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# Millimetre-wave Bessel beams using computer holograms

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A computer-generated binary amplitude hologram is used to transform an initial Gaussian electromagnetic field with spherical phase front at 310 GHz into a non-diffracting Bessel beam. The beam profile is measured with the help of a near field scanner. In contrast to the situation in the optical region, both amplitude and phase information is readily obtainable from the generated field.

*Introduction:* Computer-generated holograms (CGHs) have proven useful in controlling optical laser fields and they have also been applied in the area of millimetre-wave radio fields [1]. In this Letter we present first experimental results of an amplitude radio hologram which transforms an incident Gaussian electromagnetic field into the fundamental limited-diffraction Bessel beam. Recently, axicons were also utilised for generating millimetre-wave Bessel beams [2].

Bessel beams [3] are called non-diffracting since, ideally, they would propagate infinite distances without diffractive spreading, i.e. their lateral shape would remain invariant under propagation. The electric field of the fundamental Bessel beam has the form

$$E = J_0(\alpha r)e^{i(\beta z - \omega t)} \qquad (1)$$

where $J_0$ is the Bessel function of the zeroth order and the radial and axial wave numbers, $\alpha$ and $\beta$, respectively, satisfy $\alpha^2 + \beta^2 = k^2 = (\omega/c)^2$. The fundamental beam mode features a maximum along the $z$ axis and successively weaker fringes (which, however, would ideally each have the same integrated intensity) around the central beam.

*Hologram technique:* Computer holograms (diffractive elements) are semitransparent objects which serve to locally modify both the intensity and the phase of an incident wave field. Owing to diffraction within the hologram pattern, the initial field is changed into the desired output field. Here the hologram is a binary amplitude element which consists of a dielectric transparent film, covered with a reflecting copper layer with etched slots. Ideally, the field is either reflected, or it passes through the hologram with no change in its phase.

If the incident field is given by $u_{in}$ and $u_{out}$ is the desired output field, an ideal hologram should feature a transmission function $A = u_{out}/u_{in}$, which is a complex function describing local blocking and phase change for the field passing through the hologram. For a binary amplitude hologram, the transmission function $A_{bin}$ may be derived from the ideal function $A$ using, for instance, the algorithm presented in [4].

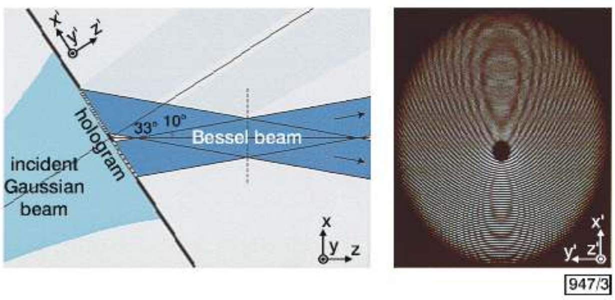


**Fig. 1** *Operation geometry for radio hologram and hologram pattern $A_{bin}$*

*a* Operation geometry
– – – plane where Bessel beam measured (31 cm from centre of hologram)
*b* Hologram pattern
Corrugated horn (feed) 1.5 m from hologram, electric field polarisation is along $y = y'$

The present hologram, see Fig. 1, admits an incident Gaussian beam and is designed to produce the fundamental Bessel beam with $\alpha = k\sin 10°$, diverted 33° from the axis of the original beam. The hologram was fabricated on a copper-plated mylar film using conventional photolithography (wet-etching) technique with the narrowest slot width of the order of 40 µm. The operation geometry and the designed hologram itself are shown in Fig. 1.

*Results:* The experimental instrumentation required for testing radio holograms at submillimetre-wavelengths include a signal source with a feed, a receiver with a probe in a planar *xy*-scanner, and a measurement controller (vector network analyser) with detection bandwidth as narrow as 10 Hz, hence a very high dynamic range is obtained [5]. Contrary to the optical region, both amplitude and phase information are readily obtainable from the generated millimetre-wave radio field.

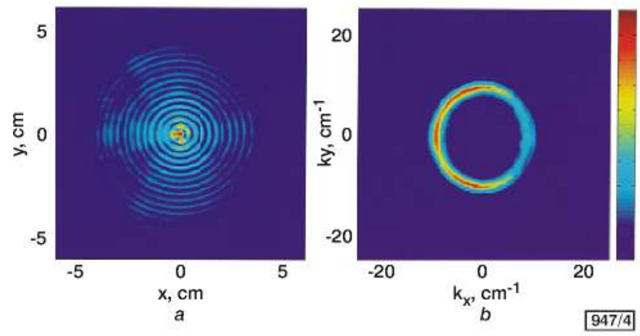


**Fig. 2** *Absolute value of measured amplitude and Fourier transform of actual complex field*

*a* Absolute value
*b* Fourier transform
Radial wave number $\alpha = k\sin 10° = 11.3\,\text{cm}^{-1}$, characteristic to all limited-diffraction beams

The measured field amplitude shows a peaked maximum on the propagation axis together with typical Bessel-beam fringes, see Fig. 2. The Fourier-transformed signal is strongly concentrated on a circumference of a circle of radius $\alpha$. The slight asymmetry arises from the off-axiality of the experimental setup and it is to be decreased by improved hologram optimisation.

*Conclusion:* A computer-generated hologram can be used to modify and control radio-frequency electromagnetic beams. Simple scalar-wave theory allows the design of satisfactory holograms which are to be further refined with the help of rigorous diffraction theory which facilitates improved control on the emitted propagating electromagnetic field amplitude and phase.

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