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ABSTRACT

The different configurations which may be used for broadband lowpass and highpass filters will be discussed for applications from 0.5 - 40 GHz. Diplexer design and their application to broadband multiplexers will be considered with examples of practical devices.

Due to the limitations of loss, narrow band bandpass and bandstop designs have restricted applications. However, one application in contiguous switched multiplexers will be considered in detail where the dissipation loss characteristic plays a very important role in the overall device performance. Such an N channel switched multiplexer may assume any one of 2^N states within 30 ns.

Finally, other special classes of networks such as constant phase difference networks will be discussed with applications to frequency discriminators.

INTRODUCTION

In the microwave industry, many components are customised and are required, at most, to be produced in tens or hundreds. As a consequence many devices require very skilled technicians in production because design techniques and technologies are not developed to a level where these skills are minimised. One example is in broadband microwave filters and multiplexers as described by Schumacher [1] which consist of a main body with many components internally milled and additional discrete components to form the complete electrical circuit. These components require long manufacturing and assembly times and great skill in tuning to meet stringent amplitude and possibly phase specifications.

To overcome these problems the SSS (Suspended Substrate Stripline) medium has been developed and many of the advantages have been previously discussed [2]. These printed filters and multiplexers can be realised in a fraction of the weight and volume are inherently more reproducible in both amplitude and phase characteristics, and can more readily be integrated into more complex sub-systems.

The SSS configuration is illustrated in Fig. 1 and consists of a microwave transmission line circuit photo-etched onto both sides (in general) of a thin, soft, woven, PTFE - based substrate, which is suspended in air between two ground planes. This medium is chosen for the following reasons.

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Firstly it enables higher unloaded Q factors to be realised as compared to microstrip or dielectric stripline. Secondly for broadband applications, impedances are more easily realised in SSS and complex circuits using the two-sided, inhomogeneous medium can be produced. Finally, SSS filters are more stable over temperature since the critical resonant sections are essentially in air. Very small temperature coefficients have been achieved by allowing the substrate to warp in a controlled manner whilst enabling the devices to meet difficult shock and vibration requirements.

PROTOTYPE FILTER

A suitable prototype filter from which selective lowpass or highpass SSS filters may be designed is shown in Fig. 2 with an insertion loss response shown in Fig. 3.

For different SSS realizations, careful choice of the location of the transmission zeros will result in impedances which are physically realizable. This contrasts significantly with the optimum, in the sense of degree, elliptic function response. Of course, since the entire filter is to be printed with the minimum level of tuning optimum with respect to degree is not necessarily important. A more suitable parameter could be the volume required to meet an electrical specification. Based upon this prototype, different designs of lowpass and highpass filters have been developed over the frequency range 0.5 - 4.0 GHz. These different designs ensure that the filter sizes remain small independent of bandedge frequency. To illustrate the types of structures, a selection of lowpass and highpass designs will be discussed. More details are given in Ref [3].

LOWPASS FILTERS

Most SSS filters are mixed lumped and distributed circuit element designs. If the normal lumped to distributed frequency transformation is applied to Fig. 2 then the capacitive elements could be realized by an open circuited array of coupled lines, and the inductive elements by short circuited stubs. However, series short circuited stubs are impossible to realise in SSS and therefore the simplest method is to approximate with a high impedance series line. Since this section must exhibit shunt components these must be accounted for and a basic two-sided circuit as shown in Fig. 4 can be derived.

The insertion loss response of such a lowpass filter is shown in Fig. 5 where the stopband is held to three times the cut-off frequency.

If the dual circuit to Fig. 2 is used as the basis for a lowpass design then we have series short circuited lines and shunt open circuited resonant lines. Again the series

elements are realized by short lengths of high impedance lines and their effective shunt effects must be accounted for. Furthermore, to restrict the impedance variations, uniform shunt lines of variable length are used in preference to stepped impedance lines. This circuit may be realised by a one sided SSS as shown in Fig. 6.

