A High-Performance W-Band Integrated Source Module Using GaAs Monolithic Circuits

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***Abstract*—A high-performance integrated source module using a U-band MMIC HBT DRO and a U-band MMIC MESFET power amplifier in conjunction with a W-band MMIC high-efficiency varactor doubler has been developed for millimeter-wave system applications. This paper describes the development and performance of this W-band integrated source module. Measured results of the complete integrated source module show an output power of 10.6 dBm at 92.6 GHz and less than −126 dBc/Hz phase noise at 5 MHz offset from the carrier. These results represent the highest reported power and phase noise achieved at W-band using HBT, MESFET, and varactor frequency-doubling technologies.**

I. Introduction

CONSIDERABLE EFFORT is currently being directed toward the development of monolithic millimeter-wave integrated circuit components for radar, communications, smart weapons, electronic warfare, and missile seeker systems to make these systems more affordable. The stable source module presented in this paper is a key component for such millimeter-wave systems. HBT's are superior to MESFET's and HEMT-based devices in phase noise performance, as applied to microwave and millimeter-wave oscillators, because the vertical currents flowing through the device interfaces are well shielded from traps in the surface regions [1]. The good stability and phase noise performance of HBT MMIC DRO's have lead to their use in microwave and millimeter-wave stable-source applications [2], [3]. W-band monolithic stable-source module using MMIC HBT DRO has potential for use in W-band missile seekers and phased-array radars. However, HBT DRO's above Ka-band have rarely been reported, in part due to the limitation of the HBT's maximum oscillation frequency, $f_{\max}$, as well as extremely tight tolerance in dielectric resonator (DR) manufacturing.

In this paper, we report the first W-band integrated local source module that employs the HBT and frequency doubling technologies for future W-band seeker and sensor system applications.

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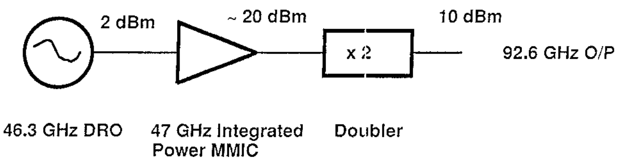

Fig. 1. Block diagram of the W-Band integrated source module.

II. Module Configuration

Fig. 1 shows a block diagram of W-band integrated source module. The developed integrated local source module is composed of a U-band MMIC HBT dielectric resonator oscillator (DRO) and a four-stage MMIC power amplifier in conjunction with a W-Band high efficiency varactor doubler. Based on this approach the state-of-the-art performance with output power of 10.6 dBm at 92.6 GHz and less than −126-dBc/Hz phase noise at 5-MHz offset from the carrier has been achieved.

The schematic of U-band HBT DRO is shown in Fig. 2. This reflection-type DRO consists of an MMIC and an off-chip DR coupled to the microstrip line circuit for frequency stabilization. The superiority of HBT devices, coupled with the advantages of a DR (high Q, small size, and temperature compensatability), make the HBT DRO very attractive as a millimeter-wave stable source. The HBT uses a $2 \times 20-\mu m^2$ emitter area for optimum output power and $f_{\max}$ and is operated in a common base (CB) configuration. The HBT device with 120-GHz $f_{\max}$ was used for the oscillator circuit. The short stub from the base of the HBT to ground is used as a series feedback element to bring the HBT to an unstable region. Since the oscillation frequency of a DRO is largely determined by the resonant frequency of the DR, the dimension and material of the DR have to be designed and controlled accurately. In addition, the quality factor Q of the dielectric resonator must be sufficiently high and the coupling coefficient, β, of the DR coupled to the microstrip line must be small enough to maintain good stability and phase-noise performance. The output-matching network was designed for maximum output power operation during the steady-state oscillation. The negative resistance is required to be about three times the load resistance [4]. The transmission line was used for the output-matching circuit, and input and output bias were provided by the shunt RF-shorted elements, which grounded through metal-insulator-metal (MIM) capacitors and via holes. For the 46.3-GHz HBT DRO, the DR is made of BaZnTaTi Oxide with a dielectric constant of 30. The DR is

