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A 6-GHz 80-W GaAs FET Amplifier with TM-Mode Cavity Power Combiner

Naofumi OKUBO, Yoshiaki KANEKO, Toshiyuki SAITO and Yasuyuki TOKUMITSU

Fujitsu Laboratories Ltd.

Kawasaki, Japan

Abstract

A novel 8-way divider/combiner using TM010- and TM020-mode cavities was developed, with an insertion loss of 0.2 dB and a bandwidth of 600 MHz at 6 GHz.

An 80-W broadband GaAs FET amplifier with combining efficiency of 85 percent was successfully demonstrated using this power divider/combiner.

Introduction [1],[2],[3]

In the microwave region, it is difficult to realize an amplifier delivering over 50 watts with only one device. Therefore, a power divider/combiner is a key component in a solid-state high power amplifier. Recently, many kinds of divider/combiner were reported [1],[2]. A resonant cavity type divider/combiner has the advantage of low insertion loss and peak power capability of several hundred watts. A previously reported resonant cavity type combiner [1] has, however, narrow bandwidth as a weak point.

In this paper a technique for broadening the operating bandwidth of the 8-way divider/combiner is described, and, a 6-GHz 80-watt GaAs FET amplifier is demonstrated to investigate the feasibility of this divider/combiner.

TM-mode cavity divider/combiner

Figure 1 shows a cross-section view of the 8-way divider/combiner using TM-mode cavities. A double tuned network composed of TM010- and TM020-mode cavities was newly adopted to get low insertion loss and broad bandwidth. The two cavities are mutually coupled.

Broad bandwidth can be obtained with a flat cavity and tight coupling. Therefore, the divider/combiner employs flat cavities with a height of less than a quarter wavelength, with a disk type probe at the center port for electrical coupling. Magnetically coupled loops at the peripheral ports are placed close to the peak point of the electric field in the TM020-mode cavity.

Figure 2 is a side view of the divider/combiner and a bottom view showing the peripheral ports. The TM010-mode cavity has a 36-mm diameter and the TM020-mode cavity has an 83-mm diameter. The height of both cavities is 8 mm.

Figure 3 shows the characteristics of the 8-way divider/combiner with double cavity (TM010 + TM020) and of a single cavity (TM020) between center port and one of the peripheral ports. The divider/combiner with double cavity has a 0.2-dB insertion loss and 0.2-dB bandwidth of 600 MHz at 6 GHz. The bandwidth is twice as broad as with a single cavity. The variation of insertion loss at peripheral port is within $\pm$0.1 dB and phase variation is within $\pm$2 degrees. Isolation between peripheral ports is more than 8.5 dB at 6.15 GHz. Return loss at peripheral ports was derived from measured S-parameters, because it is difficult to measure return loss directly in the condition of in-phase and equal level excitation at all peripheral ports. Return loss is more than 13 dB at 6.15 GHz.

Amplifier configuration

A block diagram of the 80-W amplifier is shown in Figure 4. This amplifier consists of a driver amplifier, eight unit amplifiers, connecting cables, a power divider, and a power combiner. The driver amplifier is of the same configuration as the unit amplifiers. Each unit amplifier is a two stage amplifier with 12-W output power and 13-dB gain at 1-dB gain compression point. A balanced amplifier in the final stage and an isolator in the input side are used to reduce the interference between unit amplifiers due to weak interport isolation in the divider/combiner. The device (FLM5964-6) used in the final stage of the unit amplifier has the prematching circuit, a gate width of 22.8 millimeters and an Idss of 4.4 amperes, and delivers an output power of 6 watts with 5.5-dB gain at 6.4 GHz. Typical frequency response of output power, and output power versus input power characteristics of the unit amplifier are shown in Figure 5.

Combining efficiency depends on variations in output power and transmission phase between the unit amplifiers. Figure 6 shows the calculated results of the combining efficiency. In this case, it is assumed that the distribution of the variation is uniform. From these results, it is obvious that the transmission phase variation must be adjusted, because the combining efficiency is sensitive to phase variation.

