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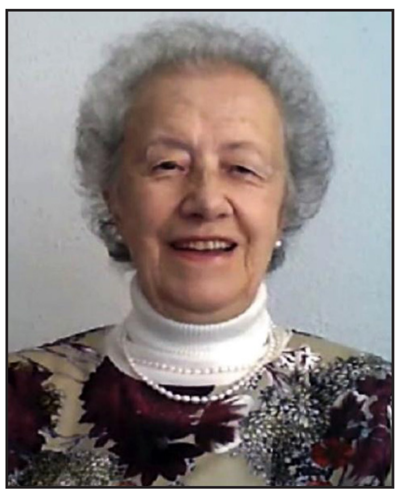

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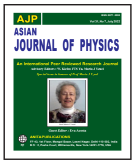

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# Introducing m-learning in the classroom: a proposal for diffraction and image processing training

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Dedicated to Prof Maria J Yzuel

We present results obtained with teaching and learning technique, the so called m-Learning (or mobile-Learning). This is a proposal with the aim to introduce an easy procedure to teach how to treat acquired images digitally, and to be detected and analyzed by undergraduate students, of the branch of physics and optics. The results indicated that m-learning could be compatible with diffraction phenomena training in the classroom. 

**Keywords**: m-learning, Diffraction, Fresnel and Fraunhofer approximation, Image processing.

## 1 Introduction

Since more than two decades, cell phones have become increasingly popular and are nowadays ubiquitous. New generations of smart phones are currently equipped with facilities as text messaging, internet access and high quality camera features, as main examples. In particular, the images acquisition facilitates the introduction of sensors data accessibility and its use by undergraduate students [1,2]. This is creating new teaching and learning techniques, the so called m-Learning (or mobile-Learning).

Because of the many facilities that mobile phones offer, teachers can use them as a supplementary teaching and learning tool. Moreover, the subsequent additional work by the teachers for introducing their students into the m-Learning in the classroom is well defined and developed. As an example, optical techniques, based upon interference and diffraction phenomena, appear to be convenient topics for m-Learning. They can be approached with simple examples and experiments with smart phones and classroom accessibility.

We will present some results carried out at the Faculty of Physical Sciences in UCM (Complutense University of Madrid) to obtain very simple Fresnel diffraction patterns recorded via cell phones. The activities were carried out in the Optical Coherence and Laser Course, offered by students in the fourth course of the Grade in Physical Sciences. This course is a part of the Specialty in Fundamental Physics.

Image sensors consist of devices that capture an image for purposes of display or storage. Current cell phones typically incorporate these image sensors, usually based on CMOS (Complementary Metal Oxide Semiconductor) technology, which enable high quality images [3]. A CMOS in mobile phones is used for digital image sensing. An image sensor captures light and converts it into electrical signals. There are two types of sensors CCD (Charge Coupled Device) and CMOS. CMOS is more common as it uses less power. Because the work on an image happens locally, processing and information transfer is faster with CMOS than with a CCD sensor.

Market volume of mobile phone CMOS image sensors has grown dramatically. In 2020, smartphones vendors sold around $138\times10^7$ smartphones, worldwide.

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Smartphones cameras (SPC) imaging technology is highly developed and continues to improve with enhanced resolution and better design. Focusing on the primary camera modules, the first SPC featured only 2M Pixels (MP). Starting from that achievement, the resolution trend has increased through the successive dominance of 5MP, 8MP and 12MP sensors. Remarkable achievements are the 48MP, 64MP or even 108MP image sensors, certainly, data depending on the manufacturer of the type of Phone. These facts allow the introduction of SPC in the classroom as a unique tool for teaching with real images and for simple technological training [4].

The objective of this study focuses on experimental methods for studying the basis of optical phenomena and which need to be extended to classroom as a routine tool for students in physics and engineering. These methods can be simplified and easily implemented by the use of the new technical assistance provided by SPC: classroom accessibility. Here, we analyze and discuss the experimental results and feasibility to be offered as part of the practical lessons.

The paper is presented as follows: section 1 contains the introduction. Section 2 is dedicated to the fundamental basis of Fresnel diffraction and its reproducibility with laser pointers along with complementary examples. Section 3 presents the experimental results, analysis and processing of the captured images. Section 4 closes with discussion and conclusions.

