# I-6. Circular Waveguide Loaded with Dielectric Discs for Increased Usable Bandwidth

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For each mode of propagation in waveguide, there is a critical (cutoff) frequency below which waves do not propagate. In practice, it is preferable to restrict the propagation to a single mode. If the dominant (TE-11) mode in circular waveguide is to be utilized, other modes may be excluded by operating at frequencies below the cutoff of the next mode (usually the TM-01). Thus the ratio of the TM-01 cutoff frequency over the TE-11 limits the waveguide's useful bandwidth. This ratio is 1.31 for uniform filling, and may be increased to 1.41 by a dielectric lining in the waveguide.[1] A much greater ratio can be achieved by periodically loading the waveguide with discs of high dielectric constant, as shown in Fig. 1. The waveguide diameter is decreased to raise the cutoff frequency of the TM-01 mode, and the dielectric discs are inserted to lower the TE-11 cutoff frequency. As will be shown, the discs have relatively little effect on the TM-01 mode.

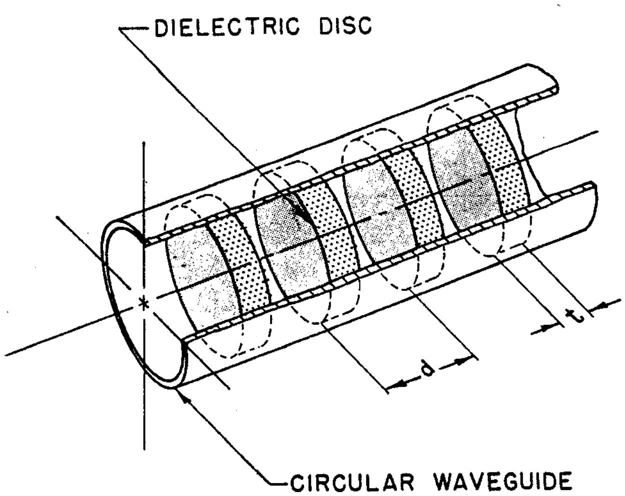


Fig. 1 Dielectric-disc-loaded circular waveguide.

This mode-selective loading can be appreciated with the aid of Fig. 2. For the TE-11 mode, E-lines are parallel to the discs and the effect is analogous to loading a transmission line with parallel capacitors. The total (loaded) capacitance is equal to the sum of the capacitance in air, $C_o$, and the capacitance in the dielectric, $C_k$. We may now define an equivalent dielectric constant, $k_e$, which is proportional to the total capacitance for the dominant mode. The TM-01 mode, at cutoff, has E-lines which are parallel to the axis, as shown in Fig. 2(b). E-lines must pass through both air and

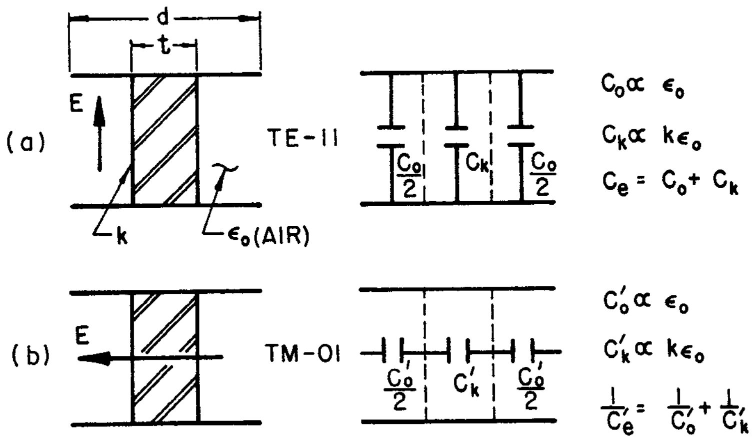


Fig. 2 Equivalent circuits at cutoff. (a) Dominant (TE-11) mode. (b) TM-01 mode.

dielectric, which is analogous to loading by capacitors connected in series. The resultant capacitance for this mode is much smaller than for the TE-11 mode. The equivalent dielectric constant for the TM-01 mode, $k_e'$, is thus much lower than for the TE-11 mode. This means that the ratio of the TM-01 cutoff frequency over the TE-11 has been increased, as desired. For example, let us assume that each period along the guide is one-third filled with a disc having a relative dielectric constant of 9 (alumina). Applying the equivalent circuits of Fig. 2, we find that $k_e$ is 3.67 and $k_e'$ is 1.42. This places the TM-01 frequency at 2.10 times the TE-11. This is a great advantage over the ratio 1.31 for simple dielectric filling.

The simple relations just stated are exact at all frequencies in the limit of infinitely thin discs and spacing, and are quite accurate at the cutoff frequency, for small thickness and spacing. In order to evaluate the frequency behavior of a circular waveguide loaded with discs of finite thickness, one must recognize the periodic nature of the loading.[2] Figure 3 shows the fre-

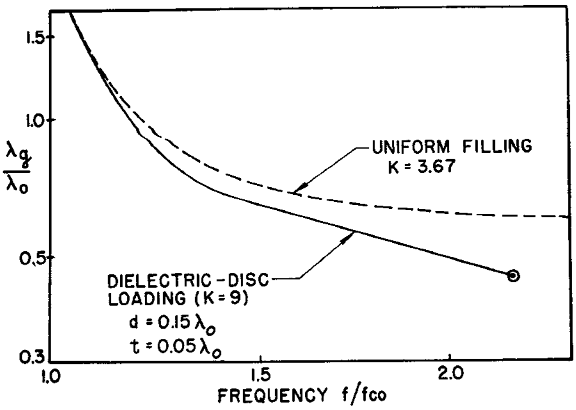


Fig. 3 Guide wavelength in first passband of TE-11 mode for dielectric-disc loading.

quency variation of guide wavelength ($\lambda_g$) for disc-loading and uniform loading with the same average $k$. Note that the TE-11 mode, for dielectric-disc loading, has a finite passband rather than the semi-infinite passband that is characteristic of dielectric filling; such behavior is peculiar to a periodic structure. The lowest cutoff frequency ($f_{co}$) of such periodic lines is calculated accurately from the equivalent-circuit concept stated earlier. All other band edges are evaluated by considering the frequencies at which the center-to-center spacing of discs is a multiple of $\frac{1}{2}\lambda_g$. Thus, $f_{co}$ is determined by the volumetric filling fraction of dielectric. All higher cutoff frequencies may be increased by decreasing the disc thickness and spacing while maintaining the same filling fraction.

