COPLANAR WAVEGUIDE FILTERS

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ABSTRACT

Examples of highpass, lowpass and bandpass filters realised in coplanar waveguide are presented. Design is based on distributed circuit theory and is improved by extensive modelling of discontinuities. Equivalent circuits for these are presented, together with some design data. Symmetric and asymmetric designs appear to be equally successful. Modelled filter responses agree well with measurements, although there is an anomaly in the lowpass design which may be associated with odd mode excitation in shunt open stubs.

INTRODUCTION

Coplanar waveguide (CPW) is attracting increasing attention as a transmission line structure for MIC's and MMIC's. As a structure realised in a single plane, it consists of a centre strip conductor with semi-infinite ground planes on either side, on a dielectric substrate [1]. Despite its advantages in ease of manufacture, and the easy connection of both series and shunt components without drilling, its use has been limited by the availability of design data, especially for discontinuities. Such data must be in a form simple enough to incorporate in CAD packages, which analyze designs purely in circuit terms.

Filters are important blocks in microwave circuits and are among the first few circuit elements studied in any new technology. Microstrip or Stripline filters have been extensively studied and very accurate design techniques have been presented in the literature [2]. However, CPW filter elements have been little investigated and no accurate equivalent circuits are available for discontinuities or other special structures such as interdigital capacitors.

This paper presents results for various CPW filters designed using extensive design data for the discontinuities.

DISCONTINUITY MODELLING

An extensive programme of discontinuity modelling was undertaken as a preliminary to attempting filter designs. Field solving software has advanced to the point where exact solutions can be readily obtained for all reasonable CPW discontinuities, but it remains to convert such solutions into the required circuit models. The most desirable situation is that an equivalent circuit can be found containing only inductors, capacitors (and possibly mutual inductors) whose values are frequency independent for a given geometry.

For this analysis, we used a field solver (*em*) which is general enough to handle any reasonable CPW structure. For each geometry, S-parameters were computed as a function of frequency. With a good choice of equivalent circuit, the desired frequency independent values could be obtained in most cases. The initial form assumed for the equivalent circuit of each discontinuity was the same as for the analogous microstrip structure. For example, the open circuit stub is represented simply by a single capacitor or an equivalent length extension. This approach was found to be successful in all the cases treated so far, including others outside the scope of this paper.

The circuits all have the property of having the same number of degrees of freedom as the lossless, reciprocal S or Z matrix at a single frequency. The filter designs discussed in this presentation contain these discontinuities: open circuits, step width changes, T - junctions and cross junctions.

Interdigital Structures

Using CPW technique, sophisticated circuit elements can be designed, which are mostly impossible to realise in conventional microstrip technique. Some elements which were already proposed by Holder [3] are shorted or open ended 90° transmission line stubs connected in series. These basic circuits function as interdigital inductors or capacitors respectively and can be used either in filter or dc-blocking applications. These were treated using a distributed rather than lumped model, again derived using *em*. Fig.1 shows the interdigital capacitor and inductor, together with their equivalent distributed models.

CPW FILTERS

The designs presented all originated as combinations of idealised series and shunt stub elements. Their characteristics were calculated using commercially available state-of-the-art microwave software and optimised using in-house generated models for the CPW discontinuities. This software, which handles a mixture of lumped and idealised distributed elements, was integrated with specially developed code incorporating discontinuity and dispersion models [4], and expressions for characteristic impedances.

To reduce the active filter area, bandstop and bandpass filter design was applied, instead of conventional low- and highpass structures. The lowpass filter structure is shown in Fig.2. It is made up of 2 series connected shorted interdigital 90° sections, which function as bandstop resonators, with 3 open ended parallel stubs. Fig.2 also shows simulated and measured responses. The lowpass filter shows low loss in the transmission region from dc up to 9.5 GHz with very good VSWR (below 0.1).

Fig. 3 shows a highpass design which now includes short circuit stubs, with the end discontinuity represented simply as a series inductor, and an open circuit 90° section. Fig. 4 shows design data for this discontinuity inductor, and also for the shunt capacitor which represents the open end discontinuity in the low pass filter. In this figure, "d" denotes the ground plane - ground plane spacing and "w" the centre conductor width. For the open end, "g" is the end gap.

A bandpass design is shown in Fig. 5 and is based on a design of Malherbe [5]. In this case an asymmetric design has been attempted for comparison; a T - junction discontinuity now occurs and is modelled as shown in Fig. 6.