## 2 Fundamentals: Light beam in near and far field free propagation and approximations.

We need to formulate the complex amplitude distribution associated, even if as a first approximation only, to the free propagation of a laser beam issued from a laser pointer.

We consider the (classical light) beam with a low divergence and propagating (along the order of few meters) under an approximation for monomode regime although, as it has been studied earlier by us, it can exhibit a regime including more than one mode [5]. Therefore, we can formulate the laser pointer free propagation as that of a Gaussian beam. Gaussian irradiance profiles are symmetric around the center of the beam and decrease as the distance from the center of the beam perpendicular to the direction of propagation increases (see Fig 1). The complex amplitude distribution of the diffracted light in an arbitrary plane in the axial propagation direction, $z > 0$ is:

$$\Psi(x, y; z) = \Psi_{\rho 0}(x, y) * G(x, y; z). \tag{1}$$

In Eq (1) and for fixed $z$, $\Psi_{\rho 0}(x, y)$ denotes the Inverse Fourier Transform (IFT) of the incoming angular spectrum and $G(x, y; z)$ is the propagator or Green's function. The symbol * denotes the convolution operation. For the near field approximation we need to consider: i) $z >> \lambda$. ii) the so-called paraxial $z >> (x^2 + y^2)^{1/2} \rightarrow \sqrt{x^2 + y^2 + z^2} \cong z + \frac{x^2 + y^2}{2z}$ approximation:

This approximation simplifies the mathematical representation for $G$ that will now be denoted by $h(x, y; z)$:

$$h(x, y; z) = \mathrm{A} \exp(-ikz) \frac{ik}{2\pi z} \exp\left(\frac{-ik(x^2 + y^2)}{2z}\right) \tag{2}$$

In Eq (2), $A$ is the amplitude distribution of the incoming wave. Then, the complex amplitude distribution of the diffracted field is:

$$\Psi_{\rho}(x, y; z) = \Psi_{\rho 0} * h(x, y; z). \tag{1}$$

For the ideal particular case of a point source, $\Psi_{\rho 0}$ can be formulated as $\delta(x, y)$, the Dirac delta function.

Then:

$$\Psi_p(x, y; z) = A\, exp(-ikz)\, \frac{ik}{2\pi z} \exp\left(\frac{-ik(x^2 + y^2)}{2z}\right) \tag{4}$$

If we consider a small diffractive circular aperture as it is, approximately, the case of the aperture at the laser pointer (say of the order of 0, 2 cm), then Eq (4) can be recast approximately as [6]:

$$\Psi_p(x, y; z) \approx A\, exp(ikz)\, [1 - \exp(i\theta)], \tag{5}$$

where, $\theta = k\left[\sqrt{r^2 + z^2} - z\right] = p\pi$, $p$: Fresnel number, $p < 1$ is equivalent to far field diffraction (Fraunhofer region) while $p > 1$ corresponds to near field regime (for a fixed wavelength).

Notice that the result in Eq (5) is equivalent to the convolution of $h(x, y; z)$ with a circular aperture with small diameter, which is the case of a standard laser pointer aperture.

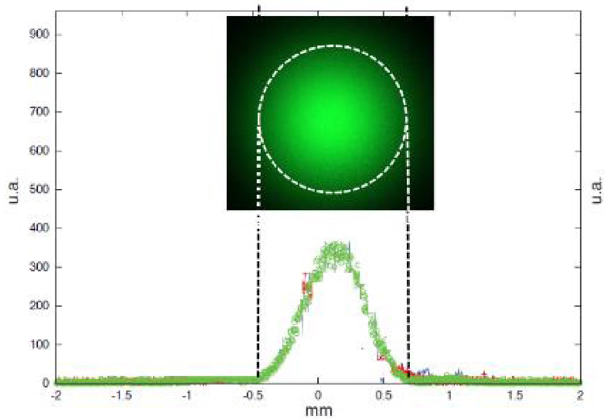



Fig 1. Image of free propagated green laser pointer (LASING S.L.), wavelength: λ = 532 nm, power: 50mW, as projected on a screen (above) and the corresponding line profile (below). The waist of a Gaussian beam is defined as the location where the irradiance is $1/e^2$ (13.5%) of its maximum value. After Ref. [5].

