A Compact Millimeter-Wave Slotted-Waveguide Spatial Array Power Combiner[1]

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Abstract — **In this paper a new 28 GHz solid-state power amplifier based on a novel slotted-waveguide spatial power divider/combiner is presented. Innovative waveguide-slot-microstrip transitions have been successfully achieved through three-dimensional electromagnetic simulations. An output power of more than 36 dBm was measured at the output of the power amplifier using a four-device combiner. The power combining efficiency of about 80 % has been achieved. The overall size of the power amplifier was only 3.6"x2.4"x1.0".**

I. INTRODUCTION

There has been an increased use of millimeter-wave (mm-wave) spectrum for wireless communication systems such as local multipoint distribution systems (LMDS). The base-station transmitters require medium and high power solid-state power amplifiers. Despite the recent advances in high-frequency semiconductor device technology and chip level combining, the millimeter-wave devices are limited by their modest output power. At present, the commercially available state of the art power amplifiers MMICs have an output power about one to two watt at mm-wave frequencies. Hence, to achieve high power output, several such MMICs have to be combined.

The spatial combiners are preferred over traditional corporate combiners because of their low insertion loss, and their high power combining efficiency, which is independent of the number of devices. The combining circuit should be as compact as possible, but the size is limited by the physical area of the devices, associated biasing circuitry, antennas, and thermal management issues. The main spatial power combining schemes used at higher frequencies are rectangular waveguide with tapered finline arrays [1], horn and patch antenna arrays [2], horn and slot antenna arrays, antenna arrays in a flared coaxial line [3], and slotted rectangular waveguide arrays [4]. Among these, the slotted rectangular waveguide array is a simple structure, easy to fabricate, low in profile, and efficient heat sinking. These have been demonstrated in [4-5] where 10 GHz and 33 GHz power amplifiers were built.

In this paper, we are demonstrating the slotted-waveguide array technique to build a 36 dBm power amplifier for LMDS system at 28 GHz. The slotted-waveguide arrays are extremely suited for LMDS system due to aforementioned advantages. Since the amplifier is designed in a modular way, the output power of the amplifier can be increased easily by replacing the MMIC amplifiers with ones that have high-output power. The MMIC power devices are very small at this frequency and extra care is needed in characterizing and assembling. We have proposed a very simple way of constructing the combiner and binning of the MMIC amplifiers.

II. SLOTTED WAVEGUIDE POWER COMBINER

The topology of a four-array slotted waveguide power divider/combiner is shown in Figure 1. It consists of broadside-coupled slots in an input feed waveguide to divide input power into four equal magnitude signals at the same phase. These signals are coupled through microstrip lines (appropriately coupled to the slots) and fed into the solid-state power amplifier devices. Then the amplified signals are combined through an identical slotted output waveguide. The spacing between the slots has to be equal to a multiple of half wavelengths (in the waveguide) for a resonant array. To have enough space for the devices and biasing circuitry, this spacing is taken as one wavelength in our design. Hence all the slots are placed on one side of the waveguide. There, is a short circuit placed a quarter wavelength after the last slot. The efficient heat sinking of the power devices is achieved by mounting them directly on the combiner metal housing.

Since Electromagnetic (EM) modeling of the whole array requires a huge amount of computer resources, the problem can be reduced to solving a single waveguide-slot-microstrip transition to achieve a normalized slot conductance of 0.25 Siemens (for four-array combiner) and an appropriate coupling coefficient from the input waveguide to the microstrip line. To achieve this tapered microstrip lines have been used for the transitions. The profile of the tapering, the slot length, slot width, and

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position of the slot (on the waveguide) have been optimized to obtain the desired scattering parameters.

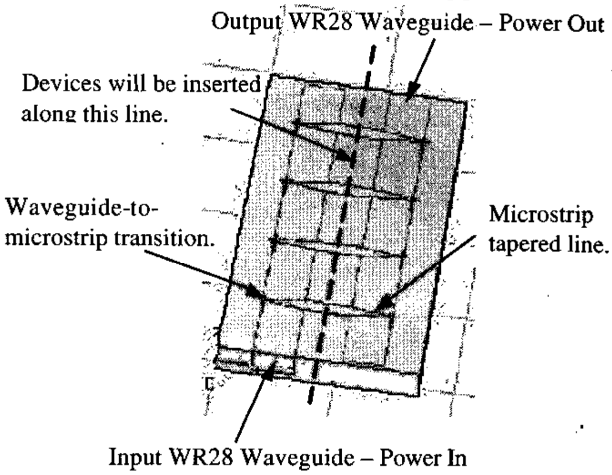

Figure 1: Slotted waveguide four-array power divider/combiner.

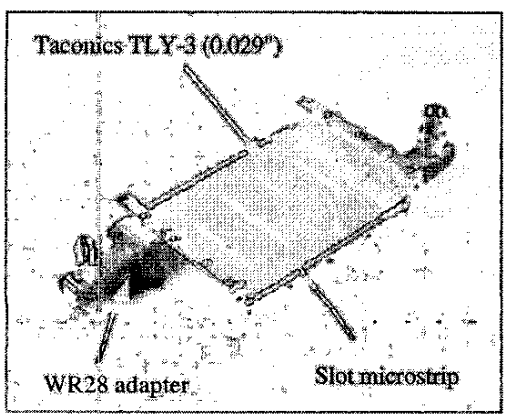

Figure 2: Passive slotted waveguide four-array power divider/combiner.

