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Title: Visual demonstration of aliasing in planar nuclear medicine imaging: The importance of correct collimator selection by nuclear medicine practitioners

Article Type: Case Report

Keywords: Aliasing artefact; nuclear medicine; quality control; planar imaging; gamma camera; bar phantom; collimator.

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09/07/2019

Dear Radiography Journal,

Thank you for your response regarding our article, *Visual demonstration of aliasing in planar nuclear medicine imaging*: *The importance of correct collimator selection by nuclear medicine practitioners*. Various alterations have been made to the original manuscript, an explanatory document has been generated for the benefit of the reviewers to explain the changes made. We note that the use of Highlights has been discontinued, hence this has been removed from our submission.

On behalf of myself and my fellow authors I would like to reconfirm:

- The manuscript is not under consideration for publication elsewhere.
- Each author has participated sufficiently in this submission to take public responsibility for appropriate portions of the content.
- A full list of contact details are found below.
- James Elliott is responsible for the integrity of the work as a whole.
- Publication has been approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out.
- There are no similar submissions/reports in existence by any author of this article.
- The authors or author's institutions have no conflicts of interest for this article.
- I can confirm that no medical images have been sent by post to the Editorial Office.

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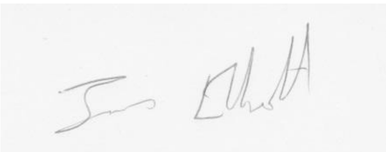
Yours sincerely,



James Elliott

Response to reviewers:

Thank you for your constructive comments. We have amended the article according to your suggestions, the changes are outlined below:

1. **Title** – We have added 'The importance of correct collimator selection by nuclear medicine practitioners' to the title to specify the relevance of the findings and who it affects. We feel 'nuclear medicine practitioners' better reflects the workforce as the modality is not limited to radiographers.

2. **Highlights** – These were changed to reflect the educational nature of the article. However, it has been noted that Highlights are no longer required as per the Author Information Pack.

3. **Abstract** – As above, the abstract has been edited to better demonstrate the educational aspects of the case report for nuclear medicine practitioners.

4. **Introduction** – As per your suggestion, the first two paragraphs from the discussion have been moved and an additional paragraph has been generated which provides the rationale for this case report. Also, as suggested, the term 'frequency' in nuclear medicine planar imaging has been clarified with an additional sentence (with supporting reference).

5. **Discussion** – This section has been re-written to bring relevance to real-world situations (based upon our clinical environment).
    a. Emphasis has been placed upon the need to understand the construction and interaction of collimators during imaging, whilst relating the observations from the imaging provided in the case report.
    b. An analogy of collimators with x-ray anti-scatter / secondary radiation grids has been included to provide the wider diagnostic radiography workforce a familiar concept on which to orientate themselves.
    c. The discussion section ends on practical recommendations and theoretical situations where the concept of aliasing/collimator selection would apply.

6. **Conclusion** – This has been adjusted to summarise when aliasing may occur, why it matters and the application of this knowledge to the real-world clinical environment.

7. **Use of old references** – We were reliant upon literature immediately available in our department. Following your suggestion we have changed or updated some references.
    a. Sharp, Gemmell and Murray (2005) have been removed and updated with Mettler and Guiberteau (2019).
    b. Cherry, Sorenson and Phelps (2003) have been updated to the most recent edition.
    c. Bolster (2003) *Quality assurance in Gamma Camera Systems* has not been changed as QA guidance from the Institute of Physics and Engineering in Medicine has not been updated since.
    d. Zbijewski and Beekman (2006) has not been updated due to the specialist nature of their article concerning interference patterns in angular aliasing.
    e. Several references were removed due to re-writing the article.

*Title Page (with author details)

Visual demonstration of aliasing in planar nuclear medicine imaging: The importance of correct collimator selection by nuclear medicine practitioners

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Declarations of interest: none.

Visual demonstration of aliasing in planar nuclear medicine imaging: The importance of correct collimator selection by nuclear medicine practitioners

Abstract

Aliasing artefact is an imaging distortion phenomenon experienced in a wide variety of medical imaging modalities. This case report illustrates its occurrence during planar gamma camera nuclear medicine imaging under non-clinical conditions using experimental incorrect selection of collimators. In accordance with provision of an optimal service, nuclear medicine practitioners are recommended to have sufficient technical expertise along with knowledge of gamma camera operation. The purpose, construction and interaction of collimators used during planar imaging are presented herein with specific regards to the aliasing phenomenon. Furthermore, this case report recommends the careful planning of worklists to avoid frequent collimator changes to reduce the risk of human error.

