43.5 TO 45.5 GHZ ACTIVE TIMES-4 FREQUENCY MULTIPLIER WITH 1.4 WATT OUTPUT POWER

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ABSTRACT

The active multiplier/amplifier described in this paper produces a minimum 1.41 W output power in a 2 GHz band centered at 44.5 GHz. Total dc power consumption is 18.7 W. The entire unit, including drive amplifier, quadrupler, EHF power amplifier and high-speed bias control circuitry, is housed in a hermetic 3.8- x 1.3- x 0.45-inch package weighing 3.7 oz. This represents an order-of-magnitude reduction in size and weight compared to existing IMPATT-based EHF transmitters. The results we present were achieved by using 0.2-μm GaAs PHEMT MMICs coupled with a low-loss planar combining scheme.

INTRODUCTION

While GaAs FET amplifiers currently dominate the microwave power amplifier field, millimeter-wave transmitters still rely on traveling-wave tube amplifiers, IMPATT-diode reflection amplifiers, and high-power varactor multipliers. While appropriate for some applications, these three approaches are poorly suited for man-portable EHF ground terminals that require small size, light weight, high efficiency, and high reliability.

This paper describes a 1.4-watt EHF transmitter based on 0.25-W pseudomorphic HEMT (PHEMT) MMICs and planar power-combiner circuits. Unlike transmitters based on two-terminal devices, no bulky waveguide ferrite components are needed for isolation and signal separation. The inherent isolation of the three-terminal devices combined with the use of low-loss, planar power-combining techniques result in an EHF transmitter an order of magnitude smaller than its IMPATT-based predecessor. By keeping device junction temperatures below 110 °C, reliable operation is expected.

The transmitter consists of a single-stage X-band drive amplifier, a monolithic frequency multiplier, and an EHF amplifier cascade. Bias circuitry incorporating high-speed, TTL-compatible shut-down capability was included to place the transmitter in a standby condition when not in use in order to conserve dc power. An overvoltage circuit is included to protect the unit from power-supply transients and careless use (see photo in Fig. 1).

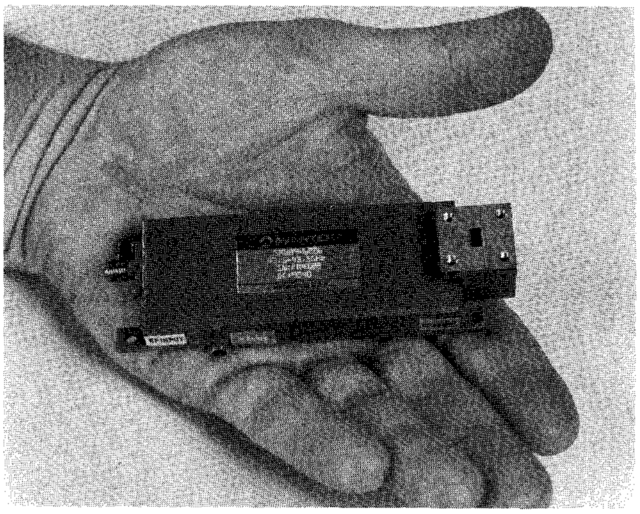


FIGURE 1.

MULTIPLIER/AMPLIFIER

The frequency-hopping synthesizer of the terminal supplies a 10 mW X-band signal to the input of the unit, which is amplified to 100 mW by the X-band driver. The monolithic multiplier generates an EHF output of 0.8 mW, which drives the EHF amplifier that provides approximately 31 dB of large signal gain from 43.5 to 45.5 GHz.

The dc input power requirement for the entire assembly is +5.0 V at 3.74 A, -5 V at 20 mA, and +12 volts at <1 mA. The +12 V is required for the high speed dc control circuit that is incorporated into the unit. The transmitter block diagram is shown in Fig. 2.

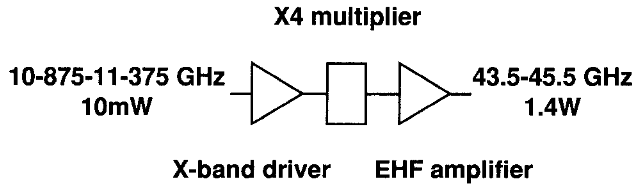


FIGURE 2. BLOCK DIAGRAM

X-BAND DRIVER AND MONOLITHIC MULTIPLIER

The frequency multiplier previously used at Avantek consisted of a Schottky-diode pair with beam lead packaging in a microstrip/coplanar/slotline/microstrip configuration. The microstrip/coplanar and slotline/microstrip transitions require a top- and bottom-side metalized substrate, and this circuit has high conversion loss.

