

Celebrating the Many Contributions of Jim Wyant

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ABOUT THIS MANUSCRIPT

This manuscript was written entirely within the program Mathematica™ and includes a number of manipulable figures. If you are reading the Proceedings of the Jim Wyant celebration, you are reading a PDF of the Mathematica document, and as such the figures will not be manipulable. However, below is a link to the Mathematica file itself, which can be read with either the Mathematica program or with the free program Wolfram Player, in both cases with full capability to manipulate the figures.

http://spie.org/Samples/Pressbook_Supplemental/OP21,11813-8_Goodman_sup.zip

HOW I FIRST MET JIM

In the early 1970's, I was asked to serve on a U.S. Air Force advisory committee tasked with monitoring the development of the first adaptive optics system to be deployed on a telescope. The company Itek was one of two competing companies developing designs for such a system. At that time, Jim was just a few years beyond his Ph.D. and was employed by Itek, where he played an important role in the conceptualization and development of a shearing interferometer wavefront sensor. It was already clear at that time that Jim was a rising star in optics.

A FIRST IMPORTANT THING I LEARNED FROM JIM

Sometime in the mid 1990's I met Jim at a professional meeting, and we had a brief discussion about the emerging World Wide Web. He asked me if I had discovered the web site named Yahoo!, which he found to contain a very useful directory to other web sites. I had not seen Yahoo! and was unaware of it, even though it was being developed and hosted on computers in my own Stanford department. When I returned home after the meeting, I found Yahoo! and I, too, found it to be very useful. So Jim introduced me to Yahoo! long before I might have found it myself. A few months later, as department chair, I was approached by two electrical engineering graduate students, David Filo and Jerry Yang, asking for my approval (among the several that they needed) to take Yahoo! off campus as a private company. They obtained all the needed approvals, including mine, and the rest is history. Thanks to Jim for preventing me from being clueless when Filo and Yang approached me.

A SECOND IMPORTANT THING I LEARNED FROM JIM

I had been a user and fan of the program Mathematica ever since I wrote the second edition of Introduction to Fourier Optics, but I had used the program only to generate static plots for illustrations. Only after my retirement did I discover that Jim had long been a Mathematica user and that he had developed a significant number of optics demonstrations in the form of manipulable figures, which he had deposited on the Wolfram Research "Demonstration Projects" website, freely accessible by anyone. Unlike my use of Mathematica, Jim had created manipulable figures, with parameters that could be changed easily by the reader.

What follows is a list of some of Jim's demonstrations on the Wolfram site.

- Point spread and modulation transfer functions for Seidel aberrations
- Point spread and modulation transfer functions from Zernike wavefronts
- Plots of Zernike polynomials
- Moiré pattern of two Fresnel zone plates
- Wavefront maps and profiles of Seidel aberrations
- Moiré pattern of two straight line patterns
- Seidel optical aberrations
- Moiré pattern of two equally spaced circular ring patterns

Now I show you one of Jim's creations, then last item in the previous list. The plot contains two binary radial gratings, for which the periods can be changed and the locations of the centers can be changed. The Moiré fringes are obvious.

Tribute to James C. Wyant: The Extraordinaire in Optical Metrology and Optics Education,
edited by Virendra N. Mahajan, Daewook Kim, Proc. of SPIE Vol. 11813, 118130A
© 2021 SPIE · CCC code: 0277-786X/21/\$21 · doi: 10.1117/12.2566422

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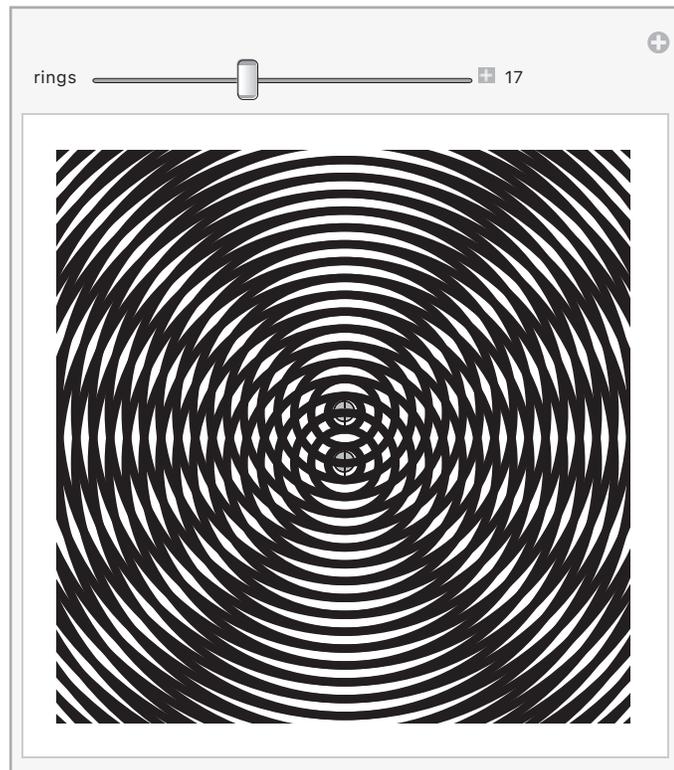


