Multichannel THz telecommunication based on mode division multiplexing (MDM) approach

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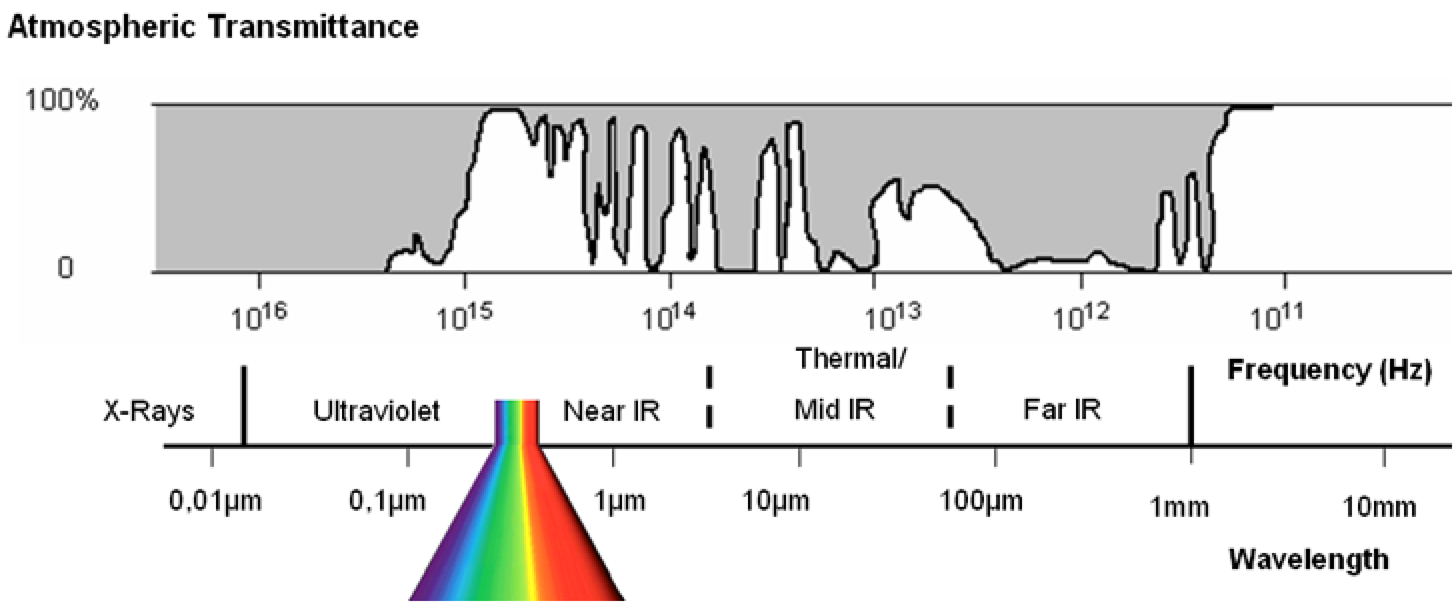
[2]Samara University, Samara, Russia

[3]Budker Institute of Nuclear Physics of SB RAS, Novosibirsk, Russia

[4]Novosibirsk State University, Novosibirsk, Russia

2020

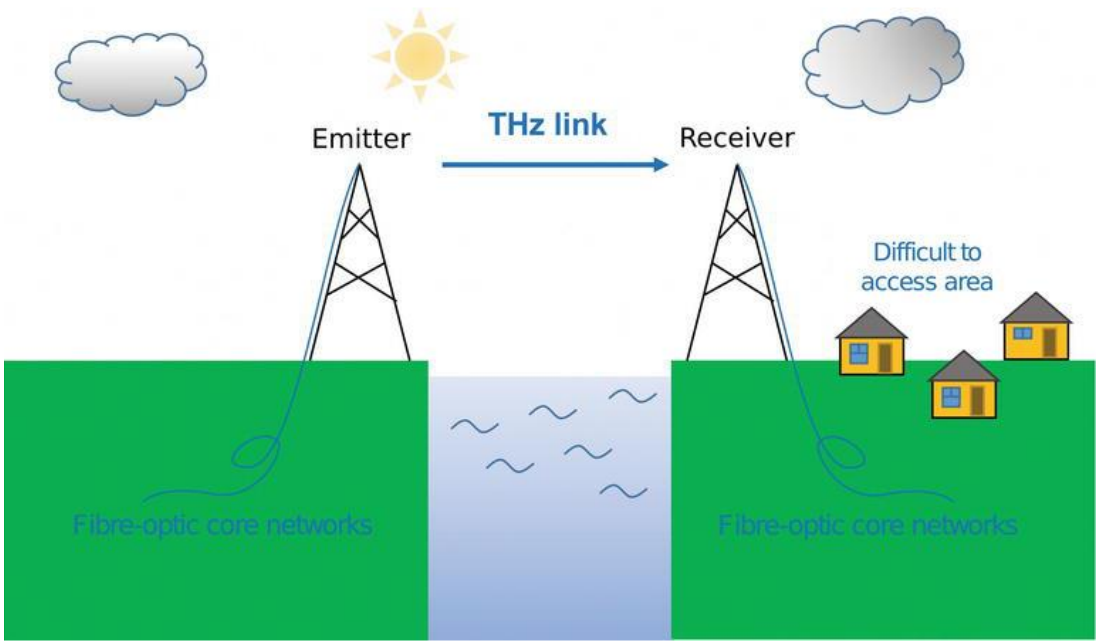
ATMOSPHERIC TRANSMITTANCE



Existence of atmospheric windows in terahertz range is stimulating research in the field of terahertz free-space communications.

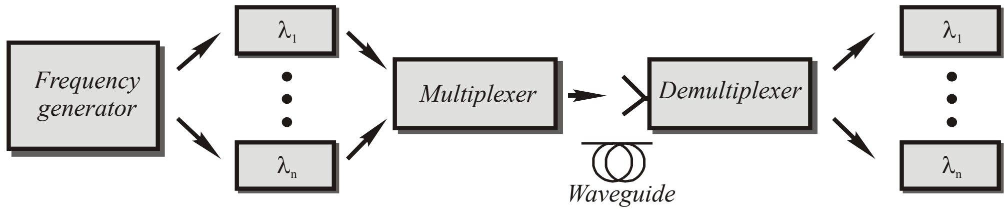
Science Education through Earth Observation for High Schools (SEOS), https://seos-project.eu/

FREE-SPACE TELECOMMUNICATION IN TERAHERTZ RANGE

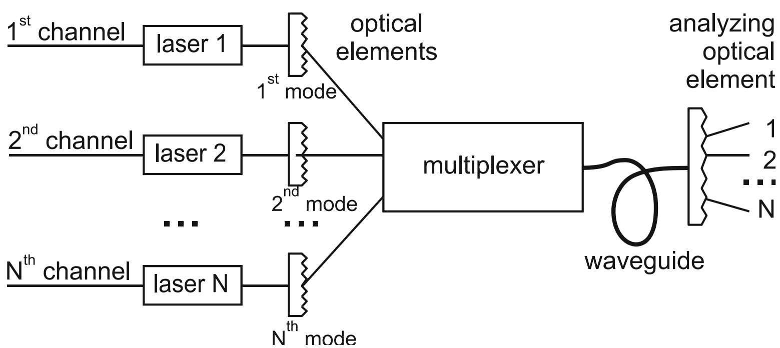


M. Tamosiunaite, S. Tamosiunas, M. Zilinskas and G. Valusis, Atmospheric Attenuation of the Terahertz Wireless Networks, IntechOpen

