An Inverted Coplanar Coupler with Integral Microstrip Interfaces and Bias Crossover

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Abstract -- **An inverted coplanar 3 dB quadrature coupler was developed for application in hybrid power amplifiers. The structure was realized on an alumina substrate using conventional thick-film construction. It includes direct microstrip interfaces and a bias crossover, both of which support compact integration of power amplifier circuits. Designs for the PCS and UMTS communications bands achieved 0.2 dB insertion loss and directivities and return losses of nominally 25 dB.**

I. INTRODUCTION

3 dB quadrature couplers have been widely applied in numerous microwave circuits, including amplifiers, mixers, single-sideband up- and down-converters, and vector modulators. The motivation for this development was to realize a balanced power amplifier, in which the input and output matches are assured by the quadrature coupled topology [1]. This quadrature-balanced amplifier topology has been very widely applied in our industry.

Coplanar coupling structures were introduced by C. P. Wen in 1970 [2]. Examples of coplanar coupler structures potentially suitable for realization with thick-film fabrication are those by E. A. Frick [3] and R. E. Stegens [4]. In all of these realizations, the coupler and the feeds (port accesses) are of coplanar nature. In this work, our goal was to design as an integral part of the coupler, interfaces with standard microstrip traces (our preferred media for the amplifier matching circuitry). Overall hybrid amplifier compactness was also a priority. This led to investigation of inverted coplanar structures with the coupler lines on the ground-plane side of an otherwise conventional microstrip topology, in which the launches to the inverted coplanar coupled lines were made directly from topside microstrip lines through connection with vias.

II. DESIGN DESCRIPTION

The preferred hybrid amplifier embodiment was, in our case, a standard microstrip circuit on 0.5 mm thick alumina, mounted on a thick metal carrier (which also served as a heat sink for power transistors). This development was constrained by a goal of minimizing fabrication costs, and in particular, of employing thick-film hybrid construction using a single alumina substrate (as opposed to, for example, a multilayer LTCC substrate). We chose to design a coupler that could be fabricated using readily achievable minimum spaces of 5 mils (127 microns) and minimum line widths of 10 mils (254 microns). These constraints led to consideration of multiple coupled coplanar lines as the main coupling elements, in an inverted coplanar structure, as shown in Figure 1. The dimensions of this cross section were chosen to support manufacturing preferences for a power amplifier, not necessarily the optimum situation for coupler realization.

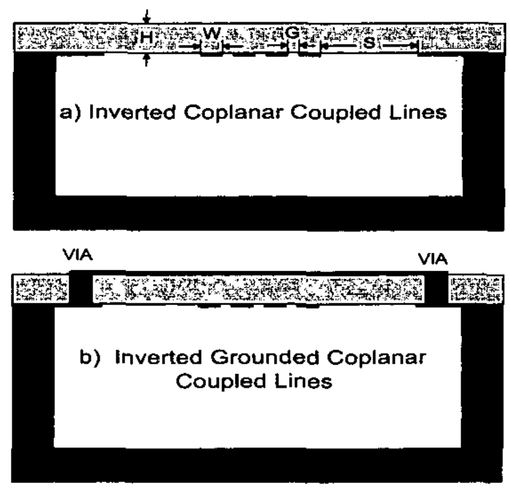

Figure 1. Coupled Line Cross-Sections

Although the coupled line cross section is central to the operation of the coupler, the operation of the total coupler was found to be particularly sensitive to the manner in which the four coupled lines were connected at the launches of the coupler. In addition, we wished to examine various combinations of inverted coplanar lines (Figure 1a) and grounded inverted coplanar lines (Figure 1b).

