Quasi-Optical Components for High Power Wave Beam Control

M.I.Petelin
Institute of Applied Phisics, Russian Academy of Sciences, 46, Ulianov Street,
603600 Nizhny Novgorod, Russia
Phone +7(831)4365921, Fax +7(831)4160616,
Email: petelin@appl.sci-nnov.ru

Abstract: This paper summarizes the simplest methods applicable to transmission and control of intense coherent electromagnetic radiation at frequencies near and within the THz band.

Key words: Intense microwave beams, Oversized structures

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I. Introduction. General motivations and specifications

At frequencies intermediate between microwaves and optics, wave transmission and control functions can be performed with components of miscellaneous types. Standard microwave components (of dimensions commensurable with the wavelength) [1] are of a limited use even at low powers: only if inevitable high Ohmic losses can be tolerated. At high RF powers, to combine Ohmic loss reduction with RF breakdown and fatigue avoidance, all dimensions of high-power systems should be, obviously, much larger than the wavelength. However, such oversized systems are usable only if the RF flow coherence is kept by efficient suppression of parasitic modes.

II. Waveguides

For any type of closed waveguide [1, 2], if the ratio of transverse size to wavelength increases, the Ohmic loss and the surface RF field for any fixed eigen-mode decrease

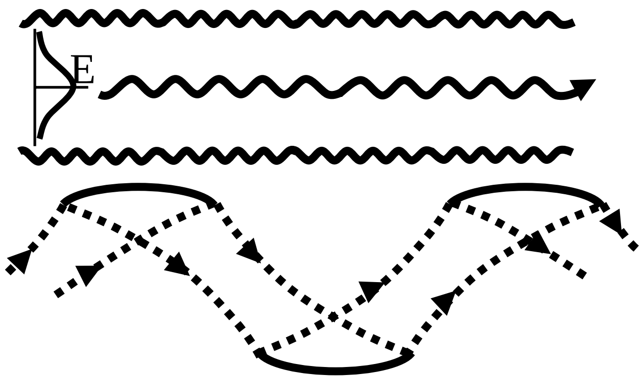

Fig. 1 Transmission of quasi-Gaussian wave flows.

(the H_{01} mode of the circular-cross-section waveguide seems especially attractive, because its electric RF field at the metal surface is zero). However, any irregularity of such a waveguide (a junction or a bend) produces spurious modes, and their out-filtering becomes a difficult problem.

For the latter reason, to meet the coherence preservation problem, many people prefer using a Gaussian-like mode of a corrugated-wall waveguide or of a mirror line [2, 3] (Fig. 1). Parasitic modes are absorbed in the first case by the limited-conductivity wall and in the second case by the free space. The mode filtration needs a limitation $F \leq 1$ on a Fresnel parameter $F = a^2 / \lambda L$, where λ is the wavelength, a is a transverse size and L is a characteristic longitudinal scale of the waveguide.

III. Matching between waveguides

As a rule, any practical system includes waveguides of different types, and matching between them needs mode converters. The simplest adiabatic converters [1, 2] (exemplified with the popular transducer between the H_{10} mode of rectangular cross section waveguide and the H_{11} mode of circular cross section waveguide) are applicable only to relatively low order modes of relatively narrow waveguides capable to transmit relatively low powers.

A higher order mode of a broad closed waveguide can be selectively scattered into another mode of the same waveguide by a proper resonant corrugation of the wall (Fig. 2) [2, 4]. Modes of two electrodynamic subsystems can be selectively coupled by a proper 2-dimensional perforation of the common wall [5]. However, the broader is the system and the higher are coupled modes, the longer should be such converter.

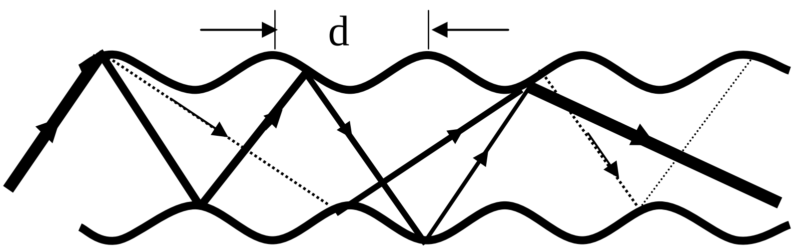

Fig. 2 Selective coupling between waves in corrugated waveguide: wave propagators h_i and h_s are related with corrugation period d by condition $h_s - h_i = 2\pi / d$.

