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A new approach to the Doppler effect

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Declaration of authorship

I, Simon FOSSAT, declare that this independant research publication "A new approach to the Doppler effect" is my own.

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Abstract

The Doppler effect characterizes the change in the frequency of a wave in relation to an observer who is moving relative to the source of the wave.

Following a revisited approach to the classic Doppler effect, we will propose an alternative approach to the relativistic Doppler effect and expose its related formulas. We will then consider the consequences of this new approach on the speed evaluation of celestial objects.

Keywords : Doppler effect, Special relativity, Lorentz transformations, cosmology.

Contents

For the whole study, we will use the following notations:

* λ_e : wavelength of the emitter

* f_e : frequency of the emitter

* λ_r : wavelength measured by the receiver

* f_r : frequency measured by the receiver

* c : speed of a mechanic wave (classic Doppler effect) or of a electromagnetic wave (relativistic Doppler effecrt)

* v_e : speed of the emitter
* $\beta_e = \frac{v_e}{c}$: normailzed speed of the emitter

* v_r : speed of the receiver
* $\beta_r = \frac{v_r}{c}$: normalized speed of the receiver

* $g_e = \frac{1}{\gamma_e} = \sqrt{1 - \beta_e^2}$: Lorentz factor connected with the emitter

* $g_r = \frac{1}{\gamma_r} = \sqrt{1 - \beta_r^2}$: Lorentz factor connected with the receiver

Chapter 1

The classic Doppler effect

1.1 The emitter and the receiver are static

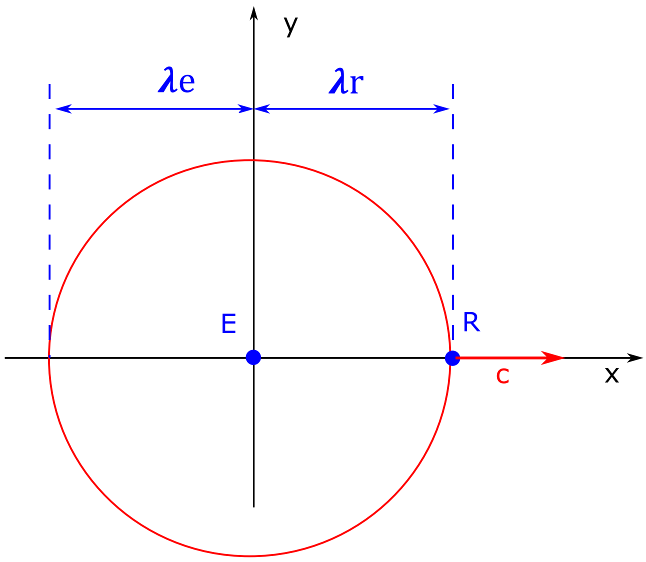

FIGURE 1.1: The emitter and the receiver are static.

The received and measured frequency trivially equals to the transmitted frequency:

$$f_r = f_e \tag{1.1}$$

That is, for the wavelengths:

$$\lambda_r = \lambda_e \tag{1.2}$$

1.2 The emitter is moving, the receiver is static

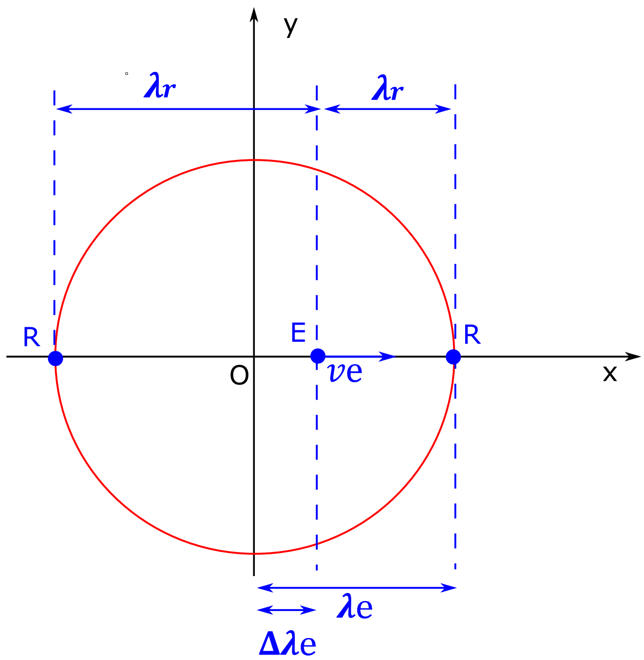

FIGURE 1.2: The emitter is moving, the receiver is static.

We have:

$$\Delta\lambda_e = \beta_e.\lambda_e \tag{1.3}$$

For the receiver at the front:

$$\lambda_r = \lambda_e.(1 - \beta_e) \tag{1.4}$$

For the receiver at the back:

$$\lambda_r = \lambda_e.(1 + \beta_e) \tag{1.5}$$

1.3 The emitter is static, the receiver is moving

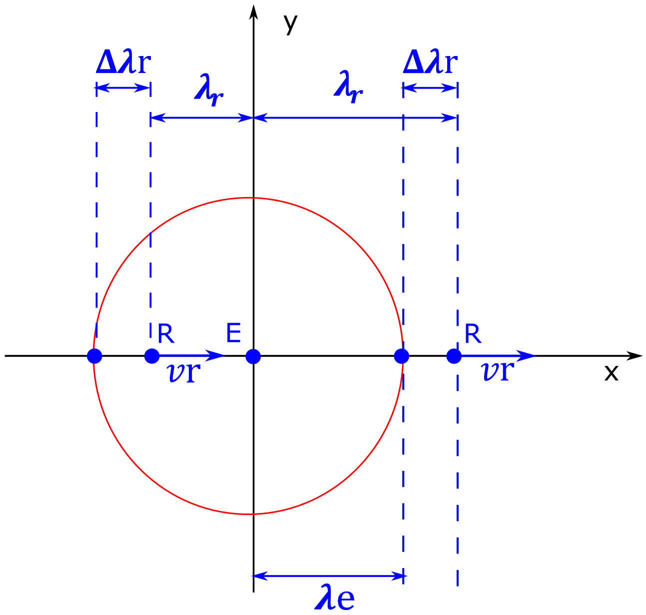

FIGURE 1.3: The emitter is static, the receiver is moving.

We have:

$$\Delta\lambda_r = \beta_r.\lambda_r \tag{1.6}$$

The wavelength measured by the receiver at the front equals to:

$$\lambda_r = \frac{\lambda_e}{1-\beta_r} \tag{1.7}$$

The wavelength measured by the receiver at the back equals to:

$$\lambda_r = \frac{\lambda_e}{1+\beta_r} \tag{1.8}$$

1.4 The emitter and the receiver are moving on one same axis

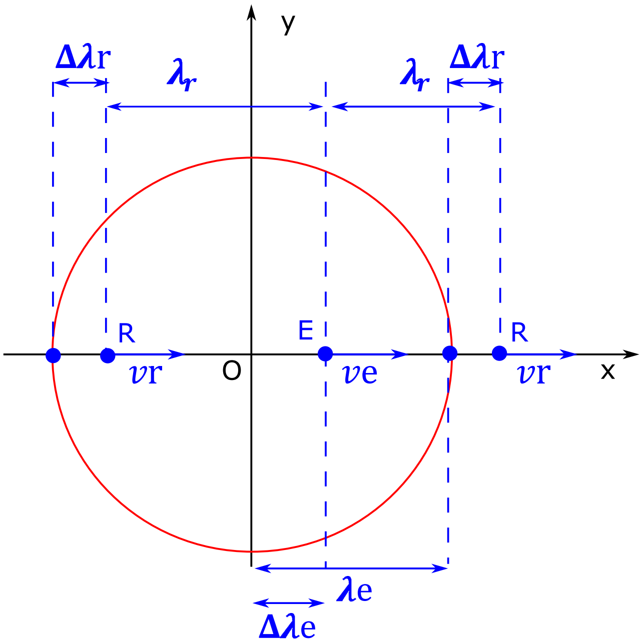

FIGURE 1.4: The emitter and the receiver are moving on one same axis.

