II-1. WIDEBAND INTERDIGITAL FILTERS WITH CAPACITIVELY LOADED RESONATORS*

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The interdigital filters described by Matthaei (Reference 1) consist of resonators formed by coupled-line elements that are λ/4 long at midband, with alternate ends of the coupled-line elements grounded, and the opposite ends open-circuited. It will be shown in this paper that the coupled-line elements can be made shorter than λ/4 at midband provided that loading capacitances are added at the open-circuited element ends. In addition to making the filter more compact in one dimension, capacitive loading has the advantage of moving the second pass band (that is, the first spurious pass band) even farther from the first pass band. The shorter the resonators are at midband, the wider the upper stop band, since the second pass band cannot occur until the resonators are somewhat greater than λ/2 long. The capacitively loaded version retains the other advantages of the version without loading, that is, the relatively large spacings between coupled-line elements permit relatively relaxed manufacturing tolerances, the rates of cutoff and strength of the stop bands are enhanced by multiple-order poles at zero frequency and between the pass bands, and they can be fabricated using little or no dielectric. The wide separation between first and second pass bands should make this filter type useful in parametric amplifiers and in frequency multipliers, the latter application has been demonstrated by Cuccia (Reference 2).

The arrangement of coupled-line elements, loading capacitances, and terminating admittances considered here is illustrated in Figure 1. The bars in Figure 1 represent the center conductors of

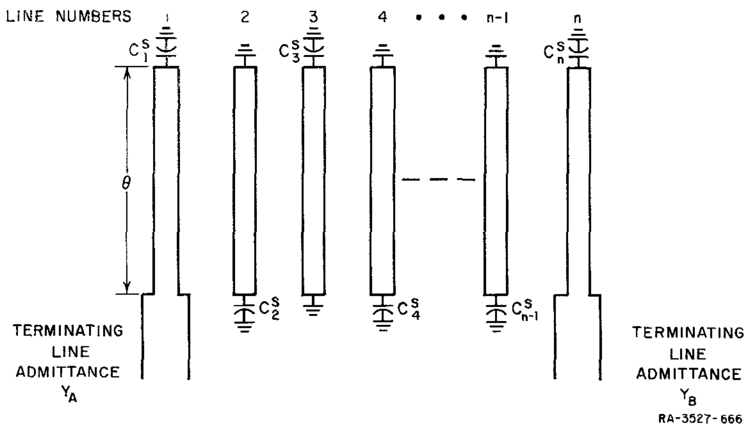

Figure 1. Capacitively Loaded Interdigital Filter with Ungrounded End Resonators

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TEM-mode transmission lines that are mounted midway between two ground planes that are parallel to the plane of the figure. Some forms that these center conductors could take are solid rectangular bars, as shown in the cross section of Figure 2, or circular bars or copper strips printed on both sides of a sheet of dielectric. The loading capacitances can be realized in any form that is most convenient for the intended application.

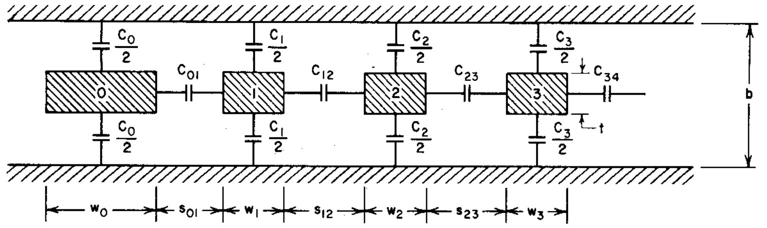

Figure 2. One Possible Cross Section of the Filter, and the Associated Capacitances

Design equations have been derived that give the mutual capacitances between lines, the self capacitances from the lines to ground, and the midband susceptances of the loading capacitances. Physical dimensions of the cross section of coupled lines can then be found using the curves of Getsinger (Reference 3) or of Cristal (Reference 4). The lengths of the coupled lines are set by the designer, subject to the restriction that they be less than $\lambda/4$ long at midband. The design equations are based on the low-pass prototype of Figure 3, whose element values are chosen to give the desired frequency response. The prototype is then modified to one in which all shunt capacitances are separated by admittance inverters (Reference 5) and then split into symmetrical sections. The open-wire-line equivalent circuit of the interdigital filter is also split into symmetrical sections. The image admittances and phases of the respective prototype and filter sections are then equated at certain key frequencies, following a method introduced by Matthaei (Reference 5). In deriving the design equations, no limitation was set on the bandwidth, but it is expected that, in practice, the equations will yield practical dimensions when the filter bandwidth is moderate (on the order of 30 percent) to wide (such as an octave). This is related to the fact that the end resonators in Figure 1 are not grounded (Reference 1).

