# SIMPLIFIED DESIGN TECHNIQUE FOR HIGH PERFORMANCE MICROSTRIP MULTI-SECTION COUPLERS


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## ABSTRACT

A new design technique has been developed which improves the design of microstrip multi-section coupler by a simplified version of the non-uniform coupler method. The design is further improved by the use of the "saw-tooth" odd and even mode equalisation technique. The measured results demonstrate an improved performance over the multi-section coupler in terms of coupling performance and bandwidth, whilst the size and the fabrication tolerance are better than the non-uniform line coupler.


## INTRODUCTION

Broadband, -3 dB, hybrid couplers are commonly employed in devices such as phase shifters, mixers, power combiners and dividers. In particular, EW systems require broader band components to ensure detection of all threatening signals. The two natural choices for an extended bandwidth microstrip coupler will either be the uniform multi-section line coupler or the non-uniform line coupler. The multi-section line coupler is simple in its design, but the sharp discontinuities between various sections, together with the even and odd mode velocity difference, degrade the coupling amplitude and isolation at high frequencies [1-3]. The non-uniform line coupler [4,5] yields better performance because of the smooth tapering along the structure. The design requires Fourier transform analysis and iterative optimisation technique, which cannot be done using standard simulators, and the whole process is therefore prohibitively time consuming. The aim of this work was to develop a design technique which could achieve an improved performance of the multi-section coupler, by a simplified version of the non-uniform coupler method, with an optimisation procedure which can be carried out quickly on a standard simulator such as Libra™.

## DESIGN METHOD

Non-uniform line couplers are designed by the evaluation of the continuous coupling distribution *k(x)* along the structure. A typical *k(x)* for a 3-section non-uniform line coupler is shown in Fig. 1(a).

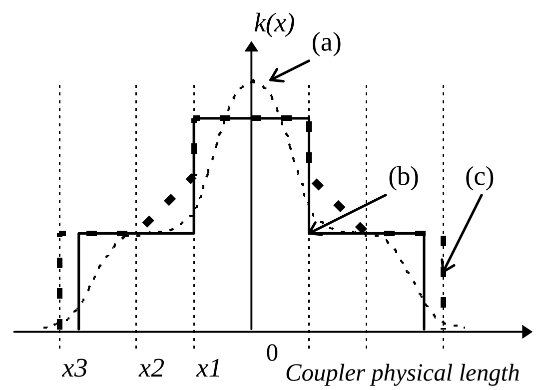


**Figure 1 :** Coupling distribution for (a) Non-uniform line (b) Multi-section line (c) Non-uniform line approximation

The coupling factor along the structure is iteratively modified until the desired response is obtained. However, this time consuming process does not necessarily give the desired response due to the complication of the continuously varying coupling factor along the non-uniform line structure [4, 5]. Further, as seen in Fig 1(a), the use of finite spacing at each end of the coupler will modify the whole coupling distribution and disturbs the amplitude of the overall coupling response. The tighter coupling required at the centre also implies more stringent fabrication tolerances. A better approximation to the non-uniform line coupling (Fig. 1 (a)) than the conventional multi-section coupling (Fig. 1(b)) can be achieved by a modified multi-section breakdown of the coupling where a linearly tapered coupler section is included between the centre and outer sections (Fig. 1(c)). This taper between the sections can be arbitrarily chosen to be short but smooth enough for minimal discontinuities. The coupling values for the various sections are chosen from the table established by Cristal *et al* [6], according to the particular desired overall coupling and ripples, as for the conventional multi-section design. The coupling distribution is now modified (referred to Fig. 1(c)), and by assuming TEM propagation, the ideal coupling response can be expressed by:

$$C(\omega) = \int_0^{x_1} sin\left(\frac{2\omega x}{v_1}\right) * ln\sqrt{\frac{(1+k_1)}{(1-k_1)}}dx + \int_{x_1}^{x_2} sin\left(\frac{2\omega x}{v_2}\right) * ln\sqrt{\frac{(1+k_2)}{(1-k_2)}}dx + \int_{x_2}^{x_3} sin\left(\frac{2\omega x}{v_3}\right) * ln\sqrt{\frac{(1+k_3)}{(1-k_3)}}dx \qquad (1)$$

where $k_1$, and $k_3$ are the coupling factors along the centre and outer sections respectively, and $k_2$ represents the varying coupling factor along the arbitrary tapered section. $v_1$ and $v_3$ are the phase velocity for the centre and outer sections respectively, and $v_2$ is the varying phase velocity for the tapered section. The length $x_1$ sets the centre frequency, and $x_2$ is an arbitrary length. It follows from (1) that there must be a value of $x_3$ which will satisfy the nominal coupling $C(\omega)$. This variable can therefore be used for optimisation.