By considering the movement of both the receiver and the emitter, the wavelength measured by the receiver at the front equals to:

$$\lambda_r = \lambda_e.\frac{1-\beta_e}{1-\beta_r} \tag{1.9}$$

The wavelength measured by the receiver at the back equals to:

$$\lambda_r = \lambda_e.\frac{1+\beta_e}{1+\beta_r} \tag{1.10}$$

Note:

If $\beta_e = \beta_r$, then $\lambda_r = \lambda_e$. The relative Doppler effect is therefore null.

If the emitter and the receiver are approaching in opposite directions, we have:

$$\lambda_r = \lambda_e.\frac{1-\beta_e}{1+\beta_r} \tag{1.11}$$

If the emitter and the receiver are distancing in opposite directions, we have:

$$\lambda_r = \lambda_e.\frac{1+\beta_e}{1-\beta_r} \tag{1.12}$$

1.5 The emitter is moving, the receiver is on another axis

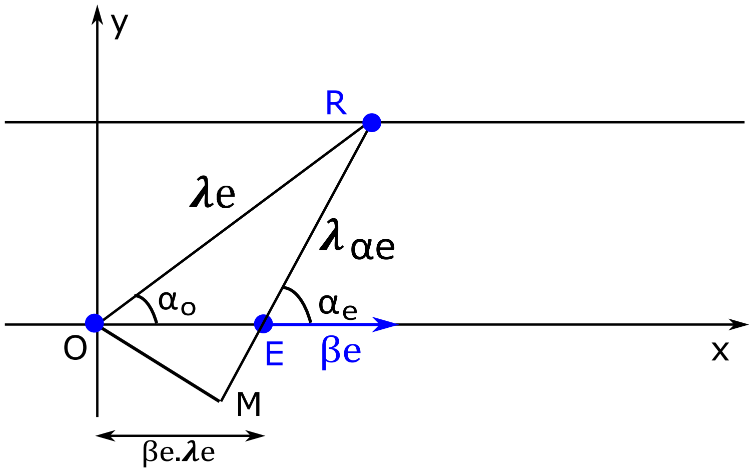

FIGURE 1.5: The emitter is moving, the receiver is on another axis.

Let us call the angle between the direction of the emitter and the axis "emitter-receiver" at the emission point : α_e

Let us call the angle between the direction of the emitter and the axis "emitter-receiver" at the emission point when the speed of the emitter tends to zero : α_e

We have:

$$\lambda_{\alpha_e} = RM - EM \tag{1.13}$$

With:

$$EM = \lambda_e.\beta_e.\cos\alpha_e \tag{1.14}$$

And:

$$RM = \lambda_e.\sqrt{1 - \beta_e^2.\sin^2\alpha_e} \tag{1.15}$$

This leads to:

$$\lambda_{\alpha_e} = \lambda_e.(\sqrt{1 - \beta_e^2.\sin^2\alpha_e} - \beta_e.\cos\alpha_e) \tag{1.16}$$

1.6 The receiver is moving, the emitter is on another axis

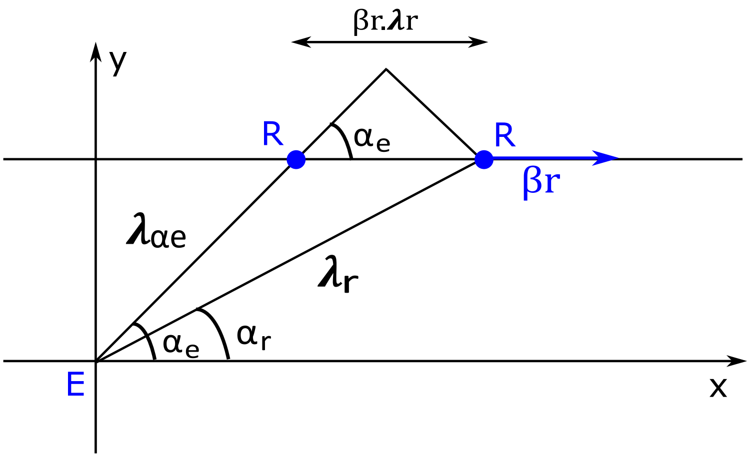

FIGURE 1.6: The receiver is moving, the emitter is on another axis

Let us call the angle between the direction of the receiver and the axis "emitter-receiver" at the reception point : α_r

We have:

$$\lambda_r^2 = (\lambda_{\alpha_e} + \beta_r.\lambda_r.\cos\alpha_e)^2 + \beta_r^2.\lambda_r^2.\sin^2\alpha_e \tag{1.17}$$

$$\lambda_r^2.(1-\beta_r^2) - 2\beta_r.\lambda_r.\lambda_{\alpha_e}.\cos\alpha_e - \lambda_{\alpha_e}^2 = 0 \tag{1.18}$$

Which leads to the remarkable expression:

$$\lambda_r = \frac{\lambda_{\alpha_e}}{\sqrt{1-\beta_r^2.\sin^2\alpha_e} - \beta_r.\cos\alpha_e} \tag{1.19}$$

1.7 The receiver and the emitter are both moving on two different axis

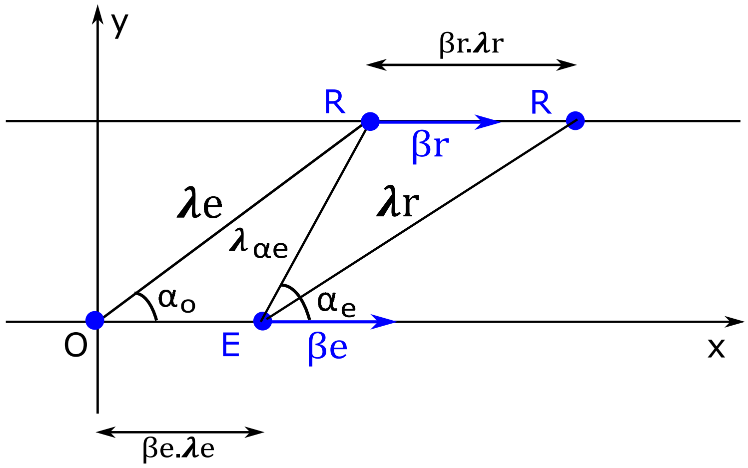

FIGURE 1.7: The receiver and the emitter are both moving on two different axis.

We assume that the emitter and the receiver are moving in a colinear way.

