

K-band Spatial Combiner using Finline Arrays in Oversized Rectangular Waveguide

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This paper presents the k-band spatial combining system based on the tapered-slot antenna arrays integrated in an oversized rectangular waveguide. The active antenna cards were designed and built monolithically, and a preliminary result of a 2x4 system has been presented in this paper.

1 Introduction

Spatial power combining techniques are believed to have higher efficiency than traditional corporate methods in large-scale power combining applications in microwave and mm-wave frequency [1]. The waveguide-based taper-slot antenna arrays have achieved the high power capability, good thermal management, graceful degradation, and broadband characteristic. Further more, this system has an inherent broadband push-pull structure, without the effort of adding the dummy load for the harmonics, and without the harmonics tuning for the individual amplifiers.

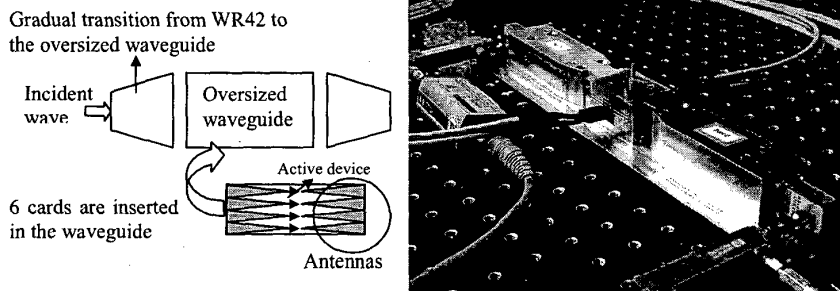


Figure 1 System Design of the K-band Spatial Power Combiner.

Based on the spatial combiner developed in X-band [1][4], the effort was made to a higher frequency range (K-band) [2]. The system (Fig1) is designed to accommodate 6 trays of active devices with 4 antennas per tray (4x6 devices), in the multi-modes rectangular waveguide.

The finline to microstrip line transition in the X-band combiner [1] using bond-wire could induce severe parasitic effect in mm-wave frequency and excite the higher order modes in the waveguide; hence a finline to CPW transition is used in this system. The active device is flip-chip bonded to the CPW line through the gold pads on the AlN substrate, and the AlN substrate is attached to the aluminum (or copper) carrier holder, which works as a good heat sink.

2 Passive Combiner Design

In an earlier paper [2], we reported the results: 18~22GHz bandwidth, less than -14dB reflection, -2.5dB system loss and 76% combining efficiency (figure 2).

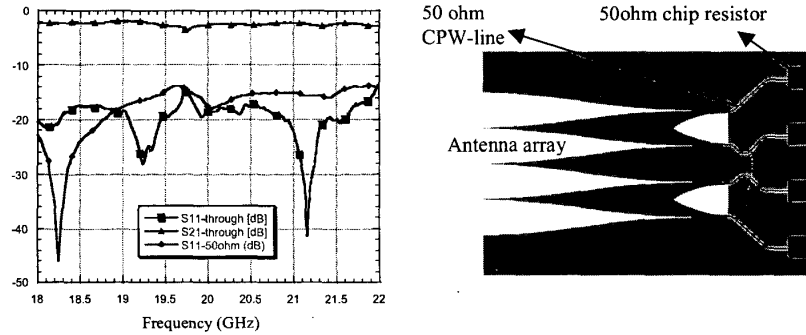


Figure 2 The passive system (4x6 antennas in the waveguide) with 50ohm chip resistor termination and through-line measurement, shows the broadband performance required.

In this oversized waveguide both TE₁₀ and TE₂₀ modes can propagate at the operating frequency, and the third order mode is just cut off. However, by symmetric loading of the structure, modes with odd symmetry such as TE₂₀ mode should be effectively suppressed. Fig3 shows the through-line measurement of one card (asymmetrical) and two cards (symmetrical) and it simply tells us the importance of symmetrical loading for high combining efficiency.

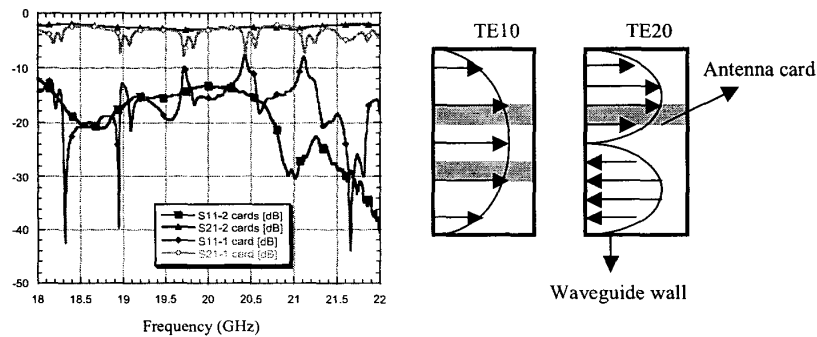


Figure 3 Through line measurement of the one card (1x4) and two cards (2x4) system. The TE₂₀ mode would be excited if the system were not symmetrical.

The waveguide-feeding structure of the system also provides a push-pull scheme for the amplifiers. To verify the structure, a two-card system was simulated by HFSS. The fundamental TE₁₀ mode of the rectangular waveguide is transformed into the slot-line mode, and the adjacent slot-lines have anti-phase filed components. While signal being amplified by the active devices, the fundamental mode is transferred into the waveguide mode and the energy combines, while the harmonics, which are “in-phase” in the transmission-line, would be out of phase when transferred into the waveguide mode and canceled each other (Fig 4).

