A 2-6.2 GHz, 300 mW GaAs MESFET AMPLIFIER

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ABSTRACT

The development of a 2-6.2 GHz GaAs MESFET amplifier with 300 mW minimum power in production, and 600 mW minimum power with high breakdown-voltage MESFETs, is described.

Introduction

Solid-state microwave amplifiers of greater than octave bandwidth have not approached the multi-watt output levels of narrow-band designs. A few hundred milliwatts at 1-dB gain compression is typical for octave-bandwidth amplifiers (1,2), with one hundred milliwatts being achieved over larger bandwidths (3). This paper describes a MESFET amplifier which, in production, has typically delivered a minimum output power of 25 dBm (300 mW) over 2 to 6.2 GHz, with a 9 dBm input level, and -20 dBc harmonics. The amplifier is highly producible, requires no tuning, and has proved to be extremely reliable.

MESFET Description

A GaAs MESFET similar to that described by Tillman and Liechti (4) was used in this amplifier. In addition, a new MESFET layout, with three times the source periphery of the Tillman and Liechti MESFET, was designed for this application and is shown in Figure 1.

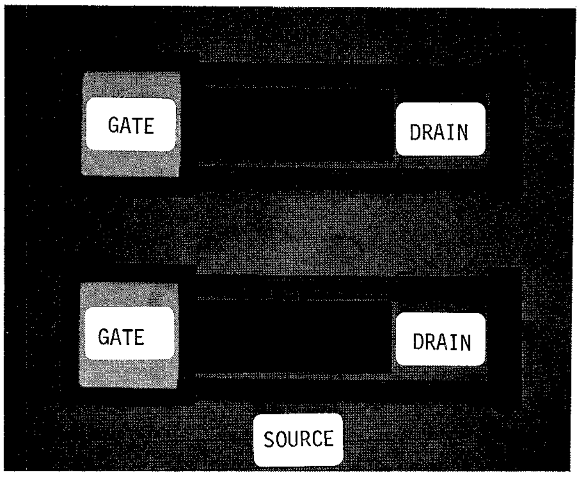


Figure 1: 1500-micron-gate MESFET

Total gate width is 1500 microns, compared to 500 microns for the smaller MESFET. Gate length was increased from 1 to 1.5 microns to aid in obtaining useable device yield despite the tripling of the gate width. The 1.5 micron gate length allowed an increase in the width of each gate finger from 250 microns to 375 microns without increasing the attenuation along the lossy gate transmission line. As a further aid to device producibility, channel length was increased from 4 to 6 microns, and the gate was centered between drain and source instead of being offset toward the source. This increased the nominal gate-to-source spacing from 1 to 2.25 microns, but the increase in source resistance per unit width was less than 50 per cent, due to the unchanged contributions of spreading and contact resistances to the total. This MESFET exhibited an f_{MAX} of 18 GHz, and tuned output power of 21 to 23 dBm (at 6 GHz and 3 -dB gain compression) for a 250 mA I_{DSS} and 5 V drain supply.

Microstrip Design Techniques

Several design techniques were important in achieving the broad bandwidth and power required for this amplifier, including lossy gate-matching circuits use of spiral inductors, and an alterable 2-way or 3 way splitter/combiner; these are described below.

Matching at the gate of each MESFET was achieved with the help of a resistive shunt (3), which lowered the input Q, provided gain equalization, and resulted in unconditional stability. Matching to the MESFET drains was relatively straightforward, since the optimum large signal load was measured to be near 50 ohms for both devices.

Square spiral inductors were employed to provide drain bias; they were superior to straight, high-impedance microstrip lines or long bond wires for the broad bandwidth involved. Data on these inductors is shown in Figure 2, as measured by two of the author's colleagues (5).