Table 1 shows the characteristics of the eight unit amplifiers connected with the 8-way divider which is excited with 39-dBm input power at the center port. Output power variation between unit amplifiers is within 0.5 dB and the transmission phase variation is adjusted to be within 6 degrees at 6.15 GHz. These variations affect the combining efficiency with a factor of less than 0.2%. Return loss at the output port of unit amplifiers are more than 10 dB because of imbalances in S-parameters between two prematched devices.

Overall performance

Figure 7 shows overall performance of the experimental 80-W amplifier with forced air cooling. Saturated output power of more than 80 watts was obtained over a frequency range from 5.9 GHz to 6.4 GHz. At center frequency of 6.15 GHz, saturated output power is 93 watts with a power gain of 22.7 dB and a power efficiency of 18.9 percent. Overall power combining efficiency was 85%. Loss factors are combiner insertion loss 0.2 dB, loss in the connecting cable from the unit amplifier to the combiner 0.2 dB, and loss in mismatch between unit amplifiers and combiner 0.3 dB. When impedance mismatch loss is reduced, this combining technique will provide 91-% (0.4-dB loss) power combining efficiency and flat frequency response. Figure 8 shows a photograph of the experimental 80-W amplifier. This amplifier is 270 mm long, 250 mm wide, and 450 mm high.

Conclusion

A novel 8-way power divider/combiner using TM010- and TM020-mode cavities was applied to a 6-GHz 80-W GaAs FET amplifier.

The double cavity technique realized a low insertion loss and a broad bandwidth of the divider/combiner. This technique is also applicable to a divider/combiner for high power solid-state amplifiers in the higher frequency region, for example, 14-GHz and 30-GHz band.

This divider/combiner will open the door to application of high power solid-state amplifiers for the earth station in satellite communication.

Acknowledgement

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References

[1] K. J. Russell and R. S. Harp,"A Multistage High-Power Solid-state X-Band Amplifier," 1978 ISSCC Digest of Technical Papers, pp166-167, 1978.

[2] M. Cohn, B.D. Geller and J.M. Schellenberg , "A 10 Watt Broadband FET Combiner/Amplifier," IEEE MTT-S, 1979 International Microwave Symposium Digest, pp292-297.

[3] N.Fukuden, F.Ogata, M.Hayakawa, H.Sugawara ,M. Takagi, Y. Arai,"A 4.5 GHz 40 Watt GaAs FET Amplifier," IEEE MTT-S, 1982 International Microwave Symposium Digest , pp 66-68.

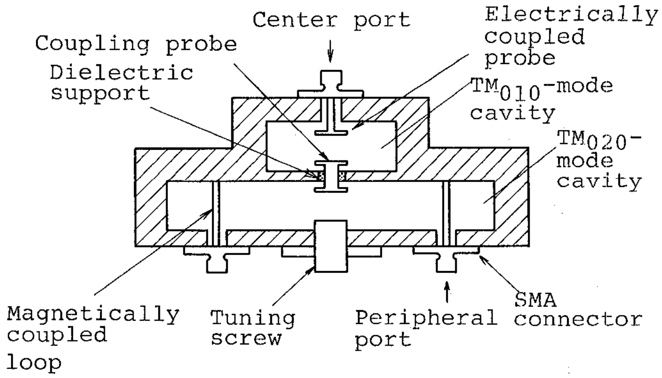

Fig. 1 Cross-section of the 8-way divider/combiner.