WAVELENGTH DIVISION MULTIPLEXING (WDM) AND MODE DIVISION MULTIPLEXING (MDM) APPROACHES

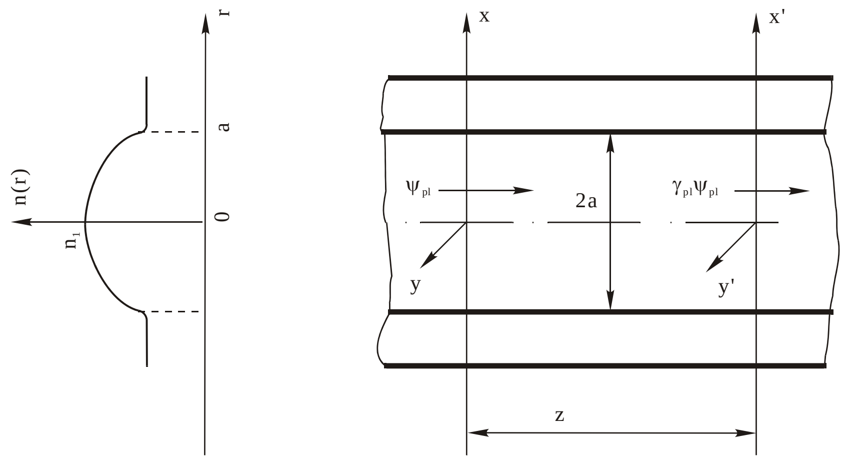


Achyut Dutta Niloy Dutta Masahiko Fujiwara, WDM Technologies: Optical Networks, Academic Press, 2004.



V.A. Soifer, M.A. Golub, "Laser Beam Mode Selection by Computer Generated Holograms", CRC Press, 1994

WAVEGUIDE TRANSVERSE MODES



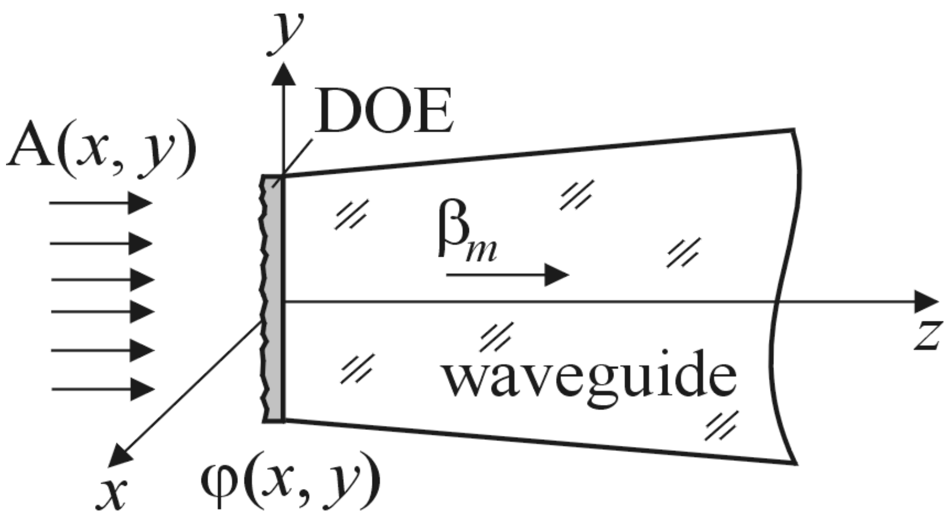
$$\tilde{P} : w(x, y, z) = \tilde{P} w(x, y, 0)$$

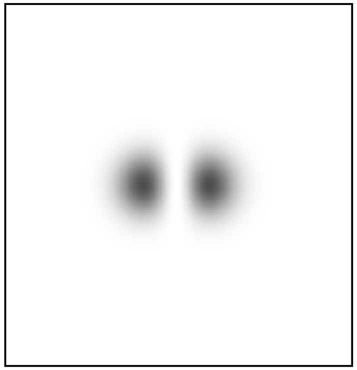
$$\psi_m(x, y) : \tilde{P}\,\psi_m(x, y) = \lambda_m \psi_m(x, y)$$

$$\iint_{\infty} \psi_m(x, y)\psi_n^*(x, y)\,dxdy = \begin{cases} 0, m \neq n \\ 1, m = n \end{cases}$$

V.A. Soifer, M.A. Golub, "Laser Beam Mode Selection by Computer Generated Holograms", CRC Press, 1994

FORMATION OF MODE BEAM FROM ILLUMINATING BEAM BY USE OF PHASE DIFFRACTIVE OPTICAL ELEMENT (DOE)





Gauss-Hermite mode (1,0)

$$\lambda_m = \exp\left(i\beta_m z\right)$$

$$\psi\left(x, y\right) = \sum_{i=0}^{m} \hat{C}_{i(m-i)} \hat{\psi}_{i(m-i)}\left(x, y\right)$$

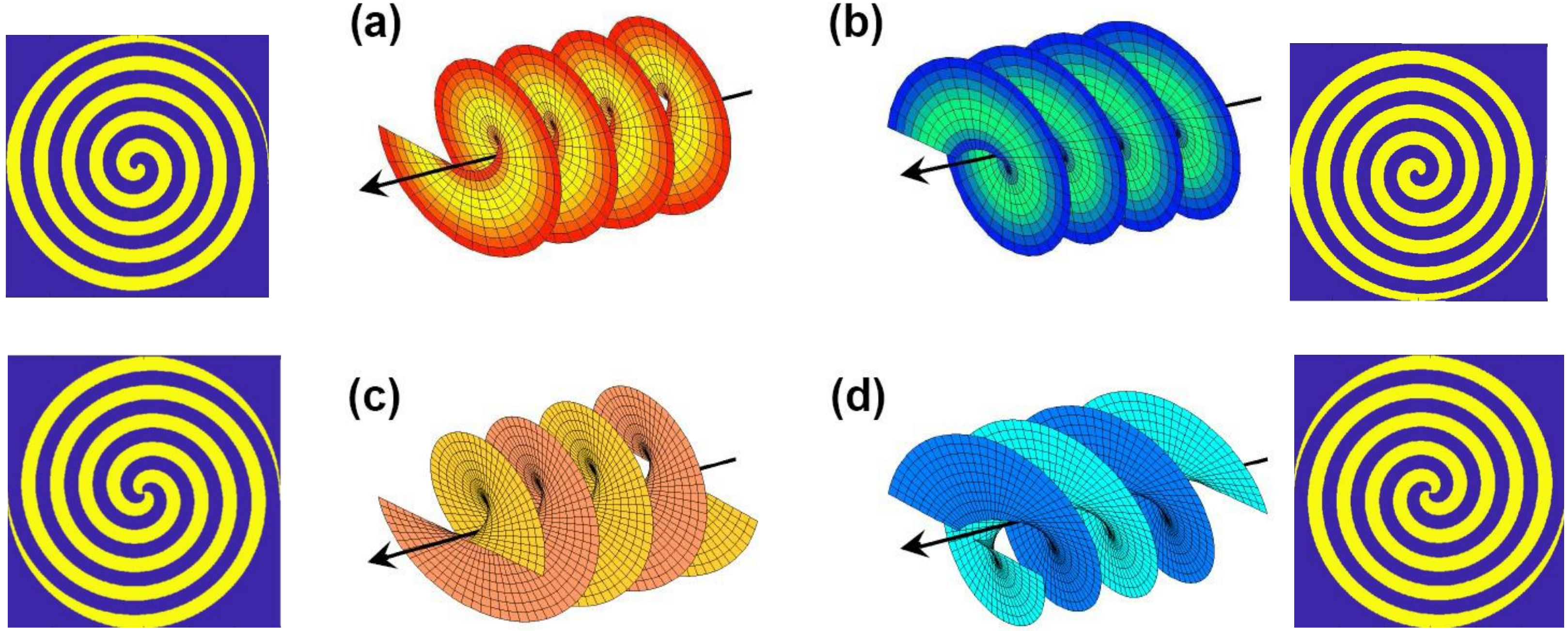
in case of parabolic profile waveguide or free-space