A typical response is shown in Fig. 7.

The easiest way to achieve a broader stopband without increasing the passband dissipation loss is to cascade two or more individual filters. In this case, the higher frequency devices are designed to exhibit a passband return loss characteristic where the minimum value increases at 6 dB per octave down from bandedge in order not to cause a deterioration of the main passband return loss. The alternative technique of designing a lowpass filter with significant shunt capacitance, normally through the substrate to realise wide stopbands, inevitably results in greater passband dissipation loss and larger bandedge variations as a function of temperature.

HIGHPASS FILTERS

A lowpass to highpass frequency transformation together with the distributed frequency transformation to the lowpass prototype shown in Fig. 2 results in a microwave structure consisting of a short circuited array of coupled lines connected by open circuited series stubs. Again the series stubs cannot be realized directly and they are approximated printed on opposite sides of the substrate. This complex inhomogeneous section has to be modeled accurately and the effective shunt components accounted for by modifications to the short circuited coupled lines. An example of a 2 GHz device of degree 13 is shown in Fig. 8.

The measured performance of such a device is shown in Fig. 9.

For higher frequencies, the above frequency transformations are applied to the dual of the prototype filter shown in Fig. 2. The finite transmission zeros are then realised by short open circuited stubs which may be designed to possess uniform impedance. The series open circuited stubs are realised by the overlapping inhomogeneous section as before but an extra two transmission zeros at the origin are located at either end of the filter and realised by short circuited shunt stubs. A typical 5 GHz filter is shown in Fig. 10 with response in Fig. 11.

SSS MULTIPLEXERS

Combinations of lowpass and highpass filters may be used to produce bandpass filters or multiplexers. For the latter, lowpass and highpass filters are combined as diplexed pairs

where a good common port match is maintained at all frequencies. The design of such filters is based upon singly terminated filter designs but rather than retaining an equiripple passband performance a 6dB per octave slope away from bandedge is designed into the return loss characteristic. This enables duplexers to be cascaded without a build up in the VSWR.

An example of a broadband duplexer is shown in Fig. 12.

Due to the broad bandwidth, the lowpass has transmission zeros at three finite frequencies and the highpass has stepped impedance stubs to maintain a 3:1 bandwidth passband. The measured response is shown in Fig. 13.

Multiplexers are formed by the cascade of duplexers and an example of a 0.5-18 GHz quadruplexer is shown in Fig. 14.

The largest filter at the lower left is a 500 MHz highpass where the series open circuited stubs are realised by overlapping elements down the short circuited coupled line structure. Above this filter is the 2 GHz lowpass which is duplexed with the 2 GHz highpass to the right. The 6 and 10 GHz duplexers are of similar design and are cascaded from the input port. The overall measured response is shown in Fig. 15 and a photograph of the basic parts is shown in Fig. 16.

Multiplexers of this type have now been built with up to seven channels and operating to 40 GHz. One of the significant advantages is the reproducibility of the devices in both amplitude and phase tracking. This factor is also important in narrow band bandstop filters where resonator bandwidths have to be accurately maintained in order to produce a high level equiripple stopband. In the case of bandpass filters where very accurate bandwidths have to be maintained, the SSS technology is again superior.

SWITCHED MULTIPLEXERS

A switched multiplexer is a single r.f. input, single r.f. output device consisting of N contiguous channels covering the total bandwidth of the device. Any sets of channels may be switched on or off simultaneously to provide 2^N states which may be switched typically every 30 ns. Ref 4.

A set of alternative channels are realised as shown in Fig. 17. Each channel consists of a pair of identical filters with a pair of integrated 3 dB hybrids which are realised on a single SSS which may be manufactured to provide excellent tracking between the filters and produce an accurate bandwidth which is important in the overall realisation. Furthermore, the switching diodes and chokes are also integrated.

