Einstein and Pound-Rebka in the Photocoupler

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Loudspeaker as gravitational field generator and photocoupler as sensor to verify Einstein's theory and Pound-Rebka's experiment at emulable gravitations up to 30g and drop towers up to 4000 kilometers high.

I. Introduction

In 1911, Einstein propagated that the energy of photons changes in a gravitational field, causing a red or blue shift.

In 1960, the Pound-Rebka experiment confirmed the expected tiny energy change of 10^{-15} in a 23 m tower with gamma rays and advanced technology.

This energy change corresponds to ten grains of sand related to the weight of the Empire State Building. The measurement error was one grain.

Pound Rebka could only record one measured value, since they could not change the gravity or the drop tower height. Even reversing the measurement system in the gravitational field was only possible with extensive modifications.

We show a generator for variable gravitational fields and drop tower heights. Coupled with this is a photocoupler as a sensor and simple electronics.

The device is used to test Einstein's theory (and thus Pound-Rebka's experiment) at different gravities and drop towers.

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II. *Influence of gravitation on photons*

The initial kinetic energy $\mathbf{E_0}$ of a photon is calculated from the Plank constant **h** and photon frequency **f** and is equal to the mass of a moving photon **m** nd the square of the speed of light **c**:

$$(1) \qquad \mathbf{E_0 = h\,f = m\,c^2}$$

In the gravitational field, according to Newton, there is a potential energy $\mathbf{E_p}$, which is calculated from **m**, the gravitation **g** and the heigh **z**:

$$(2) \qquad \mathbf{E_p = m\,g\,z = \frac{h\,f\,g\,z}{c^2}}$$

By the fall in the gravitational field $\mathbf{E_0}$ and $\mathbf{E_p}$ are added. Einstein calculated still unrelativistically [1]:

$$(3) \qquad \mathbf{E = h\,f + \frac{h\,f\,g\,z}{c^2} = E_0\left(1 + \frac{g\,z}{c^2}\right)}$$

At Earth gravity, the energy change due to Pound-Rebka's **z=23m** drop tower is about 15 decades smaller than the starting energy of the photons.

Pound and Rebka had to use the Mößbauer effect and other elaborate techniques to confirm such small changes [2].

III. *Gravitational field generator*

Therefore, a generator was developed that can emulate large homogeneous gravitational fields and drop tower heights.

At a dynamic loudspeaker the level of the feed voltage determines the membrane acceleration **a** and the frequency $\mathbf{f_m}$ of the voltage determines the acceleration time:

$$(4) \qquad \mathbf{t = \frac{1}{2\,f_m}} \text{ (approx.).}$$

According to Einstein, the longer the acceleration lasts, the further the receiver rushes towards the photons launched by the transmitter. This emulates the following drop tower:

$$(5) \qquad \mathbf{z = c\,t}$$

Substituting (5) into (3) and relativistic doubling yields the following energy change:

$$(6) \qquad \mathbf{dE = E_0\left(\frac{2\,a\,t}{c}\right)}$$

A loudspeaker achieves large accelerations **a** over long times **t**. This results in large and stable measuring values that can be scaled to Einstein or Pound-Rebka.

IV. Photocoupler

The following requirements were placed on the sensor:

- Small size and mass, because it is driven by the speaker.
- Immunity to the loudspeaker magnetic fields.
- Molded and robust so that vibrations only affect the photons.

A cheap photocoupler built into a shield box proved to be ideal.

Fig. 1 : g-sensor (left) and assembled photocoupler (mid) with his parts (right)

The photon source (red = IR-LED) and receiver (green = phototransistor) can be arranged differently in photocouplers. The speaker membrane must vibrate in the direction of the white arrow.

