

Dielectric-Loaded Waveguide as a Deflecting Structure

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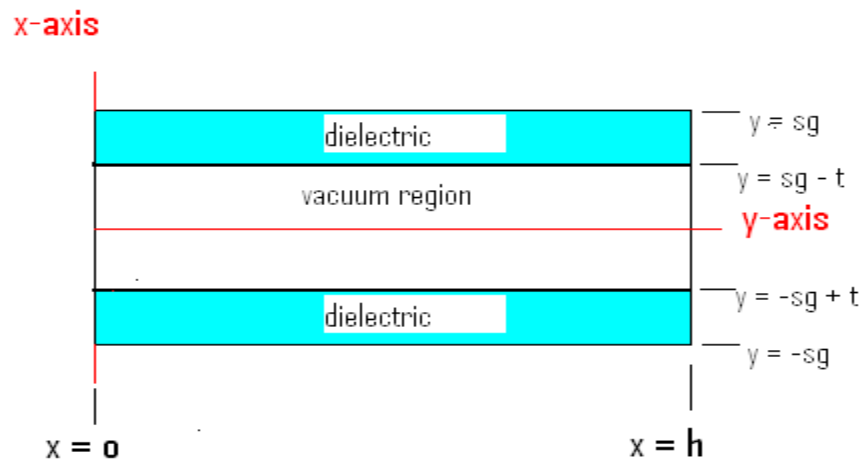
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Possibilities for Dielectric-Loaded Waveguides as a Deflecting/Crabbing Structure

- Dielectric-loaded waveguides can be designed to have a sufficiently high deflecting field on the beam axis with a phase velocity equal to the speed of light.
- Pulsed operation at 120 Hz is possible with klystrons that are within the current commercially available technology. Higher repetition rates might be possible with klystrons with higher power collectors and windows, and with higher-repetition-rate modulators.
- Deflections on the order of a milliradian/meter are practical.
- Other waveguide modes are poorly coupled to the beam because of large transit time effect.

Cross section of a dielectric-loaded waveguide



Waveguide Fields in Vacuum Region

- $H_x = H_0 \sin(\pi x/h) \cosh(\xi y) \exp(-j\beta z)$
- $H_y = H_0 \cos(\pi x/h) \sinh(\xi y) \exp(-j\beta z)$
- $H_z = -jH_0 [\beta/(\pi/h)] \cos(\pi x/h) \cosh(\xi y) \exp(-j\beta z)$
- $E_x = H_0 [(\omega\mu_0\beta)/(\xi\pi/h)] \cos(\pi x/h) \sinh(\xi y) \exp(-j\beta z)$
- $E_z = jH_0 [(\omega\mu_0)/\xi] \sin(\pi x/h) \sinh(\xi y) \exp(-j\beta z)$

where j is sqrt of -1 , ω is $2\pi f$, β is the propagation constant in z , and ξ is y -wave number.

Waveguide Fields in Dielectric Region

- $H_x = H_d \sin(\pi x/h) \cos[\alpha(sg - y)] \exp(-j\beta z)$
- $H_y = H_d [(\pi/h)^2 + \beta^2]/(\pi\alpha/h) \cos(\pi x/h) \sin[\alpha(sg - y)] \exp(-j\beta z)$
- $H_z = jH_d [\beta/(\pi/h)] \cos(\pi x/h) \cos[\alpha(sg - y)] \exp(-j\beta z)$
- $E_x = H_d [(\omega\mu_0\beta)/(\alpha\pi/h)] \cos(\pi x/h) \sin[\alpha(sg - y)] \exp(-j\beta z)$
- $E_z = jH_d [(\omega\mu_0)/\alpha] \sin(\pi x/h) \sin[\alpha(sg - y)] \exp(-j\beta z)$

where α is the y wave-number in the dielectric regions.