Figure 4 compares cutoffs for the first several modes with periodic and uniform filling. The most striking difference between the two cases is the separation of the TE-11 and TM-01 modes. For alumina discs that fill one-third of the volume, this separation is so great that it no longer limits the waveguide's useful bandwidth. The TE-21 cutoff, which occurs at a frequency 1.66 times that of the TE-11, then limits the single-mode band-

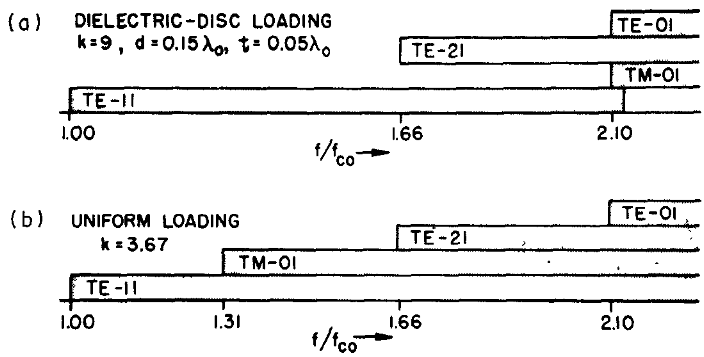


Fig. 4 Mode charts. (a) Modes propagating in disc-loaded circular waveguide. (b) Modes propagating in uniformly loaded circular waveguide.

width. For this reason, the discs need not have a $k$ as high as 9; other materials with somewhat lower dielectric constants will yield a comparable benefit. It may be shown that for any value of $k$, the greatest mode separation occurs when each loading disc fills one-half of an iterative section. With half filling, a dielectric constant of 4.3 is sufficient to move the TM-01 cutoff frequency to 1.66 times that of the dominant mode, so that it alone no longer limits the single-mode bandwidth.

We may now compare the useful bandwidths of uniformly filled and disc-loaded waveguide. It may be desirable to operate from 20% above dominant-mode cutoff to a frequency somewhat below the cutoff of the next mode. This means that uniform filling, which can be used from 1.20 to 1.30 $f_{co}$, results in an 8% useful band, while disc-loading, which can operate from 1.20 to 1.64 $f_{co}$, gives a 32% band—a fourfold increase.

In order to verify the predicted mode separation, a cavity has been constructed as shown in Fig. 5. The cavity includes two sections of disc-loaded waveguide, each one-third filled with alumina. Equivalent dielectric constants and cutoff frequencies can be computed from the resonances meas-

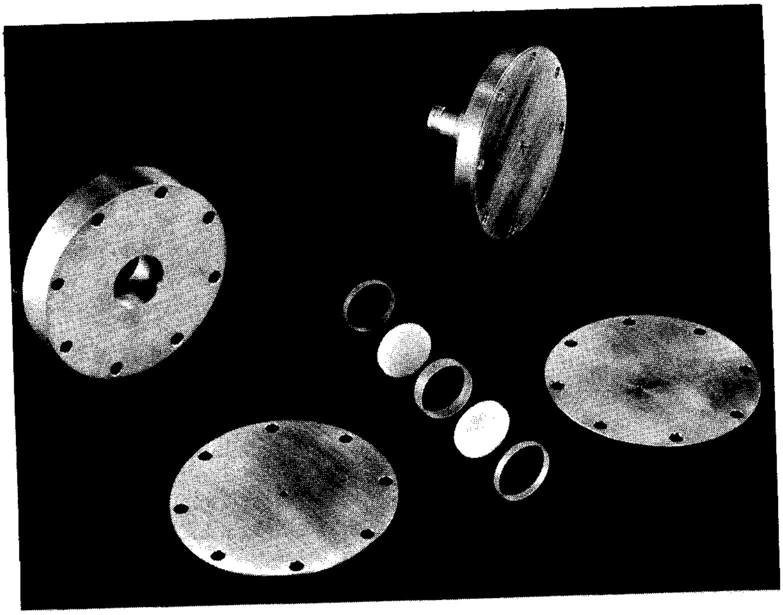

Fig. 5 Disc-loaded resonant cavity for tests of two sections.

ured in the cavity. Measurements showed close agreement with theory described earlier.

Disc loading could be helpful in various components in circular waveguide, including rotary joints, attenuators, phase shifters and array radiators. Such devices could be designed to operate over greater bandwidths. Or, for a specified design bandwidth, disc loading enables operation further from cutoff, thereby decreasing the corresponding guide-wavelength bandwidth. For an array radiator, the disc-loaded waveguide offers an additional advantage in some control over the equivalent dielectric constant. If the aperture diameter is specified, the greatest radiation loading may be obtained by adjusting the filling fraction of the discs.

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## REFERENCES

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2. R. E. Collin, *Field Theory of Guided Waves* (New York: McGraw-Hill, 1960) pp. 368-408.