For a high-order mode of a broad waveguide, a relatively compact converter can be devised, basing on approximation of this mode with a system of rays successively reflecting from the wall. Starting from this ray tracing, one can emboss the wall surface to contract the rays, after some reflections, into a desirable, for instance Gaussian-like, wave beam, extract it through a waveguide cut and reflect, with an external focusing mirror, into a necessary direction (Fig. 3) [2, 6-8].

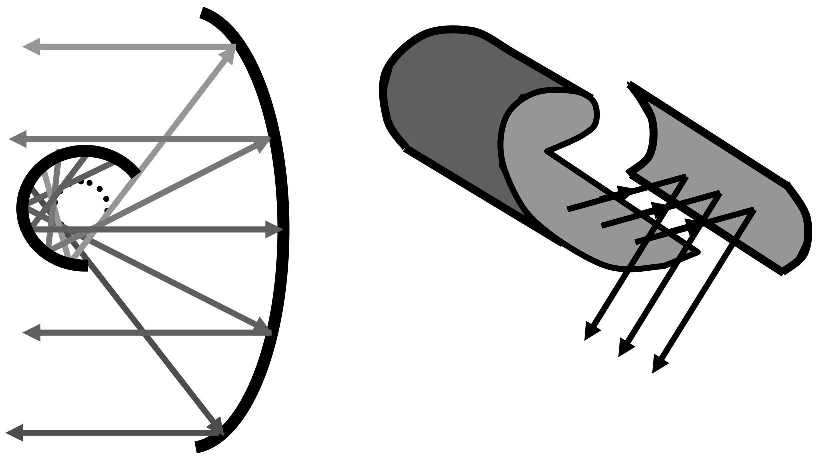

Fig. 3 Conversion of high order waveguide mode into Gaussian beam by restructuring the system of rays.

IV. Wave dividers/combiners

Wave dividers/combiners based on standard low-cross-section waveguides [1] are only of limited use at high frequencies. In oversized waveguides, wave dividing/combining can be conveniently performed using the image multiplication (Talbot) effect (Fig. 4) [9]. The transverse structure of any free paraxial quasi-optical wave beam can be easily transformed to any desirable pattern by a succession of properly embossed mirrors [9], so, in particular, the initial beam can be divided into any number of secondary beams (Fig. 5); the reverse propagation represents combining of some mutually phase-locked beams into one.

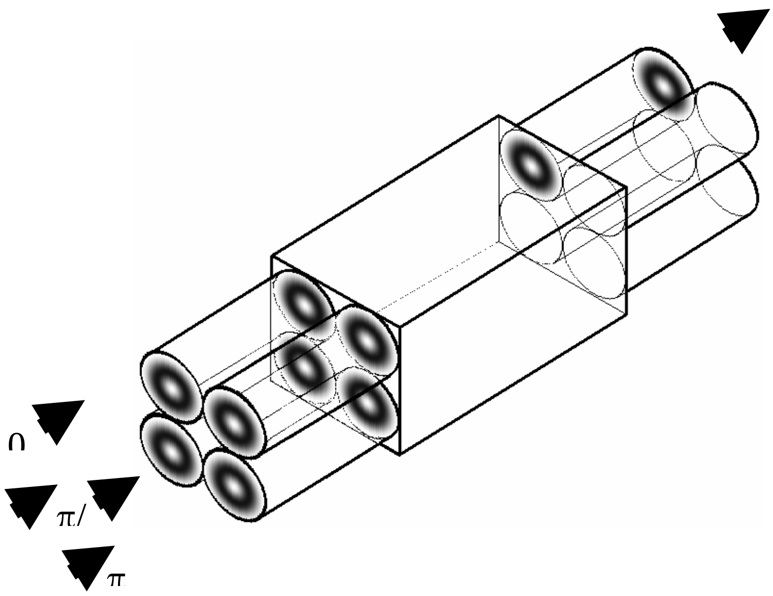

Fig. 4 A device based on the Talbot effect: waves combined from 4 waveguides enter one of 4 outputs, depending on mutual phases of primary waves. The reverse propagation divides the incident wave between 4 outputs.