Keywords: Aliasing artefact, nuclear medicine, quality control, planar imaging, gamma camera, bar phantom, collimator.

Introduction

Aliasing is a phenomenon relevant to a multitude of medical imaging modalities[1, 2, 3], not just nuclear medicine. Essentially, aliasing occurs whenever a source signal has a higher frequency than the highest sampling frequency[3] and the Nyquist Theorem is not satisfied. Frequency, in this scenario, relates to the representation of image patterns as sinusoidal waves common in modern medical imaging[4]. The theorem states that the sampling rate must be at least twice the highest analogue frequency component (>2fmax).[5] Image distortion may be further compounded with software reconstruction dependant on the degraded data.

Outside of medical imaging the often-cited example is the carriage wheel seemingly rotating backwards as the carriage travels alongside the observer; the human eye cannot sample the frequency of spoke rotation and so interprets a lower frequency instead, thus the illusion is created (Figure 1). Within magnetic resonance imaging, computed tomography and single photon emission computed tomography this artefact manifests as angular aliasing, where insufficient tomographic sampling produces interference patterns[6]. This case report demonstrates the same phenomenon during nuclear medicine planar acquisition (a two-dimensional image), demonstrated by experimental use of incorrect collimators during spatial resolution quality control.

The generation of examination-level research to inform evidence-based radiography across all specialities has seen increasing interest in recent years[7, 8]. However, literature regarding nuclear medicine practice at an examination-level is scarce, leaving a gap in the knowledge base. Although elementary in concept, this article addresses this issue by highlighting the potential implications of incorrect collimator selection.

Case presentation

A series of three spatial resolution tests were performed using a photomultiplier gamma camera (GE Discovery 670 NM/CT), bar phantom (Figure 2) and Cobalt-57 flood source (Figure 3). Table 1 outlines the methodology employed, where the main variable included changing between low, medium and high energy collimators. All other parameters remained constant, including total accepted counts. The images were then processed using an Xeleris Functional Imaging Workstation (version 3.1) using equal intensity values to ensure uniformity in image comparison. The results demonstrated an increasingly diagonal change in direction of the bar phantom as higher energy collimators were utilised (Figure 4). This represents a visual demonstration of aliasing artefact during non-clinical conditions.

Discussion

This case demonstrates an artificial replication of the conditions required for aliasing in nuclear medicine by incorrect collimator selection. Accidental selection of collimators during patient imaging is unlikely due to various integrated system failsafes, whereby the operator is informed and warned of incompatibilities between intended gamma emission energy and loaded collimators. Despite this unlikelihood, there is the potential of imaging patients of differing isotope administration and failing to change collimators accordingly, for instance when alternating between patients administered with Iodine-131 (364keV, requiring high energy collimators) or Technetium-99m (140keV, requiring low energy collimators). Technical expertise and knowledge of gamma camera operation has been listed as fundamental qualities for nuclear medicine practitioners (NMP) wishing to provide an optimal clinical service[9], with similar requirements echoed within the Register of Clinical Technologists Scope of Practice (2016)[10]. The discussion of causational effect surrounding aliasing and collimator construction therefore serves as an educational example for the NMP workforce to facilitate technical expertise and knowledge.

The primary imaging tool used in nuclear medicine is the gamma camera with scintillation of ionising radiation being detected through photomultiplier tubes or silicon diodes[5]. Within this example a bar phantom was deployed to provide an objective measurement of extrinsic gamma camera spatial resolution[11], using a Cobalt-57 (122keV) flood source for emission of gamma rays. In relation to the Nyquist Theorem, aliasing occurred as the sampling rate was decreased by a combination of two factors; collimator and bar phantom construction. The occurrence of aliasing coincided with the use of collimators which cater for greater emission energies, with individual regions of the bar phantom also forming a contributing factor.

Collimators reduce scatter and gamma rays that exit a patient's body at a tangent whilst accepting perpendicular registration, therefore improving spatial resolution[12]. Their construction is similar to honeycomb, with multiple apertures (holes) allowing passage of gamma rays from the subject to the scintillation crystal[5]. An analogy can be made to the anti-scatter grids used within plain film radiography, where the construction of slats (high density material) and interspaces are arranged as lines to reduce x-ray scatter upon the image receptor[13]. Collimators for high energy emissions have three notable differences in construction; holes are less frequent and larger, with increased hole length and thicker septum between holes to absorb higher energy scatter[14] (Table 2). The number of holes per unit length will determine the maximum frequency that can be transmitted through the collimator, thereby influencing the sampling of the resultant image. Additionally, areas of higher spatial frequency on the bar phantom (i.e. ratio of bars to gaps) are more prone to aliasing as more samples per unit length are required to satisfy the Nyquist Theorem. As a result, aliasing occurs when the spatial frequencies of the bar pattern cannot be reconstructed appropriately.

