Reflection and Acceleration Of Radio Wave

Eric Su
eric.su.mobile@gmail.com
(Dated: December 1, 2018)

The radio wave changes direction upon reflection. It also changes frequency if it is reflected by a moving surface. In the standing wave formed by the incident wave and the reflected wave, the formation of the nodes requires both waves to have the same wavelength. The nodes exist in all reference frames. This requires both the incident wave and the reflected wave to have the same wavelength in all reference frames. However, these two waves have different frequencies due to Doppler effect Therefore, these two waves travel at different speeds. Doppler radar is a good example. With two moving surfaces to reflect the radio wave between them, the radio wave can be accelerated if the distance between two reflective surfaces decreases with time.

I. INTRODUCTION

The frequency of a radio wave can be prescisely detected in the Dopper effect[1]. However, the wavelength of the reflected wave is seldom measured but instead calculated based on the assumption of the invariant speed of light. One way to measure the wavelength of the reflected wave is to examine the standing wave which is the superposition of the incident wave and the reflected wave.

The standing wave is characterized by its nodes which are where the standing wave diminshes or remains minimum at all time. The formation of nodes requires both incident wave and reflected wave to have the same wavelength.

The reflected radio wave may have a different frequency if the reflective surface is moving. If the wavelength of the reflected wave is the same as the wavelength of the incident wave, these two waves wiil travel at different speeds as manifested in the standing wave.

II. PROOF

Consider electromagnetic waves in one-dimensional space.

A. Reflection

A radio wave can be reflected by a metallic surface. Place a stationary reflective surface in the y-z plane. Let a radio wave approach this surface in x direction. By the law of reflection, the reflected wave will have the same frequency, wavelength and speed but opposite velocity of the incident wave in the vacuum.

$$L_i = L_r \tag{1}$$

L_i is the wavelength of the incident wave. L_r is the wavelength of the reflected wave.

$$f_i = f_r \tag{2}$$

f_i is the frequency of the incident wave. f_r is the frequency of the reflected wave.

$$\vec{C_i} = -\vec{C_r} \tag{3}$$

C_i is the velocity of the incident wave. C_r is the velocity of the reflected wave.

$$C_i = C_r \tag{4}$$

C_i is the speed of the incident wave. C_r is the speed of the reflected wave.

B. Wavelength In Standing Wave

The radio wave in a wave cavity can form a standing wave from the superposition of the incident wave and the reflected wave reflected by the wall. An example is the standing wave in a typical household microwave oven. The nodes of the standing wave can be detected by placing a sheet of chocolate or cheese inside the microwave oven.

Let the incident wave be represented by sin(kx-wt) and be reflected at x =0. From the reflection symmetry, the reflected wave can be represented by sin(k(-x)-wt).

The standing wave is the superposition of both incident wave and reflected wave. The nodes exist at where cos(kx) is zero.

$$sin(kx - wt) + sin(k(-x) - wt) \tag{5}$$

$$= 2cos(kx)sin(-wt) \tag{6}$$

The nodes also exist in all other inertial reference frames.

Let $2cos(k_1x_1)sin(-w_1t_1)$ be a standing wave in reference frame F_1. Let reference frame F_2 move at a velocity of $\vec{v}$ relative to F_1. This standing wave will travel at the velocity of $-\vec{v}$ and can be represented by $2cos(k_2(x_2 + vt_2))sin(-w_2t_2)$ in F_2.

$$2cos(k_2(x_2 + vt_2))sin(-w_2t_2) \tag{7}$$

$$= sin(k_2(x_2+vt_2)-w_2t_2)+sin(k_2(-x_2-vt_2)-w_2t_2) \tag{8}$$

$$= sin(k_2x_2 + (k_2v - w_2)t_2) \quad (9)$$

$$+sin(k_2(-x_2) + (-k_2v - w_2)t_2) \quad (10)$$

The formation of the nodes requires identical wavelength from both waves in F_2.

Therefore, *the wavelength of the incident wave is identical to the wavelength of the reflected wave in all reference frames.*

Let L_i be the wavelength of the incident wave. Let L_r be the wavelength of the reflected wave. The following equation holds true in all inertial reference frames.

$$L_i = L_r \quad (11)$$

C. wavelength and reference frame

An inertial reference frame can be created from the acceleration. By applying a constant acceleration for a duration to one reference frame, two identical reference frames can become two separate inertial reference frames relative to each other[2]. This was used by Su(2017) to deduce the coordinate transformaion between two inertial reference frames[2].

