SUB-MINIATURE, MICROWAVE PRINTED CIRCUIT FILTERS WITH ARBITRARY PASSBAND AND STOPBAND WIDTHS

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ABSTRACT

New classes of sub-miniature, microwave printed circuit filters whose passband and stopband widths may be independently specified are defined for realisation in triplate stripline. They are exceedingly small and highly selective devices suitable for use in the 1-20 GHz frequency range.

INTRODUCTION

In general, filters for microwave receiver systems need to be highly selective, broadband devices whose passbands and stopbands can be independently specified and, most importantly, whose phase and amplitude characteristics are closely consistent within batches of the same device. Two new classes of bandpass filter will be described which together largely cover these requirements. They are printed circuit devices to give the necessary performance tracking, and are constructed in triplate stripline to keep the cost of manufacture to an absolute minimum.

The printed circuits take the form of a collection of directly and capacitively coupled lengths of transmission line, included in which are a number of planar, lumped capacitors. In contrast to most existing types of distributed microwave filters, the transmission lines are a quarterwavelength at a predetermined frequency above the passband of the filter. It is this which is responsible for the freedom of independent specification of the passband and stopband. The resultant filter is also exceedingly small and easy to fine-tune during its design phase. Filters can be constructed in triplate for passband widths in the range 10%-100% with stopband widths which correspond to the specification of the next higher order passband at 7 times the centre frequency of the first.

The filters are derived from two new classes of prototype which have bandpass frequency characteristics in the S-plane. They are pseudo-elliptic prototypes and are synthesised with the required frequency characteristics using what are now well established exact design procedures[(1),(2)]. To the designer without specialist experience, the complexity of these procedures need be of concern no longer now that suitable software is becoming commercially available.

A number of experimental devices have been constructed to demonstrate the many and considerable advantages of the new classes of filter. All the devices were highly successful and comfortably met their design objectives.

PROTOTYPE CLASSIFICATION

The design of most microwave/distributed element filters involves the derivation of a lumped element S-plane prototype. These prototypes are invariably generalised reactive ladder networks, consisting of series and shunt reactance branches and unit elements. Two important criteria apply to all the prototypes and these are 1) they must relate directly to a physically realisable distributed network and 2) the distributed network to which they relate must have the required frequency response. Although as previously explained, the synthesis of S-plane ladder networks with prescribed transfer characteristics is now comparatively easy, few classes of network actually exist which satisfy both the above criteria over a useful range of electrical specifications. The two versatile classes that have been found are therefore valuable discoveries. The basic composition of reactive ladder networks can always be prescribed by the number and location of the transmission zeros in the S-plane. There may be an infinity of variations in the structure of the network when redundant elements are used or when the sequence of elements is allowed to change, but the minimum number of elements and their types is fixed by the zeros. Consequently, for each zero of transmission specified on the jw axis there will be at least one shunt or series reactance branch in the network which has a zero of reactance or susceptance. Similarly each half order zero specified at S = 1 on the real axis will correspond to at least one unit element. An essential part of the classification of S-plane prototypes must be a definition of the distribution of transmission zeros.

To achieve the facility of independent specification of passband and stopband widths in real filters, the new classes of prototypes have bandpass(BP) characteristics. The periodic bandpass characteristics in the real frequency plane(i.e. the f-plane) are transformed into a single BP characteristic on the jw axis of the S-plane using the Richards[(3)] transformation where:-

$$S = j\tan(\pi f/2f_s)$$

and where f_s is the centre frequency of the stopband. f_s is also the frequency at which all the distributed elements of the filter are a quarterwavelength and this is the principal reason why such small devices can be constructed since f_s may be at some considerable frequency interval above the passband. If the centre frequency of the first 'secondary' passband is a multiple m of the centre frequency of the main passband, then f_s is given by $f_s = f_o(m + 1)/2$, where f_o is the centre frequency of the main passband. For a fixed passband width, adjusting the value of m therefore effectively adjusts the width of the stopband. The transformation also converts distributed elements such as short circuit stubs, open circuit stubs and interconnecting lines into inductors, capacitors and unit elements respectively.

