FILTER REALIZATIONS WITH FIN-LINES

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Abstract

The potentials of various circuits are compared for realizing fin-line bandpass filters. These include conductive strip, notch, post coupled resonators and sections of bilateral embedded into a unilateral fin-line. Some results on bandstop filters are also presented.

Introduction

Fin-line bandpass filters are usually realized as shown in Fig.1a: Conductive strips of suitable length bridge the fin-line slot at distances of about half a wavelength thus performing coupling between the transmission resonators. The slot width usually equals the waveguide height in order to minimize insertion loss. Such filter structures have recently been treated in numerous publications /1-6/, so that their design and performance is now well known.

This contribution deals with alternative fin-line structures for both bandpass and bandstop filters in order to characterize their essential features. Their slot patterns are listed in Fig.1. In the case of bandpass filters (Fig.1a-1f), the main difference is the type of discontinuity used as coupling two-port between the resonators. Bandstop filters can be realized by the structures shown in Fig.1e and 1g. We will show how to design these filters and compare their performance.

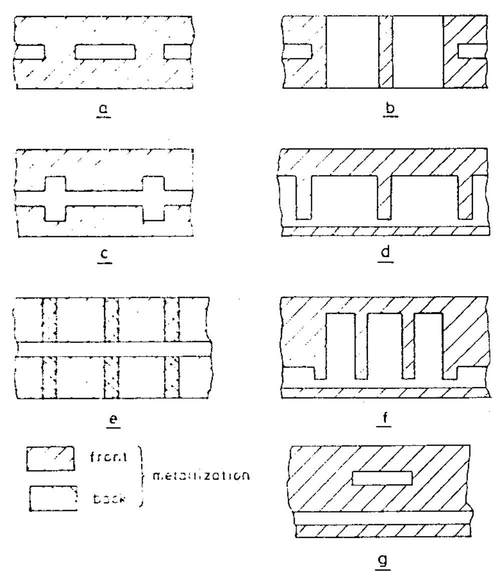

Fig.1

Slot patterns of various fin-line filters
a-e: bandpass filters, f: "lowpass filter", e+g: bandstop filters

Bandpass filters with half-wave resonators

Their slot patterns are shown in Fig.1a-1d. The circuit of Fig.1b is a generalization of that in Fig.1a by allowing for input/output ports with slot widths which differ from those of the resonators. Alternatively to a conductive strip, the coupling two-port may be realized by either a notch (Fig.1c) or a post (Fig.1d). All these types of filters are designed in the following way: The first step is to characterize the coupling discontinuity by both its equivalent circuit for the fundamental wave and its scattering matrix also including evanescent-modes.

The procedure (known as 'modal analysis' /7/) is to expand the fields at either side of the junction between two fin-lines of different cross sections into their eigenmodes whose amplitudes are then determined from matching the tangential field components at the interface. Two cascaded junctions mounted back to back can thus be described as is explained in detail elsewhere /8/. In the second step, the well-known filter design method of /9/ is applied after prescribing the response curve and the number of resonators. A K-inverter network is extracted from the equivalent circuit of the coupling two-port and cascaded with the fin-line half-wave resonator etc.. The design is straightforward, it neglects, however, higher-order mode coupling between the individual resonators. This can be taken into account in the final step, where an optimization computer program is used which varies the dimensions of all discontinuities until the prescribed response curve is best approximated. For this step, the coupling two-port is described by its scattering matrix. The procedure is similar to those used in /5,6/. Due to the preceding step by which good initial values can be obtained, its convergence is fast.

The fin-line eigenmodes have in all cases been obtained from a spectral domain approach according to /10/.

The equivalent circuit elements of some of the coupling two-ports of Fig.1 have been plotted versus the length of the coupling section in Fig.2. The results are valid for a bilateral fin-line on RT-duroid 5880 substrate ($\varepsilon_r = 2.22$). For convenience, the discontinuities have been represented by a shunt susceptance with two adjacent transmission lines of length l'. The shunt sus-