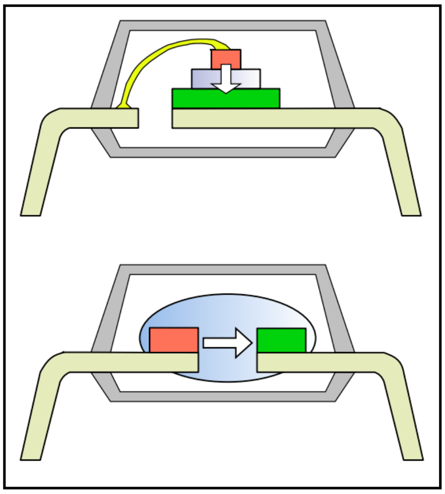

Fig. 2 : different photocouplers [3]

The structure of the photocoupler is a secret of the manufacturer. You have to try out how to align the membrane and photocoupler to get maximum signal.

V. g-Sensor

An additional sensor was developed to calibrate the generator acceleration. It consists of a low-traction mechanical contact that opens as soon as it is weightless.

The g-sensor is placed on the membrane as an alternative to the photocoupler to find the feed voltage level at which the acceleration of the membrane just compensates for the earth's gravity.

This "**a=1g**" feed voltage is then multiplied to preset arbitrary accelerations.

VI. Setup

Fig. 3 : setup

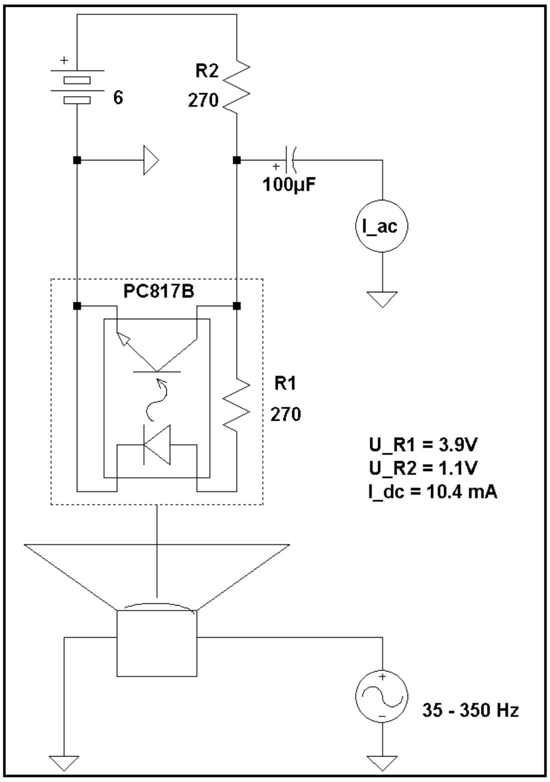

Fig. 4 : simplified setup

The left measuring station generates the feed voltage. The signal adjusted with the resistor decade is amplified and drives the loudspeaker with attached g-sensor. Pulses appear on the oscilloscope on the top right as soon as the membrane acceleration compensates the gravity. The corresponding "**a=1g**" voltage is multiplied to emulate arbitrary accelerations.

Then the g-sensor is replaced by the photocoupler. The photocoupler generates two different output quantities. A direct current $\mathbf{I_{dc}}$, on which a small alternating current $\mathbf{I_{ac}}$ is superimposed. $\mathbf{I_{dc}}$ is determined with:

$$\text{(7)} \qquad \mathbf{I_{dc} = \frac{U_{R2}}{R2} - \frac{U_{R1}}{R1}}$$

The capacitor forms the derivative of both currents. Thus $\mathbf{I_{dc}}$ is suppressed and the ammeter measures only the $\mathbf{I_{ac}}$ current with the frequency of the loudspeaker. The ammeter is realized as a transimpedance and lock-in amplifier.