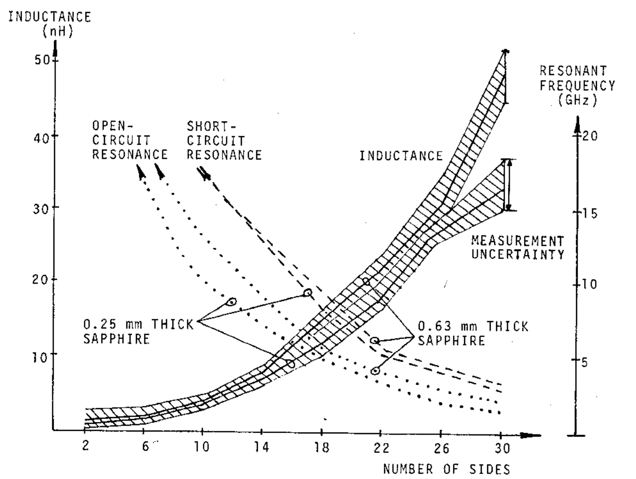


Figure 2: Inductance and resonance frequency for square spiral inductors with 51 micron (2 mil) line width and line spacing on sapphire.

When wired with one end at RF ground, these inductors can be approximately modeled as equivalent transmission lines as shown in Table 1; note the high effective impedances.

TABLE 1

0.25 mm THICK SAPPHIRE			0.63 mm THICK SAPPHIRE		
n	$Z_{o\ eff}$	l_{eff}	n	$Z_{o\ eff}$	l_{eff}
6	102	0.069	6	157	0.060
8	130	0.091	8	188	0.075
10	144	0.118	10	203	0.091
12	177	0.139	12	260	0.107
14	190	0.169	14	291	0.130
16	226	0.297	16	330	0.162
18	231	0.241	18	336	0.211
20	246	0.285	20	346	0.251
22	238	0.358	22	352	0.295
24	239	0.454	24	371	0.369

n=number of sides of square spiral inductor (metallization has 51 micron (2 mil) line widths and line spacing)
$Z_{o\ eff}$=effective characteristic impedance of equivalent transmission line
l_{eff}=length in inches of equivalent transmission line, assuming velocity 0.4 times the velocity of light

The splitter/combiner used in this amplifier was rather novel in that it could be wired for either a two-way or a three-way split or combine (Figure 3).

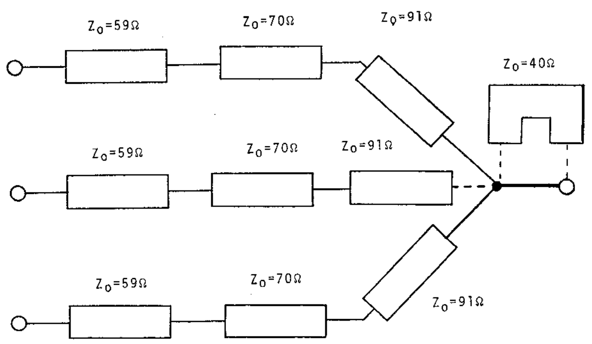


Figure 3: Alterable 2-way or 3-way splitter. Shown for 2-way split; add 40 ohm line and center branch for 3-way. All lines are quarter-wavelength at center of desired frequency band.

It is adaptable to various frequency ranges and has a fifty-ohm input and output. The trade-off is in isolation, since the resistors of a Wilkinson splitter would dissipate power when the center leg is disconnected (bondable resistors could be added if isolation were a concern). Maximum SWR at the branch end of this splitter is 1.23, or 19 dB return loss, over a one and two-thirds octave bandwidth, whether wired for a two-way or a three-way split.

Amplifier performance and reliability

A block diagram of the 2-6.2 GHz amplifier is shown in Figure 4, and a photograph in Figure 5. A three-MESFET output stage was used because the alternate two-MESFET output wiring produced a minimum output power of only 23.5 dBm over 2 to 6.2 GHz (mean for 14 amplifiers). Typical output power is 25 dBm minimum from 2 to 6.2 GHz with 9 dBm input, or 24 dBm from 1.7 to 6.5 GHz. Over 95 per cent of the amplifiers built

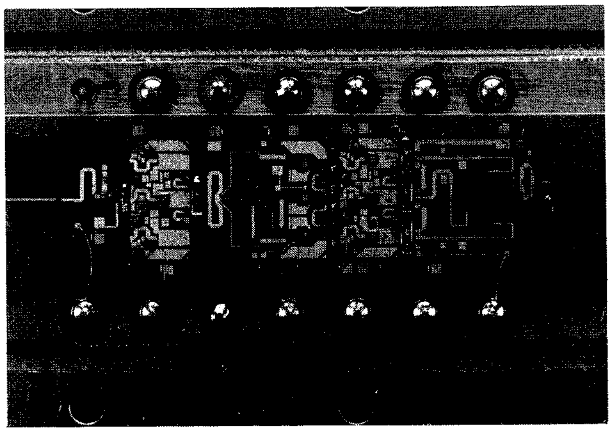


Figure 5: Photograph of 2-6.2 GHz amplifier

meet the 24.0 dBm output specification to 6.2 GHz. Figure 6 shows typical output power and harmonic performance; output SWR is less than 2.5 at rated output.

