WIDEBAND CROSSED-GUIDE WAVEGUIDE DIRECTIONAL COUPLERS

P Meyer (MIEEE) , JC Kruger

Dept. of Electronic Engineering, University of Stellenbosch
Stellenbosch, 7600, South Africa

ABSTRACT

Crossed-guide X-band waveguide couplers with bandwidths of up to 40% and coupling factors of better than 5dB are presented. The tight coupling and wide bandwidth are achieved by using reduced height waveguide. Design graphs and measured data are presented.

INTRODUCTION

Directional couplers [1, 2] are finding increased usage in the design of dividers / combiners for distributed power amplifiers [3, 4, 5, 6]. At high frequencies, waveguide structures are often used because of their low loss and high power handling capabilities. Unfortunately, to obtain wide bandwidths and tight coupling, multi-hole couplers have to be used. These couplers normally consist of two inline waveguides coupled through either the broad or narrow walls, and can be several wavelengths long.

In contrast, crossed-guide waveguide directional couplers are very compact, easy to construct and very robust. Unfortunately, they are essentially narrowband, with coupling varying by as much as 10dB across the full X-band. A basic waveguide crossed-guide coupler is shown in figure 1. Most couplers use crossed slots as coupling apertures due to the improved directivity [7].

Design data on waveguide crossed-guide couplers is only available for coupling values of up to -15dB [8, 9, 10 and various engineering handbooks]. For higher values, no data exists in standard literature, except for a single author describing a way of obtaining tighter coupling by lowering the waveguide roof [11].

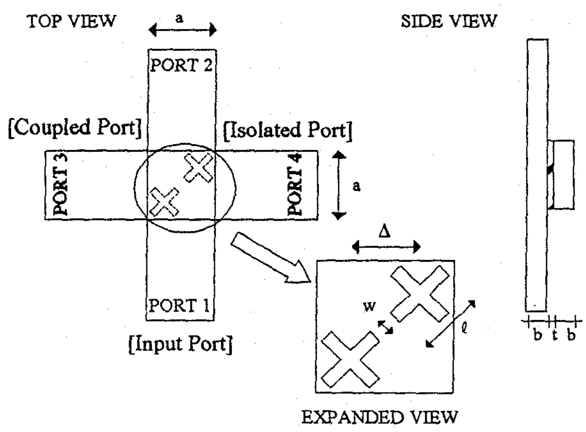
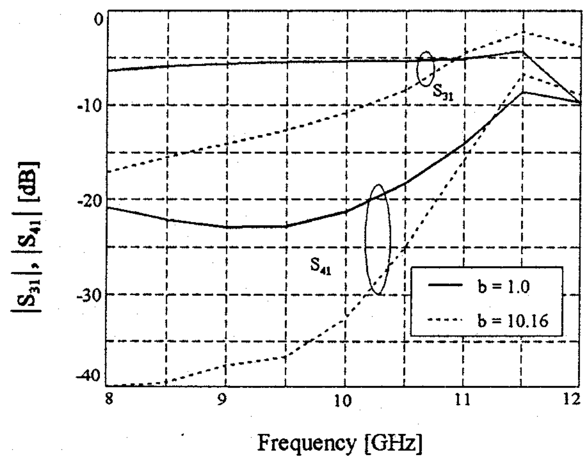


Figure 1: Crossed-Guide Coupler with Dimensions

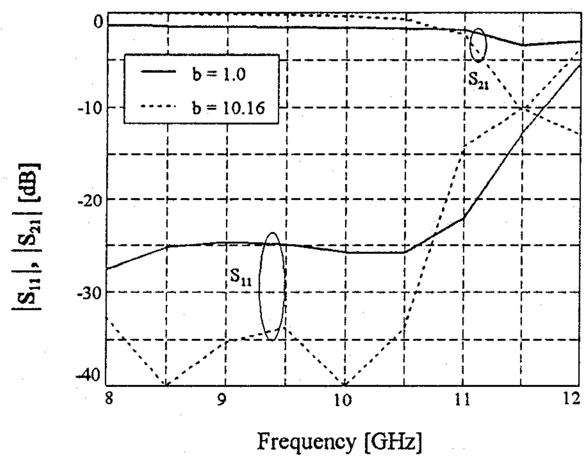
This paper will show how bandwidths of up to 40% and coupling values of up to 5dB can be achieved simultaneously in crossed-guide couplers by using reduced-height waveguide. Some characteristics of this type of coupler are presented, as well as design graphs. Two examples are presented with measured data, one a 5dB coupler with a ±0.5dB bandwidth of 40%, and the other a 4.5dB coupler with a ±0.5dB bandwidth of 30%. To the knowledge of this author, no crossed-guide couplers meeting these specifications have been published before.