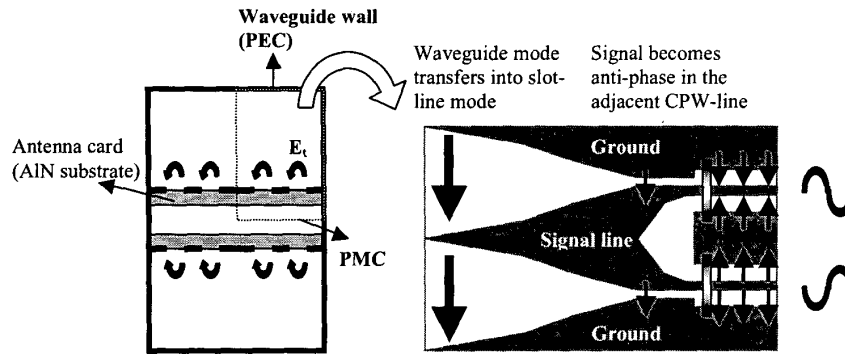


Figure 4 Anti-phase driving for the amplifiers. To simplify the problem, a two-card system was simulated.

3 Power Combiner

All passive circuit components including the antennas, the passive transmission-line, bypass capacitors, stabilized resistors, and air-bridges were built monolithically in the UCSB research cleanroom. The devices we used were AlGaGa/InGaAs PHEMT from Filtronic Solid State. The bonding of the device using flip-chip technology was also done in UCSB.

The preliminary result for this k-band combiner system was obtained using a one-stage amplifier with two antenna trays at 18GHz. A single amplifier had 6dB power gain and 26dBm output power. The system contained 8 amplifiers and has 30dBm output power at 1dB compression point. However, to obtain a high efficiency, and higher gain amplifier must be used.

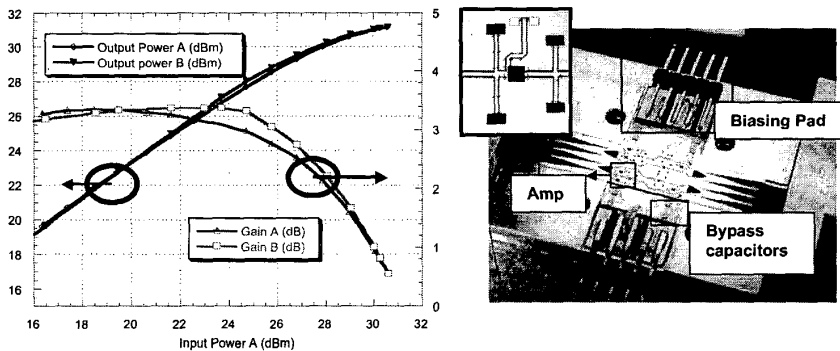


Figure 5 The preliminary result of the 2-card system.

It is known that for a power combiner system, its overall power added efficiency is limited by the passive combining loss and the PAE of the individual amplifier.

$$\eta_{sys} = \frac{P_{out} - P_{in}}{P_{DC}} = \frac{(L_i G L_o - 1) \cdot P_{in}}{N \cdot P_{DCa}} = \frac{(L_i G L_o - 1)}{L_i (G - 1)} \eta_a \quad (1)$$

η_{sys} presents the system PAE, and η_a is the PAE for individual amplifier. L_i is the input divider loss and L_o is the output combiner loss. G is the single amplifier gain. To enhance the overall PAE, it is necessary to increase G and η_a .

A pre-amplifier was added to the power amplifier to provide higher gain. The new circuit had a 13dB small signal gain at 18GHz while maintaining the same output power. The pre-amplifier had high gain but low DC power dissipation hence the overall amplifier had better PAE. Fig6 shows the small signal result for one-card combining using two-stage amplifiers.

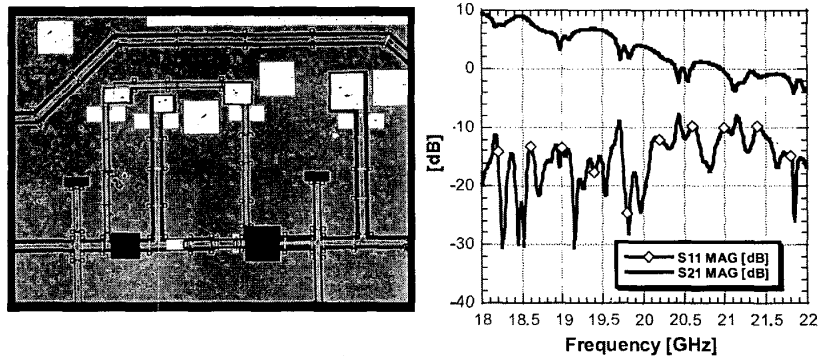


Figure 6 The two-stage amplifier and the one-card small signal measurement of the combiner using the two stage amplifiers.

4 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 >76% combining efficiency based on losses associated with the passive combiner. The combiner with one card (four amps) provides 10dB small signal gain. More cards are being fabricated and power measurement is in progress.

Acknowledgement

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Reference

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