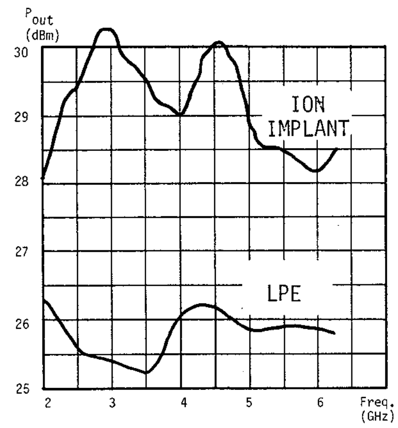
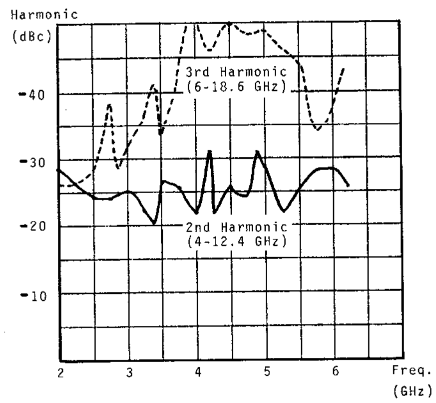


Figure 6: Performance of 2-6.2 GHz amplifier.

A) Typical output power (lower curve) and output power with n^+ selective-implant MESFETs, at 9 dBm input power.



B) Harmonics at 24 dBm fundamental output for a typical amplifier (non-implanted MESFET's)

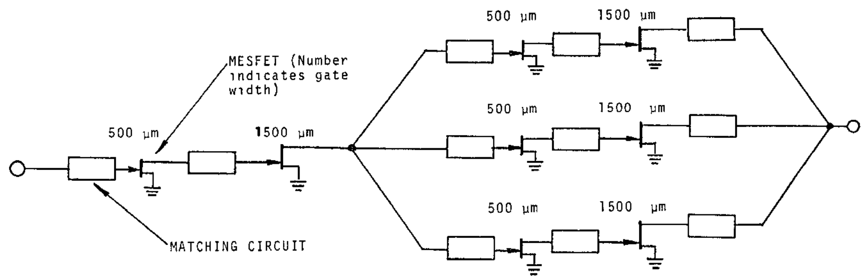


Figure 4: 2-6.2 GHz, 300 mW amplifier block diagram.

An equal-amplitude two-tone distortion measurement with 60 MHz carrier spacing indicated a 35 dBm third-order intermodulation intercept. Several amplifiers have been tested with V_{DS} = 8 V instead of 5 V for the final stage, using MESFETs with an n^+ ion implant under the drain and source (7). Minimum output power of 28 dBm over 2 to 6.2 GHz has been obtained. Further improvement could be expected with ion-implanted driver MESFETs.

Reliability studies were conducted on amplifiers operating at rated output power into a very high SWR load, with an input signal swept from 2 to 6.2 GHz at a 10 Hz rate. At 70°C case temperature and 5 V drain supply, no failures were observed in 40,000 device-hours. At 125°C and 6 V drain supply, one device failed (drain-source short) in 30,000 device-hours. Careful protection against transient voltages on the drain supply was required to take advantage of the FET's inherently good reliability; 12 V pulses as short as 10 nsec, with a 0.1% duty cycle, were found capable of producing drain-source burnout.

Conclusion

Broad-band MESFET amplifiers should achieve one watt output over greater than an octave bandwidth in the near future,* considering the recent report of 1 watt over three-quarters octave (6), and the results in the present paper, namely 600 mW over one and two-thirds octave. Further improvements will depend on higher drain-breakdown-voltage MESFETs, improvements in thermal performance, and better measuring and modeling of large signal characteristics.

Acknowledgment

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References

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* Achieved prior to publication, Ref. (8).