W-Band Oscillator Using Ion-Implanted InGaAs MESFET's

J. M. Schellenberg, C. L. Lau, M. Feng, and P. Brusenback

Abstract—**While FET devices dominate microwave applications at lower frequencies, they have not yet demonstrated sufficient power as a source at *W*-band frequencies to displace 2-terminal Gunn and IMPATT devices. A fundamental FET oscillator is reported operating at 92.3 GHz with an output power of 14 mW. This is the highest reported output power for an FET oscillator at *W*-band frequencies and is comparable to commercial Gunn diode oscillators. Further, these results were achieved with an InGaAs MESFET device that was fabricated using low-cost ion-implantation techniques.**

I. Introduction

WHILE the noise [1] and power [2] performance of 3-terminal FET devices have been reported at *W*-band frequencies, there is very little data on these devices as oscillators. Several years ago Tserng *et al.* [3] reported a monolithic FET oscillator operating from 90 to 115 GHz. However, the output power was only 0.1 mW. More recently an FET oscillator/doubler [4] and an FET frequency doubler [5] have been reported at 94 GHz with an output power of 0.2 mW and 4 mW, respectively.

It is the purpose of this letter to report a fundamental oscillator operating at 92.3 GHz with an output power of 14 mW. This represents the highest reported power for an FET oscillator at *W*-band frequencies. Further, these results were achieved with ion-implanted MESFET devices as opposed to complex HEMT structures.

II. Device Description

The 0.25 × 50 μm FET devices used in this work have been previously reported [6], [7]. The device transconductance is typically 400 mS/mm with a current density (I_{DSS}) of 550 mA/mm at $V_{DS} = 3$ volts. The device f_T and $f_{\max}$ are typically 80 GHz and 140 GHz respectively for $V_{DS} = 3$ volts and $I_{DS} = 50\%\ I_{DSS}$. As an amplifier at 60 GHz, these devices have demonstrated a power density of 0.6 watt/mm (121 mW output power for a 200 μm device) with 3 dB gain. These power results are comparable to the best results achieved with pseudomorphic HEMT devices.

III. Oscillator Configuration

The oscillator circuit configuration is shown in Fig. 1. It consists of a nominally 50 ohm microstrip chip carrier mounted between two *V*-band waveguide-to-microstrip transitions. With dimensions of 62 × 140 × 30 mils, the carrier consists of a copper base, two 5-mil thick fused silica substrates and the FET chip, in a common source configuration, mounted between the substrates. This configuration is essentially the same as that used to evaluate the device power performance at 60 GHz.

The waveguide-to-microstrip transition consists of a microstrip line on a 5-mil thick fused silica substrate which extends into the *V*-band waveguide forming an orthogonal *E*-field probe. A bias circuit is also integrated onto the transition substrate. The insertion loss of a pair of transitions connected back-to-back is typically 0.7 dB at 60 GHz, and the return loss of this transition pair is generally better than 15 dB over the 50–70 GHz band.

In order to form an oscillator, a waveguide tunable short was attached to the amplifier input port. The feedback mechanism for this oscillator is believed to be provided by coupling to a waveguide mode in the channel above the carrier. This channel is indicated in the cross-sectional view of the oscillator shown in Fig. 2. While the chip carrier is mounted in a channel that is below cutoff for any waveguide modes at *V*-band frequencies, at *W*-band frequencies the channel can support a *TE* mode (cutoff frequency of 90.85 GHz). Extending from the input transition to the output transition, we believe this channel provides both the oscillator feedback mechanism and the resonant circuit.

Evidence of this mode of oscillation was obtained by observing the effect of tuning and scribing on the microstrip circuit. Cutting the microstrip affected only the output power and had little or no effect on the oscillation frequency. This indicates that the microstrip circuit is not controlling the oscillation. We believe that the microstrip circuit simply provides the coupling to the waveguide formed by the channel above the microstrip. Further evidence of the presence of this waveguide-cavity mode was obtained by noting the sensitivity of the oscillation frequency to a metal probe that was inserted into the channel above the carrier. While these tests do not conclusively define the feedback mechanism, they do indicate the dominate role that the channel versus the microstrip is playing in the oscillation process.

IV. Oscillator Performance

With the configuration previously described, the device oscillated as a fundamental oscillator at *W*-band frequencies. To confirm the *W*-band signal as a fundamental oscillation, we searched the millimeter-wave spectrum with a spectrum

Manuscript received December 14, 1990.
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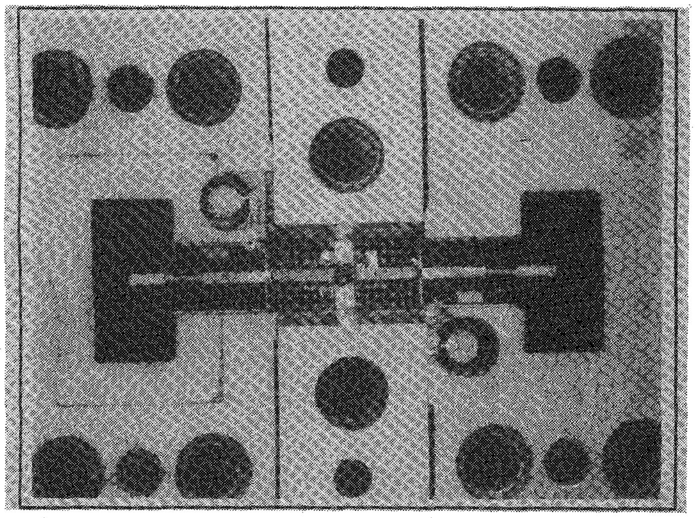

Fig. 1. Oscillator circuit configuration.