III. PASSIVE COMBINER ARRAY

The four-array slotted waveguide power divider/combiner (shown in Figure 2) was designed at 28 GHz by expanding the single waveguide-to-microstrip transition described above. A standard WR28 waveguide was used. A 29-mil thick Taconics TLY-3 substrate with a dielectric constant of 2.33 was used. The whole passive array structure (without the devices) was simulated with both HP-HFSS and CST Microwave Studio. The computed and measured S-parameters of the passive slotted waveguide power combiner are plotted in Figures 3 and 4. The simulated back-to-back insertion loss is 2.2 dB, while the measured value is 2.4 dB (after accounting for the losses in the waveguide to coaxial adapters). The input and output waveguide channels were milled in an aluminum plate.

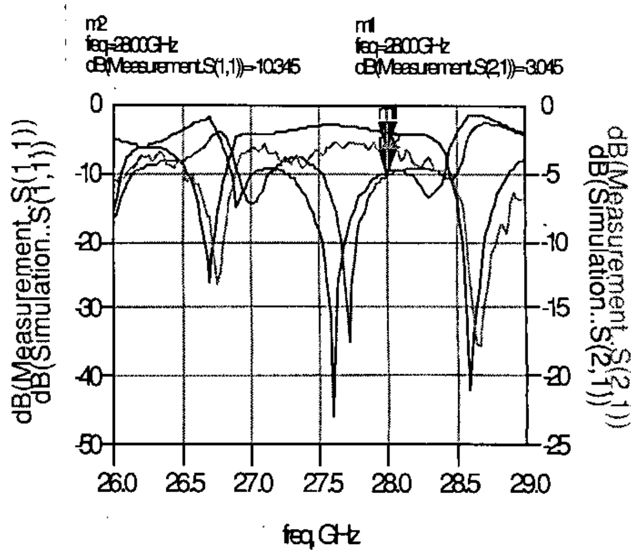

Figure 3: Measured and simulated (HP-HFSS) S-parameters of the passive slotted waveguide power divider/combiner.

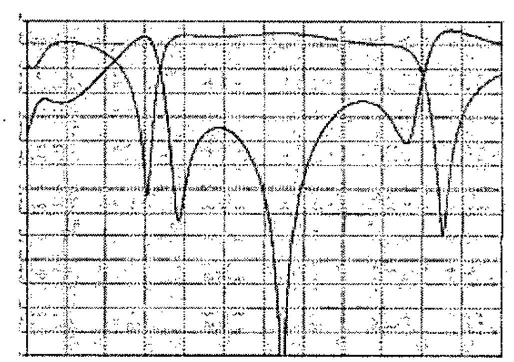

Figure 4: Simulated (CST Microwave Studio) S-parameters of the passive slotted waveguide power divider/combiner.

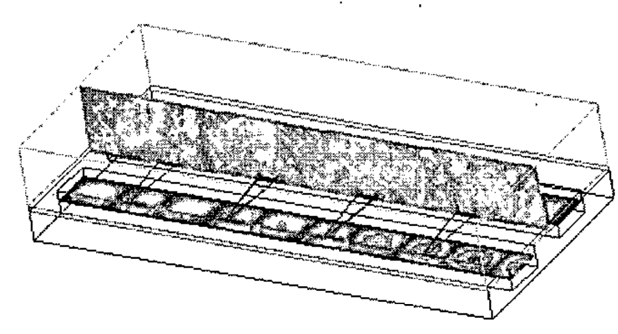

Figure 5: Electric field distribution in a slotted waveguide power divider/combiner.

The bottom metalization (with slots etched) of the TLY board forms the top wall of the waveguides The top metalization contains the waveguide-slot-microstrip transitions and the microstrip lines. The TLY board was bonded to the aluminum plate using 2-mils thick epoxy sheets. The electric field distribution is shown in Figure 5. We can see that the fields at the four slot positions are almost equal and are at the same phase.

IV. ACTIVE COMBINER ARRAY

The four-device slotted waveguide power combiner/amplifier (shown in Figure 6) was built using Fujitsu FMM5803X 1-Watt MMIC power amplifiers using the passive combiner array described in the previous section. These 3.34 mm x 2.08 mm device dies have a thickness of 1 mil. These were mounted on copper-tungsten carriers using a special process, and were tested first in a special test jig. Note that due to extreme small thickness of the dies, it was necessary to attach the dies first to a appropriate carrier prior the assembly on the waveguide. The good MMICs were then mounted on the slotted waveguide combiner plate. The input and output of the MMICs were connected to the microstrip lines using one-mil bond wires. The current circuits were made in-house and plated locally with wire bondable gold. Each device was biased at 6 V with a typical drain current of 700 mA. The output versus input powers of the amplifier at 27.8 GHz is plotted in Figure 7. The saturated output power of the amplifier is 36.8 dBm. The average saturated power of the each device is 31.8 dBm. Hence the combiner loss and the combining efficiencies are 1 dB and 79.4 %, respectively. The gain of the amplifier and the total DC current to the amplifier are plotted in Figures 8 and 9, respectively The maximum gain of the amplifier was 11 dB and the total DC current to the amplifier was 3.5 A.