Analysis was facilitated by separating the coupler into sections, as shown in Figure 2. The computational problem was partitioned, thereby facilitating rapid calculation of performance when varying individual

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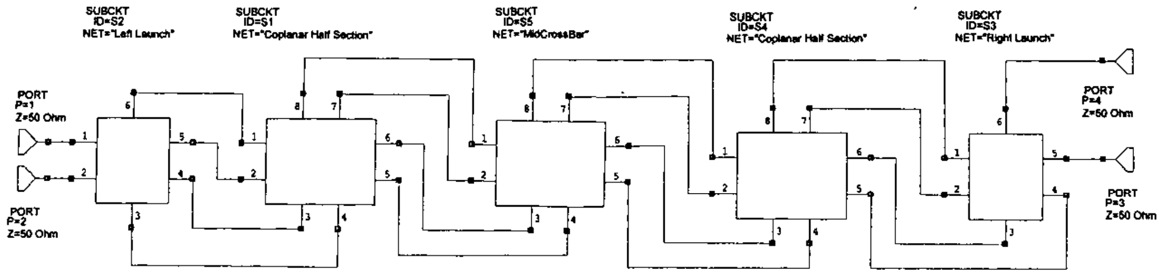

Figure 2. Block Diagram Used for Synthesis & Circuit Optimization

sections of the structure.

Separate circuit sections included launches (left & right sides), uniform 4 coupled line sections, and a center section with a grounded coplanar line segment (simulating the bias crossover). The analysis was performed using EMSight, a field-solver program integrated into the Microwave Office CAD program (a product of Applied Research Inc.). Typical computation times were only a few minutes using a laptop computer with a 750 MHz Pentium III processor and 500 MB of RAM. This allowed a wide variety of circuit variations and combinations to be efficiently examined.

After approximate optimization of the 4-coupled line main sections, the design focused on the launches. It was determined that it was possible to synthesize low VSWR launches with top-side microstrip sections interconnected to the bottom-side coplanar lines with simple vias (modeled as rectangular, realized as round). This arrangement is shown in Figure 3. It was determined that low impedance launch (top surface) sections were necessary for low port VSWR. These capacitive sections were apparently necessary in part to compensate for the inductance of the vias.

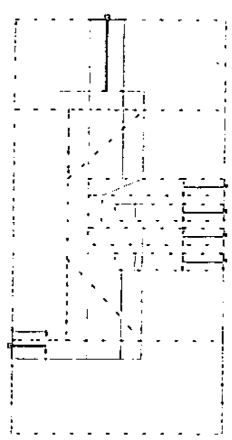

Figure 3. Left Launch (top surface) to 4 Inverted Coplanar Lines (on bottom surface).

Another objective of the coupler development was to find a convenient method of integrating a coupler cross-over, to facilitate routing of DC bias to the balanced FET amplifier circuitry (between two quadrature couplers).

It was determined that a small central segment of grounded coplanar line (see Figure 4) could be accommodated, and that in fact it could improve the overall directivity of the total composite coupler. The ground section was then DC isolated (connection to ground was made using bypass capacitors in the final physical coupler), thereby forming a bias crossover in the center of the coupler.

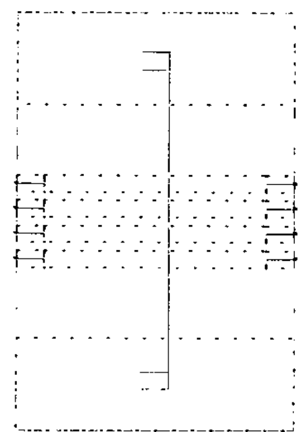

Figure 4. Center Section of Grounded Inverted Coplanar Line (ground strip is on top side of substrate)

III. Coupler Layout and Calculated Performance

The dimensions of the designs for PCS and for UMTS couplers are given in Table 1. The goal was to achieve coupling values between equal amplitude (critical coupling) to 0.5 dB over-coupling, concurrent with input and output return losses and directivity exceeding 20 dB, for at least 180 MHz of bandwidth (three times the nominal UMTS or PCS communications bandwidth).

The actual coupler layout is very similar to the simulated structure. The interconnects at the four line ends were rounded to minimize electrical length of the launches, and the via holes are round (12 mil diameter).

Table 1 – Coupler Dimensions (mils)

Parameter	PCS	UMTS
Substrate Thickness, H	20	20
Line Width, W	12	12
Line-to-Line Space, G	6	6
Line-to-Ground Space, S	52	52
Coupled Line Length	600	520

Additional coupler parameters include: Metal thickness: 10 microns, passivation overlay: 5microns, substrate distance above the ground base: 96 mils; via diameter: 12 mils.