As part of a developmental mask, a passive monolithic multiplier circuit was fabricated on gallium arsenide. The input feed to the multiplier is a 50Ω coplanar transmission line, and the output is 100Ω slotline. Impedance matching is accomplished on adjacent .005-inch-thick alumina microstrip circuits. This allows for the use of the multiplier over a wide range of frequencies. Conversion loss vs frequency is shown in Fig. 3. The input power is +20 dBm. These results showed 10 dB better conversion loss than the Schottky-diode times-four multiplier noted above.

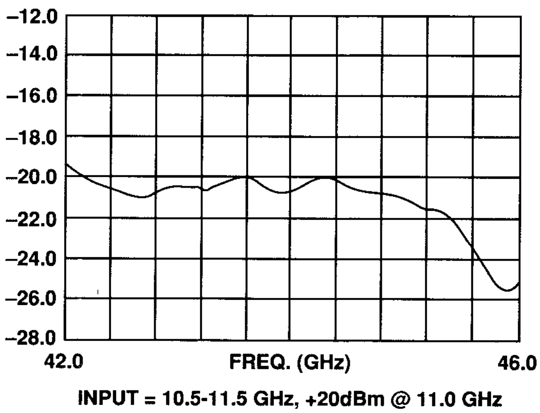


FIGURE 3. CONVERSION LOSS VS. FREQUENCY, MONOLITHIC MULTIPLIER

The balanced X-band amplifier is needed to boost the 10 mW input signal to the +20 dBm level required to drive the multiplier. A single balanced X-band amplifier stage that offers 28% power-added efficiency was employed. It provides the required drive to the multiplier and establishes a 1.5:1 VSWR at the input of the unit.

44 GHZ PHEMT POWER MMIC

The baseline device is a 640 μm-gate-periphery single-stage monolithic chip. The device is a double-heterojunction PHEMT with a high-low-high doping profile, fabricated on MBE material. Its 0.2 μm gate lengths are defined using E-beam lithography, and source grounding is achieved with via holes. A similar Avantek MESFET design was reported earlier[1]. The PHEMT version used in this design incorporates dc blocking capacitors at the drain and gate.

The untuned response of the device was centered at 50 GHz. The addition of input and output shunt capacitance on adjacent thin-film substrates lowered the operating frequency to the band of interest. Devices were dc probed and characterized for I_{max}, I_{dss}, g_m, and V_p, and RF evaluations included small signal gain, input/output VSWR, and P_{out} vs. P_{in}. The transfer characteristics of four devices are shown in Fig. 4. The monolithic chip produced typical results of 7.0 dB small signal gain and 257 mW of output power with 4 dB associated gain and 17.4% power-added efficiency. To obtain these results, 0.2 dB of fixture loss at the input and output have been removed. Typical dc characteristics of these devices are I_{max} of 420 mA, I_{dss} of 255 mA, transconductance of 205 mS, and pinchoff voltage of -1.4 V.

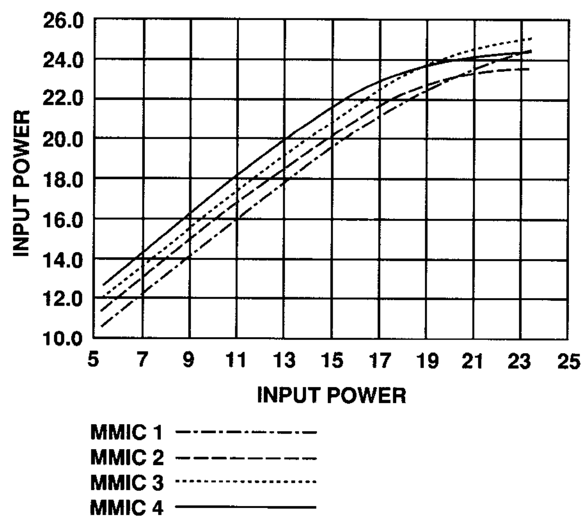


FIGURE 4. TRANSFER CHARACTERISTICS OF 640 μm PHEMT MMIC

TRAVELING-WAVE DIVIDER/COMBINER (TWD)

Typical methods of power combining at millimeter frequencies include combining thin-film hybrid balanced amplifiers with 90-degree quadrature couplers or using waveguide combiners to combine hermetically-packaged amplifiers.