Although this example demonstrates non-clinical aliasing artefact, the ramifications of incorrect collimator selection during clinical imaging are clear. In theory, neglecting to change between high and low collimators when interchanging between patients with different emission energies (e.g. I^{131} and Tc^{99m}) could potentially have disastrous consequences for image interpretation. Although probable within all varieties of Tc^{99m} imaging, notable image distortion may be more evident within bone scintigraphy due to the complexity of radiopharmaceutical uptake in some areas of bony anatomy. Recommendations arising from the authors include adequate appreciation and understanding of collimator construction and interaction during imaging by NMP staff and the careful planning of the worklist to avoid frequent changing of the collimators.

Conclusion

This case report demonstrates the importance of correct collimator selection during gamma camera imaging to avoid the phenomenon of aliasing which degrades image quality. The use of high energy collimators with low emission energy isotopes can potentially lead to under sampling of fine details within an image and therefore aliasing artefacts may manifest. Such image distortions may adversely affect the diagnostic value of examinations. To combat this, NMP staff are recommended to appreciate and understand the construction and interaction of collimators used during imaging. Furthermore, careful planning of worklists may reduce frequency of collimator changes and lessen the risk of human error.

Conflict of interest statement

The authors declare that there are no conflicts of interest regarding the publication of this article.

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Tables:

Table 1. Constants and variables used during experiment

Constants	Variables
Gamma camera General Electric Discovery NM/CT 670 **Emission source** Cobalt flood source (Co^{57}) **Bar phantom** Gamma camera spatial resolution quality control tool with bar width/separations of 3.18mm, 3.97mm, 4.77mm, and 6.35mm. **Scan parameters** 256 x 256 matrix 1.0 zoom 2000k counts Co^{57} energy window (122keV) with 10% margin **Test configuration** Bar phantom placed directly upon collimator, Co^{57} source placed 1cm above bar phantom.	**Collimator** Variable by septal thickness. Low energy high resolution Medium energy general purpose High energy general purpose **Acquisition time** (dependent on collimator selection)

Table 2. Collimator construction specifications *(courtesy of GE Healthcare)*

Collimator type	Abbreviation	Hole diameter (mm)	Septal thickness (mm)	Hole length (mm)
Low Energy Higher Resolution	LEHR	1.5	0.2	35
Medium Energy General Purpose	MEGP	3.0	1.05	58
High Energy General Purpose	HEGP	4.0	1.8	66

Figures: (all in colour)