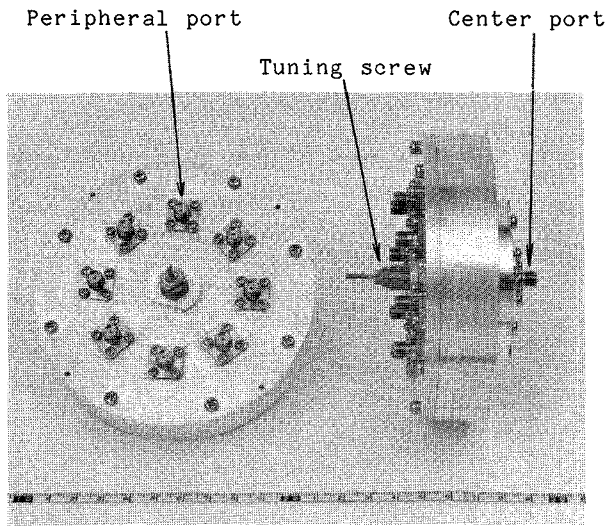

Fig. 2 The 8-way divider/combiner

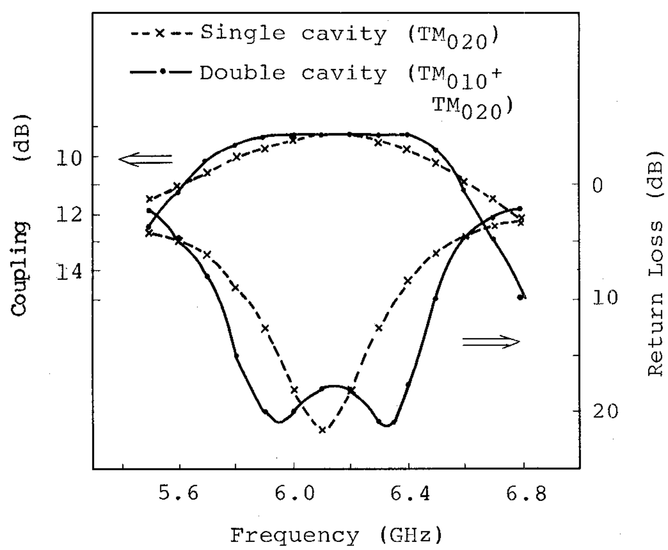

Fig. 3 Characteristics of the 8-way divider/combiner.

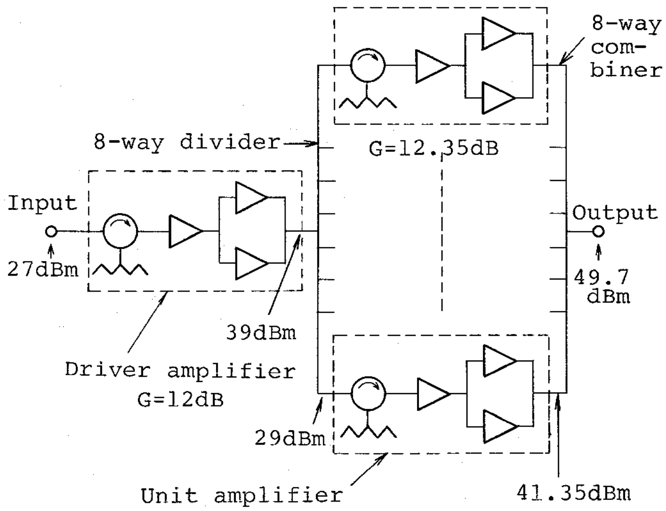

Fig. 4 Block diagram of the 80-W amplifier.

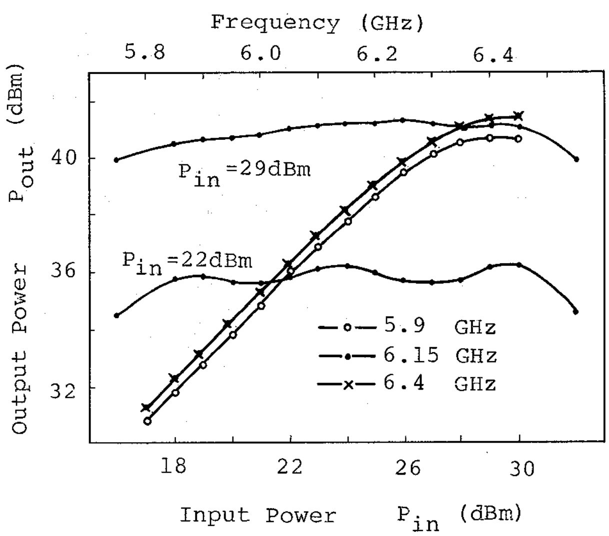

Fig. 5 Typical characterictics of the unit amplifier.

