FULL WAVE ANALYSIS OF 94 GHz PATCH COUPLER

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Abstract

This paper presents a full three-dimensional wave analysis of a patch microwave coupler operating at 94 GHz. The method of solution is a matched TLM numerical simulation of the inhomogeneous wave equation.

Amplitude and phase responses for the coupler are given for the frequency range 80-110 GHz. The effects of the package dimensions on coupler isolation and bandcentre are presented. The computed results are compared with published experimental results obtained for an empirically designed coupler. Field plots are presented for flux distribution on the patch. Radiation plots for the coupler are presented also.

Introduction

At millimetric frequencies conventional branchline hybrid couplers are not practical to implement in view of their small dimensions. Alternative planar structures are therefore required in order to operate at these short wavelengths. One such alternative was suggested by Burns[1] in 1985. Here the suggestion was to employ a rectangular microstrip resonator. The empirically described dimensions of the microstrip patch are given in [1] as:

$$a = b + w\sqrt{2} \qquad b = 0.46\ \lambda g$$

here a = length of patch, b = width of patch, w = width of feedline.

Previous attempts to validate the empirical design equations above at J-Band failed and alternative approximate equations based on a lumped equivalent model were produced [2]. No work has been reported to date on the behaviour of the coupler with frequency. This paper redresses this deficiency by using TLM simulation [3],[4] in order to account for both frequency and packaging effects and to establish details of field patterns around the coupler when operated at 94 GHz. Here an in-house expanded node T.L.M. computer program was modified to incorporate matching by terminating shunt nodes at the coupler output ports with an absorbing boundary, with a local reflection coefficient of

$$\rho = -\frac{\sqrt{\varepsilon eff} - 1}{\sqrt{\varepsilon eff} + 1}$$

ρ = reflection coefficient,
εeff = effective permittivity

Since ρ is calculated at a single frequency such a match exhibits narrow-band properties [3]. In this case the midband frequency 94 GHz is selected and effective permittivity computed by the traditional resonant mode TLM method [4], used this time for a quartz substrate. The main results of the analysis show that at 94 GHz, 3$\pm$0.5 dB coupling with 18 dB isolation can be achieved over an 8% bandwidth. The phase shift between output ports is 132 degrees.

Simulation and Results

The geometry in Figure 1 is used to define the coupler. Matched terminations are located as shown. The coupler is enclosed in a rectangular metal enclosure and excited with an impulse applied to port 1. The electromagnetic fields over the problem domain are solved by the TLM method [4]. Figure 2 shows the frequency response of the coupler from 80-110 GHz, reference [1] gives results of a single frequency only. An equal power split is obtained from ports 2 and 3 at 94 GHz. This is in exact agreement with the measured result given by Burns. Table 1 shows the TLM grid dimensions used. The computation time for this result is 140 seconds on a VAX 8650.

From Figure 2 the bandwidth is computed to be 8% for a power split variation of +/- 0.5 dB, against the 13% found experimentally [1]. The effect of coupler packaging has not been reported before and is summarised in Table 2. From this it can be seen how side wall and top cap proximity produce a 4% tuning range of the coupler centre frequency,while the maximum isolation variation is only 2.4 dB .

The value of -18 dB isolation achieved in simulation is in agreement with the open structure given in [1]. Studies of phase shift between output ports show this to be 132 degrees at 94 GHz, figure 3. This is at variance with

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the phase quadrature term applied in the title of paper [1]. However, it should be pointed out that as yet no experimental results for phase response have been published.

In order to investigate the physical mechanism operating within the device, sample field plots for the Ey component on the patch surface are shown in Figure 4. This shows the equal power split between ports 2 and 3 and the isolation at port 4. A similar study for radiation from the coupler is shown in figure 5. The results show that at a height of 1 dl above the patch surface radiation along the edge is about 8-10 dB down relative to the surface. In the centre of the coupler there is a reduction of 20-25 dB.

While the results of the thorough analysis presented above justify the experimental results for 94 GHz operation, attempts to apply the same empirical design formulae at lower frequencies results in inferior performance [2], [5].

Conclusions

This paper has presented a complete dynamic simulation of a 94 GHz patch coupler, a recent innovation in mm wave component design for which only limited experimental and no theoretical results have been reported to date. The agreement between simulated and experimental data is excellent. Additional circuit performance results not available until now have been presented.

References

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[3] Saguet et al, "TLM analysis of finline T-junctions for computer aided design", Proc. 17th EMC, Rome, September 1987, pp. 653-658.

[4] Akhtarzad, S., Johns, P.B., "Three-dimensional transmission line matrix analysis of microstrip resonators", IEEE Trans. MTT, vol 23, pp 990-997, December 1975.