In constraining the basic structure of the prototypes, certain important considerations have to be made concerning the structure of the printed circuit filter. A printed circuit filter in triplate should be composed of sections which are as simple as possible and therefore sections consisting of multiple capacitively coupled strips for example should be avoided. The number of different types of section should be kept to a minimum and the sections should as far as possible be separated by commensurate lengths of 'through' transmission line. These physical characteristics enable an error in the performance of a prototype filter to be associated with either a particular element or a number of elements of the same type, and the necessary modifications can be made with a high degree of confidence. They also ensure that the most reliable models for stripline elements are employed. In addition to keeping the circuit simple, it must not contain short circuits since these are inconvenient and difficult to make. Finally, since a high degree of selectivity will be required of the filter, the circuit should contain elements which force the insertion loss to tend to infinity at frequencies close to each passband edge.

In order to separate the filter elements as required, it is clear that the S-plane prototype must contain roughly equal numbers of unit elements and reactive elements. In terms of transmission zeros this suggests that the number of zeros on the jw axis should be roughly equal to the number specified at S = 1. It has also been found that this helps to keep the dynamic range of element values small. Secondly, to

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avoid short circuits and corresponding shunt inductors in the prototype, only a single zero of transmission may be specified at S = j0. Thirdly, if equal numbers of finite non-zero transmission zeros are placed at single frequencies on each side of the passband, the corresponding elements in the prototype are most likely to be not only of the same type but also to have similar numerical values. After considering a large number of combinations of transmission zero locations and observing all the necessary constraints, the two new classes of prototype emerged. They are designated A and B and are shown in Figs. 1 & 2. Each is an alternating cascade of the basic sections also shown in the figures, and each has a clearly prescribed set of transmission zeros. For the Class A prototypes, the set is as follows:-

zeros at $S = j0$: 1 zeros at $S = j\infty$: 1
zeros at $S = 1$: $2(p + 1)$ zeros at $S = jw_{z1}$: p
zeros at $S = jw_{z2}$: p

where p is the number of fourth order elements and the degree of the network is given by $2 \times (3p + 2)$. For Class B types, the set is:-

zeros at $S = j0$: 1 zeros at $S = j\infty$: 1
zeros at $S = 1$: $4(p - 1)$ zeros at $S = jw_{z1}$: p
zeros at $S = jw_{z2}$: p

where p is again the number of fourth order elements and the degree of the network is given by $2 \times (4p-1)$.

For the purposes of physical realisation, both classes of prototype will be assumed to consist of 1) unit elements, 2) capacitive pi sections and 3) fourth order sections. Each one has a simple stripline realisation. The unit elements correspond to commensurate lengths of interconnecting transmission line. The capacitive pi sections correspond to pairs of shunt, capacitively coupled striplines and the fourth order sections correspond to shunt open circuit stubs taking the form of either a single 4-section stub with a total length equal to 4 times the commensurate length, or a pair of 2-section stubs in parallel, with total lengths equal to twice the commensurate length. These three types of section can be clearly identified in the photographs of the experimental filter circuits given in Figs 3 & 4. In view of the high resonant frequency of the stripline sections, the sections have a decidedly 'lumped' character in the vicinity of the passband and this gives rise to many of the practical advantages associated with these filters. For example, the series and shunt distributed elements of the filter can be partly or completely replaced by lumped elements without causing significant changes in performance. In fact it is almost always necessary to use a lumped capacitor to replace some of the series coupling between the capacitively coupled strips in the filter. The lumped capacitor is mounted across the gap between the coupled strips at their junction with the 'through' line, increasing the coupling in the section and relaxing the tolerance on the gap dimension. The capacitor takes the form of a strip of gold foil, bonded to one stripline and insulated from the other with an 8 micron thick dielectric film. Another advantage is the ease with which a prototype design may be fine-tuned since trimming the length or the width of a shunt element achieves approximately the same result. Elements with excessive aspect ratios can also be tolerated to the extent that the width of an element may be equal to or greater than its length.

The two classes of prototype have relative advantages and disadvantages. Broadly speaking, the Class A prototypes are realisable for fractional bandwidths in the range 50%-100% and for stopbands specified up to 7 times the centre frequency of the passband. However, in general the realisation problem is eased as the specified stopband width decreases and it may be possible to realise devices for bandwidths outside this range if a more moderate stopband width is acceptable. This class has the advantage that the first element of the filter is a simple length of transmission line, which makes external connections particularly simple and which offers the possibility of a parallel connection of more than one such filter at a common junction to form a multiplexer. The Class B prototypes are realisable for a range of fractional bandwidths which probably extends from below 10% up to around 100% for m specified up to 7. The range of realisable bandwidths is therefore much greater than that of the Class A types. However, as a consequence of having to move a redundant unit element into the network from each termination, the Class B types do not begin and end with a simple length of line, neither are they suitable for a parallel connection in a multiplexer.

