AN ALL-TRANSISTOR, 1-KILOWATT, HIGH-GAIN, UHF POWER AMPLIFIER

by

R.L. Bailey, W.P. Bennett, L.F. Heckman, and I.E. Martin
RCA Electronic Components
Lancaster, Pennsylvania

An all-transistor power amplifier which delivers a cw power output of 1 kilowatt at 400 MHz has been designed and fabricated. In this design approach, a number of discrete transistors are connected in parallel to form a power module, and the outputs of a quantity of modules are then combined to achieve the desired total output power. The discrete transistor used in the amplifier is the RCA-2N5016 overlay type. When operated as a single device in an optimum 400-MHz amplifier circuit, this transistor produces a power output of 15 to 18 watts for a power input of 5 to 6 watts.

One of the first criteria established was the number of transistors which can be effectively connected in parallel to form a power module. As transistors are placed in parallel, the total power output increases additively. However, although the collector efficiency remains nearly constant, the power gain decreases slightly as the number of paralleled transistors increases. Simple compensating networks inserted between the base of each transistor and the common paralleling point in the input circuit overcome this problem, and, as a result, "paralleling efficiency" can be maintained at nearly 100 per cent for at least four transistors. Although more transistors could probably be operated in parallel in this fashion, it becomes quite difficult to maintain the necessary circuit symmetry and at the same time keep the required interconnecting circuitry at an acceptable level. A module consisting of four paralleled transistors was selected as a suitable compromise between the desired high power output from an individual module and the aforementioned circuit considerations. Four RCA-2N5016 transistors operated in parallel produced a module with a power-output capability of 60 to 70 watts. An array of 16 power modules is used to achieve a total amplifier output of 1 kilowatt.

The first system for combining the outputs of the 16 modules used a simple 16-way coaxial junction with an appropriate impedance transformer in the single combined output line to provide a 50-ohm impedance at all ports. A similar 16-way junction was used to divide the driving power among the 16 modules. Although this system produced a full combined output of 1 kilowatt, the system was only conditionally stable. The instability at some power levels and operating conditions required special start-up and shutdown procedures.

A completely stable amplifier was achieved at all power levels and operating conditions with almost perfect power adding when the simple combining junction was replaced by a 16-way hybrid circuit similar to that described by Wilkinson.[1] Fig. 1 shows this hybrid circuit. The principal advantage is that the circuit provides isolation between the individual ports. Fig. 2 shows a single-stage amplifier in which the 16 power modules are arrayed in "ferris-wheel" fashion around the two 16-way coaxial hybrid junctions located at the axis of the wheel. Operating conditions of the amplifier for full cw output power of 1 kilowatt are as follows:

Frequency	400	MHz
Drive Power	410	W
DC Collector Voltage	28	V
Total Collector Current	52	A
Collector Efficiency	69	%
CW Power Output	1000	W

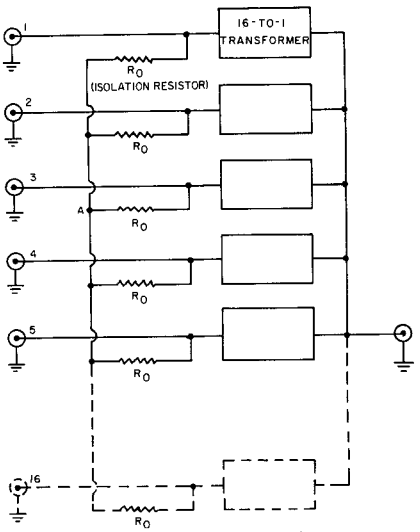

Fig.1 - A 16-way hybrid. (The terminal impedances are R_o when the hybrid is used as either a splitter or a combiner.

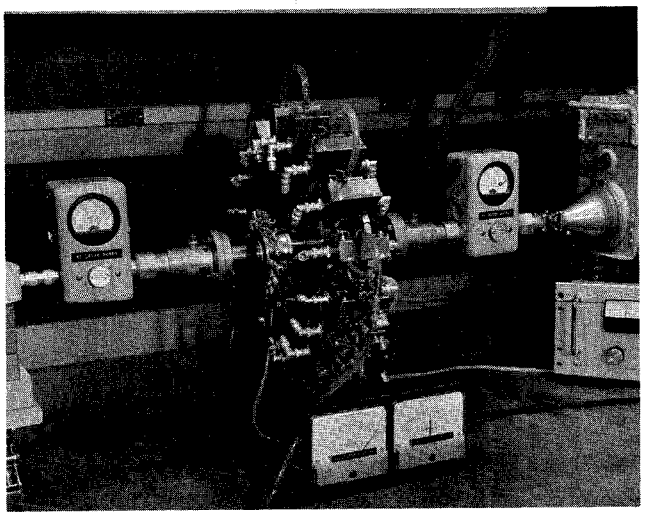

Fig.2 - A single-stage amplifier.

A single transistor driver stage incorporated in each power module improves the gain of the amplifier. Fig. 3 shows a two-stage five-transistor module with the cover removed. Performance of this module in cw and pulsed operation is as follows:

	CW	Pulsed	
Frequency	400	400	MHz
Drive Power	5	5	W
Power Gain	10	11	dB
DC Collector Voltage	28	30	V
Total Collector Current	4.2	4.6	A
Power Output	55	64	W

A complete amplifier employing 16 of the two-stage higher-gain modules provides the following performance in pulse service:

Frequency	400 MHz
Drive Power	90 W
Power Gain	10.5 dB
DC Collector Voltage	30 dB
Total Collector Current	72 A
Power Output	1000 W

A five-stage all-transistor amplifier having 33-dB gain was constructed by use of two additional two-stage modules. The outputs of the modules were combined by use of standard four-port hybrids as power