Required Matching Conditions for Deflecting Mode with Phase Velocity Equal to Speed of Light

$$\alpha^2 + \beta^2 = \omega^2 \mu_0 (\epsilon_r - 1)$$

$$\alpha \cot(\alpha t) = -\xi \coth[\xi(sg-t)]$$

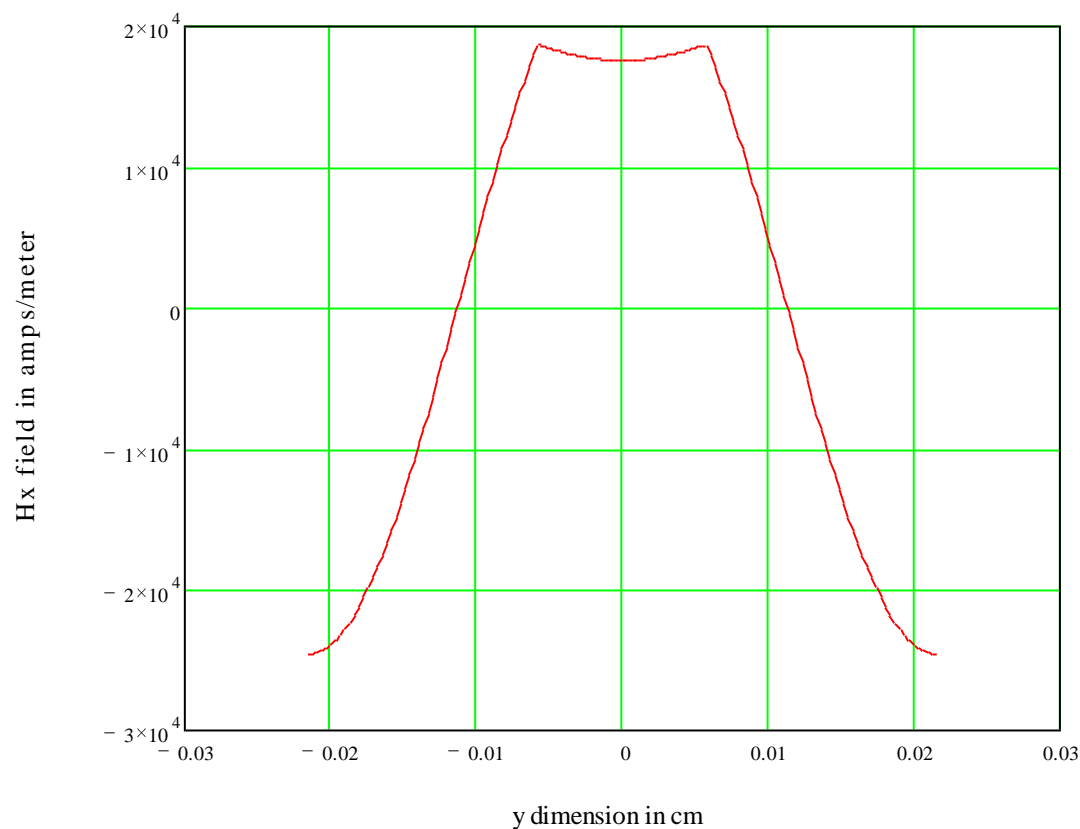
Design of a Dielectric-Loaded Waveguide as a Deflecting Structure for the APS

- The APS crabbing cavity requires an operating frequency of 2.8155 GHz
- Injection requires a minimum beam aperture of greater than 7-mm vertical height and 36-mm horizontal width
- Required deflection ($c\mu_0 H_0$) ≤ 4 Megavolts

Parameters for a Crabbing Deflector on the APS Storage Ring Operating at 2.8155 GHz

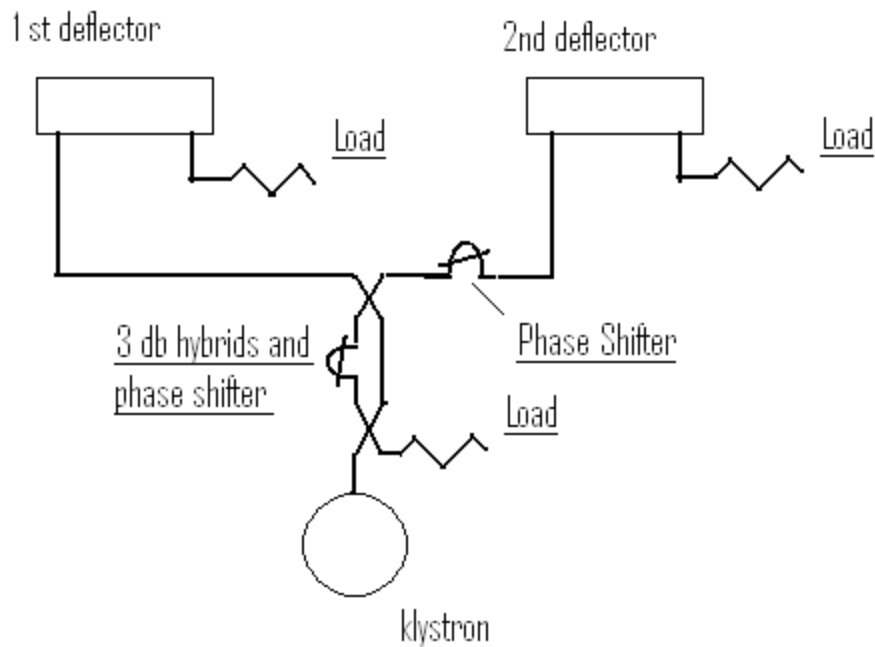
| | |
|---------------------------------------|----------------|
| ■ Dielectric material | Aluminum Oxide |
| ■ Relative dielectric constant | 9.0 |
| ■ Thickness of dielectric slabs, mm | 15.76 |
| ■ Width of waveguide, mm | 50.0 |
| ■ Full height of copper waveguide, mm | 43.0 |
| ■ Full height of vacuum space, mm | 11.48 |