Filter designs, based on a Generalised Chebyshev [6] type with additional transmission zeroes in the stopband, have also been designed with excellent agreement between measured and simulated results. A diplexer of this type has been realised; its design includes a step width change which is modelled as a single shunt capacitor.

All the filters contain cross junctions which are modelled as in Fig. 7, although there is not space to present all the design data for these.

The filters have all been fabricated on alumina with $\epsilon_r=9.5$ and thickness h=0.635mm. The diplexer occupied an area of less than 2 square inches.

DISCUSSION

An interesting departure between prediction and measurement occurs at the higher frequencies in the low pass filter. It has been speculated that this may be caused by a slotline (odd) mode in the shunt open stub sections. This mode could propagate around the open end of the stub in this case. It may be that this mode is encouraged by the very strong left-right asymmetry at the cross junction in this particular filter, and is not entirely suppressed by the earth bonding. This bonding is vital to designs using cross or T - junctions, as is shown by totally different results when it is omitted.

Asymmetric designs such as Fig. 5 appear to be as successful as the two-sided forms, and may offer a size reduction.

CONCLUSION

In general, good agreement is found between predicted and observed filter responses, and the value of discontinuity modelling is shown by markedly better predictions when it is included. Results are generally encouraging for CPW use in filter applications, and several new design techniques have been developed.

Acknowledgements

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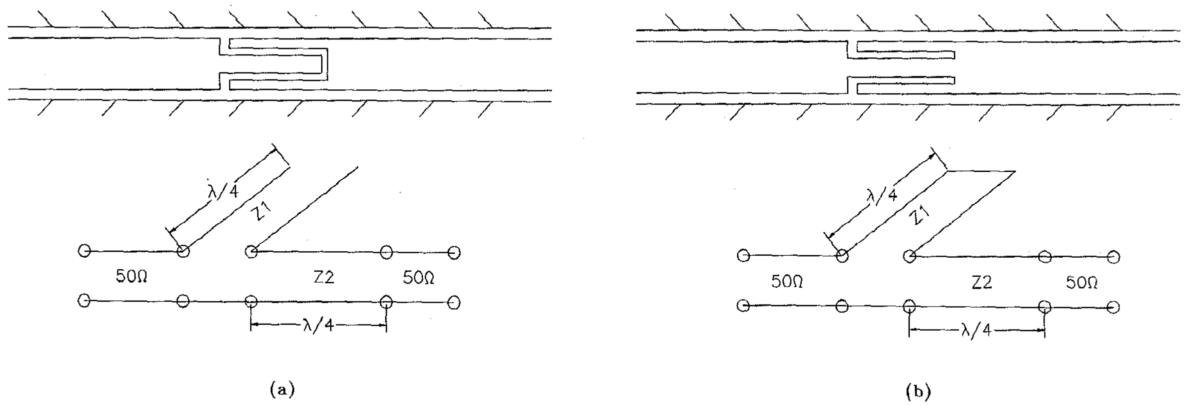

Fig.1 Interdigital capacitor (a), and inductor (b), and their equivalent circuits.