In order to test the approach, two designs were made using the GMMT alumina circuit manufacturing facilities. The first design, as shown in Fig.2(a), employs a 3-finger interdigitated coupler as the centre section. A tandem connection of two 8.34 dB couplers was used to realise 3 dB coupling because this can reduce the sharp change in tapering and also avoid narrow spacing at the centre section. The saw-tooth compensated coupled microstrip line [7] is used at the outer sections in order to reduce even/odd mode velocity variations. Comparison with the performance of the same design but without saw-tooth compensation (Fig. 2(b)), has also been experimentally investigated.

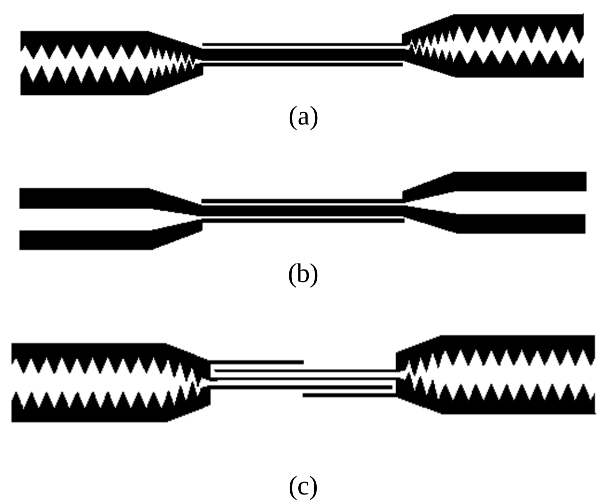


**Figure 2:** (a) 3-fingers with saw-tooth outer sections, (b) without saw-tooth, (c) Lange at centre with saw-tooth outer sections.

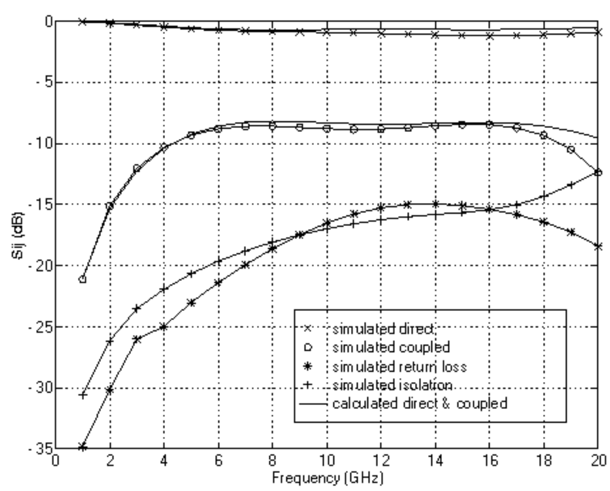


**Figure 3:** Libra™ simulation and calculated response

The second design employs the standard 4-finger interdigitated coupler as the centre section, with saw-tooth coupled line as the outer sections (Fig. 2(c)). Both couplers were designed to provide -3 dB equal power splitting over 6-18 GHz, with a maximum of 0.8 dB deviation. The couplers were designed and simulated using the HP Libra™ and Momentum™ package. Designs were produced for 254 µm alumina since it facilitated the design of RF probe pads so the couplers could be accurately characterised using a probe station and TRL calibration techniques. The simulated response from Libra™ and Eq. (1) for the second design are compared in Fig.3. Similar response were obtained for the first design.

## MEASURED RESULTS

The designs were fabricated on 254 µm alumina and measured using GMMT RFOW test facilities. The measured response of the first-run 3-finger coupler (Fig. 2(b)) without compensation is shown in Fig. 4(a). The coupling degrades rapidly with frequency, which is expected and also occurs in a non-uniform line coupler without compensation.

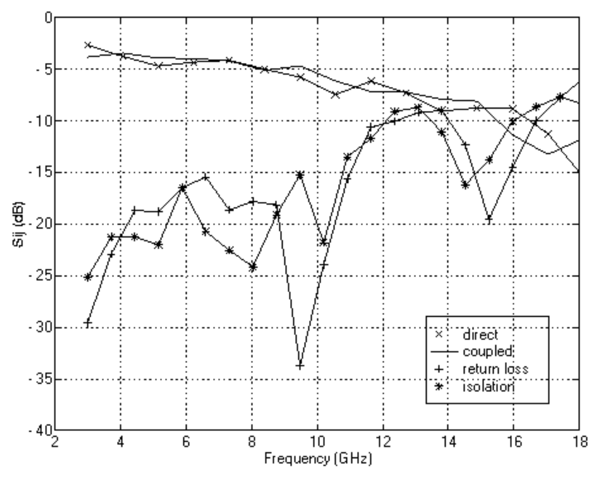


**Figure 4(a):** 3-finger coupler without compensation

With saw-tooth compensation, the coupling response in Fig. 4(b) is improved significantly. The measured coupling is -3.4±1.3 dB over 3-16 GHz. The large ripple levels were mainly caused by over-coupling of the outer sections. Because the 3-finger coupler is not compensated, the even and odd mode phase velocity difference at high frequency caused errors in coupling. From Fig. 4(a), the measured return loss and isolation of the coupler without saw-tooth are below -7.5 dB over 3-17 GHz, while the use of saw-tooth compensation suppresses them to below -11.5 dB over the same bandwidth (Fig. 4(b)). The effectiveness of the saw-tooth compensation could be further optimised for improvement.