According to the results in Eq (5) the free propagated beam has a defined structure, determined by the Fresnel number $p$. In Fig (2), the structure of a free propagated beam is displayed: in this particular case, the simulation that we show has been performed for a slow neutron beam, the behavior of which is strongly similar to and, so, behaves as that of classical light, for our present purposes. It is important to notice here that the corresponding distance of propagation for the case of slow neutron beams is the order of angstroms (propagating at de Broglie wavelength: λ = 1.8 Å ) [7]. We observe in the transverse plane (XY) the formation of a ring structure, with a maximum at the center of the projection. We notice that, in the simulation, there is a limited aperture like in the classical light case, with only much smaller dimensions (200 Å).

The structure of the image in the Fig 2 right, corresponds to a Fresnel zone. This regime is applicable, in terms of the so-called Fresnel number $F = a^2/z\,\lambda$. $F < 1$, corresponds to far field approximation, while $F >> 1$ ($F = p$ in Eq (5)) corresponds to near field one. Here, $a$ is the dimension of the diffracted object (for example, radius of the laser pointer circular aperture in the present case), $z$ is the propagation distance and $\lambda$ is the wavelength of the beam. The case for which propagation regime verifies: $F \approx 1$ is the limit for validity of the far field approximation. This case holds for the actual experiment presented here and corresponds to Fresnel regime. From the definition, $F$ equals the number of Fresnel zones that may be observed within the aperture from a point (located at the screen) at a distance $z$ from the laser pointer aperture. Therefore, the number of zones we are going to observe in the actual case is close to one. This is discussed in section 3 presenting the experimental results.

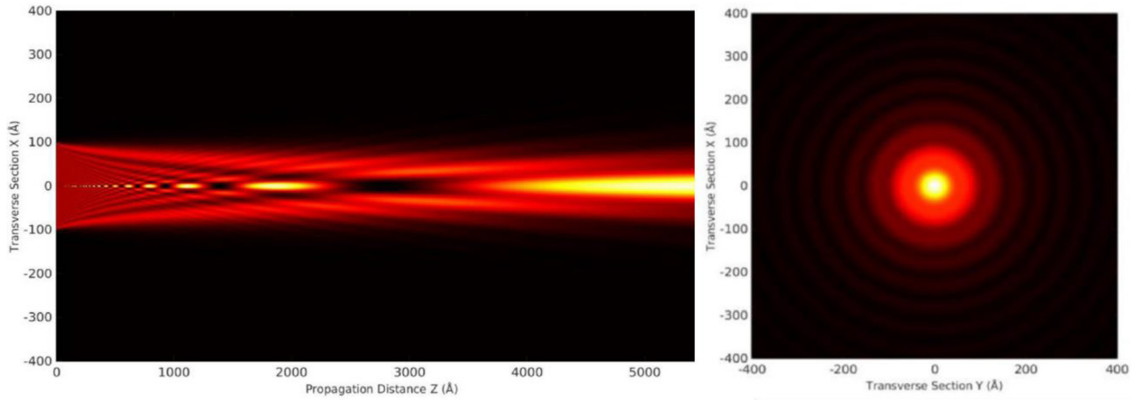



Fig 2. Computational simulation of a beam (a slow neutron beam in this particular case) as it propagates freely (in free space) under Fresnel regime. Left: axial section profile (plane XZ). Right: transverse section profile (plane XY). See text for details. After Ref [7].

In the currently studied case, we concentrate in analyzing the structure of the diffraction pattern, as recorded by the mobile phone camera, and will discuss how the phase of the Fast Fourier Transform (FFT) of the amplitude distribution associated to the recording can exhibit some periodic structure, as expected. It is assumed that, prior to performing the classroom experiment, all undergraduate students should have studied the fundamentals of diffraction theory and the Fresnel regime, as explained above.

