A band-pass filter with 70% bandwidth, effectively functioning as a pseudo-high pass filter has been designed and implemented using suspended strip-line technology. In principle such a filter can easily be fabricated by cascading low pass and high pass filters, but it is difficult to fabricate high pass filters in suspended stripline, and this filter is expected to overcome this difficulty. The filter is fabricated using coupled-line resonators, and broadside-coupled lines are used to realise the required impedance levels.

1 Introduction

The suspended stripline is known to be a versatile transmission medium for millimetre-wave frequencies. In addition to low loss (compared to the more commonly used microstrip, [1]) it also offers the option of fabricating double-sided circuits. One of the reasons why it is not universally adopted is the necessity of a channel matching the circuit, which necessitates time-consuming machining processes. This is particularly serious if the circuit contains many T or cross-junctions. However if the entire circuit fits in a single straight channel, as for example a low-pass filter using alternating high and low impedance lines, then the inherent advantages of the suspended configuration become significant.

For high-pass filters, the situation is different. One common way to realise a high-pass filter is shown in Fig. 1. As with most distributed filters, this is in reality a band-pass filter with a pass band wide enough to function as a high-pass filter in the band of interest. Here we clearly see that the channel has to follow the complicated geometry of the multiple T-junctions. It is to avoid this that we
chose to design a suitable band-pass filter with quarter-wavelength long coupled lines. This scheme is very commonly used in microstrip narrow-band filters, using edge-coupled transmission lines [2]. For wider band-widths (more than 10%), the line separation required to achieve the necessary impedance values becomes too small to fabricate. This limitation is overcome in the suspended stripline, where we can realise a much larger range of impedance values, using broadside-coupled lines.

2 Design procedure

The procedure for designing coupled line band-pass filters is well established [3]. As is usual, the starting point is an L-C low pass prototype, of order N, say, with cut-off at $\omega = 1$. From the N+2 element values so obtained (including two for the terminal impedances), knowing the desired centre frequency and bandwidth, we obtain the required even and odd mode impedances of the coupled line sections, that is, for the N+1 coupled sections shown in Fig. 2, $(Z_{oe})_i$ and $(Z_{oo})_i$, for $i = 0$ to N are determined. The relevant equations can be found in [3]. The length of each section should ideally be quarter-wavelength at the centre frequency, but since even and odd mode guide wavelengths are different, the following simple relation was used for the lengths:

$$\lambda_i = \lambda_{eff}/4, \text{ where } \lambda_{eff} = \lambda_0 \sqrt{0.5(\varepsilon_{eff,e} + \varepsilon_{eff,o})};$$

Here, $\lambda_0$ is the free-space wavelength and $\varepsilon_{eff,e}$ and $\varepsilon_{eff,o}$ are the even and odd-mode effective dielectric constants. To know $\varepsilon_{eff,e}$ and $\varepsilon_{eff,o}$, it is first necessary to determine the physical dimensions of the two printed lines, which realise the desired $Z_{oe}$ and $Z_{oo}$. This was done by tabulating $Z_{oe}$ and $Z_{oo}$ as functions of strip width (w) and strip spacing (s). The cross-section is shown in Fig. 2. From the table a suitable combination of ‘w’ and ‘s’ can be selected which give the desired $Z_{oe}$ and $Z_{oo}$. The determination of $\beta$ and $Z_0$ for this suspended structure was carried out following the procedure described in [4]. The method was extended to the asymmetric case (different strip widths), and ‘c’ and ‘$\pi$’ mode parameters were calculated. It is mentioned in [3] that coupled line band pass filters can use such asymmetric lines, but in the present case this was not necessary.

The top view of the filter layout is shown in Fig. 3. The effect of the short transmission lines, which separate adjacent sections, will be described later.