$\hat{\psi}_{pl}\left(x, y\right)$ *- Gaussian-Hermite modes with numbers p,l*

Methods for Computer Design of Diffractive Optical Elements, Edited by Victor A. Soifer/ John Wiley & Sons, Inc., New York, USA, 2002.

FORMATION OF MODE BEAMS WITH ORBITAL ANGULAR MOMENTUM (OAM) BY DOE

DOE ***DOE***



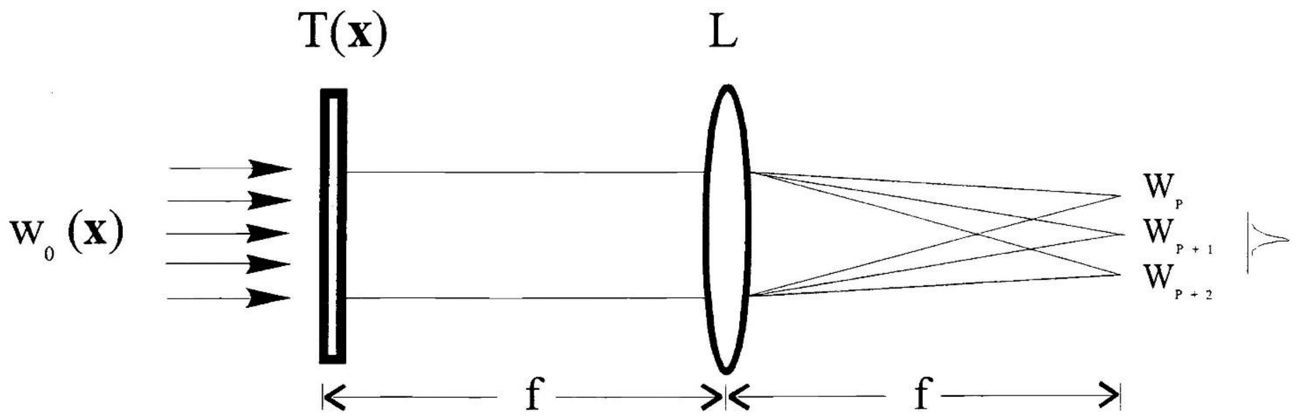
Examples of helical waves. Represented are the wavefronts of helical modes for helicities $m = +1$ (a), $m = -1$ (b), $m = +2$ (c), and $m = -2$ (d).

Allen L. Orbital angular momentum of light / L. Allen, M.J. Padgett, M. Babiker // Prog. Opt. – 1999. –Vol. 39. – P. 291-372

Choporova Yu Yu, Knyazev B A, Kulipanov G N, Pavelyev V S, Scheglov M A, Vinokurov N A, Volodkin B O, Zhabin V N 2017 Physical Review A 96(2) 023846.

MODE DETECTION BASED ON CORRELATION FILTRATION

Determination of partial mode power ***Wp*** *by use of filter with complex transmission function* ***T(x,y)***

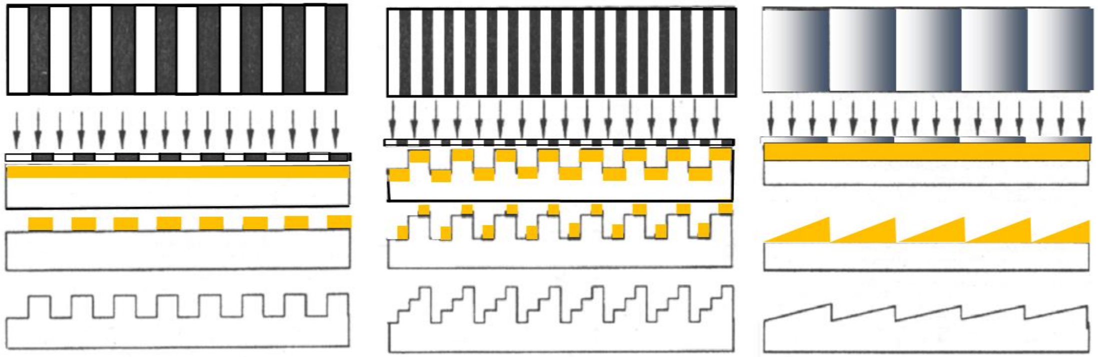


$$T(x,y) = \psi_p^*(x,y)$$

$$W_p = \left| \iint_D w_0(x,y)\psi_p^*(x,y)dxdy \right|^2$$

V.A. Soifer, M.A. Golub, "Laser Beam Mode Selection by Computer Generated Holograms", CRC Press, 1994

FABRICATION OF TERAHERTZ PHASE DOE BY LITHOGRAPHY



Advantages

–large apertures (up to 90 mm),
–relatively large etching depth (till 50 μm and more)
-high aspect ratio (Bosch-process)

Plasma chemical etching system
ETNA-100-PT produced by NT-MDT (Russia)
in Samara University

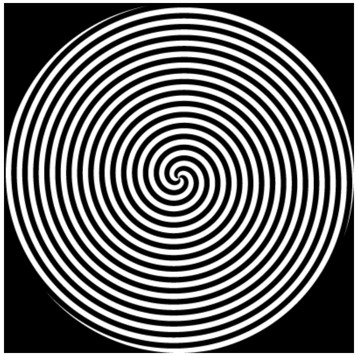
Transmissive diffractive microoptics for high-power THz laser radiation / V.S. Pavelyev , B.O. Volodkin , K.N. Tukmakov , B.A. Knyazev , Choporova Yu.Yu. // AIP Conference Proceedings. – 2018. – V. 1989. – Article number 020025.