Combining (1.16) and (1.19) leads to the following and generalized expression for the Doppler effect:

$$\frac{\lambda_r}{\lambda_e} = \frac{\sqrt{1 - \beta_e^2 . \sin^2 \alpha_e} - \beta_e . \cos \alpha_e}{\sqrt{1 - \beta_r^2 . \sin^2 \alpha_e} - \beta_r . \cos \alpha_e} \tag{1.20}$$

Chapter 2

The relativistic Doppler effect. A new approach

2.1 Introduction

Let us consider an electromagnetic wave emitter. We assume that its emission is made at a frequency which is lowered by the Lorentz factor g_e when it's moving at the speed β_e

$$f'_e = g_e.f_e \tag{2.1}$$

In other words, the wavelength of a moving emitter compared to a static emitter equals to:

$$\lambda'_e = \frac{\lambda_e}{g_e} \tag{2.2}$$

To reach the corresponding relativistic Doppler effect formula, we have then to considerate again the formulas of the classic Doppler effect and offset the frequency of the emitter according to the Lorentz factor g_e.

2.2 The emitter is moving, the receiver is static

By considering the equation (1.4), we get for the receiver at the front:

$$\lambda_r = \frac{\lambda_e}{g_e}.(1 - \beta_e) \tag{2.3}$$

$$\lambda_r = \lambda_e.\sqrt{\frac{1 - \beta_e}{1 + \beta_e}} \tag{2.4}$$

By considering the equation (1.5), we get for the receiver at the back:

$$\lambda_r = \frac{\lambda_e}{g_e}.(1 + \beta_e) \tag{2.5}$$

$$\lambda_r = \lambda_e.\sqrt{\frac{1 + \beta_e}{1 - \beta_e}} \tag{2.6}$$

2.3 The emitter is static, the receiver is moving

Let us consider an electromagnetic wave receiver. We assume that the measure in reception is made at a frequency which is lowered by the Lorentz factor g_r when it's moving at the speed β_r.

$$f'_r = g_r.f_r \tag{2.7}$$

Let us note that there is not an obvious correspondance between the wavelength received and the one measured. When the receiver is static, the measured wavelength corresponds to the received wavelength. However, when the receiver moves, the measured wavelength λ'_r is different from the one received λ_r according to the Lorentz factor g_r.

$$\lambda'_r = \frac{\lambda_r}{g_r} \tag{2.8}$$

To reach the corresponding relativistic Doppler effect formula, we have then to considerate again the formulas of the classic Doppler effect and offset the frequency of the emitter according to the Lorentz factor g_r.

By considering the equation (1.7), we get for the receiver at the front:

$$\frac{\lambda_r}{g_r} = \frac{\lambda_e}{1-\beta_r} \tag{2.9}$$

That is:

$$\lambda_r = \lambda_e.\sqrt{\frac{1+\beta_r}{1-\beta_r}} \tag{2.10}$$

By considering the equation (1.8), we get for the receiver at the back:

$$\lambda_r = \lambda_e.\sqrt{\frac{1-\beta_r}{1+\beta_r}} \tag{2.11}$$

2.4 The emitter and the receiver are moving on the same axis

Let us consider the movement of both the receiver and the emitter. According to the equation (1.9), we get the following Doppler formula for the receiver at the front:

$$\lambda_r = \lambda_e.\frac{g_r}{g_e}.\frac{1-\beta_e}{1-\beta_r} \tag{2.12}$$

$$\frac{\lambda_r}{\lambda_e} = \sqrt{\frac{(1+\beta_r).(1-\beta_e)}{(1+\beta_e).(1-\beta_r)}} \tag{2.13}$$

Let us consider the movement of both the receiver and the emitter. According to the equation (1.10), we get the following Doppler formula for the receiver at the back:

$$\lambda_r = \lambda_e.\frac{g_r}{g_e}.\frac{1+\beta_e}{1+\beta_r} \tag{2.14}$$

$$\frac{\lambda_r}{\lambda_e} = \sqrt{\frac{(1-\beta_r).(1+\beta_e)}{(1-\beta_e).(1+\beta_r)}} \tag{2.15}$$

Note:

If the emitter and the receiver are approaching in opposite directions then we get, according to the equation (1.11):

$$\lambda_r = \lambda_e.\frac{g_r}{g_e}.\frac{1-\beta_e}{1+\beta_r} \tag{2.16}$$

$$\frac{\lambda_r}{\lambda_e} = \sqrt{\frac{(1-\beta_r).(1-\beta_e)}{(1+\beta_e).(1+\beta_r)}} \tag{2.17}$$

If the emitter and the receiver are distancing in opposite directions then we get, according to the equation (1.12):

$$\lambda_r = \lambda_e.\frac{g_r}{g_e}.\frac{1+\beta_e}{1-\beta_r} \tag{2.18}$$

$$\frac{\lambda_r}{\lambda_e} = \sqrt{\frac{(1+\beta_r).(1+\beta_e)}{(1-\beta_e).(1-\beta_r)}} \tag{2.19}$$

2.5 The emitter and the receiver are both moving on different axis

The generalized expression for the relativistic Doppler effect is obtained by applying the ratio $\frac{g_r}{g_e}$ to the classic formula (1.20):

$$\frac{\lambda_r}{\lambda_e} = \frac{\sqrt{1-\beta_r^2}}{\sqrt{1-\beta_e^2}}.\frac{\sqrt{1-\beta_e^2.\sin^2\alpha_e} - \beta_e.\cos\alpha_e}{\sqrt{1-\beta_r^2.\sin^2\alpha_e} - \beta_r.\cos\alpha_e} \tag{2.20}$$

Chapter 3

Point of view of the emitter. Point of view of the receiver

3.1 Classic approach

The relativistic aberration phenomena, established by Albert Einstein [1] , enables to switch from the emitter to the receiver point of view and formulate the relativistic Doppler effect:

With the following schematic:

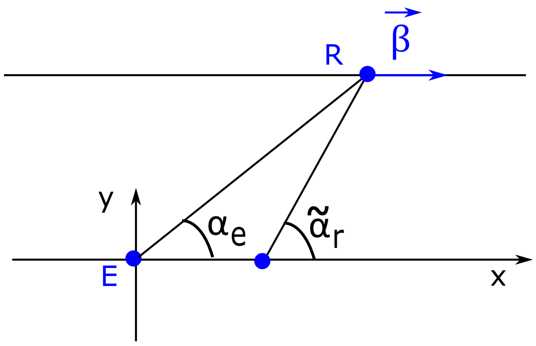

FIGURE 3.1: Aberration according to the classic formula.

Let us call the angle between the direction of the receiver and the axis "emitter-receiver" of observation : $\tilde{\alpha}_r$

We have:

$$\cos\tilde{\alpha}_r = \frac{\cos\alpha_e - \beta}{1 - \beta cos\alpha_e} \tag{3.1}$$

According to the following formula:

$$\frac{\lambda_r}{\lambda_e} = \frac{\sqrt{1-\beta^2}}{1 - \beta cos\alpha_e} \tag{3.2}$$

We get then;

$$\frac{\lambda_r}{\lambda_e} = \frac{1 + \beta cos\tilde{\alpha}_r}{\sqrt{1-\beta^2}} \tag{3.3}$$

[1] A.Einstein – On the Electrodynamics of Moving Bodies (1920 edition)