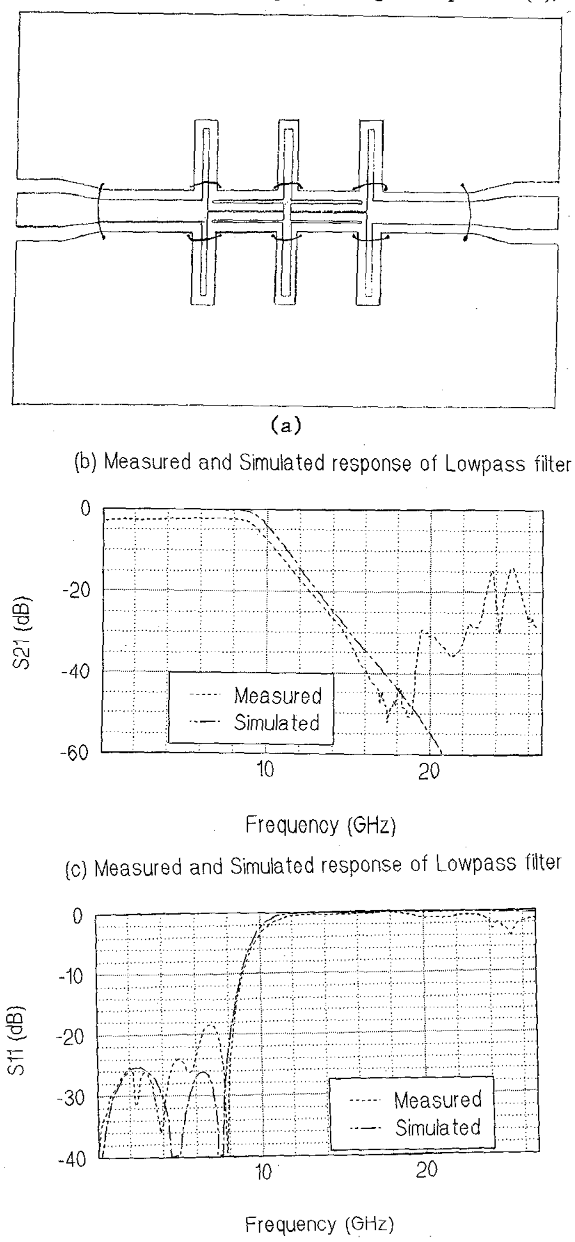

Fig.2 Lowpass filter: (a) layout, (b) S21, (c) S11

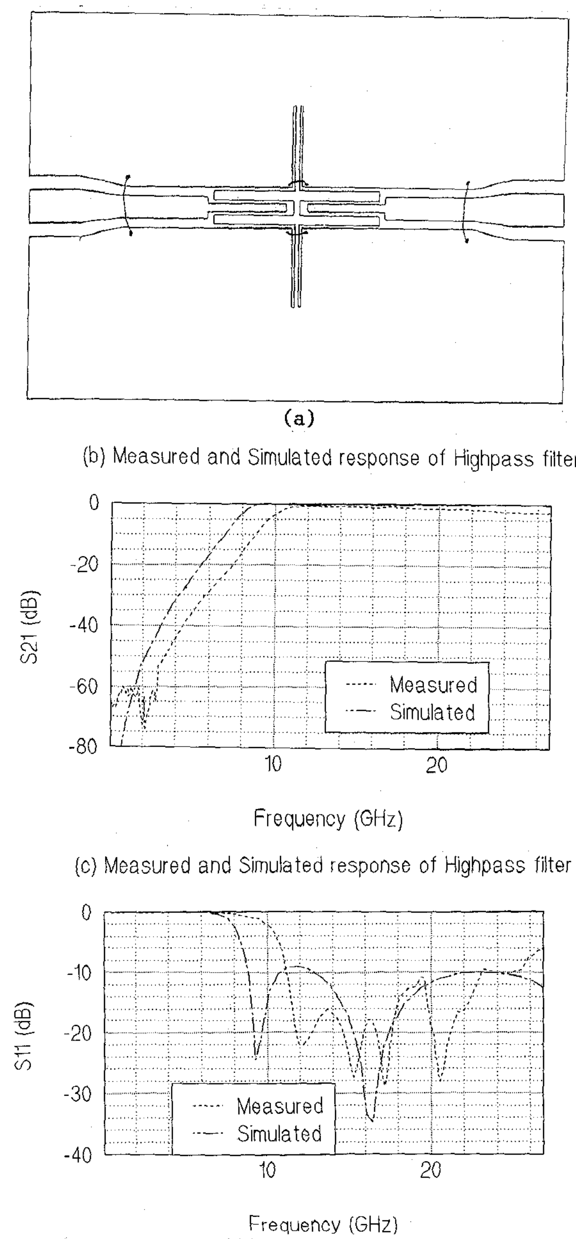

Fig.3 Highpass filter: (a) layout, (b) S21, (c) S11.

