Microstrip directional coupler with nearly ideal TEM coupler performance

S.-M. Wang, M.-Y. Hsieh, C.-H. Chiang and C.-Y. Chang

A meandered parallel coupled-line structure is proposed to achieve high directivity within a wide bandwidth. By properly increasing the meandered parallel coupled-line sections, the high-directivity bandwidth becomes much wider. An example coupler is fabricated to verify the theory. More than 50 dB of isolation is achieved over a bandwidth of zero to twice centre frequency.

Introduction: The microstrip parallel coupled-line structure has many applications in various microwave circuits because of ease of design and fabrication. However, the different modal phase velocities owing to inhomogeneous medium induce poor directivity for a coupler, spurious passband for a filter, unbalanced performance for a balun, and many other unwanted effects in these circuits. Therefore, a microstrip parallel coupled-line structure that has nearly TEM behaviour is essential in many applications. Results from [1–3] indicate that high directivity can be obtained by using a lump component, dielectric overlay and wiggly inner edge, respectively. In [1, 2], however, extra material and components are needed. In addition, the sizes of [1–3] are too long owing to their straight structure. The work in [4] meanders the coupled line to shorten the circuit size. It also indicates that the even-mode phase velocity can be speeded up more than the odd mode. Therefore, we can equalise the modal phase velocity by optimising the meandering and get a good isolation. However, the work in [4] does not observe that the multi-meandered coupled line has the ability to obtain high directivity over a wide bandwidth, so that the bandwidth of high directivity is not wide enough. In this Letter, based on the scheme of known meandered coupled line, we improve the microstrip coupler to have a nearly ideal TEM performance over a bandwidth of DC to twice the centre frequency. The behaviour and design procedures of the coupler are described in detail.

Theory: The proposed multi-section meandered parallel coupled-line is shown in Fig. 1, which is formed by cascading of several identical unit meandered sections. As [4, 5] indicate, a meandered parallel coupled-line can speed up the even-mode phase velocity by reducing the length of d, and the dispersive effect of the Schiffman section makes the response of the even-mode transmission phase θ_e against frequency to be a curve. Unfortunately, because the response of odd-mode transmission phase θ_o is almost unchanged during meandering and it is still a straight line, the modal transmission phases would only intersect each other in narrow bandwidth and make the bandwidth of high directivity not wide enough.

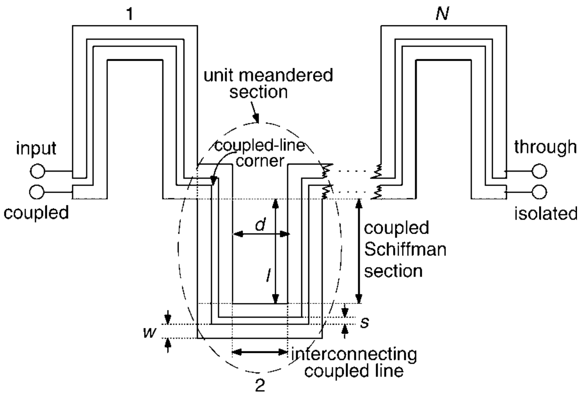

Fig. 1 *Proposed meandered parallel coupled-line coupler with N meandered sections*

Dimensions (mil): $w = 16.5$, $s = 7.5$, $d = 2.5$, $l = 119.5$

Fig. 2 shows the transmission phase of the conventional and proposed couples. Here, we pay attention the bandwidth between 0 and $2f_o$, which is the main operation bandwidth of a coupler. In Fig. 2, the modal transmission phases of the conventional parallel coupled-line coupler are shown as solid lines. In addition, in order to explain conveniently, we neglect the tiny variation of the odd-mode transmission phase caused by meandering. The even-mode transmission phases of the whole coupler with one, two and five meandered sections are shown in Fig. 2. In Fig. 2, the θ_e with one meandered section is a curve, and as the meandered section increases, the even-mode transmission phase approaches a straight line. The dispersion curve of the θ_e approaches a straight line because only a small portion of the θ_e curve is taken as the number of sections increases. Therefore, θ_e can approach θ_o over a very wide bandwidth. This was not indicated in [4]. Based on the scheme, a microstrip coupler with nearly ideal TEM coupler performance can be achieved over the entire coupler bandwidth.

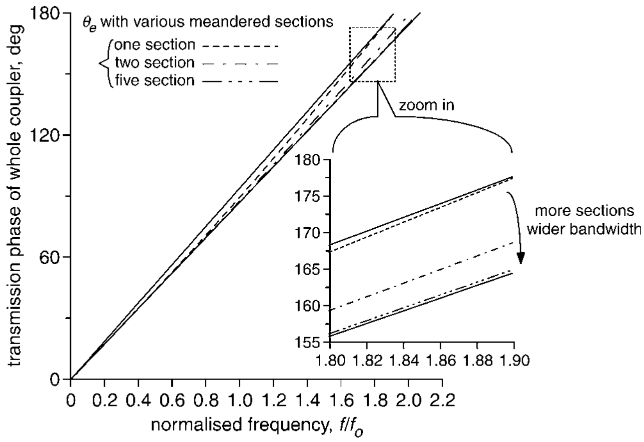

Fig. 2 *Modal transmission phases of conventional parallel coupled-line coupler (solid lines) and even-mode transmission phase with single, two, five meandered sections*

Design and realisation: Because an ideal TEM coupler repeats its response every $2f_o$, the target of the design is to equalise θ_e and θ_o within $2f_o$ (i.e. within the first period of response). We take a coupler of $f_o = 1$ GHz as a design example. The circuit is fabricated on an 8 mil Rogers RO4003 substrate with dielectric constant of 3.38.

