1-III B3

PHASE-STEP BEAM WAVEGUIDE

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The present communication is concerned with a new type of beam waveguide which seems attractive both for its constructive simplicity and for its low transmission losses.

The equivalence between beam waveguides of different types and open resonators is well known. This particular waveguide is derived from the planar Fabry-Perot open resonator with a step rim along the edges of the mirrors, extensively investigated by the authors. A very interesting property of this type of resonators is the periodical behavior of the losses as a function of the rim thickness with periodicity $\lambda/2$. The beam waveguide equivalent to the rimmed Fabry-Perot resonator is constituted by a series of identical irises in opaque screens, while the mirror rims are replaced by equivalent phase jumps. This phase step can be obtained by placing a slab of dielectric material across the iris aperture leaving empty an area corresponding to the rim of the mirror, Fig.1. Alternatively, taking into account the periodicity of the losses, the same phase step (corresponding to the same value of the losses) can be obtained with the complementary structure, i.e. by placing the dielectric material along the edge and leaving empty the central region, Fig.2.

Due to the presence of the rim, the field at the edges of the iris is extremely low, consequently the opaque screen can be eliminated without any appreciable perturbation. The resulting structure is extremely simple, being constituted by a series of dielectric frames, Fig.3. Such a wave guide has lower loss per iteration with respect to the simple iris type of the same aperture; further it presents the advantage of low sensitivity to the accuracy of construction and to misalingement along with an extreme ease of construction. The dissipation, scattering and reflection losses which are relevant in the lens type beam waveguide are here negligible, as the bulk of the travelling energy does not impinge on the dielectric frames.

A prototype of this waveguide constituted by a series of square teflon frames ($28x28\lambda$; λ=8 mm, spaced by 40λ) has been constructed and tested. The measured transmission loss is of 0.02 dB per cell.

Different structures derived from this type, which present other practical advantages of construction have been conceived and tested. They include alternate asymmetric and helicoidal structures.

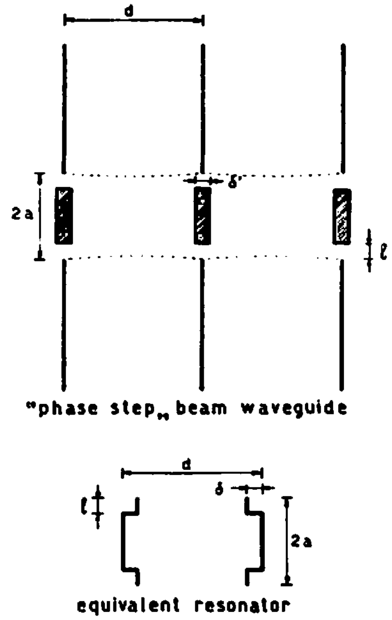

FIG. 1

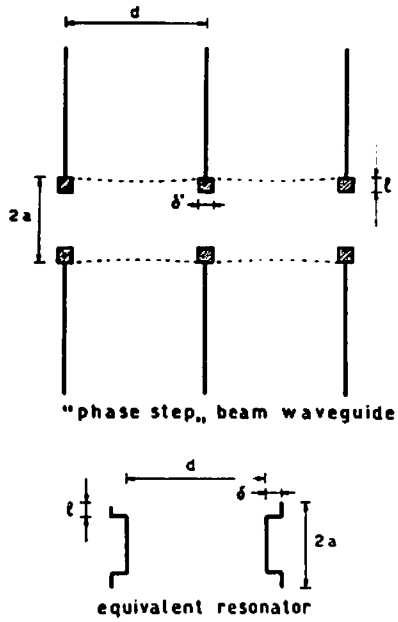

FIG. 2

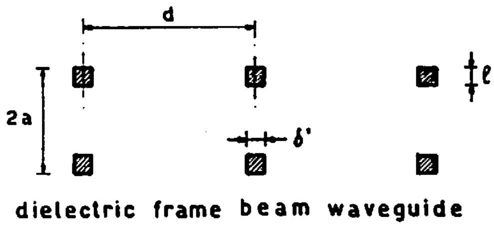

FIG. 3

$$\mathcal{F}^{-1}\langle E_{out}\rangle = \sum_{mn} i_t E_0 e^{-(a_r)_0^2 r^2} H_m((a_r)_0 x) H_n((a_r)_0 y) e^{j\omega_0 t - j\sqrt{}\,\ell}$$

