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SIMPLIFIED ANALYSIS OF INHOMOGENEOUS DIELECTRIC BLOCK COMBLINE FILTERS

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ABSTRACT

Dielectric block combline filters constructed of low - loss temperature stable high dielectric constant ceramic materials are used in very large quantities for mobile communications.

An inhomogeneous version having significant advantages in terms of achievable Q factor and symmetry of response characteristics was introduced by Fukasawa [2]. A new analysis of this structure which clearly depicts its novel aspects by giving a physically significant equivalent circuit is presented. In addition to improved understanding, the simplification could lead to wider utilization of such inhomogeneous structures and stimulate advances in the technology.

INTRODUCTION

The combline filter was introduced by Matthaei in 1963 [1]. The first section in this paper pointed out that it was necessary to foreshorten the resonators below 90° using lumped capacitors, else the filter would become an all-stop structure. This foreshortening reduces the unloaded Q.

Since the publication of the original paper there have been many others describing ancilliary improvements, e.g. various means of coupling into the combline structure, and introduction of transmission zeros. However all required the basic foreshortened resonator, until the publication by Fukasawa of a radically different coupling principle [2]. The new combline filter introduced is an inhomogeneous structure which allows the resonators to be fully one-quarter of a wavelength long. It may perhaps represent a new concept promising potential significant advances in the design and implementation of combline filters.

INHOMOGENEOUS COMBLINE FILTERS

The inhomogeneous combline filter is illustrated in Fig. 1. The filter consists of a dielectric block with resonators formed by circular holes which extend through the dielectric. All but one of the surfaces of the block and the interior of the holes are metallized, so that a combline filter structure is formed. The filter is normally cast in final configuration with no machining required (except possibly for housings and ancilliary mounting arrangements) and therefore represents a very inexpensive production method.

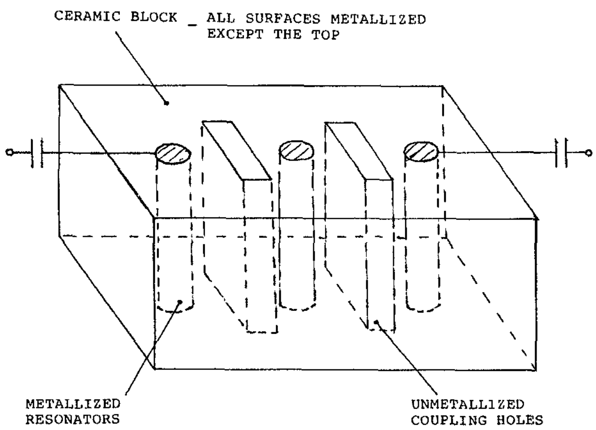

Fig. 1. Inhomogeneous combline filter.

The structure becomes inhomogeneous by the introduction of other unplated holes between each pair of resonators. The extra unplated holes have no effect on the magnetic field coupling, but reduce the electric field coupling. These couplings are of equal magnitude and of opposite sign in a homogeneous structure, and hence cancel to give an all-stop network, but in the inhomogeneous case the magnetic field coupling dominates, and a passband filter is formed.

THE EQUIVALENT CIRCUIT

The theory and results given in [2] appears somewhat incomplete and possibly subject to misinterpretation, which may cause difficulties in applying the new concept introduced. For example, the inter-resonator coupling coefficient should increase as the degree of inhomogeneity is increased, not reduce as shown in Figs. 8 and 12 of [2]. (However Fig. 14 of [2] does indicate the correct behaviour). It is unclear where the boundary conditions for the combline structure, i.e. short circuits at one end and open circuits at the other, have been applied.

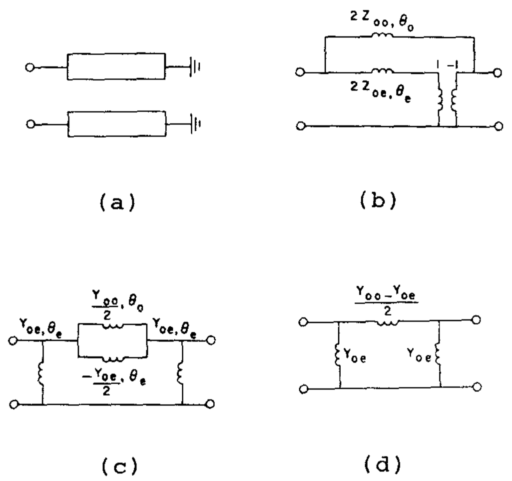

Fig 2. (a) A parallel-coupled pair of comblines, (b) Equivalent circuit of Zysman and Johnson, (c) later equivalent circuit, (d) the degenerate homogeneous equivalent circuit, $\theta_o = \theta_e$.