NOVOSIBIRSK FREE ELECTRON LASER

Budker Institute of Nuclear Physics (Novosibirsk, Russia)

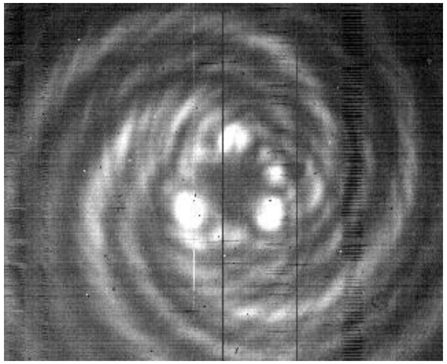
B.A. Knyazev, G.N. Kulipanov, N.A. Vinokurov Novosibirsk terahertz free electron laser: instrumentation development and experimental achievements / Measur. Sci. Techn. – 2010. – Vol. 21. – P. 13.

INVESTIGATION OF TERAHERTZ DOE FORMING BESSEL MODES WITH ORBITAL ANGULAR MOMENTUM (OAM)



Phase function of diffractive optical element (black colour – 0, white - π)

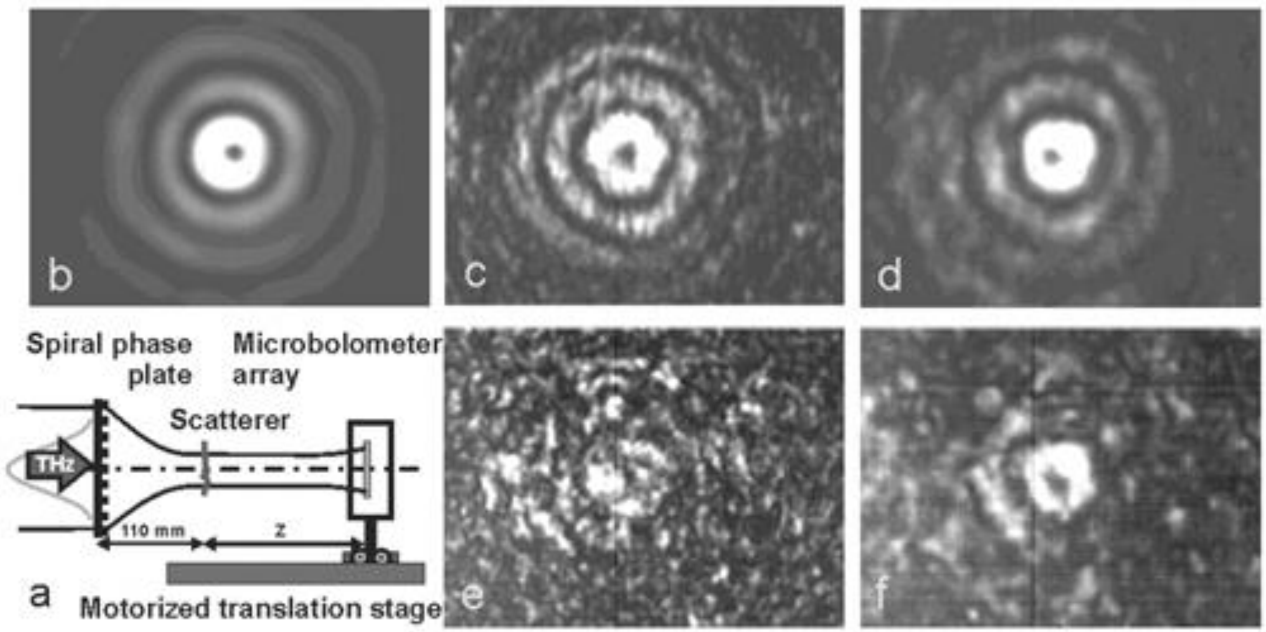
Realized diffractive optical element (Aperture diameter is 100 mm, wavelength is 129.5 μm)



Cross-section of generated beam with orbital angular momentum

Transmissive diffractive microoptics for high-power THz laser radiation / V.S. Pavelyev , B.O. Volodkin , K.N. Tukmakov , B.A. Knyazev , Choporova Yu.Yu. // AIP Conference Proceedings. – 2018. – V. 1989. – Article number 020025.

SELFRECONSTRUCTION OF THz BEAMS FORMED BY DOES DURING PROPAGATION IN NONLINEAR MEDIA

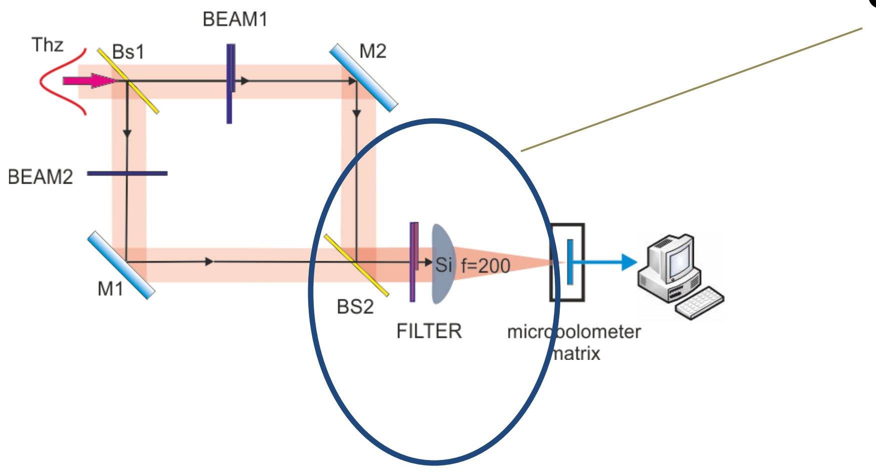


Selfreconstruction of Bessel beams. (a) Scheme of experiment. (b) Beam cross-section z=110 mm. Beam after scatterer (thin film): (c) Z = 60 mm, (d) Z = 115 mm. Beam after scatterer (thick film) : (e) Z = 60 mm, (f) Z = 115 mm.

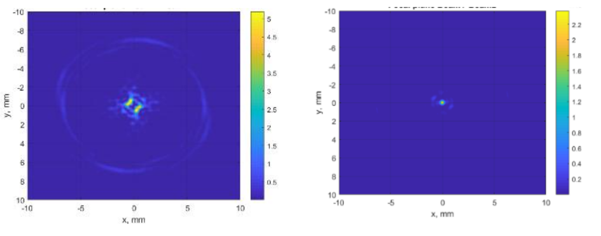
Boris Knyazev; Yulia Choporova; Mikhail Mitkov; Vladimir Pavelyev; Boris Volodkin. High-power terahertz non-diffractive Bessel beams with angular orbital momentum: Generation and application. 40th International Conference on Infrared, Millimeter, and Terahertz Waves, Hong Kong, 23 - 28 August 2015, art. no. 3129943