Let x_1 represent the x coordinate in reference frame F_1. Let x_2 represent the x coordinate in reference frame F_2. Put F_2 under a constant acceleration of A for a duration of T relative to F_1. The coordinate transformation between F_1 and F_2 is (for $t_1 > T$)

$$x_1 = x_2 + \frac{AT^2}{2} + AT(t_1 - T) \quad (12)$$

The wavelength can be represented by the distance between the positions of two adjacent crests, x^a and x^b.

In F_1,

$$L_1 = x_1^a - x_1^b \quad (13)$$

In F_2,

$$L_2 = x_2^a - x_2^b \quad (14)$$

From equation (12,13,14),

$$L_1 = L_2 \quad (15)$$

The wavelength of a radio wave is independent of inertial reference frame.

D. Doppler Effect

An observer approaching a radio wave will detect a frequency different from the original frequency of this radio wave. The detected frequency also depends on the motion of the reflective surface. This phenomenon was discovered by Christian Doppler in 1842.

By Doppler effect[1], an observer approaching the standing wave will detect two different frequencies from the two waves forming the standing wave because these two waves travel at opposite directions.

From equation (11,15), the wavelengths of both waves are identical to each other in all reference frames.

In the rest frame of the observer, these two waves have the same wavelength but different frequencies. Therefore, these two waves travel at different speeds in the rest frame of the observer.

The speed of the radio wave depends on the reference frame of the observer.

The Doppler effect shows that all reflected light by a shiny window on a building travels at various speeds to a person approaching the buiding.

A person moving toward a motion sensor will reflect the signal in a greater speed back to the motion sensor.

E. Speed and Reference Frame

Based on Fizeau's cogwheel experiment[3], Su(2018) added a second cogwheel to calculate the speed of light without reflection. With this improved pass-through arrangement, Su(2018) discovered that the speed of light depends on the reference frame[4].

Let $\vec{C_1}$ be the velocity of a radio wave in a reference frame F_1. Let F_2 move at velocity $\vec{v}$ relative to F_1. Let $\vec{C_2}$ be the velocity of the same radio wave in F_2.

$$\vec{C_1} = \vec{C_2} + \vec{v} \quad (16)$$

Let a reflective surface in the y-z plane be stationary in F_1. The incident wave travels in the x direction toward the reflective plane and is reflected back in the x direction.

Let $\vec{C_1^i}$ be the velocity of the incident wave in F_1. Let $\vec{C_1^r}$ be the velocity of the reflected wave in F_1. From equation (3),

$$\vec{C_1^i} = -\vec{C_1^r} \quad (17)$$

From equation (4),

$$C_1^i = C_1^r \quad (18)$$

Let $\vec{C_2^i}$ be the velocity of the incident wave in F_2. Let $\vec{C_2^r}$ be the velocity of the reflected wave in F_2.

From equation (16),

$$\vec{C_1^i} = \vec{C_2^i} + \vec{v} \quad (19)$$

$$\vec{C_1^r} = \vec{C_2^r} + \vec{v} \quad (20)$$

From equations (17,19,20),

$$-\vec{C_2^r} = \vec{C_2^i} + 2\vec{v} \quad (21)$$

The speeds of both waves can be obtained from equation (21) if $\vec{C_2^i}$ and $\vec{v}$ point to the same direction.

$$C_2^r = C_2^i + 2v \quad (22)$$

Or if $\vec{C_2^r}$ and $\vec{v}$ point to the same direction,

$$C_2^r = C_2^i - 2v \quad (23)$$

The reflected wave travels at a different speed from the incident wave.

F. Doppler Radar

Radar gun is used by the police to detect the speed of an approaching car. It demonstrates how the detected frequency depends on the reference frame.

The equation from Doppler effect to calculate the frequency of the radar wave in radar gun[5,6] is

$$f_r - f_i = 2v\frac{f_i}{c} \quad (24)$$

f_r is the frequency of the reflected radar wave. f_i is the frequency of the incident radar wave. v is the speed of the car.

From equation (15,22),

$$\frac{C_2^r}{L_r} = \frac{C_2^i + 2v}{L_i} \quad (25)$$

$$f_2^r = f_2^i + \frac{2v}{L_i} \quad (26)$$

This is the same equation used by radar gun in equation (24). *Therefore Doppler radar demonstrates exactly how radio wave accelerates upon reflection by an approaching car.*

G. Acceleration of Radio Wave

The speed of radio wave depends on the reference frame and reflection. A single reflection can change the speed of radio wave by a small amount. Multiple reflections can be used to accelerate the radio wave.

Let two identical reflective planes be aligned in the y-z plane. One plane P_a is placed at x=-d/2 at t=0 and moves in the positive x direction at the speed of v_a. The other plane P_b is placed at x=d/2 at t=0 and moves in the negative x direction at the speed of v_b.

