WE2D-7

Development of K-Band Spatial Combiner using Active Array Modules in an Oversized Rectangular Waveguide

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ABSTRACT

This paper presents the development of a broadband spatial combining system based on the tapered-slot antenna arrays integrated in an oversized rectangular waveguide at K-band, which could accommodate 24 or more devices. The active antenna cards are designed and built monolithically, providing planar to planar transitions between the slot antennas and the transmission-line with low return loss. A proof-of-concept passive array has been developed for 18-22 GHz, and an 18GHz amplifier has been fabricated using Flip-Chip technology (FCIC).

INTRODUCTION

Based on the spatial combiner developed in X-band [1][2], we extend our effort to a higher frequency (K-band), which appears to be more challenging to integrate a large number of devices in the much smaller space. The system diagram is illustrated in Fig1.

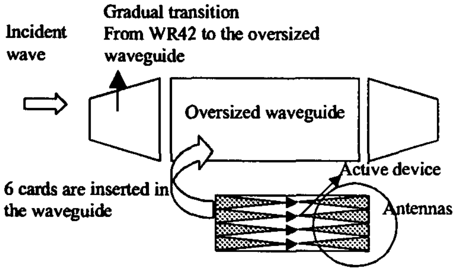

Figure 1 System Design of the K-band Spatial Power Combiner.

PASSIVE COMBINER DESIGN

An oversized combiner system was designed to accommodate 6 trays of active devices with 4 antennas per tray, for a total of 24 devices. Due to machining limitations, the waveguide aperture is approximately 3 times the size of a standard K-band (WR-42) waveguide aperture. In this case both TE10 and TE20 modes can propagate at the operating frequency. However, by symmetric loading of the structure, modes with odd symmetry such as TE20 mode should be effectively suppressed.

A gradual transition from WR42 to the oversized waveguide is designed for testing of the system. The picture is shown in Fig2. The structure has been verified by HFSS simulator.

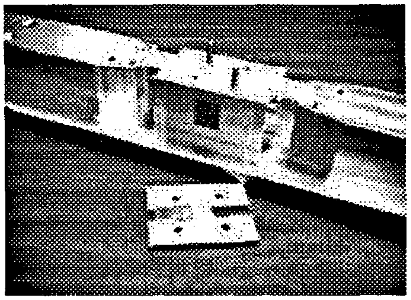

Figure 2 K-band prototype oversized array system with gradual transition from standard WR-42 waveguide.

The next step in the passive array development involves the integration of a taper-slot antenna with the slot-to-CPW transitions built on AlN substrate. Careful attention must be paid to the taper shape design [3] and the impedance matching at the transition. The 50ohm CPW-lines are terminated with 50ohm resistors simulating the input impedance of the amplifiers. The measured S-parameters suggest that a good broadband impedance match from 18 to 22GHz has been achieved.

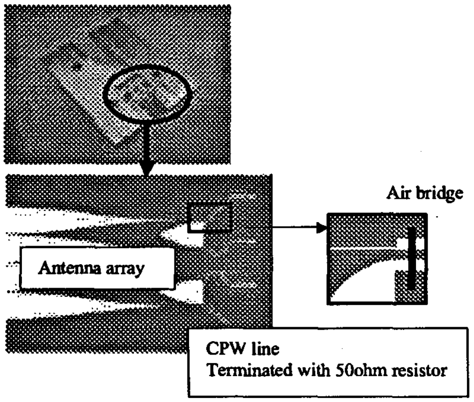

Figure 3 The structure of the slot-line antenna is scaled from the design of the X-band combiner [3], and the characteristic impedance is simulated by HFSS. The gap size of the slot-line at the transition is designed to be 50ohm at 20GHz.

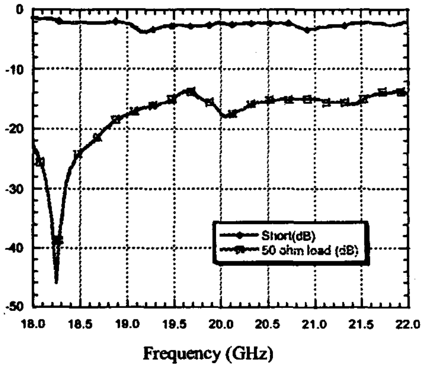

Figure 4 Return Loss for the 24-antenna system with 50ohm and short circuit termination, showed desired broadband performance.

The efficiency of a combiner system is known as the efficiency of the amplifier times the loss of the passive combiner when the gain of the amplifiers becomes very large. The combiner loss can be calculated by the following equation using S-parameters of the through line measurement.

$$LF \approx \sqrt{\frac{|S_{21}|^2}{1-|S_{11}|^2}}$$

The average 1.15dB combining loss indicates the combining efficiency better than 77% average.

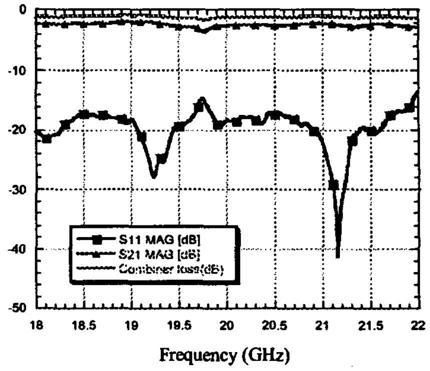

Figure 5 Through line measurement and the passive combining loss.