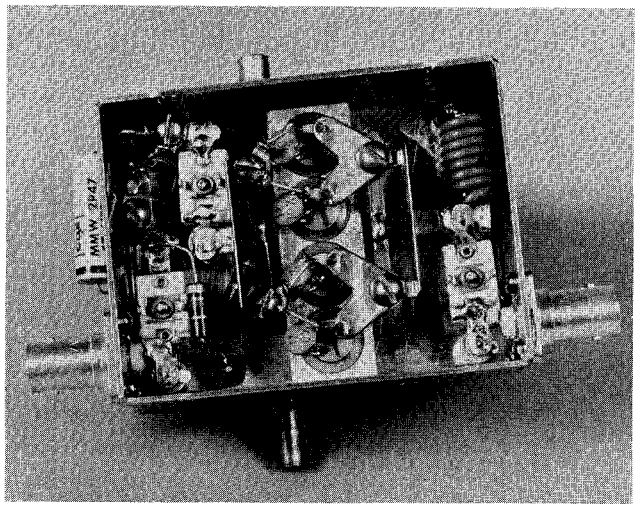

Fig.3 - An individual two-stage module.

combiners. The modules were driven by a single 2N5016 transistor stage. A block diagram of this amplifier is shown in Fig. 4; typical cw performance is as follows:

Frequency	400 MHz
Drive Power	0.4 W
Power Gain	33 dB
DC Collector Voltage	28 V
Total Collector Current	73 A
Power Output	800 W

The single-stage 1-kilowatt amplifier shown in Fig. 2 was used in a test as a driver amplifier for a super-power tetrode tube in long-pulse (500-microsecond), high-duty (6-per-cent) operation. The transistor amplifier supplied a peak output of 1.2 kilowatts to the input of the tube, which delivered a peak output of 310 kilowatts. It is important to note that no isolator was employed between the transistor amplifier and the tube. The ability of the transistor amplifier to withstand unusual operating conditions was tested by inducing simulated faults of numerous types in the tube amplifier under full-power conditions. The transistor amplifier survived all such tests without adverse affects.

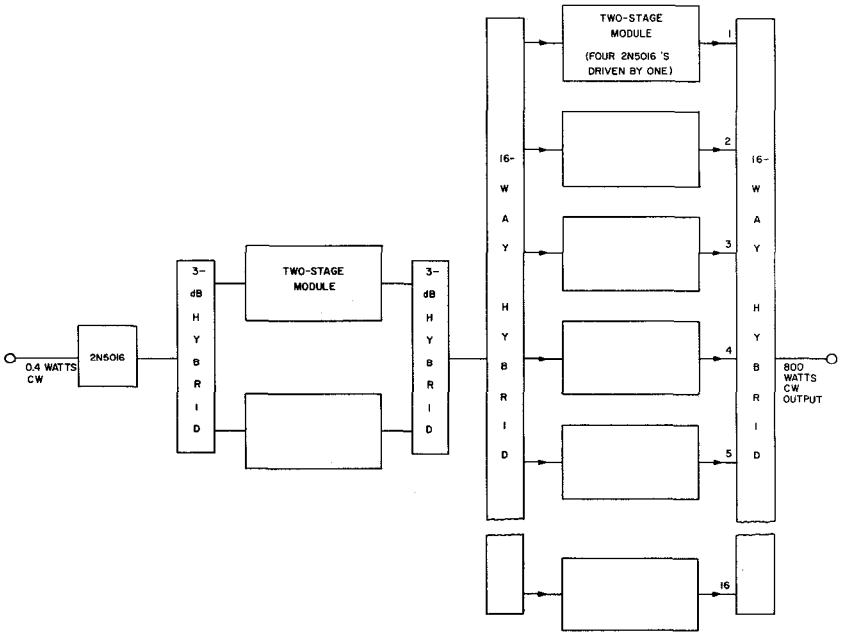

Fig.4 - A block diagram of the high-gain amplifier.

Because of the isolating properties of the N-way hybrid power combiners, it is expected that a failure in a single power module could occur without this single failure escalating into a total system failure. Tests performed on the amplifier verified this theory. Individual module failures produce a proportionate decrease in system power, but do not affect the performance of the remaining modules. As a result, degradation is gradual, not catastrophic.

The present 1-kilowatt system proves the feasibility of this design approach. Although the amplifier was designed to operate at 400 MHz, it can be aligned to operate at any frequency between approximately 200 and 400 MHz. Numerous design changes can be made to improve upon the breadboard amplifier shown in Fig. 2. First, an optimally packaged system using the same transistors would reduce the amplifier size to approximately 8 x 12 x 12 inches. The amplifier could be either forced-air or liquid cooled. Secondly, the bandwidth of the system could be increased considerably. Because 80- to 100-watt broadband modules covering the entire 225-to-400-MHz frequency spectrum are feasible, it is expected that a multitude of modules could be combined to produce power of a kilowatt or more across that bandwidth. Several combining systems are being studied to determine isolation capabilities across the 225-to-400-MHz band.

In conclusion, it has been shown that powers as high as 1000 watts cw at 400 MHz can be generated by an amplifier which combines the outputs of transistors that have a power-output capability of only 15 to 18 watts. Such an amplifier has been constructed and evaluated under various operating conditions, and has demonstrated the practicality of using transistors in this fashion for high-power applications. The techniques utilized in this amplifier can be employed to generate even higher powers as single transistors with higher power capability become available. The ultimate system would be one in which the highest possible level of integration of circuitry with the transistor chip is achieved, and would result in a compact amplifier combining high power output and broad bandwidth with excellent reliability.

Reference

1. Ernest J. Wilkinson, "An N-Way Hybrid Power Divider", IRE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, Jan. 1960, p. 116.