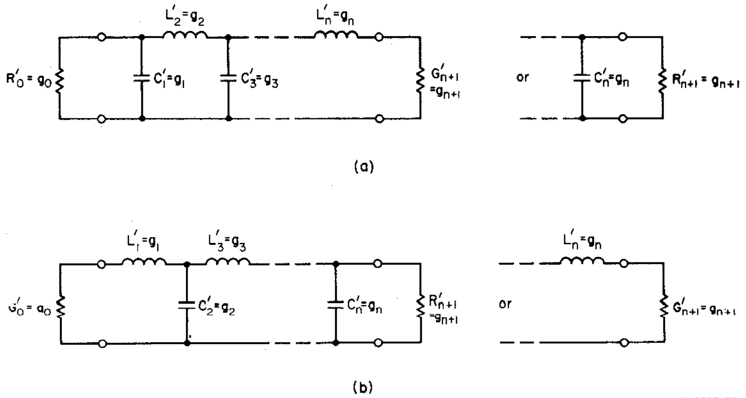

Figure 3. Low-Pass Prototype to which the Filter is Related by Means of the Design Equations

In order to verify the design equations, four different octave-bandwidth filters having $\lambda/8$ resonators were designed, and their frequency responses were calculated using an open-wire-line equivalent circuit. The best design was constructed using a printed-circuit technique, and is shown in Figure 4. The cross section of the coupled-line region is similar to Figure 2, except that only the top and bottom surfaces of each bar are metal, and the interior of each bar is the support dielectric. The loading capacitances were formed by extending the line elements into narrow grooves, with tuning screws provided on two resonators at each end of the filter. Adjustment was also provided for the spacing between the first and second, and between the seventh and eighth coupled-line elements.

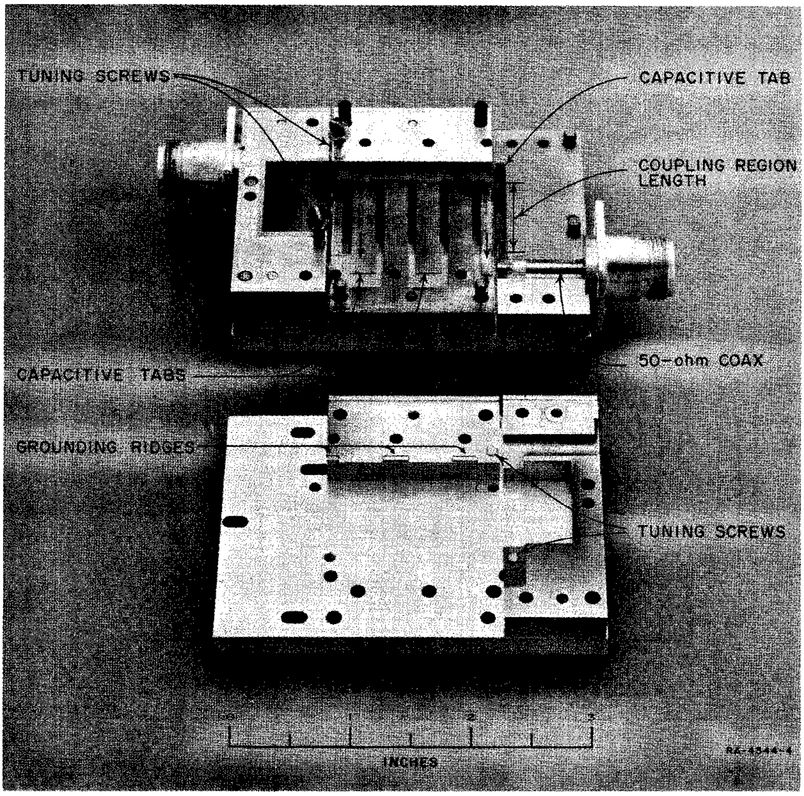

Figure 4. Photograph of the Capacitively Loaded Interdigital Filter

The calculated frequency response (neglecting dissipation loss) of the capacitively loaded interdigital filter is shown by the solid curves in Figure 5, and the measured performance is shown by the crosses and circles. If the pass band had arithmetic symmetry about the resonance frequency ω_o, the pass band would lie within $0.65 \leq \omega/\omega_o \leq 1.35$. The calculated curve shows some loss of bandwidth on the high-frequency band edge, and the measured data indicate slightly more loss of bandwidth.