In the 'on' state frequencies at f_1 corresponding to the passband of channel 1 enter at port 1 and emerge at port 3. Frequencies outside the band enter at port 1 and emerge at port 2. In the 'off' state all signals entering at port 1 emerge at port 2 and in both states all ports are always matched.

All of the even and all of the odd channels are realised on a single substrate to ensure that the appropriate tracking between channels is maintained. The final overall switched multiplexer is then assembled as shown in Fig. 18.

The phase shifts are used to provide the correct phase behaviour at the bandedges of adjacent channels. Even with finite dissipation loss in the channel filters, such a design is capable of providing both a flat amplitude and group delay response through the crossover region when adjacent channels are switched on. Measured characteristics of an 8 channel design are shown in Fig. 19 where the residual loss through the device is approximately 12 dB.

CONSTANT PHASE DIFFERENCE NETWORKS

There are several requirements where it is necessary to maintain an accurate phase difference between two networks over a broad bandwidth such as in the switched multiplexer or phase discriminators. To achieve significant phase differences using an optimum canonic structure such as a cascade of Shiffman Sections frequently leads to unrealisable impedance values in SSS. However, by combining Meander Line sections and Shiffman Sections realisable geometries can be obtained. Furthermore, due to the printed realisation, accurate phase tracking can readily be achieved and such networks have been used to produce relatively low cost digital frequency discriminators [Ref 5].

CONCLUSIONS

The use of SSS for both the design and production of microwave filters and multiplexers and related integrated structures has now become established. Using computer aided manufacturing techniques the circuits may be produced very accurately with layout programs, photolithography techniques and accurate etching methods. Furthermore, with CNC milling techniques, the boxes which house the circuits can also be manufactured with the correct relative tolerances to enable production quantities of devices with very demanding electrical specifications to be met in the minimum size and weight.

ACKNOWLEDGEMENTS

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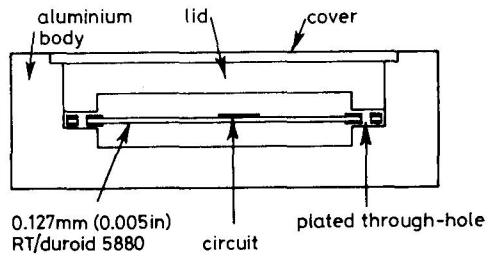


