A 10 WATT BROADBAND FET COMBINER/AMPLIFIER

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Abstract

The development of a 10W MIC combiner/amplifier which combines the powers of 12 FET elemental amplifiers over a 24%, 1 dB band is described. The combining efficiency is greater than 90 percent.

The design of both the radial combiner and the elemental amplifiers is described. Extension of the combiner design to operation over an octave will be discussed.

Introduction

The recent development of power FET's capable of generating 1W CW at X-band and the concurrent advances in power combining and broadband matching techniques have made possible the development of a power combiner/amplifier capable of delivering over 10W CW with a 1 dB bandwidth greater than 2 GHz. The unit supplies over twice the power with over four times the bandwidth of the previously described amplifier.(1)

The unit consists of a pair of 12-way MIC radial combiners, which efficiently divide the input power and combine the outputs of 12 nominally identical elemental amplifiers. Each elemental amplifier is designed to operate between a 50Ω source and load.

Radial Divider/Combiner

Figure 1 is a photo of the divider/combiner substrate, which is identical to the one reported on earlier.(1) The radial transmission line is fabricated on a circular, fused-quartz substrate 0.6 in. in diameter and 0.035 in. thick. The twelve sectors, 26° wide and 0.21 in. long, are separated by 4° gaps. A deposited tantalum thin film resistor is present between adjacent sectors to provide isolation. The radial line is excited with a coaxial-to-radial line transition (not shown in figure) mounted in the center of the radial line. An additional element, which is also not shown, is the coaxial impedance matching network which is used to match out the reactive component of the radial line input admittance. This combiner has a 1 dB bandwidth of 31% centered at 9.0 GHz and a midband insertion loss of 0.25 dB (above the 12-way power division loss of 10.8 dB). The variation of output power at the individual ports is ±0.25 dB and phase variation is $\pm5^{\circ}$. The isolation ranges from 13 dB to 22 dB, depending on the two output ports in question.

Elemental Amplifier

The individual FET chip used in this effort can be represented reasonably accurately by the unilateral equivalent circuit illustrated in Figure 2. The device has a gate width of 2400 micrometers and is designed to deliver a nominal 1.0 W. The circuit includes the effects of bondwires on both input and output. The device is mounted on a chip carrier in which partial impedance transformation networks are included. On the input side, a K-inverter (2) is used to parallel-resonate the input at 9.0 GHz and raise the input impedance to 10-15Ω. On the output side, the bondwire is used to approximately series resonate the drain circuit and a partial $\lambda/4$ transformer is brought electrically close to the device. The complete elemental amplifier is shown in Figure 3.

In addition to the K-inverter, a $\lambda/4$ transformer is used on the input side to increase bandwidth. A $\lambda/2$ open circuited stub is used to present the required slope parameter for double tuning. The output circuit achieves the same bandwidth goal with a straightforward two $\lambda/4$ transformer network.

Circuit elements on the input side are used to resistively load the gate at out-of-band frequencies in order to eliminate spurious oscillations and to equalize the gain characteristic. A U-shaped line segment is used to trim the transmission phase of the individual amplifiers. Table 1 presents the characteristics of the twelve elemental amplifiers after tuning. The gain and phase variation between amplifiers was ±1.1 dB and ±6 degrees, respectively.

Composite Combiner/Amplifier

The complete combiner/amplifier is shown in Figure 4. The large signal frequency response for several input levels and efficiency at $P_{in} = +36$ dBm are shown in Figure 5. As indicated, the 1 dB bandwidth extends from 7.7 to 9.9 GHz, with a maximum output power of 10.6 W at 9.0 GHz. These results were obtained with forced air cooling.

Figure 6 illustrates the output power and the power-added efficiency as functions of the input power at 9.0 GHz with water cooling. The water cooling resulted in some improvement in performance. As indicated, at an input power of 36.1 dBm (4.3 dB associated gain), the output power is 40.4 dBm or 10.9 W with an efficiency of 24.3%.

The radial line power combiner circuit with an integral isolation resistor network has been modeled on a computer and the results are in excellent agreement with measured values. Computer modeling of radial combiners with (1) a larger number of peripheral ports and (2) a multiple ring resistive isolation network has been carried out. Results show that improved isolation and impedance match can be obtained over bandwidths in excess of an octave for a 12-way combiner. For a combiner with a double resistive ring, for example, typical port-to-port isolations are greater that 20 dB over a 7 to 17 GHz frequency range. Adjacent port isolation is typically lowest and drops to 14 dB at the band edges. The bandwidth of this type of power combiner/amplifier is thus limited by the bandwidth of the constituent amplifiers rather than the combiner.

