# Letters

## Comments on "Gaussian Beam Representation of Aperture Fields in Layered, Lossy Media: Simulation and Experiment"

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In the above paper[1] the authors address the three-dimensional Gaussian-beam representation of an aperture-source-excited, linearly polarized electromagnetic wave propagating in a layered lossy medium and apply the relevant concept(s) to elucidate the power absorption in biological media. However, the basis of such representation, as applied to partial-body electromagnetic/microwave irradiation of biological media, is not new. The author of this communication had indicated in [1]–[12] a generalized Gaussian–Laguerre mode model of the emergent field from an aperture. He also indicated in [13]–[15] the partial-body, Gaussian-beam exposure strategies as applied to biological surfaces in determining the complex permittivity of a multilayered lossy medium such as the human skull (*in vitro*) and the medial palmar space (*in vivo*).

It may also be noted that the characteristics of a bounded beam in a layered medium have been extensively analyzed by Ooya *et al.* [16] and Tanaka *et al.* [17]. On the basis of the theoretical considerations and formulations presented in [16] and [17], the author of this correspondence (with others) successfully studied the reflection and transmission of microwaves at multilayered biological media (*in vivo* and *in vitro*), as reported in [13]–[15]. These studies therefore precede those of Lumori *et al.* by at least a decade.

The following is a summary of the relevant studies reported in [1]–[15]:

1) The radiated (near and/or far) field from an aperture can, in general, be approximated by Gaussian–Laguerre function representing a multimodal, three-dimensional Gaussian beam. However, with appropriate aperture modifications, an almost single-mode Gaussian beam can be launched from the aperture [1]–[12]. A typical example of this is the emergent beam from a scalar (corrugated) horn [2].

2) The aberrations in the aperture-radiated field can be specified by the phase terms of the Laguerre polynomial and/or by the circle polynomials of Zernike [1], [5].

3) When the Gaussian beam from an aperture is incident normally on a dielectric medium (lossy and multilayered, in general), it can be represented by the complex reflection and transmission coefficients described in [13]–[17]. The Gaussian nature of the beam is preserved (except for some added beam divergence and/or aberration effects) as the beam propagates through the multilayered (lossy or lossless) dielectric.

4) Inasmuch as the Gaussian beam that could be launched by one of the methods described in [1]–[12] represents a focused beam, as indicated by the author of this letter (and others) [1]–[12], it can be profitably used for partial-body irradiations in hyperthermic cancer therapy.

5) The studies presented in [13]–[15] indicated the practical aspects of a Gaussian beam obliquely incident on a biomedium. Relevant results lead to establishing the complex permittivity of the biomedium and/or evaluation of power deposition in the medium.

6) The studies presented in [13]–[15] further indicated the possible systematic errors in the measurements when the beam strikes a nonplanar (curved) surface and/or a region with surface irregularity (such as an external occipital protuberance or crest in a human skull). However, these errors could be reduced by controlling the spot site of the beam to be small (in comparison with the curvature of surface undulations) by the technique(s) described in [8]–[10].

7) It is the opinion of the author of this communication that the (experimental) simulation of a Gaussian beam as presented in the paper in question is rather unnecessarily elaborate. Considering the studies presented in [1]–[12] (which mostly refer to X-band and/or 2.45 GHz frequencies), simulation of a focused beam would prove to be far simpler even at 400 MHz if aperture-modification methods were adopted.

8) Considering the work addressed in the paper by Lumori *et al.*, it is implied that the Gaussian-beam model simplifies some of the boundary value problems commonly encountered when electromagnetic waves propagate in layered, lossy media. Essentially, in their work, only a two-layered medium, namely muscle and lung, was considered. However, in a multilayered medium consisting of, say, skin, fat, tissue, bone, and marrow, the complex beam divergence and reflection/transmission characteristics become quite involved when compared with plane wave propagation.

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***Reply[2] by M. L. D. Lumori,[3] J. B. Andersen,[4] M. K. Gopal, and T. C. Cetas[5]***

In our paper we have not claimed that our application of Gaussian beams is pioneering: in fact we have cited the original literature [18]–[23]. Admittedly we were not aware of Dr. Neelakanta's work, which seems to be his major objection. However, his work would not have made any difference to our paper since the goals are different. The main goal of [2], [7], [9], [11], [13]–[15] is to analyze and construct an aperture antenna

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which creates a focused beam in free space at X-band frequencies (in excess of 8 GHz). Ancillary to this he has shown measurements of single-layer dielectric properties at these frequencies (X band), frequencies which have no practical significance, whatsoever, for the applications addressed in our paper. On the other hand our main contribution is to show that an ordinary waveguide or horn aperture close to a lossy medium in itself creates a Gaussian field to a very high degree of accuracy, the reason being the additional attenuation of higher order mode contributions. This has also been demonstrated in another work which we have published [24]. These aspects as well as the discussion of beams in lossy media in general are not covered in publications preceding ours.

Although Dr. Neelakanta has alluded to the simplicity of designing Gaussian beam launchers at low frequencies (e.g. 400 MHz), this claim has not been demonstrated in his list of publications and references. In fact, one of his papers [7] mentions his research efforts to design and fabricate a launcher at the microwave diathermy frequency of 2.45 GHz, but this does not appear to have been accomplished. One might further add that it is much simpler to create a focused beam at X-band frequencies, as Dr. Neelakanta does (and probably at 2.45 GHz), than at 400 MHz for applicators of practical size. Furthermore, at these high frequencies the penetration depth in muscle tissue is very small, resulting in heating that is not of practical significance in the applications cited in our paper.