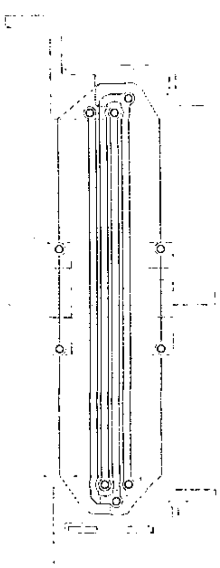

Figure 5. Coupler Layout Top View (includes bias crossover in center)

The actual coupler has a thin layer of passivation (5 microns thick, with a dielectric constant of approximately 10), which was also included in the analysis. The center section is the DC cross-over. Four surface mount capacitors (size 0603) are added to provide RF ground connections (it is DC isolated from ground).

Calculated coupler performance is presented in Figure 6. The degree of coupling can be adjusted by varying the gaps, G, as well as the line-to-ground space, S. The frequency band of operation is determined by the length of the coupled section.

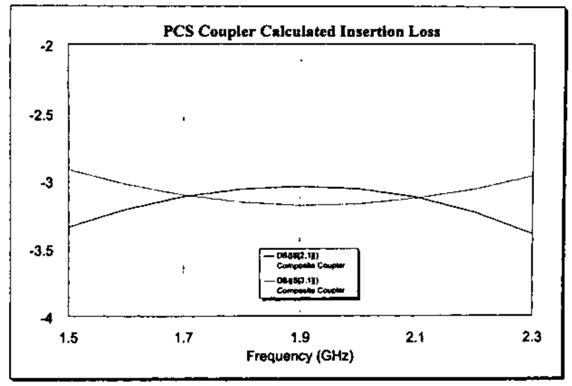

Figure 6a. Calculated Coupler Insertion Loss

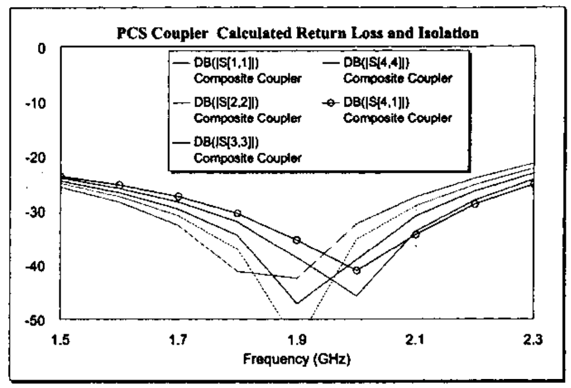

Figure 6b. Calculated Coupler Return Loss & Isolation

IV COUPLER EXPERIMENTS & MEASUREMENTS

The test couplers were fabricated on 0.5 mm (20 mil) thick alumina substrates. Topside and groundplane metal was thick-film palladium-silver, whereas coupled line metal was thick-film gold (chosen because it can be defined with better resolution). The fabricated couplers differed slightly in critical dimensions relative to the targeted design dimensions. In particular, the actual line-to-line gap, G, was 6.6 versus the target of 6.0 mils. This led to very slight (0.1 dB) undercoupling, as demonstrated by the measured data of Figure 7. The coupler launches were laid out to be slightly smaller than that suggested by the analysis, and small tweak pads were included, thereby allowing some empirical adjustment of launch capacitance. The typical launch had two small tweak pads (each 10 X 20 mils) added.

The measured insertion loss of Figure 7 is the total due to the coupler plus all fixture transmission lines and connectors. The typical test fixture included a 1.20 inch length of 50-ohm line (input-to-output) in addition to the coupler. Two additional test substrates were fabricated – one including two back-to-back couplers, and another with a 50-ohm thru-line. It is estimated that the actual ("corrected") coupler insertion loss equals one-half the loss of the back-to-back couplers minus the loss of the thru-line between the same connector locations. The "corrected" insertion loss (loss above the ideal coupling value) was determined to be only 0.2 dB for both the PCS and UMTS couplers.