With the former approach, three separate Lange couplers or Wilkinson structures are required to combine four devices. The best Lange couplers or Wilkinson combiners fabricated on alumina have shown about 0.6 dB of insertion loss per coupler at these frequencies. This type of combining scheme also adds to the number of ground interrupts and microstrip interconnects. Waveguide combiners are very low loss but generally are large and increase the weight of the unit significantly. With the use of microstrip-based circuitry, multiple microstrip-to-waveguide transitions are required, further increasing size and weight.

The class-I traveling-wave divider[2], which is similar to a Wilkinson structure, is small, low loss and offers excellent VSWR. In the design, each output of a power splitter feeds another power splitter. All transmission lines are 0.25-λ in length and provide the required impedance transformations. For the incident wave, the voltages are equal at the outputs of the splitters and the forward wave is unaffected in the absence of reflected waves. Equal power is delivered to the amplifiers and phase lags between the input ports.

In the traveling-wave divider, the reflected wave from identical mismatched loads are 180 deg. out of phase at the bridging resistors, and the circulating currents are absorbed. Realizing this structure to combine the described MMICs required the use of a low-dielectric material (in this case we used *Trans-tech* D-450). The width of the monolithic chip is .035-inch, and this width establishes the distance between the inputs of the adjacent chips. By using a low dielectric material, a longer 0.25-λ section is realized, which permits the inputs of the combiner to align properly with the devices without adding lossy transmission line. The wider transmission lines also offer lower resistive losses.

Insertion loss was measured by fabricating a one-piece back-to-back divider/combiner, as shown in Figs. 5 and 6. Probed devices were matched and mounted directly to a copper carrier along with the input and output substrates. Matching networks were included on the combiner substrates (Figure 7). The circuit produced 5.8 dB of small-signal gain, and 3 dB of gain with 812 mW of output power. The small signal gain and return loss is shown in Figure 8. A curve of the transfer characteristics is shown in Figure 9. The combiner efficiency is 4.6 dB and the power added efficiency is 13.7%.

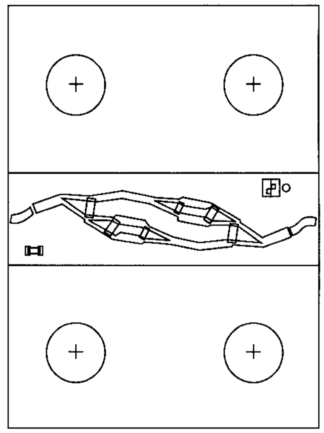


FIGURE 5. BACK-TO-BACK TEST COMBINER

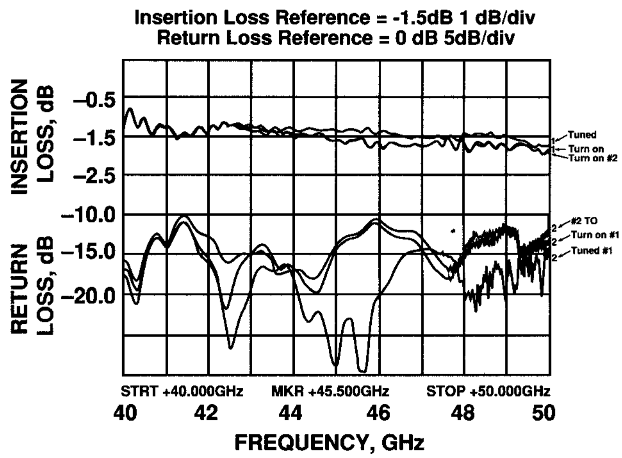


FIGURE 6. INSERTION LOSS/RETURN LOSS VS. FREQUENCY OF BACK-TO-BACK COMBINERS

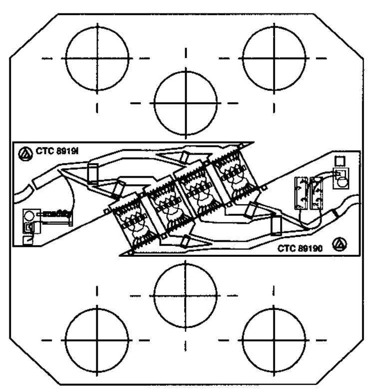


FIGURE 7. TRAVELING-WAVE DIVIDER/COMBINER (TWD)