$$\frac{1}{2^{n+m} n!\, m!}\left\{ e^{-\frac{(\xi)^2}{2}} \delta_{\underline{m}\,\underline{n}}^{\,m\,n}\, 2^{\frac{n+m}{2}} \underline{n}!\,\underline{m}! \right.$$

$$+ \frac{1}{4\pi^2}\sum_{\underline{m}\,\underline{n}} \frac{1}{2^{\underline{n}+\underline{m}}\underline{n}!\,\underline{m}!} \sum_{\zeta = z, R} F_\zeta \sum_{s} H_{s,\zeta}$$

$$\left. \cdot \frac{e^{-\frac{\xi^2}{2}}}{V_{o\zeta}(\Delta\beta')\, V_{o\zeta}(\Delta\beta'')} \left[1 - \left\{ \frac{j\Delta\beta'}{V_{o,\zeta}(\Delta\beta')} + \frac{j\Delta\beta''}{V_{o,\zeta}(\Delta\beta'')} \right\} \frac{\xi}{2^{s/2}} \right] \right\} \qquad (3)$$

where

$$V_{o,\zeta}(\Delta\beta'^{(\prime)}) = j\{(\Delta\beta'^{(\prime)})_o \mp \Omega_\zeta\} - \frac{1}{\gamma_\zeta'}, \quad \frac{1}{\gamma_\zeta} = \pm j\Omega_\zeta + \frac{1}{\gamma_\zeta'}$$

$$(\Delta\beta')_o = (\Delta\beta)_{,1} = (\underline{n} - n)\ell_y + (\underline{m} - m)\ell_x$$

$$+ \frac{1}{2\omega_o\sqrt{\varepsilon'\mu}}\left[\{(\underline{n}-n)\ell_y + (\underline{m}-m)\ell_x\}\{(\underline{m}+m+1)\ell_x + (\underline{n}+n+1)\ell_y\}\right]$$

$$(\sqrt{})_1 = \sqrt{\varepsilon'\mu} + \frac{1}{2\omega_o^2}\frac{1}{\sqrt{\varepsilon'\mu}}\left\{(n+\tfrac{1}{2})\ell_y + (m+\tfrac{1}{2})\ell_x\right\}^2$$

$H_{s,\zeta}$ are coefficient constants of ω^s expansion for

$$e^{j\Delta\beta'\ell - \frac{\ell}{\gamma_\zeta}} + \frac{1}{j\Delta\beta}\left\{ j\sqrt{} - j\sqrt{}\, e^{j\Delta\beta\ell} + \left(\sqrt{} + \frac{1}{\gamma_\zeta}\right)\left(e^{j\Delta\beta\ell} - 1\right)\right\}$$

Variables $\xi = \frac{4}{\sqrt{2}T}\left[t - \ell\{(\sqrt{})_1 - (\Delta\beta)_{,1}\}\right]$ show the pulse delay as in fig.3, and the term in [ ] of the above results give the pulse deformation, with the term of $e^{-\xi^2/2}$. Scattering coefficients F_ζ of the mode conversion and reconversion due to the irregularities can be shown to be

$$F_z = \beta_o^2 (a_r)_o^4 \langle \gamma_{\underline{m}\,\underline{n}\,:\,m\,n}\, \gamma_{\underline{m}\,\underline{n}\,:\,m\,n} \rangle \langle \delta\varepsilon(z) \rangle$$

$$F_R = \beta_o^2 (a_r)_o^2 \cdot 4 \cdot K_x(l, m, \underline{m}) K_x(l, \underline{m}, \underline{m}) K_y(o, n, \underline{n}) K_y(o, \underline{n}, \underline{n}) \cdot \langle \delta \tfrac{1}{R} \rangle$$