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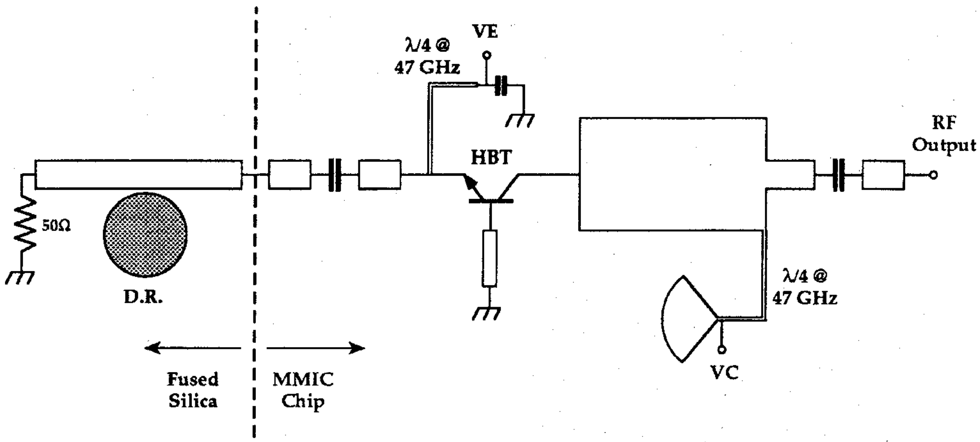

Fig. 2. Schematic of U-band reflection-type DRO.

TABLE I
KEY PERFORMANCE OF MMIC COMPONENTS FOR W-BAND INTEGRATED SOURCE MODULE

Parameter	Performance
U-Band MESFET Power MMIC	
Frequency Range	46.2 to 47.5 GHz
Gain	18 dB
Psat	180 mW
Power Added Eff.	11.2 %
Return Loss	15 dB (I/P)
	9 dB (O/P)
U- to W-Band MMIC Doubler	
Frequency	46.3 GHz
Efficiency (η)	24.6 % (η_{max})
Power Output	55 mW @ Pin=224 mW
	65 mW @ Pin=330 mW
Conversion Loss	6 dB @ $\eta=\eta_{max}$
U-Band HBT MMIC DRO	
Frequency	46.3 GHz
Power Output	2.6 dBm
Phase Noise	-132 dBc @ 5 MHz
	-140 dBc @ 15 MHz
Spurious	-80 dBc
DC-to-RF Eff.	5.8%

coupled to a 50-Ω microstrip line deposited on a 5-mil-thick fused silica substrate. The HBT MMIC chip of the oscillator circuit was fabricated on GaAs/AlGaAs material grown by MOCVD.

A high-efficiency MMIC varactor doubler, which has been reported [5], was used for this integrated local source module. A disk-type varactor diode with the optimized structure, dimension, and doping concentration was used for doubler circuit. The 46.3- to 92.6-GHz MMIC doubler exhibited maximum efficiency of 24.6 % (6-dB conversion loss), with an associated output power of 55 mW. The saturated output power is about 65 mW at 92.6 GHz. To amplify the signal from a 46.3-GHz HBT MMIC DRO, a high-performance, four-stage, 47-GHz monolithic power amplifier [6], [7] was also used to drive the doubler to achieve the system-required 10 mW of output power at 92.6 GHz. The amplifier design consists of a two-stage driver amplifier followed by a two-stage power amplifier. The baseline monolithic driver amplifier design consists of a dual-stage, 400-μm MESFET amplifier. The power stage consists of two dual-stage driver amplifiers combined using integrated in-phase Wilkinson-type divider/combiner circuits. The amplifier associated gain is about 14.2 dB across the frequency band from 46.3 to 47.5 GHz with an output power of 162 mW. A saturated power greater than 180 mW was also achieved [6].

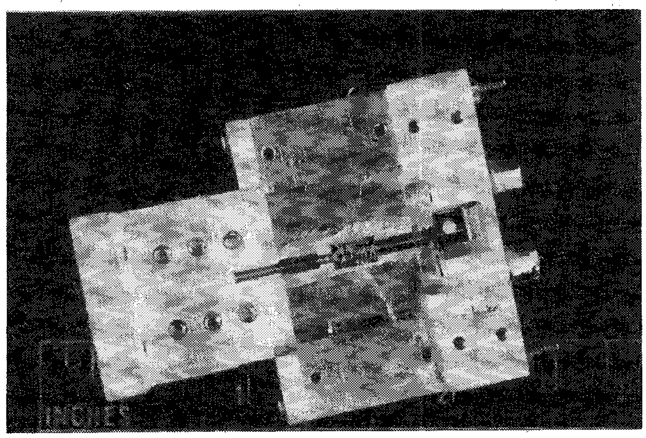

Fig. 3. Complete W-band integrated source module assembly.