Fig. 1 Basic suspended stripline device

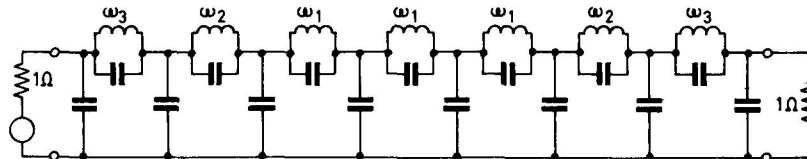


Fig. 2 Generalised Chebyshev Lowpass Prototype Filter

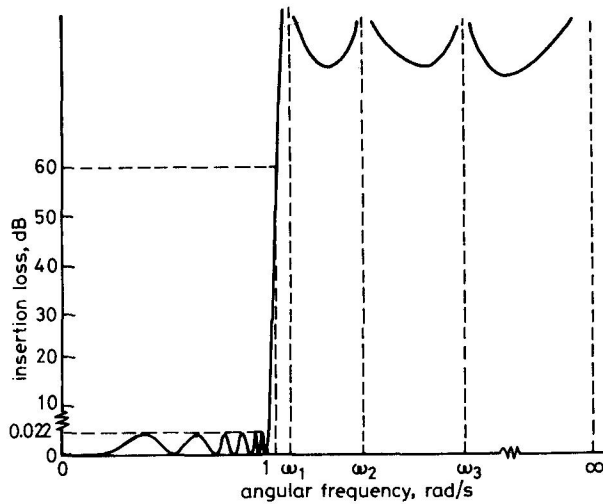


Fig. 3 Insertion Loss response of prototype filter

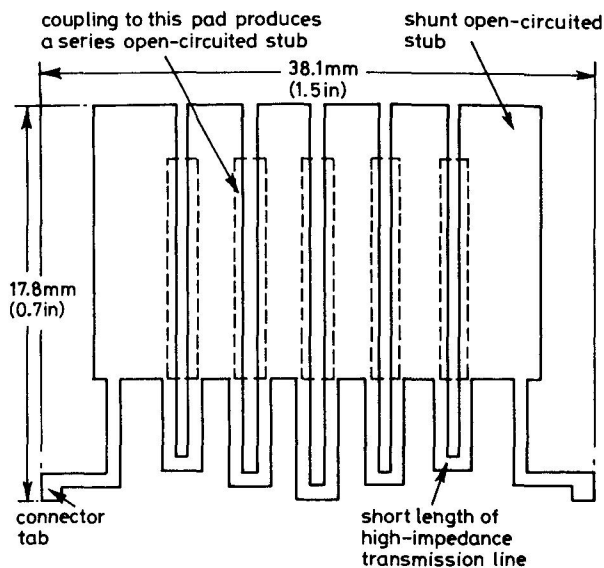


Fig. 4 Printed Circuit for 13th degree 2 GHz Lowpass Filter

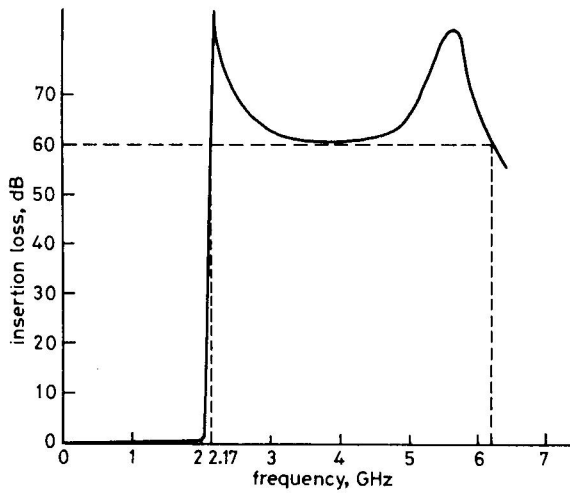


Fig. 5 Insertion Loss Response of 2 GHz Lowpass Filter

Fig. 6 15th degree Lowpass Filter

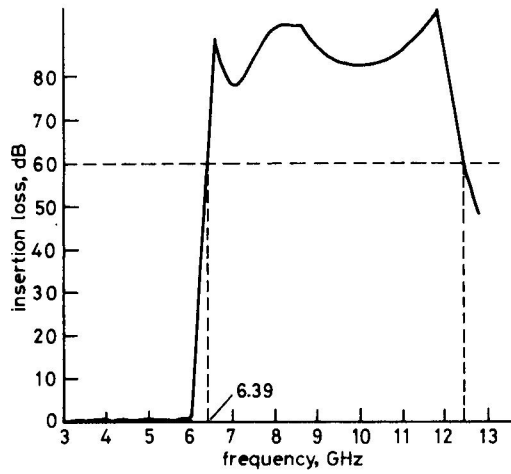
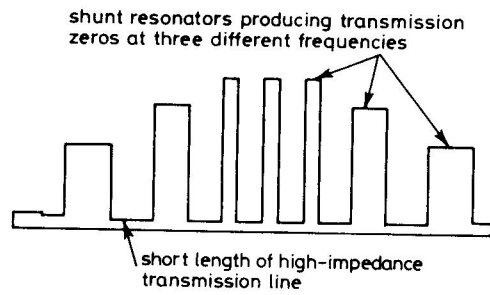
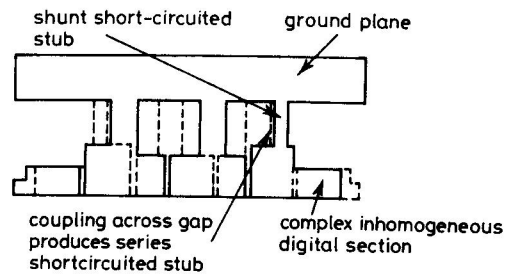


