LOW LOSS LINEAR PHASE FILTERS

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Abstract

A new filter structure in which low loss linear phase filters can be realized is described. These filters are longitudinal and employ TE_{103} dual mode resonators. Experimental results of such a filter are presented and compared with results of equivalent fundamental mode Chebyshev and linear phase filters. These results demonstrate that such filters are suitable for multiplexers in satellite transponders operating above 10 GHz.

Introduction

The realization of a direct coupled cavity linear phase bandpass filter requires a filter structure which permits the cross coupling between its non-adjacent resonators. Existing waveguide structures capable of realizing these couplings are: (a) single mode "U" shaped[1,2], (b) dual mode longitudinal[3], and (c) dual mode "U" shaped[4].

In the above filters the type of response is determined by the sign of cross couplings. A negative sign results in optimum amplitude filters (elliptic), while a positive sign provides optimum phase filters (linear phase). In the linear phase filter function the transmission zeros produced by the positive cross couplings are either complex or on the real axis of the complex frequency plane.

It is the object of this paper to use the simple dual mode axial configuration for the realization of a low loss linear phase filter. This filter differs from the dual mode elliptic filter[3] in that it has all its coupling elements positive and employs high order TE_{103} resonators for the reduction of its insertion loss. Experimental results of this filter are presented and compared with the results of the TE_{103} dual mode Chebyshev filter. Additional results of dominant mode linear phase filters having single or multiple transmission zeros are also included and compared with results of the equivalent Chebyshev filter. All the linear phase filters described in this paper have equiripple passband and monotonic stopband attenuation.

The TE_{103} Linear Phase Filter Structure

The axial TE_{103} dual mode cavity structure subject of the above discussion is shown in Fig. 1. It consists of an array of square waveguide cavities supporting the TE_{103} mode and inductively coupled through their cross sections. Each cavity has an electrical length of 3π at the centre frequency of the filter. The sequential couplings M_{12}, M_{23}, M_{34}, etc., present also in the Butterworth and Chebyshev filters are provided by the 45° coupling screws, and the long coupling slots of the common walls between cavities.

The cross couplings M_{14}, M_{36}, M_{58}, etc., are obtained by the short common wall slots. Their positive sign is obtained by placing in line all the 45° coupling screws (zero phase difference between each other) along the length of filter. The electric field vectors of Fig. 1 show the two orthogonal TE_{103} modes along with their positive coupling signs indicated by the vector direction. If the number of physical cavities in this filter structure is odd, the input and output ports are rotated 90° otherwise have the same polarization.

The design procedure for the TE_{103} linear phase filters uses the approximation given in (1) and the equivalent circuit of (3) for the determination of the filter elements. TE_{103} filters require special attention in determining the cavity length and cross section, otherwise spurious modes will occur within the operating communications band. Details on the selection of the cavity cross section and unloaded Q's of the TE_{103} elliptic filters are given in (5).

Dominant Mode Linear Phase Filters

The TE_{103} linear phase filter is intended to meet stringent insertion loss specifications and should be used only if necessary. The same passband amplitude and group delay equalization can be achieved using cavities operating in fundamental TE_{101} or TE_{111} modes in the arrangement of Fig. 1.

In all the linear phase filters mentioned above there is optimum use of the cross couplings for passband equalization. Under such conditions the passband amplitude and group delay flatness reaches the limit of about 60% of the filter's bandwidth. A further increase of these couplings to extend the flat portion of the passband above this limit causes passband ripples and complicates the tuning of the filter. Note that increasing the percentage of the passband equalized causes a corresponding degradation in the stopband attenuation.

Most communications systems require filters with equalization over 30 to 40% of their passband. Such filters are obtained either by decreasing the cross coupling coefficient or the number of cross couplings.

The filter of Fig. 2 employs only one cross coupling and can provide flat bandwidths up to about 40%. This filter uses a combination of rectangular TE_{101} and dual TE_{111} cavities. The filter order is increased by adding equal number of rectangular waveguide cavities separated by inductive posts at each end of the two dual mode cavities. By doing so its symmetry is maintained with the cross coupling always at the centre. The use of the rectangular waveguide sections in the filter of Fig. 2 reduces the number of dual mode cavities and makes the manufacturing and tuning of this filter easier. An additional advantage of this filter is that its input and output ports have the same polarization independent of the filter order.