EXPERIMENTAL DEVICES

So far, five experimental bandpass filter designs have been constructed, two of which are illustrated in Figs. 3 & 4. The first has a 2-6GHz passband with a stopband extending to 22 GHz and the second a 2-4 GHz passband with a stopband extending to 20 GHz. They are very much smaller than the equivalent LP/BP combinations of more conventional printed circuit filters that would be required to meet the same electrical specifications and both filters were designed using the standard procedure of specifying zero locations, synthesising a prototype, followed by calculating the physical dimensions of the stripline elements. Occasionally, the sequence needs repeating until the zero locations give both a satisfactory frequency response and physical realisation.

The 2-6 GHz filter is a Class A device using a prototype of degree 28. Lumped capacitors are mounted in the middle of all the edge coupled sections. Adjusting the symmetry of the outermost coupled sections enables the internal impedances of the filters to be raised or lowered as required and in this particular case, these sections have degenerated into L sections, all the series coupling being provided by a lumped capacitor. Insertion loss reponses of the filter are shown in Fig.5 and there is close agreement between theory and practice. Loss in the centre of the passband is approximately 0.6dB and 60dB of rejection is achieved at a frequency 2% from the bandedge(i.e 120 MHz). No spurious responses below 60dB are observable in the stopband up to 18 GHz.

The 2-4 GHz filter is also a Class A device but uses a prototype of degree 22. This filter has an extremely wide stopband, having specified m = 7. Again lumped capacitors are used throughout the circuit. As can be seen in Fig.4, it was necessary to modify the circuit at each end to achieve the most satisfactory physical dimensions and these modifications are the result of introducing a redundant unit element into the prototype from each termination. Fig.6 is evidence of the exceptionally close agreement between the measured and theoretical responses of the filter. Insertion loss is just under 1dB in the passband and stopband rejection is 60dB at 170 Mhz from each bandedge.

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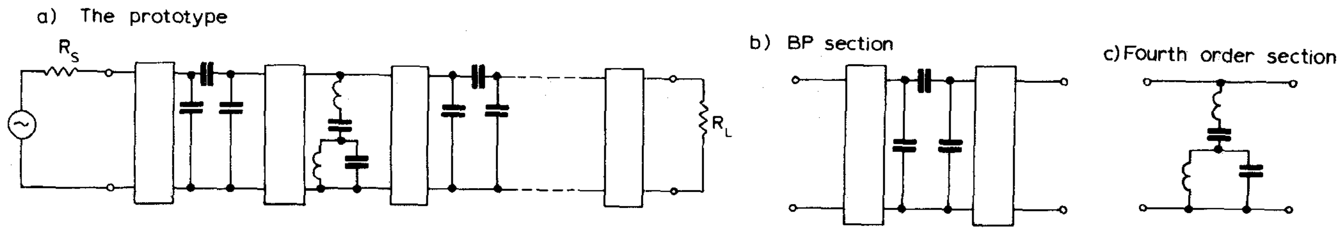

Fig. 1. Class A prototype.

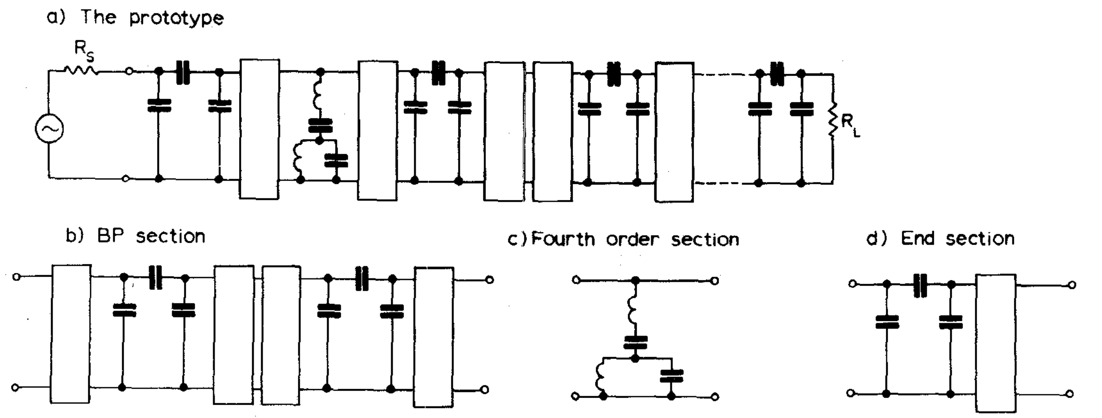

Fig. 2. The class B prototype.