Fig. 7 Measured Response of 6 GHz Lowpass Filter

Fig. 8 Printed Circuit of Highpass Filter



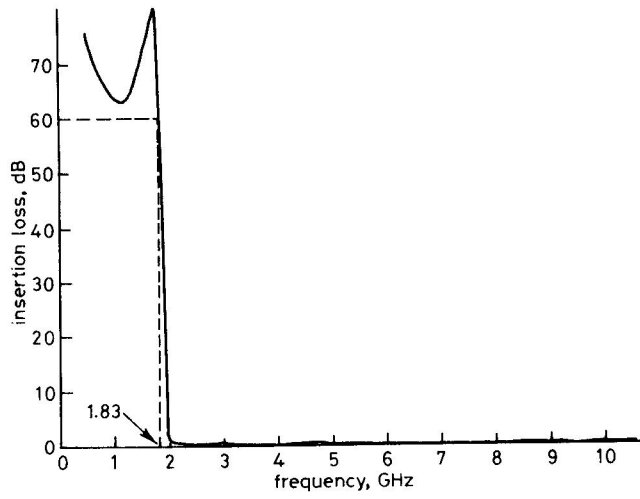


Fig. 9 Measured Insertion Loss of 2 GHz High-pass Filter

Fig. 10 Printed Circuit of 5 GHz Highpass Filter

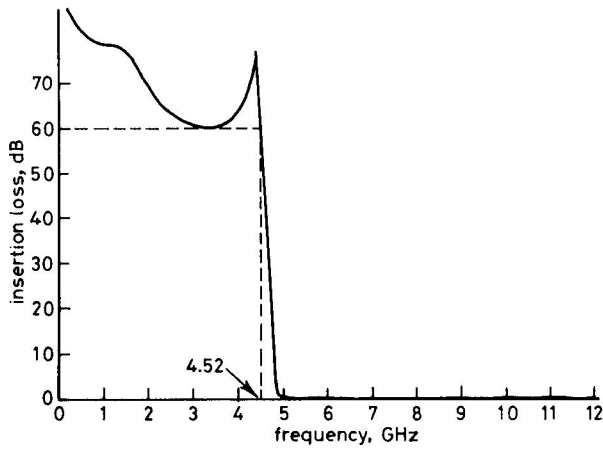
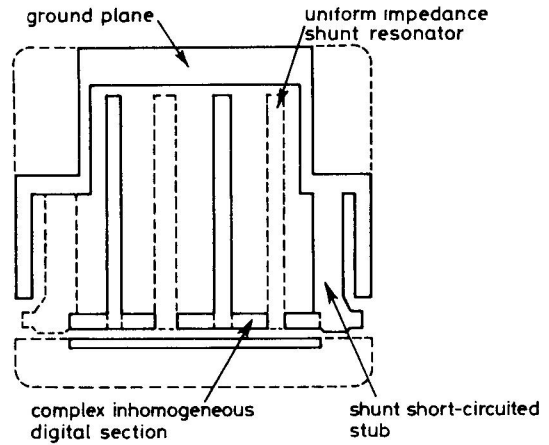
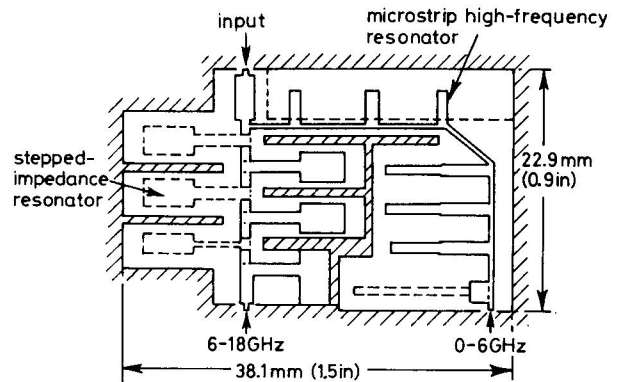


Fig. 11 Measured Insertion Loss of 5 GHz High-pass Filter

Fig. 12 Printed circuit for Diplexer, 0-6, 6-18 GHz.



