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It has been previously demonstrated theoretically[1, 2] that, if Coulomb collisions are the primary source of energy loss, a hollow plasma waveguide or cavity resonator can have a much lower attenuation or higher Q-factor than a hollow copper waveguide. The ability to construct waveguides that have low losses is of considerable interest to designers of high-energy particle accelerators of the rf linear accelerator type. For particle accelerator applications it is necessary to maintain synchronism between the particle beam and the rf wave supplying energy to the beam. Therefore, any proposed accelerator waveguide must guide waves of electromagnetic energy with a phase velocity no greater than the velocity of light.

The earlier theoretical treatments analyzed only fast-wave plasma waveguides. These earlier analytical demonstrations were made under the simplifying assumptions of infinite static magnetic field and infinite outer radius of the plasma column. The promise of lower-loss structures led to the experimental investigations, which showed that the losses may actually be higher by a factor of 3 to 4 than predicted on theory.[3]

This letter presents a summary of the results obtained from computer solutions of the dispersion relation of a hollow plasma waveguide of finite transverse dimensions and a finite axial magnetic field.[4] These results show: (a) that it is possible to guide the appropriate slow waves by a smooth hollow plasma waveguide, and (b) that despite the higher values of collision frequency found experimentally, a plasma waveguide can have losses lower than a copper waveguide. The structure considered consisted of an evacuated central cylindrical region of radius R_0, surrounded by an annular plasma region containing a fully ionized uniformly distributed gas with no time variations of the plasma properties; the plasma region is contained within an outer copper conductor of radius R_w.

The dispersion relation for finite axial magnetic fields for the structure described above cannot be solved practically except by numerical methods on a large-scale digital computer.

Under the conditions of a finite axial magnetic field, hybrid wave solutions exist. It has been previously shown[5] that it is possible to find solutions that consist of predominantly transverse magnetic waves. It is waves of such type that are desirable for possible particle accelerator applications.

The phase characteristics shown in Fig. 1 were obtained for several values of external axial magnetic field. For each curve shown, the ratio of cyclotron frequency, ω_c, to plasma frequency, ω_p, was held constant. The cutoff frequency, ω_0, of the hollow plasma waveguide is lower than the TM_{01} mode cutoff frequency of a round copper waveguide of radius R_0 because of penetration of the rf fields into the plasma region. If the ratio of plasma frequency to the rf frequency, ω_p/ω_0, is increased, the penetration of the rf fields into the plasma region is decreased. R_{eq} is the radius of an equivalent copper waveguide with the same TM_{01} mode cutoff frequency as the hollow plasma waveguide.

The important result apparent in the curves shown in Fig. 1 is that the phase velocity of the resulting TM waves may be smoothly adjusted over a wide range from fast to slow with respect to the velocity of light by varying the axial magnetic field of the hollow plasma waveguide. (It should also be restated that the structure considered is uniform in the axial direction.)

The results of the theoretical calculations of the attenuation of a hollow plama waveguide as compared with that of an equivalent copper waveguide for several ratios of collision frequency, ν, to rf frequency, ω, are shown in Fig. 2. The losses of such a waveguide may, under certain combinations of plasma properties, be significantly lower than that of conventional copper waveguides, despite the fact that experimentally determined plasma losses are higher than those calculated from classical collision processes.

The work discussed here was submitted in partial satisfaction of the requirements for the Master of Science degree at the University of California, in Berkeley. The assistance and guidance of Professor J. R. Woodyard and Professor A. J. Lichtenberg are gratefully acknowledged.

Footnotes and References

[*] Work done under auspices of the U. S. Atomic Energy Commission.