To achieve the design goal, we implemented the coupler with five unit meandered sections. As shown in Fig. 1, the unit meandered section comprises an interconnecting coupled line, a coupled-Schiffman section, and four coupled-line corners. Because there are no analytical equations for a unit meandered section, we must use a circuit simulator such as Agilent ADS or AWR Microwave Office to analyse the behaviour of the unit meandered section. The models used in the circuit simulation are described as follows. The interconnecting coupled line uses the standard microstrip coupled-line model in the circuit simulator. The coupled-line corners and the coupled-Schiffman section are modelled in most circuit simulators based on a look-up table of EM results. Using a circuit simulator can quickly achieve the required design parameters. Before cascading the unit meandered sections, we used the circuit simulator to extract optimal dimensions of w, s, l and d (Fig. 1). These dimensions have different weightings for the coupler's modal characteristic impedances and modal transmission phases. To obtain the desired coupling (20 dB for this example), the goal of even- and odd-mode characteristic impedance should be 55.3 and 45.2 Ω, respectively. Because the dimensions w, s, and d have larger weightings than l for the modal characteristic impedances of the coupler, we optimise w, s, and d in the circuit simulator to obtain the desired modal characteristic impedances. On the other hand, to make the centre frequency locate at 1 GHz, the θ_o should be 18° (90° divided by 5) at 1 GHz and θ_e must be as close to θ_o as possible. The dimensions d and l have larger weightings than w and s for the modal transmission phases of the meandered section. The desired modal transmission phases can be obtained by adjusting d and l. However, because the modal characteristic impedances and modal transmission phases affect each other during the adjusting process, iteration is needed. After obtaining the appropriate dimensions of the unit meandered section, the coupler design is completed by cascading five identical meandered sections. Finally, the whole coupler is fine-tuned by the EM simulator Sonnet.

The EM-simulated and measured coupling, return loss and isolation are shown in Fig. 3. Good matches are observed. The Figure also shows the simulated and measured isolations; both have excellent response of below −50 dB from 0 to 2 GHz. Also in Fig. 3, the isolation of a conventional straight 20 dB coupler is measured for comparison, and a significant improvement can be observed.

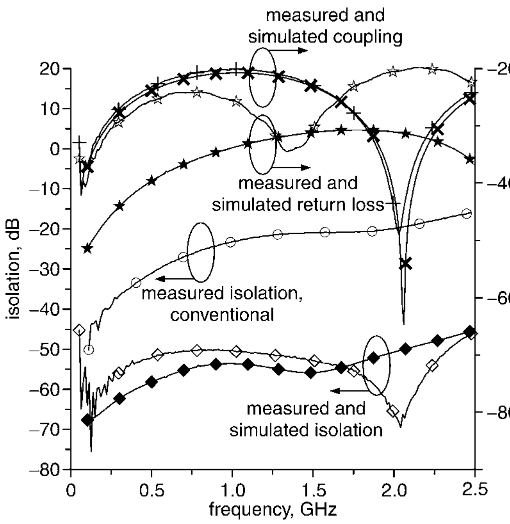

Fig. 3 *Simulated and measured coupling, return loss, and isolation of proposed coupler*

Measured isolation of conventional coupler with same specification shown for comparison

Conclusions: The proposed microstrip multi-section meandered parallel coupled-line has successfully achieved nearly ideal TEM performance over a bandwidth of 0 to $2f_o$. Significant size reduction is also obtained. The coupler uses no additional materials, components, and fabricating process. The ideas of speeding up the even-mode phase velocity by a meandered section and straightening the dispersion of the even-mode phase angle by dividing the coupler into multiple meandered parallel coupled-line sections are proven to be successful. The design procedures have been described in detail. Good agreement of simulated and measured results has been achieved. Finally, the proposed coupler has shown an excellent isolation of 50 dB over a bandwidth of 0 to 2 f_o (0 to 2 GHz).

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References

1 March, S.L.: 'Phase velocity compensated in parallel coupled microstrip', *IEEE MTT-S Int. Microw. Symp. Dig.*, 1982, **82**, (1), pp. 410–412

2 Klein, J.L., and Chang, K.: 'Optimum dielectric overlay thickness for equal even- and odd-mode phase velocities in coupled microstrip circuits', *Electron. Lett.*, 1990, **26**, pp. 274–276

3 Uysal, S., and Aghvami, H.: 'Synthesis, design, and construction of ultra-wide-band nonuniform quadrature directional couplers in inhomogeneous media', *IEEE Trans. Microw. Theory Tech.*, 1989, **37**, pp. 969–976

4 Rehnmark, S.: 'Meander-folded coupled lines', *IEEE Trans. Microw. Theory Tech.*, 1978, **26**, pp. 225–231

5 Wang, S.-M., Chen, C.-H., and Chang, C.-Y.: 'A study of meandered microstrip coupler with high directivity', *IEEE MTT-S Int. Microw. Symp. Dig.*, 2003, pp. 63–66