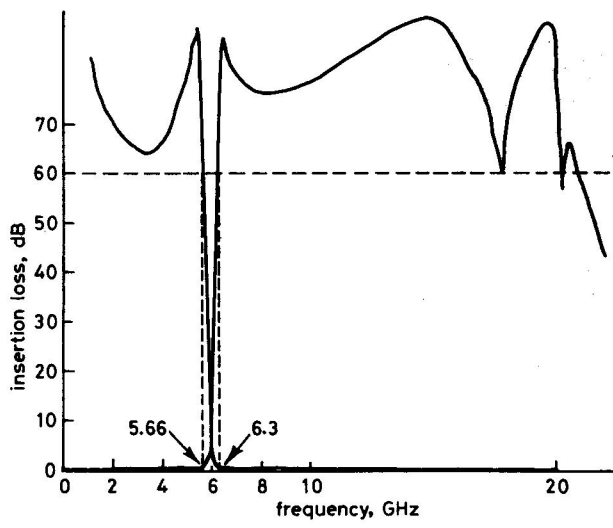


Fig. 13 Measured Insertion Loss of 6 GHz Diplexer

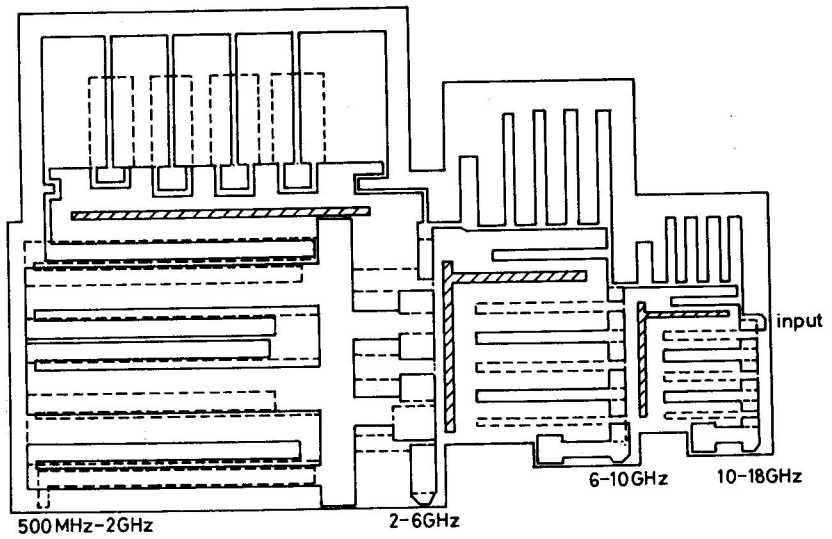


Fig. 14 Printed Circuit of 0.5 - 18 GHz Quadruplexer

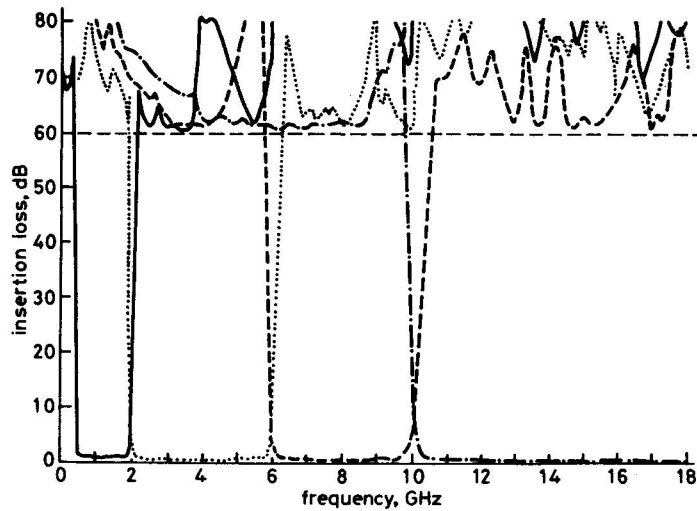


Fig. 15 Measured Insertion Loss of 0.5 - 18 GHz Quadruplexer

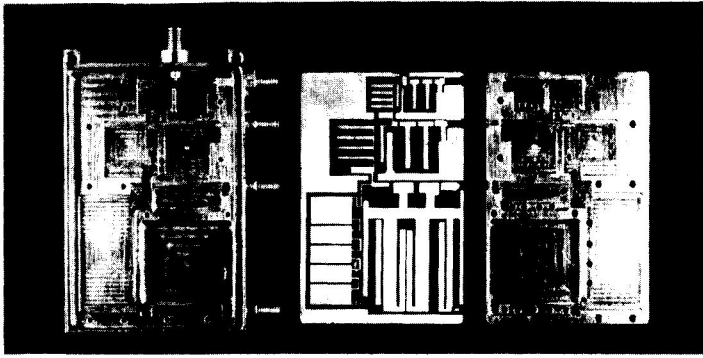