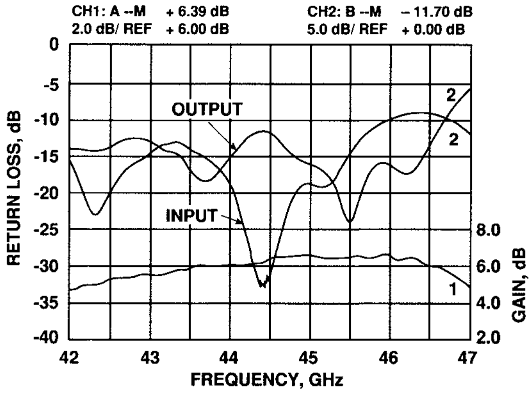


FIGURE 8. SMALL SIGNAL GAIN AND RETURN LOSS VS. FREQUENCY, TWD AMPLIFIER

RESULTS

Two of these cells were combined with a one-piece Wilkinson combiner in a hermetic package to produce 1.41 W of output power from 43.5 to 45.5 GHz. The TTL-compatible bias control circuitry switches the dc power from operation to standby in <500 ns. The output power is shown in Figure 10. The unit block diagram is shown in Figure 11.

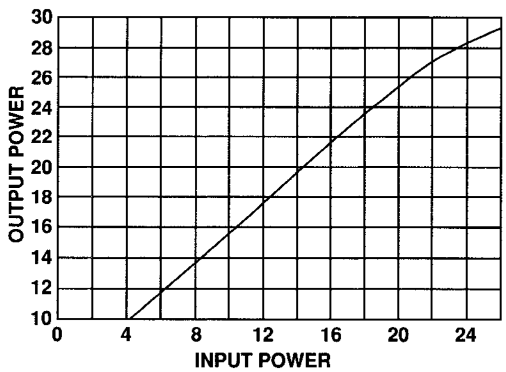


FIGURE 9. TRANSFER CURVE, TWD

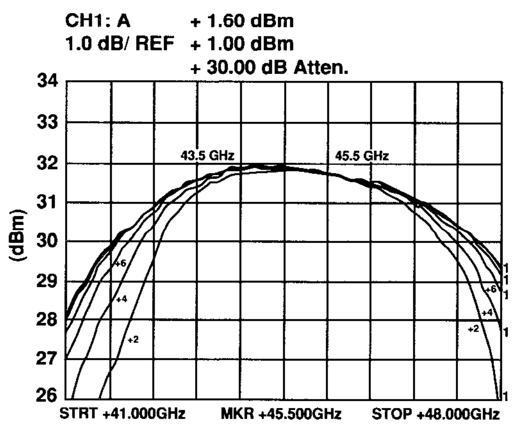
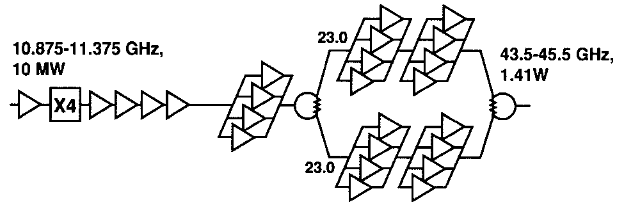


FIGURE 10. POWER OUT VS. FREQUENCY @ +20°C (INPUT POWER = +2, +4, +6, +8, +10 DBM)



P DC (W)	.33	0	.25	.24	.25	1.4	4.0	2.1/Channel=4.2	4.0/Channel=8.0
Module Type	BAL	X4	BAL	BAL	BAL	S.E./BAL	TWD	TWD	TWD
Device Size (Microns)	100		75	75	75	640	640 (4)	640 (4)	640 (4)
Output Power (DBM)	20	-1	5	9.7	14.5	22 5	26.5	26.0/Channel	29.1/Channel

FIGURE 11. UNIT BLOCK DIAGRAM

CONCLUSIONS

We have shown that by using efficient PHEMT MMIC devices along with improved microstrip combining techniques, output power in excess of 1.4 watts has been achieved at 44 GHz. This is the first time this power level has been reported using GaAs-based FET devices.

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