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	Reference [1] (m)	TLM Simulation	dl
a	1130	1125	9
b	780	750	6
w	250	250	2
h	120	125	1

Table 1 Simulation Dimensions

Width (dl)	Height (dl)	Length (dl)	Frequency (GHz)	Isolation (dB)
11	7	16	97.5	-15.7
13	7	16	97.0	-16.8
15	7	16	96.5	-17.9
15	8	16	95.25	-18.0
17	8	16	95.0	-18.1
17	9	16	94.0	-18.1
19	9	16	94.0	-18.1

Table 2 Packaging Effects on 3 dB Patch Coupler

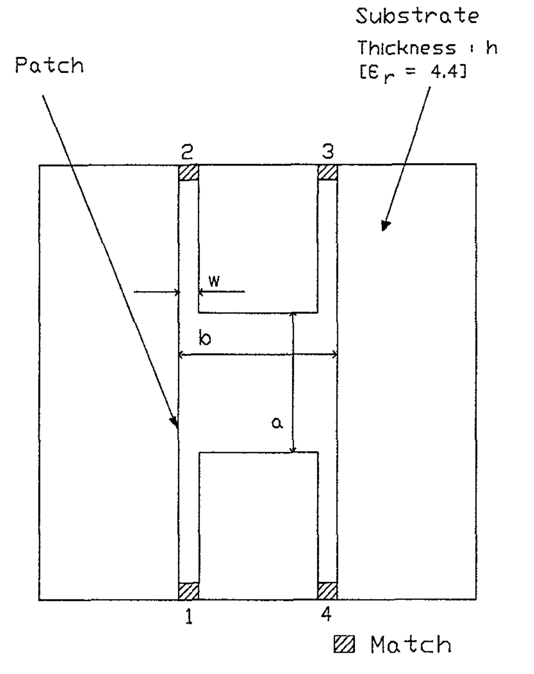

Figure 1. Geometry of Patch Coupler

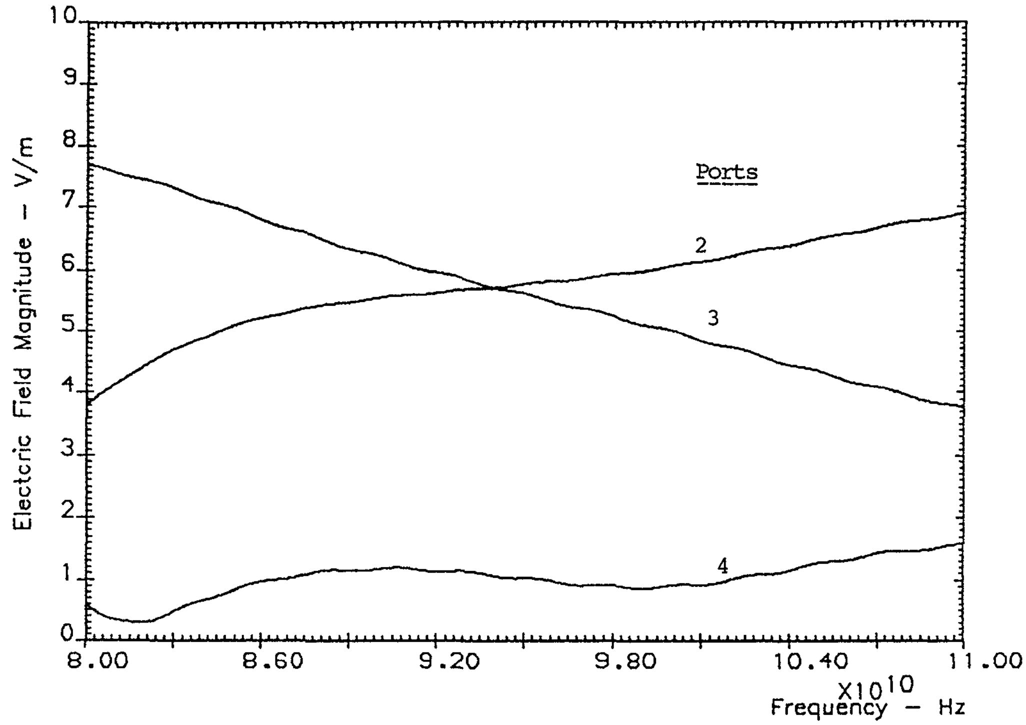

Figure 2. Electric Field Amplitude vs Frequency

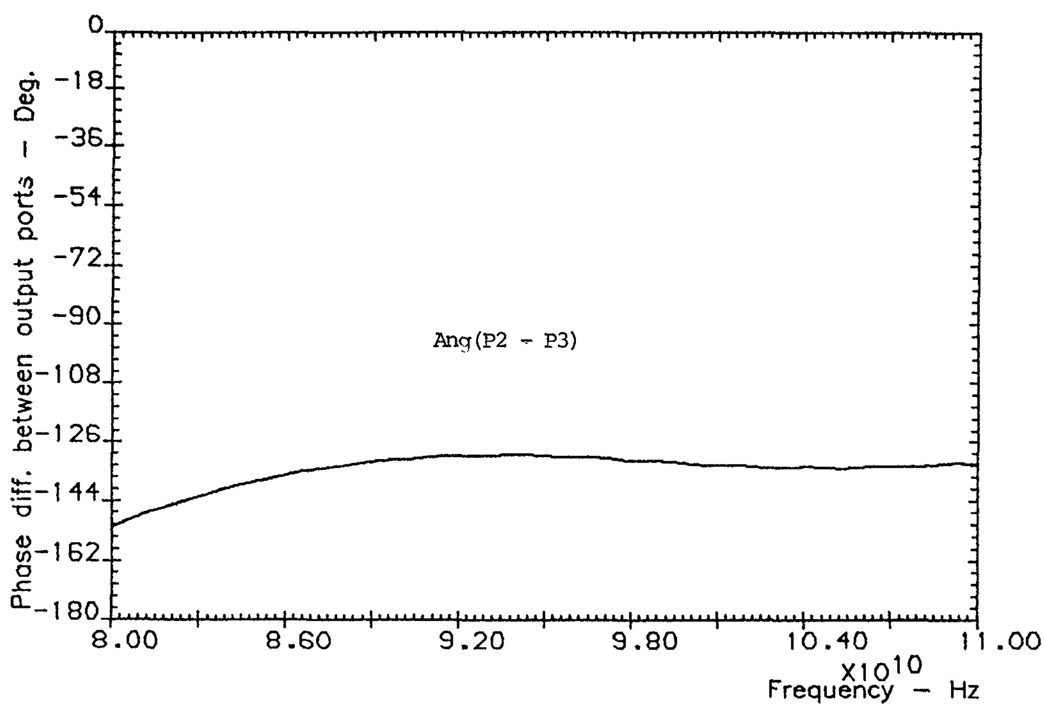

Figure 3. Phase diff. between output ports vs Frequency

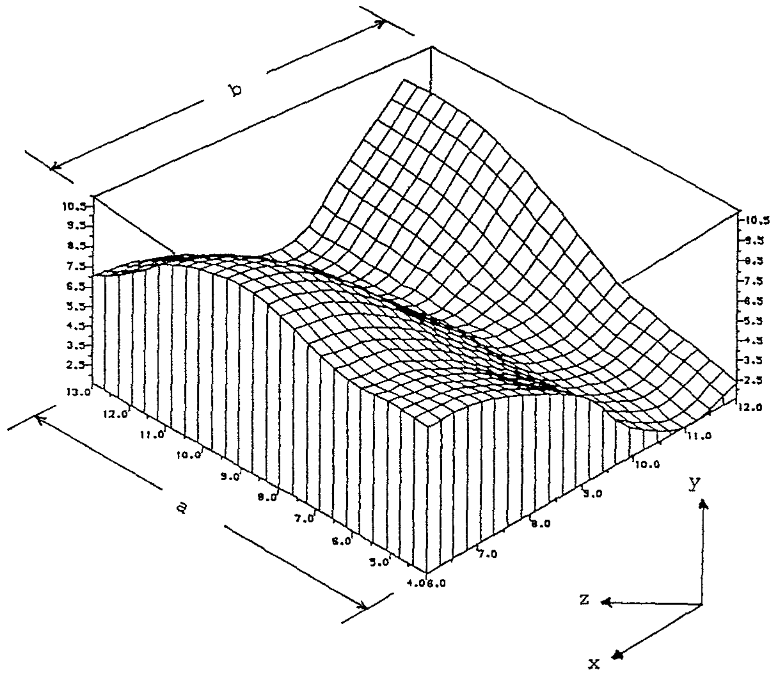

Figure 4. Ey on Patch Surface

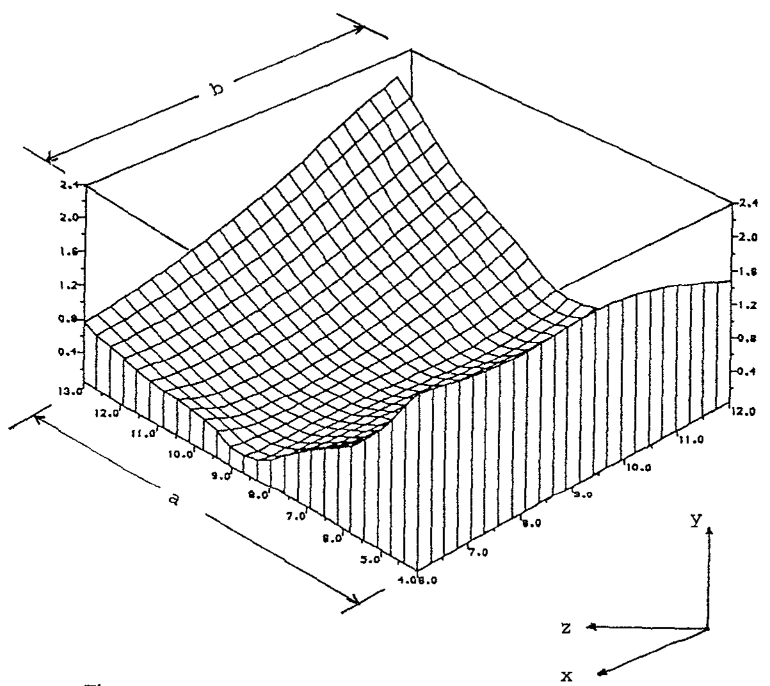

Figure 5. Ey 1 dl above the Patch Surface