III. MODULE PERFORMANCE

The developed integrated source module consists of an MMIC HBT DRO, a four-stage MMIC power amplifier, and an MMIC varactor doubler. The key performance of each MMIC component is summarized in Table I. Fig. 3 shows the complete integrated module assembly with the W-band ridged waveguide-to-microstrip transition. The transition has a typical insertion loss of 0.6 dB and a return loss of better than 16 dB over the frequency range from 90 to 97 GHz. Fig. 4 shows a measured output spectrum of the integrated source module. The measured output power of 10.6 mW was achieved at 92.6 GHz. The amplifier was biased with $Vds = 4$

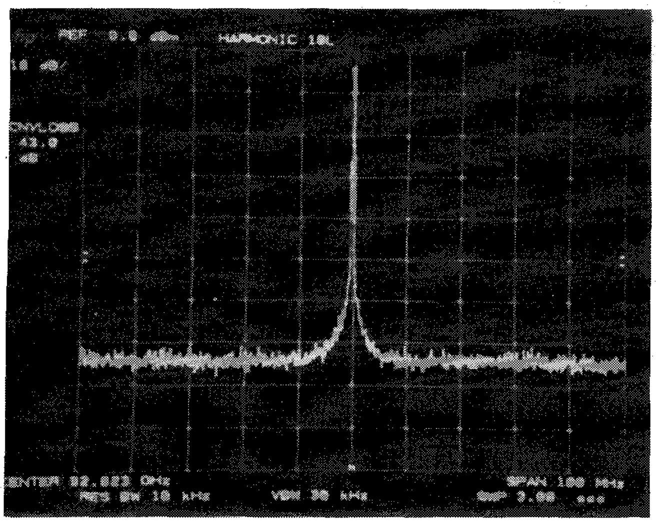

Fig. 4. Output spectrum of W-band integrated source module.

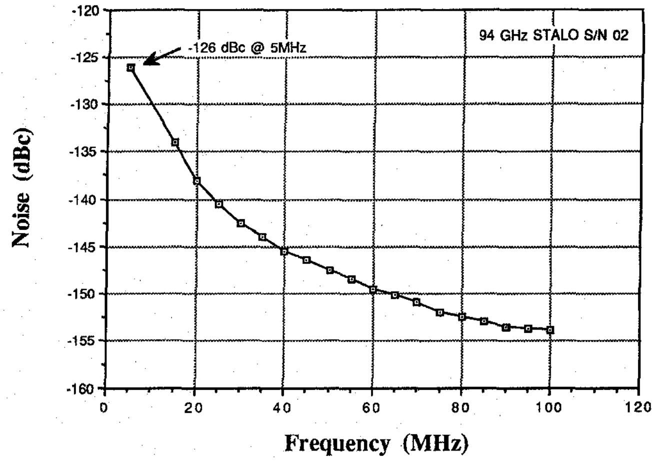

Fig. 5. Measured noise performance of W-band integrated source module.

V and $Vgs = -0.8$ V, doubler was biased with $Vd = 6.2$ V, and HBT DRO was biased with $Vc = 0.5$ V and $Ic = 16$ mA. The total current input of this integrated source module is about 430 mA. The phase noise has been measured by using a phase noise analyzer. Fig. 5 shows the measured phase-noise performance. Phase noise of less than -126 dBc/Hz at a frequency offset of 5 MHz from the carrier was measured. The spurious of less than -70 dBc was also measured from this integrated source module.

IV. Conclusion

A high-performance integrated source module using a U-band MMIC HBT DRO and a U-band MMIC MESFET power amplifier, in conjunction with a W-band MMIC high-efficiency varactor doubler, has been successfully developed for millimeter-wave system applications. Measured results for the complete integrated source module show an output power of 10.6 dBm at 92.6 GHz and less than -126 dBc/Hz phase noise at 5-MHz offset from the carrier. This is the first integrated source module with the highest phase noise reported yet at W-band using HBT, MESFET, and varactor frequency-doubling technologies. This integrated source module is suitable for W-band missile seeker applications.

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