Experimental Results

Three dual mode linear phase filters having six poles and operating at 12 GHz are fabricated and evaluated. Photographs of these filters are shown in Figs. 3 and 4. Fig. 5 shows the measured passband return loss of the three prototypes. For comparison purposes all the filters are designed for a typical bandwidth of 80 MHz and return loss level of 26 dB (0.01 dB passband ripple).

Plots of the measured stopband attenuation, passband insertion loss and group delay of the TE_{103} linear phase filter are shown in Fig. 6. In the same figure the corresponding results of the TE_{103}, five and and six pole dual mode Chebyshev filters are also plotted. Realization of the five section Chebyshev filter is obtained using two dual mode end cavities and a rectangular single mode centre cavity.

The out-of-band attenuation of the linear phase filter is half way between the five and six pole Chebyshev filters. Its centre frequency insertion loss is 0.62 dB and is flat up to 60% of the filter's bandwidth. With the exception of a 0.2 nSec dip at the centre of the passband, the same flatness exists also in the passband group delay. The centre frequency insertion loss of five and six pole Chebyshev filters is 0.5 and 0.58 dB respectively. Additional results of the passband gain slope and band edge group delay of the three filters are shown in Fig. 6.

Test results of the TE_{111} and TE_{101}/TE_{111} dual mode linear phase filters are plotted in Fig. 7 along with the results of a TE_{111} dual mode six pole Chebyshev filter. The cross couplings of the two linear phase filters are optimized for maximum passband flatness with minimum group delay ripple. Measured values of the flat portion of the passband are 37% for the TE_{101}/TE_{111} filter and 60% for the TE_{111}.

The effect of the flat passband portion on the stopband attenuation is clearly demonstrated here by noting that the isolation of the TE_{101}/TE_{111} filter is close to that of the Chebyshev filter. The centre frequency insertion loss of the three filters is 0.84 dB for the Chebyshev, 0.9 dB for the TE_{111} linear phase and 0.95 dB for the TE_{101}/TE_{111}. Note that the higher insertion loss of the TE_{101}/TE_{111} linear phase filter is due to the rectangular cavities. More results of the three filters are in Fig. 7. All filters mentioned above are silver plated.

Conclusions

The use of positive cross coupling between non-adjacent TE_{103} dual mode resonators for the realization of low loss longitudinal linear phase filters has been demonstrated. The insertion loss improvement of the TE_{103} linear phase filter in comparison to the TE_{111} linear phase filter is 30%. Finally it was also shown that linear phase filters with one cross coupling provide sufficient equalization without increasing significantly the manufacturing cost.

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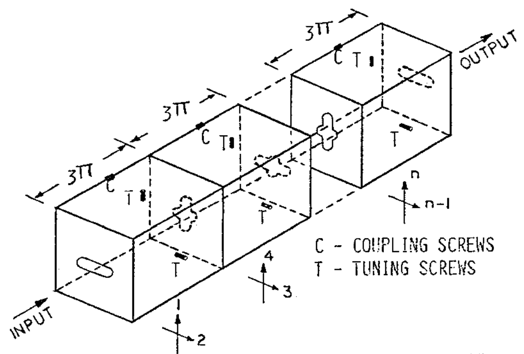
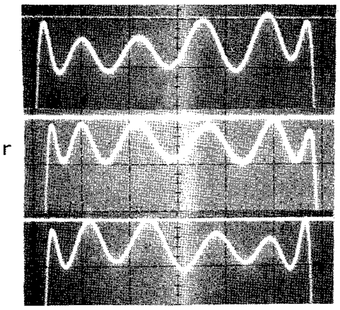


FIG. 1 TE_{103} LINEAR PHASE FILTER STRUCTURE

FIG. 5 Passband return loss of linear phase filters (log scale)

Top - TE_{103} filter
RL - 25.6 dB, BW 84 MHz
Center - TE_{101}/TE_{111} filter
RL - 26.4 dB, BW - 79 MHz
Bottom - TE_{111} filter
RL - 26 dB, BW - 80 MHz