Figure 1: Sampling rate inadequacy and aliasing phenomenon

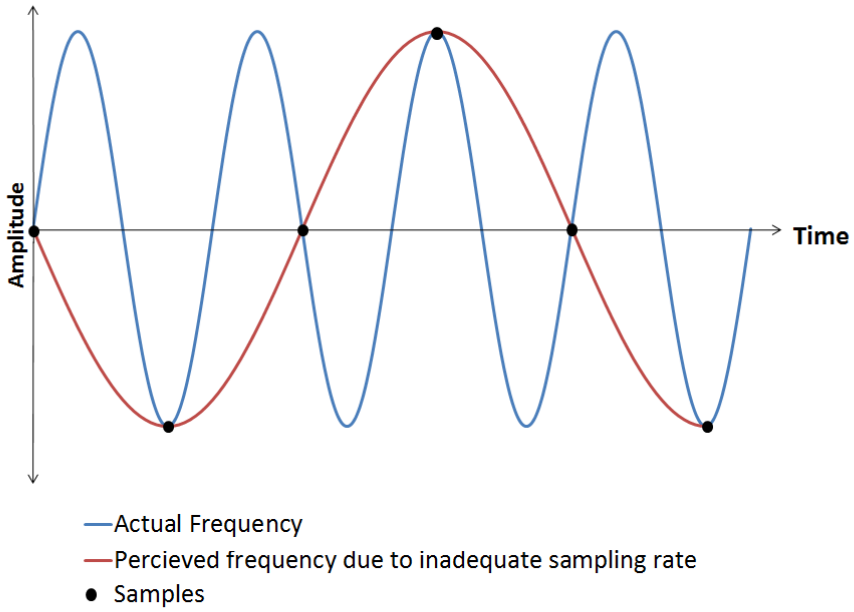
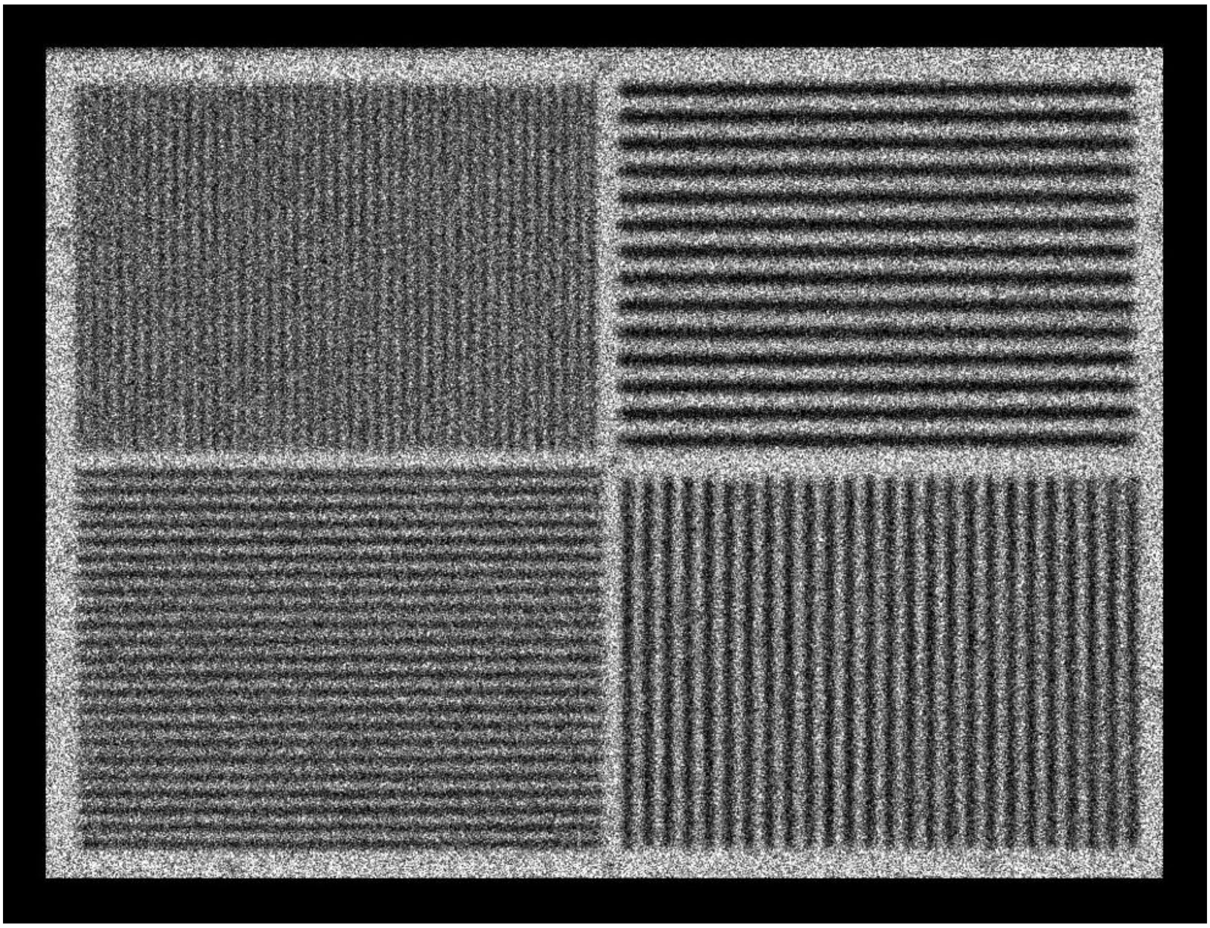


