# W-Band Fin-Line Broad-Band Directional Couplers with Different Coupling Ratio

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ABSTRACT ---- W-band broad band couplers, having 6, 10 and 3dB coupling ratio realized by coupled fin-line are reported. For looser coupling such as 6 and 10dB coupling we take advantage of over coupling configuration in order to lower the requirments of fin-line geometrical dimension. The experimental results of prototype couplers show a flat frequency response and low loss performance in a broad band.

## Introduction

Fin-line directional couplers have many advantages over other kind of couplers, such as compact size , low cost and low insert loss, easier fabrication and easier connection to other integrated planar components as well as conventional rectangular waveguide. It has a forward coupling and $90^{o}$ phase difference between the outputs from coupling port and direct port.

As far as the authors are aware, the most research work for fin-line directional couplers are limited in Ka-band and 3dB hybrid case. In W-band the commercial product of directional couplers are only waveguide type. But in many millimeter wave systems, however, the W-band directional couplers with low cost and small size, loose coupling are needed.

In this paper, the investigation of W-band fin-line directional couplers with different coupling ratio are described. The coupling is 3-,6-,10-dB respectively. The analysis is based on even- and odd-mode conception and spectral domain method.

It is well known that in fin-line couplers loose coupling is much difficult to realize than tight coupling due to strict tolerance requirements in fabrication. In our experiments 6 and 10dB couplers are realized by an overtight coupling mechanism. The majority of power from input port is coupled to coupled port and only a little part comes out of direct port.

The experimental results in W-band are quite good. For 3- and 10-dB couplers the coupling ripples in a bandwidth of 78-102 GHz are 0.5dB and 1dB respectively, for 6-dB coupler the ripple is 0.5dB from 83 to 102GHz. The insert loss of all of them is around 1dB.

## Coupling Equations

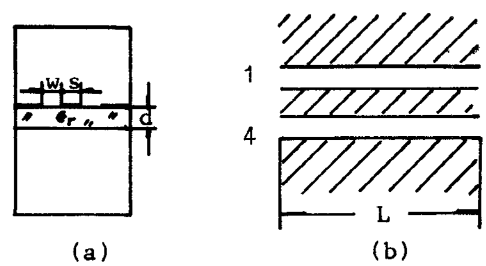


Fig. I coupled fin-line
(a) cross-section view
(b) top view

Fig. I shows two parallel slots in a fin-line directional coupler. Because of symmetry, such configuration can support odd and even mode. The voltages of two modes will propagate along the coupled fin-lines in different propagation constants $\beta_e$ and $\beta_o$. By superimposing principle one can obtain the following voltages at port 2 and port 3:

$$V_2=\cos\frac{\beta_e-\beta_o}{2}L \qquad (1)$$

$$V_3=\sin\frac{\beta_e-\beta_o}{2}L \qquad (2)$$

In which L is the length of coupling section. The coupled voltage depends only upon the difference of phase velocities when the length of coupling section is fixed.

The phase velocities $\beta_e$ and $\beta_o$ are computed by



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spectral domain method (SDM) [3]. The computed values of $\beta_e$ and $\beta_o$ against frequency shown in Fig. II reveal the following interesting points:

(a) Both $\beta_e$ and $\beta_o$ are approximatly linear functions of frequency.

(b) Their slop are nearly equal. The difference between $\beta_e$ and $\beta_o$ is nearly constant. This fact suggests that a potential of wide band property exists.

(c) By means of optimizing the various parameters of the coupler, it is possible to extend the frequency bandwidth as wide as possible.

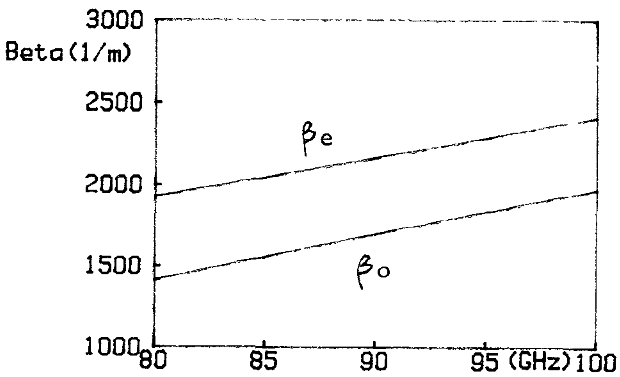


Fig. II curves of $\beta_e$, $\beta_o$ vs frequency

## Design of Fin-Line Directional Couplers

In principle, one can design the couplers with any coupling ratio from eqs. (1) and (2), for example, if ( $\beta_e - \beta_o$ )= $\pi/2L$, a 3dB coupler is obtained. This has been done in Ka-band fin-line couplers [1][2]. If loose coupling is desired, one has to decrease both w and L. But in a pratical coupler with shorter L, the influence from the bends will become dominant and the performance of coupler will be degraded. If w is decreased to some extent, the dimensional error caused by etching processing becomes signific ant and can not be neglected. Hence, in the case of very short length L and very narrow slot width the design becomes difficult.

Instead of decreasing L or w for loose coupling, we increase the width of slots and make the coupling between input port and coupled port very tight, so that only a little amount of power comes out of the direct port. If the direct port is taken as a coupled port then a loose coupling coupler is obtained. In our design an equal length of coupling section is used for different couplers. But the values of w and s are different for different couplers. This measure makes the design much more easier.

