II-3. CIRCULAR TE_{011}-MODE, TRAPPED-MODE BANDPASS FILTERS*

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The filters to be described are called "trapped-mode filters" because for their desired resonator mode the energy is trapped within the resonator structure to give a high-Q resonance. However, the side walls of the resonator are partially open so unwanted modes will radiate out the side walls of the structure so as to completely kill or at least greatly dampen unwanted resonances. Thus one of the main objectives in using this type of resonator is to obtain bandpass filters which will give a low-loss pass band, with no other pass bands. Though the principles to be described can also be used with other forms of resonators, in this paper, the resonators described employ the circular TE_{011}-mode which has the advantage of providing a higher unloaded Q than would rectangular TE_{101}-mode resonators.

Circular TE_{011}-Mode, Trapped-Mode Resonators. Figure 1 shows a circular TE_{011}-mode resonator. It consists of three metal plates, two of which are iris plates and could be of the form in Figure 2(a). The middle plate will be called a "mode-trap plate," and it has the form shown in Figure 2(b). For the circular TE_{011} mode the electric field will have the circular pattern indicated in Figure 2(b), the electric field being parallel to the metal plates as indicated in Figure 1. The region be-

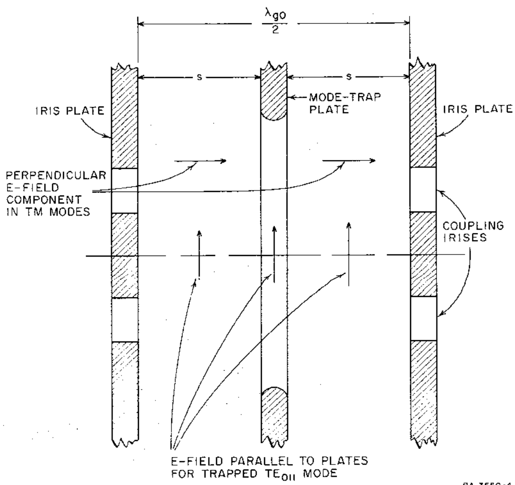

Figure 1. Enlarged Sketch of the Center Portion of a Trapped-Mode Resonator

*This research was supported by the U. S. Army Electronics Laboratories, Fort Monmouth, New Jersey, under Contract DA 36-039-AMC-00084(E).

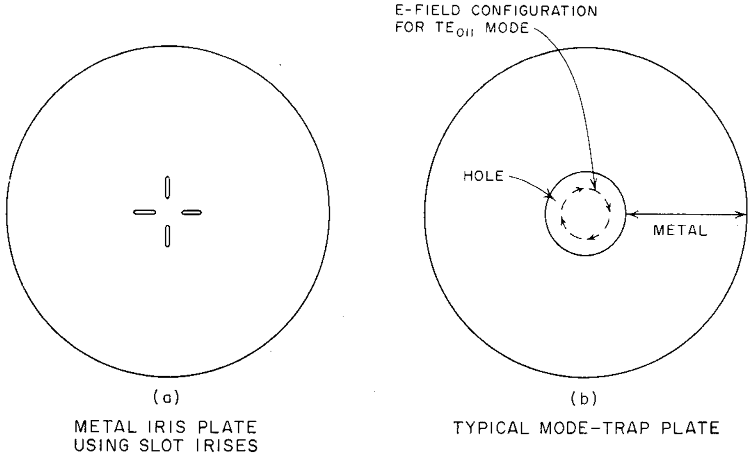

Figure 2. Iris and Mode-Trap Plates
(Experiments have shown that the annular irises in Figure 3 are preferable to the slot irises in the plate shown at (a) above)

tween the metal plates operates as a radial transmission line, and if the electric field is parallel to the plates, all transmission out through the sides is cut off unless the plates are spaced at least by a half-wave length. At the TE_{011}-mode resonance, the spacing between the plates is considerably less than one-half wavelength so energy cannot escape. However, due to the open sidewalls of the structure, the energy of other possible modes tends to radiate freely. This is especially true of modes which normally have an electric field component which would be perpendicular to the plates. In a practical structure the energy of unwanted modes is absorbed by use of resistive load material placed between the metal plates around their outer perimeter. It should be noted that bandpass filters using this type of resonator are not "leaky-wave" filters, since "leaky-wave" filters do not make use of cavity resonances (Reference 1). In contrast, trapped-mode filters use resonances in their pass band, and reflect energy at other frequencies. The energy absorbing material in trapped-mode resonators is used primarily to suppress unwanted cavity resonances.

A trial trapped-mode resonator using iris plates of the form in Figure 2(a) was found to give a disappointingly low unloaded Q as a result of small unwanted field components which were excited by the slot configuration. It was found that the use of irises having perfect circular symmetry such as the irises in Figure 3 would eliminate this difficulty. Using annular irises of these types, unloaded Q's of the order of 8000 were measured at X-band (Reference 2).

