T-14

30-WAY RADIAL POWER COMBINER FOR MINIATURE GaAs FET POWER AMPLIFIERS

E. Belohoubek, R. Brown, H. Johnson, A. Fathy,
D. Bechtle, D. Kalokitis, E. Mykietyn

RCA Laboratories

Princeton, NJ 08540

ABSTRACT

A compact radial divider/combiner structure is described that combines 30 miniature GaAs FET power amplifiers. A power output of 26 W has been achieved at 11.3 GHz with a 0.5-dB bandwidth of 600 MHz. The combiner is small, lightweight, low loss and offers graceful degradation.

INTRODUCTION

The demands for higher power at higher frequencies reflected in todays military as well as commercial systems are in most cases fulfilled by traveling wave tubes (TWTs). Solid state power amplifiers (SSPAs) which, in general, offer better linearity, higher reliability, smaller size and weight, and have lower supply voltage requirements are limited by the power output capability of state of the art active devices. This can be partially overcome by combining several devices or amplifiers as was demonstrated by the recent successful introduction of SSPAs in C-band satellite transmitter channels by RCA [1]. Similar efforts to replace TWTs at higher frequencies and higher power levels require the efficient combining of a large number of individual amplifiers to reach typical TWT performance.

Radial power combiners have been shown in the past to be promising candidates for low loss, multiport combining [2, 3, 4]. The present paper describes a particularly compact, 30-way divider/combiner structure that has excellent low-loss, wide-band characteristics and in addition permits the direct integration of miniature amplifiers within a very small volume with good heat dissipation capability.

DESIGN OF COMBINER STRUCTURE

Conventional combining schemes, such as binary combining, become rather cumbersome as the number of amplifiers is increased and incur high combining losses caused by the multitude of couplers and connecting transmission line segments. We selected a radial combiner configuration that permits the placement of a large number of amplifiers very close to the central combining point. To keep the combining path and corresponding losses to a minimum, the transverse dimension of the amplifiers must be made as small as possible. Fig. 1 shows the resulting divider/combiner structure designed for wideband operation in the lower part of Ku-band.

The coaxial input feeds a radial transmission line that is segmented into 30 individual microstrip lines. The power from the 30 lines is fed to the upper level through coaxial feedthroughs where they are connected to the input of miniature beryllia circuit (MBC)

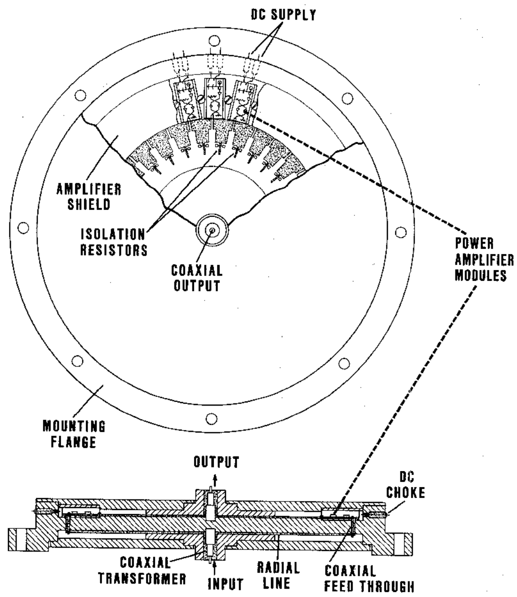


Fig. 1 Cross section of divider/combiner structure

amplifiers.[5] The amplifiers in turn are directly connected to the 30 arms of a complimentary radial transmission line structure which combines the outputs of all amplifiers. This arrangement not only keeps the overall dimensions very small but also reduces the interconnect transmission line length and, therefore, the combining loss. The heat generated by the individual amplifiers is carried through a short, low thermal resistance path, to the outside rim of the combiner which is directly attached to a heat sink. Fig. 2 shows the input VSWR of the 30 way combiner when each arm is terminated in 50 ohms. The combining loss of the structure is less than 0.6 dB including connector losses over a bandwidth of approximately 3 GHz. The excellent low-loss, wide-band performance is attributed to a careful design of the various transformer sections forming the radial combiner. The input 50-ohm coaxial line is transformed to each of the 30 microstrip lines via 5 transformer sections including the radial line which also acts as a transformer. Damping of higher order modes is achieved by $\lambda/4$-slots at the transition from radial to microstrip lines that are bridged by isolation resistors. A separate choke section at the transition point provides the necessary conversion from a balanced to unbalanced transmission line. The minimum isolation between inidividual combining ports is 16 dB. Accurate machining and assembly ensures excellent amplitude and phase uniformity between all 30 ports. The maximum amplitude variation is less than ± 0.4 dB with the maximum phase deviation being $\pm$ 3 degrees. A high degree of uniformity in amplitude and phase between ports as well as between individual amplifiers is mandatory to achieve low loss combining.