3.2 Alternative approach

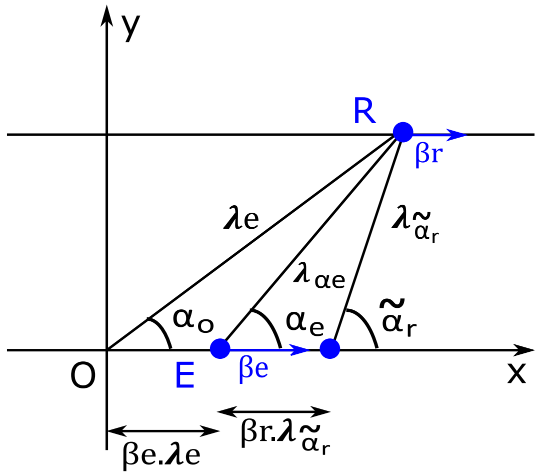

FIGURE 3.2: Aberration according to the alternative formula

We have:

$$\lambda_{\alpha_e} = \lambda_{\tilde{\alpha}_r}.\sqrt{1+\beta_r^2+2\beta_r.\cos\tilde{\alpha}_r} \tag{3.4}$$

By considering the following relation:

$$\lambda_{\alpha_e}.\sin\alpha_e = \lambda_{\tilde{\alpha}_r}.\sin\tilde{\alpha}_r$$

We get:

$$\sin\alpha_e = \frac{\sin\tilde{\alpha}_r}{\sqrt{1+\beta_r^2+2\beta_r.\cos\tilde{\alpha}_r}} \tag{3.5}$$

$$\cos\alpha_e = \frac{\cos\tilde{\alpha}_r+\beta_r}{\sqrt{1+\beta_r^2+2\beta_r.\cos\tilde{\alpha}_r}} \tag{3.6}$$

Chapter 4

The transvserse Doppler effect

4.1 Results with the classic formula

4.1.1 Case where $\alpha_e = \frac{\pi}{2}$

We get then, according to the formula (3.2):

$$\frac{\lambda_r}{\lambda_e} = \sqrt{1-\beta^2} \tag{4.1}$$

We get then, according to the formula (3.1):

$$\cos\tilde{\alpha}_r = -\beta \tag{4.2}$$

4.1.2 Case where $\tilde{\alpha}_r = \frac{\pi}{2}$

We get then, according to the formula (3.3):

$$\frac{\lambda_r}{\lambda_e} = \frac{1}{\sqrt{1-\beta^2}} \tag{4.3}$$

We get then, according to the formula (3.1):

$$\cos\alpha_e = \beta \tag{4.4}$$

4.2 Results with the alternative formula

4.2.1 Case where $\alpha_e = \frac{\pi}{2}$

We get then, according to the formula (2.20):

$$\frac{\lambda_r}{\lambda_e} = 1 \tag{4.5}$$

We get then, according to the formula (3.6):

$$\cos\tilde{\alpha}_r = -\beta_r \tag{4.6}$$

4.2.2 Case where $\tilde{\alpha}_r = \frac{\pi}{2}$

We get then, according to the formula (3.6):

$$\cos \alpha_e = \frac{+\beta_r}{\sqrt{1+\beta_r^2}} \tag{4.7}$$

We get then, according to the formula (2.20):

$$\frac{\lambda_r}{\lambda_e} = \frac{\sqrt{1+\beta_r^2-\beta_e^2} - \beta_r.\beta_e}{\sqrt{1-\beta_r^2}.\sqrt{1-\beta_e^2}} \tag{4.8}$$

Moreover, if $\beta_e = 0$, we get:

$$\frac{\lambda_r}{\lambda_e} = \frac{\sqrt{1+\beta_r^2}}{\sqrt{1-\beta_r^2}} \tag{4.9}$$

Moreover, if $\beta_r = 0$, we get:

$$\frac{\lambda_r}{\lambda_e} = 1 \tag{4.10}$$

Chapter 5

The longitudinal Doppler effect

5.1 Classic formula

5.1.1 The emitter and the receiver are distancing

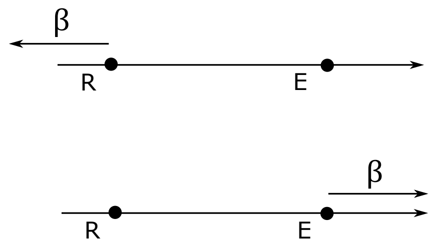

FIGURE 5.1: The emitter and the receiver are distancing.

The classic Doppler formula when the emitter and the receiver are distancing is as follows:

$$\lambda_r = \frac{\lambda_e}{1-\beta} \tag{5.1}$$

Let us consider the time dilation factor connected with the reference frame of the moving receiver:

$$t_r = \frac{1}{\gamma}.t_e \tag{5.2}$$

We get then for the relativistic Doppler formula:

$$\lambda_r = \frac{1}{\gamma}.\frac{\lambda_e}{1-\beta} \tag{5.3}$$

$$\lambda_r = \lambda_e.\sqrt{\frac{1+\beta}{1-\beta}} \tag{5.4}$$

5.1.2 The emitter and the receiver are approaching

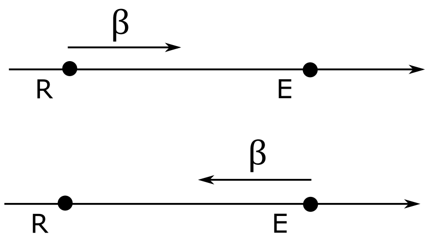

FIGURE 5.2: The emitter and the receiver are approaching.

When the receiver and the emitter are distancing, we get the same way:

$$\lambda_r = \lambda_e . \sqrt{\frac{1-\beta}{1+\beta}} \tag{5.5}$$

5.2 Alternative formula

5.2.1 The emitter and the receiver are distancing (the same direction)

Let us consider the case where the receiver and the emitter are distancing in one same direction ($\beta_r > \beta_e$). The corresponding formula (2.13) can be also written as follows:

$$\frac{\lambda_r}{\lambda_e} = \sqrt{\frac{1+(\beta_r-\beta_e)-\beta_e.\beta_r}{1-(\beta_r-\beta_e)-\beta_e.\beta_r}} \tag{5.6}$$

5.2.2 The emitter and the receiver are approaching (same direction)

Let us consider the case where the receiver and the emitter are approaching in one same direction ($\beta_r > \beta_e$). The corresponding formula (2.15) can be also written as follows:

$$\frac{\lambda_r}{\lambda_e} = \sqrt{\frac{1-(\beta_r-\beta_e)-\beta_e.\beta_r}{1+(\beta_r-\beta_e)-\beta_e.\beta_r}} \tag{5.7}$$

5.2.3 Comparison between the classic and alternative formula

Let us express the relative speed between the emitter and the receiver with the classic Doppler formula:

If the emitter and the receiver are distancing:

$$\beta = \frac{(\frac{\lambda_r}{\lambda_e})^2 - 1}{(\frac{\lambda_r}{\lambda_e})^2 + 1} \tag{5.8}$$

If the emitter and the receiver are approahcing:

$$\beta = \frac{1 - (\frac{\lambda_r}{\lambda_e})^2}{(\frac{\lambda_r}{\lambda_e})^2 + 1} \tag{5.9}$$

Let us express the speed of the emitter in terms of the speed of the receiver and the Doppler measure.

If the emitter and the receiver are distancing in one same direction:

$$\beta_e = \frac{(\frac{\lambda_r}{\lambda_e})^2.(1+\beta_r) - (1-\beta_r)}{(\frac{\lambda_r}{\lambda_e})^2.(1+\beta_r) + (1-\beta_r)} \tag{5.10}$$

If the emitter and the receiver are approaching in one same direction:

$$\beta_e = \frac{(1+\beta_r) - (\frac{\lambda_r}{\lambda_e})^2.(1-\beta_r)}{(\frac{\lambda_r}{\lambda_e})^2.(1-\beta_r) + (1+\beta_r)} \tag{5.11}$$

When $\beta_r \ll 1$, the formulas (5.8) and (5.10) on one hand, (5.9) and (5.11) on the other hand, lead to similar results though their expressions are different.