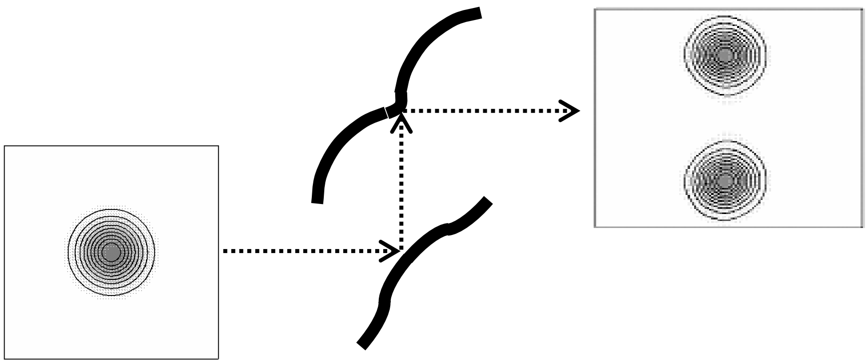

Fig. 5 Dividing of wave beam by a succession of two curved mirrors.

The same function can be performed with a grating of period commensurable or larger than the wavelength [10] (Fig. 6).

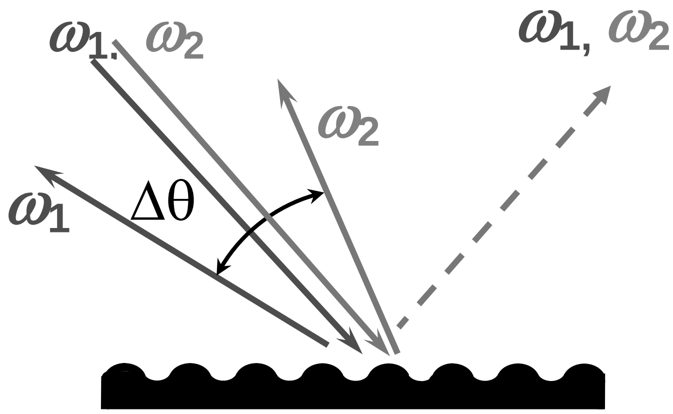

Fig. 6 Diffraction of wave by grating with period exceeding the wavelength. For non-specular scattered waves, propagation angles are frequency dependent.

V. Phase-controlled wave combiners-commutators

In some practical systems it is necessary not only to combine waves, but also to control the combined wave direction. At relatively low frequencies such functions are performed with the magic T, directed couplers and so on [1]. In oversized waveguides, the phase-controlled wave combining can be performed basing on the Talbot effect (Fig. 4) [9]. A 3 dB hybrid performance can be realized with a 3D Littrow grating where the combined wave beam direction is changed by ±90° mutual phase-shift between the input beams (Fig. 7) [11, 12].

VI. Frequency-controlled wave combiners-commutators

Microwaves differing in frequencies are used to be divided/combined by means of multiplexers based on standard waveguides and resonators [1]. At frequencies higher than microwaves, when intense electromagnetic flows are transmitted mostly with relatively broad wave beams, the simplest version of multiplexer may be a metallic grating which period is commensurable to the wavelength [10]: in this case the multiplexing is based on a non-specular scattered beam direction dependence on the incident beam frequency (Fig. 6).

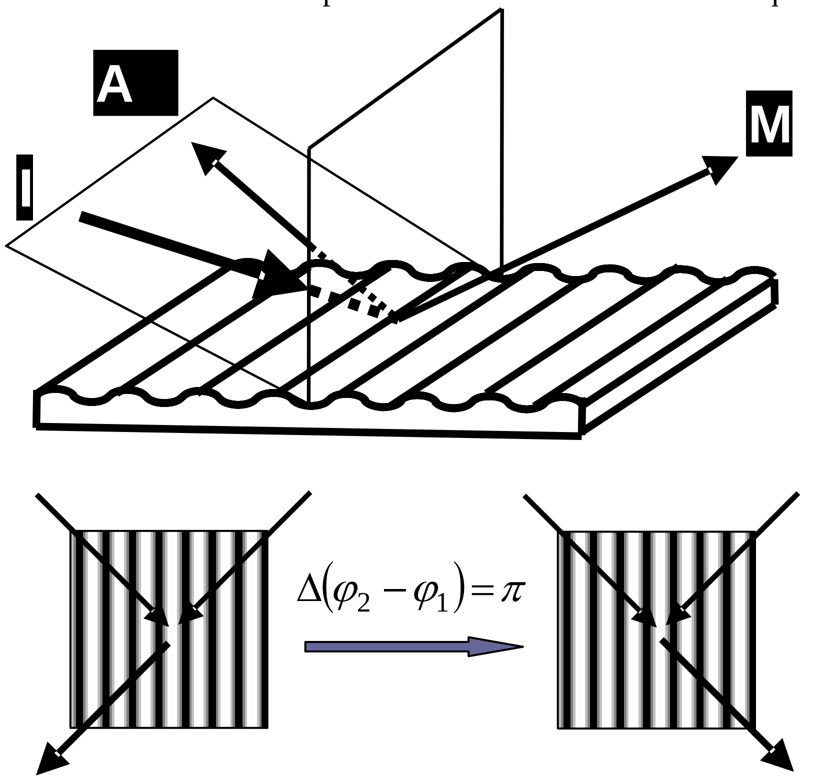

Fig. 7 Phase-controlled quasi-optical wave beam combiner-commutator (magic Y) in the form of 3D-Littrow grating.