Individual FET chips have already demonstrated CW power outputs of 5 watts at X-band in laboratory tests. Projecting the future availability of such devices in production quantities and incorporating them in larger

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radial line combiners, power outputs of hundreds of watts can be expected from individual X-band power combiner/amplifiers.

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References

1 - J. M. Schellenberg and M. Cohn, "A Wideband Radial Power Combiner for FET Amplifiers", 1978 ISSCC Digest of Technical Papers, pp 164-165, 273; February 15-17, 1978.

2 - G. L. Matthaei, Leo Young, and E. M. T. Jones, "Microwave Filters, Impedance Matching Networks, and Coupling Structures, McGraw Hill, 1964, pp. 434-438.

Table 1

SUMMARY OF ELEMENTAL AMPLIFIER PERFORMANCE

Amplifier No.	FET No.	I_{DS} (mA)	V_{GS} (V)	Gain (dB) Pin = 25 dBm F = 9 GHz	Phase (Deg)	Output (W)	EFF (%)
1	13-5	378	-3.3	4.9	86	0.9772	21.67
2	2-5	350	-2.4	5.0	86	1.0000	24.21
3	7-5	320	-1.2	5.3	90	1.0715	29.17
4	1-5	372	-2.5	5.15	86	1.0351	24.16
5	7-4	265	-1.8	4.75	95	0.9441	29.25
6	8-4	285	-2.0	4.5	96	0.8913	24.85
7	5-5	300	-1.7	5.1	98	1.0233	28.92
8	12.5	310	-2.0	4.95	96	0.9886	26.38
9	1-4	202	-2.0	4.0	90	0.7943	28.90
10	4-4	197	-1.8	3.1	90	0.6457	20.42
11	3-4	215	-1.8	3.95	88	0.7852	26.67
12	2-3	275	-2.0	4.9	87	0.9772	29.60
Totals		3469		4.675		11.1335	26.11