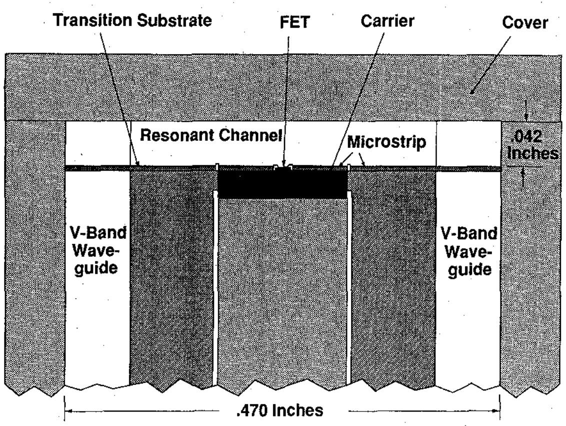

Fig. 2. Cross-sectional view of oscillator circuit.

analyzer from 40 GHz (the cutoff frequency of *V*-band guide) to *W*-band for harmonically related frequencies. None was found. Further, the power level of this *W*-band signal is uncharacteristically high for a harmonic. The presence of a *W*-band signal was also confirmed with a *W*-band frequency meter, and the oscillator output power was measured with a calibrated *W*-band thermistor mount.

The oscillator power and efficiency are summarized in Fig. 3. The bias and input/output tuning were optimized for maximum power. As shown in the figure, this device demonstrated an output power of 14 mW at 92.3 GHz with V_{DS} = 3.9 volts. The efficiency is 11% at this point. This data is referenced to the waveguide output port with no corrections for the transition or fixture loss. By tuning the input waveguide short, the device oscillation frequency could be tuned from approximately 91–93 GHz. However, maximum power was attained at 92.3 GHz.

The output spectrum of this oscillator is shown in Fig. 4. The sideband noise is approximately −70 dBc/Hz for an offset frequency of 15 KHz. This is comparable to commercial *W*-band Gunn oscillators.

V. Conclusion

These results, achieved with an InGaAs MESFET, are comparable in power and noise spectrum to commercial

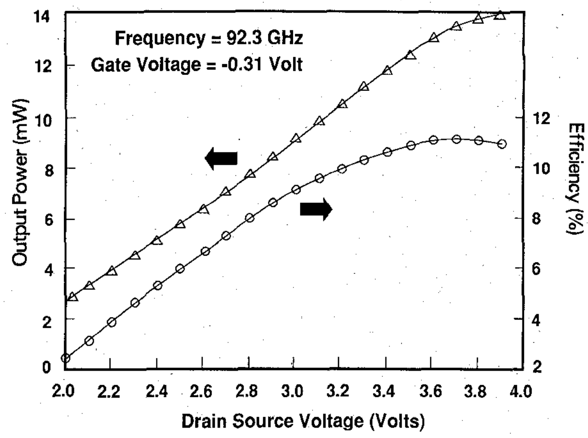

Fig. 3. Oscillator power and efficiency versus drain-source voltage.

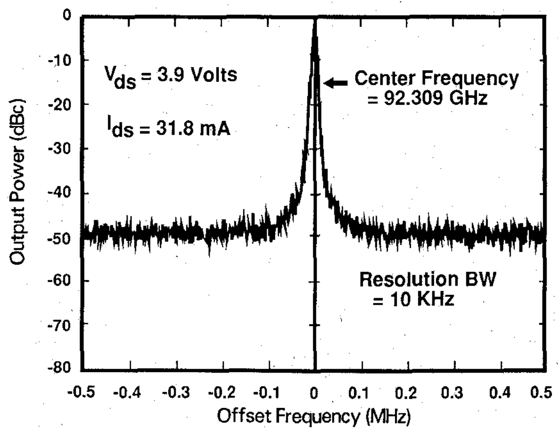

Fig. 4. Oscillator output frequency spectrum.

Gunn diode oscillators. FET devices are much more desirable as active devices for MMIC applications than Gunn or IMPATT devices due to their compatibility with exciting IC processes, demonstrated reliability and extensive data base. However, until now FET devices have not demonstrated, at *W*-band frequencies, the power levels required by system applications. These results clearly demonstrate that 3-terminal devices, specifically low cost ion implanted MESFET devices, can compete as power sources at *W*-band frequencies.

Acknowledgment

The authors thank Mr. Joe Cadwallader of Hughes Microwave Products Division for his help with the *W*-band measurements.

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