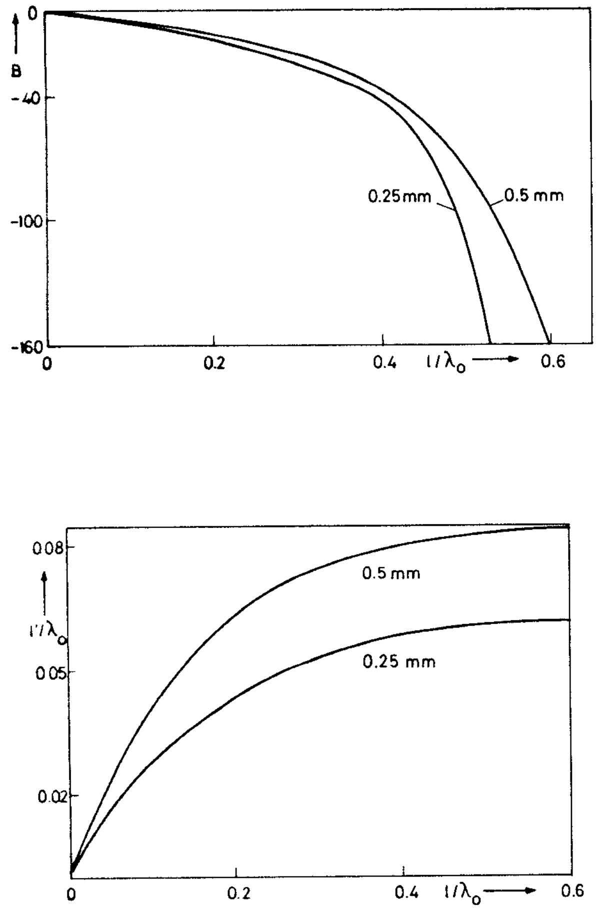

Fig.2a

Shunt susceptance and equivalent line length of a conductive strip versus length at 32 GHz
Parameter: Slot width

ceptance of the conductive strip is of course purely inductive (Fig.2a). It rapidly increases versus the length l so that it is difficult to achieve an extremely loose coupling and thus extremely narrow bandwidth. The post and notch discontinuities show nearly dual equivalent circuit elements which vary almost periodically with length (Fig.2b). Different to the conductive strip, they vary smoothly with length. Hence tolerance problems in filter design and realization are not so stringent. On the other hand, the maximum shunt susceptance which can be realized is in the order of 1 to 10 depending on the slot width ratio. Hence these structures are only suited to realize bandpass filters with at least medium bandwidth. - Fig.2c finally illustrates that the frequency dependence of the equivalent circuit elements is but smooth.

When judging on the potentials of the presented discontinuities for realizing bandpass filters one has the following criteria: Does there exist a maximum/minimum bandwidth which can be realized? What about the sensitivity of the response curves with respect to dimensions? Are there differences in transmission loss? Does higher-order mode coupling between the coupling sections influence the design? The first two questions can be answered by comparing various numerical results of which examples have been given in Fig.2. One can conclude that the slot pattern of Fig.1a is superior to all others for the realization of bandpass filters if the slot width of the half-wave resonators is chosen to be equal to the waveguide height. This simultaneously minimizes the transmission loss as can be concluded from measurements. Hence practical fin-line bandpass filters can always be designed by either the simple procedures presented in /1,2,4/ which neglect any higher-order mode coupling, or by the rigorous methods presented in /5,6/ which take this type of additional coupling into account. Moreover, these latter methods show excellent agreement to measurements.

In order to give an impression on the effect of higher-order mode coupling, we have calculated some of the field amplitudes a quarter of a wavelength apart from the coupling sections. While the reflection coefficient of the fundamental mode is 0.26, the corresponding values for the higher-order modes are 0.013 (2nd mode), 0.00008 (3rd mode), 0.0003 (4th mode), 0.00003 (5th mode), 0.0002 (6th mode) in case of a step in slot width from 1.0 to 0.4 mm at 30 GHz. Hence higher-order mode coupling between different resonators is negligible for notch/post structures.

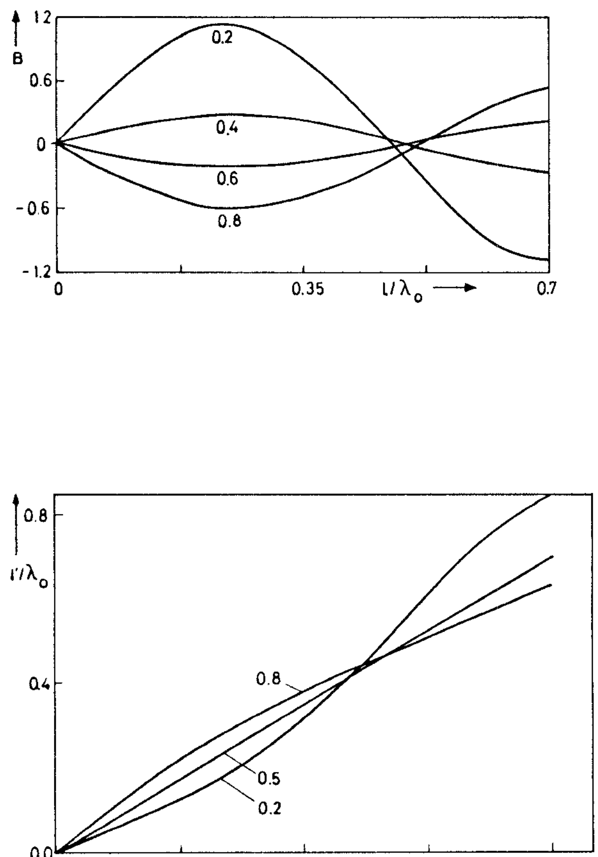

Fig.2b

Shunt susceptance and equivalent line length of strip or post, respectively, versus length at 35 GHz. Slot width at ports is 0.5 mm.
Parameter: Slot width of strip/post in mm.