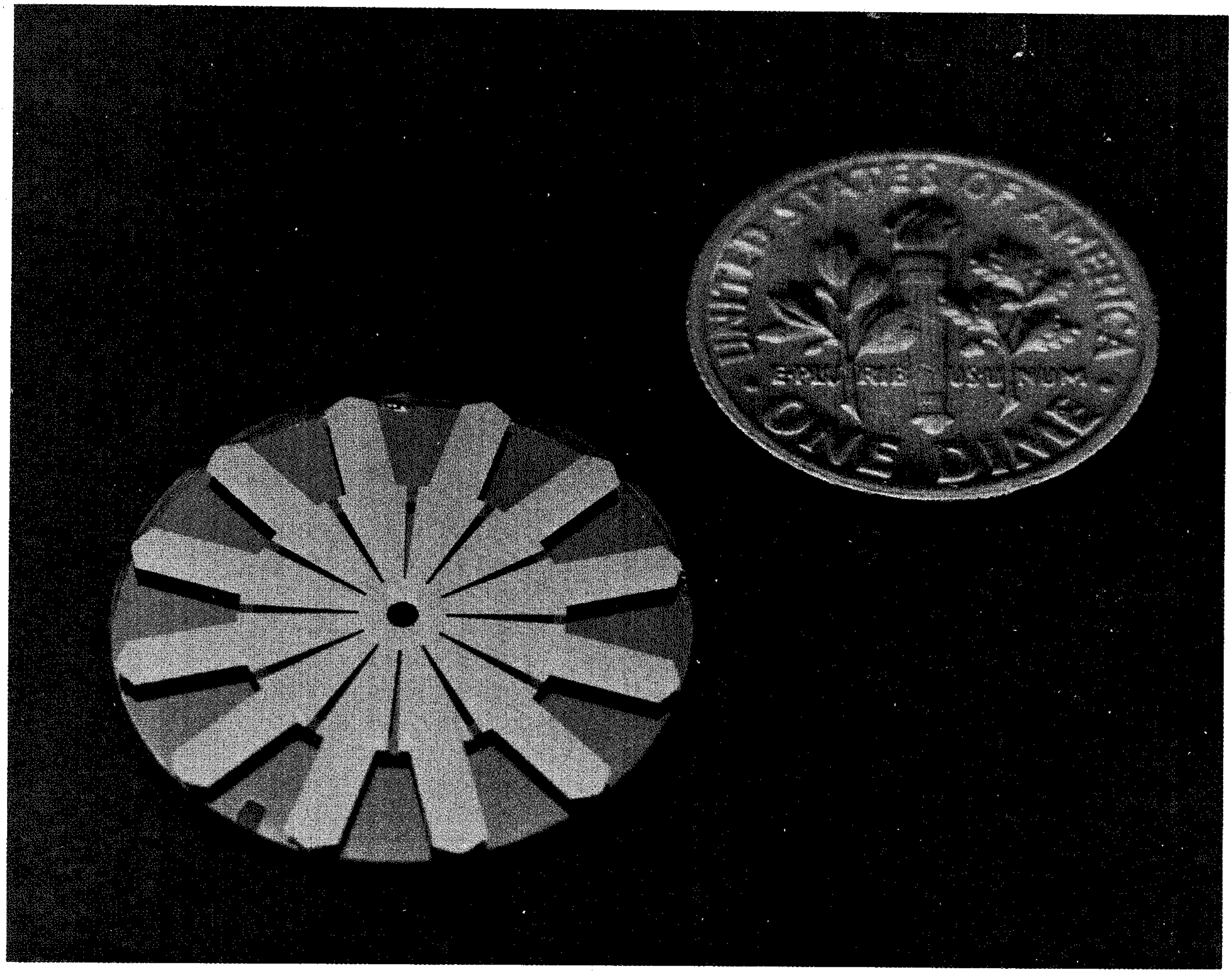

Figure 1 - 12 Way Radial Combiner Substrate with Integral Thin Film Resistive Isolation Network.

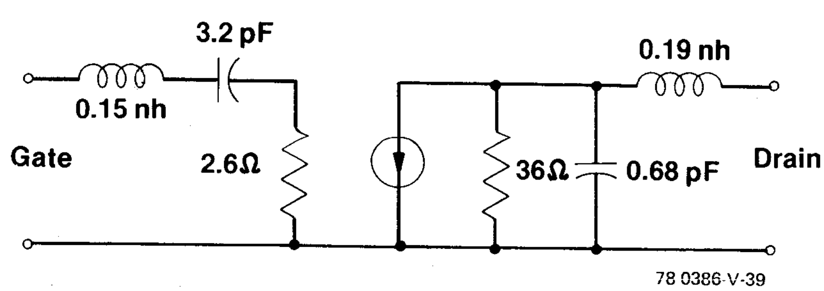

Figure 2 - Equivalent Circuit for 1-Watt FET.