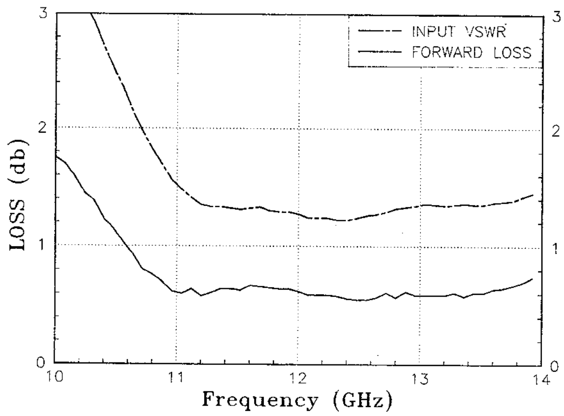


Fig. 2 Input VSWR and combining loss of combiner structure

AMPLIFIER DESIGN

The original two-stage amplifier configuration on which the design of the combiner structure was based is shown in Fig. 3. The performance values shown represent measured data on early amplifier samples. Because of low initial yields and time limitations for the fabrication of the full complement of two-stage amplifiers we decided to populate the combiner with single-stage amplifiers. Existing three-device amplifiers circuits were diced up into single amplifier stages and the unused area in the module bridged by a microstrip throughline on Duroid as shown in Fig. 4a. Typical performance characteristics of this amplifier are shown in Fig. 4b A power output of 1 W with approximately 5 dB of large signal gain is available per amplifier with the power peak occurring at approximately 11 GHz.

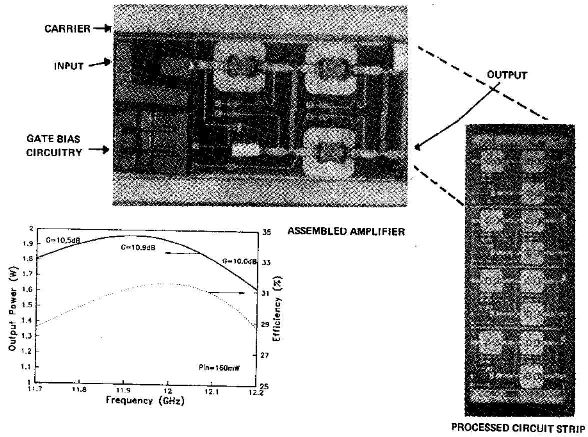
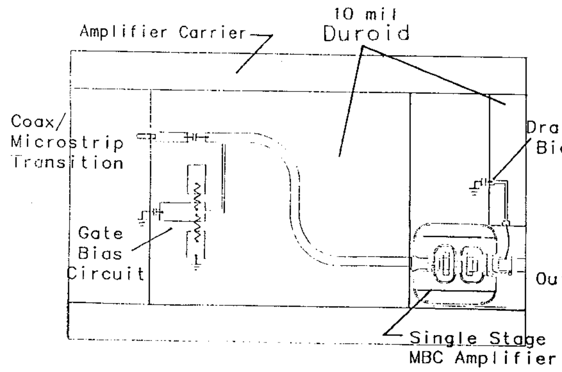
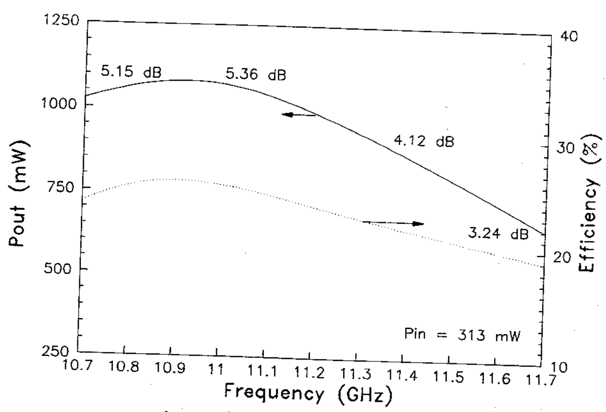