Let a radio wave be emitted from P_a toward P_b at t=0 in the x direction. Upon emission, the wave will travel from P_a to P_b and be reflected back to P_a.

Let t_1 be the time for the wave to travel from P_a to P_b. Let C_1 be the speed of the radio wave before reflection. The distance travelled by the radio wave is

$$C_1 t_1 = d - v_b t_1 \quad (27)$$

Upon reflection by P_b, the wave will travel at the speed of C_2 from P_b to P_a. Let t_2 be the duration. The distance travelled by the radio wave is

$$C_2 t_2 = C_1 t_1 - v_a t_1 - v_a t_2 \quad (28)$$

Upon reflection by P_a, the wave will travel at the speed of C_3 from P_a to P_b. Let t_3 be the duration. The distance travelled by the radio wave is

$$C_3 t_3 = C_2 t_2 - v_b t_2 - v_b t_3 \quad (29)$$

The series continues in iteration and can be generalized with a positive integer, n, from equations (28,29).

$$C_{2n} t_{2n} = C_{2n-1} t_{2n-1} - v_a t_{2n-1} - v_a t_{2n} \quad (30)$$

$$C_{2n+1} t_{2n+1} = C_{2n} t_{2n} - v_b t_{2n} - v_b t_{2n+1} \quad (31)$$

The reflection by P_a increases the speed of radio wave by $2v_a$.

$$C_{2n+1} = C_{2n} + 2v_a \quad (32)$$

The reflection by P_b increases the speed of radio wave by $2v_b$.

$$C_{2n} = C_{2n-1} + 2v_b \quad (33)$$

Define v as the sum of v_a and v_b.

$$v = v_a + v_b \quad (34)$$

From the equations (32,33,34),

$$C_{2n+1} = C_1 + 2nv \quad (35)$$

$$C_{2n} = C_1 + 2(n-1)v + 2v_b \quad (36)$$

Define C_0 as the speed of the radio wave in the rest frame of P_a at t=0.

$$C_0 = C_1 - v_a \quad (37)$$

t_n can be derived from equations (30,31,34,35,36,37) as

$$t_n = \frac{d * C_0}{(C_0 + n * v)(C_0 + (n-1)v)} \quad (38)$$

Total elapsed time can also be derived as

$$T_1^{2n+1} = \sum_{i=1}^{i=2n+1} t_i = \frac{d}{v}\left(1 - \frac{C_0}{C_0 + (2n+1)v}\right) \quad (39)$$

To accelerate the radio wave to be twice faster, set

$$C_{2n+1} = 2C_1 \quad (40)$$

From equations (35,40)

$$n = \frac{C_1}{2v} \quad (41)$$

From equations (39,41), the distance between two planes will be

$$d - v * T_1^{2n+1} = \frac{d}{1 + (\frac{C_1}{v} + 1)\frac{v}{C_0}} \quad (42)$$

III. CONCLUSION

The radio wave changes speed if it is reflected by a moving reflective surface. The reflected wave accelerates if the reflective surface approches the incident wave. The reflected wave slows down if the reflective surface moves away from the incident wave.

The radio wave between two reflective surfaces facing each other will be reflected continuously. For example, two mirrors facing each other will create an infinite number of images.

Move one reflective surface away from the other. The radio wave between two surfaces will slow down. The frequency of the wave will decrease. Move both surfaces toward each other. The radio wave will accelerate.

The wavelength remains intact upon reflection. As a result, the frequency of the wave increases if the reflective surface is moving toward the wave emitter. This is called Doppler effect and is manifested in Doppler radar.

[1] Possel, Markus (2017). "Waves, motion and frequency: the Doppler effect". Einstein Online, Vol. 5. Max Planck Institute for Gravitational Physics, Potsdam, Germany. Retrieved September 4, 2017.
[2] Su, Eric: Coordinate Transformation Between Inertial Reference Frames. viXra: Relativity and Cosmology/1709.0120 (2017), http://vixra.org/abs/1709.0120
[3] https://en.wikipedia.org/wiki/Fizeau
[4] Su, Eric: One Way Speed Of Light Based on Fizeau's Experiment. viXra: Relativity and Cosmology/1807.0278 (2018), http://vixra.org/abs/1807.0278
[5] Ditchburn, R.W. "Light", 1961, 1991. Dover publications Inc., pp331-333
[6] Jaffe, Bernard M., "Forward Reflection of Light by a Moving Mirror," American Journal of Physics, Vol. 41, April 1973, p577-578
[7] Su, Eric: List of Publications, http://vixra.org/author/eric_su