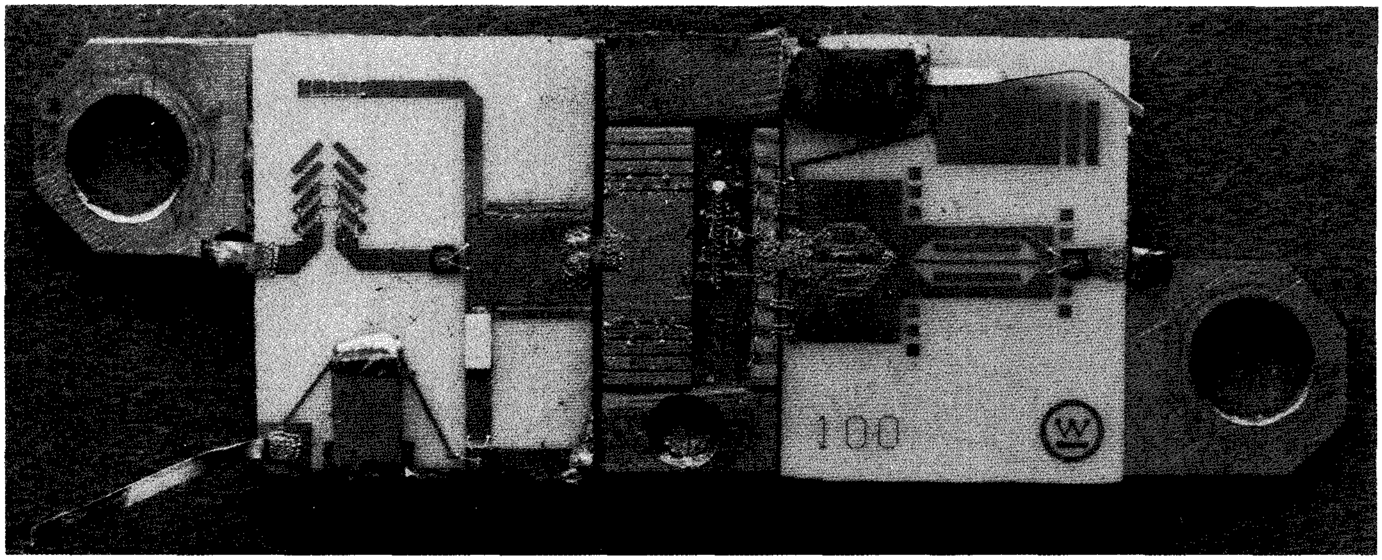

Figure 3 - Elemental 1 Watt FET Amplifier.

