AN IMPROVED MULTI-LAYER QUADRATURE COUPLER FOR MMICs

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ABSTRACT

A novel technique for significantly reducing the insertion loss of multi-layer quadrature couplers is presented.

With previous broadside multi-layer couplers, realized on GaAs MMICs, the upper conducting layer track is overlayed exactly onto the much thinner lower conducting layer track – resulting in a high insertion loss. A new multi-layer structure is presented that has an upper track which is offset – so that the lower track can be plated-up with the much thicker metal from the upper track, thus, reducing the even-mode insertion loss.

A coupler, with a centre frequency of 7.7GHz, incorporating this technique has been realized on a GaAs MMIC, with maximum dimensions of only 1.1x0.8mm. The resulting insertion loss at centre frequency is less than 1dB. The overall performance has been found to equally match that of the Lange coupler.

INTRODUCTION

Multi-layer quadrature couplers have been around for the past two decades, being realized with both hybrid [1] and MMIC [2] technologies. The resulting broadside-coupling offers the advantage of very tight coupling over the traditional edge-coupled 2-line coupler. The design layout is less intricate than those required for interdigitated couplers, such as the Lange coupler, which has been used on MMICs for many years [3]. Also, since the conductive tracks of the multi-layer coupler are much wider than those used for interdigitated couplers, they are less sensitive to process variations.

With previous multi-layer couplers, realized on GaAs MMICs, the lower conducting track is made from the lower underpass metal, (titanium platinum gold). The upper conducting track, being overlapped exactly onto the lower track, is made from the upper bulk metal, (gold). Inherently, the resulting insertion loss is high with this structure, due to the very thin lower track.

In order to overcome the high even-mode insertion loss, a new multi-layer structure is proposed. Here, the upper track is offset so that, with the aid of a suitable dielectric via, the lower track can be plated-up with the upper bulk conductor metal.

The cross-section of the coupler is illustrated in Figure 1. It can be clearly seen that significant edge-coupling, as well as broadside-coupling, occurs between the two tracks. This additional edge-coupling helps to compensate for the reduction in the broadside-coupling, due to the offset process.

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COUPLER FABRICATION

The structure presented here was fabricated at the GEC-Plessey foundry.

The conductor tracks are 30μm wide. The lower conductor layer track is very thin and normally used for the underpass connections of spiral inductors and to produce schottky barriers junctions for the gates of MESFETs. The upper conductor layer track has a thickness that is six times that of the lower conductor layer track and normally used for plating-up Ohmic contacts and forming transmission lines.

The tracks are separated by a thin dielectric layer (polyimide), with a small relative dielectric constant. This layer is traditionally used for realizing low valued capacitors.

The semi-insulated GaAs substrate is 200μm thick, with a high relative dielectric constant, and coated with a thick gold backface for the ground plane.

The total length of the coupler is 3.3mm, corresponding to a centre frequency, Fc=7.7GHz. The coupler is folded using four bends in order to reduce its aspect ratio. It is important to keep the number of bends to a minimum, since the effect of the resulting discontinuities is to reduce the input return loss & isolation and degrade the phase quadrature performance. Also, sections of the coupled lines should be sufficiently spaced from the other sections, in order to reduce the resulting stray coupling from distorting the predicted performance. The resulting layout of the 1.1x0.8mm coupler is shown in Figure 2.

MEASUREMENTS

The MMIC chip was mounted in a 1.0x1.0 inch alumina chip carrier. Each MMIC bond pad was connected to its associated 50Ω microstrip feed line via two 17μm gold bond wires. Standard SMA launchers, attached to the brass sub-carrier, were used to interface between the microstrip lines and the external coaxial measurement cables. The complete test jig is shown in Figure 3.

A Hewlett Packard 8510B automatic network analyser was used to make 2-port measurements. The results of these measurements are given in Figure 4. It can be seen in Figure 4(a) that a coupling of 3.6dB is measured at centre frequency, with a 1.4dB insertion loss. However, with an ideal test jig, the coupling is expected to increase to below 3dB and the insertion loss to decrease to below 1dB. An excellent match is obtained at the input port – resulting in a return loss of better than 14dB up to 1.40Fc. A good isolation of better than 11dB is obtained up to 1.43Fc. There are many well documented techniques for equalizing the even and odd-mode phase velocities to further improve the isolation [4,5]. Figure 4(b) shows near perfect phase quadrature, with an imbalance of only ±2° up to 1.49Fc. It can be seen from these power and phase responses that this offset multi-layer coupler equally matches the octave bandwidth performance of the Lange coupler.

Due to the non-idealities associated with the test jig and the matched load terminations, the rigorous procedure of de-embedding the six required sets of 2-port network measurements; embedding the four sets of 1-port load termination measurements and then the final matrix renormalization were not performed. This is because of the inherent difficulties in fully characterizing the non-idealities of the complete test jig. As a result, the performance of the coupler is expected to be much better than that portrayed in the 2-port measurements.

MODELLING

In order to develop this new type of coupling structure further, a simple means of modelling the couplers transmission and coupling performance was needed. It has been found that crude
conformal mapping techniques can be adopted. Here, offset coupled transmission lines in a stripline structure [8] gives a close match to the measured performance, as shown in Figure 5. In this model, the distance between the tracks and both ground planes remains the same. The width; offset and vertical separation of the tracks must be scaled down by approximately a factor of two – in order to compensate for the approximate halving of the even and odd-mode impedances when mapping directly from a microstrip to a stripline structure. From the resulting model, LINCALC shows an even-mode impedance of 119Ω; an odd-mode impedance of 16Ω; a coupler impedance of 43Ω and a coupling of -2.3dB – all at centre frequency.

CONCLUSIONS

When compared to the directly overlayed MMIC structure, this new offset MMIC structure results in a significant reduction in the insertion loss as well as a much improved phase quadrature performance. The electrical performance of the offset multi-layer coupler has been found to equally match that of the octave bandwidth Lange coupler. However, when compared with the Lange coupler, the offset multi-layer coupler eliminates the need for air bridges/underpass connections, thus, improving yield. Also, its variable aspect ratio enables greater layout flexibility for the designer.

3dB coupling can be achieved by simply reducing the amount of overlap. This will increase the impedance of the coupler. However, since the impedance of the coupler is in the order of 43Ω and, therefore, less than the desired 50Ω, the reduction in the overlap will prove useful. A further increase in the coupler impedance can be made by carefully reducing the width of the tracks. The resulting desired value of coupler impedance will make an even greater improvement in the input return loss and isolation.

In order to overcome the difficulties in achieving true coupler measurements when using non-ideal test fixtures, wafer probeable MMIC couplers must be designed. As a result, the relatively simple procedure of matrix renormalization [7] can be adopted to give accurate measurements.

From the cross-section, in Figure 1, it can be seen that the coupler has irregular conductor geometries in a multi-dielectric medium. This is due to the restrictive design rules imposed by the foundry. Therefore, in order to obtain accurate predictions for the couplers performance, a powerful software tool, such as the SFPMIC+ 3D electromagnetic simulator [8], is required to perform the rigorous numerical full-wave analysis.

REFERENCES


Fig 1: Cross-section of the offset multi-layer coupler

Fig 3: MMIC coupler in its test fixture
Fig 4: Measured (a) Power; (b) Phase quadrature characteristics

Fig 5: Measured and modelled characteristics of the Transmission & Coupled responses