To provide a wave beam direction switching by a small shift of the beam frequency, a diplexer can be realized as an interferometer or as a mirror cavity coupled to input and output wave flows by a mirror corrugation (Fig. 8) [11, 12]. Resonant diplexers can be composed into multiplexers (Fig. 9) [13].

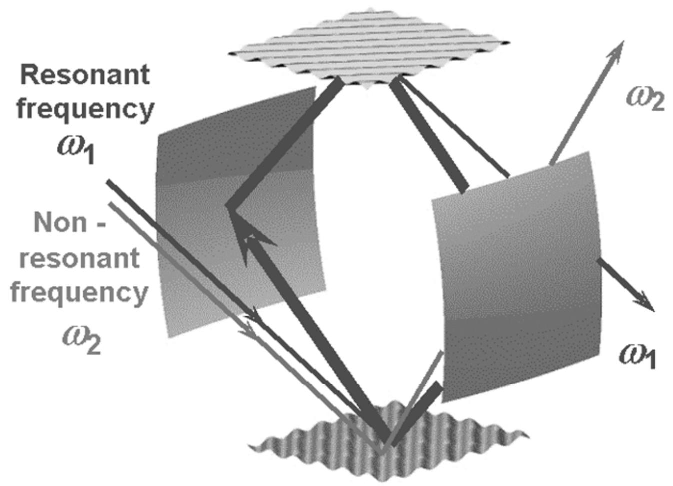

Fig.8 Quasi-optical resonant diplexer.

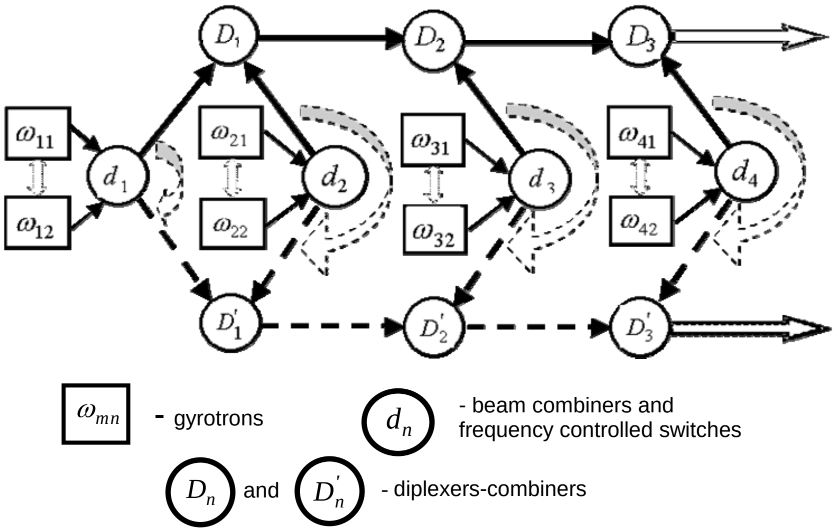

Fig. 9 Scheme of multi-resonant wave beam combiner-commutator: radiation from a number of voltage-controlled gyrotrons is scanned between two output channels.

VII. Polarizers

If the grating period is small compared with the wavelength, the incident beam is reflected only in the specular direction, but due to the grating surface unisotropy, the phase shift between reflected and incident beams depends on the wave polarization [10]. Two successive gratings, each with controllable rotation around the axis perpendicular to the grating surface, can function as an universal polarizer: capable to convert any incident polarization into any desirable one (Fig. 10) [14].