MULTICHANNEL FREE-SPACE TELECOMMUNICATION THz SYSTEM ON THE BASE OF BESSEL MODES SELECTION

Correlation filter



Intensity in the output plane of correlation filter

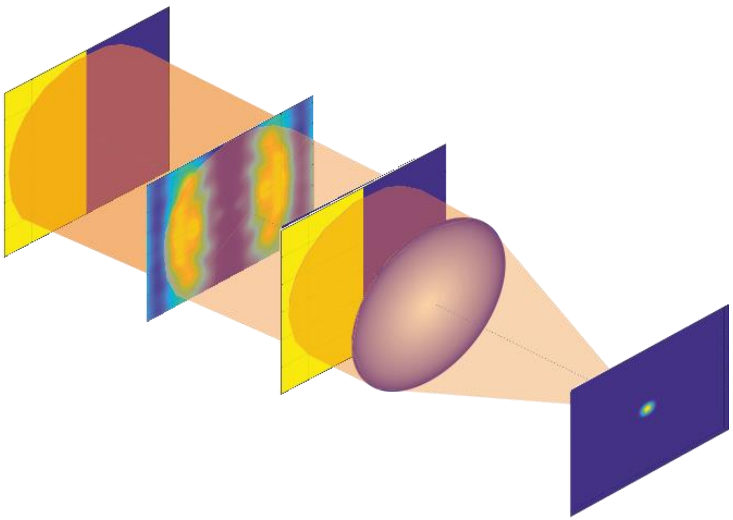


Absence of signal **Presence of signal**

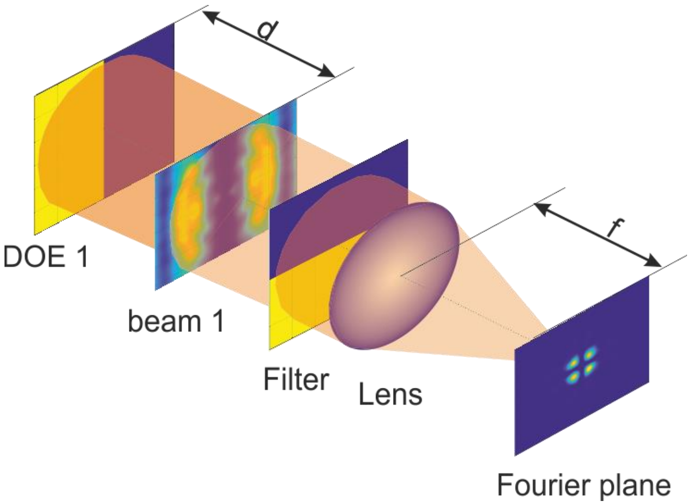
Novosibirsk free electron laser (wavelength is λ=141 μm)

Two channel terahertz communication based on spatial mode multiplexing / Y.Y. Choporova, B.A. Knyazev, N.D. Osintseva, V.S. Pavelyev, K.N. Tukmakov // 2019 44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz). – 2019.

CORRELATION FILTERING OF GAUSSIAN HERMITE MODES



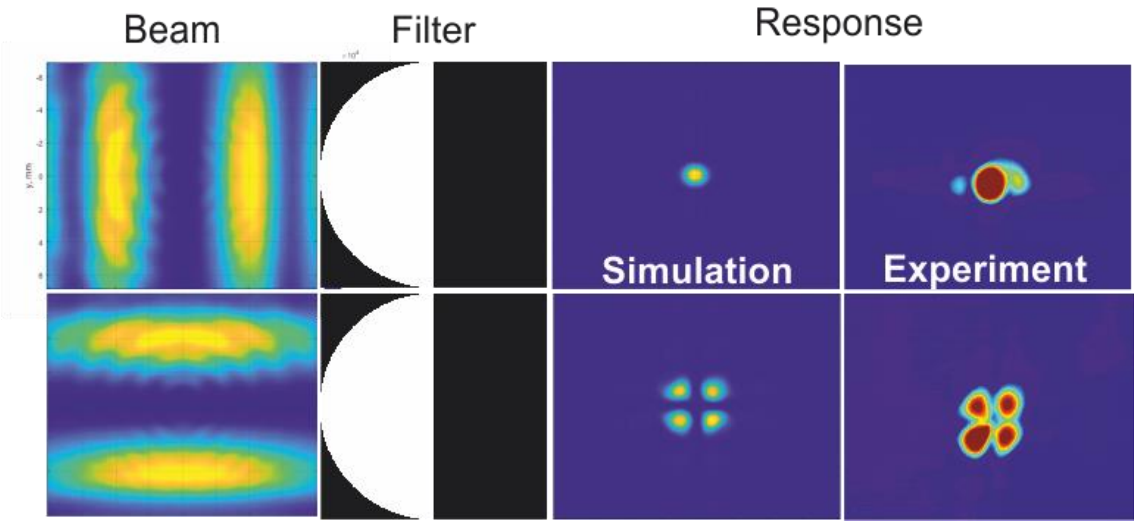
“positive” response



“negative” response

Two channel terahertz communication based on spatial mode multiplexing / Y.Y. Choporova, B.A. Knyazev, N.D. Osintseva, V.S. Pavelyev, K.N. Tukmakov // 2019 44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz). – 2019.