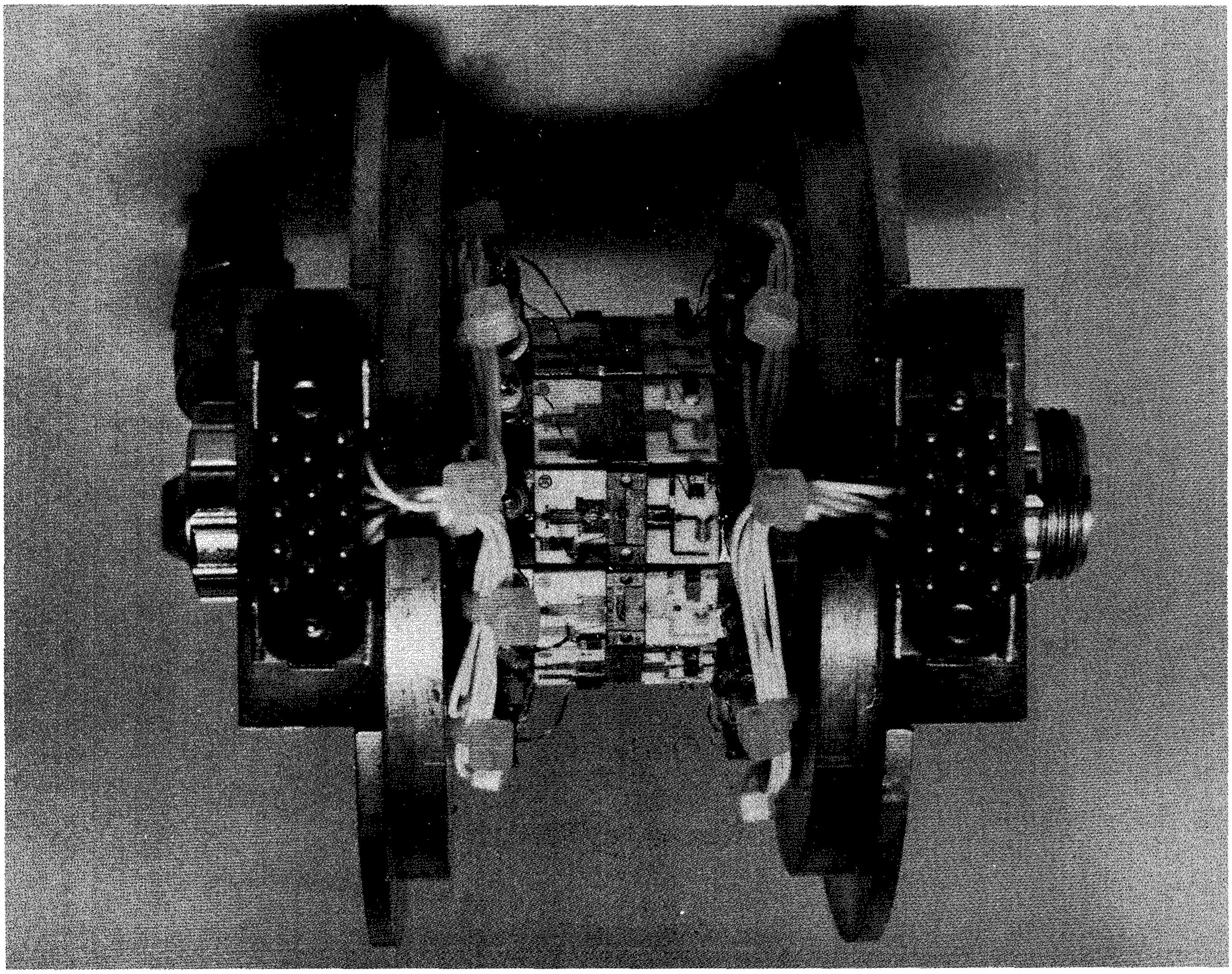

Figure 4 - Complete 10 Watt Radial Combiner/Amplifier.

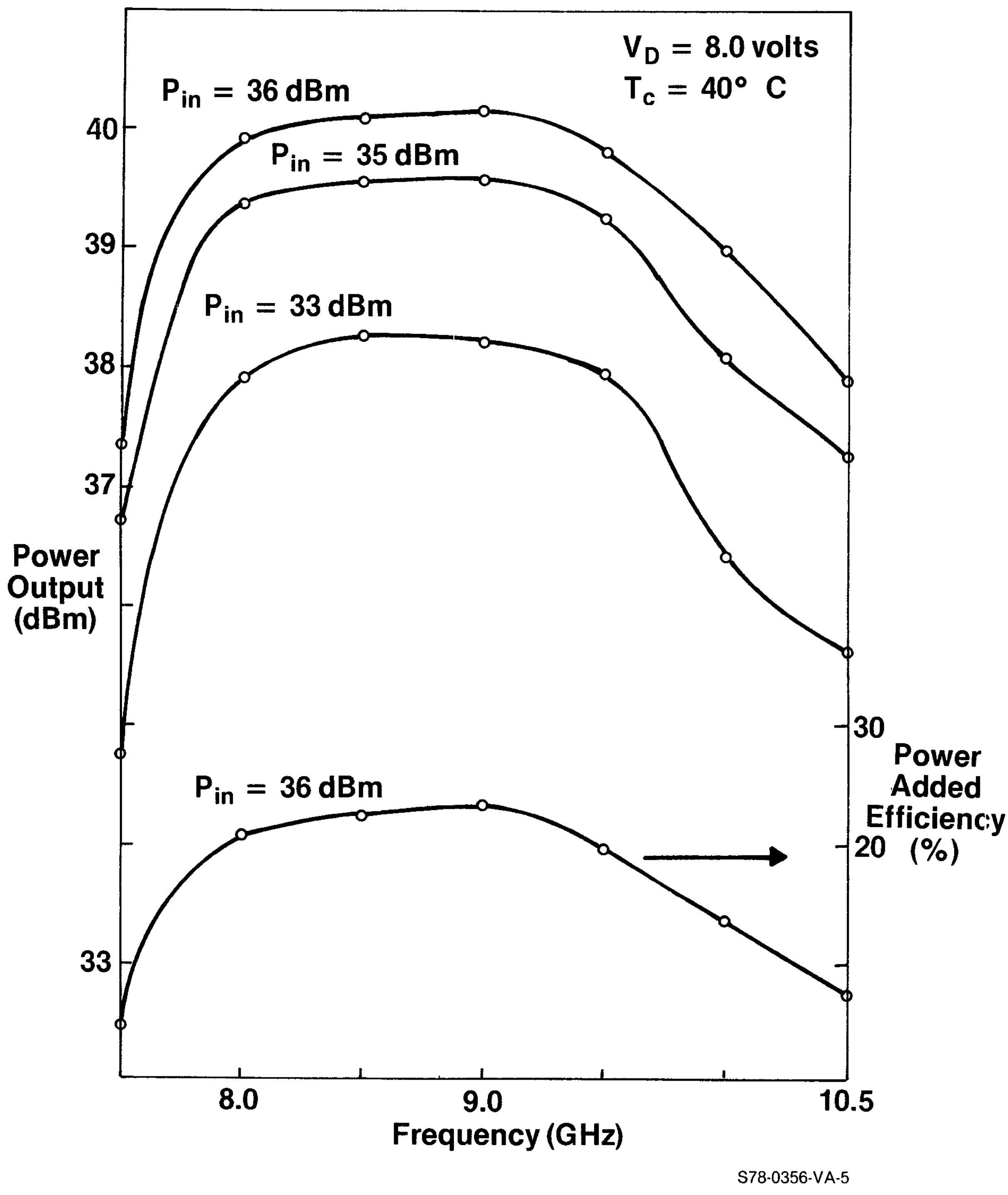

Figure 5 - 12-Element Amplifier Combiner Large Signal Frequency Response.

