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SYNTHESIS OF LOW-PASS ELLIPTIC FILTERS FOR MIC AS A CLASS OF NON-COMMENSURATE DISTRIBUTED CIRCUITS

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SUMMARY

A new synthesis technique of low-pass elliptic filters particularly suited for realization in printed circuit version is presented. The synthesis is based on the use of non-commensurate transmission line sections and stubs. Microstrip filters of seventh order with cutoff frequency in the X-band have been fabricated and measured in the frequency range 2-18 GHz. The performance is shown to be quite satisfactory particularly in the pass-band.

INTRODUCTION

Low-pass filters with elliptic-function response allow very high selectivities to be achieved with a reasonable number of elements, thus offering substantial size advantages over other low-pass filter forms.

A new design technique is presented in this paper using non-commensurate transmission line sections and stubs. The filters are particularly suited for realization in printed circuit version for microwave applications. The presence of unwanted reactances and of parasitics due to discontinuity effects, which make necessary adjusting procedures in other synthesis techniques [1], are highly reduced by means of a proper choice of the characteristic impedances of the transmission line lengths of the filter.

The experimental behavior of a seventh-order elliptic filter with 8 GHz cut-off frequency realized in microstrip version is illustrated in the frequency range 2-18 GHz. The performance is shown to be quite satisfactory particularly in the pass-band.

SYNTHESIS METHOD

Fig. 1 shows the schematic of the distributed-element filter consisting of m cascaded line sections with m + 1 parallel stubs. Such a structure has been extensively studied in the case of commensurate lines; in this case only 2m + 1 free parameters are usable for synthesizing the filter, i.e. one half of the 2 (2m + 1) parameters defining the entire structure. The present synthesis method is based on the use of non-commensurate lines with the condition that each stub has the same characteristic impedance as one of the contiguous lines.

Besides increasing the number of degrees of freedom to 3m + 1, this has the important consequence that each line length together with the contiguous stubs having the same characteristic impedance can be realized as a single transmission line element, so reducing the number of discontinuities. Moreover, as will be shown next, the structure has a low frequency equivalent model exactly coincident with that of a lumped low-pass elliptic filter.

In order to demonstrate this point, let us analyze as a single two-port network the set constituted by a transmission line length and the contiguous stub(s) having the same characteristic impedance. Two configurations are possible depending wheter only one (a) or both (b) the stubs connected to the line have the same impedance Z_0, as illustrated in fig. 2a and fig. 2b, respectively. With reference to the general scheme of fig. 1, it is evident that the case (b) occurs only in one case, while the case (a) occurs m - 1 times.

In the case (b) (fig. 2b), the impedance matrix is given by

$$[Z] = \frac{-jZ_0}{\sin\beta l} \begin{vmatrix} \cos\beta l_1 \cos\beta(l_2 + l_3) & \cos\beta l_1 \cos\beta l_2 \\ \cos\beta l_1 \cos\beta l_2 & \cos\beta(l_1 + l_3)\cos\beta l_2 \end{vmatrix} \quad (1)$$

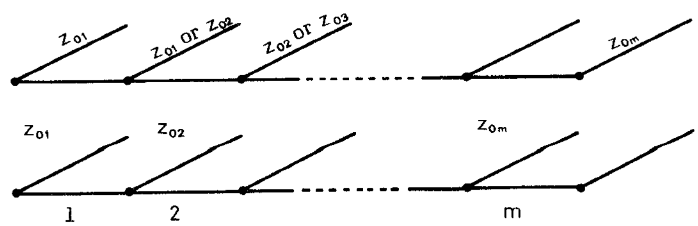

Fig. 1
General scheme of distributed-element filter

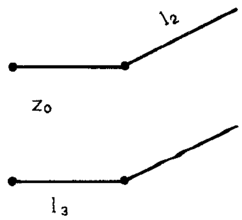

Fig. 2a
Distributed cell with one stub

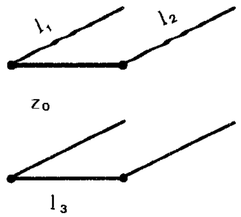

Fig. 2b
Distributed cell with two stubs

where $\beta = \omega / c$ is the propagation constant and $l = l_1 + l_2 + + l_3$.