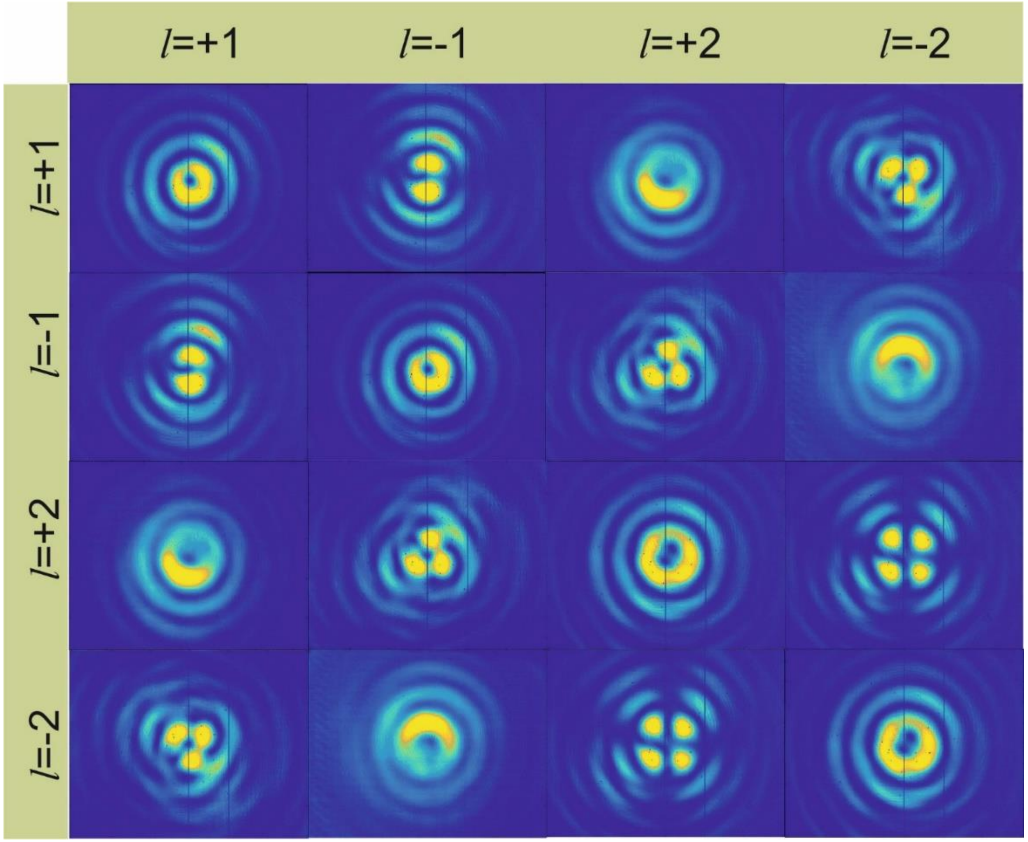
SUPERPOSITION AND SELECTION OF GAUSSIAN-HERMITE MODES



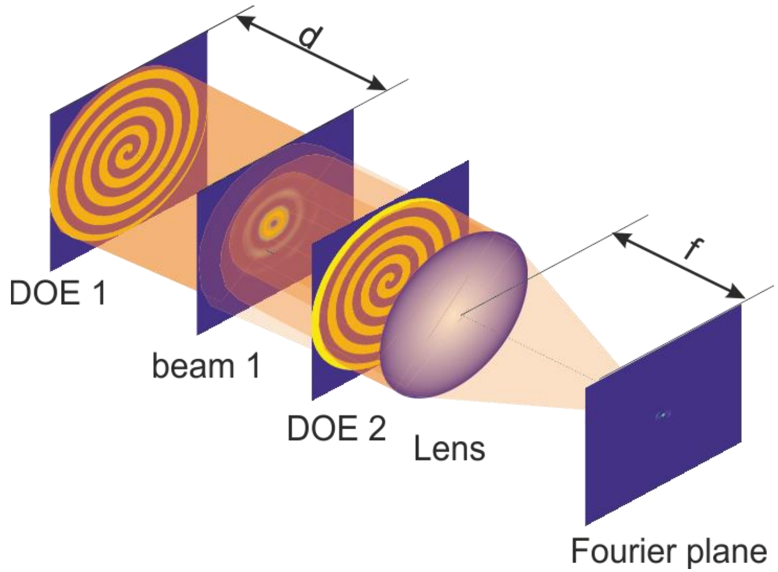
Appearance of correlation peak is confirming presence of pre-given mode in the THz beam!

Two channel terahertz communication based on spatial mode multiplexing / Y.Y. Choporova, B.A. Knyazev, N.D. Osintseva, V.S. Pavelyev, K.N. Tukmakov // 2019 44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz). – 2019.

VORTEX BEAMS SUPERPOSITION EXPERIMENT

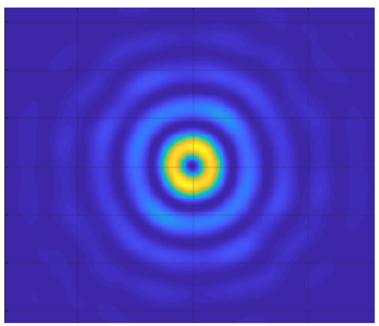


CORRELATION FILTERING OF VORTEX BEAMS



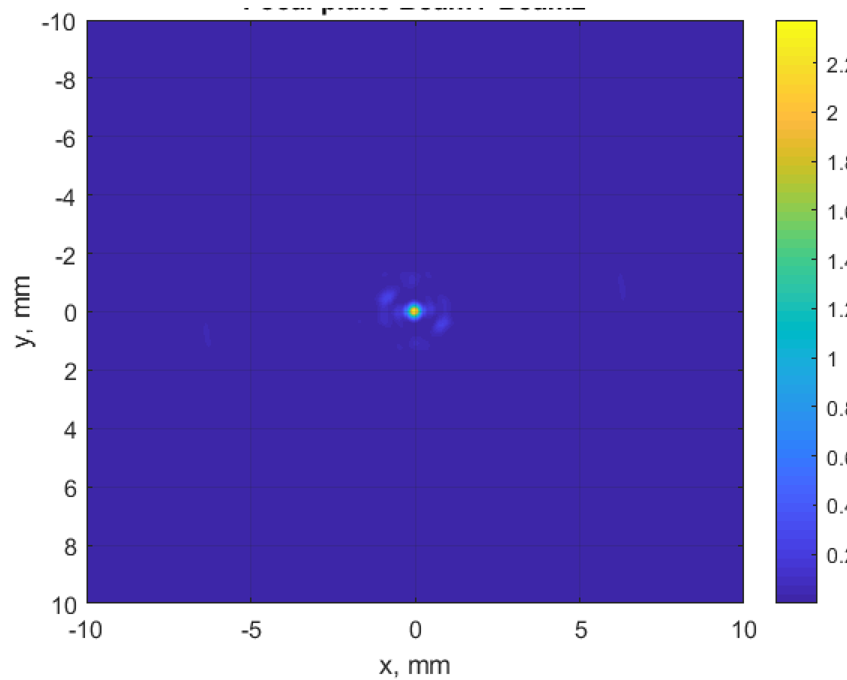
DETECTION OF VORTEX *l*=+1 BY FILTER *l*=+1

Vortex *l*=+1



Filter *l*=+1

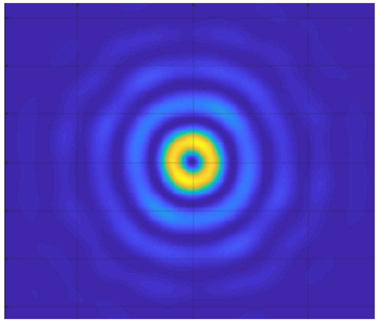
Fourier plane



The correlation peak is present

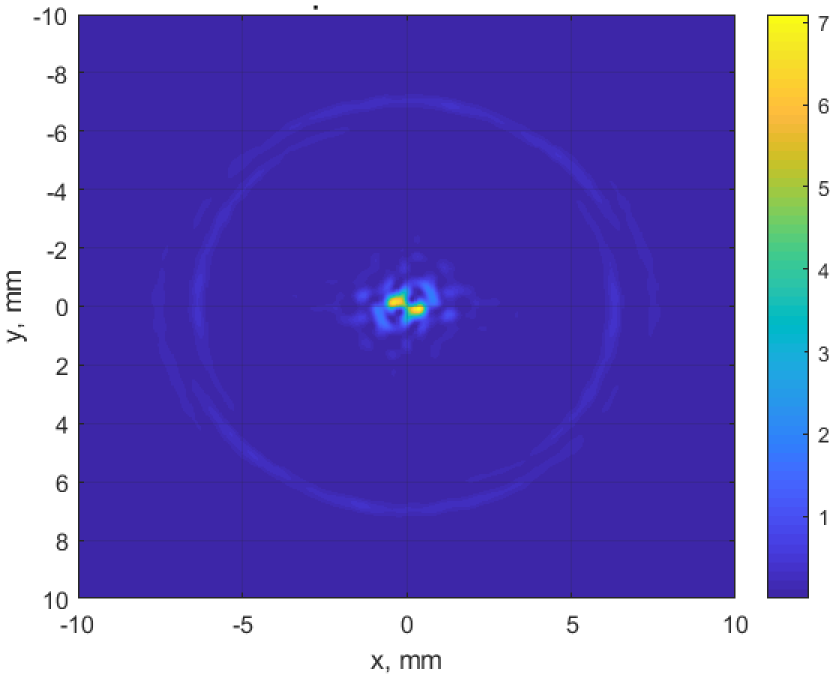
UNDETECTION OF VORTEX *l*=+1 BY FILTER *l*=-1