The paper in question clearly shows that our work was not limited to a two-layered medium. It clearly presents up to three layers (muscle–Plexiglas–lung) and the method in general has no limitations in tracking a higher number of layers, including all the associated multiple reflections.

Finally, we would like to state that, contrary to Dr. Neelakanta's comments on the experiments, we find our experiments to be extremely essential in checking the accuracy of approximate models.

## References


[1] P. S. Neelakantaswamy, "Studies on open-ended circular waveguide radiators with modified aperture-ends," Ph.D. thesis, Indian Institute of Technology, Madras (India), 1975.

[2] P. S. Neelakantaswamy, K. K. Gupta, and D. K. Banerjee, "A Gaussian-beam launcher for microwave exposure studies," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, pp. 426–428, 1977.

[3] P. S. Neelakantaswamy, D. K. Banerjee, and K. K. Gupta, "Near-field characteristics of a scalar horn-fed dielectric spherical radiator," *Arch. Elek. Übertragungs.*, vol. 31, pp. 173–175, 1977.

[4] P. S. Neelakantaswamy, K. K. Gupta, and D. K. Banerjee, "A compact Gaussian beam launcher for microwave exposure studies at 2450 MHz," presented at Int. Symp. Biological Effects of Electromagnetic Waves, June 27–30, 1978, Ottawa, Canada.

[5] P. S. Neelakantaswamy, D. K. Banerjee, and K. K. Gupta, "Field abberations in the focal region of a microwave Gaussian-beam launcher," *Arch. Elek. Übertragungs.*, vol. 32, pp. 85–87, 1978.

[6] P. S. Neelakantaswamy, K. K. Gupta, and D. K. Banerjee, "A simple microwave Gaussian-beam launcher for selective partial-body exposure of biological substances," presented at 8th European Microwave Conf., September 4–8, 1978, Paris, France.

[7] P. S. Neelakantaswamy, K. K. Gupta, and D. K. Banerjee, "A compact light-weight Gaussian-beam launcher for microwave exposure studies," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, pp. 665–666, 1978.

[8] P. S. Neelakantaswamy and F. C. Hong, "Design of microwave Gaussian-beam launcher with prescribed constraints on its beam characteristics," *Arch. Elek. Übertragungs.*, vol. 33, pp. 174–177, 1979.

[9] P. S. Neelakantaswamy and F. C. Hong, "Dielectric hemisphere-loaded scalar-horn as a Gaussian-beam launcher for microwave exposure studies," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-17, pp. 797–799, 1979.

[10] P. S. Neelakantaswamy and F. C. Hong, "Spot-site controlled Gaussian-beam launcher for microwave exposure studies," *Z. Elek. Inform.-u. Energietechnik* (Leipzig), vol. 10, pp. 231–234, 1980.

[11] P. S. Neelakantaswamy and D. K. Banerjee, "Radiation characteristics of a dielectric sphere-loaded corrugated pipe," *IEEE Trans. Antennas Propagat.*, vol. AP-23, pp. 728–730, 1975.

[12] P. S. Neelakantaswamy, "Diffraction of electromagnetic Gaussian-beams by dielectric spheres," *Wave Electron.*, vol. 4, pp. 153–162, 1982.

[13] P. S. Neelakantaswamy, K. K. Gupta, and K. Basavaraju, "A noninvasive, partial-body exposure method for measuring the complex permittivity of biological substances at microwave frequencies," *Med. and Biol. Eng. and Comput.*, vol. 16, pp. 419–424, 1978.

[14] P. S. Neelakantaswamy, "Noninvasive beam-wave reflectometric instrumentation for measuring complex permittivity of dielectric materials at microwave frequencies," *Rev. Sci. Instr.*, vol. 49, pp. 858–860, 1978.

[15] P. S. Neelakantaswamy and R. Govindarajan, "Noninvasive beam-wave spectrometric instrumentation for measuring dielectric constant at microwave frequencies," *Rev. Sci. Instr.*, vol. 50, pp. 649–651, 1979.

[16] T. Ooya, M. Tateiba, and O. Fukumitsu, "Transmission and reflection of a Gaussian beam at normal incidence on a dielectric slab," *J. Opt. Soc. Amer.*, vol. 65, pp. 537–541, 1975.

[17] M. Tanaka, K. Tanaka, and O. Fukumitsu, "Transmission and reflection of a Gaussian beam at oblique incidence on a dielectric slab," *J. Opt. Soc. Amer.*, vol. 67, pp. 819–825, 1977.

[18] H. Kogelnik, "On the propagation of gaussian beams of light through lenslike media including those with loss or gain variation," *Appl. Opt.*, vol. 4, no. 12, pp. 1562–1569, Dec. 1965.

[19] H. Kogelnik and T. Li, "Laser beams and resonators," *Proc. IEEE*, vol. 5, pp. 1550–1167, Oct. 1966.

[20] J. A. Arnaud and H. Kogelnik, "Gaussian light beams with general astigmatism," *Appl. Opt.*, vol. 8, pp. 1687–1693, Aug. 1969.

[21] G. A. Deschamps, "Gaussian beam as a bundle of complex rays," *Electron. Lett.*, vol. 7, no. 23, pp. 684–685, Nov. 1971.

[22] G. A. Deschamps, "Ray techniques in electromagnetics," *Proc. IEEE*, vol. 60, pp. 1022–1035, Sept. 1975.

[23] A. Yariv, *Quantum Electronics*. New York: Wiley, 1975.

[24] M. L. D. Lumori, J. W. Hand, M. K. Gopal, and T. C. Cetas, "Use of Gaussian beam model in predicting SAR distributions from current sheet applicators," *Phys. Med. Biol.*, vol. 35, no. 3, pp. 387–397, Mar. 1990.