5.2.4 Speed composition

Let us combine the formula (5.4) and (5.6) on one hand (the emitter is distancing the receiver at the front), the formula (5.5) and (5.7) on the other hand (the receiver at the back is approaching the emitter), we get then:

$$\beta = \frac{\beta_r - \beta_e}{1 - \beta_e.\beta_r} \tag{5.12}$$

If $\beta_e > \beta_r$, let us rather combine the formula (5.5) and (5.6) on one hand (the emitter is approaching the receiver at the front), the formula (5.4) and (5.7) on the other hand (the receiver at the back is distancing the emitter), we get then:

$$\beta = \frac{\beta_e - \beta_r}{1 - \beta_e.\beta_r} \tag{5.13}$$

Let us also combine the formula (2.19) and (5.4) on one hand (the emitter and the receiver are distancing in opposite directions), the formula (2.17) and (5.5) on the other hand (the emitter and the receiver are approaching in opposite directions), we get then:

$$\beta = \frac{\beta_e + \beta_r}{1 + \beta_e.\beta_r} \tag{5.14}$$

These formulas remind us the law of speed composition already established in its time [2] .

[2] A.Einstein – op. cit.

Chapter 6

Conclusion

In a first step of our study, we have established a new general formula for the Doppler effect in the non-relativistic case.

The classic study of the relativistic Doppler effect is usually based on the application of the Lorentz transformations to the energy of a photon, and thus to its frequency properties.

Our study is rather based on the following assumption : the change of the frequency of the electron when it is in movement, and of its associated phenomena like the electromagnetic radiation.

If we call f_0 the frequency of a static electron and f_β the frequency of the same electron moving at the speed β, then we have:

$$f_\beta = g.f_0 \tag{6.1}$$

With:

$$g = \sqrt{1 - \beta^2} \tag{6.2}$$

If we distinctly consider the speed of the transmitter and the receiver rather than their relative speed, we obtain Doppler equations which differ from the classic theory.

The recent discovery of the cosmic microwave background and its anistropy measured from the solar system, due to its movement [3] , allows us to consider this distinction in the future.

[3] Astronomy & Astrophysics, Volume 641, id.A1

Chapter 7

References

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  - Wikisource of the 1920 edition : https://en.wikisource.org/wiki/On_the_Electrodynamics_of_Moving_Bodies_(1920_edition)
- Planck Collaboration
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  - Astronomy & Astrophysics, Volume 641, id.A1 : https://www.aanda.org/articles/aa/pdf/2020/09/aa33880-18.pdf

Chapter 8

Appendix : Doppler Simulator

The use of a numeric Doppler effect simulator will enable us to test the new formula for the classic Doppler effect. Let us recall its expression:

$$\frac{\lambda_r}{\lambda_e} = \frac{\sqrt{1-\beta_e^2.\sin^2\alpha_e} - \beta_e.\cos\alpha_e}{\sqrt{1-\beta_r^2.\sin^2\alpha_e} - \beta_r.\cos\alpha_e}$$

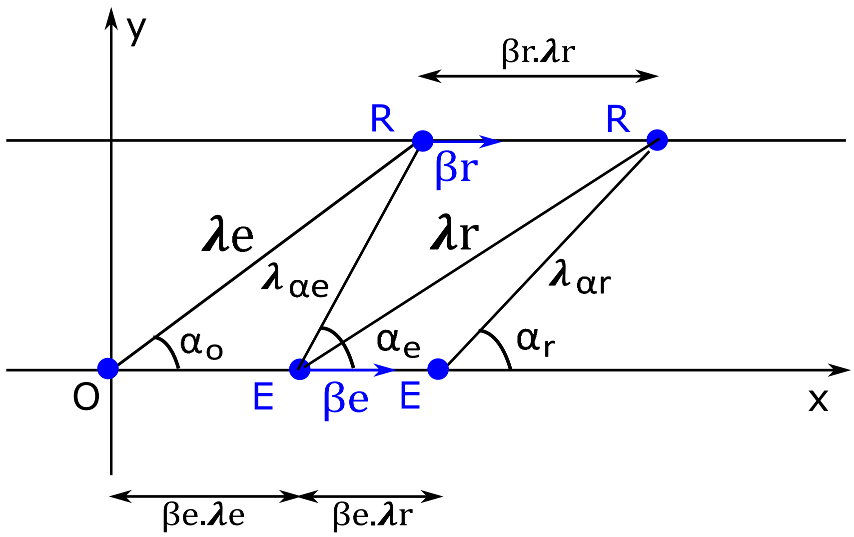

FIGURE 8.1: The emitter and the receiver are moving on different axis. Schematic.

The relation between the angle of emission α_e and of reception α_r is given by:

$$\sin\alpha_e.(\sqrt{1-\beta_r^2.\sin^2\alpha_e} - \beta_r.\cos\alpha_e) = \sin\alpha_r.(\sqrt{1-\beta_e^2.\sin^2\alpha_r} - \beta_e.\cos\alpha_r)$$

8.1 The emitter and the receiver are static

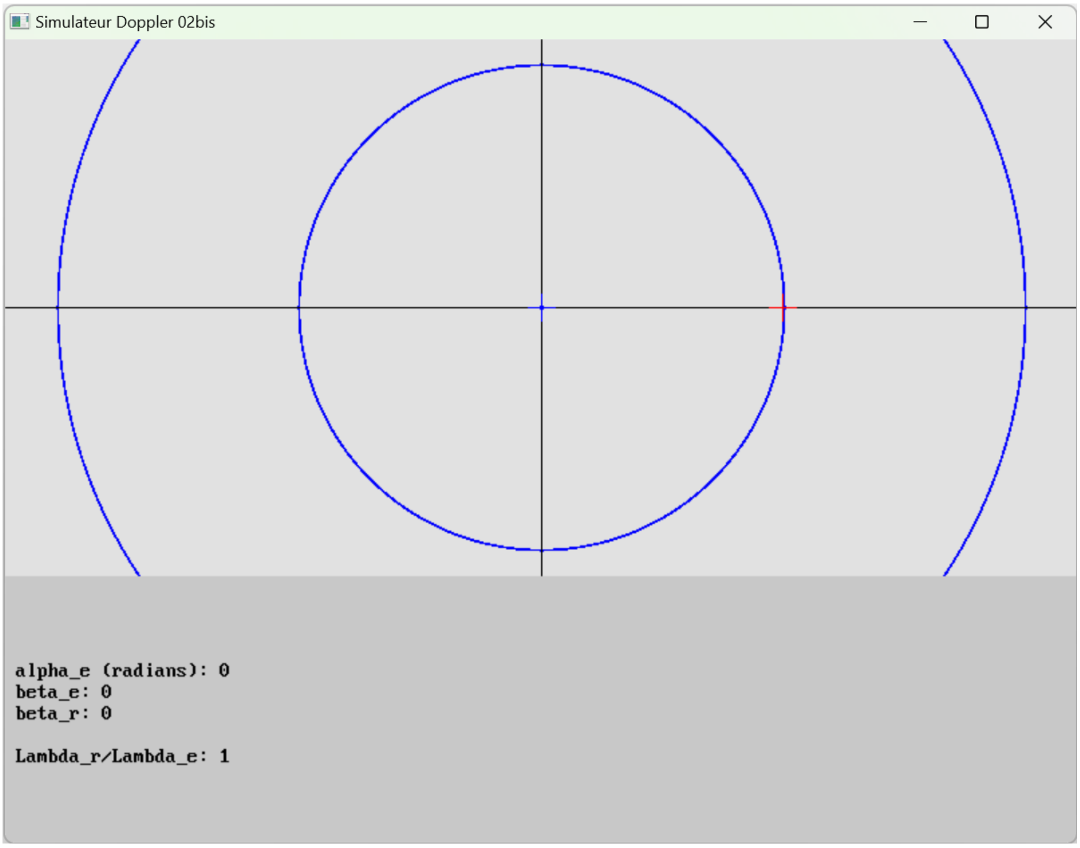

FIGURE 8.2: The emitter and the receiver are static.