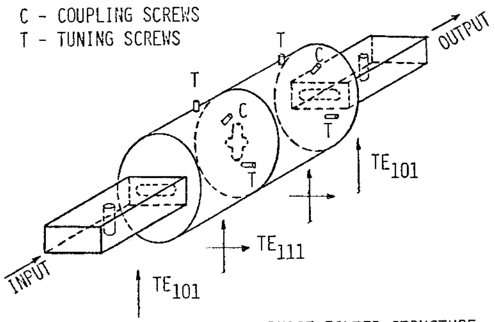
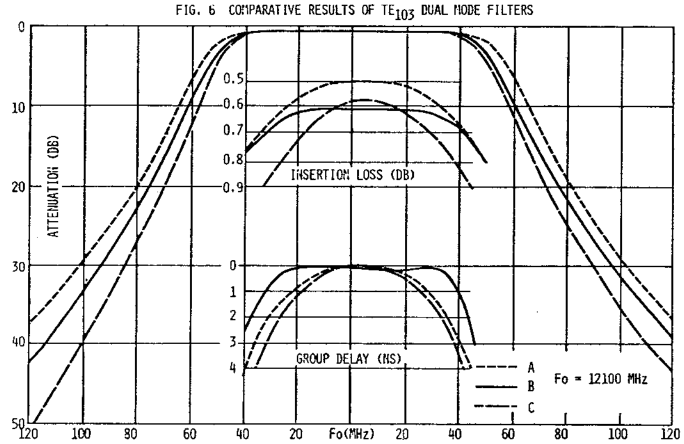


FIG. 2 TE_{101}/TE_{111} LINEAR PHASE FILTER STRUCTURE

FIG. 6 COMPARATIVE RESULTS OF TE_{103} DUAL MODE FILTERS



A - TE_{103} 5 POLE CHEBYSHEV FILTER, BW = 82.5 MHz, RL = 26.7 DB
B - TE_{103} 6 POLE LINEAR PHASE FILTER, BW = 84 MHz, RL = 25.6 DB
C - TE_{103} 6 POLE CHEBYSHEV FILTER, BW = 83 MHz, RL = 26 DB

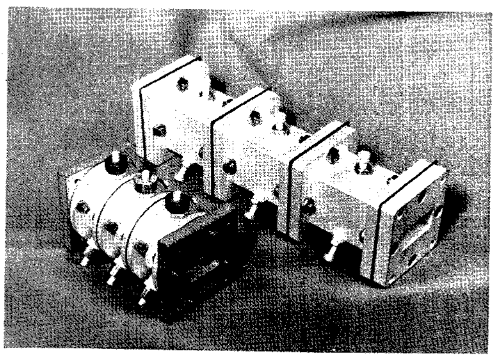
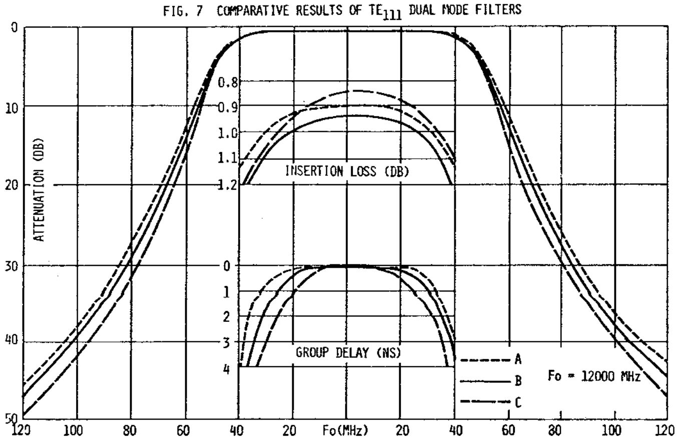


FIG. 3 12 GHz six pole TE_{103} and TE_{111} dual mode linear phase filters with two cross couplings.

FIG. 7 COMPARATIVE RESULTS OF TE_{111} DUAL MODE FILTERS



A - TE_{111} 6 POLE LINEAR PHASE FILTER, BW = 80 MHz, RL = 26 DB
B - TE_{101}/TE_{111} 6 POLE LINEAR PHASE FILTER, BW = 79 MHz, RL = 26.4 DB
C - TE_{111} 6 POLE CHEBYSHEV FILTER, BW = 81 MHz, RL = 25.5 DB

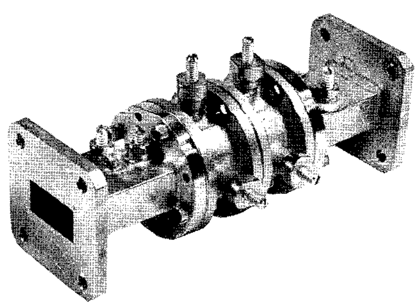


FIG 4 12 GHz six pole TE_{101}/TE_{111} linear phase filter with one cross coupling.