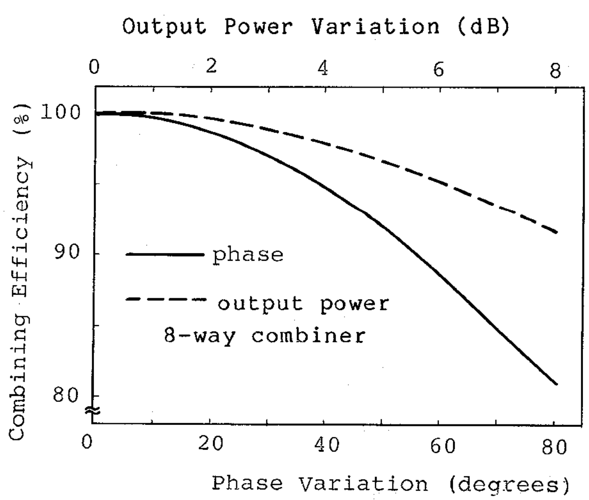

Fig. 6 Effect of phase and output power variation.

Table 1 Summary of unit amplifier performance (including divider).

Amplifier number	Pin=39dBm , f=6.15GHz	
	Output power (dBm)	Phase (degrees)
1	41.3	-50
2	41.1	-51
3	41.4	-48
4	41.6	-51
5	41.5	-45
6	41.2	-49
7	41.2	-51
8	41.5	-50
Average	41.35±0.25	-48±3
Total	50.4	---------

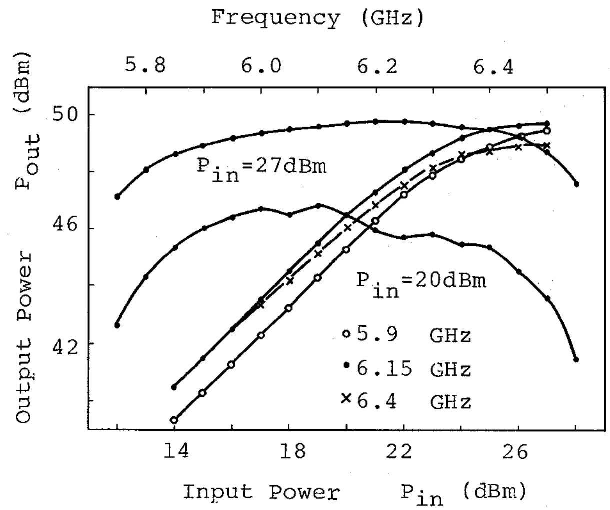

Fig. 7 Characteristics of the 80-W amplifier.

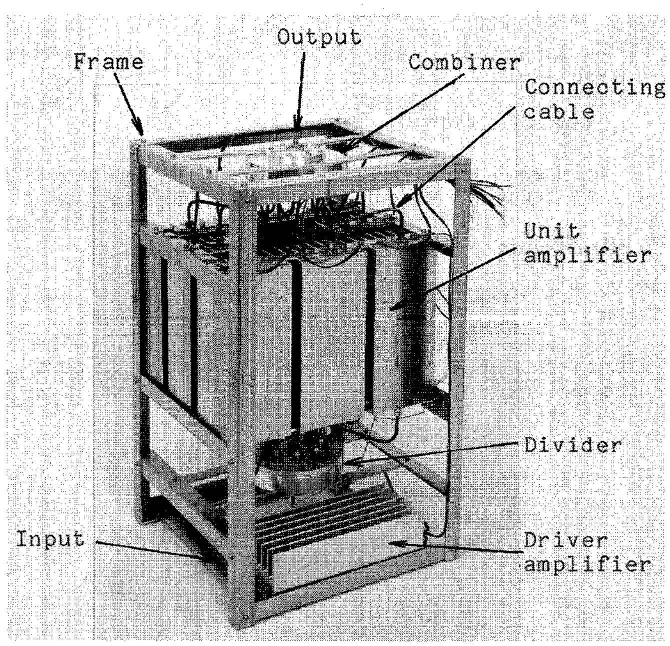

Fig. 8 The experimental 80-W amplifier