Datas:

$$\alpha_e = 0$$
$$\beta_e = 0$$
$$\beta_r = 0$$

The calculated Doppler effect according to the formula leads to:

$$\frac{\lambda_r}{\lambda_e} = 1$$

The estimated Doppler effect according to the Doppler simulator leads to:

$$\frac{\lambda_r}{\lambda_e} = 1$$

8.2 The emitter is static, the receiver is moving

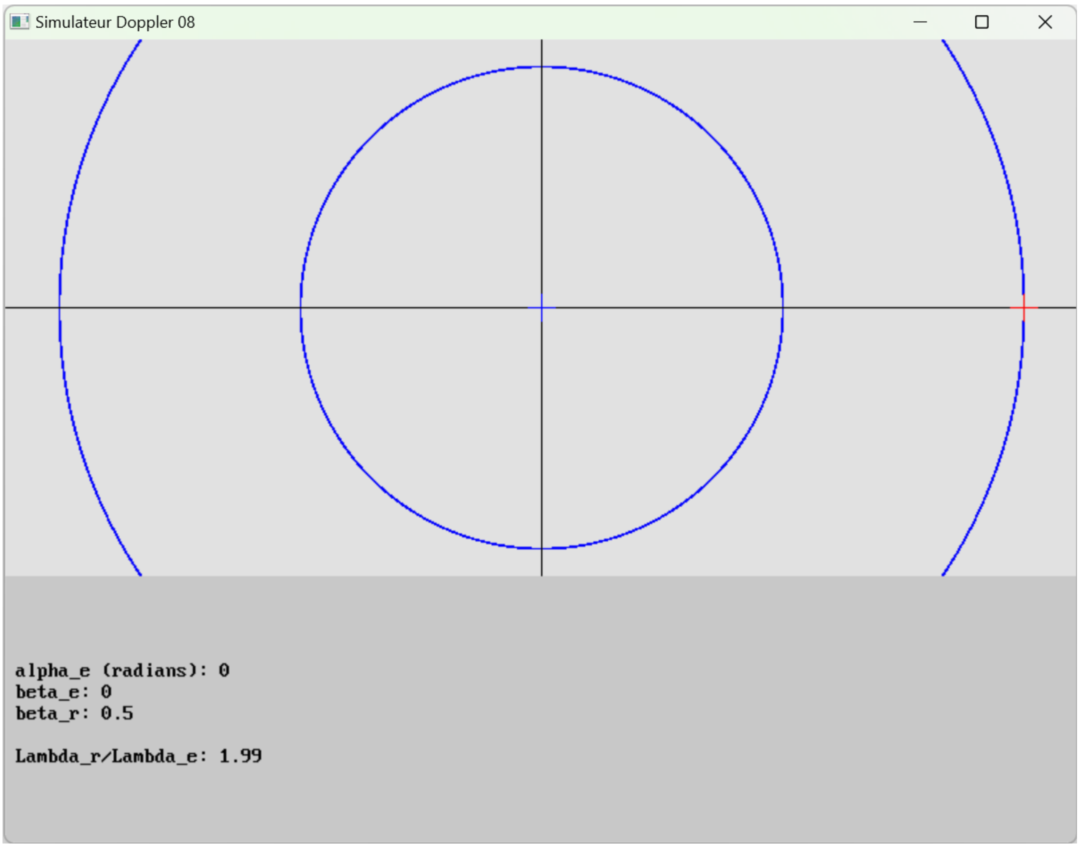

FIGURE 8.3: The emitter is static, the receiver is moving

Datas:

$$\alpha_e = 0$$
$$\beta_e = 0$$
$$\beta_r = 0.5$$

The calculated Doppler effect according to the formula leads to:

$$\frac{\lambda_r}{\lambda_e} = 2$$

The estimated Doppler effect according to the Doppler simulator leads to:

$$\frac{\lambda_r}{\lambda_e} = 1.99$$

8.3 The emitter is moving, the receiver is static

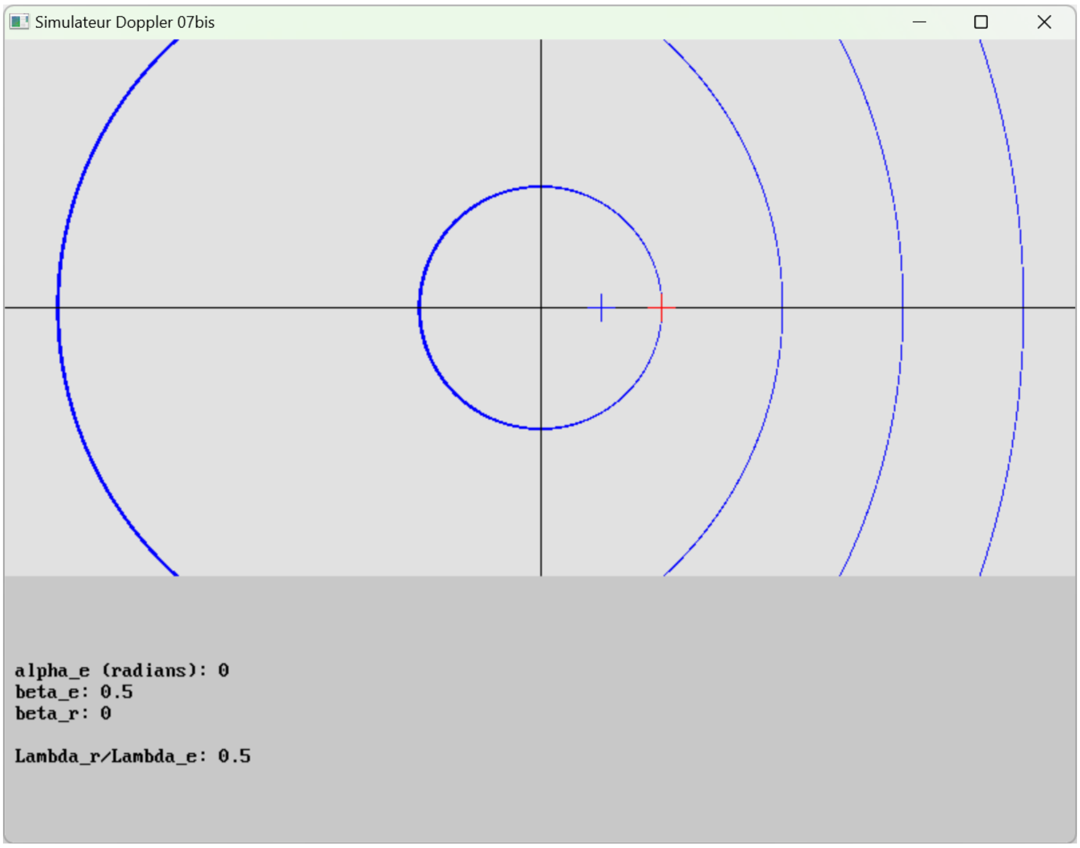

FIGURE 8.4: The emitter is moving, the receiver is static.