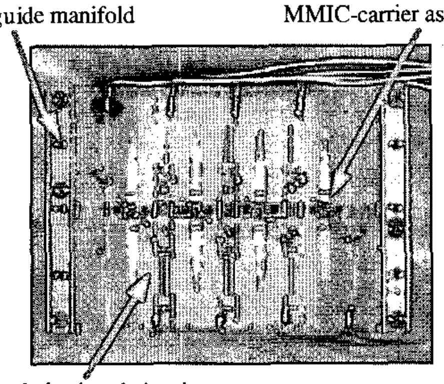

Figure 6: 28 GHz slotted waveguide array power amplifier assembly.

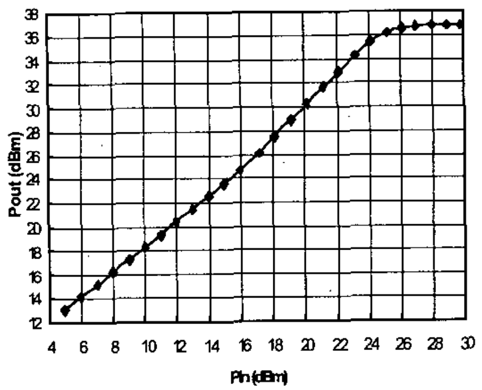

Figure 7: Measured output power versus input power for the four-device power amplifier.

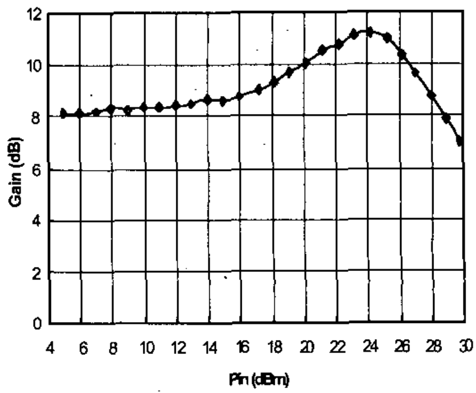

Figure 8: Measured gain for the four-device slotted waveguide power amplifier.

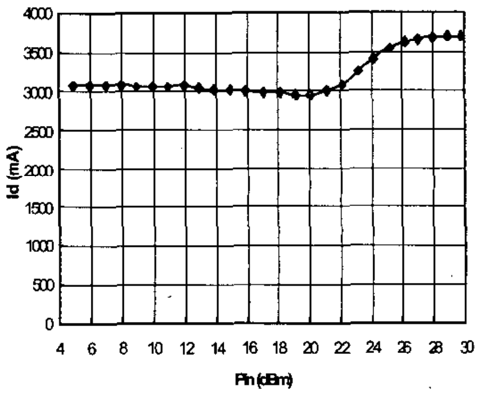

Figure 9: Total DC current versus input power of the power amplifier.

V. CONCLUSION

The development of a 28 GHz LMDS power amplifier using slotted waveguide array divider/combiner has been presented in this paper. It offers a unique mm-wave integration technology. This technology can potentially replace TWT power amplifiers. A power combining efficiency of about 80 % has been achieved. It could be further improved by using stubs for matching the slots. The use of full-wave EM simulations has resulted in first pass success of the power amplifier.

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REFERENCES

[1] N. Cheng, A. Alexanian, M.G. Case, D.B. Rensch and R.A. York, "40W CW Broad-band Spatial Power combiner Using Dense Finline Arrays," *IEEE Trans. on MTT*, vol. 47, no.7, pp. 1070-1076, July 1999.

[2] J. Hubert, L. Mirth, S. Ortiz, and A. Mortazawi, "A 4 Watt Ka-band Quasi-Optical Amplifier," *IEEE MTT-S Digest*, pp. 551-554, 1999.

[3] P. Jia, Y. Liu, L. Chen and A. York, "Analysis of a Passive Spatial Combiner Using Tapered Slotline Array in Oversized Coaxial Waveguide," *IEEE MTT-S Digest*, pp. 1933-1936, 2000.

[4] R. Bashirullah and A. Mortazawi, "Slotted-Waveguide Power Amplifier for Spatial Power-Combining Applications," *IEEE Trans. on MTT*, vol. 48, no. 7, pp. 1142-1146, July 2000.

[5] X. Jiang, L. Liu, S.C. Ortiz, R. Bashirullah, A. Mortazawi, "A Ka-Band Power Amplifier Based on a Low-Profile Slotted-Waveguide Power-Combining/Dividing Circuit", *IEEE Trans. on MTT*, vol. 51, no. 1, pp. 144-147, January 2003.