Deflecting Field, H_x , Plotted vs y across Middle of Chamber



H_x FIELD vs y PLOTTED AT $x = h/2$

Single Klystron Topology for Driving Dielectric-Loaded Waveguides



Klystron and Drive Power Options for Deflector/Crab

- Frequency of operation is within standard s-band where 35-to 40-MW pulsed klystrons are available.
- CW operation in the WG mode is not an option because power consumption, even if it was available, would be prohibitive.
- Operation at 100- to 400 Hz repetition rates and 3- to 4-microsecond pulses is within the average power capabilities of existing pulsed klystrons.
- No klystron is commercially available to match the 16-MW power required at > 400-Hz repetition rates, although the Thales TH2158 does operate at 500 Hz and 5- MW (45 kW collector and window). NRE and first-article development would have to be part of the program if higher repetition rate operation is needed. Much higher repetition rates are not an option.

Dielectric Waveguide Ability to Handle Fields and Power

- Pulse length is about $3.7 \mu\text{s}$ and, if at 1000-hertz repetition rate, the average power consumption is about 4 kW/meter, about 1.45 kW/m per dielectric slab.
- Handling this power should not be difficult since aluminum oxide is a good thermal conductor, but a detailed design and ANSYS calculation have not been done. There also needs to be an analysis of the effect of pulsed heating to be sure this isn't an issue.
- Operation at high fields, $> 8.5 \text{ MV/m}$, parallel to the dielectric and vacuum boundary has been demonstrated, so operation at the field levels needed for this example should not be a problem.

Peak Deflection for Various Waveguide Lengths assuming 16-MW of Forward Power in Each Deflecting Structure

| Waveguide meters | deflection milliradians |
|---------------------|----------------------------|
| 1.0 | 0.93 |
| 1.5 | 1.38 |
| 2.0 | 1.82 |

Phase Velocities for Lower $E_y = 0$ Modes

| Frequency GHz | m,n | vp/c |
|------------------|-----|----------------------|
| 5.631 | 1,n | 0.3866, 1.071 |
| | 2,1 | 0.4139 |
| | 3,1 | 0.4756 |
| | 4,1 | 0.6406 |
| 8.447 | 1,n | 0.4495, 0.364 |
| 11.26 | 1,n | 0.346, 0.519, 0.3902 |
| | 2,n | 0.5349, 0.3967 |

Phase Velocities for Lower $H_y = 0$ Modes

| Frequency GHz | m,n | vp/c |
|------------------|-----|--------------|
| 2.816 | 1,1 | 0.43 |
| 5.631 | 1,1 | 0.586 |
| | 2,1 | 0.697 |
| | 3,1 | 1.249 |
| 8.447 | 1,n | 0.758, 0.404 |
| | 2,1 | 0.697 |

Comments

- Dielectric-loaded waveguides can provide adequate transverse deflection and can be used in pulse mode up to 120-Hz and maybe 1000 Hz with klystron and modulator development. (APS users can operate with 1-MHz data rates so SC technology is the APS baseline).
- Operation in waveguide mode is not likely to create a multibunch instability since phase velocities of the non-deflecting modes are weakly coupled due to transit time effects.
- The input and output coupler designs must be well matched to avoid standing-wave issues. No design has been done to verify this is possible.
- No studies have been done on short-wavelength instability to see if there are any issues.