Datas:

$$\alpha_e = 0$$
$$\beta_e = 0.5$$
$$\beta_r = 0$$

The calculated Doppler effect according to the formula leads to:

$$\frac{\lambda_r}{\lambda_e} = 0.5$$

The estimated Doppler effect according to the Doppler simulator leads to:

$$\frac{\lambda_r}{\lambda_e} = 0.5$$

8.4 The emitter and the receiver are moving on one same axis

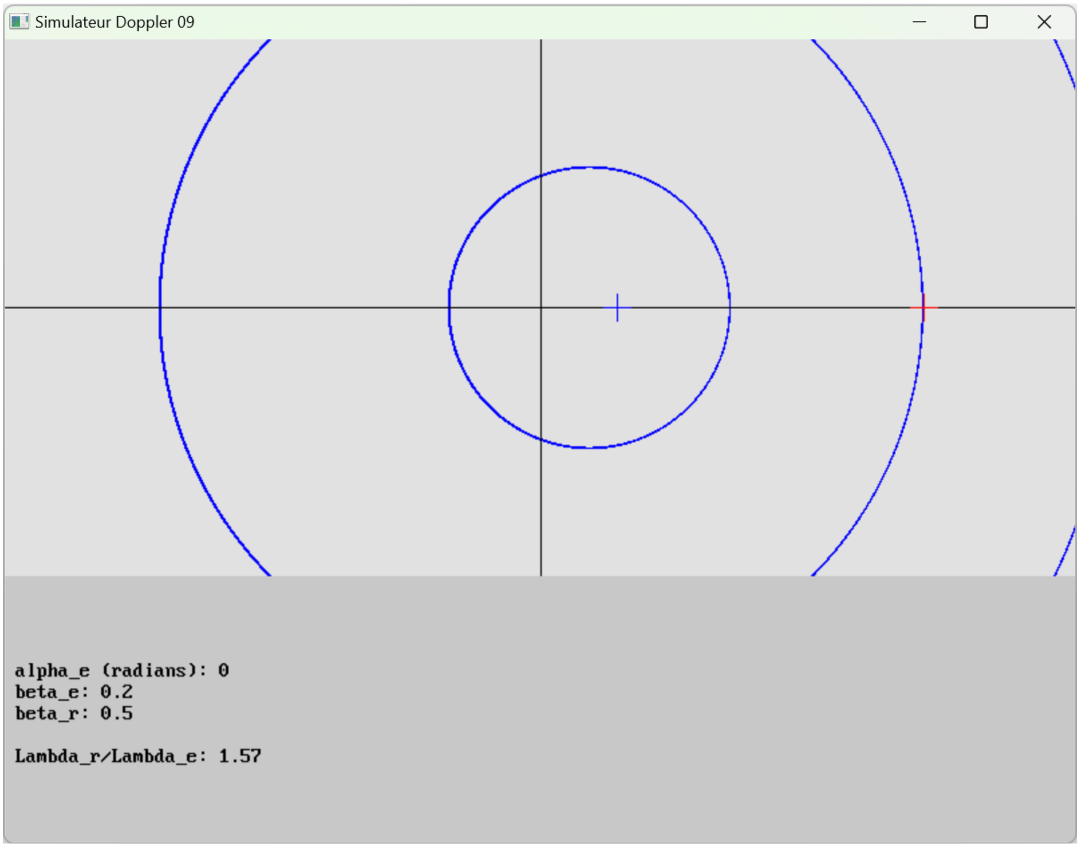

FIGURE 8.5: The emitter and the receiver are moving on one same axis.

Datas:

$$\alpha_e = 0$$
$$\beta_e = 0.2$$
$$\beta_r = 0.5$$

The calculated Doppler effect according to the formula leads to:

$$\frac{\lambda_r}{\lambda_e} = 1.6$$

The estimated Doppler effect according to the Doppler simulator leads to:

$$\frac{\lambda_r}{\lambda_e} = 1.57$$

8.5 The emitter is static, the receiver is moving on a different axis.

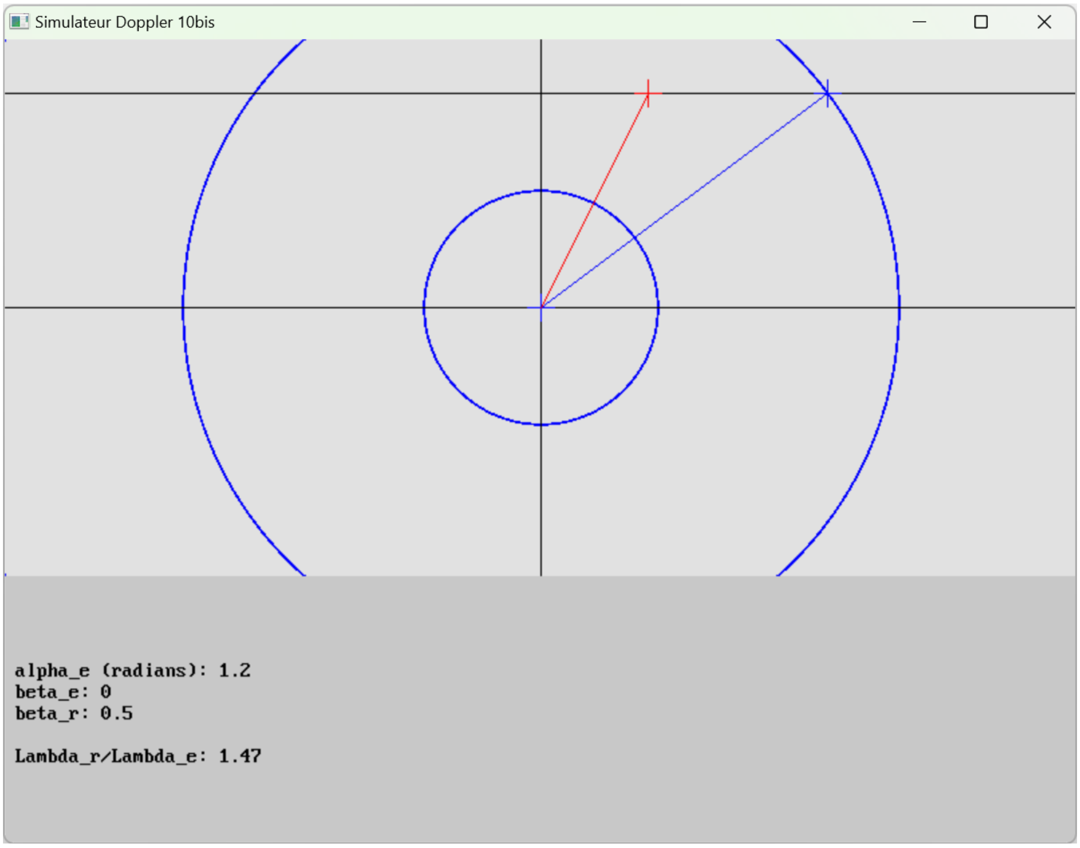

FIGURE 8.6: The emitter is static, the receiver are moving on a different axis.