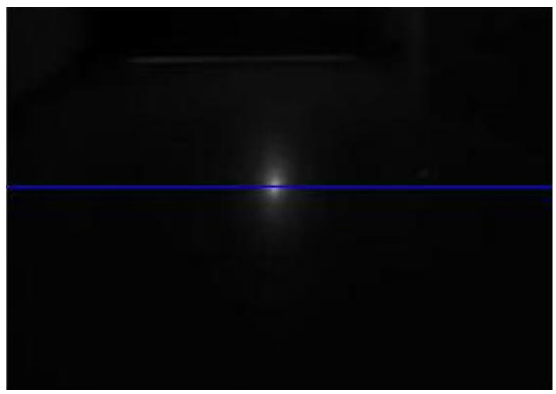
## 3 Experimental results

The main objective of the proposed classroom experiment is to teach undergraduate students in Physics the basic principles of Fresnel diffraction and digital image processing. For this purpose, only very simple elements are required for the experimental procedure. Previously, the teacher must indicate to the students that they have to carry mobile phones for the classroom experiments. Usually, peer work is advised then the number of mobile phones and results to be compared can be reduced. The peer work applied in the actual case involved two students per group, one shared mobile phone and one report per group [8].

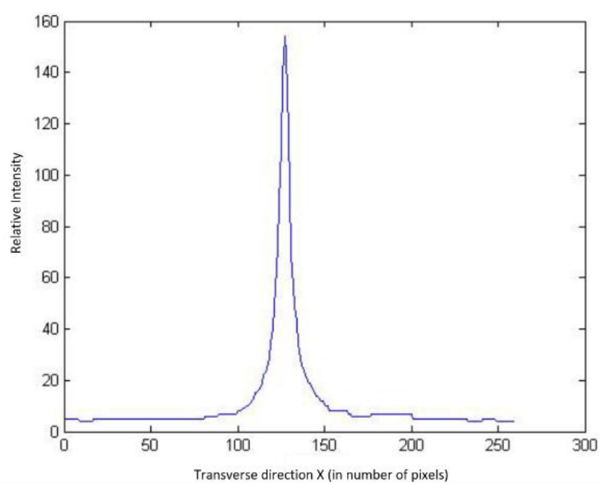
Fig 3. Operating in the classroom: A white screen is needed to project the laser beam source after propagating a certain distance (usually larger than 1 m.).

A simple tape meter can be used to fix the distance of propagation. Undergraduate students have to take a photograph of the projected laser pointer image [after Ref 8].

As seen in Fig 3, a laser beam emitted from a laser pointer is projected onto the screen after propagation. The pattern has to be recorded as an image with the mobile phone camera. The distance of the laser beam propagation has to be fixed. For example, a distance between 1 m and 3 m could avoid certain overexposure and that the image be saturated. After the capture of the image, students have to treat the recorded images as a personal task, by transferring it to a computer (in the laboratory) and using a software for digital image treatment, intensity line profile determination and Fast Fourier Transform (FFT) operations. Figure 4(a) displays the pattern recorded with a green laser pointer with a propagation distance the order of 3 m ($\lambda$ = 532 nm, output power 3mW/cm$^2$, then belonging to a laser class 3R). In general, standard green laser pointers are of DPSS lasers type (DPSSFD standing for "diode pumped solid state frequency-doubled"). We may notice that this particular type of laser operates under multimodal configuration, as it was previously studied by us in a separate experiment [5]. Moreover, the degree of spatial coherence turns out to be high enough (for a particular exit power) so as to obtain a good contrast of the captured image [9]. We notice that much of the light is distributed as dictated by geometrical optics [10].



(a). Captured image at the screen




(b) Intensity Line profile

Fig 4. (a) Diffraction pattern of the projected beam onto the white screen, captured by a mobile phone (NOKIA X3-02), see text for details. Propagation distance: $z$ = 3 m. (b) Line profile of the corresponding image. Abscissa horizontal line indicates the selected location for obtaining the line profile. Transverse distance is measured in number of pixels.