in particular, when $\underline{m} = m = \underline{n} = n = o$,

$$F_z = \beta_o^2 (a_r \gamma_r)_o^2 \{(a_r\gamma_r)_o^2 + 1\}^{-(\underline{m}+\underline{n})/2 - 1} \langle \delta\varepsilon(z) \rangle$$

$$F_R = 4\pi^2 \beta_o^2 (a_r)_o^{-2} \langle \delta \tfrac{1}{R} \rangle$$

as shown in fig.1 and fig.2. The intensity $I(t)$ of the output at the finite receiving surface S_f is

$$I(t) = \frac{E^4}{(a_r)_o^4}\sum_{m,n} |S_{mn}|^2 \frac{1}{N_{mn}^2} \int_{S_f} e^{-2(a_r)_o^2 r^2} H_m^2(a_r x) H_n^2(a_r y)\, dS$$

where S_{mn} is the term in { } in eq.(3), N_{mn}^2 is the normalization factor given by the infinite integral.

It can be seen from the above results that when $(a_r)_o \gamma_r \approx 1$, the mode conversion is very large. Hence, this corresponds the strong coupling between the beam waist and the transverse correlation of the randomness. Further, if $V_{o,\zeta}(\Delta\beta'^{(\prime)}) = j\{(\Delta\beta'^{(\prime)})_o \mp \Omega_\zeta\} - \frac{1}{\gamma_\zeta'}$ $(\zeta = z, R)$ is small, namely, $|(\underline{n} - n_1)\ell_y + (\underline{m} - m_1)\ell_x| = \Omega_z$ or Ω_R resonance phenomena caused by the interaction between the beat modes and the periodic component Ω_ζ of the irregularities of the refractive index and bends along the axial direction of the guide may be produced. In this condition the pulse delay and deformation is extremely large. For $\ell = 10^4\ m$, $\beta_o = 10^6 \sim 10^7\ m^{-1}$, $\ell_r = 1 \sim 10^3\ m^{-1}$, ($10^{-2}$ ~ a few) nano second delay and the pulse deformation with a broadening phenomena may be obtained.

Further consideration about radiation phenomena in the waveguide of the finite cross section has been also investigated.

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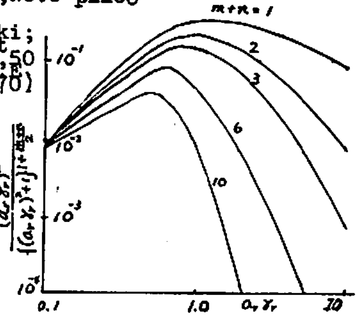

Fig.1- Fluctuation by random index distribution

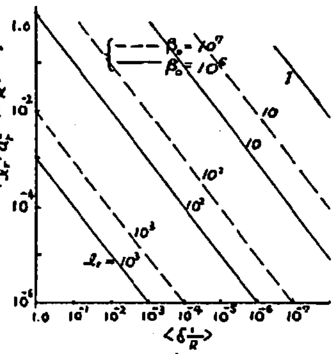

Fig.2- Fluctuation by random curvature of waveguide

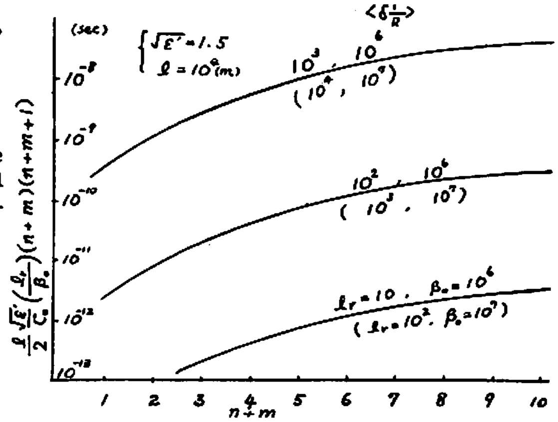

Fig.3- Delay distortion of pulse signal