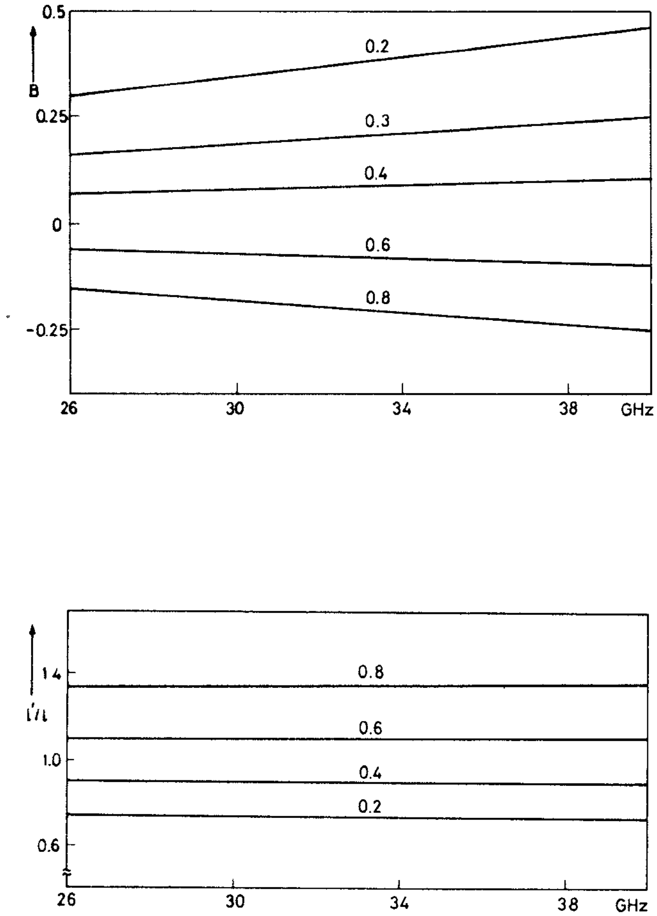

Fig.2c

Shunt susceptance and equivalent line length of strip or post, respectively, versus frequency. Length of strip /post is 0.5 mm.
Other parameters as in Fig.2b.

We have designed and realized bandpass filters with all types of discontinuities: conductive strip, notch, and post. The agreement between theory and measurement was good except for a shift in center frequency of about 100 to 300 MHz. In all cases, the measured center frequency was lower than its theoretical values. We attribute this effect to the influence of the slit in the waveguide housing which has been used for mounting the substrate.

Bandpass filters without half-wave resonators

The structures discussed so far have been designed following guidelines given in /9/. The circuit is composed of half-wave resonators coupled by K-inverters. There is, however, one discontinuity in fin-line which enables a filter design without the need for half-wave resonators: a section of bilateral fin-line embedded into a unilateral fin-line. It is shown in Fig.1e. Its equivalent circuit has been derived in /11/ using a modal analysis and applied to designing a pin-diode switch. The discontinuity is, however, also suited to realize a bandpass filter. This can be understood from the frequency plots of the circuit elements of an equivalent T-circuit which are given in Fig.4 of /11/. Both series reactance and shunt reactance show a pole at the same frequency if the slot width is properly chosen. The equivalent circuit can be reduced to a parallel circuit in shunt to the transmission line, because the shunt reactance is equal to twice the series reactance. This means that the discontinuity itself can be used as a resonator presenting the following advantages:

1) The length of the bilateral fin-line section is relatively small at resonance, so that the circuit losses are small, too.
2) The K-inverter is now realized by a quarter-wave unilateral fin-line thus reducing again overall length and losses.

A circuit which has been called a "lowpass filter" in literature is shown in Fig.1f. It consists of a cascade connection of notches and posts with equivalent circuit showing series inductances and shunt capacitances. It does of course not represent a real lowpass filter but shows a finite lower cutoff frequency. The circuit can be utilized to realize a broadband bandpass filter whose bandwidth is in the range of some 10 per cent. Analyzing the circuit of Fig.1f turns out to be very computer time-consuming because about 20 higher-order modes interact between single steps in the slot width. Up to now we have designed a filter with two notches and one post with 20 per cent bandwidth and a measured insertion loss in between 1.0 and 1.5 dB.

Bandstop filters

These filters have been realized by either using the circuit shown in Fig.1g or by modifying the slot pattern of Fig.1e. In the first case, a second slot is coupled to the main fin-line. It is approximately half a wavelength long. Then both an even and an odd mode may exist in the two-slot fin-line. They have been calculated according to /12/. The bandstop filter design then proceeds in the same way as for a bandpass filter. - A similar approach leads to the realization of a bandstop filter by means of embedding half-wave sections of bilateral fin-line into a unilateral fin-line (Fig.1e). If the slot width is suitably chosen, the first higher-order mode (HE_{20}-mode) of the bilateral fin-line shows a cutoff frequency which falls well into the normal waveguide band (e.g. $f_{c20} \approx 30$ GHz for Ka-band waveguide and slot width of 0.6 mm). The reaction cavity of a bandstop filter can hence be realized by the half-wave resonance of this mode. The filter design again proceeds in the same way as described above. More than 30 dB attenuation have been achieved for a 3-resonator filter using the structure of Fig.1g and about 15 dB for a single resonator with the structure of Fig.1e.

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