Figure 1. One of Jim Wyant's manipulable Plots.

Jim is what I would call an expert user of *Mathematica*, at least compared to me. His work motivated me to try to exploit manipulable figures as a teaching tool for both Fourier transforms and optics. My examples are less sophisticated than his, but I think they are instructive none-the-less.

As I ventured into the realm of manipulable figures, I first considered some classic results in Fourier transform theory that could benefit from a manipulable figure. One I illustrate here illustrates aliasing that arises in sampling theory when the spacing between samples is too small. Let the function to be sampled be the $\text{sinc}^2(x)$ function, which has a triangular spectrum that extends from -1 to $+1$ in the frequency domain. The function will be sampled with spacing X between samples, or equivalently a sampling rate $1/X$ samples per unit time or space. Since the spectral width of the $\text{sinc}^2(x)$ function is 2 units, the Nyquist sampling rate, which is the minimum rate that allows recovery of the function from its samples, is $1/X = 2$ or $X = 0.5$. After sampling, a rectangular filter extending from frequency -1 to frequency $+1$ is applied. If the sample spacing X is larger than 0.5 , aliasing occurs.

Out[50]=

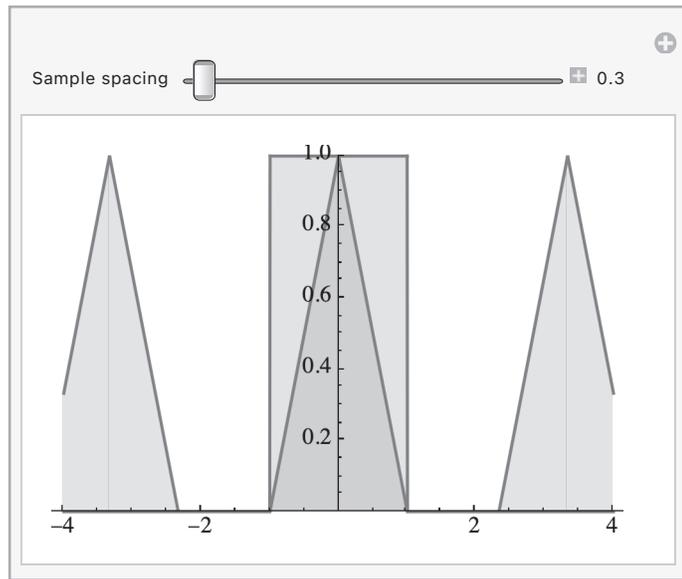


Figure 2. Demonstration of aliasing in sampling theory

Let me now turn to optics and explore a phenomenon that Jim has told me he especially likes to see illustrated. This example is based on Zernike phase-contrast imaging, in which a small, on-axis, dielectric dot in the focal plane of an imaging lens shifts the phase of the on-axis component of transmitted light by $\pi/2$ radians, thereby making the phase structure of the object directly viewable.

The theory behind phase-contrast imaging is based on the assumption that the phase-shift ϕ of the object is much less than 2π , allowing the approximation

$$\exp(j\phi) \approx 1 + j\phi.$$

With a $\pi/2$ phase shift applied only to the on-axis component in the focal plane, we obtain an intensity

$$I(x,y) \approx |j + j\phi|^2 = 1 + 2\phi + \phi^2 \approx 1 + 2\phi,$$

which we call positive phase contrast. If instead the phase shift is $\pm\pi/2$, we obtain negative phase contrast,

$$I(x,y) \approx 1 - 2\phi.$$

Two questions are addressed here: 1) How does the diameter of that dielectric dot affect the image that is observed, and (2) what happens when the phase shift is not $\pm\pi/2$? We answer these questions by simulation.

The phase distribution of the object $\phi(x,y)$ that I have chosen to consider consists of 3 circularly-symmetric pyramids, with different widths, all with height $\pi/8$ radians.