Figure 2. Typical bar phantom *(courtesy of Leeds Test Objects Ltd)*

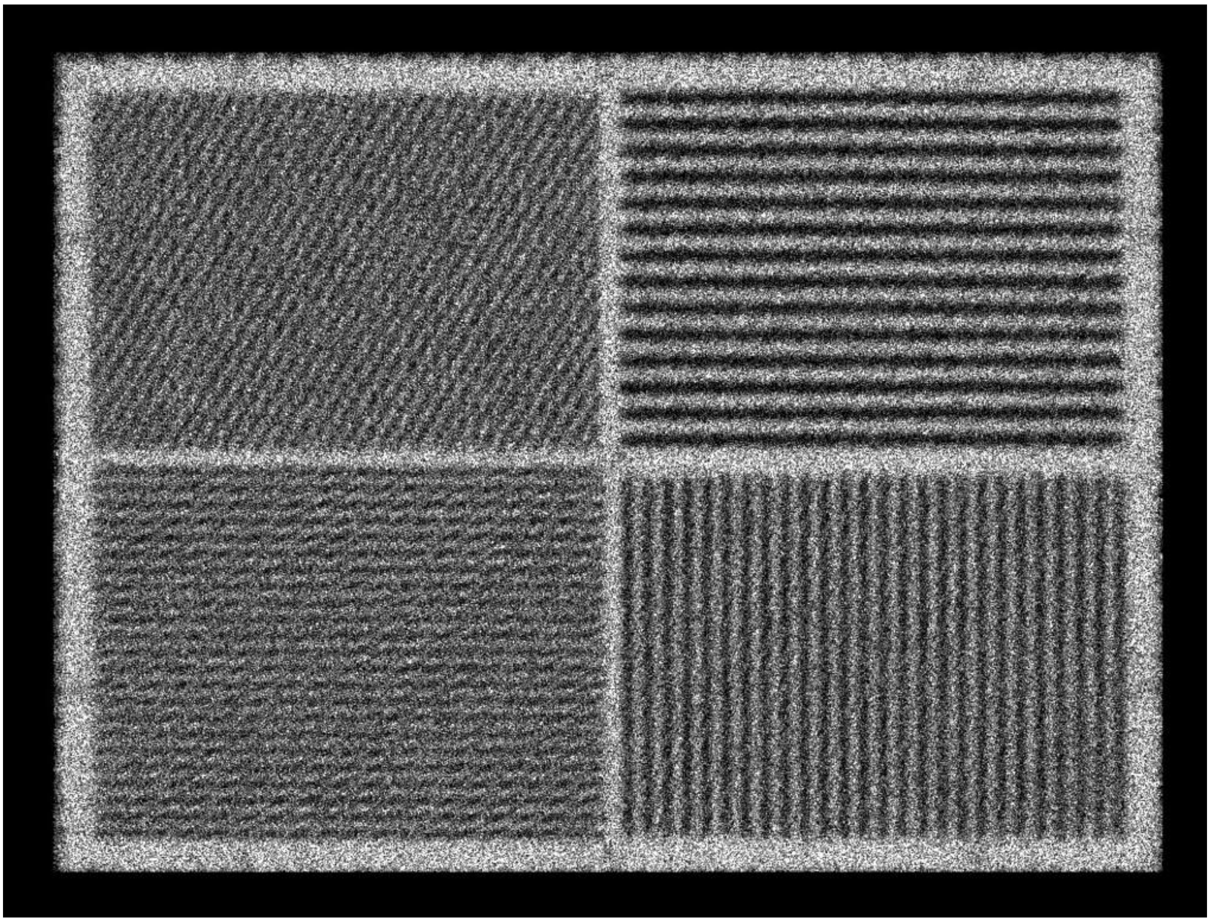
Figure 3. Cobalt-57 flood source *(courtesy of Eckert and Ziegler Isotope Products)*

Figure 4. Imaging results of Co^{57} flood source, bar phantom and varying collimator type. (a) Low Energy High Resolution (b) Medium Energy General Purpose, (c) High Energy General Purpose.