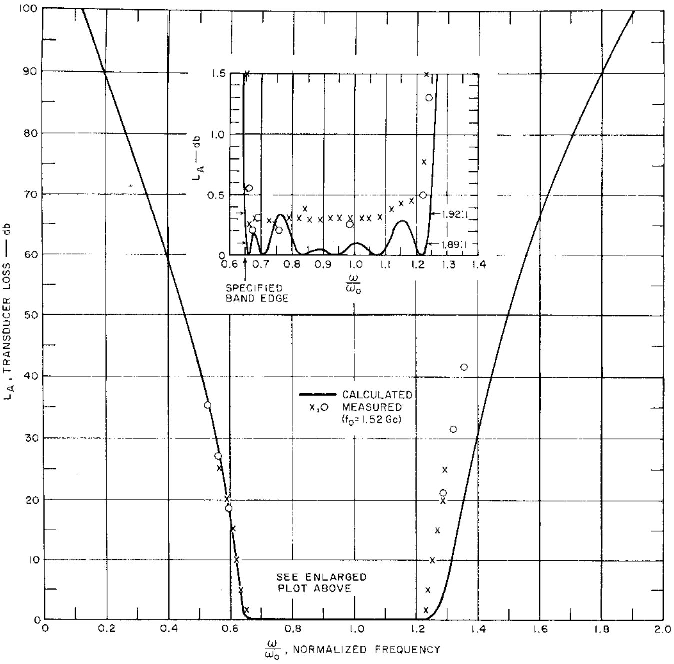

Figure 5. Calculated and Measured Attenuation of the Filter Shown in Figure 4

Also, if the filter faithfully reproduced the performance of the prototype, the ripple peaks in the pass band would not exceed 0.1 db. Most of the measured transducer loss within the pass band is due to dissipation loss, since the peak VSWR shown in Figure 6 produces only 0.1 db of transducer loss. The peak VSWR of the actual filter is less than predicted by the calculated curve in Figure 5, showing that normal tune-up procedures with swept-frequency generators can partially compensate for some of the approximations made in derivation of the design equations. The second pass band was calculated to be at $4.2 \leq \omega/\omega_0 \leq 4.5$, and measured at $4.1 \leq \omega/\omega_0 \leq 4.35$. No spurious responses were found between the first and second pass bands using swept-frequency recording equipment that could detect spurious responses with less than 45 db of transducer loss.

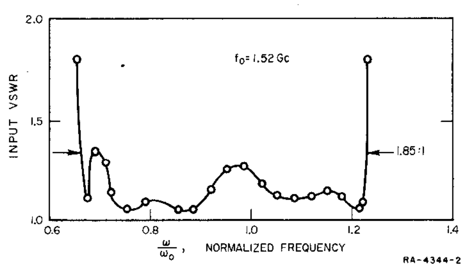

Figure 6. Measured VSWR of the Filter Shown in Figure 4

It is of interest to compare the performance of the filter discussed above with that of a previously reported octave-bandwidth interdigital filter without capacitive loading (Reference 1). It is found that the advantages of capacitive loading are gained at the expense of slight loss in control of the pass-band ripple, bandwidth, and center frequency. With experience however, it should be possible to predict and compensate for these effects. The capacitively loaded interdigital filter also bears some resemblance to the comb-line filter (Reference 6) except that the latter has all the ground points along the same side of the filter. For a given bandwidth, number of resonators, and resonator length, the spacings between coupled-line elements would be smaller in the comb-line configuration This would be a disadvantage in maintaining manufacturing tolerances, although the difference between filter types would be only slight for coupled-line lengths that are very small compared to wavelength. Furthermore, the design equations presently available for comb-line filters are limited to narrow bandwidths.

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