Fig. 3 Two-stage, miniature GaAs FET power amplifier



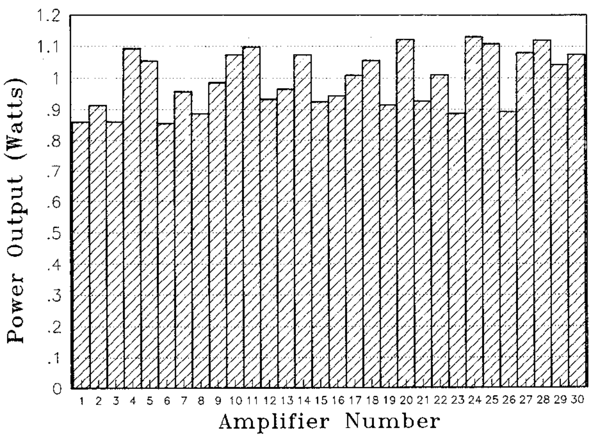
a. amplitude distribution



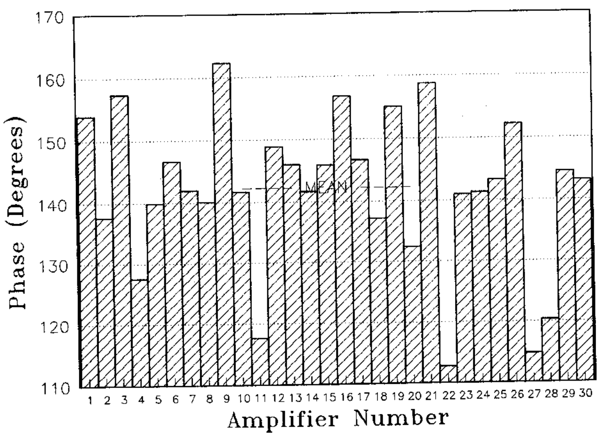
b. phase distribution

Fig. 4 Modified amplifier (single stage)

All 30 amplifiers were assembled and then tested without additional tuning or trimming. The amplifiers use a flip-chip mounted GaAs FET type MGFC 2124 made by Mitsubishi. Fig. 5a and



a. amplitude distribution



b. phase distribution

Fig. 5 Performance of 30 amplifiers as built

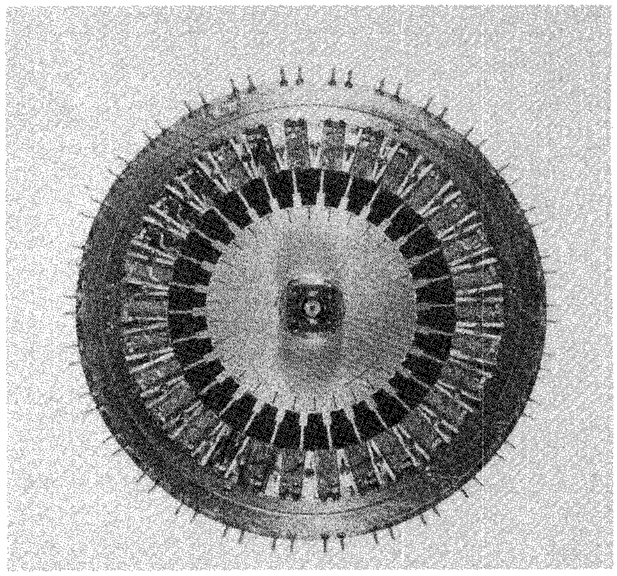


Fig. 6 Photo of divider/combiner with 30 single-stage amplifiers in place

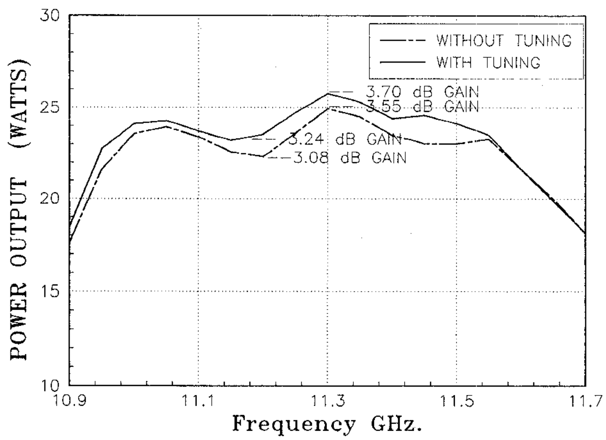


Fig. 7 Performance of divider/combiner structure with 1-W amplifiers

5b show the amplitude and phase distribution of these amplifiers as built.

COMBINER PERFORMANCE WITH 1-W AMPLIFIERS

The complete divider/combiner structure with 30 single-stage amplifiers in place is shown in Fig. 6. The overall dimensions exclusive of the coaxial connectors are 5 dia. x 1.2 and the weight is approximately 1.1 lbs. The dotted line in Fig. 7 shows the bandwidth performance of the combiner-amplifier as first assembled. The power output is 25 W with 3.5 dB gain and a 0.5 dB bandwidth of 600 MHz. Note that the amplifier passband sits at the lower edge of the combiner passband leading to the multi-humped response and reduced output power at 11 GHz.

