{\Omega_A}{\Omega_S} T_A \qquad (3)$$

Ω_A is the antenna solid angle and approximated to Half Power Beamwidth (θ_{HPBW}).
Ω_A is converted to steradian (sr) according to following formula:

$$\Omega_A(sr) = \theta_{HPBW}^2 \times \frac{1}{\left(\frac{180}{\pi}\right)^2}$$

Ω_S is solid angle that subtended by the sun. Ω_S could be given as:

$$\Omega_S = \frac{\pi R^2}{r^2}$$

R is sun radius, r is the distance between the earth and the sun. The angular diameter of the sun is Ƨ = 32':
where,

$$\frac{R}{r} = \frac{Ƨ}{2} \text{ rad.}$$

Now,

$$\Omega_s = \pi \left(\frac{R}{r}\right)^2 \text{ sr.}$$

Methodology

- Input the received power in logarithmic scale (dBm) then convert it to (dBW).
- dBW should be converted to Watt (W).
- Calculate Antenna Temperature (T_A) using eq. (2). Using G =30 dB and dv= 2×10^7 Hz.
- Input Ω_A and Ω_s and convert them to sterdian (sr).
- Calculate brightness temperature (T_B) using eq. (3)
- Complete the following table.

v (GHz)	P_A (dBm)	T_A (K)	T_B (K)
1.415	-91		
1.416	-90.3		
1.417	-91.5		
1.418	-88		
1.419	-76		
1.420	-68		
1.421	-73		
1.422	-85		
1.423	-91.2		
1.424	-92		
1.425	-91.5		

- Plot T_B as a function of the frequency (v).

Questions

Explain the radio hydrogen line emission mechanism.

Does the brightness temperature depend on the frequency or not?

Compare your results with the recent published studies.