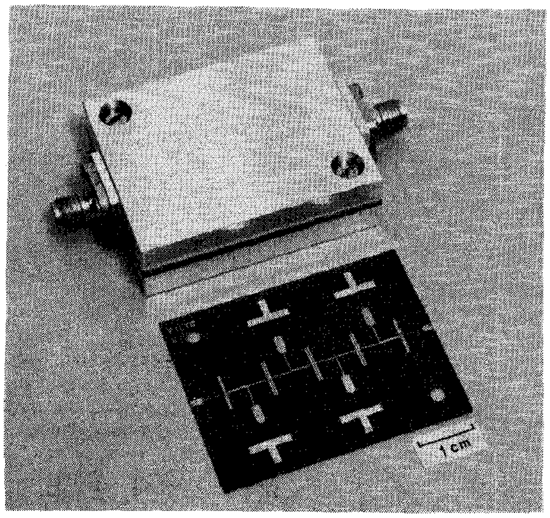

Fig. 3. 2-6GHz bandpass filter

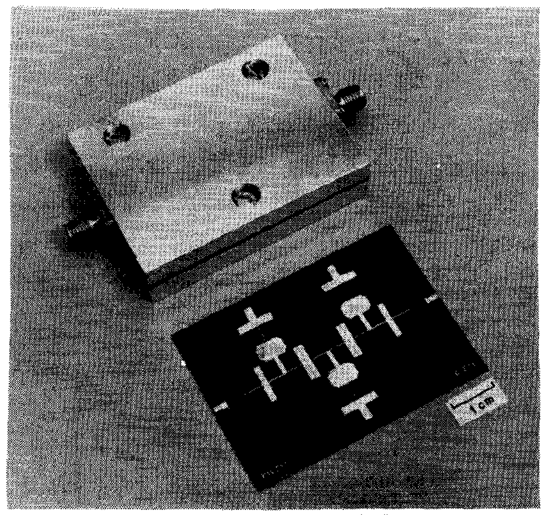

Fig. 4. 2-4GHz bandpass filter

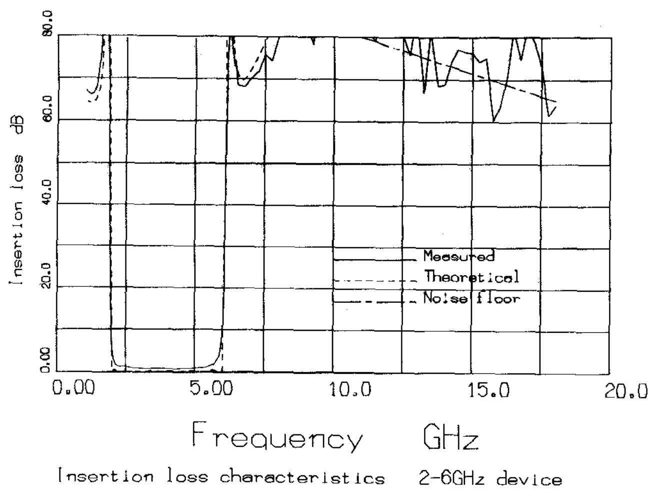

Fig. 5. 2-6GHz bandpass filter

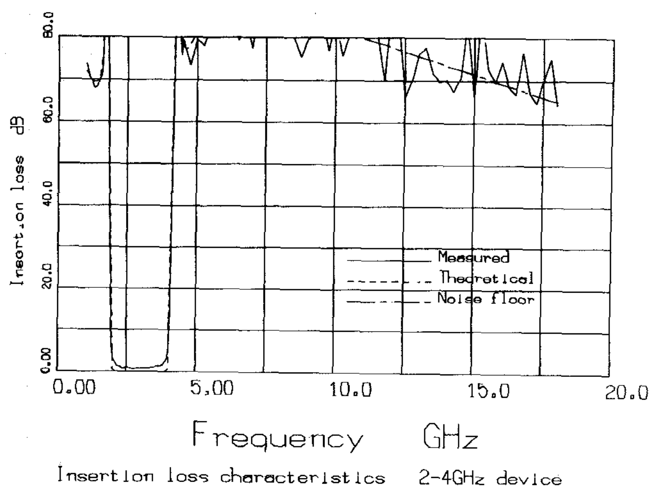

Fig. 6. 2-4GHz bandpass filter