Datas:

$$\alpha_e = 1.2$$
$$\beta_e = 0$$
$$\beta_r = 0.5$$

The calculated Doppler effect according to the formula leads to:

$$\frac{\lambda_r}{\lambda_e} = 1.48$$

The estimated Doppler effect according to the Doppler simulator leads to:

$$\frac{\lambda_r}{\lambda_e} = 1.47$$

8.6 The emitter is moving, the receiver is static on a different axis

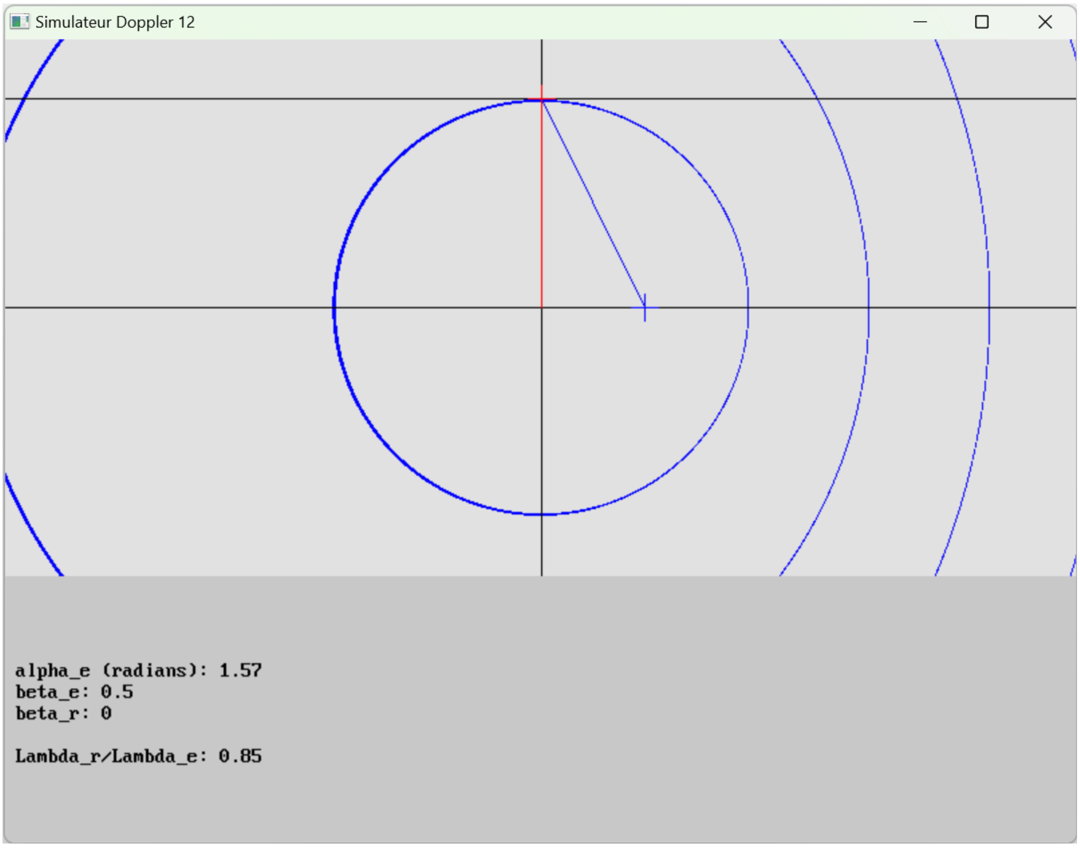

FIGURE 8.7: The emitter is moving, the receiver is static on a different axis..

Datas:

$$\alpha_e = \frac{\pi}{2}$$
$$\beta_e = 0.5$$
$$\beta_r = 0$$

The calculated Doppler effect according to the formula leads to:

$$\frac{\lambda_r}{\lambda_e} = 0.866$$

The estimated Doppler effect according to the Doppler simulator leads to:

$$\frac{\lambda_r}{\lambda_e} = 0.85$$

8.7 The emitter and the receiver are moving on two different axis

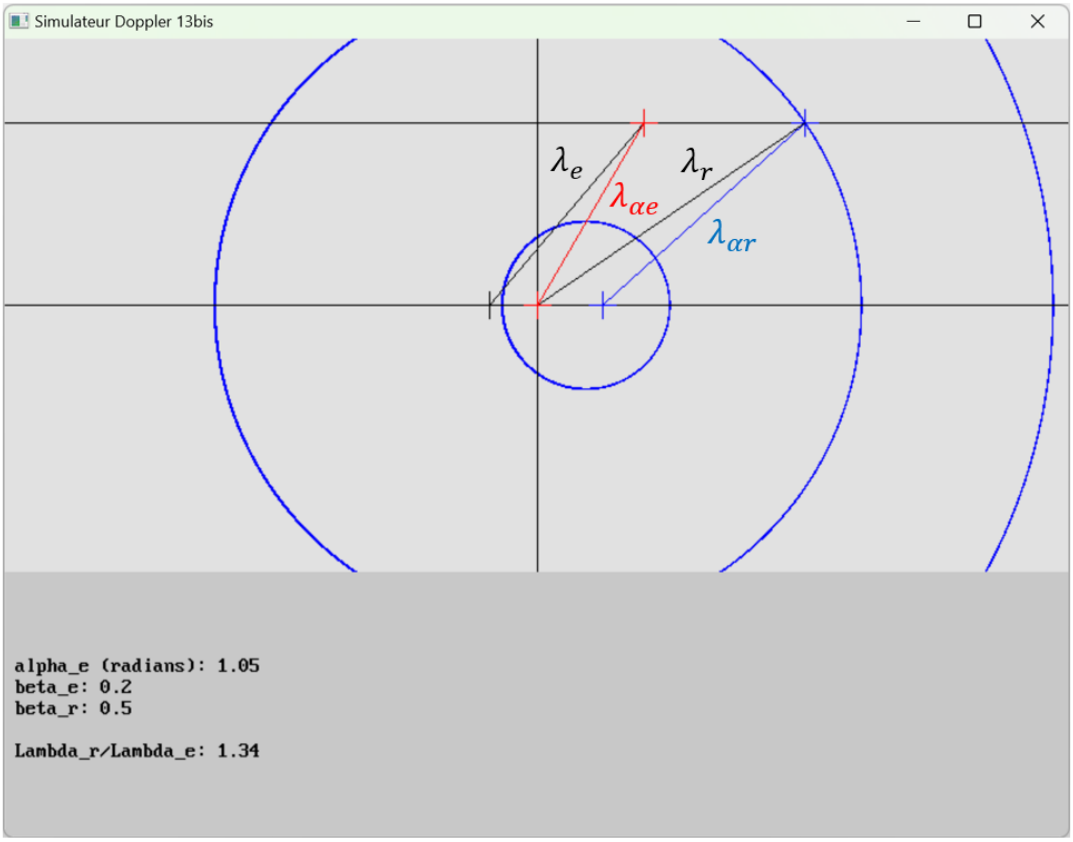

FIGURE 8.8: The emitter and the receiver are moving on two different axis.

Datas:

$$\alpha_e = 1.05$$
$$\beta_e = 0.5$$
$$\beta_r = 0.2$$

The calculated Doppler effect according to the formula leads to:

$$\frac{\lambda_r}{\lambda_e} = 1.36$$

The estimated Doppler effect according to the Doppler simulator leads to:

$$\frac{\lambda_r}{\lambda_e} = 1.34$$