---

**Fig. 2.** Cross-section of suspended stripline

**Fig. 3.** Layout of the band-pass filter (top view).
2.1 Specifications

The lower cut-off frequency was kept at 18 GHz. Since the filter was expected to function as a pseudo high-pass filter, there is some arbitrariness about the upper cut-off frequency. We aimed for 40 GHz, which is the maximum we could measure. To keep the cut-off characteristics comparable to some previously designed high-pass filters at lower frequencies, attenuation of $-60$ dB at 15.6 GHz, with a pass-band ripple of 1 dB was decided upon. This resulted in a 15th order Chebyshev design with 1 dB ripple.

2.2 Design results

The values of $w$, $s$, $Z_{oo}$, $Z_{oe}$, and the lengths of the first 8 sections required are:

<table>
<thead>
<tr>
<th>$w$ (mm)</th>
<th>$s$ (mm)</th>
<th>$Z_{oo}$ (Ω)</th>
<th>$Z_{oe}$ (Ω)</th>
<th>$\varepsilon_{eff,o}$</th>
<th>$\varepsilon_{eff,e}$</th>
<th>$\lambda_g/4$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.79</td>
<td>0.59</td>
<td>30</td>
<td>134</td>
<td>1.71</td>
<td>1.12</td>
<td>2.1</td>
</tr>
<tr>
<td>0.475</td>
<td>0.315</td>
<td>36</td>
<td>185</td>
<td>1.76</td>
<td>1.13</td>
<td>2.08</td>
</tr>
<tr>
<td>0.54</td>
<td>0.45</td>
<td>41</td>
<td>165</td>
<td>1.66</td>
<td>1.13</td>
<td>2.12</td>
</tr>
<tr>
<td>0.55</td>
<td>0.47</td>
<td>42</td>
<td>162</td>
<td>1.64</td>
<td>1.13</td>
<td>2.12</td>
</tr>
<tr>
<td>0.555</td>
<td>0.485</td>
<td>42</td>
<td>161</td>
<td>1.63</td>
<td>1.13</td>
<td>2.13</td>
</tr>
<tr>
<td>0.56</td>
<td>0.49</td>
<td>42</td>
<td>160</td>
<td>1.63</td>
<td>1.13</td>
<td>2.13</td>
</tr>
<tr>
<td>0.56</td>
<td>0.49</td>
<td>42</td>
<td>160</td>
<td>1.63</td>
<td>1.13</td>
<td>2.13</td>
</tr>
</tbody>
</table>

The last 8 sections have the same values in reverse order, as is well known.

3 Simulation and measurement

It is obvious from Fig. 3 that the filter cannot be built using coupled sections alone, since adjacent sections will touch. So these sections were separated out by inserting 0.2 mm transmission lines between adjacent coupled line sections. Also, we have neglected the open-end capacitances during the design. The effect of inserting 0.2 mm transmission lines was to shift the pass-band down, which was compensated by scaling down the lengths appropriately. This gave the simulated response shown in Fig. 4, which did not match the measured result. Upon including 0.02pF capacitances at the open ends, we arrive at a satisfactory agreement between simulation and measurement, as shown in Fig. 5. This filter has a pass-band from 18 GHz to 34 GHz (61%), with the loss going up to 5 dB at the higher end.

![Fig. 4. Simulated result incorporating 0.2 mm lines but not open end effect.](image-url)
This is caused partly by the SMA (3.5 mm) connectors, which are not appropriate for the higher portion of the pass-band. This defect can be remedied by switching to 2.4 mm connectors. The main problem that still remains is the discrepancy in the roll-off at the lower cut-off. This is probably caused by inadequate modelling of the open ends.

One important effect, which prevents the use of this technique for lower bandwidths, is the coupling between sections across the 0.2 mm gaps. This causes undesirable pass-bands, which are undetected in this wide-band filter. However, for narrow band filters, many other techniques exist.

4 Conclusion

The design and implementation of a wide-band band pass filter has been presented. It has been demonstrated that the commonly used edge-coupled band pass filter can be adapted to give the requisite bandwidth in suspended stripline. Some problems remain with the design, which may be resolved by the use of sophisticated modelling such as in [5].

References