The object of this paper is to present a simple equivalent circuit for the inhomogeneous combline filter using the technique described in [3, 4]. To recapitulate, the equivalent circuit for a pair of inhomogeneous coupled lines, originally derived by Zysman and Johnson [5], was simplified by using a more appropriate set of extractions in the synthesis. The result for a pair of coupled-comblines is shown in Fig. 2, which gives also the Zysman and Johnson equivalent circuit and the homogeneous case for comparison. The inhomogeneous circuit of Fig 2(c) is obviously simpler than that of (b), degenerates naturally to the homogeneous commensurate circuit of (d) when $\theta_e = \theta_o$, and gives physical insight into the behavior to be expected from the inhomogeneous network.

It is reasonably obvious that the equivalent circuit for a set of n coupled-comblines should be represented by a simple extension of Fig 2(c), as indicated by the equivalent circuit of three resonators within the combline filter, as shown in Fig. 3. Here each resonator is represented by a short-circuited shunt stub of length 90^{o} at resonance. It is assumed that the resonators are of equal diameter, a desirable condition which is simple to achieve by applying the familiar admittance matrix transformations. This avoids asymmetric inhomogeneous analysis, which although feasible is an unnecessary complication. In Fig 3, for clarity the

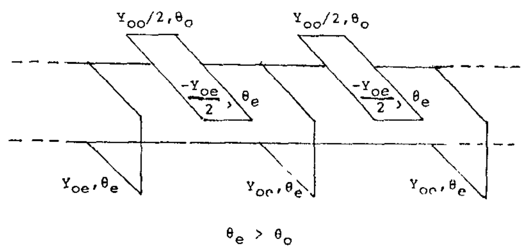

Fig. 3. Equivalent circuit of a portion of an inhomogeneous combline filter.

two inter-resonator couplings are shown as being equal, but of course this is not a requirement.

The characteristic admittance of each shunt resonator is given by Y_{oe}, the even mode admittance, with an electrical length equal to the even mode phase length, θ_e. Each coupling is represented by a pair of series short circuited stubs connected in parallel, one of admittance $Y_{oo}/2$ and length θ_o, the other of admittance $-Y_{oe}/2$ and length θ_e, as shown in Fig. 2(c). Note that there are no lumped capacitors in this ideal equivalent circuit, although in practice small fringing capacitors would be present. Actually small shunt capacitors may be introduced to provide admittance-inverter coupling, as described later.

This equivalent circuit degenerates to the all-stop circuit when $\theta_e = \theta_o = 90^o$ since then each pair of series stubs which form the couplings combine giving a single stub of admittance $(Y_{oe} - Y_{oo})/2$, which becomes a series open circuit when $\theta = 90^o$. However with inhomogeneity, θ_o is less than θ_e, and the open circuit condition at the resonant frequency of the shunt stubs no longer occurs. Actually the even mode series stub does become an open circuit in series with the main line at resonance, but it is shunted by the odd-mode stub, which is inductive at that frequency, hence giving finite coupling.

Given this equivalent circuit, evidently the design equations for combline filters may be modified in order to incorporate the inhomogeneous case. Of equal importance is the physical insight given by the new circuit.

ADVANTAGES OF THE INHOMOGENEOUS FILTERS

It is well known that the Q of a resonator decreases with increase of capacitive end loading if the capacitor Q is larger than the Q of the coaxial line [6]. Since the resonators of the inhomogeneous combline filters may be substantially equal to the maximum 90^o length, the Q is maximized.

A second advantage is the more symmetrical insertion loss characteristic of the inhomogeneous combline filter, due to :-

(a). The 90^o electrical length of the resonators, giving symmetrical behaviour around the resonance frequency, and

(b). The transmission zeros always present in homogeneous combline filters caused by simple series inductive stubs are modified in the double-stub inhomogeneous circuit.

Experimental observation of this improved symmetry is given in Fig. 15 of [2], which depicts the characteristic of a 7-section combline filter at 850 MHz having an equi-ripple bandwidth of ± 18 MHz. The 35 dB points are symmetrically disposed at 850 ± 30 MHz about the mid band frequency. On the other hand a homogeneous combline filter having resonators foreshortened to 60^o has attenuation of 33 dB at 820 MHz and 43 dB at 880 MHz.