A Trial Four Resonator Filter. Figure 4 shows a trial four resonator bandpass filter which utilizes two conventional circular TE_{011}-mode resonators (Reference 3), and two circular TE_{011}-mode, trapped-mode resonators. The conventional resonators are placed at each end of the filter, and they serve as transducers from the rectangular TE_{01}-mode to the circular TE_{011}-mode, as well as serving as resonators. These resonators use tuning plungers which are backed with polyiron so as to help reduce some of their many spurious resonances (Reference 3). The two trapped-mode resonators in the middle of the filter serve both as resonators and as means for eliminating unwanted pass bands. The iris couplings between each conventional resonator on each end to the adjacent trapped-mode resonator make use of annular irises somewhat similar to that in Figure 3(b).

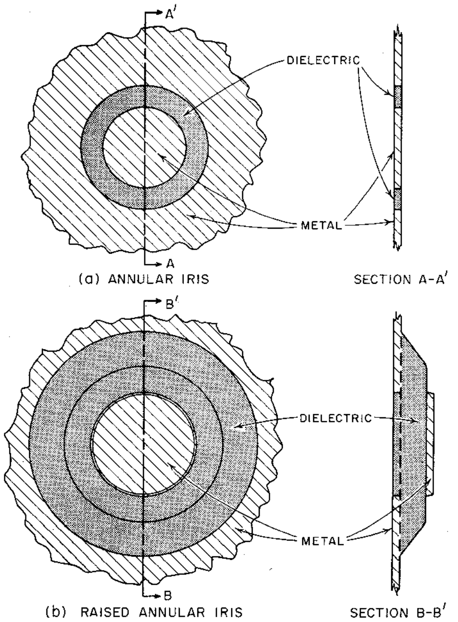

Figure 3. Two Annular Iris Configurations for Possible Use in Circular TE_{011}-Mode, Trapped-Mode Filters

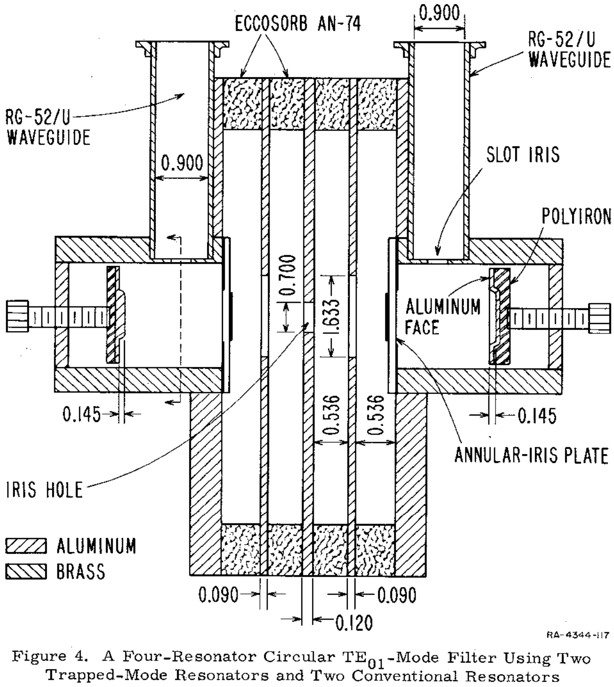

Figure 4. A Four-Resonator Circular TE_{01}-Mode Filter Using Two Trapped-Mode Resonators and Two Conventional Resonators

The coupling between the two trapped-mode resonators is achieved by a simple circular hole in the metal plate at the center of the filter. At the outer edge of the metal plates, Eccosorb AN-74 absorbing material is used to provide a load for energy radiated between the plates.

Initial tests on this filter were somewhat dissappointing in that the filter did have a number of spurious pass bands. However, it was discovered that these were primarily due to resonances in the conventional resonators, with the energy coupling directly from one of the conventional resonators to the other through the trapped mode resonator opening. In order to eliminate this difficulty, the faces of the tuning plungers of the conventional resonators were made to be dissimilar. This caused the higher-order resonances of the conventional resonator at the left end of the filter to occur at slightly different frequencies than the higher-order resonances in the conventional resonator at the right end of the filter. Separating the higher-order resonances of the two end cavities, along with the padding effect provided by the trapped-mode resonators in between, made possible very broad stop bands having high attenuation. The stop band attenuation was generally so high as to be unmeasurable with the equipment at hand, but at discrete points where some cavity resonances were attempting to develop, the attenuation did drop low enough to be measurable. In making tests from 7.4 to 22 gc, most detectable spurious responses had a minimum attenuation of approximately 60 db, while several up close to 22 gc had minimum attenuation of approximately 45 db. The minimum loss in the pass band was 2 db or less (depending on adjustments) and the 3-db bandwidth was approximately 13.5 mc. Of course, by designing for a larger bandwidth the minimum loss would be less.

Conclusions. The use of trapped-mode resonators in microwave bandpass filters was demonstrated to provide a means for obtaining a prescribed pass band, with very broad stop bands. It appears that by re-designing the conventional resonators at the ends of the filter so as to make their cavity proportions more dissimilar, the resonances in the conventional resonators could be further separated in frequency, and as a result the minimum stop-band attenuation could be maintained at an even higher level.

ACKNOWLEDGMENTS

The trial trapped-mode filter was constructed by Mr. C. A. Knight and Mr. Robert Pearce. The laboratory tests on the filter were performed by Mr. York Sato.

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