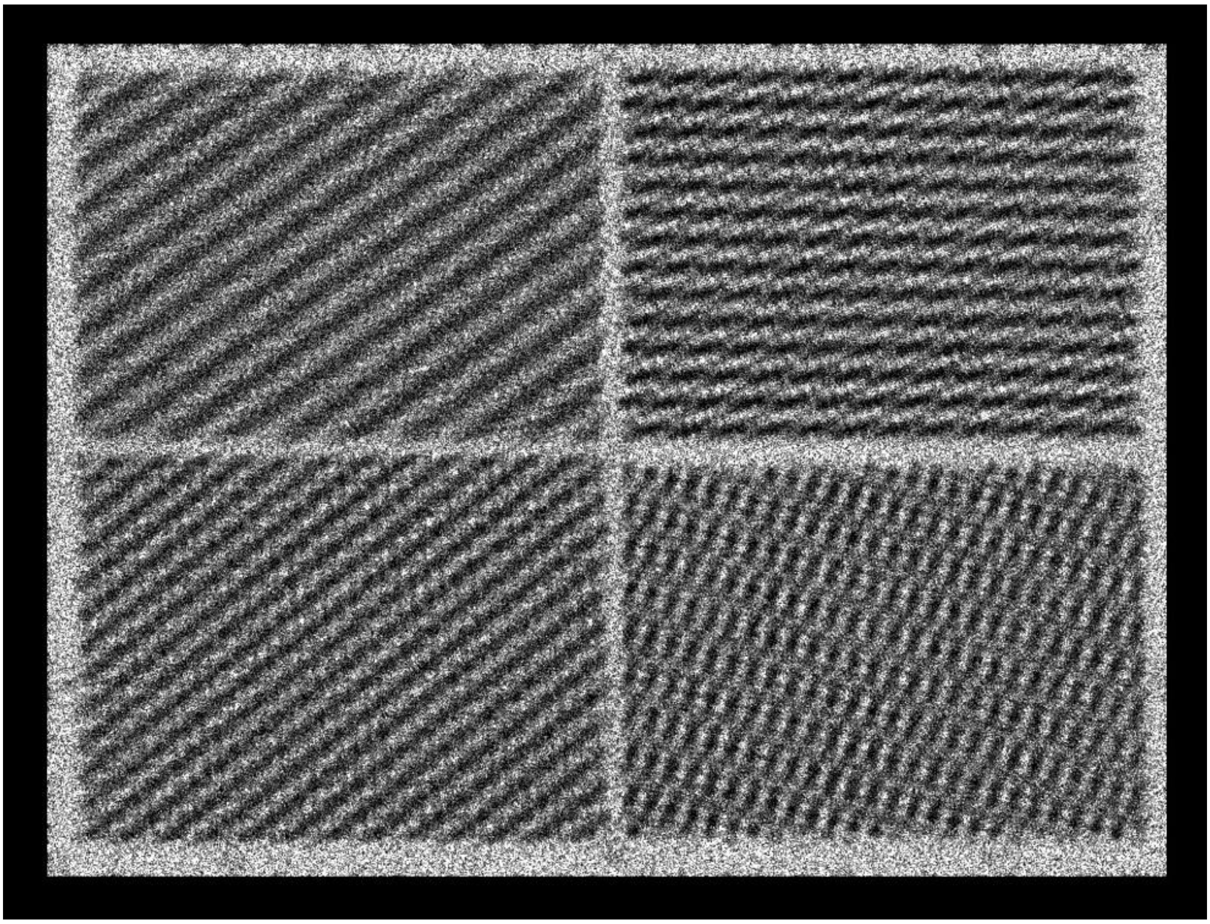
(a) Low Energy High Resolution



(b) Medium Energy General Purpose



(c) High Energy General Purpose



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Acknowledgements and ethical approval:

Visual demonstration of aliasing in planar nuclear medicine imaging: The importance of correct collimator selection by nuclear medicine practitioners

Ethical approval
Ethical approval approved by Canterbury Christ Church University, reference 18/H&W/10C.

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Figure(s)

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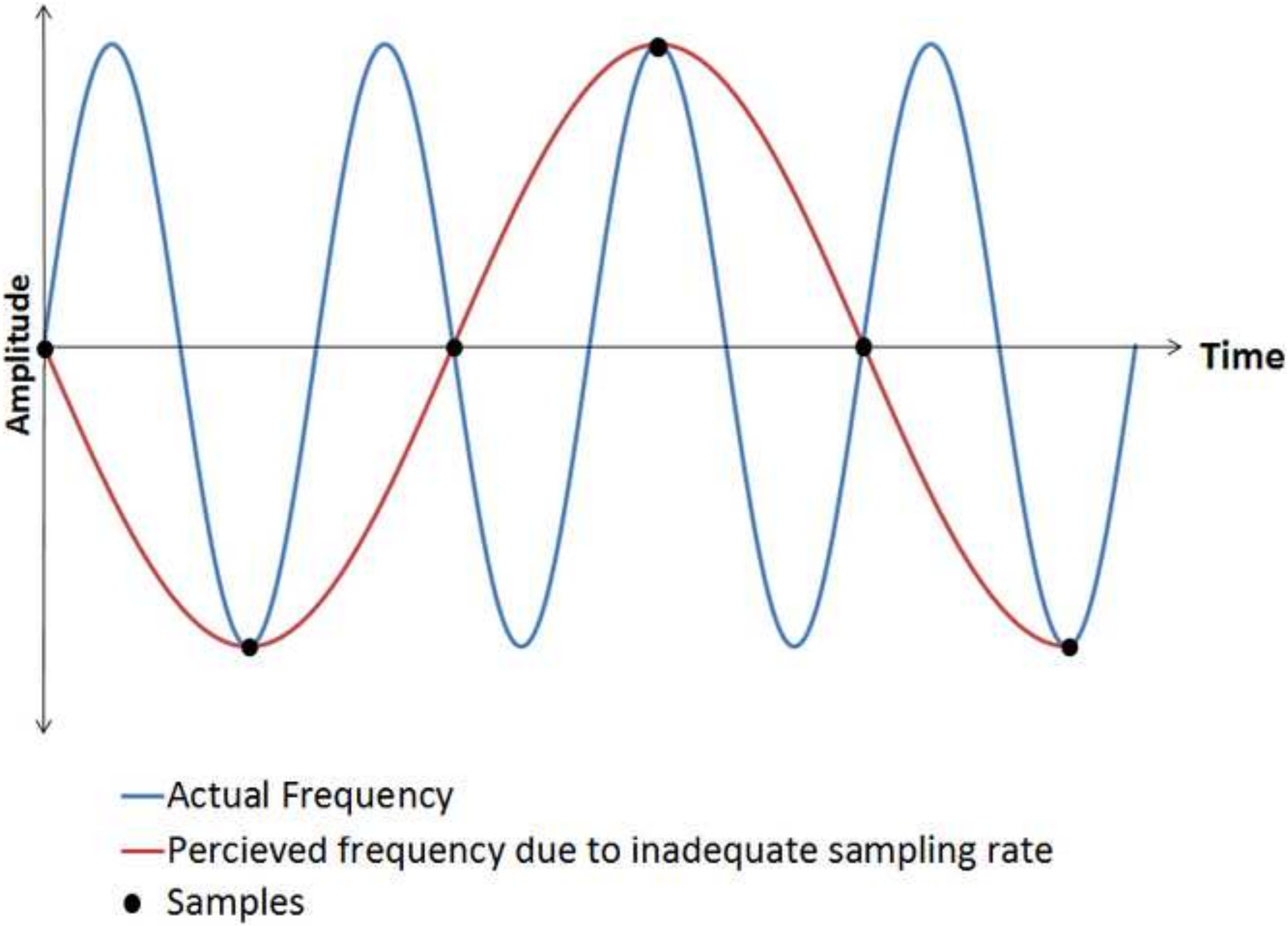