The partial fraction expansion of the above matrix is

$$[Z]=\frac{jZ_0 c}{l}\sum_{m=0}^{\infty}\frac{\delta_m\,\omega}{\left(\frac{m\pi c}{l}\right)^2-\omega^2}\begin{vmatrix}\cos^2\frac{m\pi l_1}{c} & (-1)^m\cos\frac{m\pi l_1}{c}\cos\frac{m\pi l_2}{c}\\ \ldots\ldots & \cos^2\frac{m\pi l_2}{c}\end{vmatrix} \qquad (2)$$

with $\delta_m = 1$ for $m = 0$ and $\delta_m = 2$ for $m \neq 0$.

It is interesting to observe that the above series expansion corresponds to a resonant mode expansion of currents and voltages in the distributed structure; such a technique has been used for deriving lumped element equivalent circuits in the more general case of two-dimentional microwave structures [2].

An equivalent circuit of the structure in fig. 2, which is valid in the lower frequency range, is obtained by retaining in (2) only the first two terms, i.e. considering the poles at $\omega = 0$ and $\omega = \pi c/l$. It can be easily seen that, under such an approximation, the equivalent circuit of fig. 3 is obtained, where

$$C_1 = \frac{1}{Z_0\, c}\cos\left(\frac{\pi l_2}{c}\right)/ A \qquad (3)$$

$$C_2 = \frac{1}{Z_0\, c}\left(\frac{1}{2} - \cos\frac{\pi l_1}{c}\cos\frac{\pi l_2}{c}\right) / A^2$$

$$C_3 = \frac{1}{Z_0\, c}\cos\frac{\pi l_1}{c} / A$$

$$L_2 = \frac{2 Z_0 l}{\pi^2 c} A^2 \;;\; A = \cos\frac{\pi l_1}{c} + \cos\frac{\pi l_2}{c}$$

The case (a) can be obtained from the (b)-one, putting $l_1 = 0$; its equivalent

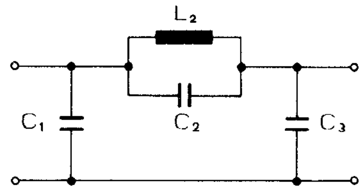

Fig. 3
Equivalent circuit of the distributed cells

circuit is still that of fig. 3, but with the following constraint on the values of the three capacitances:

$$C_1 = \frac{C_3}{2}\,\frac{C_3 - 2C_2}{C_3 + C_2} \qquad (4)$$

The equivalent circuit of the entire structure of fig. 1 consists of the cascade of m elementary sections of the type of fig. 3, and thus has the same structure as a low-pass elliptic filter of order $n = 2m + 1$. This permits a direct synthesis procedure of the distributed filter starting from the values of the lumped element prototype quoted in the tables [3].

The synthesis of a n-th order (n odd) low-pass elliptic filter proceeds along the following steps:

1) identify the m sections of the type of fig. 3 from the prototype, using relation (4) iteratively for the first $m - 1$ sections;
2) synthesize the first $m - 1$ sections, as distributed elements of fig. 2a;
3) synthesize the last section, as a distributed element of fig. 1b.

EXPERIMENTAL RESULTS

Fig. 4 shows the theoretical and experimental behaviors of the scattering parameter $|s_{12}|$ of a 7-th order filter realized in the microstrip version, with 8 GHz cut-off frequency in the frequency range 2 - 18 GHz. The theoretical results have been obtained following [4]. For comparison, the lumped prototype behavior is also shown. The geometry of the microstrip structure is sketched in the same figure. It is worth specifying that in the microstrip synthesis of the filter, account has to be taken of the finite widths of the elements [5], which leads to some sligth modifications of the synthesis formulas valid in the ideal case of fig. 1.