AMPLIFIER DESIGN

The amplifier is designed at 20GHz in the CPW-line environment on AlN substrate using flip-chip technology, simulated by HP EESOF/ADS and built monolithically. The fabrications of all circuit components including the passive transmission-line, bypass capacitors, stabilized resistors, and air-bridges are done in the UCSB Research Cleanroom. The device we use is AlGaGa/InGaAs PHEMT from Filtronic Solid State. The bonding of the device using flip-chip technology is also done in UCSB.

The photo of the amplifier and S-parameters are shown in Fig6. Due to some layout parasitic (extra capacitance of the bridges, bonding pad capacitance, etc), the operating frequency is shift to 18GHz from the designed frequency.

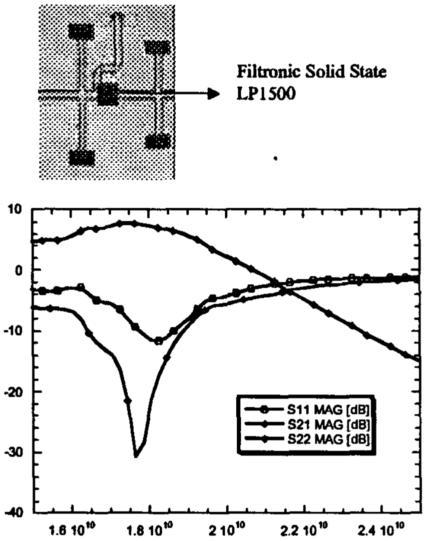

Figure 6 The small signal performance of the amplifier. S21=7.33dB at 18GHz.

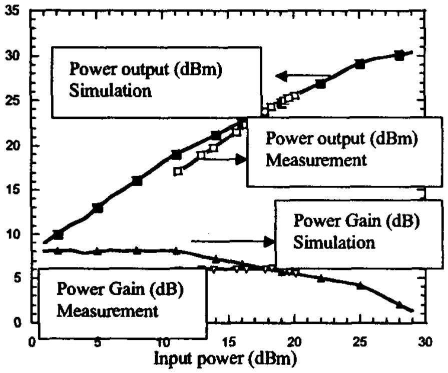

Figure 7 The output impedance is matched to the optimal load of the device. Above shows the simulated and measured results.

COMBINER ASSEMBLY

The next step is to combine the slot antennas and the amplifiers, and integrate these active antenna cards in the oversized waveguide. The amplifiers are characterized by its small signal performance to insure that all active devices can be seen identical. This is illustrated in Fig8.

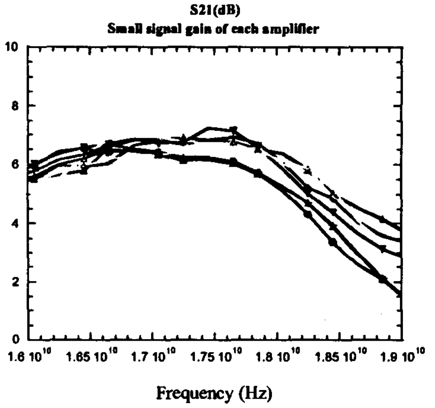

Figure 8 The small signal gain of 8 amplifiers. This shows that all the amplifiers we use in the combiner would be identical.

The layout design of the active antenna cards is shown in Fig9 together with a simplified picture. In order to have a compact structure, each amplifier may have different phase shift at the input and output stages, but the overall phase shift (input + output) would be the same for all amplifiers.

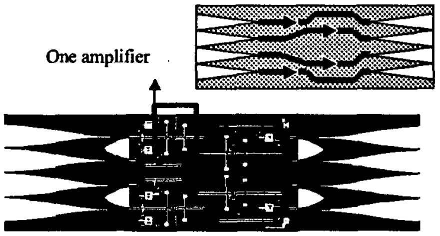

Figure 9 Layout of the monolithic active antenna array.

CONCLUSION

This paper has demonstrated that broadband combiners can be achieved in oversized waveguide, provided careful attention is paid to the electromagnetic design of the structure. This structure is capable of >77% combining efficiency based on losses associated with the passive combiner. A compact, monolithic structure has been designed specifically for the system in order to accommodate high density of active devices.

ACKNOWLEDGEMENT

This work is supported by ARO MURI program (contract DAAG55-98-1-0001) and ARO program (contract DAAG55-97-1-0352).

REFERENCES

[1] N.-S. Cheng, A. Alexanian, M.G. Case, D. Rensch, and R.A. York, "40 Watt CW Broadband Spatial Power Combiner using Dense Finline Arrays", *IEEE Trans. Microwave Theory Tech.*, 1999.

[2] N.-S. Cheng, T.-P. Dao, D.B. Rensch, and R.A. York, "60 Watt X-band Spatially-Combined Solid-State Amplifier", *IEEE Microwave Theory and Techniques Symposium MTT-S*, Anaheim, CA, June 1999.

[3] N.-S. Cheng and R.A. York, "Analysis and Design of Tapered Finline Arrays for Spatial Power Combining", *AP-S Conference*, 1998.

[4] John L.B. Walker, "High-Power GaAs FET Amplifiers".