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List of Figures

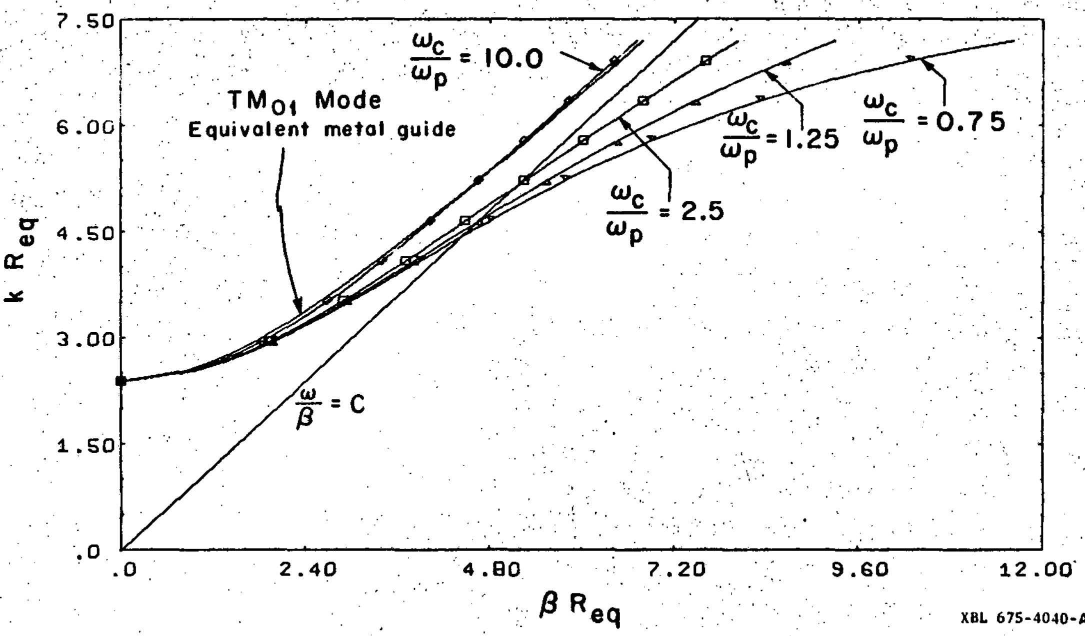

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Fig. 1

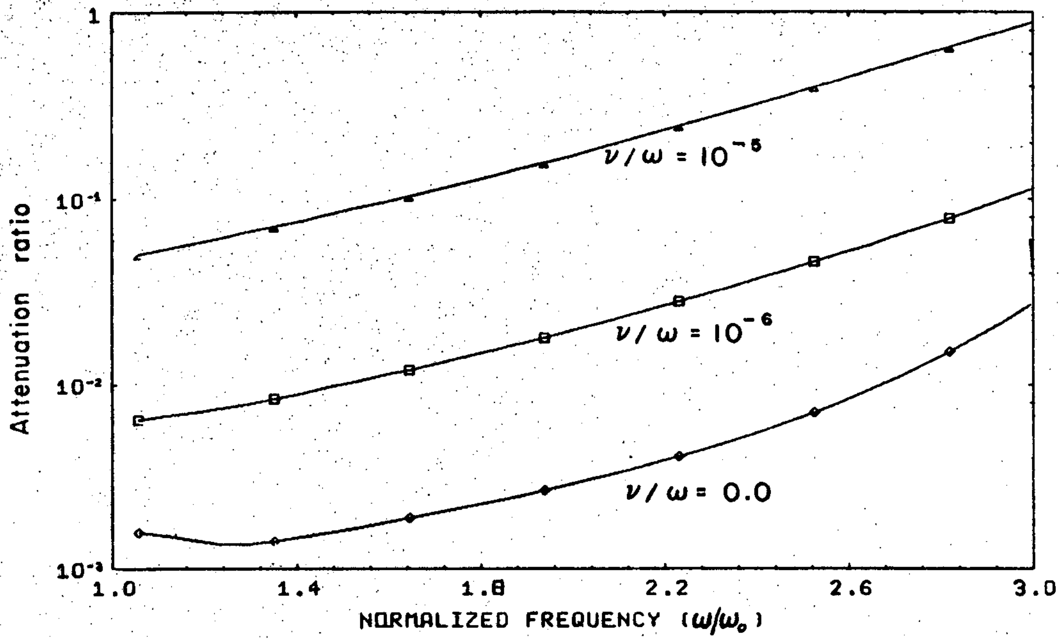

Fig. 2

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