Fig. 16 Component parts of 0.5 - 18 GHz Quadruplexer

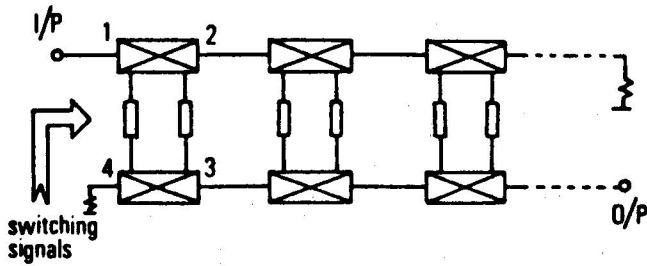


Fig. 17 Cascaded Hybrid Channels

Fig. 18 Overall Switched Multiplexer Configuration

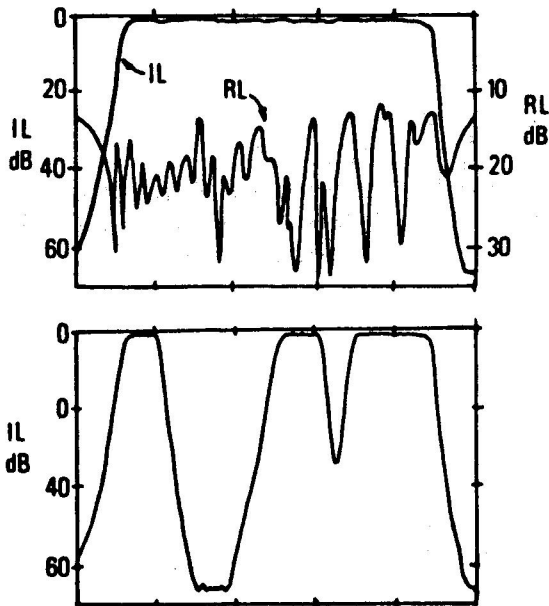
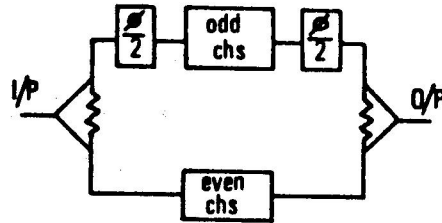


Fig. 19 Measured Performance of 8 channel switched Multiplexer with all channels on and channels 1, 4, 5, 7, 8 on.