Vortex *l*=+1



Filter *l*=-1

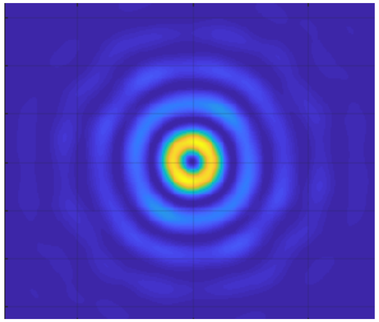
Fourier plane



No correlation peak

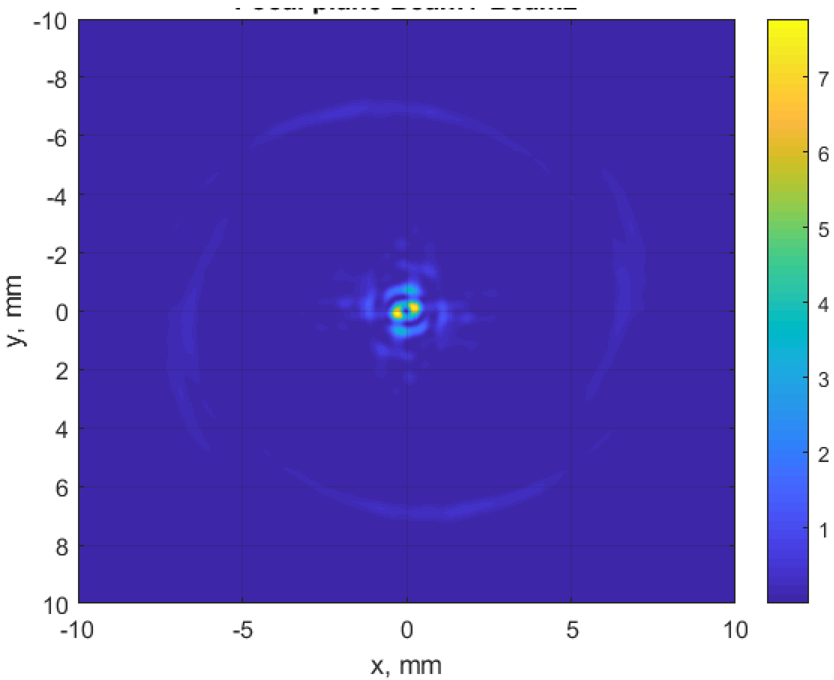
UNDETECTION OF VORTEX *l*=+1 BY FILTER *l*=+2

Vortex *l=+1*



Filter *l=+2*

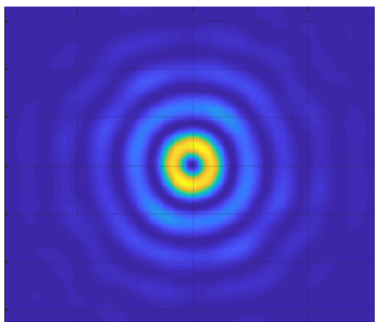
Fourier plane



No correlation peak

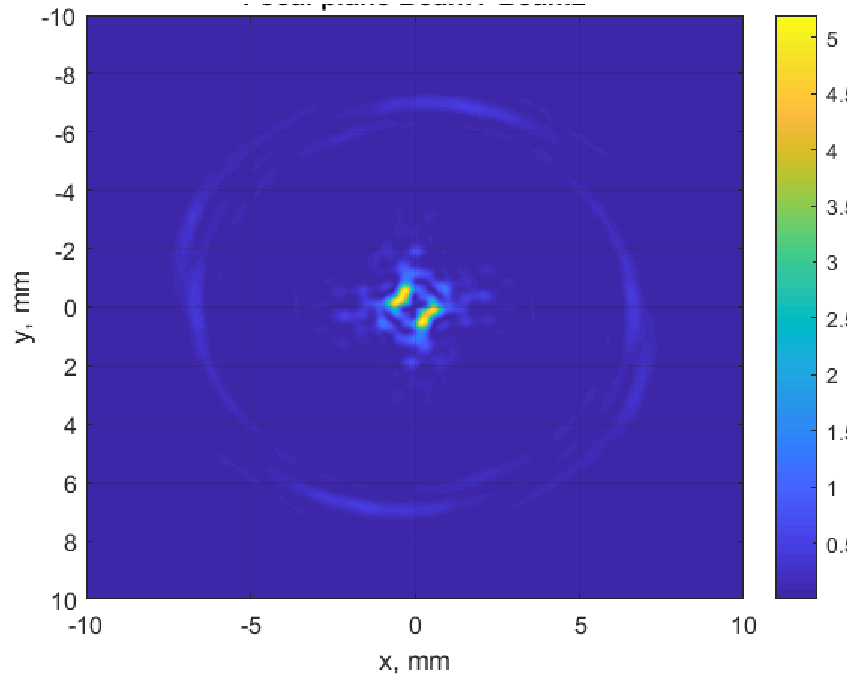
UNDETECTION OF VORTEX *l*=+1 BY FILTER *l*=-2

Vortex *l=+1*



Filter *l=-2*

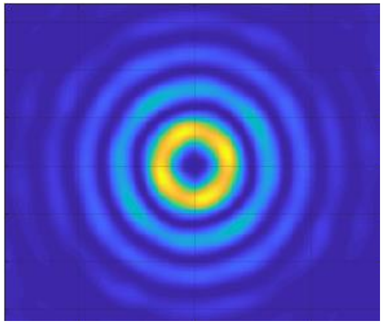
Fourier plane



No correlation peak

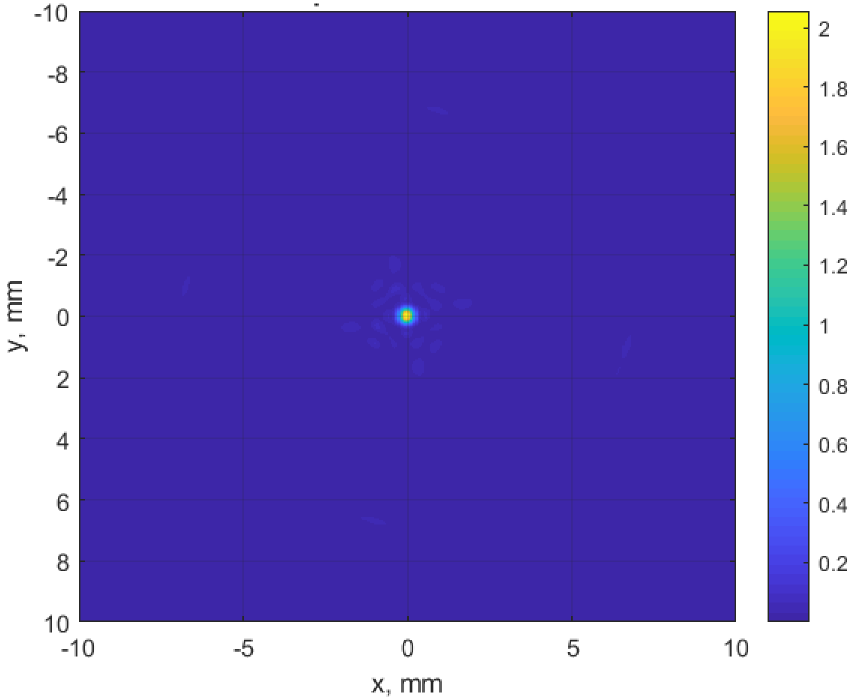
DETECTION OF VORTEX *l*=+2 BY FILTER *l*=+2