REDUCED-HEIGHT COUPLERS

The influence of waveguide height is shown in figure 2 for the limiting case of zero thickness waveguide walls. Port numbers refer to figure 1, with S_{31} representing the coupling value and S_{41} the coupling to the isolated port. A Finite Element (FEM) technique (Maxwell Eminence from Ansoft) was used for all theoretical results presented in this paper.



(a)



(b)

Figure 2: Effect of waveguide height: a=22.86, t=0, Δ=11.43, w=1.0, ℓ=12.0

For the same slot length, the coupling for the reduced height case changes by 1dB from 8 to 11 GHz, while for the full-height case the change is 13dB. In addition, the coupling value at 10GHz is approximately 7dB higher for the reduced height case. However, an increase in coupling forces an increase in reflection and a slight reduction in directivity.

DESIGN GRAPHS

Three detailed graphs, showing coupling values for a number of waveguide heights and coupling slot lengths, are shown in figures 3 to 5. All variables are fixed at the following values: a=22.86, Δ=11.43, w=2.0, t=0.1. All theoretical values in this paper are for lossless structures.

It is clear that a reduction in waveguide height results in a substantial increase in coupling value in each case. However, the increase in bandwidth can be seen to be most pronounced for the case of longer coupling slot lengths.

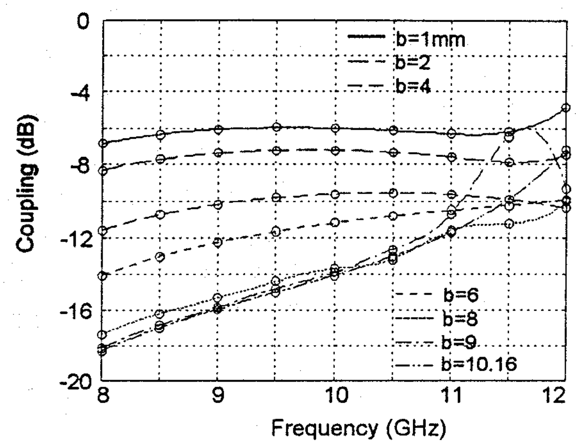


Figure 3: Coupling values for different height waveguides and slot length 11mm.

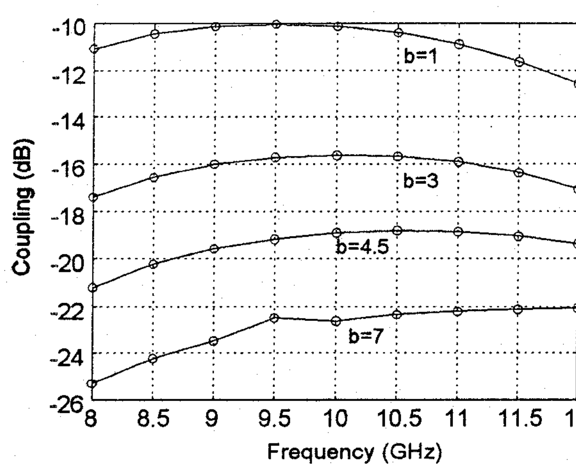


Figure 4: Coupling values for different height waveguides and slot length 9mm.