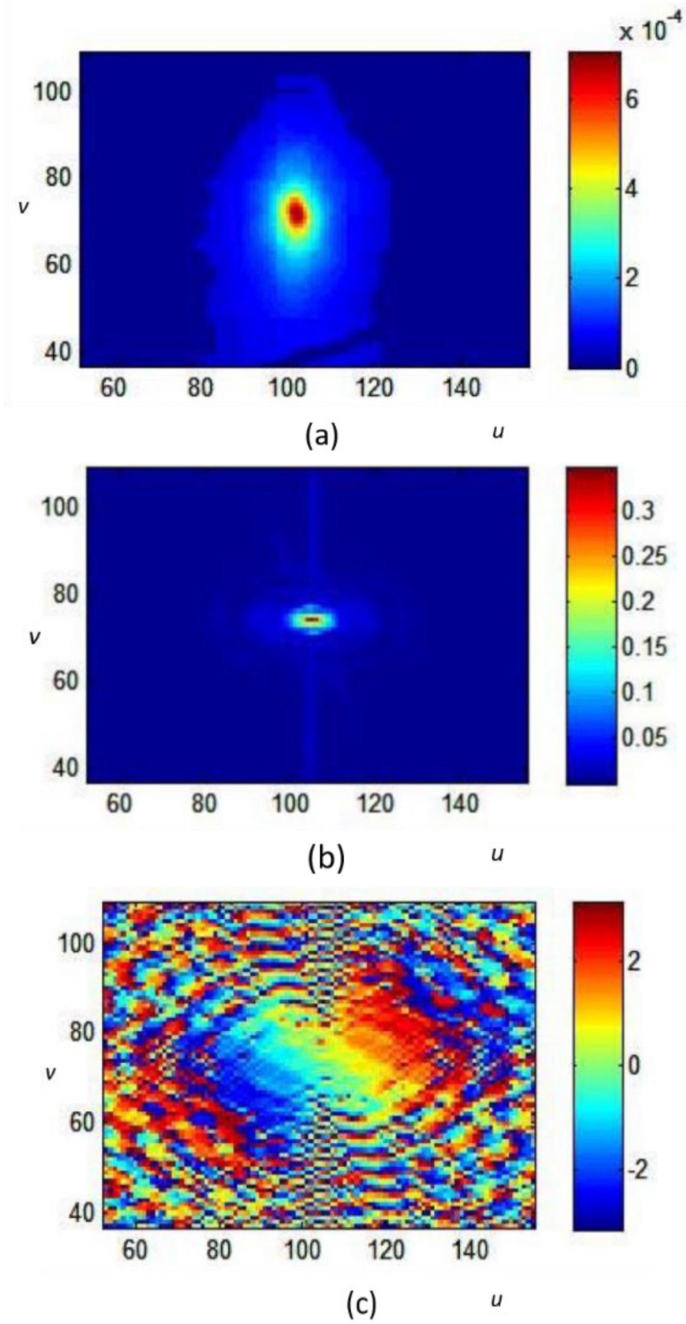



Fig 5. (a) Pretreated image of the laser beam as projected on the white screen. The RGB image is converted to a single intensity gray scale in order to perform the FFT. (b) FFT of the laser beam projection as obtained in (a). (c) Phase of the FFT as obtained in (b). Data: wavelength of the laser pointer beam: $\lambda = 532$ nm. Distance of propagation 3 m. Output power of the laser pointer 3mW/cm$^2$.

An important fact, in order to avoid hazardous injuries, is the following: the teacher has to warn the students not to be close to either the laser pointer (operated by trained assistants) or the screen where the image is projected. One should notice that National Institute of Standards and Technology tests conducted on laser pointers labeled as Class 3a or 3R in 2013 showed that about half of them emitted power at twice the Class limit, thereby making those corresponding to the designation Class 3b – more hazardous than Class 3a [11]. Obviously, those prescriptions make compulsory to take all precautions while operating in the classroom.

Figure 4(b) shows the corresponding intensity line profile. The relative intensity values are represented in terms of gray levels. The software works with 8-bits images, comprising a total of 256 gray levels. In the particular study corresponding to the data in Fig 4(b), we used a special program implemented in MathLab in our laboratory for obtaining the line profile [12]. The intensity line profile represents the intensity distribution as a function of distance, measured in pixels. In the actual case, each pixel corresponded to 8 mm. The contrast can be estimated as well with a value of: $C = 0.8$. For the technical data, the used mobile phone was a NOKIA X3-02, whose camera had a sensor with 5 Mpixels and a digital zoom up to x4. The format of the recorded image is JPEG.

The image is first captured in a RGB format, comprising three superimposed images (i.e. channels) in red, blue and green, respectively. In order to perform the Fast Fourier Transform (FFT), it has to be converted into a gray scale image, merging the three channels into a single intensity value for each pixel (Fig 5a). Then, the FFT algorithm is applied and the result for the intensity distribution is shown in Fig 5b. We can observe a certain degree of saturation arising from the digital processing. The phase of the previously obtained FFT is displayed in Fig 5c. In all cases $(u, v)$ is the pixels array. As expected, Fig 5c recreates the phase map distribution with a quasi-circular geometry indicating the distribution associated with Fresnel zones, as discussed in section 2 [13]. We have to consider that due to the particular experiment no further optimization has been performed and a certain distortion in the geometry is observed.