Theoretical results given later in this paper appear to indicate less symmetry for the case of full half-wavelength resonators, although the general trend to better symmetry in the inhomogeneous structure is well established.

THEORY

Designs suitable for narrow bandwidths may be obtained using the standard admittance inverter approach. Referring to Fig. 3, if θ_e is 90^o at mid band then the coupling is by means of a series stub of admittance $Y_{oo}/2$ and electrical length θ_o. Since Y_{oo} is quite large, θ_o can not be much less than 90^o, since the coupling would become too tight. The lower limit on θ_o for a filter of 5% bandwidth is around 86^o, but this is sufficiently different from 90^o to produce a pass band, as shown in the design example.

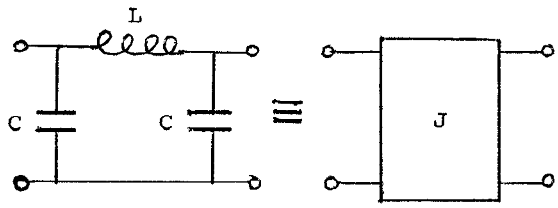

Fig. 4. Admittance Inverter.

$$LC\omega_o^2 = 1$$

The series stub coupling may be converted to an admittance inverter by adding shunt capacitors at either end to form a Pi network having the appropriate admittance and with 90^o phase shift at the mid band frequency, as indicated in Fig. 4. The condition for the Pi network to be an admittance inverter is

$$LC\omega_o^2 = 1 \qquad (1)$$

The alternative procedure of introducing extra negative shunt inductors is difficult since it requires an increase in the lengths of the existing shunt stubs, which have been set equal to 90^o. However there is no reason why this method could not be used for slightly foreshortened resonators having extra lumped capacitive tuning.

EXAMPLE

The example in Fig. 5 compares 3-section homogeneous and inhomogeneous filters at f_o = 850 MHz having .05 dB equi-ripple bandwidths of 38 MHz. The inhomogeneous filter has $\theta_e = 90^o$ and $\theta_o = 87^o$, and displays two finite frequency stop band poles at 985 MHz and 1550 MHz. The first pole occurs when the coupling admittances becomes zero, i.e. when

$$Y_{oe} \cot \theta_e - Y_{oo} \cot \theta_o = 0 \qquad (2)$$

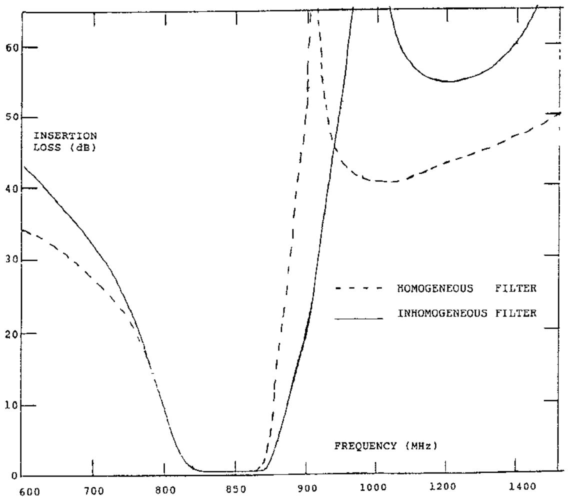

Fig. 5. 3-section 90^o inhomogeneous filter compared with an 85^o homogeneous design.

which for the mid band electrical lengths stated above and $Y_{oo} / Y_{oe} = 1.5$ occurs at a frequency of 1.16 f_o, i.e. considerably above the passband.

The second pole is at approximately $2f_o$, where the shunt stubs behave like band stop resonators.

This filter is compared to a homogeneous design of the same bandwidth with $\theta = 85^o$, which places the pole close to the pass band without destroying it. The inhomogeneous filter demonstrates stop bands with improved symmetry about the mid band frequency.

CONCLUSIONS

A simple equivalent circuit for inhomogeneous combline filters is presented, giving a clear physical picture of the properties of the structure, and enabling analysis and synthesis to be carried out. A simple theory for combline filters having full quarter-wavelength resonators was outlined. It would be interesting to carry out a more detailed synthesis and analysis for inhomogeneous combline filters having somewhat shorter resonators, e.g. 60^o, to quantify the expected improvement in response symmetry.

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