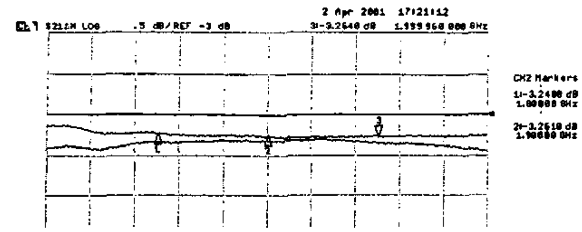

Figure 7. Measured PCS Coupler Transmission Loss (Frequency scale: 1.70 – 2.10 GHz, 40 MHz per division. Loss scale: 0.5 dB per division)

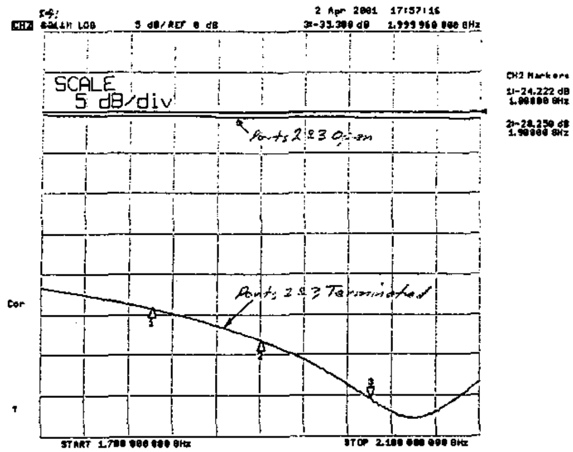

Figure 8 Measured PCS Coupler Isolation

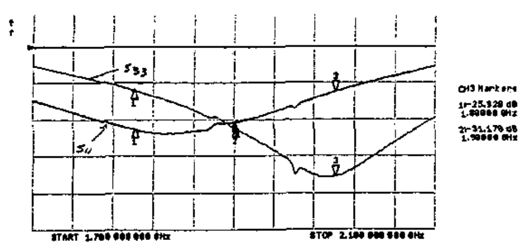

Figure 9 Measured PCS Coupler Return Loss (S11 & S33, reference line = -20 dB, scale = 5 dB/div)

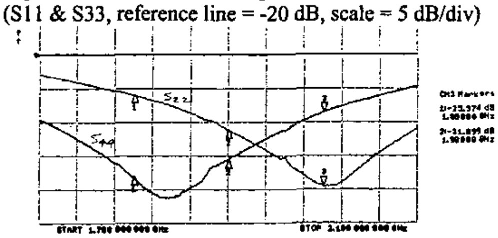

Figure 10 Measured PCS Coupler Return Loss (S22 & S44, reference line = -20 dB, scale = 5 dB/div)

The measured RF band center and bandwidth (at which coupling imbalance was 0.25 dB) was 1920 MHz (360 MHz BW) for the PCS coupler, and 2160 MHz (520 MHz BW) fro the UMTS coupler. The isolation of the DC crossover from the RF input exceeded 35 dB. Additional measurements were made of back-to-back couplers in a fixture with an opening in the metal base, so that the traces could be scanned with an IR camera to evaluate power handling by the couplers. It was determined that the maximum temperature rise was 32 degrees C with a continuous power of 30 Watts applied. Additional work is continuing on variations of the reported design to enhance power handling capability.

The coupler has been incorporated in compact power amplifier circuits using thick-film fabrication with a combination of distributed and surface-mount lumped-element matching [5].

V. CONCLUSION

A compact design of a 3 dB quadrature coupler appropriate for realization on an alumina substrate with typical thick film fabrication of traces was presented. The coupled transmission lines are bottom-side inverted coplanar lines, with launches realized in top-side microstrip media. Additionally, a center section of grounded coplanar line serves as a DC crossover for routing bias over the coupler in power amplifier applications. Both PCS and UMTS couplers were fabricated, and low insertion loss and good directivity and terminal VSWRs were demonstrated. These couplers are enabling structures for several hybrid power amplifier products.

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