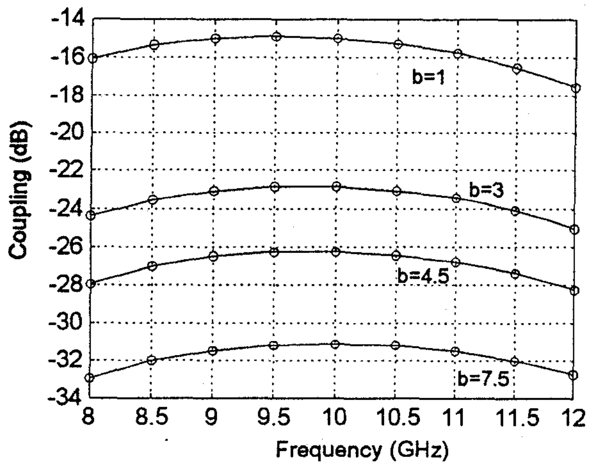


Figure 5: Coupling values for different height waveguides and slot length 7mm.

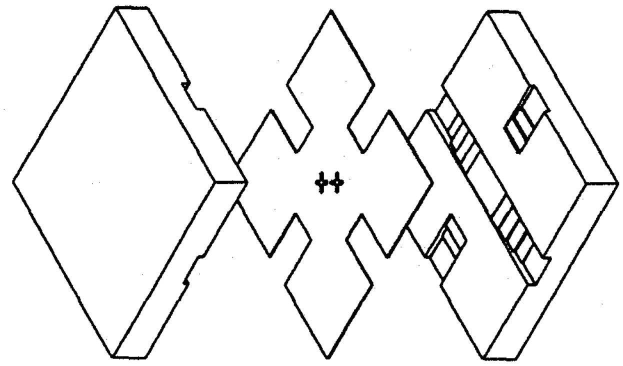


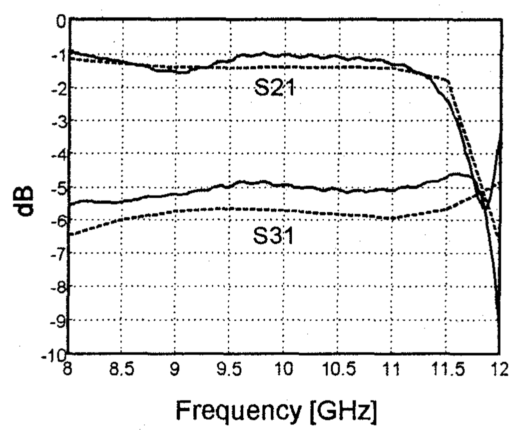
Figure 6: Crossed-guide coupler measurement setup showing quarter-wave transformers and coupling slots.

PROTOTYPE COUPLERS

The measurement setup of two couplers is shown in figure 6. The coupler is embedded into 4-section quarter-wave transformers at each port to create transitions from standard waveguide to the reduced height guide. A waveguide height of 1mm was chosen for both examples. The spacing between guides is created by means of a metal sheet of 0.1mm thickness, replacing the waveguide walls. This structure has the advantage of allowing etched slots, which are easy and inexpensive to manufacture, even for stringent tolerances. Measurements were carried out using a HP8510 vector network analyser with a TRL full-height waveguide calibration.

The results of the two prototypes are shown in figures 7 and 8, with the dotted line in each case representing the predicted response and the solid line the measured response. Due to the effects of the transformers, S_{11} measurements below -20dB are meaningless.

It is clear that wide-band couplers have been constructed with coupling values of 5±0.5dB across a 40% bandwidth and 4±0.5dB across a 30% bandwidth. The good correspondence between simulated and measured results validates the design graphs to within 1dB error in coupling value.



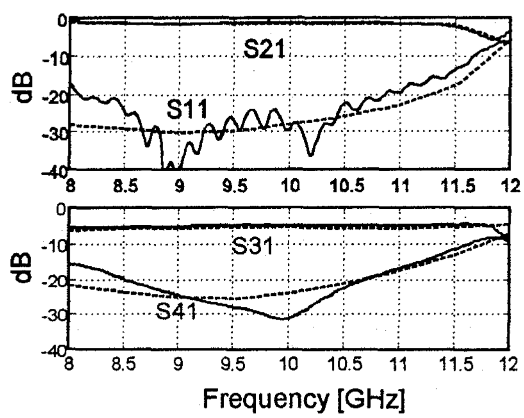
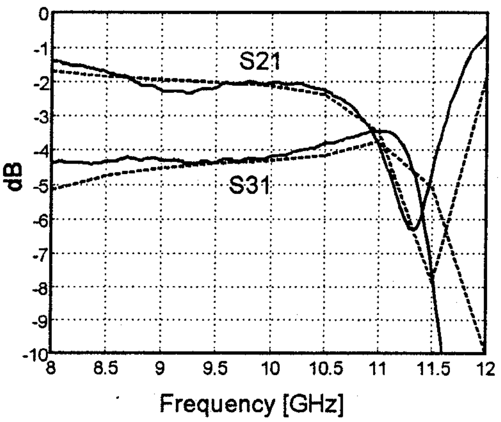