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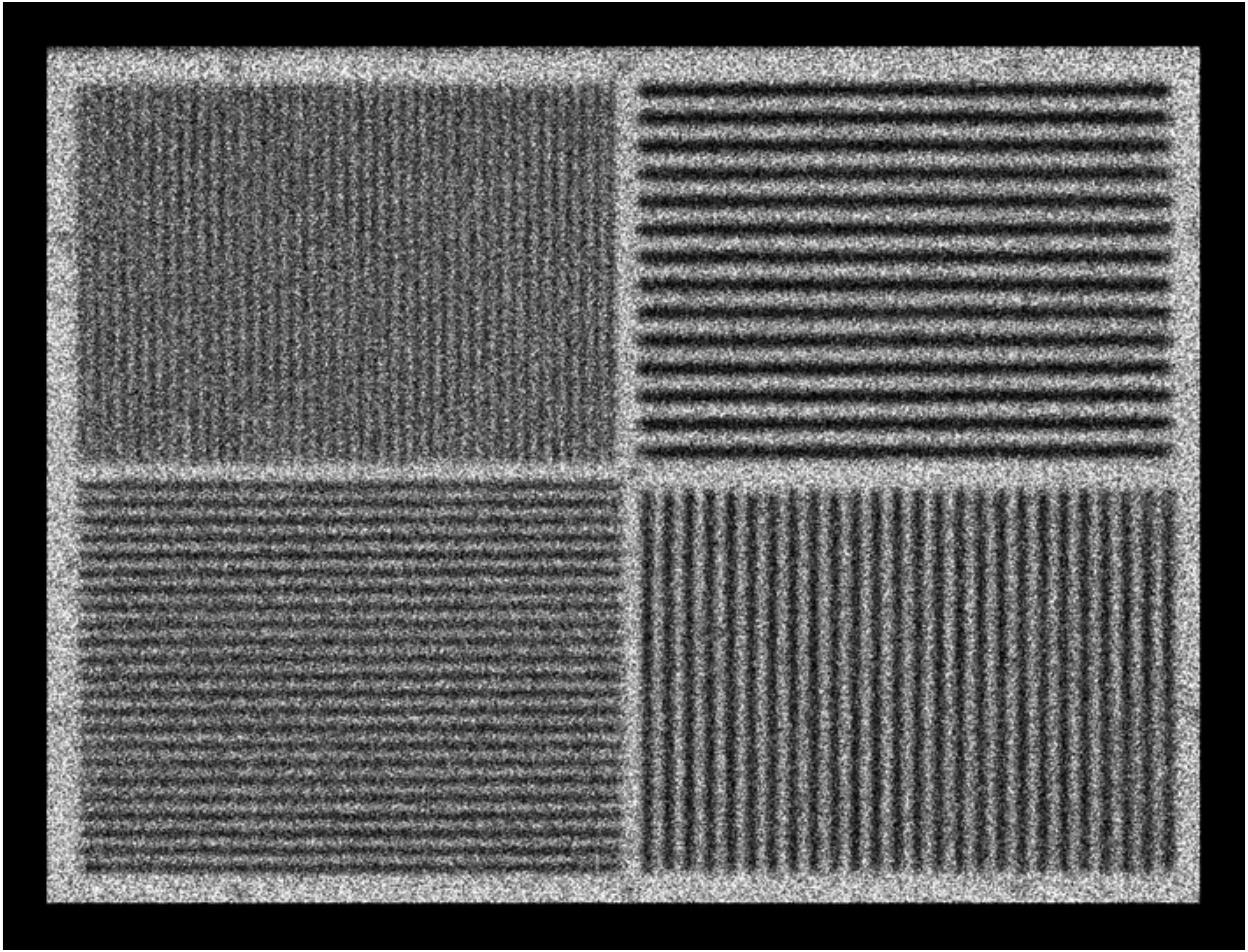