## Experimental Results

A set of W-band fin-line couplers of 3-, 6- and 10-dB coupling have been tested. The practical circuit configuration of them is shown in Fig III, and fabricated on Duroid 5880 substrate ( $\varepsilon_r$=2.22).

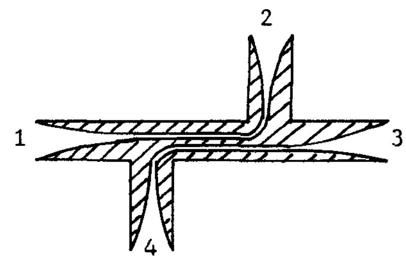


Fig. III circuit of fin-line directional coupler

For 3dB and 6dB couplers the coupling ripple is less than 0.5dB, and for 10dB, 1dB ripple is obtained. The isolation is greater than 20dB in the frequency range of 78-102GHz for 3dB and 10dB couplers. For 6dB coupler the bandwidth is 83-102GHz, it is narrower than others. It is perhaps due to the imperfect design of fin-line taper.

Fig. IV shows the measured results. Some quantities are defined as follows:

$$S_{i1} = \frac{P_i}{P_1}, \quad i=2,3,4$$

All couplers have an insertion loss around 1dB, which is calculated by the following equation:

$$\text{Loss} = 10\lg \frac{P_2+P_3}{P_1}$$

The size of metal housing of the couplers is 24*20*20(mm)$^3$. Its photograph is shown in Fig. V.

## Conclusion

The W-band fin-line broad band directional couplers with different coupling ratio have been developed. The main advantages of fin-line directional couplers over waveguide couplers are low cost, compact size and low insertion loss. The developed couplers have been used in a millimeter wave modulator(3dB coupler) and a single-end mixer of a front-end(10dB coupler).

Acknowledgement

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References

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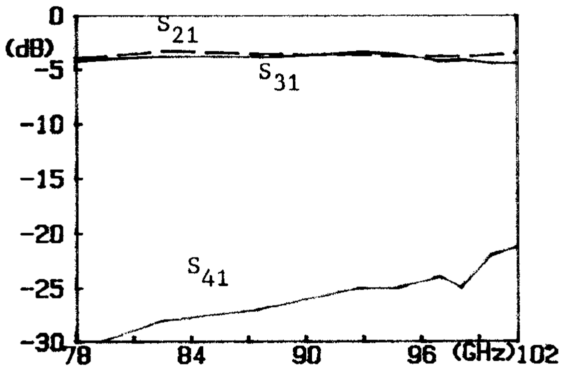
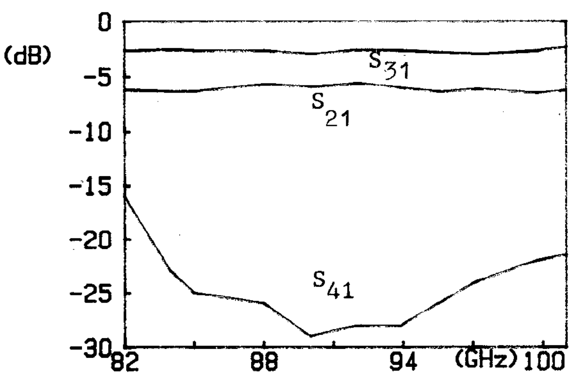
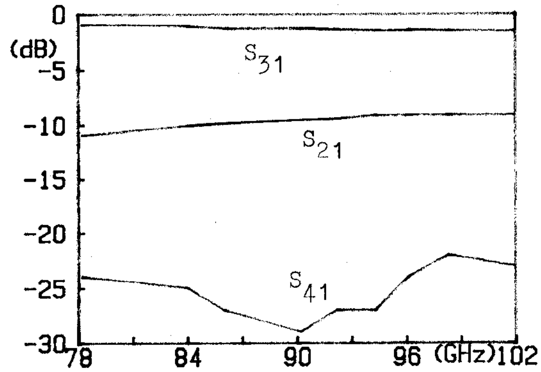



(a) 3dB coupler




(b) 6dB coupler




(c) 10dB coupler

Fig.Ⅳ performances of W-band fin-line directional couplers

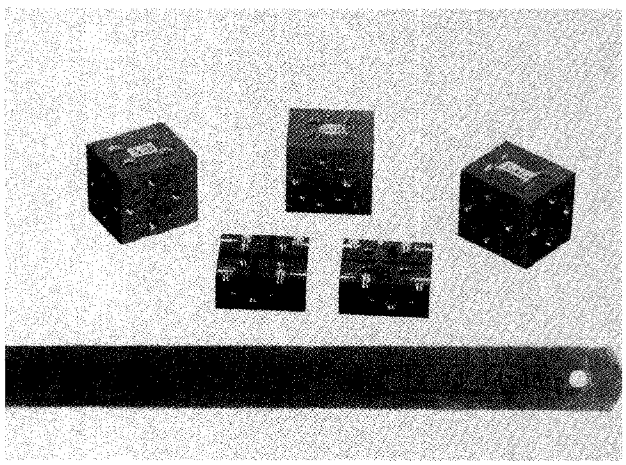


Fig.V photograph of W-band fin-line directional couplers