A series of measurements were performed to determine the amount of power lost in the isolation resistors due to asymmetries. First the temperature difference of all resistors was measured with respect to the radial combiner top metallization. Based on a calibration of power dissipated versus temperatures taken on resistors mounted with similar boundary conditions the original readings were converted to power dissipated in the resistors. As expected, a few isolation resistors dissipated significantly more power than the rest. By placing tuning chips on the four amplifiers that had the largest phase deviations the power output could be increased by approximately 1 W, as shown by the solid line in Fig. 7. The power dissipated in the isolation resistors under this condition is shown in Fig. 8. The overall power loss due to asymmetrics is about 0.9 W or 3% of the total power. Even this amount could be further reduced if the power amplifiers individually had been corrected for phase deviations of less than $\pm 15^{\circ}$.

Based on the average gain and power output values of the 30 amplifiers the actual insertion

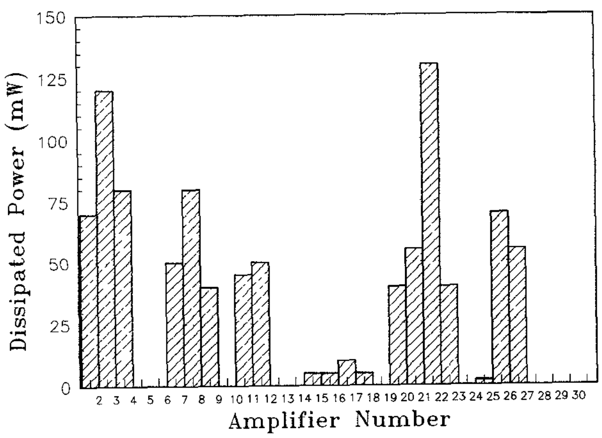


Fig. 8 Power dissipated in isolation resistors (P_o = 26 W)

loss of the 30 way combiner is less than .4 dB. The power added overall efficiency of 17% is low because of the rather low efficiency and gain of the unit amplifiers.

A number of graceful degradation tests were performed with up to seven amplifiers turned off. The results are shown in Fig. 9. We also investigated the effect of shorts that may occur when power devices fail. By placing shorts in different positions the degradation could be increased or decreased with respect to the results shown in Fig. 9. At most an additional drop in power output of 1 W per amplifier failure was found at the worst location for the short.

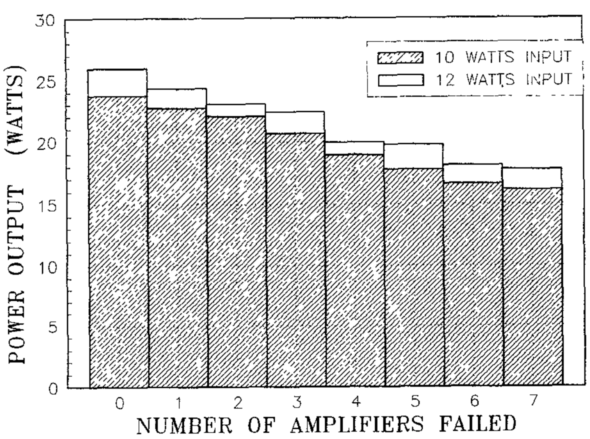


Fig. 9 Power output degradation as function of amplifier failures

CONCLUSION

Large-N power combining in a very compact, light weight structure ideally suited for space and airborne applications was demonstrated. The overall combining efficiency for a 30-way combiner was approximately 90% including the residual power dissipated in the isolation resistors. Phase deviations should be kept to below ±15° and amplitude variations below ±10% to ensure high efficiency combining. By further increasing N and using better heat-sunk isolation resistors combined power levels in the 100 W range should be feasible.

ACKNOWLEDGEMENT

The authors want to acknowledge the support and help from a number of individuals who all contributed to the success of this program. Special recognition should go to P. Jozwiak, V. Lawson, and S. Bennett in processing, to R. Farkas in assembly and R. Askew, V. Pendrick, T. Chu and R. Marx in testing.

REFERENCES

1. J. N. Laprade, Solid State C-band Power Amplifiers for Communication Satellites, Digest of International Telemetering Conf., San Diego, pp. 755-763, Oct. 1983.

2. M. Cohn, et al, A 10-Watt Broadband FET Combiner/Amplifier, IEEE MTT-S Symposium Digest, pp. 292-297, June 1979.

3. K. Russell, Microwave Power Combining Techniques, IEEE Trans. MTT-27, pp. 472-478, May 1979.

4. S. Foti, 60-Way Radial Combiner Uses no Isolators, Microwaves and RF, pp. 96-118, July 1984.

5. F. Sechi, et al, Miniature Beryllia Circuits - A New Technology for Microwave Power Amplifiers, RCA Review 43, pp. 363-374, June 1982.