Figure 7: Results for prototype 1 a=22.86, b=1.0, Δ=11.43, w=2.0, t=0.1, ℓ=11.0
—— = measured - - - = predicted



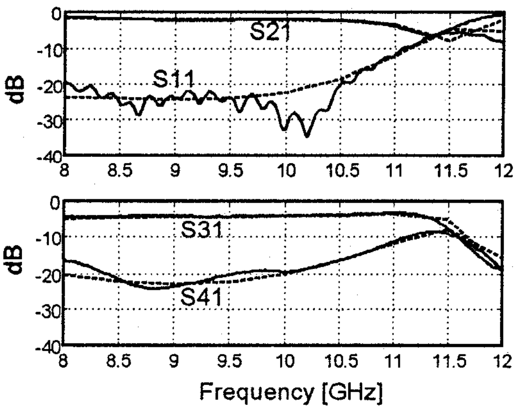


Figure 8: Results for prototype 2 a=22.86, b=1.0, Δ=11.43, w=2.0, t=0.1, ℓ=12.0
—— = measured - - - - = predicted

CONCLUSIONS

The full advantages of using reduced-height waveguide for crossed-guide directional couplers are illustrated for the first time in this paper, using both FEM analysis results and measurements performed on two prototype couplers. Both coupling and bandwidth are increased dramatically with a decrease in waveguide height. Disadvantages include reduced directivity and, more importantly, reduced power handling capability and increased transmission loss. For applications where small size, wide bandwidth and tight coupling are required, however, the advantages outweigh the disadvantages by a large margin.

REFERENCES

[1]: WE Caswell, 'The Directional Coupler - 1966', *IEEE Transactions on Microwave Theory and Techniques*, February 1966, pp. 120-123.

[2]: SB Cohn, R Levy, 'History of Microwave Passive Components with Particular Attention to Directional Couplers', *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-32, no.9, September 1984, pp. 1046-1055.

[3]: M Faulkner, P Chye, R Hansen, 'V-Band PHEMT Power Amplifier Using an N-way Chain Combiner', 1994 IEEE International Symposium Digest, pp. 265-268.

[4]: G Ferrel, L Dickens, J Grippich, B Hayes, F Sacks, 'A High-Efficiency 10 Watt Power Amplifier Assembly Using Combining Techniques', 1995 IEEE International Symposium Digest, pp.327-330.

[5]: J Gipprich, L Dickens, B Hayes, F Sacks, 'A Compact 8-14GHz LTCC Stripline Coupler Network for High-Efficiency Power Combining with better than 82% Combining Efficiency', 1995 IEEE International Symposium Digest, pp. 1583-1586.

[6]: M Knox, R Youmans, M Kumar, L Forker, H Voigt, P Brand, F Marcotte, AS Hughes, '400W X-Band GaAs MMIC CW Amplifier', 1995 IEEE International Symposium Digest, pp. 1605-1608.

[7]: RE Collin, Field Theory of Guided Waves: Second Edition, IEEE Press, 1990, pp.499-523.

[8]: WAG Voss, 'Optimized Crossed Slot Coupler', *The Microwave Journal*, May 1963, pp. 83-87.

[9]: TN Anderson, 'Directional Coupler Design Nomograms', *The Microwave Journal*, May 1959, pp. 34-38.

[10]: M Surdin, 'Directive Couplers in Waveguide', *Physical Review*, 1946, pp.725-736.

[11]: RZ Gerlack, '10dB X_L Cross Guide Coupler', *IEEE Transactions on Microwave Theory and Techniques*, May 1961, p. 571.