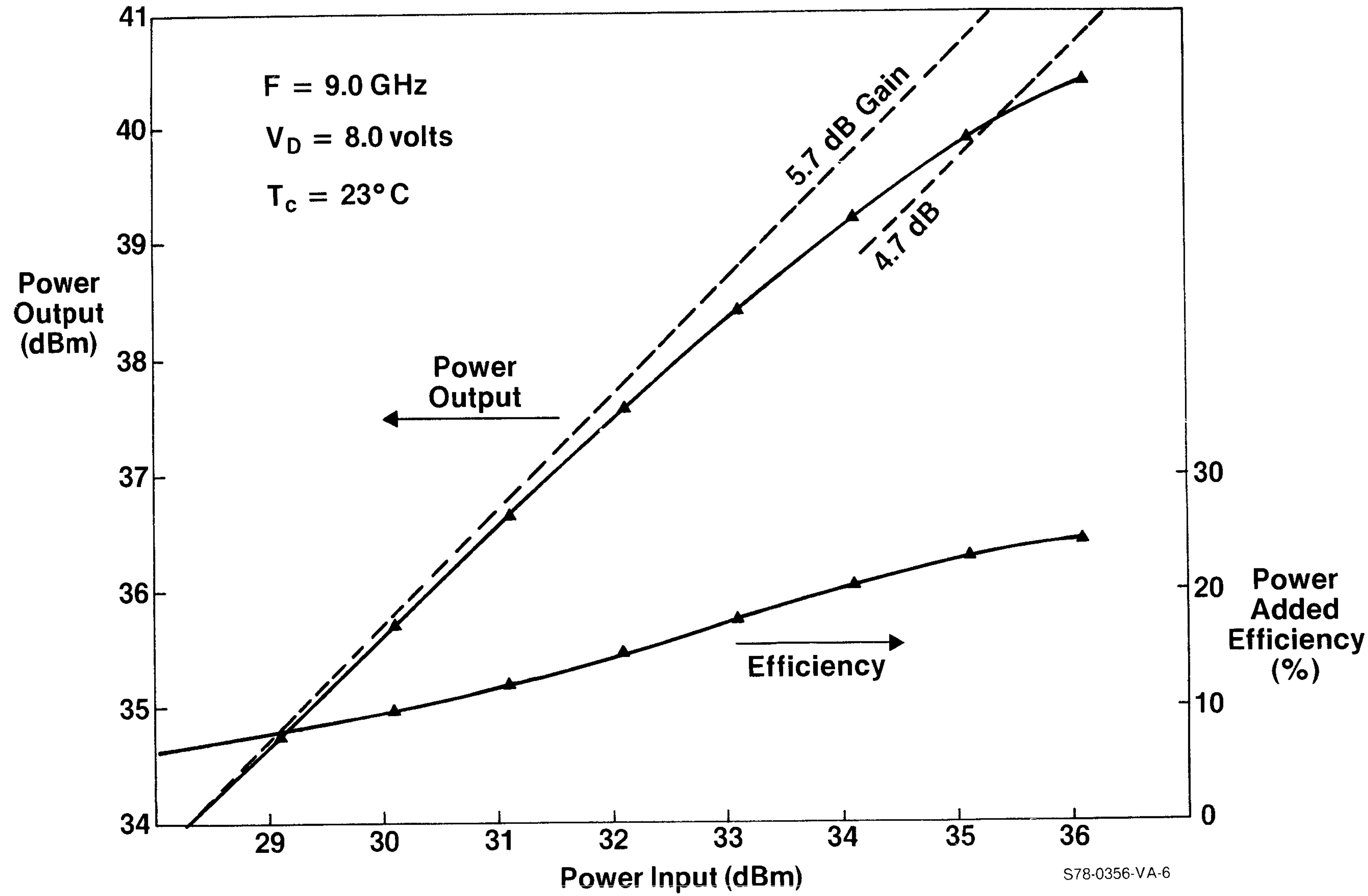

Figure 6 - Output Power and Efficiency vs Input Power.