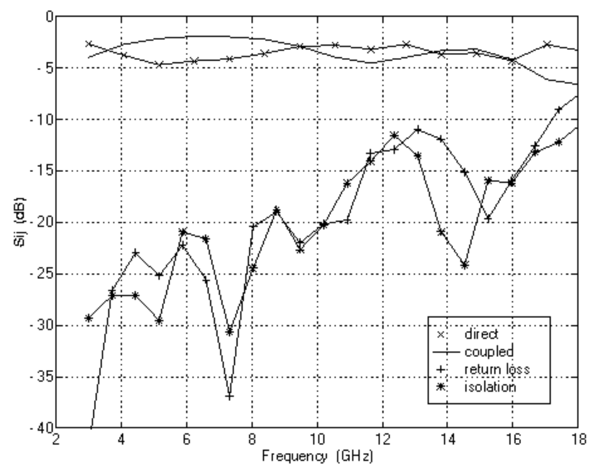


**Figure 4(b):** 3-finger coupler with compensation

The measured coupling and direct ports of the 4-finger coupler with optimised saw-tooth compensation are shown in Fig. 4(c). Both direct and coupling are -3±0.7 dB over 4.5-17.4 GHz. The coupling response at high frequency is improved because the even and odd mode fields are more evenly distributed in the 4-finger centre section, as compared with the 3-finger coupler. The measured isolation is better than -14 dB over 3-18 GHz, while the return loss is better than -14 dB over the same bandwidth, with worst case of approximately -12 dB at 18 GHz. The phase difference between the direct and coupled is 90±6° below 17 GHz, as shown in Fig. 4(d). Although the centre frequency is 0.5 GHz lower than expected, but the 4.5:1 bandwidth requirement is met.

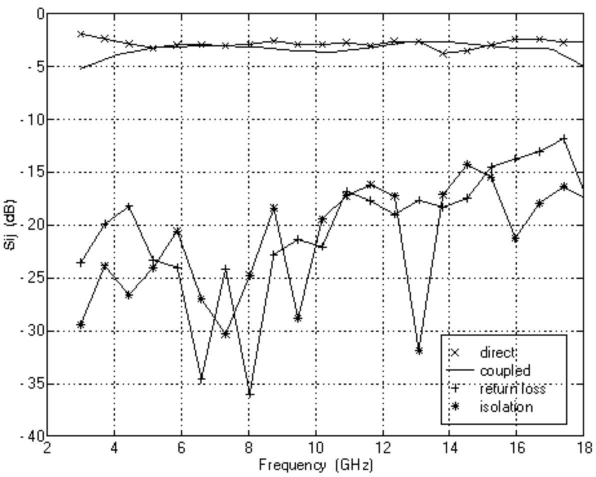


**Figure 4(c):** 4-finger coupler with compensation

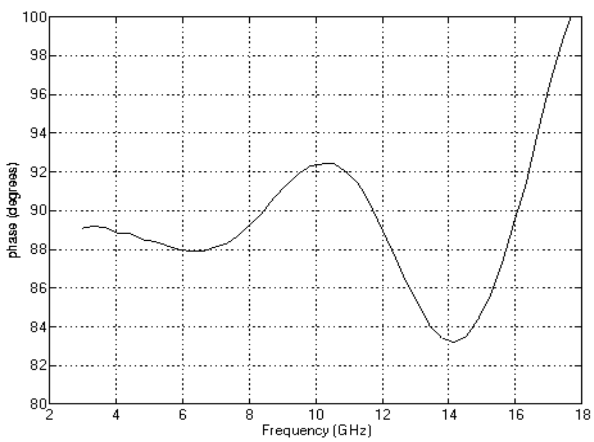


**Figure 4(d):** phase difference between direct and coupled port for 4-finger coupler

## CONCLUSION

A new microstrip multi-section coupler design technique has been developed and verified against coupler measurements. The technique permits the design of high performance, very broadband couplers, similar to non-uniform couplers but by a much simpler technique. The inclusion of a linear tapered section provides the following advantages:

- a good approximation of the whole coupling,
- a reduction in discontinuities, and
- easy simulation in a standard simulator for a coupler of any number of sections.

The measured results show -3 dB coupling ±0.7 dB from 4.5 to 17.4 GHz, and -14 dB isolation, which exceeds the performance of standard multi-section microstrip couplers.

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