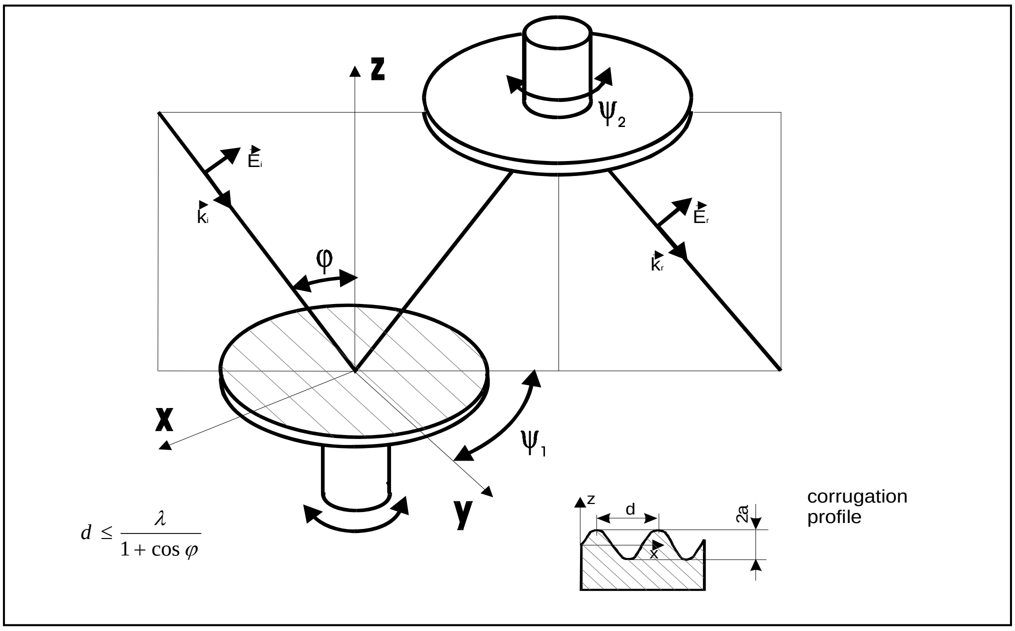

Fig. 10 Universal quasi-optical polarizer.

VIII. Polarization separators

A 3D Littrow grating of optimized profile can function as a polarization separator: when the E-polarized wave is reflected into one direction and the H-polarized wave is reflected into another direction [10]. A succession of such a polarization separator and a polarizer represents a duplexer: a signal from a transmitter is forwarded to an antenna, and an echo signal is forwarded to a receiver (Fig. 11) [11, 15].

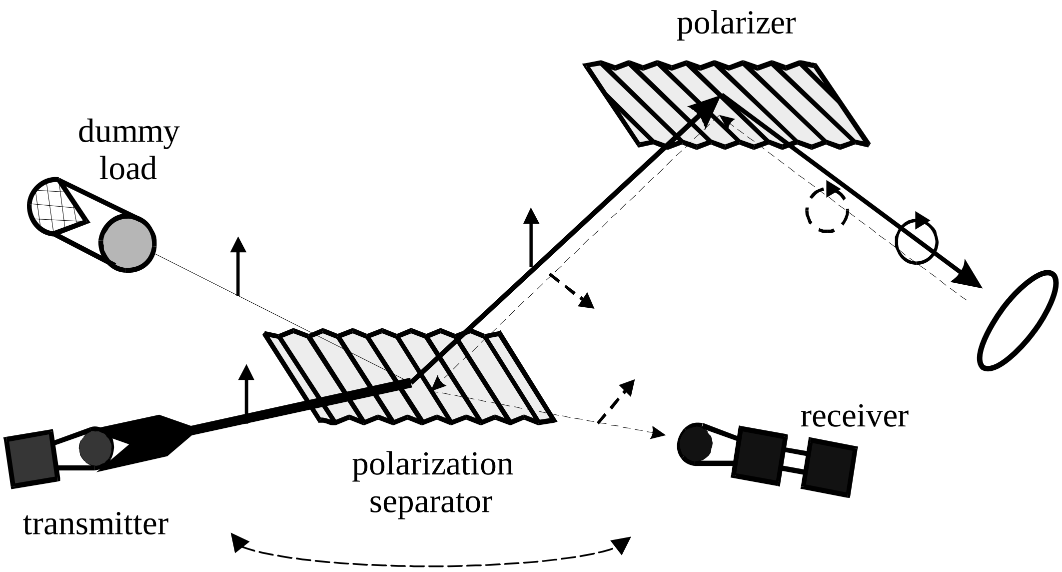

Fig. 11 Duplexer based on metallic gratings.

IX. Conclusions

At the millimeter / sub-millimeter (THz) wave band, the above mentioned quasi-optical components seem of interest for the plasma fusion (plasma diagnostics, ECR heating and current drive, suppression of hydrodynamic instabilities),long-range communication and radar (multiplexers, antenna feeders),technologies (non-reflection resonant rings, gas discharge plasma reactors), future electron-positron colliders (delay-line-distribution systems, pulse compressors, feeders to the particle acceleration channel).

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