As can be seen the filter performance differs from that of the lumped prototype because of the presence of a pseudo pass-band at about 15 GHz. As is known, this is a typical behavior of microwave structure; however, the use of non-commensurate line sections makes the second pass-band quite different from the first one.

The pass-band behavior is quite satisfactory; the differences between the prototype and the theoretical characteristics are due to the excitation of higher order modes. The partial disagreement between the analysis and the experiment has to be ascribed to the excitation of surface waves, to ohmic and radiation losses and to the well known dispersive behavior of microstrip structures.

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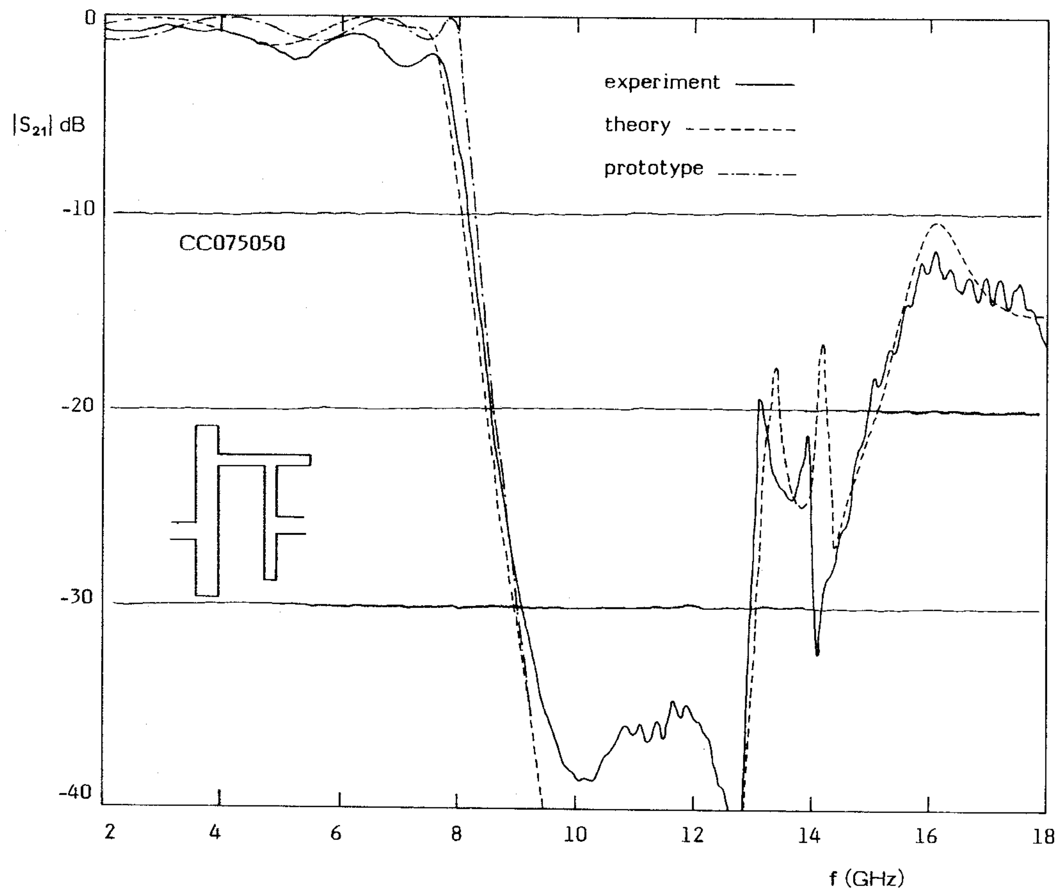

Fig. 4
Theoretical, experimental and prototype behaviors of an elliptic filter CC.07.50.50, with the sketch of the geometry of the microstrip structure