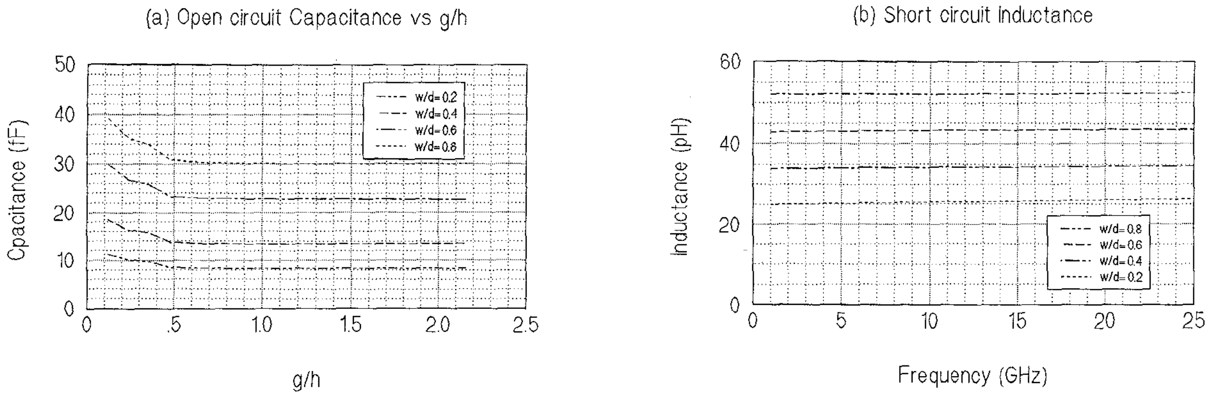

Fig.4 Design data for (a) open circuit, (b) short circuit.

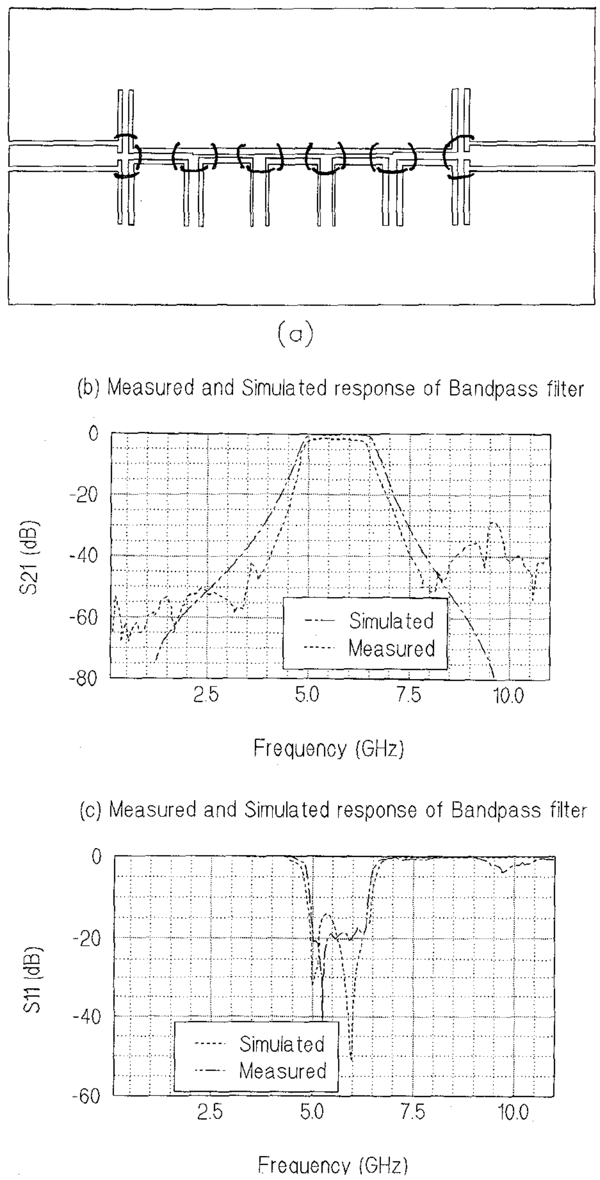

Fig.5 Bandpass filter: (a) layout, (b) S21, (c) S11.

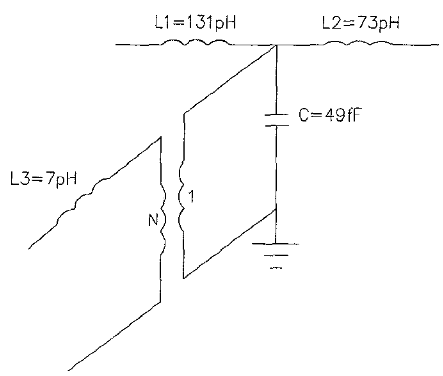

Fig.6 Equivalent circuit of an asymmetric T-junction.

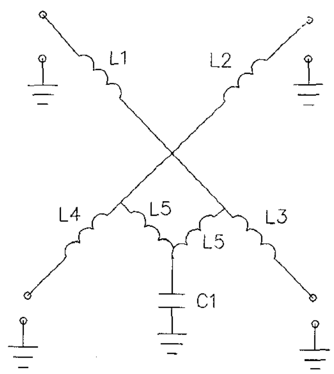

Fig.7 Equivalent circuit of an asymmetric cross-junction.