Vortex *l=+2*



Filter *l=+2*

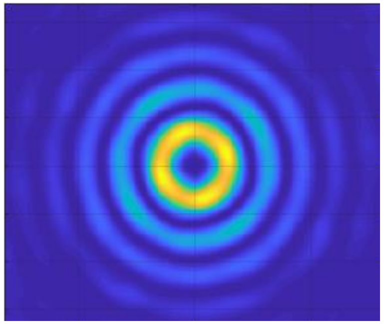
Fourier plane



The correlation peak is present

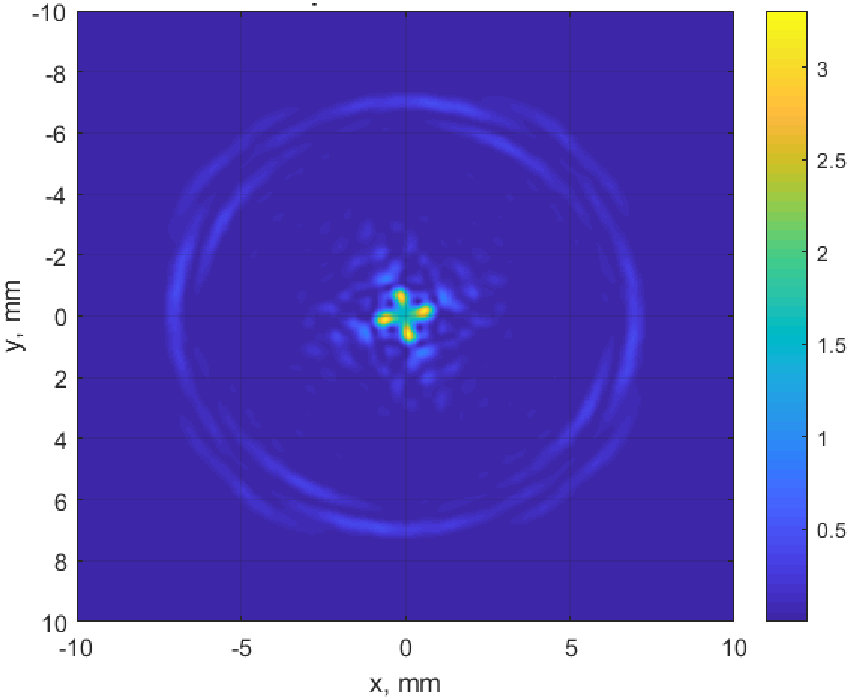
UNDETECTION OF VORTEX *l*=+2 BY FILTER *l*=-2

Vortex *l=+2*



Filter *l=-2*

Fourier plane



No correlation peak

SUBWAVELENGTH AXICON FOR CONVERSION OF LINEARLY POLARIZED THz BEAM INTO CYLINDRICALLY POLARIZED BEAM

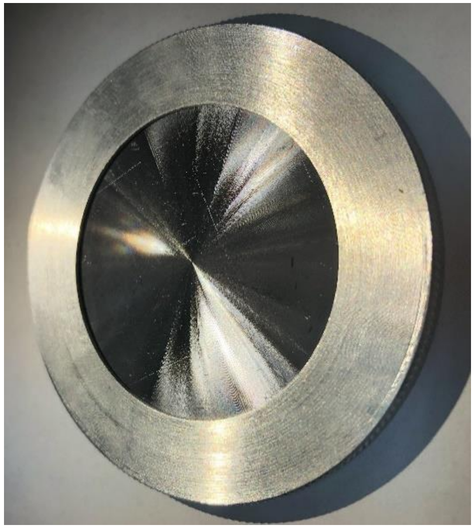
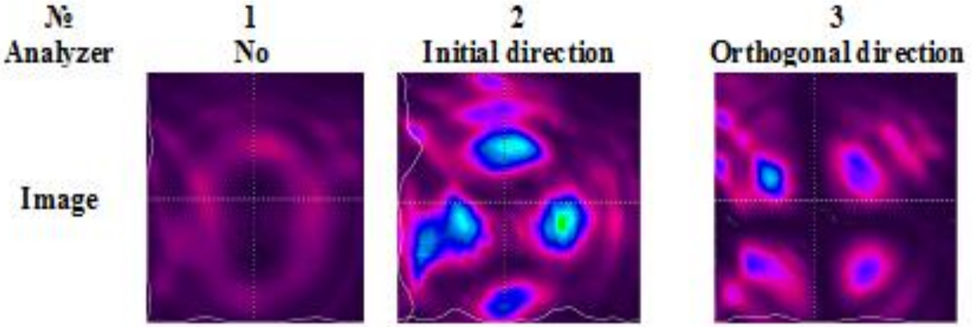


Photo of realized subwavelength axicon

(working wavelength is 128,7 μm)



Formed beam intensity distribution depending on analyzer orientation

The development of methods for control of the mode content and polarization state of a terahertz beam will allow developing terahertz telecommunication systems with high information capacity.

Khonina, S.N. Design, fabrication and investigation of a subwavelength axicon for terahertz beam polarization transforming/S.N. Khonina, K.N. Tukmakov, S.A. Degtyarev, A.S. Reshetnikov, V.S. Pavelyev, B.A. Knyazev, Yu.Yu. Choporova// Computer Optics.- 2019. – Vol. 43, Issue 5.-P. 756-764.

CONCLUSIONS

The feasibility of organizing a multichannel terahertz (THz) communication system based on controlling the transverse-mode composition of a coherent beam of terahertz radiation is demonstrated.

In the long run, the development of methods for simultaneous control of the transverse mode composition and polarization state of a terahertz beam will allow developing multichannel terahertz telecommunication systems with high information capacity.

REFERENCES

[1] Yu.Yu. Choporova, B.A. Knyazev, G.N. Kulipanov, V.S. Pavelyev, M.A. Scheglov, N.A. Vinokurov, B.O. Volodkin, V.N. Zhabin, "High-power Bessel beams with orbital angular momentum in the terahertz range", Physical Review A, vol. 96(2), 023846, 2017.

[2] Y.Y. Choporova, B.A. Knyazev, N.D. Osintseva, V.S. Pavelyev, K.N. Tukmakov, "Two-channel terahertz communication based on spatial mode multiplexing, Proceedings of 44th International Conference on Infrared, Millimeter, and Terahertz Waves", IRMMW-THz, 2019.

[3] S.N. Khonina, K.N. Tukmakov, S.A. Degtyarev, A.S. Reshetnikov, V.S. Pavelyev, B.A. Knyazev, Yu.Yu. Choporova, "Design, fabrication and investigation of a subwavelength axicon for terahertz beam polarization transforming", Computer Optics, vol. 43(5), pp.756-764, 2019.

ACKNOWLEDGEMENTS

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Thank you!
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