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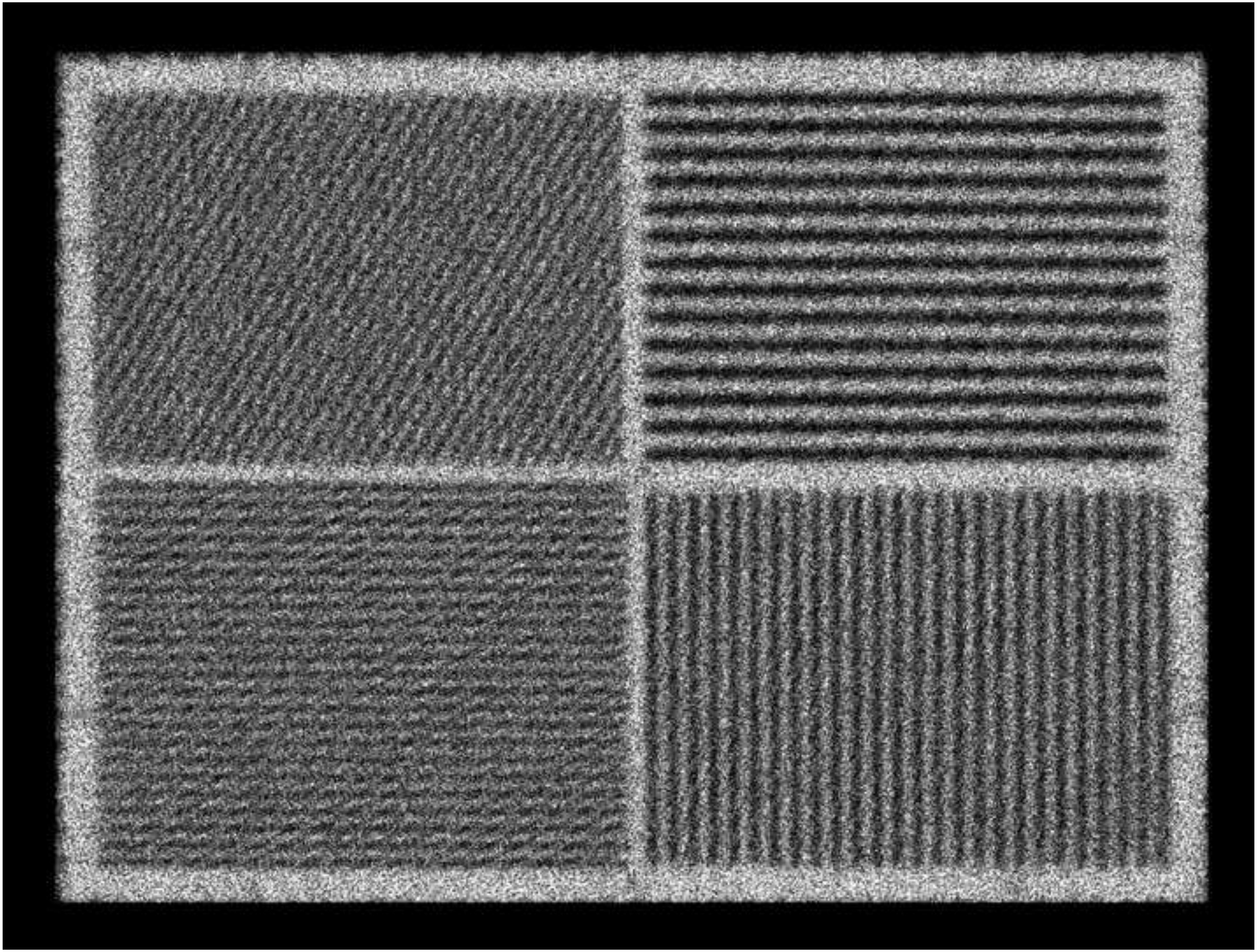

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