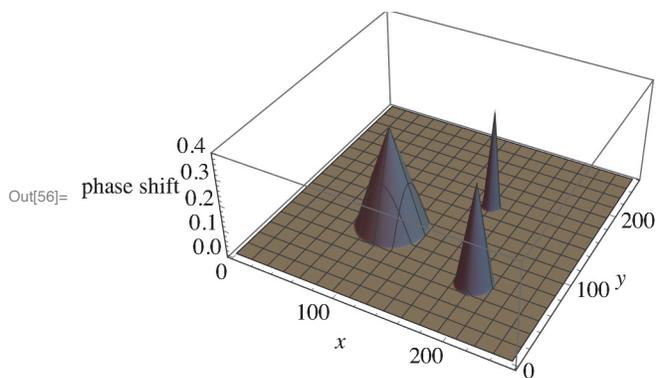


Figure 3. Phase distribution in the object to be imaged.

The phase object to be imaged thus has amplitude transmittance $\exp[j\phi(x,y)]$. The figure below shows an (spatially) inverted) image of the object with manipulable dielectric dot width and dot phase shift.

Out[60]=

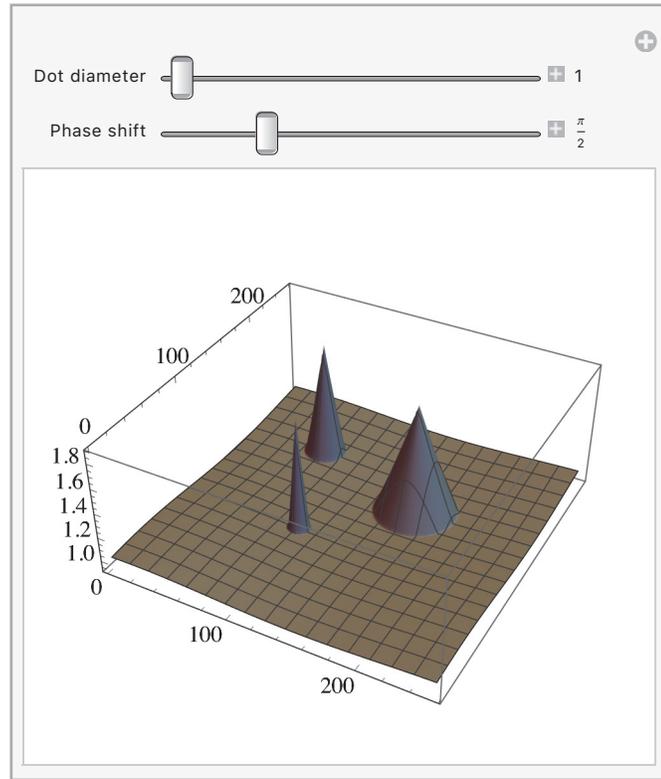


Figure 4. Effects of changes of dielectric dot diameter in Zernike phase-contrast imaging

First fix the dot diameter at 1 pixel and vary the dot phase shift. The initial plot assumes the phase shift is $\pi/2$, in which case the image intensity is proportional to the phase shift of the object, riding on a background of value unity. If, by using the slider, the phase shift is changed to 0 or 2π , the image intensity vanishes. If the phase shift is set to $3\pi/2$, we observe the phase object in negative contrast. If the phase shift is π , the an image intensity distribution appears, but it is an image of the squared values of the phase distribution, rather than linearly proportional to the phase.

Now fix the phase shift of the dot at $\pi/2$ and vary the diameter of the dot. When phase shifting dot is one pixel in diameter, we see an image intensity that is an (geometrically) inverted image of the phase distribution of the object. But now increase the diameter of the phase-shifting dot. Move the slider to the right to see the effects of that increase. When the dot diameter is about 4 pixels or greater, the larger pyramid begins to drop into a depression. If we increase the dot diameter further, all the pyramids begin to sink into depressions. What is the reason for this phenomenon? The largest pyramid has the narrowest spectrum, and as we increase the diameter of the dot, not only is the on-axis component of the spectrum phase shifted, but eventually all of the spectrum of the largest phase pyramid is phase shifted, destroying the ability to see an intensity proportional to phase shift. The same happens to the narrower pyramids as the diameter of the phase-shifting dot is increased further. Thus ultimately the image returns to a uniform intensity distribution with no variations due to the phase shifting object, as was the case without the phase-shifting dot.

The above examples suffice to illustrate the effect Jim has had on my own use of *Mathematica*, and on my attempts to show dynamic figures of interesting optical phenomena. Thanks Jim for your influence on me, and more generally for your impact on the entire field of optics.