Indeed, the use of sophisticated high resolution mobile phone cameras will allow a high quality image and, therefore, a higher quality image processing. Notice that the results displayed here were based on an image capture with a reasonable good quality phone camera. Anyway, the same process can be performed with different mobile phone cameras having other performance levels. As a key point, the students have to control not to record saturated images that will give diffraction patterns with a flat profile. Highly saturated images will be too bright i. e. white. A contrast visibility factor closer to 1 is advised.

## 4 Conclusions

We have presented experimental results obtained with the free propagation of a green laser pointer and projected on a screen, as a simple practical teaching in the classroom for light diffraction in the near and far field approximations. The posterior digital image treatment has to be performed by the undergraduate students in the laboratory, as a complementary work for learning this particular optical techniques, as well. Camera mobile phones are very useful for education and technical purposes, offering many benefits and facilities for learning. They are nowadays very popular in the classroom, as experimental teaching tools, and they constitute what is known as m-learning. The combination of laser sources with easy access to classroom, such as laser pointers, and cell phones, provide an interesting tool for the experimental demonstration of diffraction phenomena. In the present experiment, students can observe Fresnel diffraction phenomenon and study the structure of a particular diffraction pattern. An important advantage is that it requires a much reduced infrastructure and images can be stored in standard mobile phones. Combination with digital image processing provides a promising tool for the training of image data manipulation.

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## References

1. Lakhdar Z B, Dhaouadi Z, Ghalila H, Lahmar L, Majdi Y, Using mobile camera for a better exploitation and understanding of interference and diffraction experiments, Proc ETOP Conf 2009; doi.org/10.1364/ETOP.2009.ETC5.
2. Rath G, Mobile phones in physics teaching-an overview of development and research activities, *J Phys Conf Ser*, 1286(2019) 012050; doi.org/10.1088/1742-6596/1286/1/012050.
3. Gove R J, CMOS image sensor technology advances for mobile devices, (Ed) Durini D, In Woodhead Publishing Series in Electronic and Optical Materials, High Performance Silicon Imaging, 2nd Edn, (Woodhead Publishing), 202), pp 185–240.
4. Saini S S, Sridhar A, Ahluwalia K, Smartphone optical sensors, *Opt Photonics News*, 30(2019)34–41.
5. Paredes-Barato D, Calvo M L, On the Thompson-Wolf experiment: a study with laser sources, *J Europ Opt Soc, Rapid Publ*, 5(2010) 10051s; doi. 10.2971/jeos.2010.10051s
6. Ghatak A, Optics, 5th edn, (Tata Mc Graw Hill, New Delhi, India), 2012.
7. Molina de la Peña I, Calvo M L, Alvarez-Estrada R F, Neutron Optics: New algorithm based on Green's functions for simulating waveguides with Dirichelet boundary conditions, *Appl Math Mod*, 101(2021)694–715.
8. Calvo M L, m-Learning and holography: compatible techniques?, Proc SPIE, 9289(2014) 928903-2; doi.org/10.1117/12.2068494.
9. Astadjov D N, Prakash O, Spatial coherence of low-cost 532nm green lasers, Proc SPIE, 8770( 2013) 87701P-1; doi.org/10.1117/12.2012849.
10. Bass M (Ed.), Handbook of Optics, 3rd edn, Vol. 1, (Mc Graw Hill, New York), 2010.
11. NIST Tests Underscore Potential Hazards of Green Laser Pointers, (March 2013), https://www.nist.gov/news-events/news/2013/03/nist-tests-underscore-potential-hazards-green-laser-pointers (page checked January 2022).
12. Calvo M L, Alieva T, Rodrigo J A, Martinez Matos O, Moreno A, Aliev T, Holografía. Laboratorio Virtual [A virtual laboratory of holography], Editorial Complutense, Madrid (November 2007, CD in Spanish). ISBN 10: 8474918588ISBN 13: 9788474918588.
13. Rolleston R, George N, Stationary phase approximations in Fresnel-zone magnitude-only reconstructions, *J Opt Soc Am A*, 4(1987)148–153.

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