The energy change is proportional to the ratio of the squared currents ($E \sim I^2$) and the normalized light path length, which was assumed to be 1,8 mm with a refractive index of ~1,5.

$$\text{(8)} \qquad \mathbf{dE = E_0\left(\frac{1m}{2{,}75\ mm}\ \frac{I_{ac}^2}{I_{dc}^2}\right)}$$

VII. Measurements

Four series of measurements were made with different accelerations and frequencies. In the Y-direction, the measured energy change (8) was compared with the theoretical energy change (6), with $\mathbf{E_0=1}$ in both cases:

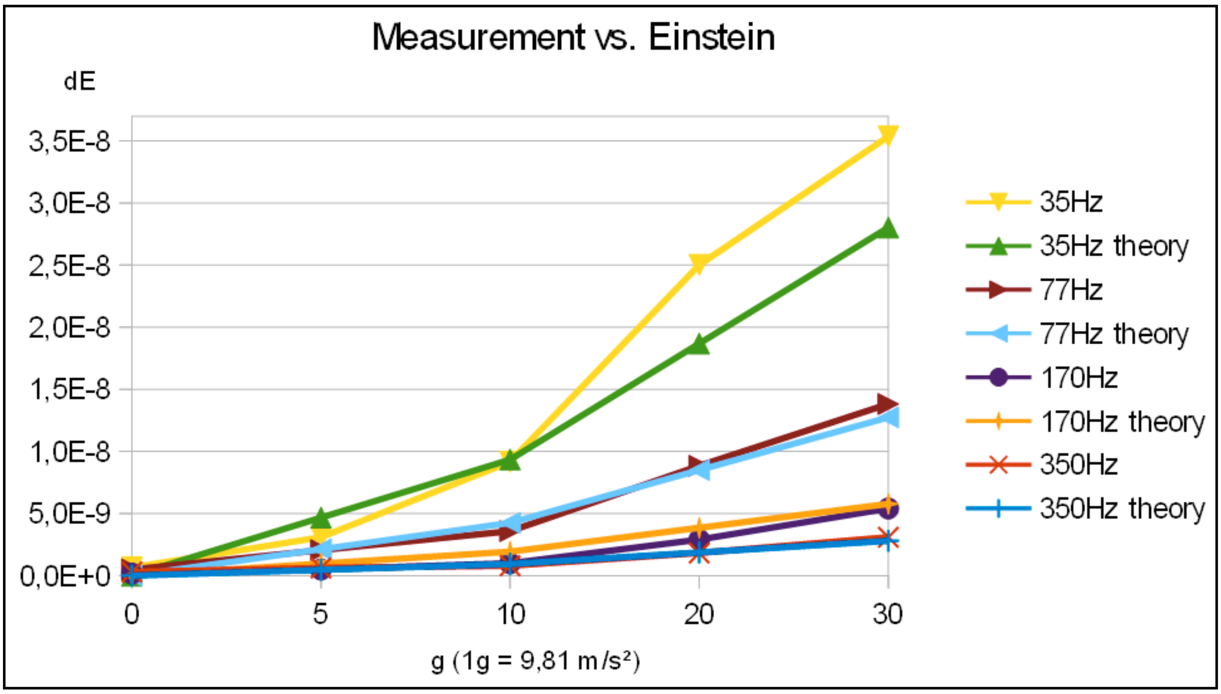

Fig. 5: Measurement vs. theory

The measured data show good conformity with the theoretical expectations. At 35Hz and above 10g, the membrane exceeds the linear operating range. With the system, Einstein, Pound-Rebka and the ART can be checked at almost arbitrary gravitations and drop towers on the laboratory bench. One must only take care that the membrane deflection does not become too large, because then the accuracy decreases.

Acknowledgement

We appreciate Miroslaw Wilczak for his inspiration, motivation and helpful explanations.

[1] Einstein, Albert: Über den Einfluß der Schwerkraft auf die Ausbreitung des Lichtes. Annalen der Physik. Bd. 35, 1911, S. 898

[2] Pound, R.V. and Rebka, G. A. Jr.: Apparent Weight Of Photons, Physical Review Letters, Vol. 4, Nr. 7. April 1, 1960

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